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Using TWDP to Quantify Channel Performance with Frequency-Domain S-Parameter Data

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***Abstract-* This paper presents an approach to quantify channel performance using TWDP (Transmitter Waveform and Dispersion Penalty) with frequency-domain S-parameter data. TWDP is initially defined to characterize the performance of a transmitter in optical links. The same concept has been extended to quantify channel performance as well, especially in high-speed copper links. This paper focuses on channel characterization. Instead of using time-domain oscilloscope measurements as defined in the original approach, a new method is proposed by using the frequency-domain S-parameter data, obtained either from measurements or simulations. A parametric study on TWDP with respect to bit rate, number of samples per bit, rise/fall time, etc., is also presented with discussions.**

***Keywords*-Transmitter waveform and dispersion penalty (TWDP), high-speed link analysis, channel performance, frequency-domain S-parameter**

INTRODUCTION

Transmitter Waveform and Dispersion Penalty (TWDP), in its original definition, is a parameter used to define and quantify the performance of a transmitter. It is commonly specified and used in high-speed optical links such as 10GBASE-LRM [1-2].

A high-speed digital signal has a broad spectrum with many frequency components. These frequency components do not travel through a transmission channel at the same speed. Therefore, they reach the receiver at different time. This phenomenon is referred to as dispersion [3]. The nonlinearities in the transmitter waveform along with a highly dispersive cable/channel can cause failure of the link because the common equalizer structures are designed for linear channels. This requires a testing procedure to find out if the link would work without failing. The TWDP test was designed for this exact purpose.

Before the TWDP test was introduced, the TDP (transmitter and dispersion penalty) test was often specified, such as by the IEEE 802.3ae standard committee, to test if the transmitter was good enough to be used in the link. The TDP testing procedure unfortunately has some drawbacks. It involves dealing with several hardware components such as transmitter, cable and receiver; thus increasing the cost. Furthermore, it is burdensome to manage these hardware components well so that the results can be repeatable and consistent for different setups. Compared to the TDP method, the TWDP test does not require all the actual hardware components. For example, reference transmitter, channel, and receiver are no longer needed. Therefore cost can be cut down and complexity reduced. As a consequence, the overhead of calibrating the reference transmitter and receiver for every setup is overcome [2].

The standard procedure to calculate the TWDP value is shown in Figure 1. It involves time-domain oscilloscope measurements at the output of the system under test that is a transmitter in the original TWDP application. An ideal data pattern (specified as PRBS9 in the IEEE standard) is used in the test. The output waveform from the system under test is captured using an oscilloscope with the 4th order Bessel Thomson response for waveform acquisition. This output waveform is used as an input to the TWDP algorithm that is defined by the IEEE standard, where it compares with the ideal data pattern [1]. Both the output waveform from the system under test (a transmitter) and the ideal undistorted input waveform are fed into an emulated channel cascaded with an emulated equalizer and an emulated receiver in the algorithm. Obviously, for the transmitter output waveform, a larger signal to noise ratio (S/N) is needed due to its non-linearities and distortion than the ideal input waveform to achieve the same output bit error rate (BER) at the receiver. The value of TWDP is then set as the difference in the required S/N levels for a fixed output BER, normally 10^{-12}.

The TWDP procedure can be extended to quantify channel performance as well. In this extended application, the system under test is a physical channel (for example, a cable), instead of a transmitter. Then an emulated channel is no longer needed in the TWDP algorithm. The output waveform from the system under test and the ideal input waveform are directly fed into an emulated equalizer and an emulated receiver. In this kind of applications, the TWDP

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value is the decrease in the input signal to noise ratio when the physical channel is replaced with an ideal lossless channel while keeping the output bit error rate the same for both the cases. The extended TWDP application has already been specified to characterize high-speed copper links such as the 10 Gb/s SFP+ copper link [4-5].

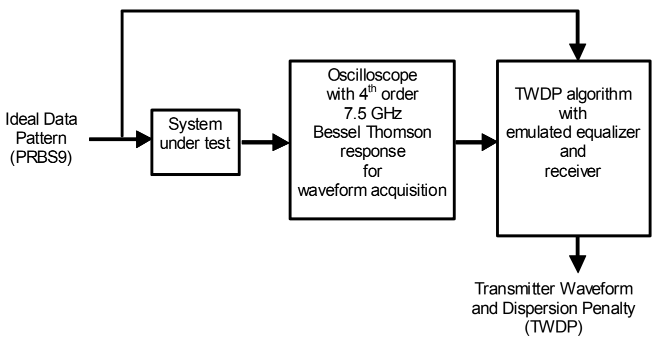

Figure 1: Conventional TWDP measurement procedure.

