Nexans	Importance of Cable Balance For Improving Noise Susceptibility
Data Communications Competence Center	DCCC03101702 July 11, 2007

Summary

In a study of category 5e and category 6 UTP cables, a strong correlation is found between noise immunity and balance. Evaluation of cables using Longitudinal Conversion Loss (LCL) for cable balance and Electrical Fast Transient (EFT) noise to assess noise susceptibility demonstrates that well balanced cables are much less susceptible to external noise. Category 6 UTP cables are shown to have better balance than category 5e UTP cables indicating that category 6 cables minimize the number of errors due to noise on Ethernet data traffic.

Background

What is cable balance and how is it measured?

Cable balance is an important parameter in modern high-speed computer networks. In category 5e or category 6 cables, the pairs are twisted to improve the immunity to noise and crosstalk as well as reduce emissions. The cable is designed so that the impedance of the two wires of each pair is balanced relative to ground. Ideally, unwanted noise and crosstalk is coupled equally onto both conductors of a pair and subtracted from the signal by the differential receiver in the switch or network adapter. In the real world, pairs are not perfectly balanced so the receiver is unable to remove all the noise – leading to possible errors and reduced network reliability.

Longitudinal Conversion Loss (LCL) is a measure of well a pair is balanced and provides a useful metric of a cable's ability to reject noise from external sources and to limit electromagnetic radiation from the cable to the environment. Examples of external noise sources include noisy power lines and electrical equipment, walkie-talkies, radio and radar stations, and alien cross talk from other telecommunications cables. As structured cabling is applied in industrial environments and as network speeds increase, balance is becoming increasingly important.

The importance of balance in UTP is demonstrated by the recent standards activities related to balance. The Telecommunications Industry Association (TIA) has made recommendations concerning balance of cable and connectors in the category 6 standard (TIA/EIA-568-B.2-1). The TIA TR-42.7 Balance Task Group is currently studying cable balance measurement methods and recommended specifications.

In the test procedure currently recommended by TIA, longitudinal conversion loss (LCL) is measured using a network analyzer by injecting a "differential mode" signal between the wires in a pair and measuring the resulting "common mode" noise signal between the pair and ground. LCL is the ratio between these signals expressed in decibels (dB), with higher values indicating better balance. By optimizing cable design and manufacturing processes, manufacturers can manufacture cables with enhanced balance.

What is EFT and why is it used to measure noise susceptibility?

The EFT test signal was originally developed to test susceptibility of electrical devices to high-voltage spikes on power lines. The EFT pulses, as specified in International Electrotechnical Commission (IEC) 801-4, are a good representation of real noise on power lines. Such noise is typically generated by office equipment (particularly equipment with electric motors) and switching transients for fluorescent lighting.

The frequency content of the EFT pulses is within the bandwidth of modern computer networks and cabling systems. Since EFT noise is both common in a commercial environment and occupies the same frequencies spectrum as the network signals, EFT noise susceptibility measurements performed on data cables with controlled separation to a power cable provide a good indication of overall noise immunity of cabling systems.

Test Setup

Cable Selection

1000-foot spools (or boxes) of 14 different cables were procured from distribution. These included seven category 5e and seven category 6 cables from six different manufacturers. Three 100-meter lengths were cut from each spool and subjected to both balance and EFT testing.

Balance Measurement

Cable LCL was measured in accordance with TIA/EIA-568-B.2-1 Annex D and compared to the recommended limit in clause 7.6.1.1 of the same document:

$$LCL_{cable} \geq 30 - 10\log\left(f/100\right) dB$$

with values above 40 dB reverting to 40 dB. Please note that while this recommendation applies only to category 6, it was also used it for comparison purposes for category 5e.

EFT Noise Susceptibility Measurement

Each cable was shortened to 90 meters, terminated to connectors of the appropriate category, and the resulting link connected to ports of a Gigabit Ethernet switch using patch cords. The switch was connected optically to two ports on an Ethernet LAN analyzer. Full duplex, Gigabit Ethernet traffic (1000BASE-T) was passed over the link. 10 meters of 12-2 type NM power cabling was placed with minimal separation next to one end of the link and was in turn connected to the output of an EFT generator. The test setup is shown schematically in Figure 1.

