Performance Comparison of Reduced Diameter Category 6A Cables

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Abstract

This paper describes the performance of various reduced diameter Category 6A cable designs in electrically noisy environments. Noise immunity of cables is becoming more important due to enhanced Ethernet link speeds of 2.5Gb/s and higher that require low noise to properly perform. HDBaseT applications at 4k resolutions also stress the noise immunity performance of all Category cables. There are several approaches to achieve Category 6A cables with reduced diameter that also offer improved alien crosstalk. However, it has been found that alien crosstalk is not a good predictor of performance in an electrically noisy environment among the different design options for reduced diameters. This paper explores the noise immunity of two different types of barrier designs over the core, and provides comparisons with standard UTP and F/UTP designs. Testing included the effects of the external electrical noise on a 10Gb/s Ethernet link and a HDBaseT link at up to 2160/30p resolution.

Keywords: EMC; shielding; shields; category cable; 10Gb; 5Gb; 2.5Gb; HDBaseT; alien crosstalk; RF immunity; UTP; F/UTP; discontinuous

1. Introduction

This paper expands on work presented at the 2016 IWCS conference. Additional and new test results are included, and new cable designs have been tested and compared. A new cable construction designated 'Barrier Design E' has been added. Also, HDBaseT BER testing across several of the different cable designs is new to this paper.

Such testing is important because copper Ethernet BASE-T continues to move forward with enhanced standardized data rates such as 2.5Gb/s, 5Gb/s, 10Gb/s. However, each of these standards are based on the complex 16 level encoding scheme that requires a high signal to noise ratio. External noise, whether from adjacent cables or from other noise sources, are known to be a limiting factor in establishing and maintaining reliable link performance.

HDBaseT applications are a growing segment within Category cables, and this protocol is also sensitive to electrical noise induced on to the cable system. New data is included for bit error rates at various video resolutions.

Electrical interference noise from adjacent cables through alien crosstalk is well known. Guidelines and specifications are established in the industry for adjacent cable alien crosstalk requirements. Given the known weaknesses in cable noise immunity, alien crosstalk mitigation techniques are still being developed in the standards bodies to allow a broader range of cables to support higher data rates.

The mechanism of alien crosstalk coupling and coupling from external noise sources is quite different. Cables are available that include an isolation barrier over the cable core which significantly improves alien crosstalk performance. However, due to the different coupling mechanisms for electrical noise, alien crosstalk is not a good predictor of immunity to outside electrical noise. A further study was conducted on different 'barrier' type configurations to measure the voltages induced on the pairs from external electrical fields, as well as the effect on an active data stream. For a comparison, identical testing was also conducted on conventional UTP and F/UTP type constructions.

Several cables were manufactured by Hitachi to evaluate differences between the cable designs. The testing was conducted to identify those cable designs that improve alien crosstalk beyond Category 6a requirements, and provide immunity performance that is equivalent (or better) to that of Category 6A UTP cabling. It is possible for a design to have robust alien crosstalk performance, yet have degraded immunity to external noise.

2. Noise Environments

Electrical noise induced on category cables comes from a wide array of sources. Motors, ballasts, relays, wireless communications, and many others can result in high electrical fields around and along an installed length of cable.

The 'MICE' concept is outlined in the TIA 1005 standard which describes the Mechanical, Ingress, Climatic/Chemical, Electromagnetic (MICE) environment. The MICE concept is also adopted in several other standards that are concerned with the effects of external electrical noise.

The MICE table for the electrical environment includes immunity against levels of radiated RF signals of 1, 3, and 10 Volts per meter. These levels were chosen for the testing that was conducted.

A key purpose of the testing was to identify cables that perform well in a range of electrical noise sources including the influence of alien crosstalk.

3. Background and Testing Protocol

As in the 2016 IWCS paper, RF immunity testing was patterned after IEC 61000-4-3. The test cable was placed on a non-conductive test frame within the chamber and placed in the plane of the calibrated electrical field. The cable length was 90 meters for the 10Gb/s testing and 80m for the HDBaseT testing. The unused portion of the cable on the reel was placed in the corner of the chamber. The cable was direct attached to the BER test sets using field installable plugs.

