Cabling for 10GBASE-T
The case for UTP

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Cabling for 10GBASE-T - The Case for UTP

Abstract

This white paper discusses the subject of 10 Gigabit/second data transmission over balanced twisted-pair cabling. Balanced twisted-pair cabling refers to either unshielded twisted pair (UTP) or screened twisted pair (ScTP) cabling. The term screened or shielded twisted pair generally refers to a TIA recognized cable construction with an overall metallic screen over a 4-pair core, also designated as F/UTP in the International standards. Arguments can be made in support of unshielded twisted-pair (UTP) or screened twisted-pair (ScTP) cabling for 10 Gb/s applications over copper.

It is important for the end user to understand that shielded cabling is not a magic cure to solve the problem of noise. It can often make the situation worse. When considering all the issues, advanced UTP solutions such as Belden's IBDN™ System 10GX provide not only superior noise performance, and do so without the additional bonding and grounding requirements of ScTP cabling.

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What is different about Category 6A?

The ANSI/TIA-568-B.2-10-2008 Category 6A Standard was published April 2008.

The main differences between Category 6A and Category 6 cabling are shown in Table 1.

Cabling parameter / feature Versus Category 6	Category 6A provides:
Lower Insertion Loss (resulting in greater Signal strength)	4dB lower @ 500 MHz
Better NEXT Loss	~ 4 dB higher @ 500 MHz (TIA) ~ 6 dB higher @ 500 MHz (ISO)
Significantly better alien crosstalk loss	~13 dB higher PSANEXT @ 500 MHz ~ 4 dB higher PSAACRF @ 500 MHz
Category 6A does not require mitigation techniques to support 10 Gb/s Tx rates	Designed to meet alien crosstalk requirements in a worst-case 6-around-1 bundled cabling configuration
Category 6A exceeds 10GBASE-T requirements in all channel topologies and configurations	Supports 'worst-case' 100 meter, 4 connector topologies AND provides alien NEXT and NEXT margin for 'short channel' configurations beyond minimum 10GBASE-T requirements
Supports 10GBASE-T short reach mode	Supports lower power mode for data centers, creating opportunities for reduced energy costs and reduced heat dissipation
Uses larger 23 AWG vs. 24 AWG conductors	Lower Insertion Loss; stronger signal Lower temperature rise / higher remote powering capability (PoE Plus)
Larger cable diameter	Up to 0.354 inch diameter is permitted in standard Belden's IBDN System 10GX RoundFlex cable is 0.295 inch nominal diameter
Larger bundle diameter (bundle size for 48 cables)	Cable OD Bundle Dia. 0.260 in 2.08 in 0.295 in 2.36 in 0.354 in 2.84 in

Table 1 - Differences between Category 6A and Category 6 cabling

Unshielded vs. Shielded Cabling

There is a perception that screened cable provides better noise immunity because the screen acts as a defensive barrier against electromagnetic interference.

The effectiveness of shielding as an electromagnetic barrier depends on many things, including;

1. the quality and the reliability of the shield terminations,
2. the balance of the twisted pairs,
3. the impedance of the ground connection, and;
4. the ground potential difference between local and remote grounds.

All these factors can have a **significant impact** on system performance and **noise immunity**.

Noise immunity performance depends very much on the pair balance for both unshielded and shielded cabling. It is important to understand the sources of external noise and the mechanisms for counteracting external noise.

Shielding Works, Right ?

Here is a quote from a noted expert on shielding:

"In high-speed digital applications, a low impedance connection between the shield and the equipment chassis <u>at both ends</u> is required in order for the shield to do its job." [1]

Two conditions are necessary to ensure that shielding works at high frequencies.

- First, the screen needs to be grounded at both ends.
- Second, the screen needs to be terminated with a low impedance connection to ground. A low impedance ground connection requires a 360 degree contact between the foil and the shielded connector housing. A short length of ground wire (sometimes called a pigtail) <u>is not a low impedance connection</u>.

What is a Low Impedance Connection?

