SYSTIMAX®
SOLUTIONS

# Modal Decomposition

## The Ultimate Testing Methodology for UTP Cabling Systems

White Paper
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SYSTIMAX® Structured Connectivity Solutions

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## 1. Abstract

**The performance of UTP cabling systems has been traditionally measured by high precision baluns. This process has some serious limitations that are the result of calibration difficulties and balun bandwidth. A 16-port modal decomposition system was developed at SYSTIMAX® Labs to resolve these problems. In addition to traditional measurements such as Insertion Loss, NEXT, PSNEXT, ELFEXT, PSELFEXT, Return Loss, Delay and Delay Skew, this advanced technique can facilitate the measurement of high frequency balance that has always been a very challenging problem for the cabling industry.**

## 2. Introduction

There are two types of signals that can co-exist in a four-pair cabling system. Differential mode signals have equal but opposite polarity traveling on the two conductors of a pair. Common mode signals have equal and the same polarity. Differential mode signals are generally preferred, while common mode signals are undesirable. Unfortunately, due to the imperfection of the transceivers, common mode signals always exist. Imperfection in cable and connecting hardware can also create additional common mode signals.

Modal decomposition is a sophisticated tool to analyze the interaction of these signals. The concept of modal decomposition is based on a theory of multiconductor transmission lines. When a differential or common mode signal strikes a boundary, i.e. from a cable to a connector, it will be scattered into multiple waves. Some will continue to propagate through, while others will be reflected. These waves may be either differential mode, common mode or a combination of both. Modal decomposition recognizes all transmission modes that are naturally present in a multi-conductor transmission system. In a four-pair cabling system, the potential scatterings are described in a 16x16 reflection coefficient matrix denoted by $p$.

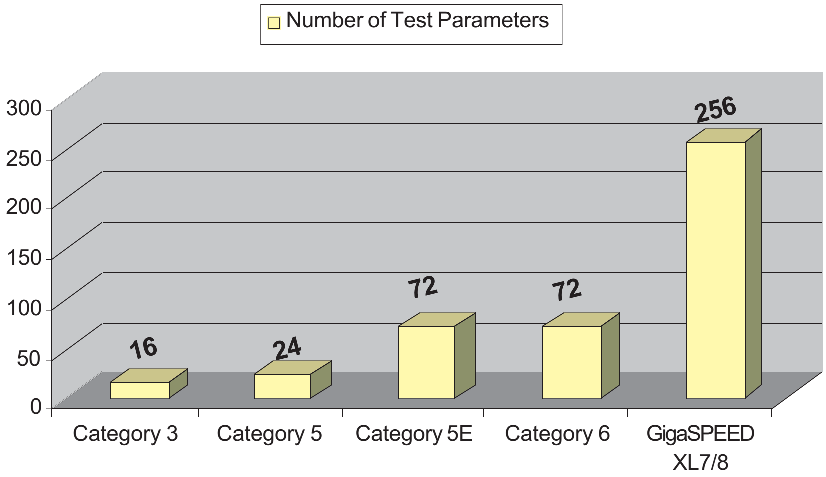
$$\rho = \begin{bmatrix} Differential \rightarrow Differential & Common \rightarrow Differential \\ Differential \rightarrow Common & Common \rightarrow Common \end{bmatrix}$$

The *Differential* ➔ *Differential* element is an 8x8 matrix. This matrix is fully defined by the cabling standards via four fundamental parameters of insertion loss, pr-pr NEXT, pr-pr FEXT and return loss. After proper computation, ELFEXT, PSNEXT, PSELFEXT, delay (insertion loss phase) and skew can be derived from these fundamental parameters as well.

Balance issues have been considered in the standards over the last several years and have not moved forward because of the complexity of making consistent balance measurements. The *Common* ➔ *Differential* and the *Differential* ➔ *Common* element are both 8x8 matrices. They can be used to define the balance of the network. Unlike LCL and LCTL which examine mode conversion on the same pair, the modal analysis characterizes the cross coupling of different pairs as well.

The *Common* ➔ *Common* element can be used to define common mode behavior. The definition of this matrix is very similar to that of the *Differential* ➔ *Differential* element. It also consists of the same four basic parameters as described above. However, it characterizes the reflecting and coupling effect among twisted pairs when common mode signals are launched.

Modal measurements quantify all these modes and their interaction to help us understand the transmission phenomena occurring in cabling in much greater depth. The following chart and table illustrate the numbers of testing parameters specified by the standards for different categories of the cabling system.



