SerDes_Channel_Impulse_Modeling_with_Maxim

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Introduction

This paper discusses SerDes channel impulse modeling for SerDes system simulation using Channel Simulators. The focus is on modeling SerDes channels using S-Parameters and the problem inherent in Channel Simulators when converting frequency domain S-Parameters into their equivalent time domain impulse responses. A solution is offered to the problems encountered. The solution is based on converting an S-Parameter file into Causal S-Parameters. By using Causal S-Parameters in a Channel Simulator, one avoids encountering impulse modeling problems in a Channel Simulator and will inherently obtain consistent impulse modeling among different Channel Simulators.

Problem Statement

High speed digital (HSD) integrated circuits (ICs) are used in Serializer/Deserializer (SerDes) systems. In such systems, a lossy channel exists between the transmitter (Tx) circuit and the receiver (Rx) circuit. At high data rates the received data stream is severely distorted and requires reconstruction (equalization) before use. For system design, there is often the need to model the SerDes system in a custom simulator called a Channel Simulator that provides high speed simulation of millions of bits and tailored statistical analysis to determine the SerDes system metrics which include symbol eye diagrams and bit error rate (BER) characteristics.

Modeling work for SerDes systems in a Channel Simulator is typically done by signal integrity (SI) engineers. A key step in this process is to convert HSD IC input and output buffer circuits into Input/Output Buffer Information Specification (IBIS) models using the IBIS AMI (Algorithmic Modeling Interface) standard to achieve fast simulations for evaluation and system performance prediction.

A SerDes system channel typically is a differential signal transmission channel. A hardware SerDes channel is typically characterized by measuring its N-port S-parameters versus frequency and is typically a 4-port. The 4-port differential input ports are typically port 1 (+) and port 3 (-). The associated differential output ports are typically port 2 (+) and port 4 (-). Other port assignments can be used. The differential characteristic (Port 1 – Port 3 vs. Port 2 – Port 4) is the channel transmission characteristic.

S-Parameters are commonly used to represent a SerDes channel in a Channel Simulator.

A key Channel Simulator process is to convert the frequency domain S-Parameters to their equivalent time domain impulse response.

Problem: S-Parameters inherently cause problems when used in a time domain simulation.

S-parameters, though measured on actual hardware, actually deviate from 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. These corrections must be achieved when converting S-Parameters to equivalent impulses in the time domain.

All SerDes system channel simulators convert the frequency domain S-parameter characteristics into time domain impulse characteristics. While doing this, all such simulators attempt to correct for all impairments in the S-parameters. However, some are less successful than others.

In fact, all of the top 6 EDA channel simulation tools have problems in doing this. As has been observed by many and especially reported by Romi Mayder of Xilinx Inc. at the 2015 DesignCon conference, Jan 27-30, Santa Clara Convention Center, Santa Clara CA, the top 6 EDA Channel Simulators in the industry gave widely varying impulse modeling of S-parameters as well as widely varying channel BER performance. See this link: > IBIS-AMI Model Simulations over Six EDA Platforms.

Solution: The key to obtaining consistent S-Parameter use with any time domain based tool, including any channel simulator, is to convert S-Parameter data into what is called "Causal S-Parameters".

Causal S-Parameters for an N-port are based on the frequency domain equivalent of the NxN causal impulse responses generated from the original NxN S-Parameters. Causal S-Parameters will typically provide better eye and BER results while also providing close agreement with the frequency domain response of the original S-Parameters. Causal S-parameters will typically provide faster simulations. Causal S-parameters typically result in impulse responses that have a smaller number of data points. A 2x shorter impulse length results in a 4x faster convolution time.

The following discussion in this paper considers the S-Parameters for a typical channel and their use in the Keysight Technologies Advanced Design System (ADS) Channel Simulator, ADS 2016.01

- The channel frequency domain characteristics are shown.
- Conversion of S-parameters into Causal S-Parameters is discussed.
- The ADS channel impulse modeling is discussed.
- Problems inherent in the ADS channel impulse responses are discussed.
- Use of Causal S-parameters provides better fidelity in the channel impulse responses.
- Use of SerDesDesign.com for better SerDes system modeling.