In the standards, an impedance of 1 Ohm or less is considered to be a low impedance connection. #6 AWG ground wire is typically used for grounding connections for equipment, racks and patch panels. It is generally assumed that it provides a low impedance path to ground. Table 2 shows the DC resistance impedance of a 6 AWG conductor

At power line and audio frequencies the impedance of a grounding conductor is approximately equal to the DC resistance. As you can see in Table 2, the DC resistance of a 12 inch length of a 6 AWG conductor is very low, less than one thousandth of an Ohm. Above audio frequencies inductance begins to dominate and at radio frequencies the inductive impedance of even a short wire or circuit-board trace can be quite high. For example, at 100 MHz, the impedance of 2 inches of a 6 AWG ground conductor is

19 Ohms and is nowhere close to the 1 Ohm impedance that is required. 10GBASE-T transmission bandwidth goes up to 400 MHz!

A ground conductor (pigtail) is not a low impedance ground at high frequencies. One approach to achieve lower impedance at high frequencies is to use a flat strap instead. To ensure that the inductance of a ground strap is sufficiently low, its width must be at least one-fifth or, better yet, one-third of its length. If a designer cannot achieve this ratio, there will not be a satisfactory high-frequency current return path.

Length	**Frequency**	**Impedance (Zg)**
12 inches	DC	0.0005 Ohms
2 inches	100 MHz	19 Ohms
6 inches	100 MHz	77 Ohms
12 inches	100 MHz	180 Ohms

Table 2 – Impedance of 6 AWG ground wire at DC and at 100 MHz

As you can see, it is very difficult to achieve a low impedance ground at high frequencies. Distances to the ground reference plane must be kept very close. That is why most circuit board designs have a ground substrate very close to the circuit traces. Also, shielded connectors need to be 360 degree bonded to shielded equipment enclosures and to the shield of the cable to ensure a low impedance path to ground.

Noise Coupling Mechanism

Let's look at how noise is induced into a balanced twisted pair cable due to the presence of an external electromagnetic field. The noise voltage that is induced into each conductor of a pair is shown Figure 1 as Vcm1 and Vcm2 respectively. This voltage is called the common-mode voltage because each wire of a pair is exposed to approximately the same field at any distance along the length of cable. The magnitude of this common mode voltage is proportional the field strength (usually specified in amperes/meter for magnetic field or volts/meter for electric field), the rate of change of field (frequency), and the loop area, which depends on the distance of the cable above the ground plane.

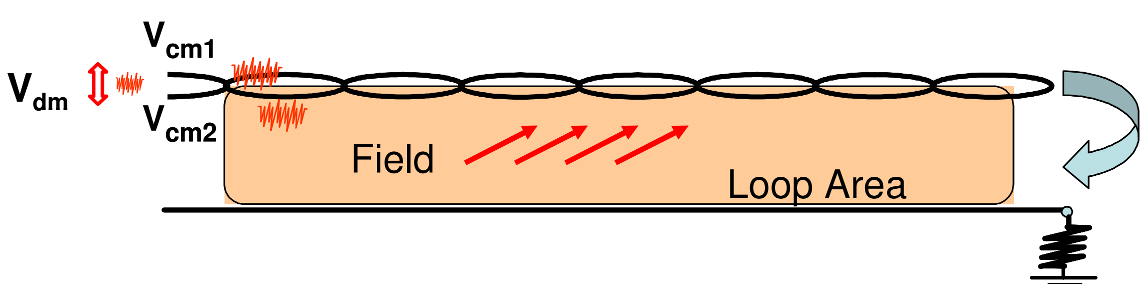


Figure 1 – Noise coupling mechanism for UTP Cabling

The whole concept of balanced pair transmission is that the signal is applied across the two conductors of a pair in differential-mode, also called transverse mode, where equal and opposite voltages (+V/-V) are applied on each conductor of a pair. If the twisted pair is well balanced with respect to ground, the difference in the noise voltage between Vcm1 and Vcm2 (Vdm) is approximately zero. The Pair Balance is expressed as the ratio between the common-mode voltage (Vcm) and the differential-mode voltage (Vdm) in dB. TIA Category 6 and 6A standards define this parameter as TCL or Transverse Conversion Loss.

A tightly twisted well-balanced pair, such as a bonded pair, with equal conductor diameter, equal spacing and equal conductor length achieves the best TCL performance.