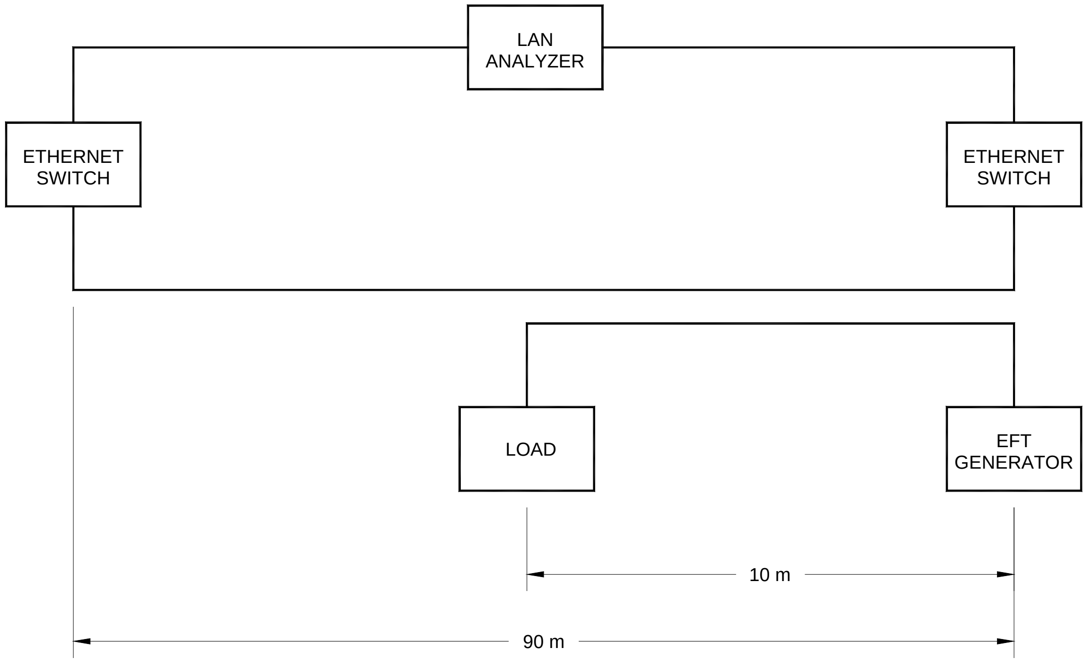

Figure 1: EFT noise immunity test setup

At increasing EFT voltage settings, Gigabit Ethernet packets were sent containing a total of 10^{11} bits and the number of errors recorded. Using the total number of EFT pulses during the test time, a ratio between errors and noise pulses was calculated and graphed.

Test Results

Cable LCL

A significant difference was seen between category 6 cables and category 5e cables as a group, with the category 6 cables performing much better than category 5e cables. The single exception was one category 6 brand which had the worst performance of all cables tested. It is noted that all samples exceeded the recommended LCL limit in TIA/EIA-568-B.2-1.

Figures 2 and 3 show the LCL performance of the worst and best cables compared to the recommended limit for category 6.

