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EMI Shielding of Cable Assemblies

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Abstract

Shielded cables are a common component in today's standard electronic systems that transmit high-speed video and data. However, industry standard cables don't necessarily exhibit standard shielding performance. This paper is a survey of the shielding performance actually measured on commercially available cable assemblies. When significant differences in performance were discovered, autopsies were performed in order to determine, where possible, the cause of the difference.

Author(s) Biography

Dana J. Bergey earned his BS degree in Physics from the Pennsylvania State University, and his MSEE from the Air Force Institute of Technology (AFIT). While in the United States Air Force, he served as the Senior Engineer of the AFIT Advanced Development Laboratories, where he supervised the microwave, IR, laser, and radar cross-section labs. He spent several years working on stealth technology and teaching microwave and electromagnetics classes at the school. Bergey has spent the last 18 years working as a signal integrity and EMC engineer at AMP Incorporated, W.L. Gore & Associates, and FCI. He is presently manager of FCI's US signal integrity team, which is involved in the development of high-speed interconnects.

Nathan E. Altland has worked as a signal integrity engineer at FCI for the past 8 years. He has been involved in all aspects of signal integrity and EMC test and measurement, including the support of next-generation, high-speed connectors and cable assemblies, development of test systems and methodologies, product qualification, failure analysis, and customer application support. He works closely with SI simulation engineers to validate connector models. His current responsibilities include managing the day-to-day operations of FCI's Signal Integrity Laboratory, including supervising SI co-ops and interns.

Introduction

As high-speed serial data transmission technologies have proliferated, numerous industry standards have been published. These standards document specific electrical performance requirements for high-speed cable assemblies. However, while signal integrity parameters, such as characteristic impedance, insertion loss, crosstalk, propagation delay, and skew are thoroughly addressed, the EMI shielding performance of these standard cable assemblies is rarely specified. This paper reports on several studies that were conducted to determine the variability of shielding performance that can be found in commercially available cable assemblies. Sample groups of Fibre Channel, HDMI, USB, FireWire, and Infiniband cable assemblies were tested. In each case, when "outliers" were discovered (i.e. samples that exhibited much better or much worse shielding performance than the average of the group), an exploratory investigation was performed to diagnose the cause of the performance difference.

Shielding Effectiveness Test Procedures

Absorbing Clamp Test Method

The Fibre Channel cable assemblies were tested using an absorbing clamp procedure (See Fig. 1) similar to the Common Mode Power Transfer (CMPT) method described in the SFF-8410 Specification for High Speed Serial Copper Testing and Performance Requirements [1]. Modifications to the documented procedure included use of shielded boxes with receptacles installed, rather than the suggested "stovepipe" enclosure and direct measurement of the input signal, which enables a more accurate calibration than using a "T" connector.

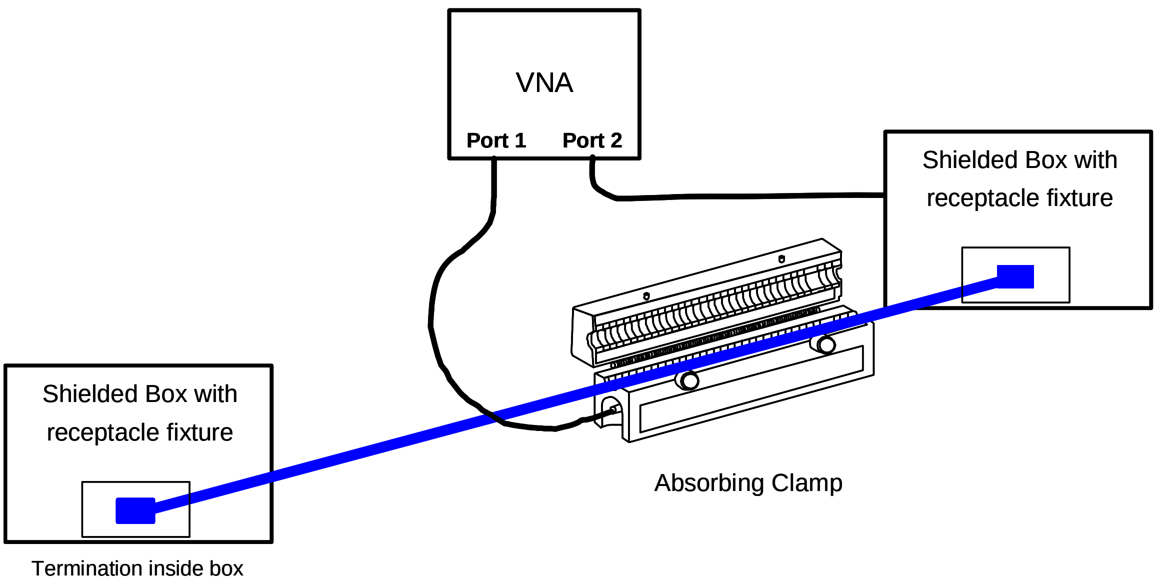

Figure 1. Test Setup – Absorbing Clamp Test Method

Mode-Stirred Chamber Test Method

The HDMI, USB, FireWire, and Infiniband test samples were all tested in a mode-stirred chamber (see Fig. 2), using the Electromagnetic Radiation (EMR) procedure described in the SFF-8410 Specification. Some mode-stirred chamber procedures call for the test sample to be moved away from the chamber wall and/or for a reference antenna to be utilized rather than an unshielded sample [2]. However, for our purposes, which were limited to determining the relative performance of a group of cables, these enhancements were not employed.

