Cable Analysis

Extracting Information from Measured Data

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Introduction

Every cable tells a story. Cable certification measurements can be presented as a string of numbers or as a series of plots. Most of us are not good at reading numbers. It is much easier to interpret graphical information. This paper explains how to extract information from certification plots and talks about the importance of preserving plot data for future analysis.

Importance of Preserving Plot Data

Industry standards for physical layer signaling are constantly evolving and creating new requirements for cabling specifications. Preserving all the data collected during a certification allows future analysis of the data with respect to new industry standards without the need to re-test.

Often a cable test record contains only "pass/fail" status and worst case measurements. While this information summarizes the outcome of the test per the requirements of the target standard, it is of limited usefulness for any further analysis. Plotted test results present a comprehensive pictorial view of cable parameters and carry considerably more information about the cable quality than tabulated worst case measurements. Let's look at a familiar Near End Crosstalk (NEXT) plot measured to 350 MHz.

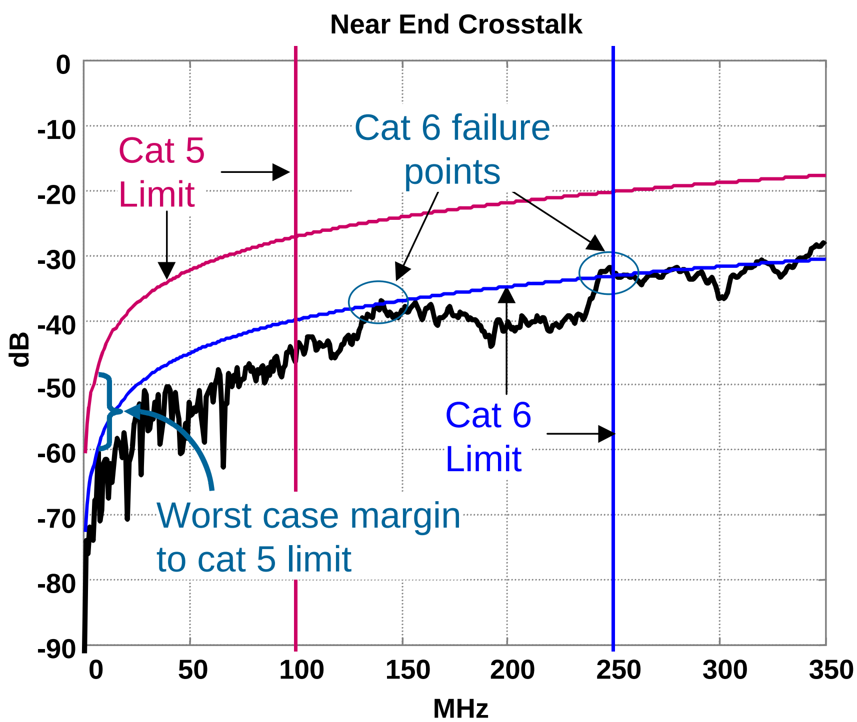

Figure 1: NEXT plot with category 5 and category 6 channel limits superimposed. Worst case margin with respect to category 5 limits is 12.5 dB at 7.1 MHz. Typically, only this worst case point will be stored in a category 5 certification record. This NEXT response meets the cat 5 limit but violates the draft cat 6 limit at two points.

If the certification test is performed today, most likely the cable is being certified to category 5 [1] or to category 5E [5] and will pass the test. If the same cable is certified a couple of years from now, the test limits will probably be category 6 [6]. If the data collected today during the certification test is saved, then this data can be compared to the future category 6 limit a few years from now.

What story does the NEXT plot tell? First, it is obvious that this cable meets the category 5 NEXT limit with substantial of headroom but violates the draft category 6 limit at two frequency points. And although this information is obvious from the plot, it isn't available from a typical certification test record (table 1).

Table 1: Typical certification test record of a NEXT measurement

Worst-case Margin	Measured Value	Test Limit	Frequency
12.5 dB	59 dB	46.5 dB	7.1 MHz

The data typically saved by a certification instrument is the point with the worst case margin to the test limit. If the cable was certified to category 5 and if the saved worst case point violates the category 6 limit, we know that the cable does not meet category 6. However, the reverse is not true. If the saved point meets the category 6 limit, we still don't know whether the entire plot meets the limit. All plot points are needed to re-certify the cabling and saving plot data is the only way to future-proof the investment in cable plant certification.