## Table 1

| Specification | Test Parameters for Full Characterization of a Channel |
|---|---|
| Category 3 | 4 - Attenuation, 12 - NEXT → 16 Parameters Total |
| Category 5 | 4 - Attenuation, 12 - NEXT, 4 - Delay, 4 - Skew → 24 Parameters Total |
| Category 5e | 4 - Insertion Loss, 12 - NEXT, 8 - Return Loss, 4 - Delay, 4 - Skew, 24 - ELFEXT, 8 - PSNEXT, 8 - PSELFEXT → 72 Parameters Total |
| Category 6 | 4 - Insertion Loss, 12 - NEXT, 8 - Return Loss, 4 - Delay, 4 - Skew, 24 - ELFEXT, 8 - PSNEXT, 8 - PSELFEXT → 72 Parameters Total |
| **GigaSPEED® XL7/8** | **64 - Differential Mode Terms, 128 - Balance (Mode Conversion) Terms, 64 - Common Mode Terms → 256 Parameters Total** |

**Note:** For modal measurements, 64 fundamental differential mode terms can be used to compute all 72 Category 6 differential mode parameters described above. Conversely, the 72 Category 6 standard parameters correspond to 48 fundamental parameters (4 –IL, 12-NEXT, 24-FEXT, 8-RL). These fundamental parameters match modal fundamental parameters exactly when the 4 symmetrical IL and 12 NEXT parameters are dropped from the 64 modal differential parameters. The total 256 modal fundamental parameters can be used to derive thousands of useful computed parameters highlighting transmission properties that have never been analyzed.

Since baluns are not involved in the process, the maximum testing frequency of this modal decomposition system depends on the actual bandwidth of the test instruments, which can be in the giga-hertz region.

## 3. Applications of Modal Decomposition

The benefit of this innovative platform is not only measurement accuracy but also its ability to mathematically cascade individual components into a link or a channel. Each component such as cable, cordage and mated connector, is characterized by a 16x16 matrix and the data file is stored in computer. A virtual link or channel can be constructed by using these characterized components from a database of such measurements. Through a mathematical process, one can simulate a link or a channel as if all components were physically connected. The correlation between the simulated channel and the actual channel has been established at SYSTIMAX Labs. Figure 1 shows the agreement of these two.

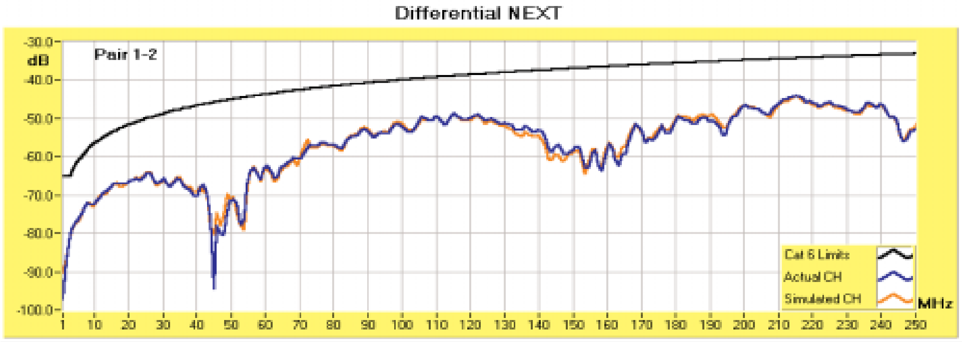


**Figure 1**

## 3.1 System Design and Diagnostic Tool

In practice, few links or channels will be at the maximum distance allowed by the standards. In most cases, the horizontal cables are much shorter. There is a false assumption that a link or a channel with the maximum distance can be used to identify the worst-case performance. This assumption may be true for insertion loss, ELFEXT and PSELFEXT. However, this is not the case for NEXT, PSNEXT and return loss. The interaction of multiple connectors in a short link starts to surface because the cable attenuation may not be strong enough to taper the multiple reflections and couplings caused by connectors. If the connecting hardware is poorly designed, the degradation of system performance is inevitable under these conditions. An example of this was a strange phenomenon called the “short link resonance”. Some of the Category 5 components reportedly met all the industry standards but still failed Category 5 channel specifications in a short link. It was found that the channel failure was due to unbalanced transmission resonance between closely spaced connectors. The following plots (Figures 2-5) demonstrate the effect of unbalanced connectors in a Category 5e channel.