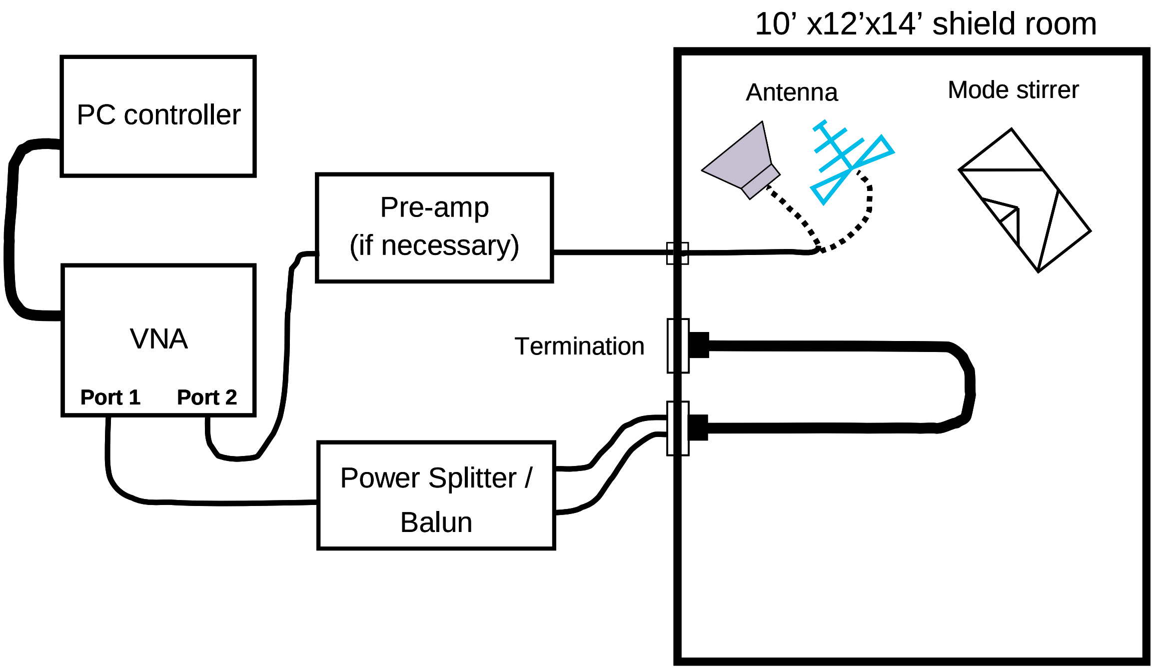

Figure 2. Test Setup – Mode-Stirred Chamber Test Method

Common-mode vs. Differential-mode Drive Signals

An additional modification to the shielding test procedures was that for both methods, the cables were tested while driven with common mode signals and then tested again while driven with differential signals. (See Fig. 3) The shielding performances exhibited by a cable assembly when driven in these conditions reveal very different characteristics of the assembly. The common mode drive condition, where all return current is effectively forced to flow on the inside of the cable shield, is used to determine the performance of the raw cable shield (foil and/or braid), the cable shield to connector backshell termination, the connector backshell (seams and apertures), and the plug-to-receptacle backshell mating interface. All of these features are important contributors to keeping the current on the inside of the shield system, minimizing current flow on the outside of the cable shield which generates radiated EMI.