The Value of Re-certification -- Evolving Industry Standards

What's the value of re-certifying cabling? Let's consider the likely scenarios that would call for re-certification.

ISO expects to publish the category 6 specification approximately 2 years from now. Until then, category 6 installations cannot be certified. However, if plot data is collected today, the cabling can be certified to category 6 in the future without re-testing.

Although the emerging IEEE 1000Base-T gigabit Ethernet will operate over the installed category 5, there is some indication that IEEE might be interested in specifying the next generation 10 Gb/s twisted pair Ethernet network in the not too distant future. Once the signaling scheme for such a new network is agreed upon, the measured data can be analyzed with respect to the new network requirements. Other physical layer signaling schemes may be developed by organizations such as the ATM Forum.

We are practically assured that new physical layer requirements will emerge in the future. Technological progress in the communications industry has a tremendous momentum. The data rates will keep on climbing and the cabling will have to be re-analyzed with respect to new requirements.

The Meaning of Plot Data

Plots not only serve to future proof the investment in cable certification -- they provide visual information about cable quality. This information can be viewed either as a function of frequency or as a function of distance.

The cabling standards specify cable parameters in the frequency domain because frequency domain representation of data describes the available bandwidth of the channel. However, the measured data can also be viewed in the time domain to see how the quality of the cable varies as a function of distance.

The field certification standards [3] [4] require that the following parameters be measured as a function of frequency:

1. Attenuation
2. Near End Crosstalk (NEXT)
3. Far End Crosstalk (FEXT) [1]
4. Return Loss (RL)

These four parameters tell a story about the strength of the desired signal and about the coupled and reflected noise.

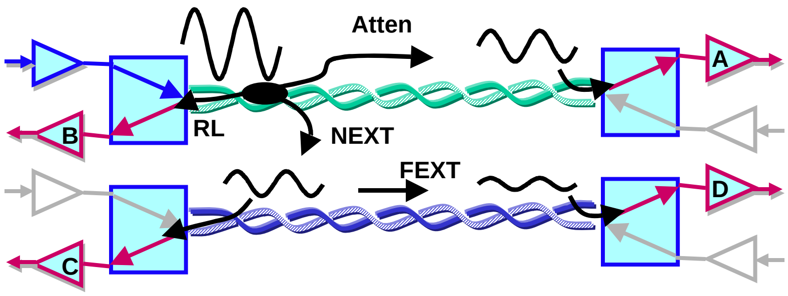

Figure 2: Propagation of transmitted sine wave signal. Receiver A gets the desired attenuated signal. Receivers B, C and D receive undesired noise coupling in the form of return loss, NEXT and FEXT respectively.

Figure 2 demonstrates how a transmitted signal propagates into the target receiver and how it couples in various ways into the other receivers that may be connected to the cable. When a signal (e.g. a sine wave) is transmitted onto a pair, this signal propagates to the destination receiver A and arrives there attenuated by the cable attenuation. Some portion of the signal is reflected back into receiver B in the form of return loss noise. Some of the signal is coupled onto the adjacent pair in the form of NEXT noise entering receiver C. This coupled signal also travels toward receiver D and arrives there in the form of FEXT noise.

The coupled signal is the undesired noise. The goal is to maximize the power of the signal at the target receiver (receiver A) and to minimize the coupling into the adjacent receivers. To maximize the power of the desired signal, attenuation must be minimized. To minimize the undesired noise coupling, NEXT loss, FEXT loss and return loss must be maximized. When the desired signal is maximized and the coupled noise is minimized, the Signal to Noise Ratio (SNR) at the receiver is optimized and the probability of bit errors is minimized. The limits for the coupled noise -- NEXT loss, FEXT loss and return loss -- are designed to provide acceptable SNR environment for the new generation gigabit networks that use all four pairs in full duplex (e.g. draft IEEE 1000 Base-T).

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[1] The far end crosstalk can be represented as Equal Level Far End Crosstalk (ELFEXT). ELFEXT is measured with respect to the attenuated signal while FEXT is measured with respect to the injected signal. Mathematically, ELFEXT = FEXT-Attenuation.

