CW and EFT Noise Coupling to Category Cables and the effect on 1Gb/s Ethernet traffic

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Abstract

This paper explores the electrical noise immunity and noise coupling of category cables in adverse environments. For industrial environments, typical electrical noise interference would be expected to be transient in nature. Such interference would be caused by sources with intermittent and spectrally diverse signatures in the noise spectrum. It is also expected that noise sources can be quite local in nature, inducing interference along only a small portion of a comparatively long length of communication cable.

Although there are efforts in cabling standards to help reduce the effects of noise effects on cables suitable for 10Gb ethernet traffic (Alien Crosstalk), there are fewer standards that directly deal with effects on 1Gb traffic in severely noisy environments. This paper provides test results for the effect on 1Gb/s Ethernet traffic for a range of category cable designs subjected to different types of electrical noise.

Keywords: EMC; RFI; EFT; Gigabit Ethernet; Common Mode; Differential Mode; susceptibility; immunity.

1. Introduction

The mechanism of alien crosstalk coupling and coupling from external noise sources is quite different. Some cable designs are available that include an isolation barrier over the cable core to significantly improve 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. Although 1Gb/s data rates do not require alien crosstalk mitigation, barrier type cable designs were also tested to measure the voltages induced on the pairs from external electrical fields, as well as the effect on the 1Gb/s active data stream. For this series of tests, several cables were manufactured by Hitachi to evaluate differences between the cable designs.

The testing to measure the effect of electrical noise interference included stepped frequency Continuous Wave (CW) interference at MICE (E3) level of 10V/m as well as Electrical Fast Transient (EFT) interference. EFT testing was chosen specifically for the wide spectral density and randomness of the interfering noise, as well as the significant amount of low frequency content in the signal. Electrical Fast Transient (EFT) testing was patterned after IEC 61000-4-4. This test generates fast transient noise on the cable that more closely simulates the type of random, erratic noise that might be generated by a number of signal sources, such as switches, electronic ballasts, motors, etc.

The effect on the 1Gb/s traffic was measured by tracking the throughput of a fully loaded bidirectional data transfer stream at 1Gb/s. The data also compares the results when using different versions of network interface card (NIC).

The cable types that were tested include designs ranging from 5e to 6A and include shielded and non-shielded iterations. The data includes summaries of both Common Mode and Differential Mode voltages induced on the cable, the throughput effect at 1Gb/s, the effect of pair balance on noise immunity, and the comparison of immunity data to standard industry standard testing results.

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.

The MICE standard also defines possible areas along the channel where the 'E' environment may be different from other areas. The EFT test induces interference along a length of cable only 1m in length which may have coupling and noise immunity characteristics different than RFI testing with a longer section under test.

A key purpose of the testing was to identify cables that perform well in a range of electrical noise sources at a data rate of 1Gb/s.

3. Cable Testing

Cable testing was conducted in both an RF chamber with swept CW frequency interference as well as EFT interference which is generated by repetitive spark events coupled to the cable within a test fixture.

3.1 Cable RFI Testing

Previous testing presented at the IWCS revealed different amounts of common mode voltages on the pairs that depended on the cable design. This data was also obtained in an RFI chamber with swept frequency interference. For the testing reported in this paper, the frequency sweep extended down to 20MHz. Although the calibration of the chamber is conducted at 80Mhz and above, the data below 80MHz is a meaningful indicator of relative performance of the cable designs.

Figure 1

The test arrangement consisted of a cable strung upon a dielectric frame. The antennal polarity is aligned with the loops of the cable as shown in Figure 1. The cable frame is placed in the calibration plane of the chamber.

