Subject: Typical Channel Characteristics and Displays

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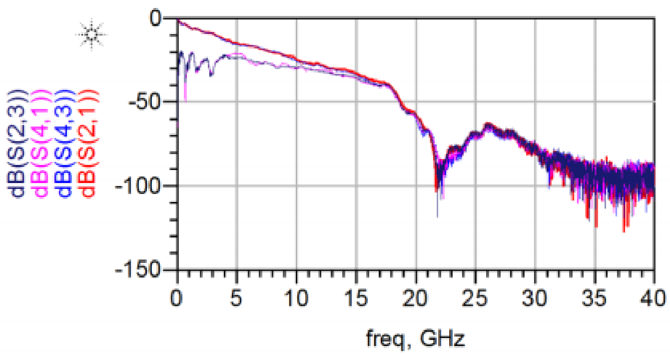
This paper discusses features on the web site: **https://www.serdesdesign.com**

This section discusses typical channel characteristics and displays. Let us know if you would like the tool enhanced with additional capability.

A typical SerDes channel, with about 18 nsec time delay, defined for use with serial data at a bit rate of 25 Gbps has its hardware 4-Port S-parameters measured from 10 MHz to 40 GHz in steps of 3.125 MHz as shown here:

Figure 1: S-parameters magnitude response versus frequency; only S21, S41, S23, S24 are displayed.



Its differential transmission characteristic is defined as the differential response from the input differential pair of ports to the output differential pair of ports (positive side: port 1 -> port 2; minus side: port 3 -> port 4):

The S-parameters, though measured on actual hardware, actually deviate from the constraints for physical realizability such as passivity, reciprocity, and causality or include noise in the measured S-parameters for various reasons. For physical realizability, the S-parameters should ideally be measured continuously from 0 Hz to infinity and with no noise or distortion. For practical reasons, the S-parameters are band limited, are tabulated only at discrete frequencies, and are corrupted by measurement noise. These measurement limitations typically cause the S-parameters to be non-causal, non-reciprocal, and non-passive.

Thus, to achieve a physically realizable transmission characteristic, the S-parameters must have corrections applied. The total channel, inclusive of the S-parameters, is then converted to an equivalent single ended impulse response.

See channel impulse response detail in References > **Channel Time-Domain Response**

The typical approach involves zero-padding the S-parameters for the time domain SampleRate (SampleRate = BitRate * SamplesPerBit) for a maximum frequency of SampleRate/2.0 and applying the constraints for physical realizability which include meeting the mathematical aspects of the Kramers-Kronig relations applied to linear time invariant (LTI) systems. This zero-padding approach often results in high frequency aliasing.

SerDesDesign.com uses a proprietary algorithm to obtain the causal channel impulse response which inherently does not result in any high frequency aliasing. Direct use of the S-parameter data inherently introduces errors.

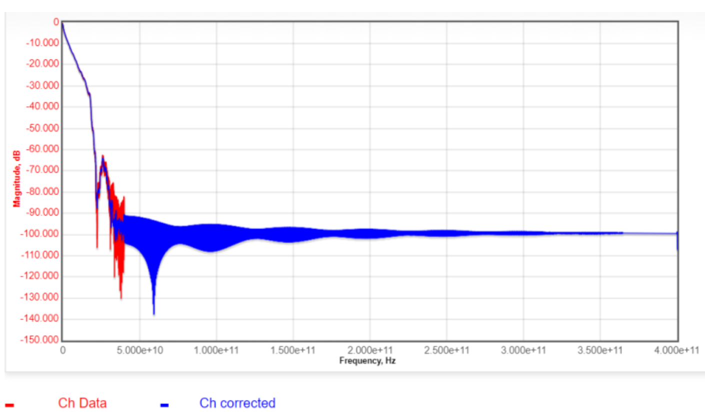
See Causal S-Parameters detail in: **About the Generate Causal S-Parameters Tool**

See also discussion below on **'Obtaining the Differential Channel Frequency Domain Characteristic'.**

With physical realizability corrections applied, various measurements are made.