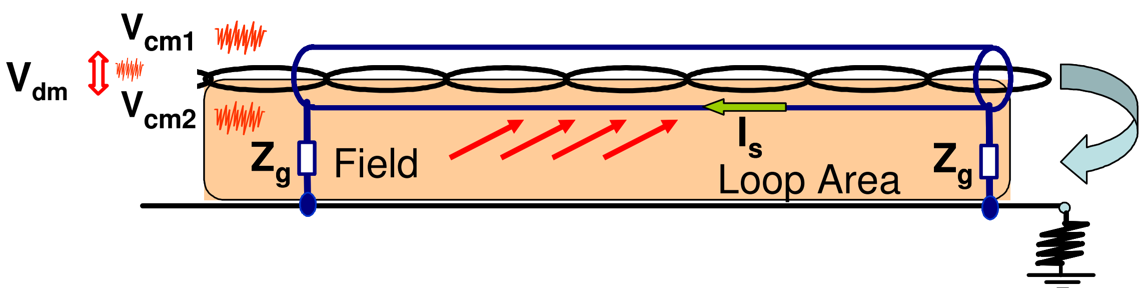


Figure 2 – Noise coupling mechanism for ScTP Cabling

The purpose of the screen is to counteract the effect to the external field as shown in Figure 2. The external field causes a current to flow in the shield, which induces an opposing voltage on each conductor of a pair. The net effect is to reduce the common-mode Voltage Vcm1 and Vcm2. The extent to which the common-mode noise voltage is reduced depends on the design of the screen (screening effectiveness) and on the impedance to ground (Zg). A high impedance to ground at either end defeats the purpose of the screen; which needs a low impedance path to ground to be effective.

From this one may conclude that the presence of the screen would help to reduce external noise coupling. This is only part of the story. The other part has to do with the balance of a pair. By bringing the screen in close proximity to the pair, increases the capacitive and inductive coupling to ground. The unbalance to ground is amplified due to the presence of a screen. Also any asymmetry or displacement of the screen due to manufacturing or installation can worsen the Pair Balance. It is possible to have a condition where Vcm is improved and Vdm gets worse due to pair unbalance.

As you could see from the previous charts, the noise immunity performance of both UTP and ScTP cables is directly related to the Pair Balance. The TIA 568 B.2-9 and TIA 568 B.2-10 standard specifies Pair Balance requirements for Category 6 and Category 6A cables, connectors and channels. The specified parameter for Pair Balance is called TCL. TCL is a test that is currently performed by manufacturers of cable and connecting hardware.

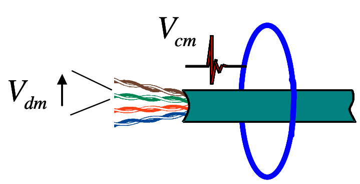
The pair balance of cables is affected by the manufacturing process and design. The pair balance of connecting hardware is primarily affected by design. TCL is not a parameter that can be measured in the field at this time. This might change in the future.

The TCL requirements for Category 6A UTP and ScTP cables are shown in the Table 2. The Cable TCL is 40 dB at 10 MHz, 30 dB at 100 MHz and 23 dB at 500 MHz. The slope is 10 dB / decade.

Cable TCL Requirements	
Frequency (MHz)	**Minimum TCL (dB)**
1-10	40
25	36
100	30
250	26
500	23

Table 2 – TCL Requirements for Category 6A Cables per TIA 568 B.2-10

In order to understand the meaning of TCL, see Table 3. An electrical transient on a power line that is running in close proximity to a telecommunications cable induces a common mode voltage on each conductor of a pair relative to ground. For the example shown in Table 3, the induced common mode voltage is 1 volt. A TCL balance of 40 dB means that 1% of this common-mode voltage is converted into a differential mode voltage, or 10 mV between the two conductors of a pair. It is this differential-mode voltage that appears as noise at the input of a transceiver. It is desirable to achieve a TCL balance of 40 dB or better to mitigate the noise coupling from power line transients and other sources of external noise.



$$TCL = 20 \cdot \log\left(\frac{V_{cm}}{V_{dm}}\right)$$

TCL	V_{dm}	V_{cm}
20 dB	100 mV	1 V
30 dB	32 mV	1 V
40 dB	10 mV	1 V
50 dB	3.2 mV	1 V

Table 3 – Differential mode noise (Vdm) for different values of TCL

Example TCL measurements for 100 meters of Category 6A U/UTP cable and Category 6A F/UTP cable compared to the TIA limit line are shown in Figure 3. The Category 6A U/UTP cable provides about 15 dB better pair balance performance over the frequency range from 1 MHz to 600 MHz. Typically the margin is 20 dB better than the TIA cable limits above 100 MHz. The balance performance of screened Category 6A (F/UTP) cable is close to the TIA limit for frequencies above 100 MHz.