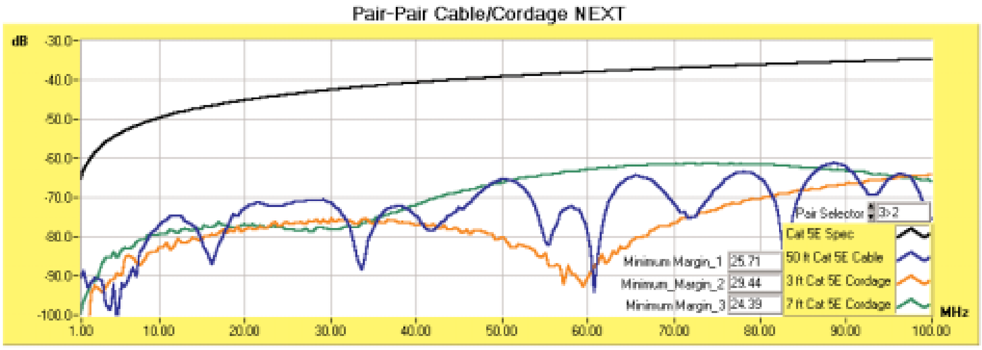


**Figure 2**

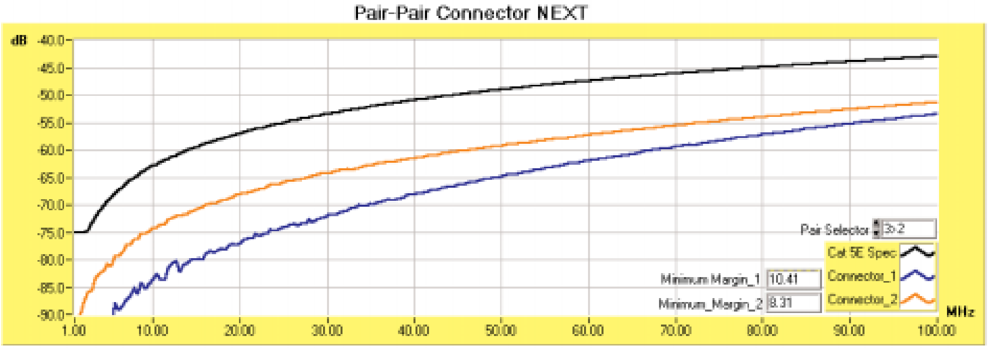


**Figure 3**

Modal test data indicates that these 5e components have ample margins to their appropriate specifications for pair 2-3 combination as shown in Figures 2 and 3. However, when these components are comprised to form a channel, surprisingly, the pair 2-3 (green trace) fails to meet the Category 5e channel NEXT specification as highlighted in Figure 4.

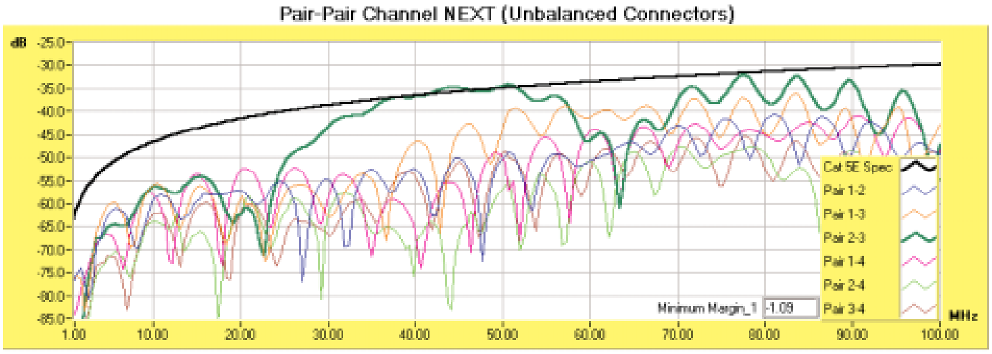


**Figure 4**

After an extensive investigation on the entire cross modal coupling paths, the root cause for this performance degradation is identified. The cross modal conversion of these connectors is too high. In addition to the pure differential crosstalk between pair 2 and 3, common mode crosstalk is generated and converted back to the differential mode and becomes additional differential crosstalk causing a severe resonance in the channel.
This additional coupling is not part of the original design criteria and only occurs in certain conditions.
Figure 5 shows the re-simulated channel NEXT with two balance-optimized connectors. Since data was organized in a matrix format, the cross modal terms of these connectors can be easily modified as if they were perfectly balanced. The resonance on pair 2-3 (green trace) disappears. The difference in the channel performance is dramatic.