The electrical field was unmodulated RF, with the frequencies stepped across the range of 80 to 680Mhz in 10MHz steps. Electrical fields of either 1, 3, and 10 Volts/meter were chosen for the cable testing which match the MICE environmental guidelines.

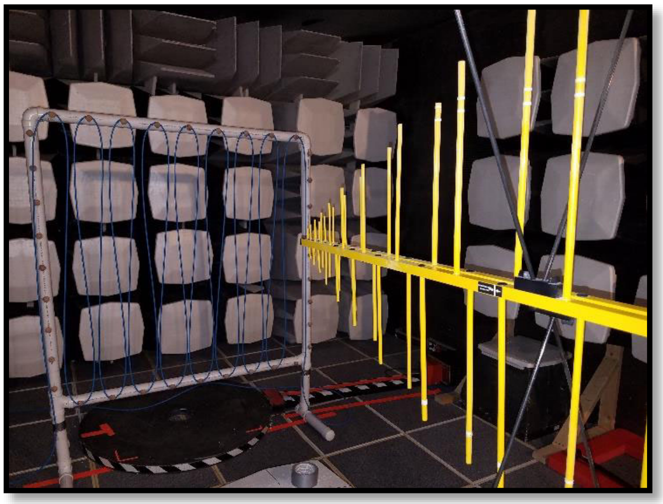

Figure 1. RF Immunity Test Configuration

Common mode coupling to the pairs is of significant interest, since the frequency response and strength of the coupling to each of the wires in the cable can vary widely with different core and barrier designs. Only F/UTP cables are designed with the intention of significantly reducing common mode pair voltage.

Common mode coupling from the environment is important because the common mode rejection capability of the attached electronic devices could be a limiting factor in the link performance. The common mode energy will be induced on attached electronic devices, independent of the amount of pair balance in the system.

Figure 2. Cable arrangement within chamber

4. Cable Constructions

The cable constructions manufactured for testing consisted of 4 pair cables. Each cable consisted of the pairs and central separator cabled together in a round configuration. The cables were compliant to TIA-568-C.2 internal electrical requirements, and all cables tested were also compliant to alien crosstalk testing.

There are four constructions tested in this paper.

Design U – Conventional UTP Category 6A

Design F – Conventional F/UTP Category 6A

Design D – Discontinuous segment barrier 6A

Design E – Encapsulated conductive barrier 6A

Several variations of Design D have been manufactured and tested, and some of the comparative results are included in the 2016 IWCS paper. For this paper, the chosen variation of design D resulted in some of the highest noise immunity performance results among the discontinuous designs available.

Design U **Design F**

Figure 3 – Cable Designs U and F

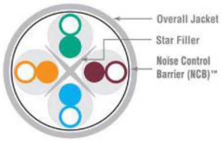

Figure 4 – Designs D and E

5. Test Results

5.1 Pair Balance Performance

Pair balance was measured to better understand how balance can predict immunity against outside electrical noise. The testing was done on the 90m lengths of cable, using a conventional balun based system with a network analyzer.

For all cables, including the F/UTP and UTP designs, the pair balance met the TIA requirements with a comfortable margin. None of the cables exhibited a significantly different structure to the response curve.

Figure 5 includes the TCL performance as a ‘worst case’, using the lowest value of balance of any pair in the cable at each frequency. It is important to note the similarity of all cable designs, particularly as the data later in the paper shows significant differences in other balance and noise immunity properties among the different cable designs. Pair balance turns out to be a poor predictor for other types of noise immunity.