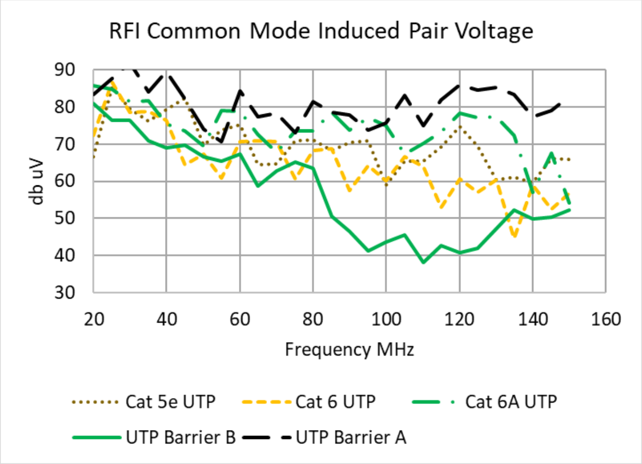

Figure 2

The common mode induced voltages vary widely among the cable samples as shown in Figure 2. However, among the 5 cables tested in this arrangement, the Cat 6A designs A and B reflect the high and low extremes of common mode voltage coupling. The other 3 cables are conventional UTP designs and tend to have similar common mode coupling within that group. It is significant to note that the differences in common mode coupling can vary from 20 to 40db, depending on the cable design.

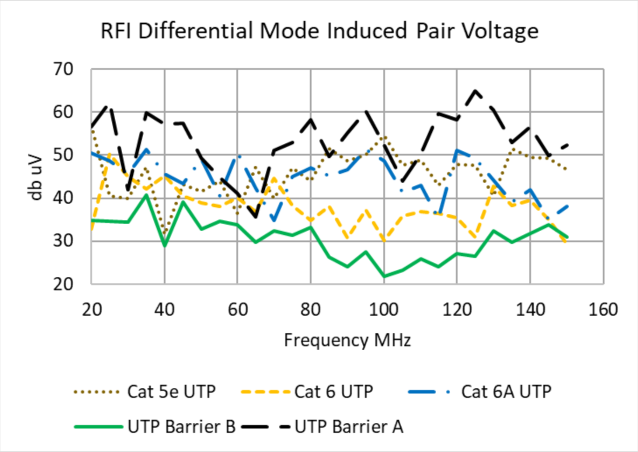

Figure 3

The differential mode noise coupling shown in Figure 3 also exhibited a similar pattern as the common mode voltage. The voltage magnitude differences among the cables are very similar to the common mode results. The differences ranging from about 15 to 40db.

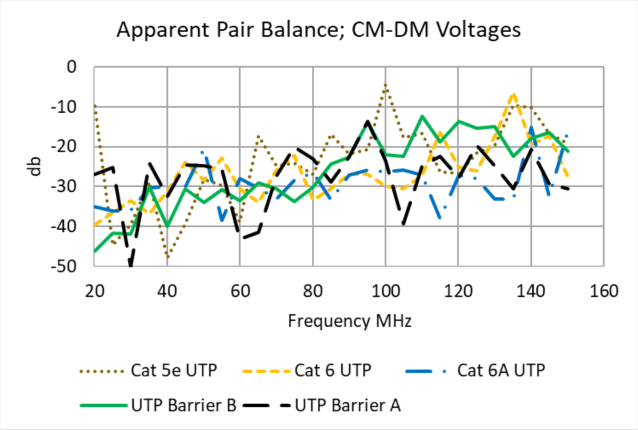

Figure 4

The apparent balance was calculated by subtracting the differential mode voltage from the common mode voltage. The apparent balance resides in a much narrower range than the differences in pair voltages among the different designs. It is reasonable to view the results as a measure of the cable antenna effect, or in other words, the strength of common mode coupling in the test arrangement. The data indicates that the stronger the common or differential mode voltage compared to the other cables, the stronger the antenna effect.

3.2 Cable EFT Testing

EFT testing previously reported at the 2016 IWCS symposium resulted in serious degradation of 10Gb/s traffic, depending on the transient repetition rate. EFT testing was again chosen for testing links at 1Gb/s because this test induces noise over a wide spectrum and is also more random in nature. This noise spectrum also includes substantial low frequency content that may be more relevant for ethernet data rates of 1Gb/s. Also, the noise is induced over a relatively short length of cable which can be more representative of many types of localized interference generated by lamp fixtures, relays, motors, etc.