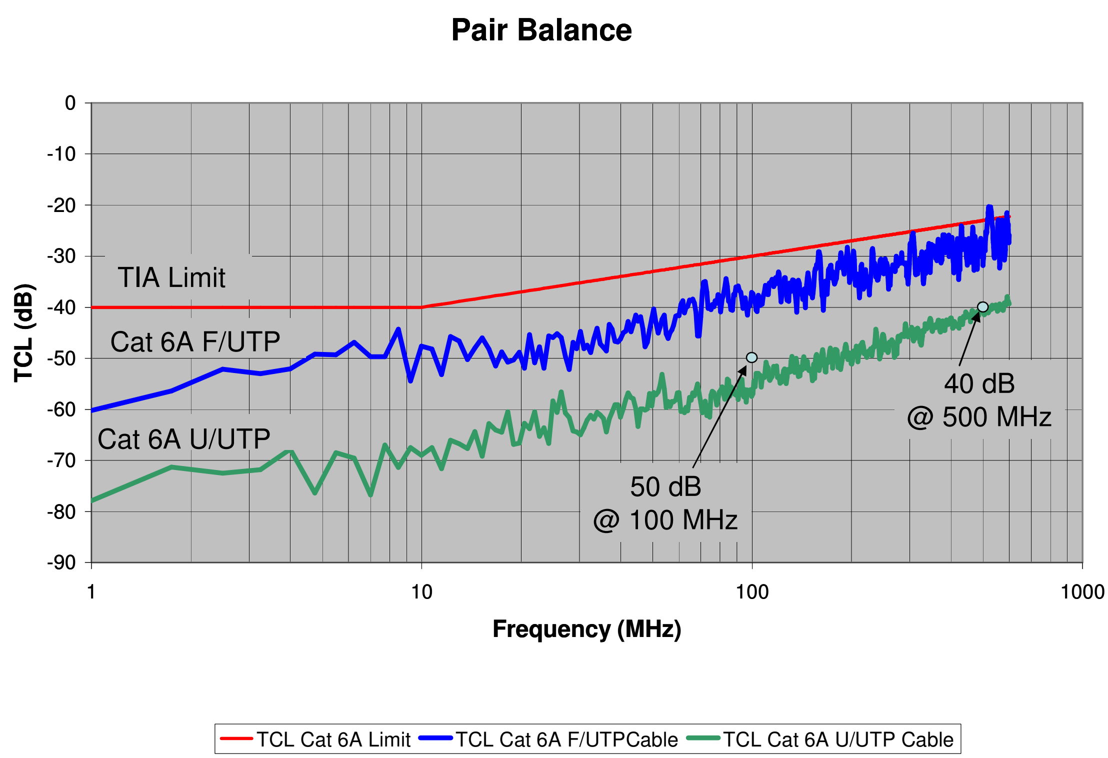


Figure 3 – Example TCL Measurements for Category 6A UTP and ScTP Cables

The reason that the Pair Balance is worse for screened cable is because of the increases in capacitive and inductive coupling to ground and the difficulty to maintain the position and symmetry of the screen during manufacturing and due to bending and installation. It requires a very good design and process to do this properly.

Finally, you may have the best balanced cable in the world, but the Pair Balance performance of the channel can be dragged down by the performance of the connectivity (the mated plug/jack connection). The native RJ-45 plug and jack are inherently unbalanced because of the capacitive and inductive unbalance between the contacts in plug that is not fully compensated in the jack. The method of compensation needs to compensate not only for pair-to-pair crosstalk but also the balance within and between pairs.