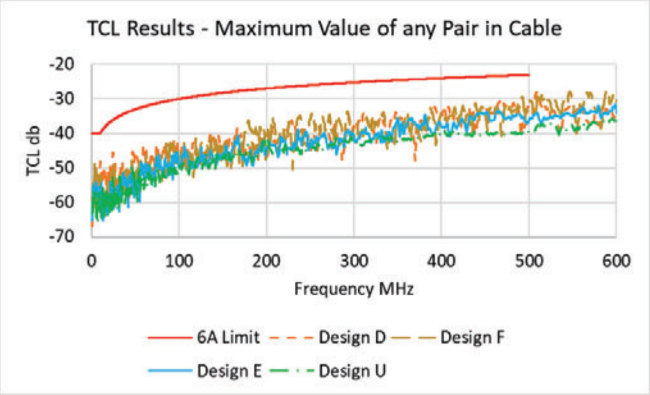

Figure 5 Worst Case TCL for each cable design

5.2 Alien Crosstalk Performance

The alien crosstalk performance of the cable designs varied widely, depending on the overall construction. This is due to the very different coupling mechanisms from cable to cable, with different proportions and magnitudes of common mode and differential mode coupling.

The impact of the cable designs with a barrier are quite evident in Figure 6. Standard UTP cables exhibit a response curve typical of the relatively larger diameter cables available in the industry. The barrier designs alter the type of coupling from one cable to another and have dramatic reductions in alien crosstalk coupling, even with a smaller diameter. In the case of barrier design E, the alien crosstalk performance essentially matches that of design F. This chart shows the worst-case results of all pairs within the cable. There was no significant difference in overall response among the pairs in any of the cable designs.

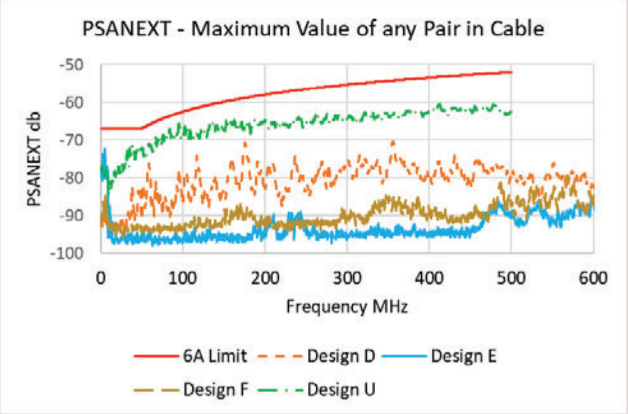

Figure 6. PSNEXT – Worst Case for each design

5.3 Coupling Attenuation

Coupling attenuation is another test method that measures mode conversion for communication cables. The absorbing clamp method was used for all UTP type cables and the tri-axial method was used for design F. The coupling attenuation was conducted on 90m lengths of cable, with absorbing clamps to measure the common mode signal generated by the cable characteristics.

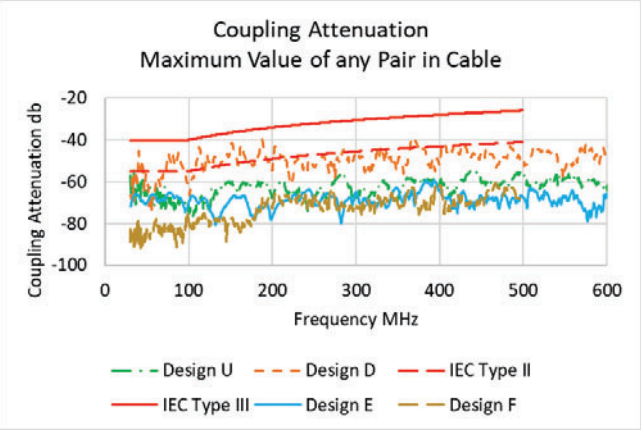

Figure 7. Worst Case Coupling Attenuation for each cable design

Figure 7 includes the ‘worst case’ pair coupling attenuation performance of each cable across all 4 pairs. Coupling attenuation provided a very different picture across the cable types tested. It is an important observation that three of the four cables had relatively similar results. Design D was an outlier, resulting in worse coupling attenuation across the frequency range. Coupling attenuation for design U was well controlled across the frequency range, and measured with only slightly worse coupling attenuation than designs E and U. Designs E and design F had essentially the same performance. Although the chart shows the worst case results of all pairs, there was no significant difference in overall response among the pairs in the cable.

The noise immunity data later in the paper does show some correlation to the coupling attenuation ranking, while the pair balance and alien crosstalk show no such correlation.