Figure 5

Figure 5 shows the coupling clamp in which the cable is placed. For this test the total length of cable was 80m, with about 10m of cable extending in one direction from the fixture and the remainder extending in the other direction.

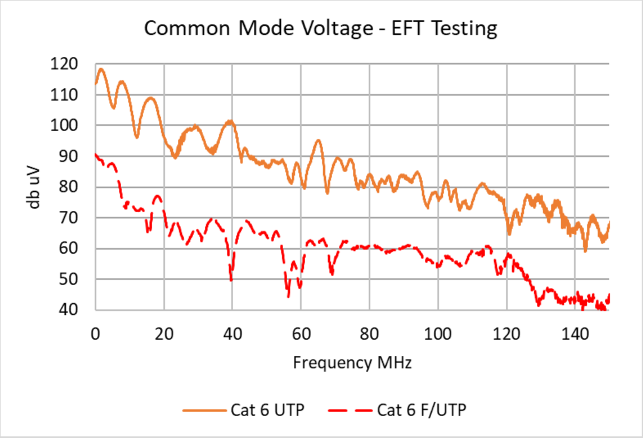

Figure 6

Figure 6 is a chart of the common mode coupling induced on Category 6 UTP and F/UTP constructions. The strong low frequency content of the EFT test is apparent with coupled voltages dropping approximately 35db as the frequency increases from essentially zero to 100MHz. This spectral density characteristic of EFT type testing may also be useful in future testing to evaluate the effects of noise on ethernet data rates of 1Gb/s and below, as well as link lengths under consideration that far exceed 100m. The effect of the screening attenuation is apparent for the F/UTP design with the significant reduction in common mode voltage.

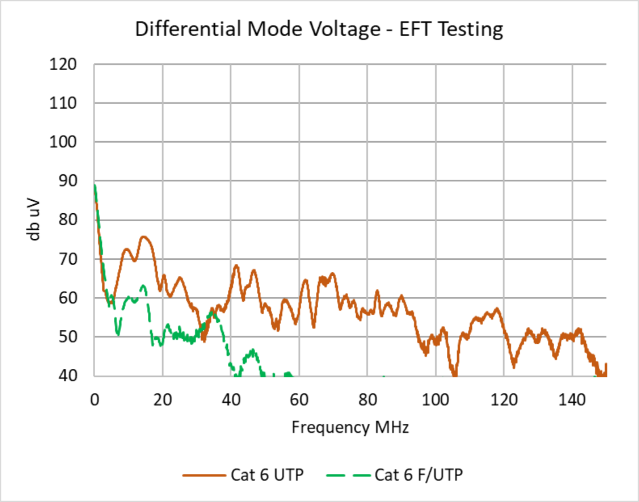

Figure 7

The measured differential mode voltages shown in Figure 7 also reveal the effect of screening attenuation. The level of differential mode voltage on the pairs is substantially lower for the F/UTP design compared to the UTP design.

Voltage Coupling Results – UTP type designs

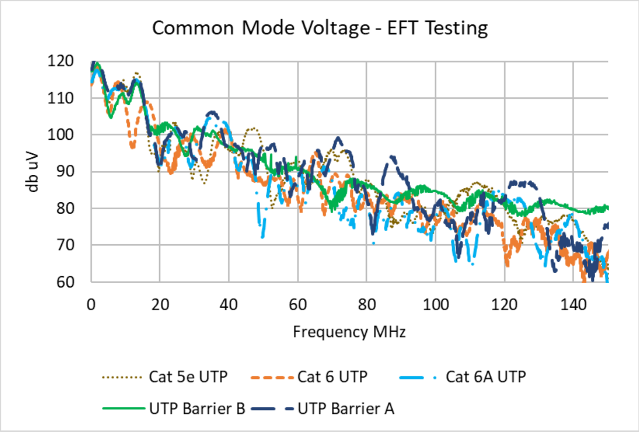

Figure 8

Figure 8 shows the induced common mode voltage during the EFT test. In contrast to the RF testing, the induced common mode voltages on the pairs were essentially the same for all the UTP type cables. The RFI test configuration resulted in different common mode voltages depending on the cable design.