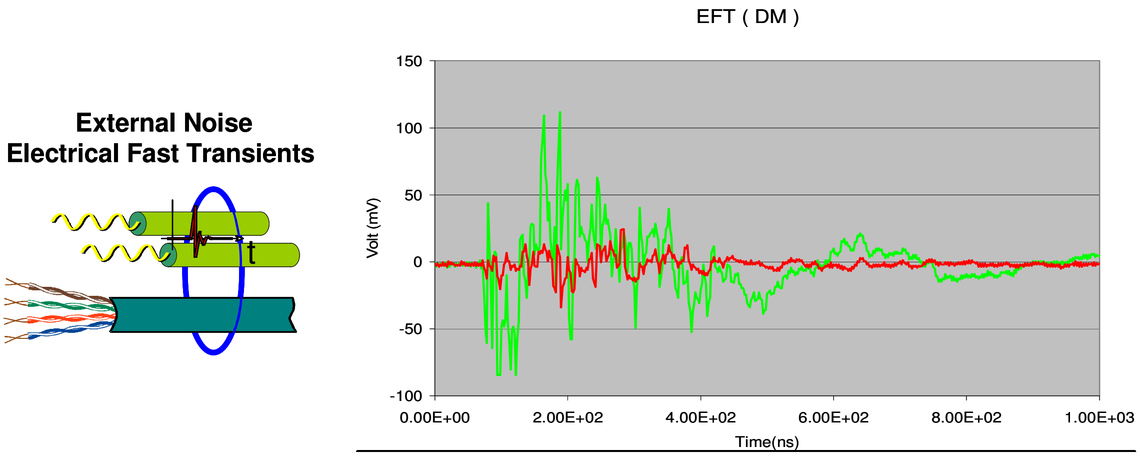


Figure 4- EFT Noise measurements for different connecting hardware

A source of external noise can be a power line that is running in parallel to a communications cable. The power line can have electrical fast transients (EFT) that can be as high as 500 volts for a commercial environment and 1000 volts for an industrial environment. These transients are caused by rectifiers, switching power supplies, motors, dimmers, etc. In our labs, we simulate this noise source using an IEC standard EFT noise generator.

EFT tests were performed on a Category 6A UTP permanent link using different connecting hardware at each end. Noise was injected on a power cable that was taped alongside the data cable for a distance of 10 meters. This is much worse than the 2 inch separation distance that Belden recommends in our IBDN installation guidelines. The reason for this is to provide a worst case comparison of the noise coupling resulting from the pair balance of the cable and connectors.

The results of this experiment are shown in Figure 4. The green curve is the noise measured using Vendor A connector. The red curve is the same test using a Belden 10GX connector. The peak noise voltage is about 110 mV using Vendor A connector compared to about 30 mV using 10GX connector. For these conditions a 500 volt transient was applied over the power cable. Although these test conditions are quite severe and would be significantly less for a power separation of 2 inches, it does illustrate the importance of a well balanced connector design to ensure very good noise immunity.

Ground Loops – Grounding at both ends

Last but not least is the problem of ground loops. In consulting the literature, it is reported that a vast majority of all EMC problems have inadequate grounding as the main culprit. And as you can see from the earlier charts having a low DC resistance #6 AWG conductor does not ensure a low impedance path to ground at high frequencies.

Ground loop is a problem when a cable shield is terminated at both ends to a local ground and a remote ground. A ground potential difference between these ground points can cause stray currents to flow in the shield and couple noise into the signal conductors.