5.4 10Gb/s BER Testing Results

The 10Gb test system has several different indicators for link status and performance. It was discovered that some of the ‘link stress’ on the physical interface device are not directly reported at a high level on the software test system. Specifically, the network card indicators would show link stress, while the reporting software was taking in to account error correction effects. In severe cases of interference, the network card would be re-setting with no data transfer, while the software would not show a problem while waiting for the link to be re-established.

The indicators on the physical network cards were used as the key measures of link stability and to measure the interference to the link. These indicators light up red when packet and link losses occur within the network card hardware.

By tabulating the events as shown on the network card itself, meaningful measures of the extent of the interference on the 10Gb data link can be summarized. There are two types of events of importance. Packet loss is less severe and indicates rapidly recoverable errors or packet retransmissions. On the other hand, link loss terminates data transmission and requires the system to reset the timing clocks and resume data transmission. The link loss is the more severe effect of excessive noise on the cable.

The network card indicators were recorded during the test, and for each frequency hold period, the ‘worst’ condition of the indicators was registered.

The frequency was stepped in 10MHz increments from 80 to 680MHz, with a hold period of nominally 10 seconds. This resulted in 61 'hold periods'. At each hold period, the worst case link status was recorded. The status was 'good', 'packet loss', or the most severe 'link loss'. With this summary method, there are a maximum of 61 of occurrences of the status events.

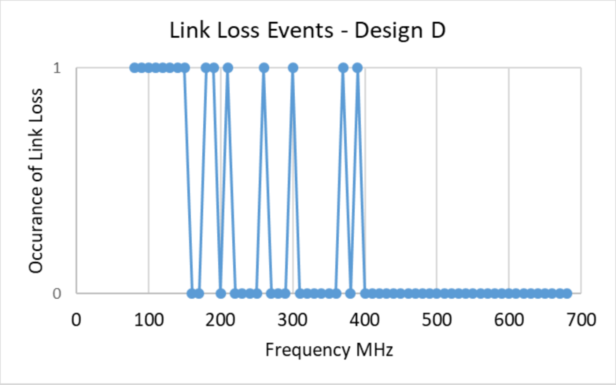

Figure 8. Frequency Dependence of Interference

The response to the interfering signal was dependent upon the frequency. At frequencies above 500MHz, the effect on the data loss was reduced, and many steps above about 500MHz showed no effect at all. This is expected, since the spectrum of the 10Gb/s encoding extends very little beyond that frequency. And internal filters in the network cards are likely reducing noise effects as well. An example of this effect at 3 Volts/meter is shown in Figure 8.

Figure 9 summarizes the data at 1V/m, which is the least severe level of interference in the MICE table. Only design D was affected at 1V/m by the induced field. At this level of MICE 1, the other designs did not suffer any link or packet disruption events.

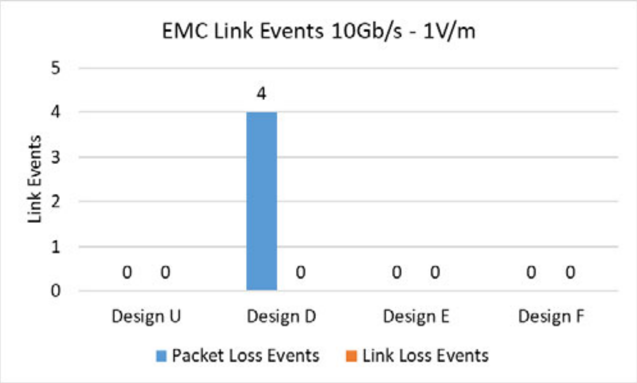

Figure 9. Packet and Link loss count at 1V/m

However, at 3 Volts per meter field strength, the effect on the 10Gb/s stream is much higher as shown in Figure 10.