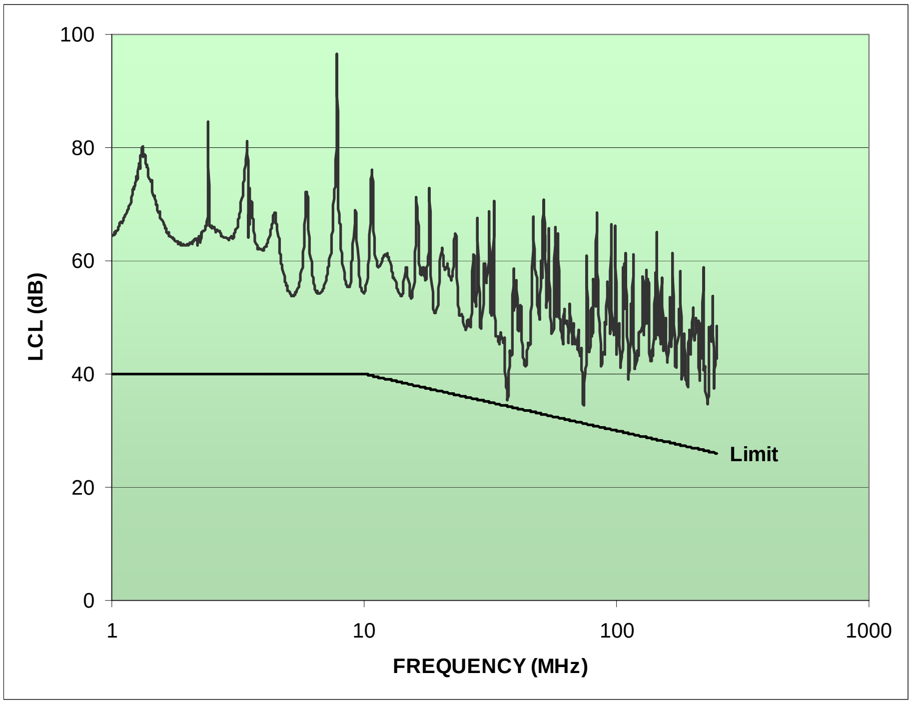

Figure 2: LCL measurement for worst category 6 cable

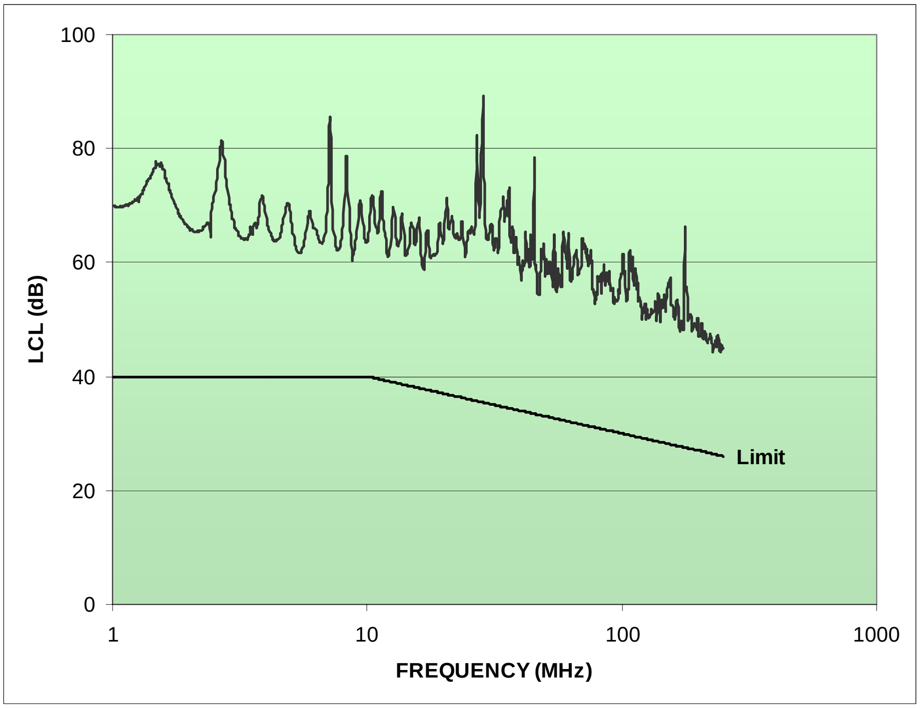

Figure 3: LCL measurement for best category 6 cable

The best cable, a category 6, had nearly an 18 dB margin. The category 5e samples exceeded the recommended limit by less than 8 dB. The worst cable meets the recommended limit with a margin of 1 dB.

EFT Noise Susceptibility

Similar to the balance results, category 6 cables outperformed category 5e in the EFT noise susceptibility tests. The one exception was the same brand of category 6 that had exhibited the worst LCL performance.

Figure 4 shows EFT noise susceptibility for the best category 6 cable, typical category 5e, typical cat 6 and the worst cable. The worst sample, a poorly balanced cable, begins to experience errors at just over 10 V induced common mode noise. The typical category 5e cable was almost twice as good with errors beginning at about 20 V. The best category 6 cable was better still. It achieved nearly error free performance with 40 V induced common mode noise. At this noise level all of the category 5e samples had 100% errors per pulse.