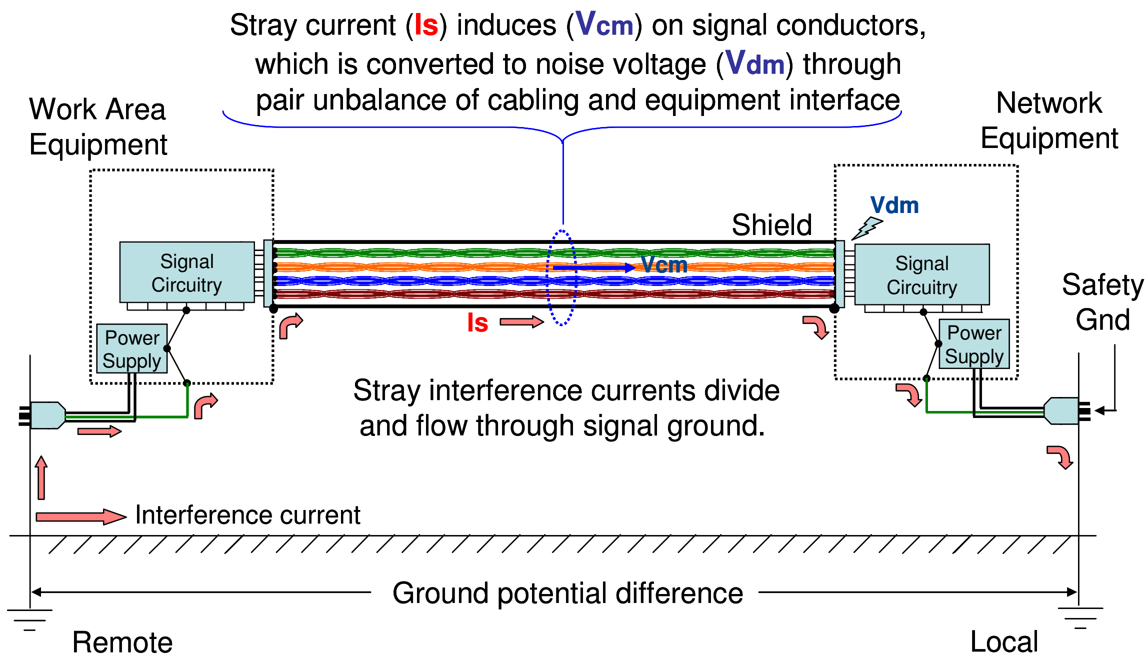
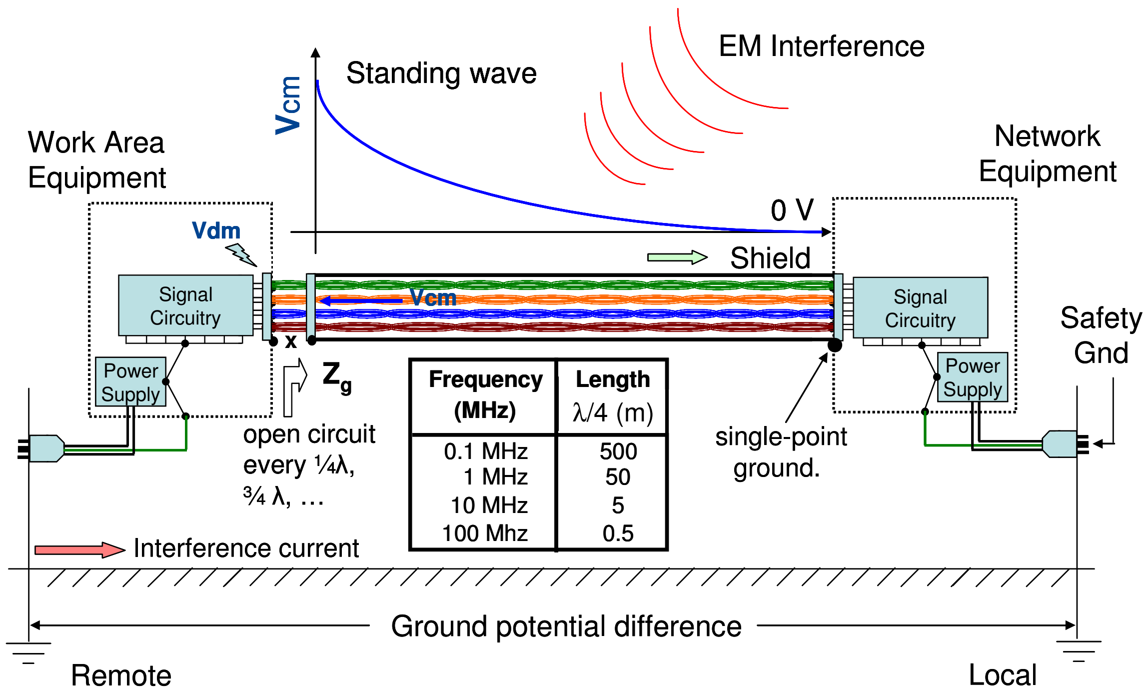


Figure 5 – Interference Currents due to ground loops

What size of ground potential difference problems we are talking about: TIA and ISO standards are speaking about Common Mode Noise of a maximum of 1 Volt in "well grounded" plants. Literature is also speaking of the current measured on a main service grounding (in a large building) in terms of Amps. These currents are an accumulation of all the stray ground currents throughout the building.

What can those grounding currents and voltage differences do? Small voltage differences just cause noise to be added to the signals. This can cause humming noise to audio, interference bars to video signals and transmission errors to computer networks. Higher currents can cause more serious problems like sparking in connections, damages to equipment, heating cables and burned signal cables.