Physical channels are often band limited with loss. Further, the transmission loss of a channel usually increases with frequency. For example, both conductor and dielectric losses exist in a copper cable. The high-frequency conductor loss, i.e., the skin-effect loss, is proportional to the square root of frequency, while the dielectric loss increases with frequency proportionally. This frequency-dependent loss of a channel is one of the major factors that cause digital signals to be distorted when they pass through the channel. Another important factor is the phase of the channel transfer function. If this phase is not linear, the channel can result in dispersion in the output signal.

The TWDP parameter quantifies the effects of the transfer function of a channel on high-speed digital signal transmission. It is related to the inter-symbol interference (ISI), but is more intuitive as it is a quantifiable value. Obviously the higher the TWDP value is, the more distortion the output waveform of the channel. In other words, the channel is less preferable for a high-speed link.

The focus of this paper is put on channel characterization using the TWDP parameter. All the discussions herein are thus limited to this specific application of the TWDP parameter.

A new approach to calculate the TWDP value associated with a physical channel based on its frequency-domain S-parameter data is introduced below, followed by a parametric study on the effects of some factors that could be easily modified using the new approach.

FREQUENCY-DOMAIN APPROACH

The conventional approach to calculate the TWDP value, as shown in Figure 1, involves a time-domain oscilloscope measurement. A new approach is proposed in this work. As shown in Figure 2, this new approach starts with the frequency-domain S-parameters of the channel under test, which can be obtained from a vector network analyzer (VNA) measurement or even a numerical modeling. The S-parameters, combined with an emulated input signal having a specified data pattern, generate the time-domain output waveform of the channel under test through a link path analysis. This output waveform is then compared with the ideal input waveform in the TWDP algorithm, and the TWDP value for the channel under test is calculated.

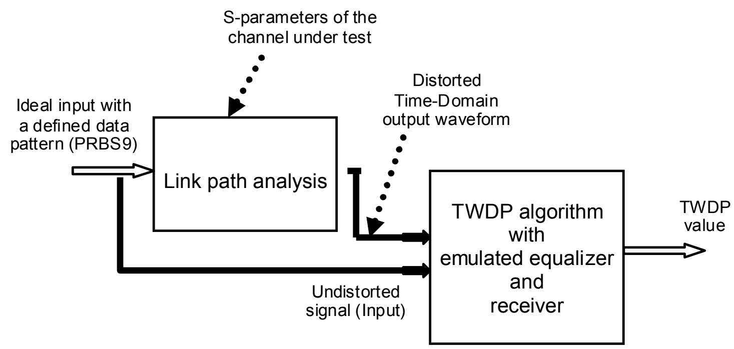

Figure 2: New approach to calculate the TWDP value of the channel under test.

The flow chart of the link path analysis is shown in Figure 3. A time-domain input waveform is first generated with a specified data pattern. Many parameters of this input waveform can be defined and adjusted, including bit rate, rise/fall time, high/low voltage levels, number of samples per bit, number of repetitions of the bit pattern, etc. Then the time-domain input waveform is transformed into the frequency domain through the Fast Fourier Transform.

Another input needed for the link path analysis is the frequency-domain S-parameter data of the channel under test. However, the data need to be preprocessed before any further usage, to make sure that they are physical and that any minor measurement errors are corrected. This preprocessing is necessary for obtaining a meaningful result. Both passivity and causality of the data are checked and enforced if needed [6].

In addition, the S-parameter data normally need to be extrapolated to DC and interpolated at a preferred frequency sampling rate, to ensure an accurate and meaningful inverse Fourier Transform later on.

After the necessary preprocessing, the frequency-domain S-parameter data are multiplied with the frequency-domain input, resulting in the frequency domain output of the channel under test. Inverse Fourier Transform is then employed and the time domain output waveform of the channel under test is obtained.

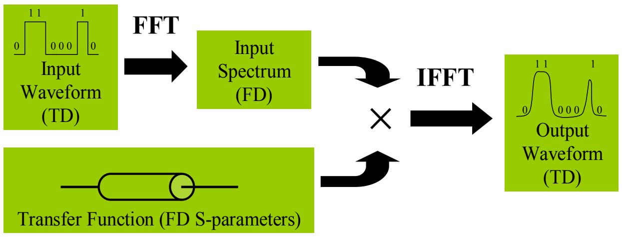

Figure 3: Link path analysis.

The TWDP value is calculated by comparing the time-domain output waveform of the channel under test with the ideal time-domain input waveform. The comparison requires an alignment of the two signals. In other words, the delay in the output waveform caused by the channel shall be removed so that corresponding bits in the input and output waveforms can be aligned.