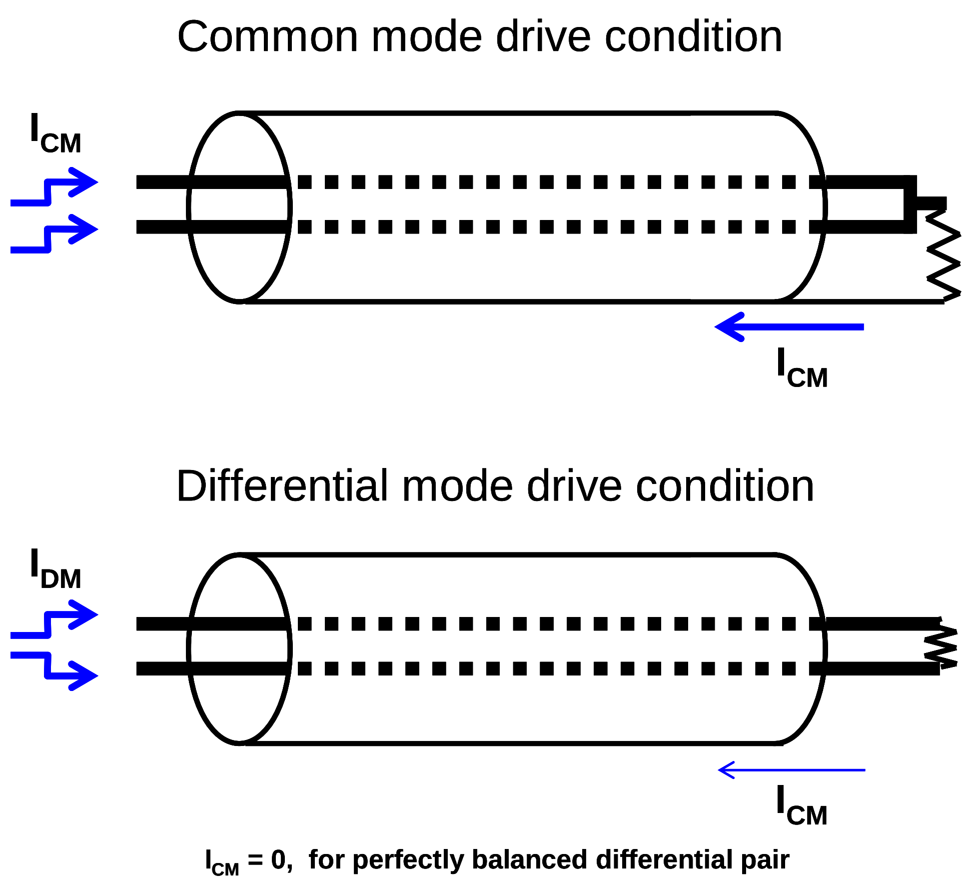

Figure 3. Common mode and differential mode drive conditions

The differential mode drive condition brings the balance of a differential pair into play. A perfectly balanced differential pair will result in zero net current flowing on the inside of the cable shield – and hence, zero current flowing on the outside of the shield, resulting in zero radiated emissions. (Note: We have yet to test any perfectly balanced differential pairs.) The degree of imbalance in the differential pair will relate to the amount of common mode conversion and common mode current flow on the shield, which will be measured directly, or as emissions in our tests. The most commonly discussed type of cable imbalance that contributes to the creation of common mode signal is in-pair skew. However, it should be noted that loss-imbalance, a difference in insertion loss experienced by the two halves of a differential signal, can also lead to common mode conversion.

If a cable sample possesses a high degree of balance, we will measure lower emissions from it when driven differentially than when driven with a common mode signal. If the cable is poorly balanced, most of the signal will be converted to common mode, and the test results from the two drive conditions will be similar.

Fibre Channel Cable Assemblies

Twelve Fibre Channel cable assembly samples from various suppliers were tested using the absorbing clamp method described above. The shielding performance of these cables when driven with common mode signals is shown in Fig. 4, and their performance under differential mode drive conditions is shown in Fig. 5.

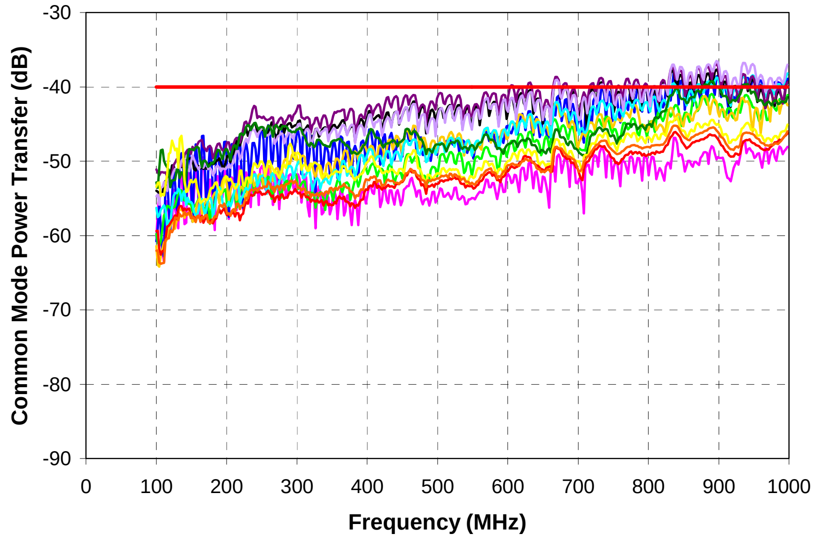

Figure 4. Fibre Channel assemblies driven common mode.

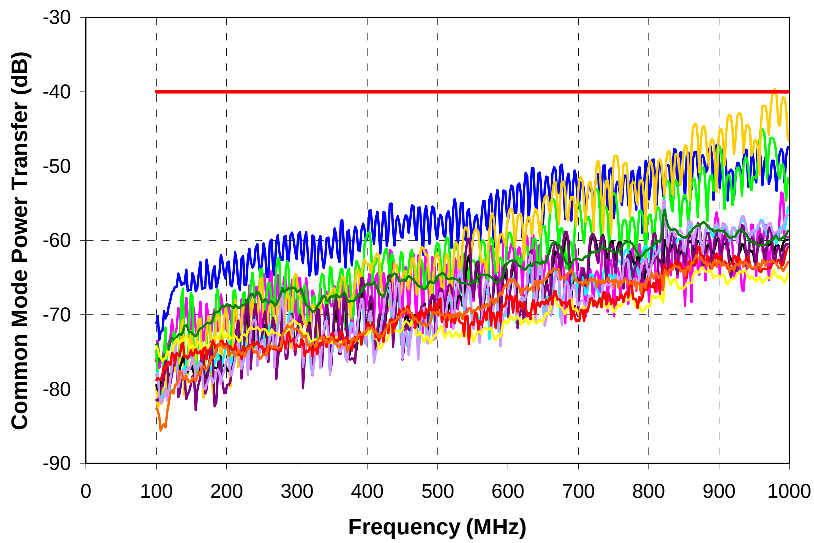

Figure 5. Fibre Channel assemblies driven differential mode.