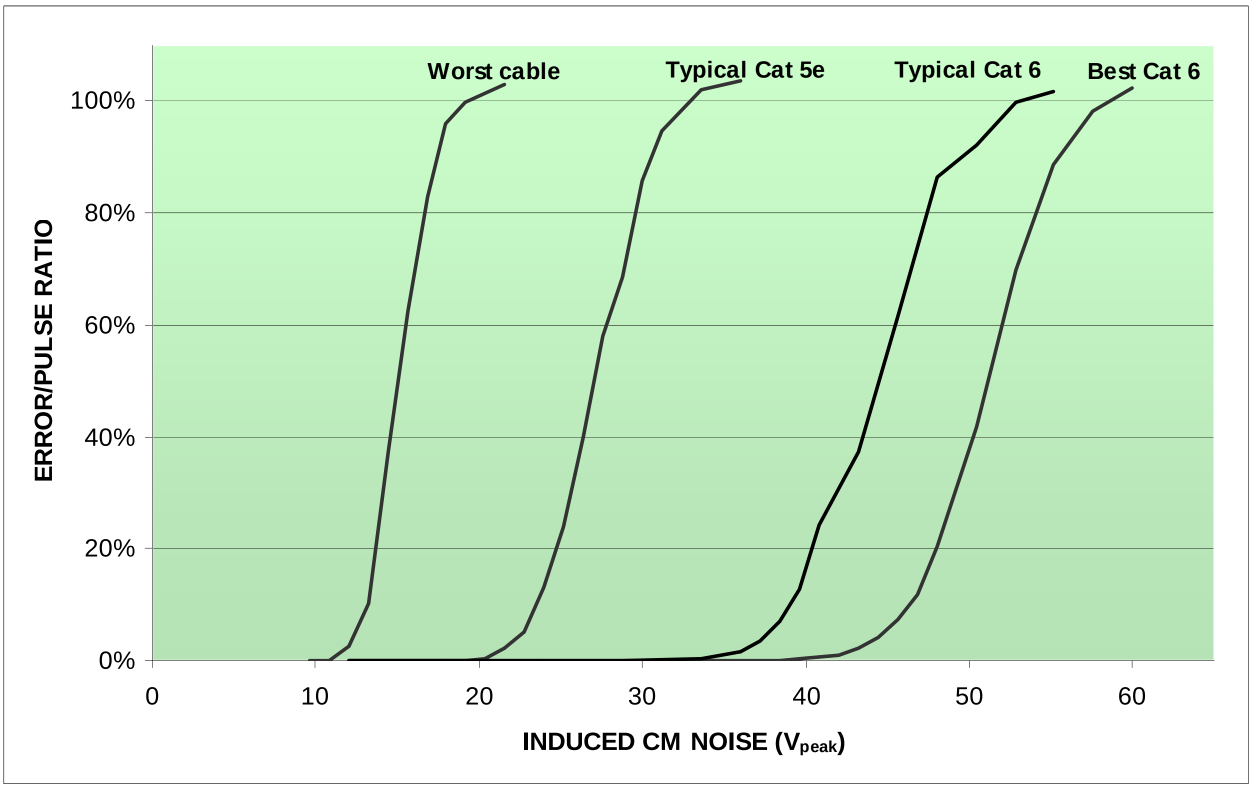

Figure 4: EFT noise susceptibility measurements

Correlation of EFT Noise Susceptibility and LCL Measurements

For each cable sample, the voltage where the ratio of errors to noise pulses equaled 10% was calculated. These voltages were graphed in a scatter chart vs. cable LCL margin above the recommended limit. Figure 5 shows the correlation. The trend line was derived using linear regression across all samples.

As a group, the category 6 cables with LCL margins of more than 10 dB performed much better than the category 6 cables with lower margins and all the category 5e cables.

Note that all three samples of the worst category 6 cable are in the lower left corner of the chart showing poor balance and poor EFT susceptibility performance.