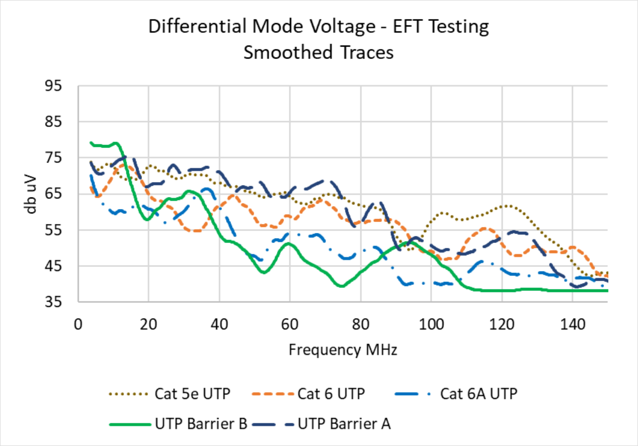

Figure 9

Figure 9 shows the differential mode voltages coupled to the pairs during the EFT test. A running average was used to smooth the curves to better show the overall differences among the cables. Even though the common mode voltages were similar, there was a significant difference in coupling characteristics compared to the RFI test configuration.

Screening Attenuation Effect

It is of some value to briefly discuss the ability of various cable designs to provide controlled differential voltage isolation in noisy environments. The balance of a pair is not a measure of the reduction in externally induced common mode voltage, but is a measure of the ratio of mode conversion between common mode and differential mode voltage within the pair.

The reduction of differential voltage on the pairs can be considered as the sum of the measured pair balance and screening attenuation. This combination is related to the coupling attenuation measurement.

Ac = Au + As

Ac = Coupling Attenuation

Au – Unbalance attenuation

As – Screening attenuation

Screened data cables provide a level of isolation for common mode voltages, and the test data in Figure 6 resulted in effective screening attenuation of about 30db.

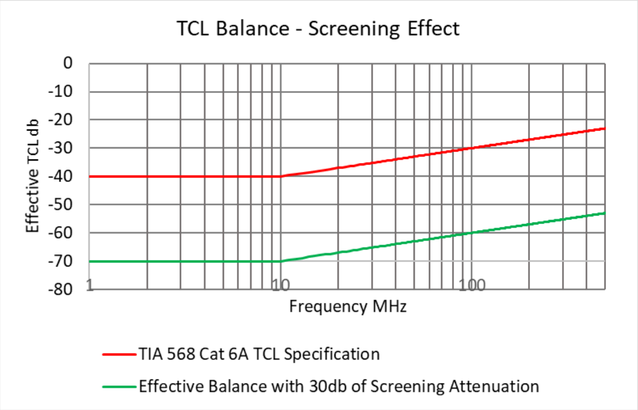

Figure 10 Effective TCL with Screening Effect

When comparing the expected pair voltages for UTP and F/UTP cables with the same level of pair balance, screened cable will have significantly lower differential voltage, as well as reduced levels of common mode voltages. UTP cables would require extraordinary levels of pair balance to come close to the level of differential mode isolation of screened cables. Even with extraordinary pair balance, common mode voltages inflicted on the rest of the channel components with UTP cables would be much higher than with F/UTP cables.