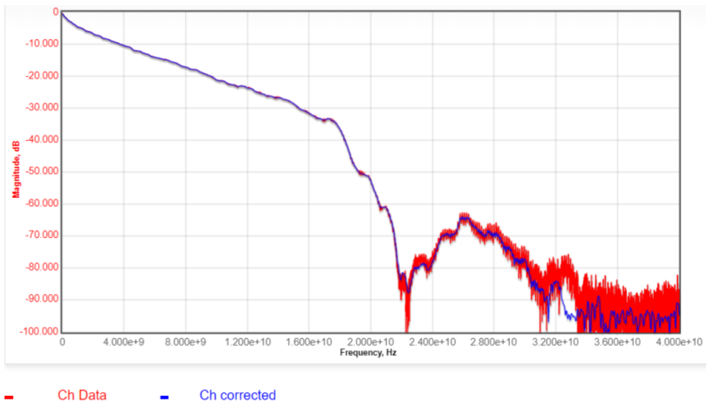
1A. Channel spectrum magnitude

The data (red) and corrected (blue) differential transmission magnitude (in dB) characteristic is shown in the frequency domain up to the maximum sample rate frequency of SampleRate/2.0 = 400 GHz. Observe no high frequency aliasing in the corrected data.



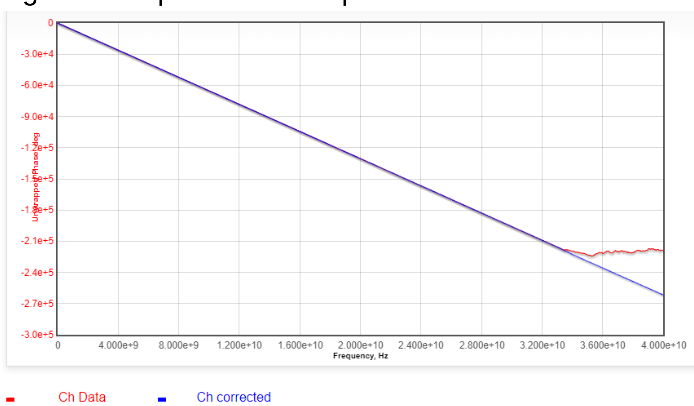
1B. Channel spectrum magnitude zoomed

The data (red) and corrected (blue) differential transmission magnitude (in dB) characteristic is shown in the frequency domain up to the maximum dta frequency of 40 GHz. Observe that the corrected data tracks the suck out between 20 GHz and 24 GHz and reduces the noise in the original data.



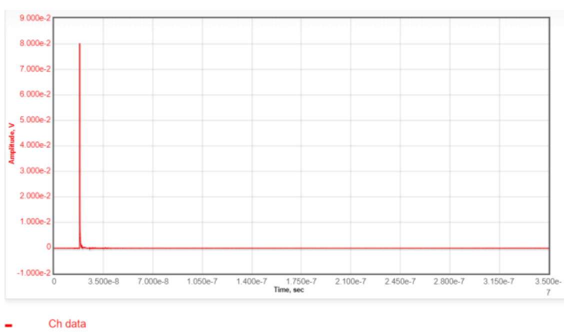
2. Channel spectrum phase

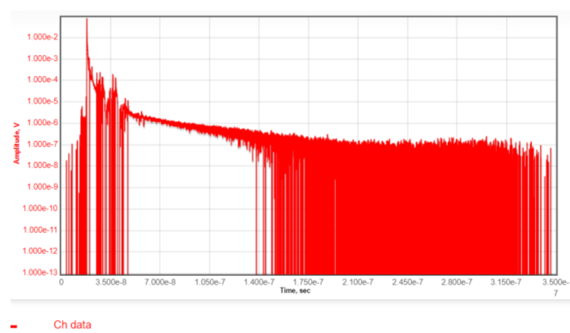
The data (red) and corrected (blue) differential transmission unwrapped phase (in deg) characteristic is shown in the frequency domain up to the maximum sample rate frequency of SampleRate/2.0 = 400 GHz. Observe that the corrected data phase is continuous whereas the original data phase is corrupted due to noise.