The common mode drive results showed approximately 10dB variation in shielding performance between the different cable assemblies. This level of variation was expected, since the cable samples were constructed with different vendors' plug connectors and different raw cable. Some assemblies used cable made from shielded twisted pairs inside of a braid, and others used a quad cable design with a braided shield. Also as expected, the cables exhibited lower emissions (less common mode current on the outside of the shield) when driven with a differential signal. However, the variation in performance was greater than in the common mode drive condition, which implied that these samples varied more in the quality of their balance than in their shielding designs.

Autopsies were performed on two of the cable samples. Sample 1 and Sample 2 exhibited very similar common mode performance, but significantly different differential mode performance. The most glaring difference discovered during the cable autopsies was the skew of the two assemblies – Sample 1 had approximately 350ps of in-pair skew, while Sample 2 had only around 35ps. Fig. 6 compares the two cables' EMI results.

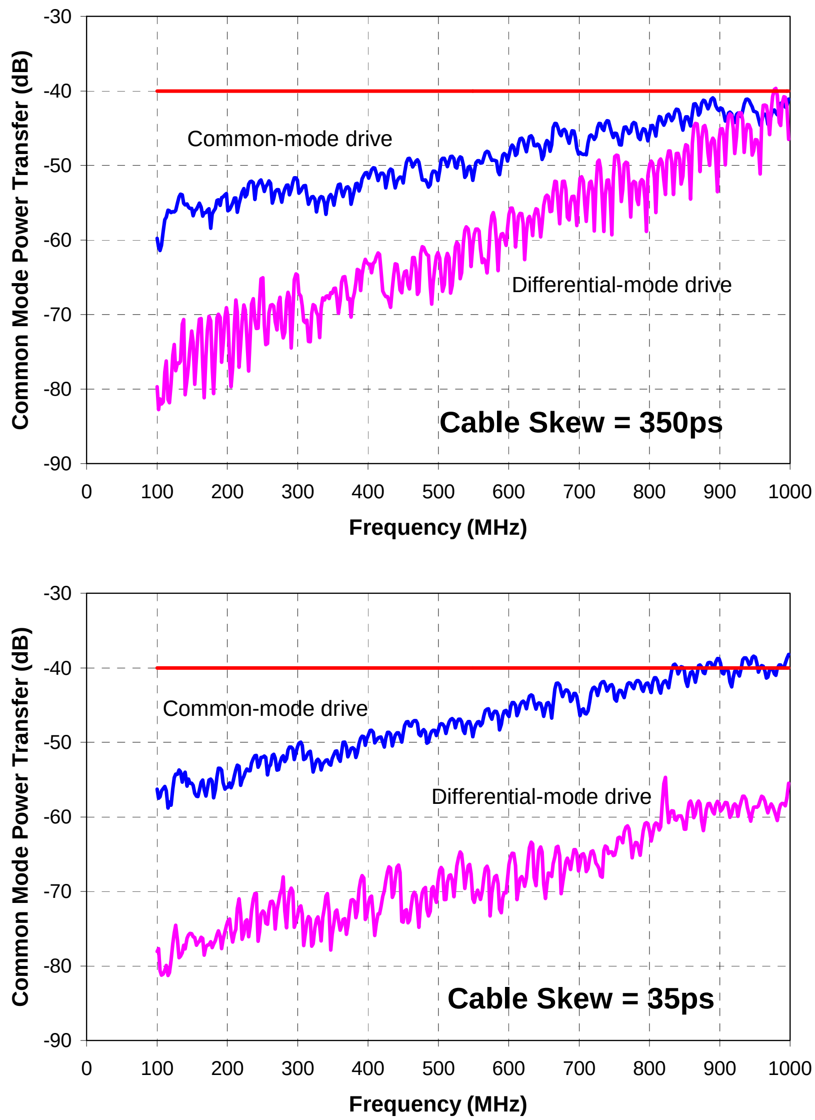

Figure 6. Common-mode and differential shielding results of low-skew and high-skew cable assemblies.

The difference in differential mode results is consistent with work reported in [3,4]. [3] concludes that at a frequency of 531.25 MHz, common mode current and radiated emissions increase at a rate of approximately 9 dB/decade of skew. [4] predicts a radiated field increase of approximately 10 dB for a skew increase from 35 to 350ps. These conclusions correspond closely to the observed difference in differential results at 531.25 MHz between Samples 1 and 2. Additionally, results reported in [4] indicate that at 1 GHz, the same difference in skew will produce an even larger difference in emissions. Fig. 6 shows that the difference in differential results for Samples 1 and 2 increases to almost 20 dB at 1GHz.

HDMI Cable Assemblies

Eight commercially available HDMI (High-Definition Multimedia Interface) cable assemblies were tested using the Mode-Stirred Chamber method described above. A summary of their differential-mode emissions results is shown in Fig. 7.