Time and Frequency Domains

Although the test limits for attenuation, NEXT, FEXT and return loss are specified in the frequency domain [1] [2], measured data can be analyzed in either frequency or time domain. There is a mathematical conversion between the two domains -- the Fourier Transform and the Inverse Fourier Transform.

The Fourier Transform can be used to convert sampled time-domain data to the frequency domain and the Inverse Fourier Transform can be used to convert the data collected in the frequency domain to time domain.

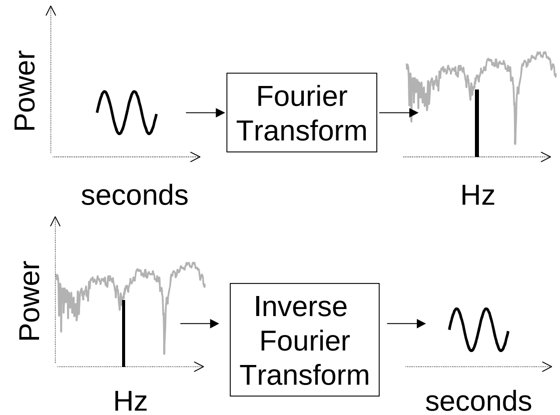

Figure 3: Fourier Transform -- time to frequency domain; Inverse Fourier Transform -- frequency to time domain

As shown in figure 3, each point in the frequency domain is converted to a sine wave in the time domain. When all the sine waves corresponding to each frequency point are added together mathematically, the result is the time-domain representation of the entire signal. The theory behind the Fourier Transforms is beyond the scope of this document. Suffice it to say that the measurement can be performed in either time or frequency domain and then converted to the other domain.

Why time-domain? Although the standard test limits are specified in the frequency domain, the time-domain view of the data is very helpful for analyzing the cable properties as a function of distance so that installation faults can be easily located. Look, for example, at the failing FEXT plots below.

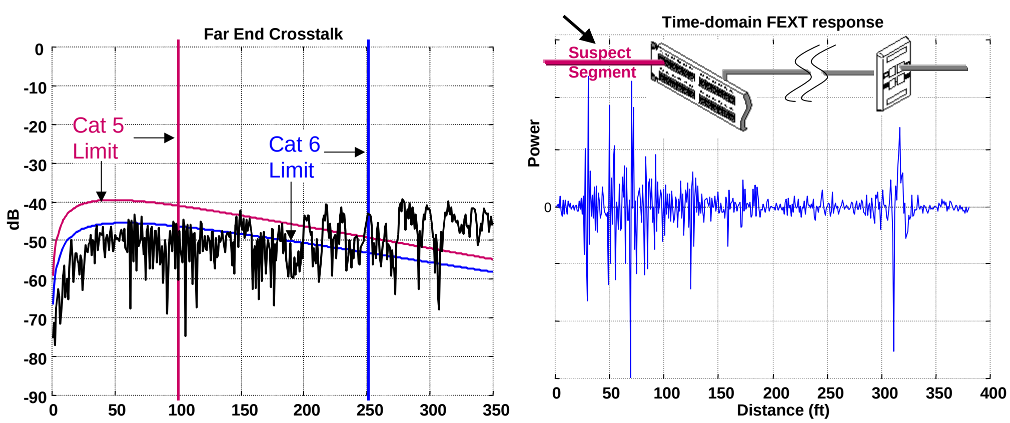

Figure 4: Failing FEXT response. Frequency-domain view (left) is not very useful for trouble-shooting. Time-domain view (right) shows how the FEXT power is distributed along the cable and points to the problem area.

It is clear from the frequency domain plot that FEXT violates the test limit but it is not at all clear which component in the channel causes the failure. If the wiring topology is known and if a time domain plot is available, then the problem segment can be isolated immediately, as shown in figure 4.

But while the time domain view is great for troubleshooting, measurements should be performed in the frequency domain and then mathematically converted to time domain if troubleshooting is in order. Frequency domain data is required because the test limits and instrument accuracy are both specified in the frequency domain. Time-domain data on the other hand is only needed in cases of failure -- typically, only a few times in a full day of testing. So, there is no need to incur the unnecessary time and accuracy penalty of first measuring in time domain and then converting the data to frequency domain to see if the measurements meet the test limit. Frequency-domain measurements are more direct and more accurate.