4. Evaluation of Balance and Induced Voltages

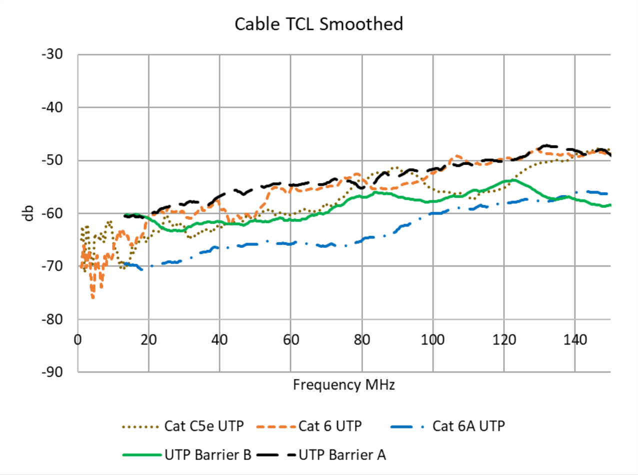

Figure 11

Correlating the level of coupled voltages to the cable balance measurements taken with a network analyzer using TIA 568 industry standard test methods may provide some insight in comparing different cable designs. Figure 11 is a chart of the pair balance data when measured using a network analyzer. The traces are smoothed to better view the relative positioning of the curves over the frequency range.

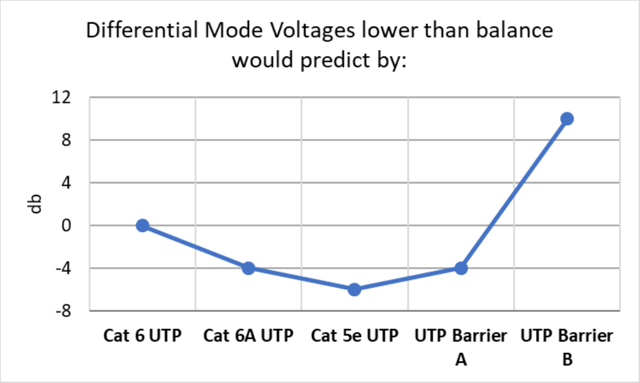

Figure 12

Figure 12 is a view of the difference in expected pair voltages compared to the observed pair voltages using the 80MHz values on the curves. The trend expected is that better balance would result in lower differential mode. The values in Figure 12 show the deviation from that assumption. The difference of the pair voltage and balance of the Cat 6 UTP cable is used as the reference or 'zero' point. The higher the number in the chart, the lower the differential mode voltage compared to expected values based on the balance performance.

5. Data Throughput Testing

5.1 Gb/s Throughput Results

The throughput data presented in this paper is focused on 1Gb/s traffic. Two computers were used to provide a full bi-directional 1Gb/s ethernet link. Large data files were created to generate traffic as they were copied from PC to PC. The file copy was conducted in both directions at the same time. Precautions such as using solid state drives were taken to allow the NIC cards to be the weak link in the data rate chain.

Swept Frequency Interference Effects

The cable arrangement for the swept frequency test is shown in Figure 1, with the antenna in the vertical polarization. In summary, there was essentially no effect on data throughput for CW (Continuous Wave) interference at up 10V/m for all the cable types. The frequency interference consisted of 27 frequency steps from 20 to 150MHz in 5 MHz increments with a hold at each frequency of a few seconds.

EFT Interference Effects

The more erratic and random interference from the EFT test produced significantly more effect on the data throughput.

The EFT test was conducted using the same cable and test arrangement that was used for the pair coupled voltage tests. There were 12 EFT 'events' for each test. Two positive and two negative pulse trains were generated at each voltage, and spark voltages of 1000, 1250, and 1500V were used.

Importantly, the repetition rate of the pulse train has a significant effect on the data throughput. For this testing, all pulse trains were generated at a 100kHz repetition rate. In testing reported previously, slower pulse train rates induced less impact on data throughput.

5.2 Test results with different PHY's

Throughput testing was conducted in two phases, each with as different set of PHYs. One set utilized an Intel 217 and 219 NIC's on the PC motherboards, and the other test utilized Intel 219 NIC on each of the PC motherboards.