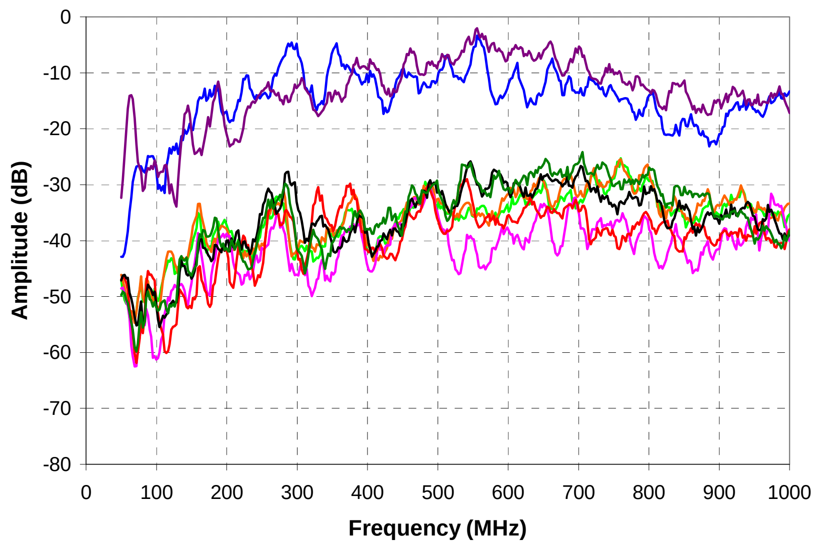

Figure 7. Emissions from HDMI cable assemblies when driven with a differential-mode signal.

The Mode-Stirred Chamber results showed that two of the HDMI cables performed approximately 20dB worse than the rest of the group. Measurements completed during cable autopsies showed that all eight cables had similar skew, so our attention was drawn to the structural aspects of the assemblies' shield system. As described in [5], cable shield construction, apertures and seams in the plug connector, the connector mating interface, and the cable shield to connector backshell termination are all potential areas of concern. Poor design in any of those areas can result in a shield system that leaks EMI or allows current to flow on the outside of the cable shield, which will radiate.

In the case of the poorly shielded HDMI cables, the mating interfaces were essentially identical to the other cables, and no open seams or apertures were evident. Additionally, a similar type of raw cable was used for all of the samples. The cable construction included shielded differential pairs with individual drain wires and foil shields, surrounded in an overall foil shield, with a braided shield around the foil.

When the plastic overmolds were surgically removed from the two poorly shielded cables and one of the better performing samples, a clear diagnosis was obvious. Figs. 8-10 show extreme differences in the care taken to effectively terminate the cable shields to their connector backshells during construction of the cables. The better shielded sample, shown in Fig. 8, had copper tape around the back end of the plug. The cable shield was soldered to the copper tape, and the tape was soldered to a large metal tab, which extended from the front section of the plug. One of the poorly performing cables, shown in Fig. 9, had foil tape around the back of its connector plug, but only a few strands of the cable braid were caught in the overmold to secure electrical contact with the tape. The second poorly performing cable, shown in Fig. 10, used no tape at all. Its cable braid was stripped back further than the other cables and only attached to the plug shell by a twisted pigtail.

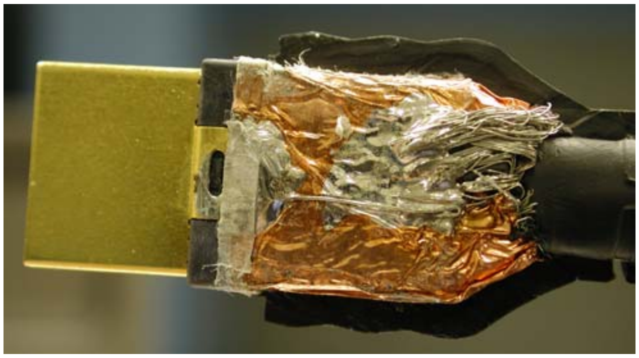

Figure 8. Well-shielded HDMI cable with braid soldered to copper tape and tape soldered to metal tab.

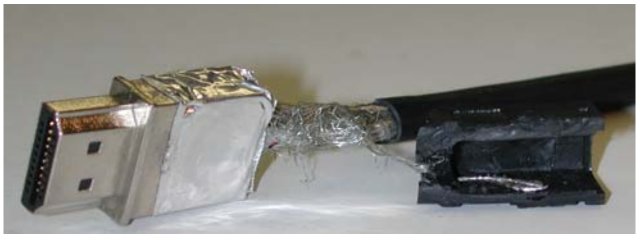

Figure 9. Poorly-shielded HDMI cable with only a few strands of braided shield contacting the metal tape on the plug.

Figure 10. Poorly-shielded HDMI cable with cable braid stripped back and then attached to plug shell at only one point with a twisted pigtail.

USB Cable Assemblies

Ten different USB (Universal Serial Bus) cable assemblies and a USB swivel adapter were tested using the Mode-Stirred Chamber method described above. A summary of their common-mode emissions results is shown in Fig. 11. Once again, the cable samples fell into two distinct levels of performance, with one group exhibiting approximately 25dB better shielding performance than the other group.