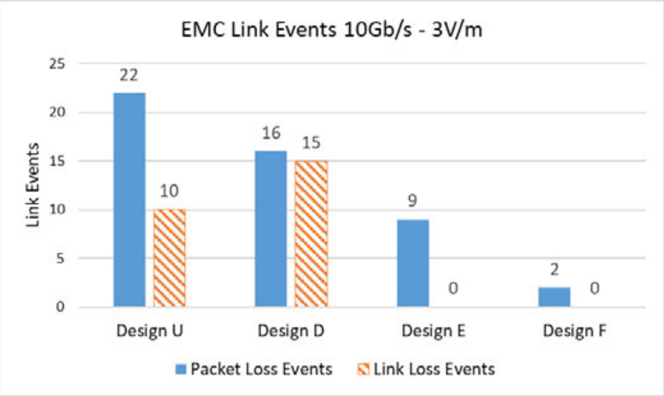

Figure 10 – Packet and Link Loss count at 3V/m

Link loss is a more severe disruption than packet loss, so there tended to be fewer link loss events than packet loss events. It is notable that at 3V/m only design E and design F experienced no link losses at any of the frequency steps. Design D containing a barrier experienced more packet loss events than design U.

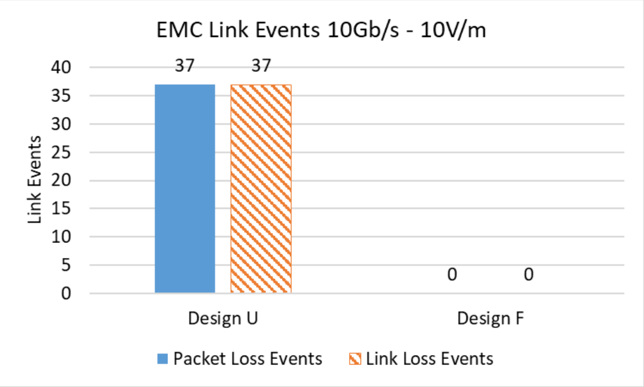

Figure 11 – Packet and Link Loss count at 10V/m

Testing at 10V/m was suspended before all the cables were tested because only Design F withstood the voltage field without essentially continuous disruption of the 10Gb/s data stream. As shown in Figure 11, at 10V/m, the 10Gb link was effectively shut down with cables other than design F. At this level of interference in this test, it was difficult to discern differences in noise immunity among the different designs.

5.5 HDBaseT BER Testing Results

It is of interest to measure the Bit Error Rate for HDBaseT applications as well. The energy spectral density and signaling protocol is quite different compared to multi-gigabit Ethernet. The investigation is useful to compare the performance of different cables, but it is also useful to compare the sensitivity of the protocols to outside electrical interference.

Cables were tested in the same chamber and configuration as the 10Gb Ethernet data. The cable was placed on the same dielectric frame used for the 10Gb Ethernet testing, and the voltage intensity in the chamber was set to 3V/m. The interference voltage was unmodulated CW, and held for a duration sufficient to capture 3 BER readings on the test set.

A Quantum Data model 780C was used to measure the Bit Error Rate at resolutions from 480 to 2160p/30. The cable under test was 80 meters for all HDBaseT test samples. At each interference frequency, three separate readings for BER were taken and the average of the 3 readings are reported in the following data.

The cables were 'direct attached' to the BER test set using field installable plugs to better measure the influence of the cable design on the level of BER events and eliminate the effects of patch cables and other connectivity.

Design D HDBaseT Results

The bit error rates with Design D are surprisingly higher than with any of the other cable designs. Of the 27 frequency steps from 80 to 340MHz, all except 4 steps resulted in either total loss of signal transmission or reported errors of more than 1 million. Also at several frequency steps, there was no signal transmission at any of the lower resolutions such as 480p. For this reason, Design D is not shown on the following graphs (Fig. 12 & Fig. 13).

Design E, F, and U Results

The data in figure 12 summarizes the number of Bit Errors reported at 2060/30p for the different designs, except for design D. For the 3 designs in the chart, it is notable that there were no bit errors reported at resolutions of 1080 or below.

There were distinct and significant peaks in the error rate that were dependent on the interference frequency. Also, the data reveals significant differences between the cable designs tested.