3. Channel data impulse response

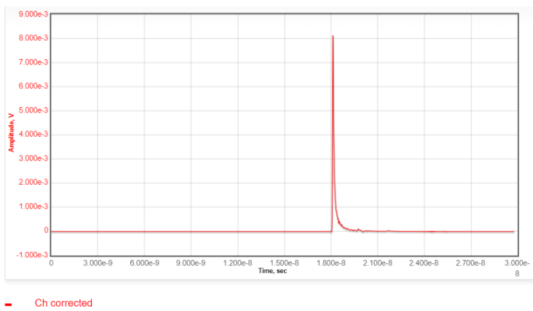
The data differential transmission impulse response is shown here along with a view with a logarithmic y-axis. The total time duration is about 350 nsec. With the logarithmic view, the non-causal artifacts are visible before the 18 nsec transit time of the channel.

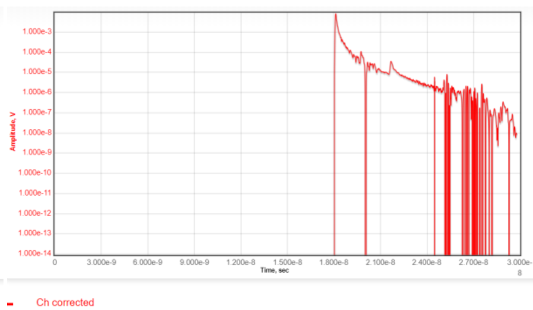




4. Corrected channel impulse response

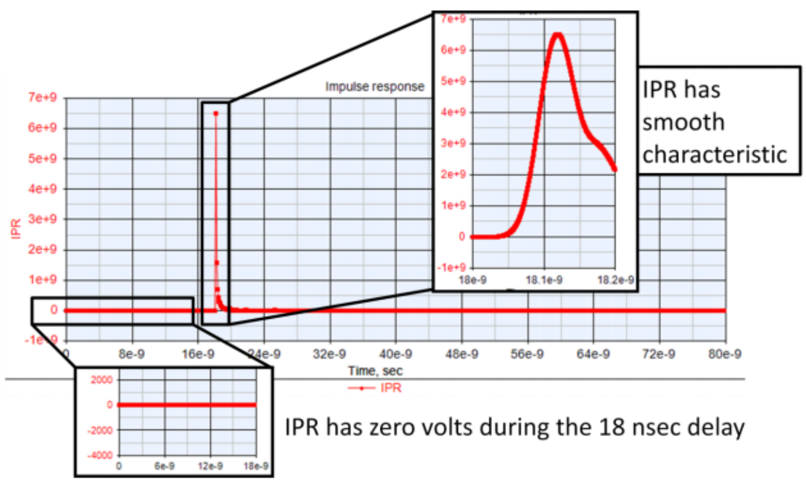
The corrected differential transmission impulse response is shown here along with a view with a logarithmic y-axis. The total time duration is about 30 nsec, which is 10x shorter than the impulse response based on the un-corrected data. With the logarithmic view, one can see that the corrected impulse response has no non-causal artifacts are visible before the 18 nsec transit time of the channel.





The corrected channel impulse response can be downloaded and reused in future analyses so that the channel corrections do not need to be recalculated thereby eliminating the simulation time needed to do these calculations.

Additional detail on the causal corrected impulse response.