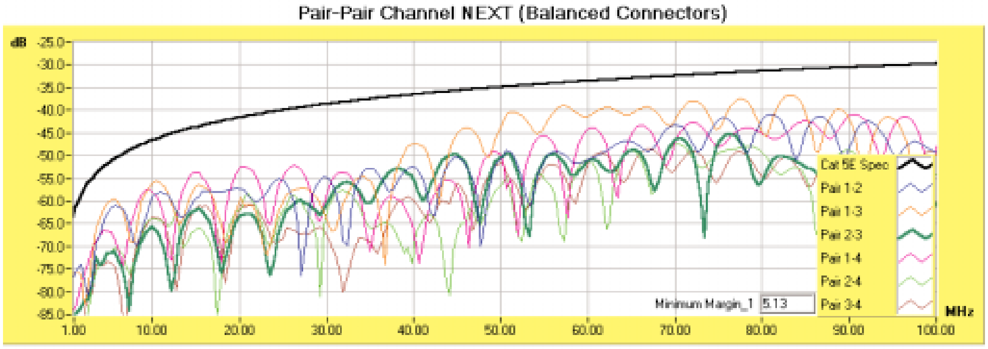
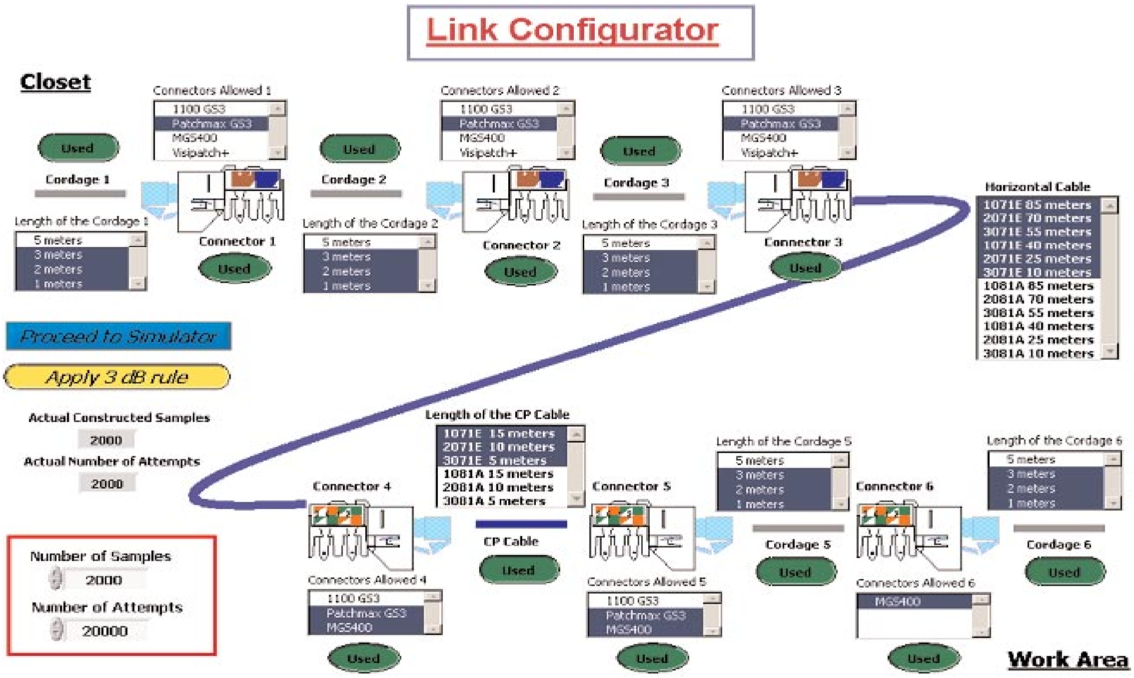