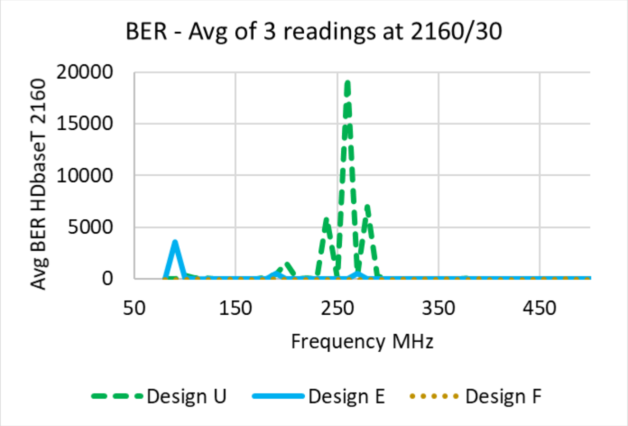

Figure 12. BER count at 2160/30p vs frequency at 3V/m

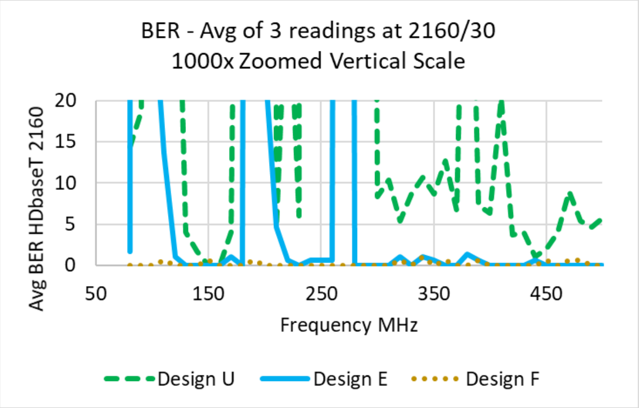

Figure 13. Detail view - BER count at 2160/30p vs frequency at 3V/m

Figure 13 contains the same data, but is 'zoomed in' by a factor of 1000x to reveal the trend of the data where the overall BER was much lower. This view also shows significant differences in BER among the cable types. The error count for design F was zero or near zero across the frequency range. Barrier design E provides notably improved BER rates compared to design U, and barrier design E also performs nearly as well as design F at nearly all frequencies.

This testing also highlights that for HDBaseT applications where signal integrity is critical, either cables with a well-designed barrier or a conventional shield offer measurably superior performance.

5.6 Induced Pair voltages - RF Immunity tests

Differential and common mode pair voltages were captured with a spectrum analyzer. A small breakout circuit board consisted of an RJ45 jack and individual length matched PCB traces for connection to the eight SMA connectors. For each test, six of the SMA connectors were terminated with an SMA 50 ohm load, and cables were attached to the remaining two SMA connectors for pair voltage data capture. At the other end of the cable, the same PCB was used, and all eight of the SMA connectors were terminated with a 50 ohm load.

As the frequency was swept from 80 to 680MHz at 3V/m,, the induced voltage was constantly measured. The peak values at each frequency step are shown the charts below.

For differential mode voltages, the balun input was connected to the two SMA outputs corresponding to the pair conductors. The coaxial balun output was connected to a spectrum analyzer. A BH 040-0229 balun was used which is rated to 1.3GHz, and with a rated longitudinal balance from 60 to 45db at a frequency range of 10Mhz to 1000MHz.

For common mode voltages, two spectrum analyzers were employed such that each conductor is connected and terminated to the 50 ohm input impedance of the analyzer.