Ground loops - Grounding at one end only



Frequency (MHz)	Length λ/4 (m)
0.1 MHz	500
1 MHz	50
10 MHz	5
100 Mhz	0.5

Figure 6 - Effects of a standing wave on a single-point grounded cable shield

One way to avoid the problem of ground loops noise currents flowing in the shield is to ground the shield at one end only. However this solves one problem but creates another. A single ended ground does not work at high frequencies because of signal propagation and standing wave effects at the end of the cable when the screen is floating.

The input impedance of a screen that is grounded at one end, as illustrated in Figure 6, looks like an open (infinite impedance) at the opposite end of the cable at a quarter wavelength and at every odd multiple of a quarter wavelength. At 100 MHz, a quarter wavelength corresponds to ½ a meter of cable, which is quite short indeed. At those resonant frequencies a maximum voltage (standing wave) is induced on the shield in the presence of EM interference. Grounding the screen at one end, works well for audio signals (less than 20 kHz) because these standing wave effects do not occur for cable lengths that are shorter than 1 km.

All that being said, it does not mean that a floating shield cable can not be effective to reduce external noise coupling. It all depends on the pair balance of the cable conductors. It is possible to design and manufacture screened twisted pair cables with much better pair balance than indicated in figure 3. For example, Belden uses a patented floating screen design for its 10GX patch cords. The essential elements of the design include a circumferential screen that is interposed between the two jackets. The stable position of the screen and the bonded-pair construction ensures an electrically-balanced design that is the key to ensuring exceptional EMC performance. For more information consult a Belden white paper on this subject, reference [4].

Summary

a) Unshielded cabling solutions

LAN cabling is predominantly UTP, and the design and installation practices for UTP are much simpler, better known and more widely used by technicians and throughout the cabling contractor community. There is much less experience with shielded cabling in North America, with less than 3 % of network cabling installations utlilizing shielded products and techniques in 2007.

IEEE's 10GBASE-T Ethernet standard does not require screened cabling. In fact, one of the development criteria for this standard was operability over UTP cabling in order to leverage and protect both the installed-base and the knowledge-base in the market. Category 6A UTP complies fully with 10GBASE-T requirements for worst case channels up to 100 meters and for 30 meter short reach mode operation

Category 6A UTP cabling can offer a very significant improvement in noise immunity, because of better pair balance characteristics and the elimination of problems due to ground loops. Pair balance performance is about 10 to 15 dB better than what is currently specified in the TIA Category 6A standard.

b) Shielded cabling solutions

Screened cabling relies heavily on the reliability of three subsystems.

1) Signal transmission integrity

2) Shield integrity and quality of shield terminations

3) Building bonding and grounding system

Proper shielding terminations are critical to ensure good electromagnetic shielding performance, including alien crosstalk performance. In one example, a shielded system failed the Category 6A alien crosstalk requirements because the foil connection did not make good contact with connector housing. Although shield continuity was present because of the drain wire, leakage around the connector housing was significant enough to cause alien crosstalk failures.

Shielded cables are more susceptible to performance degradation because of the deformation of the screen during installation. There are currently three different types of shielded systems: F/UTP, U/FTP, S/FTP. Not all are compatible with each other; and there are trade-offs in performance and shielding effectiveness.

Certain “Category 7” connectors are not backward compatible with 8-position (RJ-45) modular plugs and require a proprietary patch cord.

Generally speaking, network installation time and labor costs are higher for shielded systems due to the additional time required to terminate each shielded connector.

The shield needs to be grounded at both ends through a low impedance ground to work effectively at high frequencies. A ground at one end only looks like an open circuit at a ¼ wavelength and at odd multiples of ¼ wavelength. At those frequencies, the screen acts as an antenna, not a barrier, leaving only pair balance as an effective countermeasure against EMI and network performance degradation.

References:

[1] High-Speed Digital Design *On-Line Newsletter* Dr. Howard Johnson, Vol. 2 Issue 2

[2] Noise Reduction Techniques for Microcontroller-Based Systems by Imad Kobeissi, Freescale Semiconductor

[3] “Using Grounding to Control EMI”, William D. Kimmel and Daryl D. Gerke, Medical Device & Diagnostic Industry Magazine, originally published August, 1996

[4] “EMC Performance For 10GBASE-T over Category 6A Cabling” by Paul Kish, Belden white paper - http://www.belden.com/pdfs/Techpprs/WP_10GigandEMI28Apr06.pdf