**Figure 5**

### 3.2 Modal Cascade Simulator

Resonance occurs when multiple connectors are placed in close proximity with specific lengths between multiple connectors. The only way to ensure all possible configurations have been accounted for is to test or simulate thousands of foreseeable combinations. The SYSTIMAX SCS guaranteed claims for the GigaSPEED XL Solution are derived from an extensive modal simulation of all conceivable configurations. Several component databases were built for modal cascade simulation and thousands of simulations are done for each channel or link configuration.
For example, all of the connecting hardware, cables and cordage were randomly selected from the factories. Great care was exercised to ensure that the components were from different manufacturing lots manufactured in different time periods. A set of computer simulation programs was developed to run a Monte Carlo test on the performance of various cascaded links and channels. A sizable number of simulations (>5000) can be done within a short period of time. This powerful simulator allows SYSTIMAX SCS to assess the link and channel performance much more accurately than what the cabling industry has adopted at this time. There is no need to physically set up bulky links and channels for testing nor sacrifice the sample size to accommodate space. Any large installation site with multiple link and channel configurations can be simulated. The prediction of the link and channel performance will be very close to the true population statistics. The following clips from the simulation programs illustrate this process.

a) **Link Configurator** - Allows engineers to choose a specific configuration. The number of simulations can be set arbitrarily. As shown in Figure 6, a six-connection channel configuration is chosen. Components are picked at random from the database to configure a 6-connector channel. The specific components selected for each channel are noted so that replicated configurations can be rejected automatically. When the number of simulations is set in the modal configurator (2000 in this case), it means 2000 distinctive channels will be simulated.



Actual Constructed Samples 2000

Actual Number of Attempts 2000

Number of Samples 2000

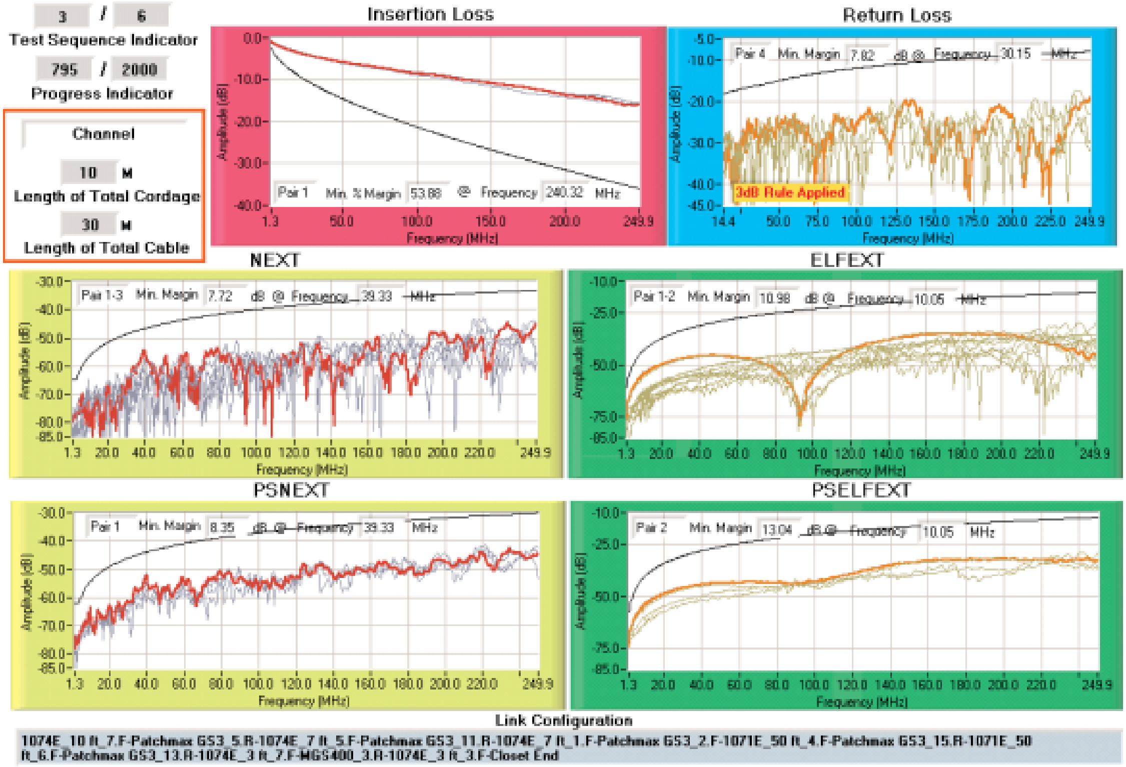
Number of Attempts 20000

Figure 6

**b) Modal Cascade Simulator** – Channel or link performance of a pre-specified configuration is computed.

The worst-case margin for each test parameter and the corresponding frequency are stored to a database.