Test Data with Intel 217 and 219 NIC Cards

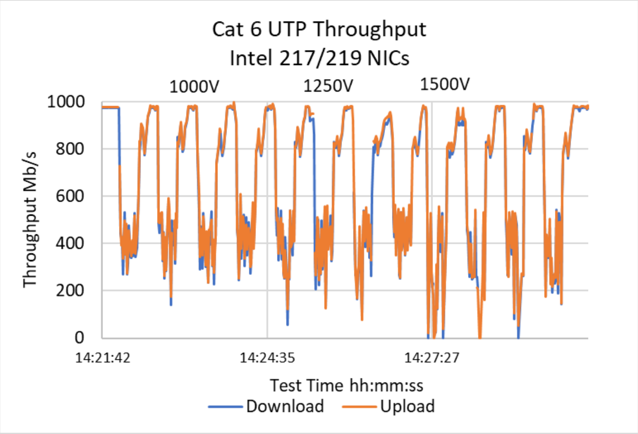

Figure 13

Figure 13 shows the complete cycle of 12 EFT pulse trains used for this testing. The horizontal scale is the test time, and the entire test lasted about 8 minutes. Each group of 4 events has increasing spark levels. The overall throughput is distinctly affected by the voltage level of the pulses, with the higher voltages creating more severe reductions in throughput during the pulse train events.

Test Data with identical Intel 219 NIC Cards

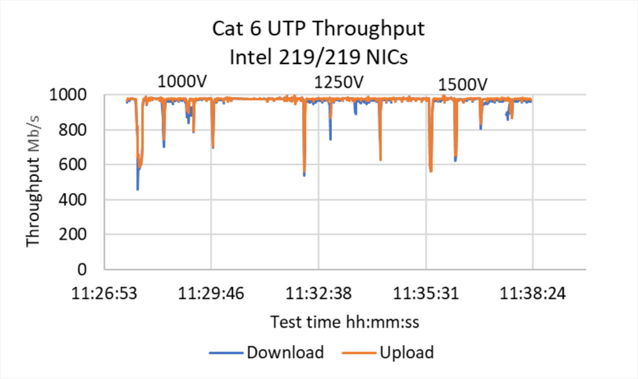

Figure 14

Figure 14 is a chart of the data throughput with the same 12 EFT events that occurs over the same test sequence. When the same type of NIC card is used at each end, the results seem to become less severe as repeated noise events occur.

5.3 Throughput Test Interpretation

Throughput or BER (Bit Error Rate) testing interpretation is at best, difficult. Modern network cards have powerful adaptive digital signal processing capability (DSP) to cancel noise effects such as crosstalk, echo, and other interference effects. It is the nature of these chips to 'learn' about the noise interference and then cancel that interference.

Test results in electrically noisy environments are affected by the performance of the DSP system on each chip, as well as the coordination of cancellation between the send and receive network cards. This test data suggests that cancellation effectiveness can be affected whether the same or different types of cards are used. Throughput or BER testing results can affected by the capability of the interface cards as much as noise immunity properties of the cables under test.

BER and throughput data can and does provide a valuable insight for the effects of noise in a channel. However, caution should be used when trying to directly compare BER test results or provide correlations between interference types. It is vital to realize that the actual results are affected not only by the cable and environment but also the interoperability capability, firmware quality, and the inherent capability of the processing power of the NIC cards. Also, the characteristic of the interfering electrical noise has a strong effect on the degradation of the channel.

To evaluate the performance of different cable designs, a measure of induced pair voltages is a more repeatable and valid comparison method.

6. Conclusions

Measuring the voltages induced on the cable pairs due to a adverse electrical environment is an effective and repeatable method of characterizing cable performance. Coupling differences were observed with different test methods, which should be understood when choosing an appropriate cable design for an application. An important observation is that higher common mode coupling affects the level of mode conversion on all components of the system, adding to the potential for additional signal interference. When common mode coupling of the cable is lower, the mode conversion characteristics of connectivity and the electronics is less critical.

Measuring the effect on 1Gb/s ethernet traffic when subjected to electrical noise provides critical insight and guidance about the appropriate limits for these induced voltages. However, this type of testing, by nature, adds many variables that affect the overall results. Evaluating interference effects of 1Gb/s traffic using only one type of test as a reference can be misleading.

7. Biographies

Eduardo Garza is the Director of Engineering 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.