Here are some examples of frequency and time-domain plots of the required field test parameters.

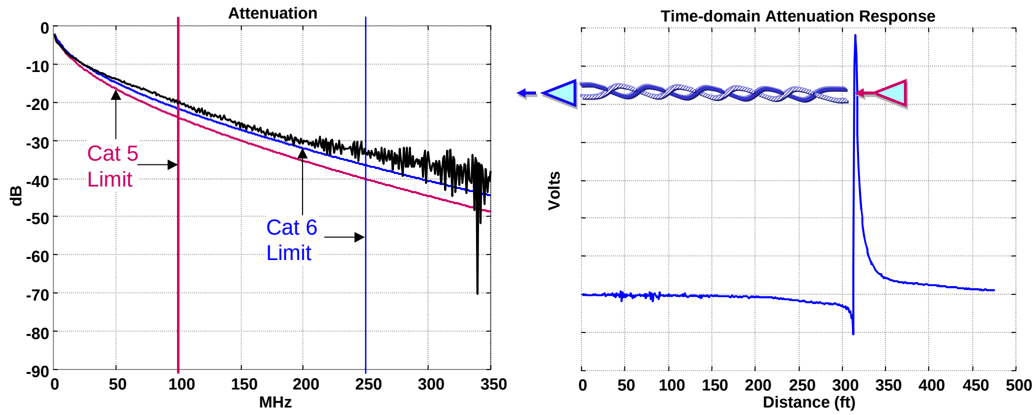

Figure 5: Attenuation of a 330 ft cable; Most of the signal energy is concentrated at the far end of the cable where it is injected for measurement.

The length of the cable under test is easily deduced from the time-domain view of the attenuation measurement. Most of the energy is at the far end of the cable where it is injected.

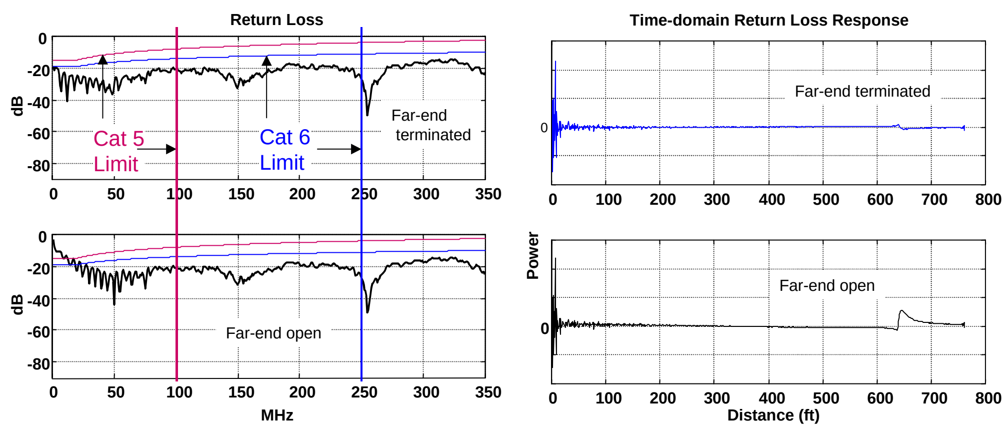

Figure 6: Return loss response of the same 330 ft cable; top - far end terminated with 100 ohms, bottom - far end open

Return loss signal is a reflected signal that travels round trip distance before it is measured. Therefore, the distance shown on the plot -- the distance traveled by the signal -- is double the distance to the corresponding point in the cable.

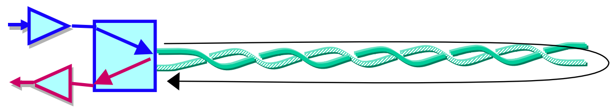

Figure 7: The distance shown on the time-domain return loss plot is the actual distance traveled by the signal round trip -- twice the distance to the corresponding point on the cable.

Thus, the reflected power shown at 660 ft on the bottom time domain plot of figure 6 is actually reflected off the unterminated end of the 330-ft cable. The upper time domain plot shows that if the cable is properly terminated, the reflection is minimized.