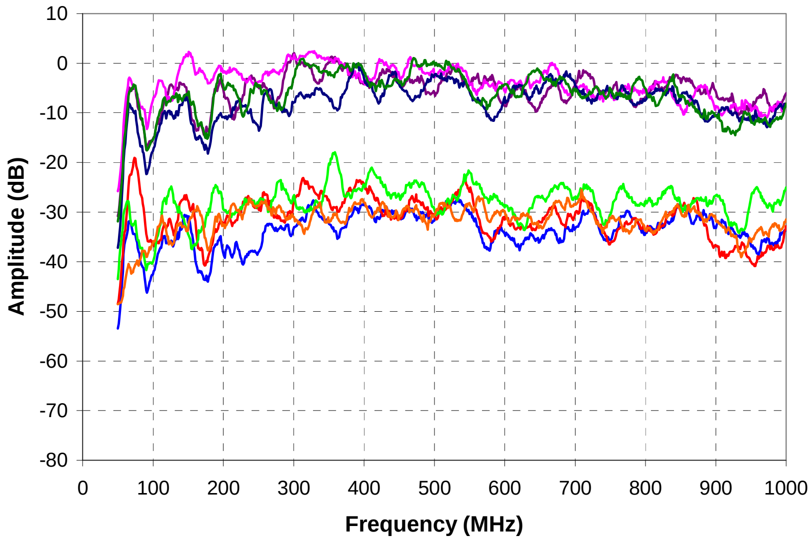

Figure 11. Emissions from USB cable assemblies when driven with a common-mode signal.

The differential emissions results (not shown) demonstrated a similar grouping with the same cable samples showing poor performance. An investigation into the cables' skew performance revealed that most of the cables possessed very low in-pair skew (<20ps), and the remaining two had approximately 50ps of skew. Impedance and insertion loss studies of the USB cable assemblies also failed to reveal an obvious difference between the two groups of cables.

Once again, scalpels were employed and autopsies performed on the group of samples that exhibited the highest emissions.

The first sample from the poorly-shielded group to be studied was a rather expensive USB cable with a unique feature (See Fig 12). It employed special connectors on each end, into which various adapter plugs could be inserted to provide different USB connections. (For our purposes, a USB "A" plug was used on one end and a USB "B" plug was used on the other, creating the same style of cable as all the others that were tested.) The adapter plugs, with an overmolded plastic grip, had a fully-shielded connector on the cable side, which inserted snugly into the metal receptacle which was terminated to the cable. It was not obvious that any seams or apertures should leak EMI from this adapter.

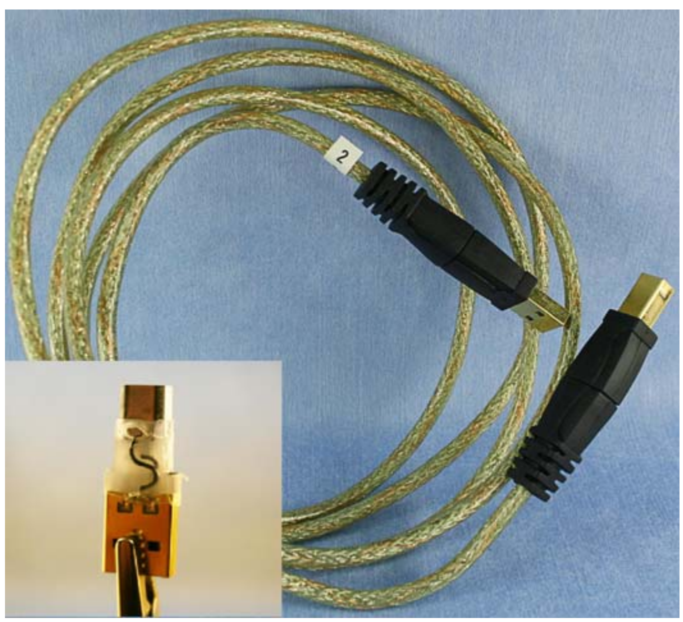

Figure 12. USB cable with special adapter ends.

However, when the plastic overmold was removed, as shown in the insert of Fig 12, an "aperture" became evident. In fact, the adapter consisted of two separate shielded connectors, whose shields were connected only by a short wire soldered between them.

Similar shielding design problems were discovered with the other three samples of the poorly-shielded USB group. Fig 13 shows a USB swivel adapter where again a wire was used to bridge the shields between two well-shielded connectors. In another case, a braid pigtail was used to attach the cable shield to a tab on one side of the connector backshell. The final poor-performing USB sample was an attractive cable assembly with a flashing green LED (See Fig 14). The cable insulation was clear, so one could see its heavy braided shield. The connector was made of clear plastic, so that one could see a neat little circuit board and, of course, the green LED. In order to not block the view of the circuit board with a big ugly cable braid, the braid was twisted into a thin pigtail which could be routed out of the way to terminate to a backshell tab on the bottom side of the connector.

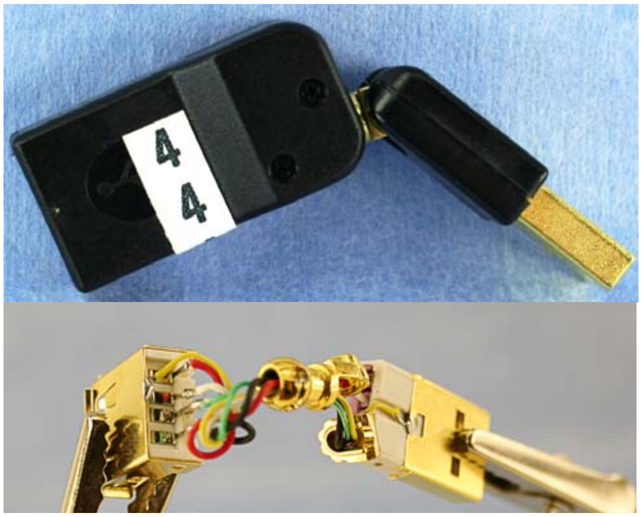

Figure 13. USB Swivel Adapter with plastic overmold and with plastic overmold removed.