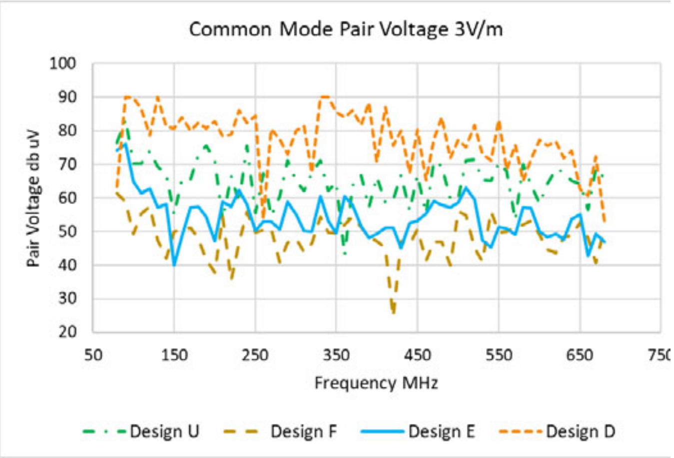

Figure 14. Common Mode Induced Pair Voltages at 3V/m

The induced common mode voltages were substantially different from design to design. The 'stair stepping' of the pair voltages also track the results of the BER testing for 10Gb/s ethernet as well as HDBaseT.

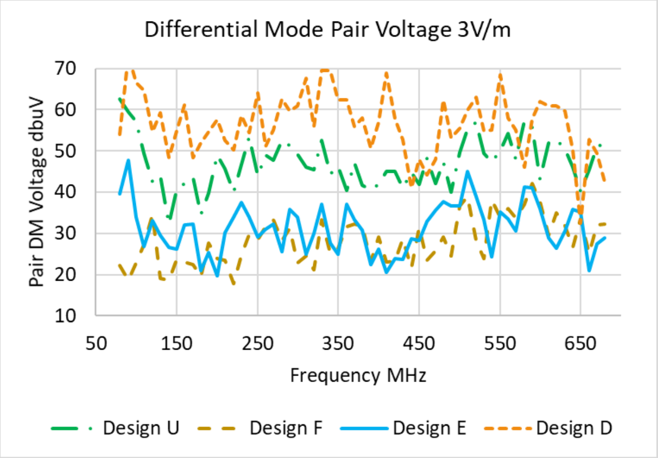

Figure 15. Differential Mode Induced Pair Voltages at 3V/m

The differential mode voltages were at a lower level than the common mode voltages as expected. However, the 'stair stepping' of the voltage levels is similar in magnitude.

Common and Differential Pair voltage observations:

Design D voltages are approximately 30db (1000x) higher than design F.

Design D voltages are approximately 10-15db higher than design U.

Design E and F voltages are the lowest, and are quite similar across the tested frequency range.

Apparent Pair Balance

Pair balance is defined as the difference between common and differential mode voltages. It is of interest to plot the differences of the observed pair voltages and compare to conventional balance test requirements.

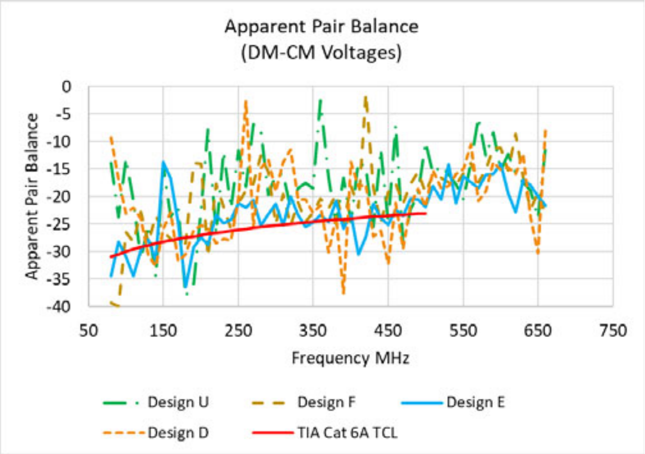

Figure 16 – Apparent Pair Balance (Difference of CM and DM voltages)

The traces in figure 16 shows the voltage difference value at each frequency for the tested cables. The peaks and valleys in the difference values may be expected to some degree due to the type of testing conducted. However, it is significant that all the cable designs resulted in a similar trend line for the apparent balance.

The apparent balance was not as high as the horizontal cable requirement, but this test also included an RJ45 plug and jack at each end of the signal path. It is important to observe that these results are consistent with the laboratory balance results of the cables, which also show remarkable consistency from cable design to cable design.

6. Summary and Observations

6.1 Correlation of link disruption to other cable test results

Pair balance correlations to test results

The pair balance results across all cable samples were quite similar, without notable differences. It is an important observation that cable pair balance results have essentially no predictive capability for the performance of these types of cables in an electrically noisy environment. This result was observed with both the 10Gb/s Ethernet protocol and the HDBaseT signal protocol.