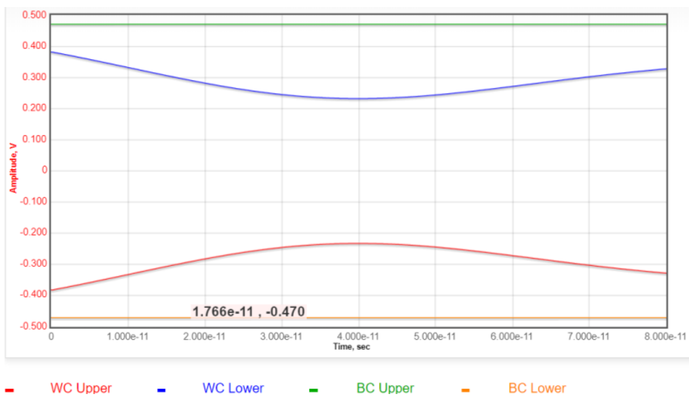


For the 25 Gbps data rate, one unit bit time interval (UI) is 40 psec. Thus, the transmission 18 nsec delay is equal to 450 UI time intervals. Notice that the impulse response has a zero value for this time delay interval, has a sharp turn on after the time delay, and has a realistically smooth characteristic. Most tools in the Electronic Design Automation (EDA) industry do not generate such a good IPR response from S-parameter data. In fact, any impulse response that is derived from S-parameters and has non-zero values during the transmission delay is inherently a non-causal impulse response. Also, any impulse response that is derived from S-parameters and has a non-smooth peaking value inherently has a problem with aliasing.

5. Channel worst/best case eye contours

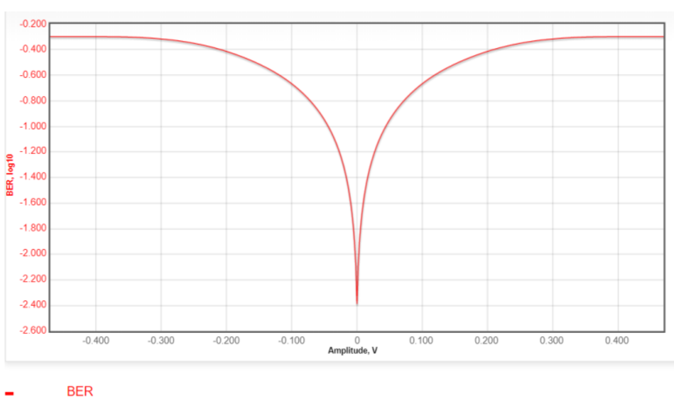
From the corrected channel impulse response, a statistical analysis can be performed to determine what is the associated eye diagram peak (and minimum) distortion characteristics. For this channel, due to its large loss, the peak distortion (Worst Case Upper and Worst Case Lower) results in a closed eye.

See Channel Pulse Model detail in References > **Channel Pulse Model**



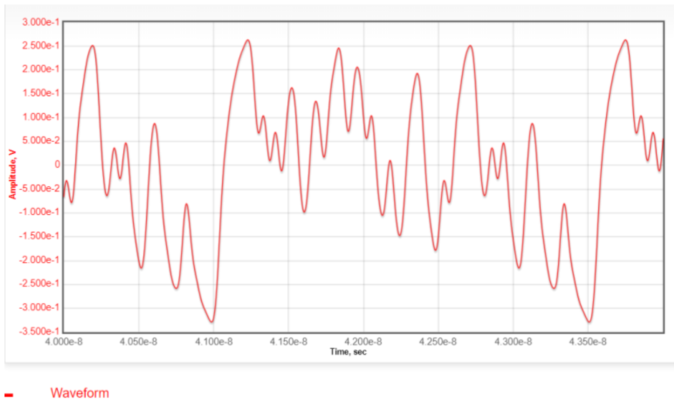
6. Channel amplitude bathtub BER

From the corrected channel impulse response, a statistical analysis can be performed to determine the BER amplitude bathtub curve vs eye time. Since the channel eye is closed, the BER for this channel will also show a low minimum BER (log10) at the eye center sampling time instant.



7. Channel waveform

From the corrected channel impulse response, a statistical analysis can be performed to determine the channel waveform response. The channel waveform specification are based on the Analysis Setup Options: **Setup Options**



For detail channel eye analysis, including jitter and BER characteristics, use the **Eye Analysis Tool** after analyzing a channel. The Eye Analysis Tool uses the channel characteristics obtained using this Tool.

Obtaining the Differential Channel Frequency Domain Characteristic

The differential transmission characteristic is the differential response from the input differential pair of ports to the output differential pair of ports. For the S-parameters discussed in this report, the plus side channel is S21. The minus side channel is S43. The differential characteristic is Diff Ch = (S21+S43-S41-S23)/2.