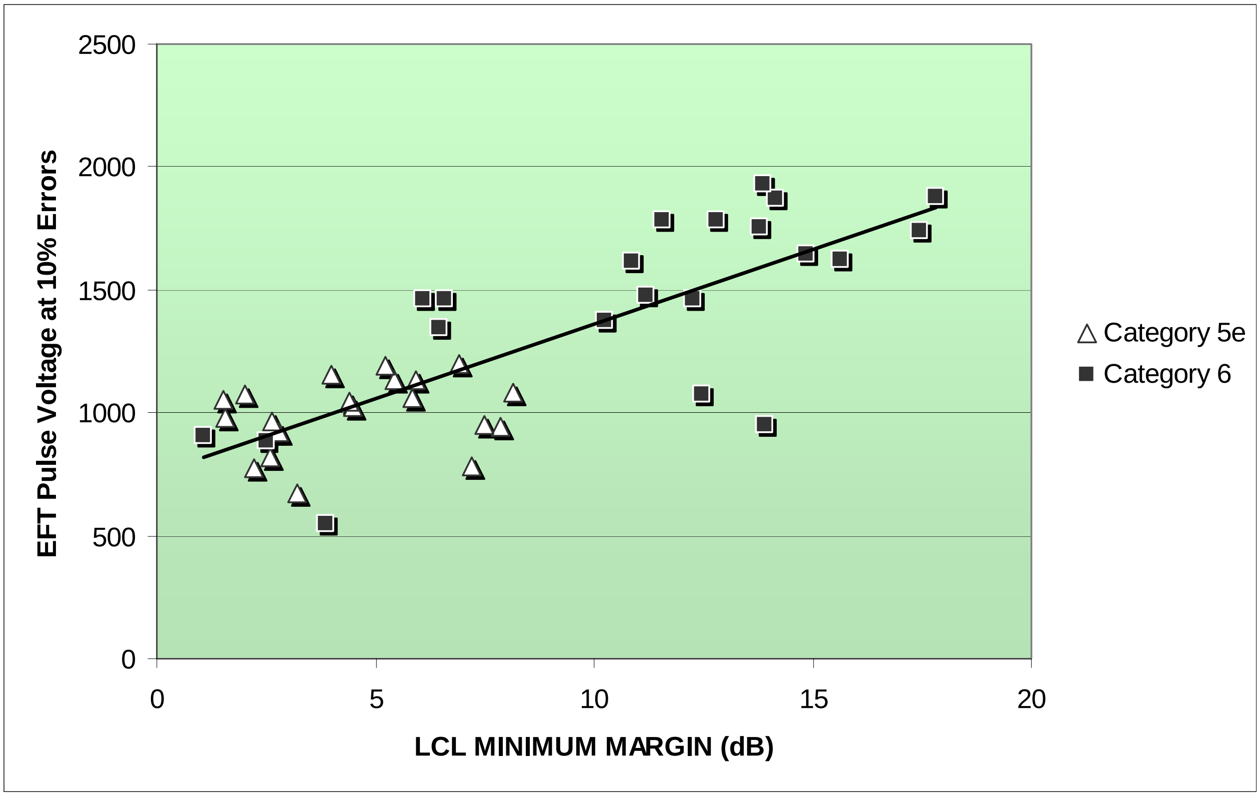

Figure 5: Correlation of EFT noise immunity and LCL measurements

Conclusions

There is a strong correlation between cable balance (LCL) and the threshold noise voltage at which network errors occur. A direct relationship between balance and noise immunity is shown with better balanced cables corresponding to better noise immunity.

In general, category 6 cabling provides better balance and immunity than category 5e cabling. However, not all category 6 cables provide this extra protection showing the differences in cable design and manufacturing consistency. This also occurs because the current recommended limit in TIA/EIA-568-B.2-1 is not mandatory and is too low.

As Ethernet networks move into the industrial environment, they can be exposed to much higher noise voltages than are seen in an office environment. Draft documents from TIA TR-42.9 (Industrial Telecommunications Cabling) require EFT testing to voltages up to four times higher than for commercial equipment.

Gigabit Ethernet implementation is increasing. In addition, IEEE 802.3 has formed a study group to determine the feasibility of 10 Gigabit Ethernet over copper cabling which is expected to become the P802.3an task group in early 2004. The increased data rate will require higher signaling speeds and more complex encoding resulting in increased susceptibility to external noise.

Balance for the current Gigabit Ethernet networks and the developing Industrial Ethernet and 10 Gigabit Ethernet will gain noise immunity from better balanced cables. For the best performance, category 6 cables with at least 10 dB of margin above the existing limit should be specified.

Table 1: Definitions of Acronyms

Abbreviation	**Description**
EFT	Electrical Fast Transient
EIA	Electronic Industry Alliance
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
LAN	Local Area Network
LCL	Longitudinal Conversion Loss
TIA	Telecommunications Industry Association
UTP	Unshielded Twisted Pair

Data Communications Competence Center

Nexans' Data Communications Competence Center, located at the Berk-Tek Headquarters in New Holland, Pennsylvania, focuses on advanced product design, applications and materials development for networking and data communication cabling solutions. The Advanced Design and Applications team uses state-of-the-art, proprietary testing and modeling tools to translate emerging network requirements into new cabling solutions. The Advanced Materials Development and Advanced Manufacturing Processes teams utilize sophisticated analytical capabilities that facilitate the design of superior materials and processes. The Standardization and Technology group analyzes leading edge and emerging technologies and coordinates data communication standardization efforts to continuously refine Nexans' Technology Roadmap. An international team of experts in the fields of cable, connectors, materials, networking, standards, communications and testing supports the competence center. The competence center laboratories are a part of an extensive global R&D network that includes eight competence centers, four application centers and two research centers dedicated to advanced technologies and materials research.