All traces are displayed on the graphs. The worst-case trace is highlighted on each graph for each test parameter as shown in Figure 7.



3 / 6
Test Sequence Indicator
795 / 2000
Progress Indicator

Channel
10 M
Length of Total Cordage
30 M
Length of Total Cable

Insertion Loss: Pair 1 Min. % Margin 53.88 @ Frequency 240.32 MHz

Return Loss: Pair 4 Min. Margin 7.82 dB @ Frequency 30.15 MHz

3dB Rule Applied

NEXT: Pair 1-3 Min. Margin 7.72 dB @ Frequency 39.33 MHz

ELFEXT: Pair 1-2 Min. Margin 10.98 dB @ Frequency 10.05 MHz

PSNEXT: Pair 1 Min. Margin 8.35 dB @ Frequency 39.33 MHz

PSELFEXT: Pair 2 Min. Margin 13.04 dB @ Frequency 10.05 MHz

Link Configuration

1074E_10 ft_7.F-Patchmax GS3_5.R-1074E_7 ft_5.F-Patchmax GS3_11.R-1074E_7 ft_1.F-Patchmax GS3_2.F-1071E_50 ft_4.F-Patchmax GS3_15.R-1071E_50 ft_6.F-Patchmax GS3_13.R-1074E_3 ft_7.F-MGS400_3.R-1074E_3 ft_3.F-Closet End

Figure 7

c) **Statistics Analyzer** – Based upon the simulation results, cumulative distributions and probability density functions are generated and plotted. The guaranteed claims of the SYSTIMAX GigaSPEED XL7/8 Solution are derived from these statistics (Figure 8).

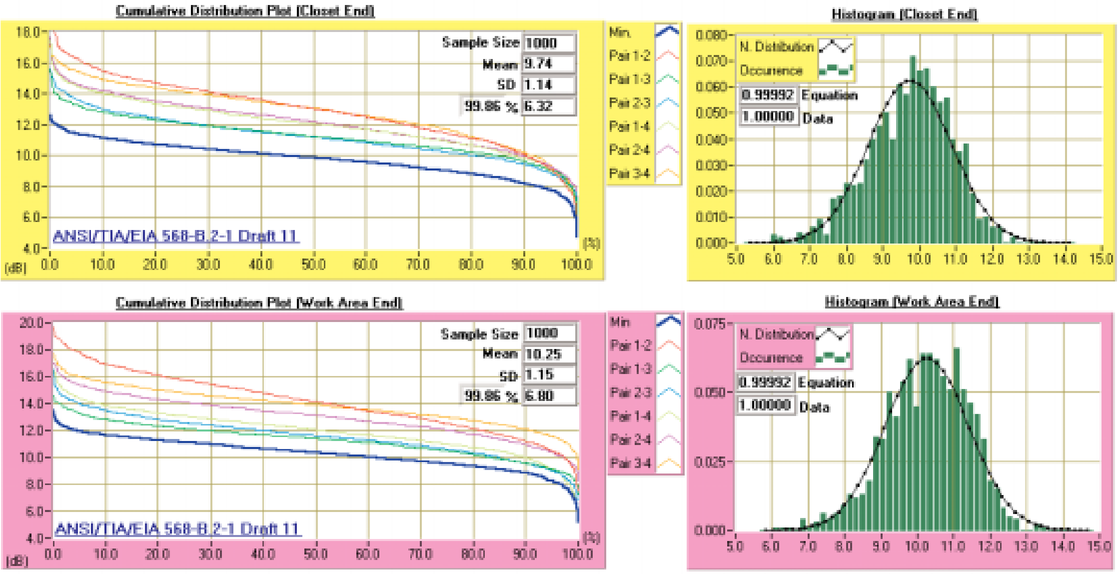


**Figure 8**

## 4. Conclusion

Assuring reliable channel performance is no easy task. Mode coupling between components can degrade channel performance dramatically in certain configurations. Physical testing of all possible configurations is simply not practical. SYSTIMAX labs has developed the ultimate channel testing tool to accurately simulate all foreseeable channel configurations. This tool helps identify mode coupling and other weak links early in the design process to guide further refinement and tuning. The final GigaSPEED XL7 and XL8 claims are based on analysis of thousands of simulated channels. All conceivable configurations and coupling paths were taken into account by these extensive modal simulations. You can be confident that GigaSPEED XL7 and XL8 channels have been engineered for reliable networking. WE GUARANTEE IT, and we don't use that word lightly!

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