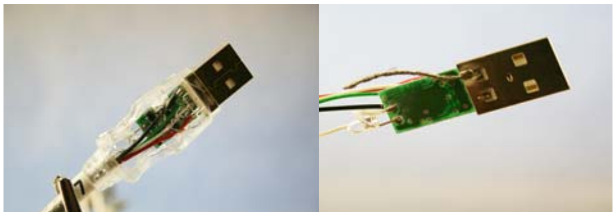

Figure 14. USB cable with green LED and long pigtail from cable braid to connector backshell tab.

FireWire (IEEE1394) Cable Assemblies

Six different commercially available FireWire (IEEE 1394) cable assemblies were tested using the Mode-Stirred Chamber test method. The results of their common-mode and differential-mode emissions tests are shown in Fig 15 and 16. The differential results show quite a spread of shielding performance (~30dB) among the assemblies, while the common-mode results show a much tighter cluster, with only one sample exhibiting significantly worse performance. Our previous experience led us to expect that the one common-mode "outlier" likely suffered from a shield continuity problem, while cable imbalance – most likely skew – probably contributed to the variation in differential emissions results.

Autopsies indeed confirmed our diagnoses. A TDR (time-domain reflectometer) showed that the poorly-performing common-mode sample had a huge impedance discontinuity in the connector. An increase in impedance along a cable assembly often is a symptom of the shield being separated from the signal conductors. This can occur in the termination area where the connector is attached to the cable. In this case, the sample incorporated a flashing LED (as described in the case of one of the poorly-shielded USB cables). As in the case of the USB cable with a flashing LED, the cable braid had been attached to the connector shell with a pigtail wire.

Skew measurements once again illustrated the direct correlation between in-pair skew and radiated emissions from a cable driven differentially. Except for the sample with the shield continuity problem, emissions from the FireWire cables fell in an order from lowest to highest that also corresponded to lowest skew to highest skew.

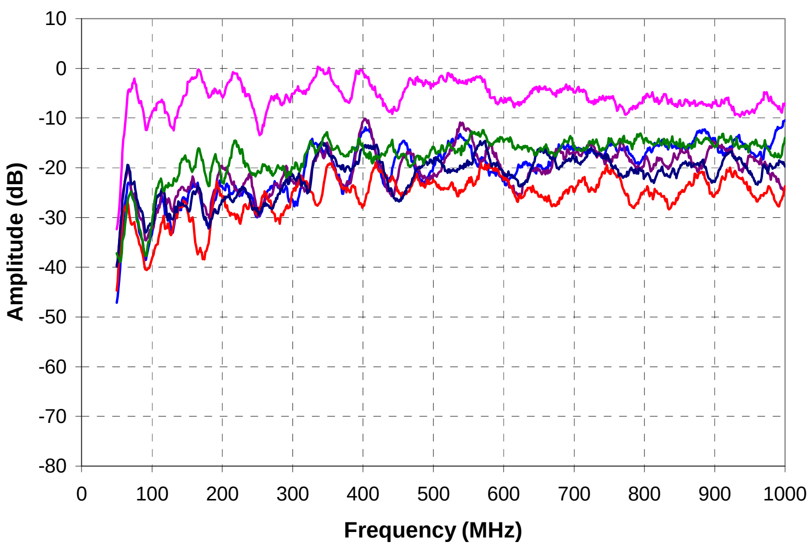

Figure 15. Emissions from FireWire cable assemblies when driven with a common-mode signal.

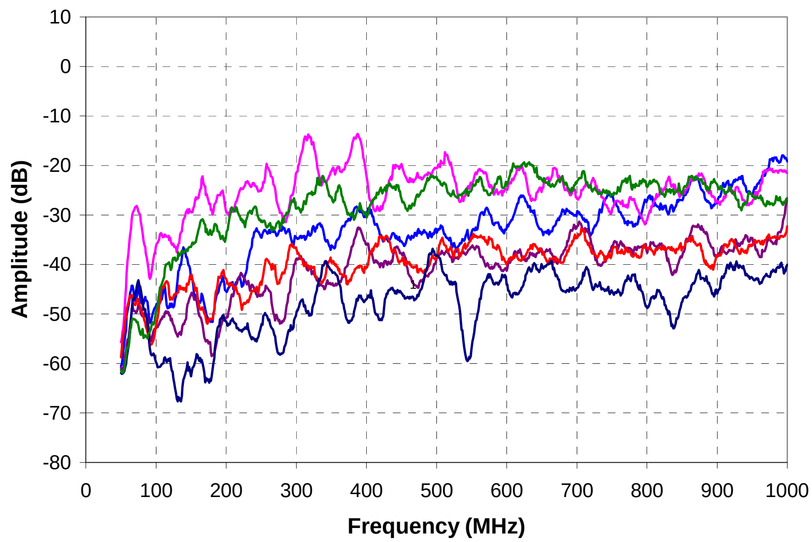

Figure 16. Emissions from FireWire cable assemblies when driven with a differential-mode signal.