The advantages of the new TWDP approach over the conventional procedure are somewhat due to the elimination of the time-domain oscilloscope measurement. In the new approach, the frequency-domain S-parameters can be obtained from a VNA measurement or a numerical modeling. The frequency-domain VNA measurements are much more repeatable than the time-domain oscilloscope measurements. The dynamic range of VNAs is much larger, which can accurately capture smaller as well as larger signals than oscilloscopes. Further, VNA measurements make the test fixture calibration and compensation possible, so that the effects of the test fixtures, such as testing cables, connectors, adapters, etc, can be eliminated from the measured results resulting in accurate and reliable data.

In addition, the conventional approach requires a pattern generator to obtain an input waveform to the channel under test. This pattern generator is no longer needed in the new frequency-domain approach. The input waveform is emulated instead of being generated by a pattern generator. This greatly cuts down the cost and reduces the complexity in measurement setups.

Lastly but not the least, the conventional approach suffers from the property of pattern generator and sampling scope. The same channels (cables) tested in different labs with different equipments could give slightly different results. This is not the case with S-parameters which change little when measured on different systems with proper handling and calibration.

The new approach offers some side benefit too. Almost all the parameters can be freely changed now to study various what-if scenarios. For example, the data rate is not limited to 10.3125 GHz and the number of samples per bit not to 16 any more. In addition to PRBS9, any data patterns are allowed. The user has a lot of freedom to design various test setups. Thus the new approach provides a useful tool to further understand the TWDP parameter and makes the future improvement and adjustment possible.

RESULTS AND DISCUSSIONS

A parametric study on the TWDP with respect to the setup parameters such as data rate, number of samples per bit, rise/fall time, number of pattern repetitions, etc. was conducted using the new approach discussed in the last section. The TWDP values as a function of a setup parameter are plotted. The channel under test is a 6 meter 24AWG SFP+ copper cable. It includes two differential pair.

Figure 4 shows the TWDP value of one differential pair as a function of the data rate. As expected the TWDP value increases with frequency. The frequency spectrum of a higher-speed digital signal has more higher-frequency components, while the loss of the copper cable increases significantly with frequency. Thus more distortion is caused by the channel to the higher-speed digital signal, resulting in a larger TWDP value. The figure further indicates that the relationship between the TWDP value and the data rate is approximately linear. So it may be possible to estimate the TWDP value for a cable at a frequency, provided that the TWDP values at a certain set of frequencies are already known.

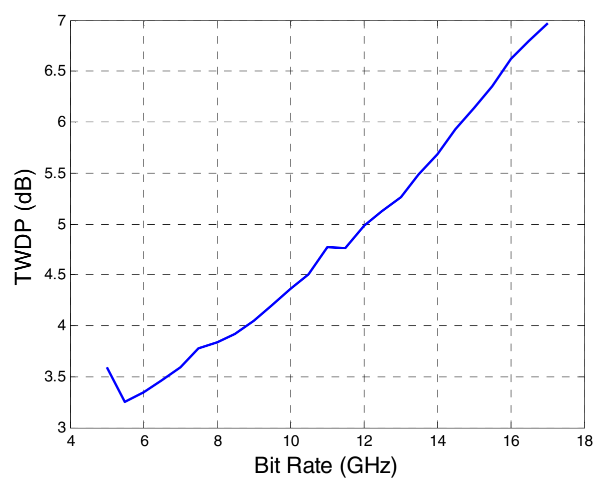

Figure 4: TWDP versus bit rate.

Figure 5 shows the variation of the TWDP value with respect to the number of samples per bit. As clearly shown in the figure, 16 samples per bit as defined in the current standard may not be sufficient. The TWDP values starts to converge when the number of samples per bit is larger than 40. Increasing this sampling rate can result in a more accurate TWDP value.

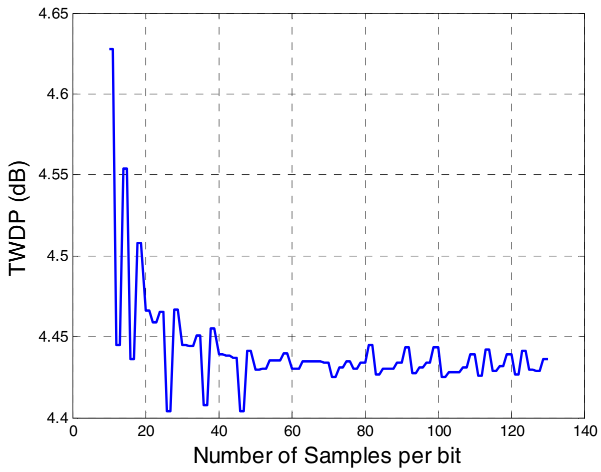

Figure 5: TWDP versus number of samples per bit.