If the S-parameters are used directly to form Diff Ch, then this formulation inherently operates on S-parameter values that include deviations from physical realizability (passivity, reciprocity, causality, noise-free) for various reasons.

Thus, the values for S21, S43, S41 and S23 need to be corrected for physical realizability first before forming the differential characteristic Diff Ch.

The typical approach involves zero-padding the S-parameters for the time domain SampleRate (SampleRate = BitRate * SamplesPerBit) for a maximum frequency of SampleRate/2.0 and applying the constraints for physical realizability which include meeting the mathematical aspects of the Kramers-Kronig relations applied to linear time invariant (LTI) systems. This zero-padding approach often results in high frequency aliasing.

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The following plots show the original (Ch) plus (P) and minus (M) side channel characteristics and their corrected values (Ch corrected).

Figure 10: Plus side channel magnitude response versus frequency.

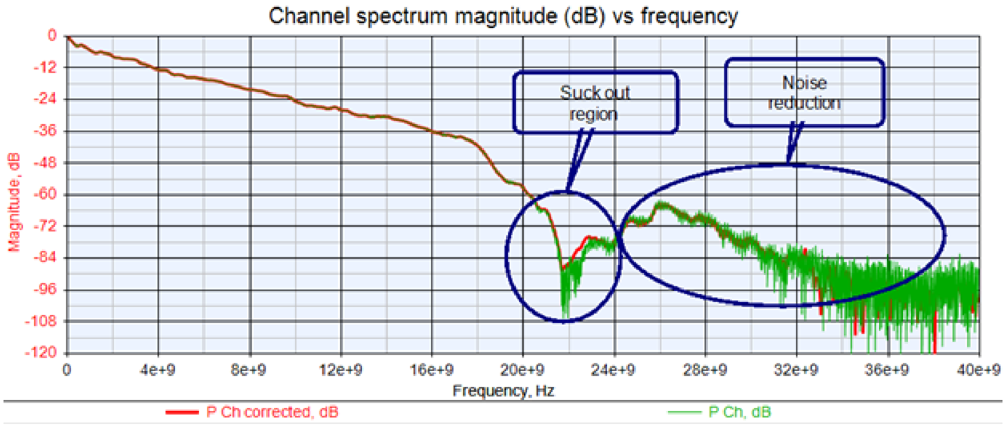
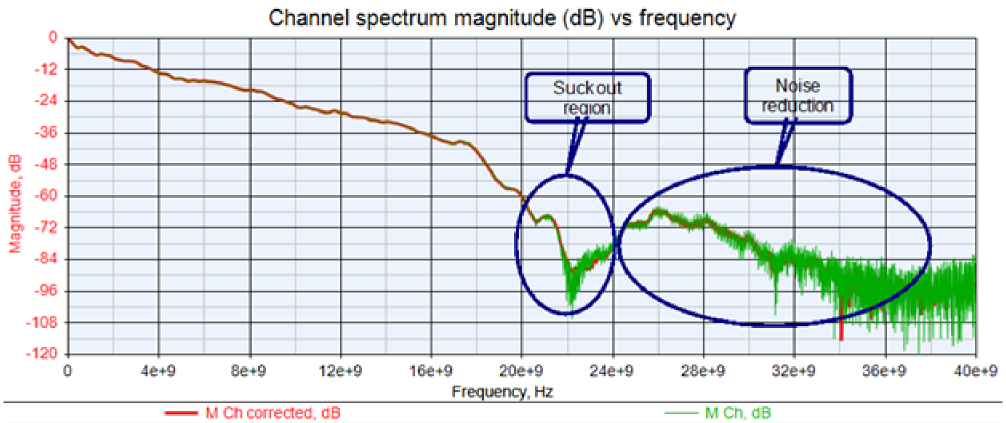


Figure 11: Minus side channel magnitude response versus frequency.



For these spectrum magnitude plots, notice how well the corrected plus and minus channel spectrums track the suck out region. Also, notice the noise reduction at frequencies above the suck out region.

When these corrected plus and minus channel characteristics are combined, the resultant corrected differential channel characteristic has a significant reduction in the noise content above the suck out region as shown in the above Figure 2.

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