InfiniBand Cable Assemblies

Eight InfiniBand (4X) cable assemblies were tested using the Mode-Stirred Chamber test method. The results of their common-mode emissions tests are shown in Fig 17. All of the samples in this study performed similarly. They also all exhibited low in-pair skew and similar emissions when driven differentially (data not shown).

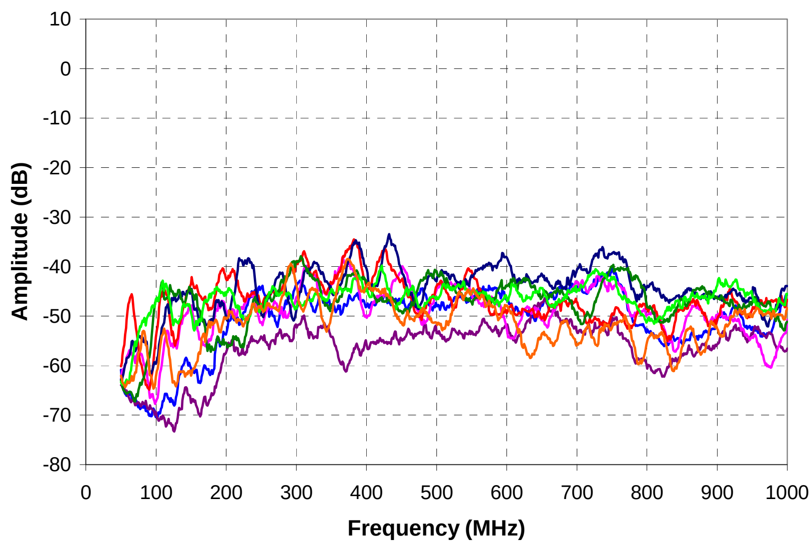

Figure 17. Emissions from InfiniBand (4X) cable assemblies when driven with a common-mode signal.

Since some of the samples appeared to use different cable termination techniques, autopsies were performed in order to investigate what assembly methods had been employed. (In this case, no dangerous sharp cutting tools were required, as the connector shells could be disassembled by simply removing some screws.) Fig 18 shows three samples with different cable termination methodologies.

Figure 18. InfiniBand cable assemblies with different termination methods.

In one case, the cable braid is squeezed between two pieces of a metal collet; in a second case, the braid is wrapped around a plastic collet which has copper tape around it and is squeezed between the two halves of the connector shell; and in the third case, this copper tape is extended to cover all of the folded braid, rather than just around the collet as in case 2. While the metal collet solution is likely more expensive, the plastic collet techniques provides equal shielding performance.

One observation made during the InfiniBand study was that the cable assembly which included connectors with jack-screws (see Fig 19) performed approximately 4-6dB better than an identical cable which had connectors with a latch feature. In this case, the jack-screws permitted a tighter connection between the cable plug and the mating receptacle shells.

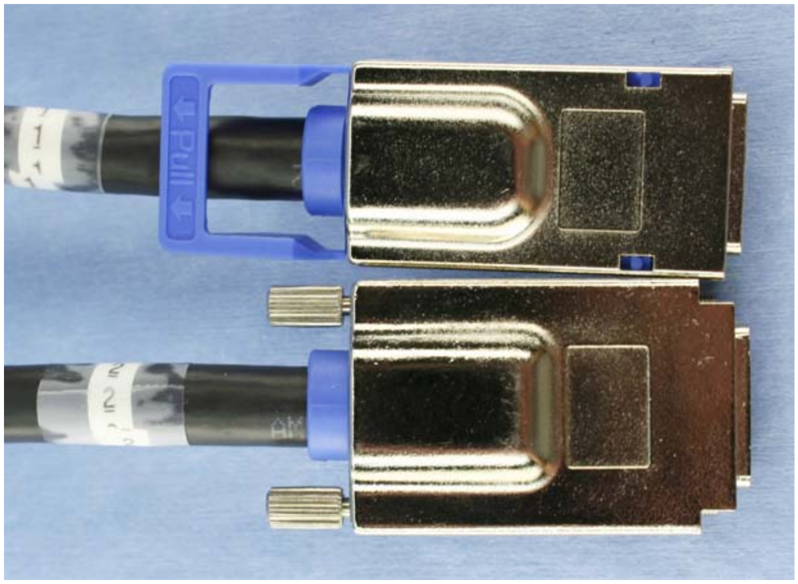

Figure 19. Infiniband connectors with jack-screws and with a latch.

Conclusion

Industry standard cable assemblies were shown to exhibit varying levels of shielding performance. While variations of 10dB were observed for each of the cable types tested, some samples were measured at 20 – 30dB worse emissions than the average performance of their group. In-pair skew was identified as one contributor to higher emissions, but the most common flaw witnessed in these studies was use of a pigtail connection between cable shield and connector backshell. It was noted by the authors that while the higher priced samples of each type generally exhibited the best signal integrity performance (ie. matched impedance, low insertion loss, and low in-pair skew), there was no correlation between price and shielding performance.

Acknowledgements

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