Alien Crosstalk and Noise Immunity Performance

Alien crosstalk is typically improved with the presence of a barrier layer over the cable core. However, different types of barrier constructions can have notably different amounts of susceptibility to external noises in the environment. Importantly, comparing alien crosstalk results does not reliably predict the cable performance in the presence of external noise.

Coupling Attenuation

Coupling attenuation does have correlation to the amount of link disruption. Cables with smoother and more well controlled coupling attenuation performed better in the noise immunity tests. Barrier designs E and F have the better coupling attenuation results and also have the better immunity to external noise.

Induced Pair Voltages

Both common mode and differential mode induced pair voltages are important because each of those voltages are directly induced on the attached electronics and connected channel connectivity. Pair balance parameters such as TCL measure the reduction ratio of differential mode to common mode, but the amount of pair balance has no effect on the common mode signal inflicted upon the attached electronics. A cable design with reduced levels of common mode voltage benefits the performance of the entire channel.

6.2 Coupling Mechanisms

Electrical noise immunity is more related to coupling attenuation type measurements than alien crosstalk measurements. The coupling mechanisms are quite different when considering different cable types and types of testing. The following table summarizes the coupling paths for common mode (CM) and differential mode (DM) interference signals to the cable pairs.

Table 1. Coupling Mechanism for Noise

Coupling Attenuation	CM→DM
EMC Effects	CM→DM
Alien Crosstalk (UTP)	CM+DM→Spacing→CM+DM
Alien Crosstalk (F/UTP)	DM→CM→Spacing→CM→DM

The addition of HDBaseT BER testing in this paper has added another view of the relationship of cable test parameters and cable performance in adverse electrical environments. Because the coupling mechanisms are very different for the different types of established cable test procedures, it is not surprising that results of any one particular cable test are not well correlated with results of immunity testing.

Because the coupling mechanism is the most similar for both coupling attenuation and the effects of EMC interference, the coupling attenuation parameter seems a better measure of EMC performance that the other types of cable tests.

It is quite possible to have a cable with significant alien crosstalk margin perform poorly in a noisy environment. And it is possible for different cables with very similar pair balance to perform very differently in a noisy environment.

7. Conclusions

The testing of the two signaling protocols of 10Gb Ethernet and HDBaseT has added another view of the effects of cable design on noise immunity. Overall, the noise immunity trends among cable designs were similar for both types of signaling.

Shielded category cables offer a level of electrical noise immunity and alien crosstalk unmatched by different types of UTP cables. Whether the interference is from cable to cable, RF signals, or transient noise effects, the F/UTP cables offer consistent and high levels of protection against loss of the communication link due to electrical noise.

However, reduced diameter Category 6A UTP type cables such as design E can provide excellent alien crosstalk performance along with improved noise immunity performance compared to standard 6A UTP constructions.

The testing identified both correlation and the notable lack of correlation of various electrical tests intended to aid in the prediction of noise immunity of cables. These results provide key information to select a UTP type cable design with a balanced combination of immunity to external noise, alien crosstalk, and other key performance parameters.

8. Biographies

Eduardo Garza is the Design & Development Engineering Manager for Hitachi Cable America Inc. He oversees new product development of Copper Premise, Fiber Optic as well as custom Electronic & Power cables. He graduated from Instituto Tecnológico y de Estudios Superiores de Monterrey with a Bachelor’s degree in Mechanical & Electrical Engineering. In addition, he obtained an MBA from Southern New Hampshire University as well as a Master’s of Science in Operations and Project Management from the same University.

Ken Cornelison is an industry consultant with experience in the design, development, and testing of a wide range of copper and fiber optic cables and processes. He was graduated from Rose-Hulman institute of technology with a BSEE in Electrical Engineering, and from Ball State University with an MBA. He has also worked with cable high frequency testing and monitoring equipment, and developed new equipment useful for twisted pair cabling process control. His most recent experience is in the design and development of new category cables with enhanced performance.