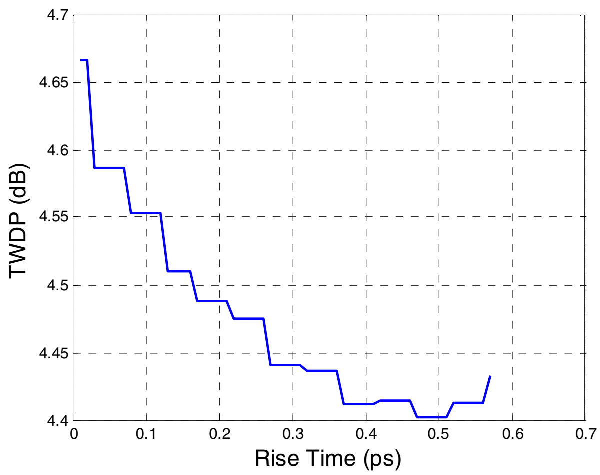

Figure 6: TWDP versus rise/fall time.

The TWDP value also changes with the rise/fall time, as illustrated in Figure 6. The data rate in this case is fixed at 10.3125 GHz, and the rise/fall time varies within the allowable range. Generally speaking, the TWDP value decreases with the increase of the rise/fall time. This can be accounted for by the fact that the shorter rise/fall time causes more higher-frequency components in the signal spectrum. Because the channel adds more loss at higher frequencies, the signal with shorter rise/fall time is distorted more after it passes through the channel. An interesting observation is that the relationship is not a linear line. Instead it has many step shapes, which needs further investigations.

Figure 7 shows the TWDP value as a function of the number of pattern repetitions. The number of pattern repetitions is the number of times the input waveform pattern is repeated, so it determines the length of the input data stream. Obviously the TWDP value slightly decreases with the increase of the number of pattern repetitions. This could be explained by the possible transient response when the input waveform starts. Therefore, the TWDP value shall converge to the steady-state value when sufficient repetitions are used.

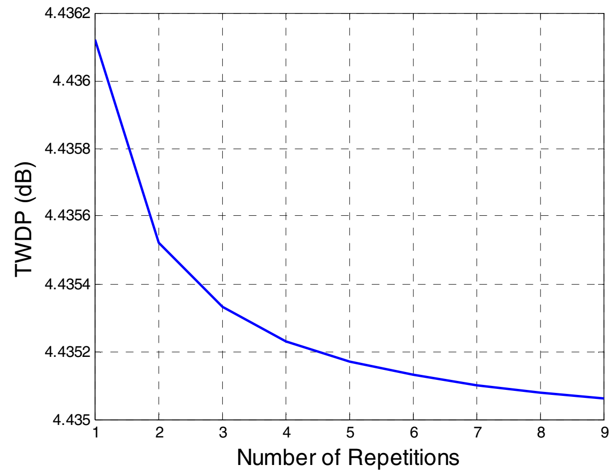

Figure 7: TWDP versus number of pattern repetitions.

CONCLUSION

A new approach to calculate the TWDP value of a channel based on its frequency-domain S-parameter data is presented. This new approach provides many advantages over the conventional approach, such as reduced cost, improved repeatability, reduced setup complexity, more accuracy, etc. A parametric study on TWDP with respect to some setup parameters is also reported. The results indicate that the TWDP value increases with the increase of frequency and the decrease of the rise/fall time. The results also demonstrated that more samples per bit and more pattern repetitions may be needed to obtain a more accurate and repeatable TWDP value.

REFERENCES

[1] IEEE Std 802.3aq, 2006.

[2] Norman L. Swenson, Paul Voois, Tom Lindsay, Steve Zeng, "Standards compliance testing of optical transmitters using a software-based equalizing reference receiver".

[3] Ben Willcocks, Nick Weiner, Ian White, Richard Penty, and Jonathan Ingham, "Electronic dispersion compensation steps up to 10-Gbit/s link challenges," CommsDesign, Jan 14, 2004.

[4] SFF-8431 Specifications for Enhanced 8.5 and 10 Gigabit Small Form Factor Pluggable Module SFP+, Revision 2.2, 19 December 2007.

[5] A. Ghiasi, "Higher Speed Copper Operation", *IEEE 802.3 HSSG Meeting*, San Francisco, July 17, 2007.

[6] Vittorio Ricchiuti, Antonio Orlandi, James L. Drewniak, and Francesco De Paulis, "Characterization of serial links at 5.5Gbps on FR4 backplanes", submitted for publication to *EMC Europe,* September 8-12, 2008, Hamburg, Germany.