The frequency domain plots of return loss show that if the cable is left unterminated, return loss is likely to fail at low frequencies where attenuation of the reflected signal is low (figure 6, bottom left). At higher frequencies, the signal reflected off the unterminated end is attenuated and falls within the test limit.

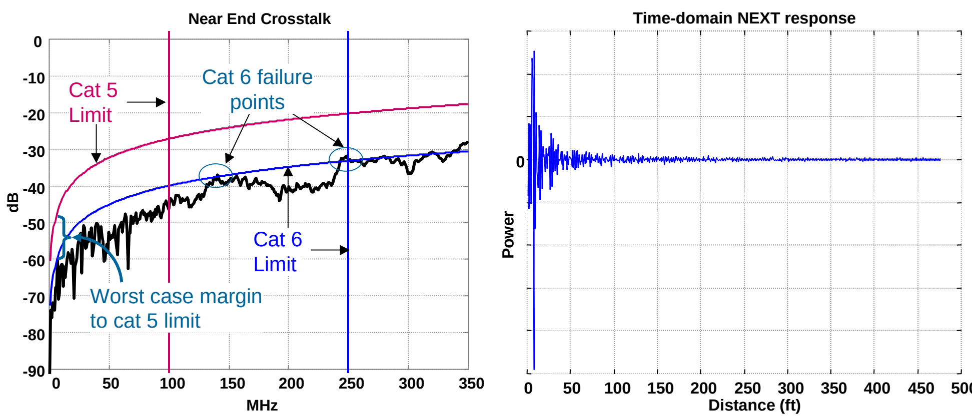

Figure 8: NEXT frequency response and the corresponding time domain response

Near end crosstalk also propagates in a round trip manner, but couples from one pair to another instead of being reflected from the same pair, as is return loss.

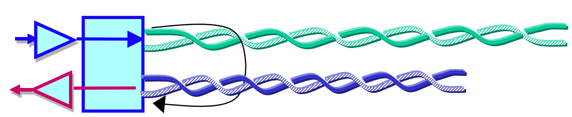

Figure 9: NEXT signal propagates in a round trip manner.

It is obvious from the time domain plot of the NEXT response that NEXT is strongest at the source and diminishes as a function of distance as the coupled signal undergoes round-trip attenuation.

Clearly, a lot can be learned from each plot if we are able to interpret the information. Frequency domain plots show the quality of the cable with respect to the test limits and are required for certification. Time domain plots show the quality of the cable as a function of distance and are useful for troubleshooting. If frequency domain test data is saved, it can be later converted to time domain and the cabling can be analyzed either as a function of frequency or as a function of distance.

Summary

Plot data collected during a certification test should be saved for two reasons. First, saving the plot data protects the investment in certification allowing the user to re-certify cabling to future standards without re-testing. Second, plot data carries valuable visual information about the quality of the cable with respect to the test limits and as a function of distance. When viewed as a function of distance, plot data helps diagnose failed and marginal cabling.

Plots convey an intuitive pictorial description of the cable that traditional worst case summary results simply can not match. In the realm of cable analysis, as in everyday life, a picture is still better than a thousand words.

And when it comes to industry standards, one thing is certain: new standards are coming -- it is only a matter of time. If the plot data is not saved during the certification, the cabling will have to be re-tested as each new standard arrives.

References

[1] ANSI/TIA/EIA-568-A, "Commercial Building Telecommunications Cabling Standard", October 6, 1995

[2] ISO/IEC 11801, "Generic Cabling for Customer Premises", 1995

[3] TIA/EIA Telecommunications Systems Bulletin, TSB67, “Transmission Performance Specifications for Field Testing of Unshielded Twisted-Pair Cabling Systems”, October 1995

[4] TIA TSB95 (draft) “Additional Transmission Performance Specifications for 100 Ω 4-Pair Category 5Cabling”, 8/98

[5] TIA-568-A Addendum 5 (draft) "Additional Transmission Performance Specifications for 4-Pair 100 Ω Enhanced Category 5 Cabling" , 8/98

[6] Category 6 Draft 3 - Addendum to TIA-568-A, "Transmission Performance Specifications for 4-Pair 100 Ω Category 6 Cabling", April 9, 1998

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