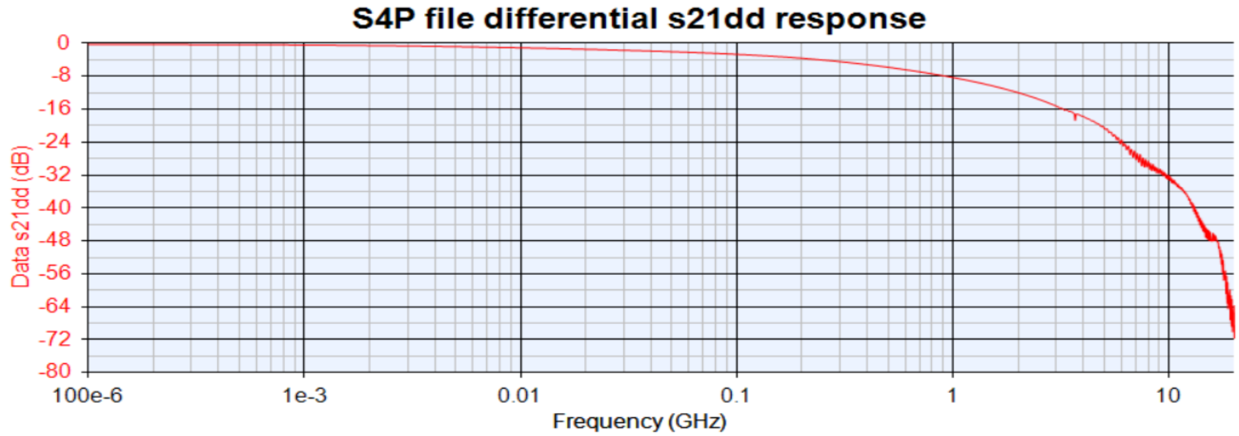
Example S-Parameter Test Case

For test purposes, the SerDes system will use a bit pattern with a 12 Gbps bit rate and sampled at 32 samples per bit. Here is the channel used as test cases.

Channel	Filename	Max freq.	Comment
S4P	two_coax_parallel_2.s4p	19.9991 GHz	Hardware measured package S4P file from Maxim Integrated.

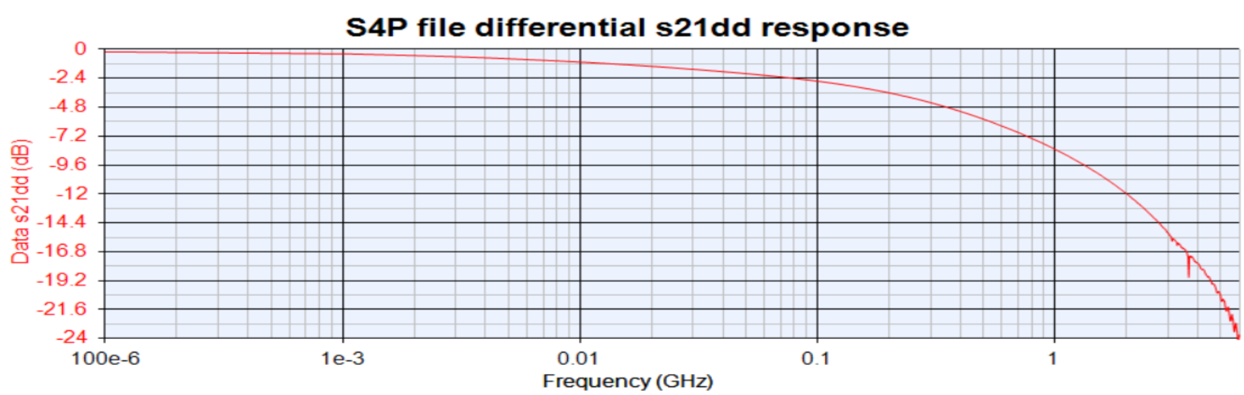
The S-parameter files represent hardware measured S-parameters for frequencies up to the maximum frequency listed.

The frequency domain differential channel characteristics for this S4P files is shown here:

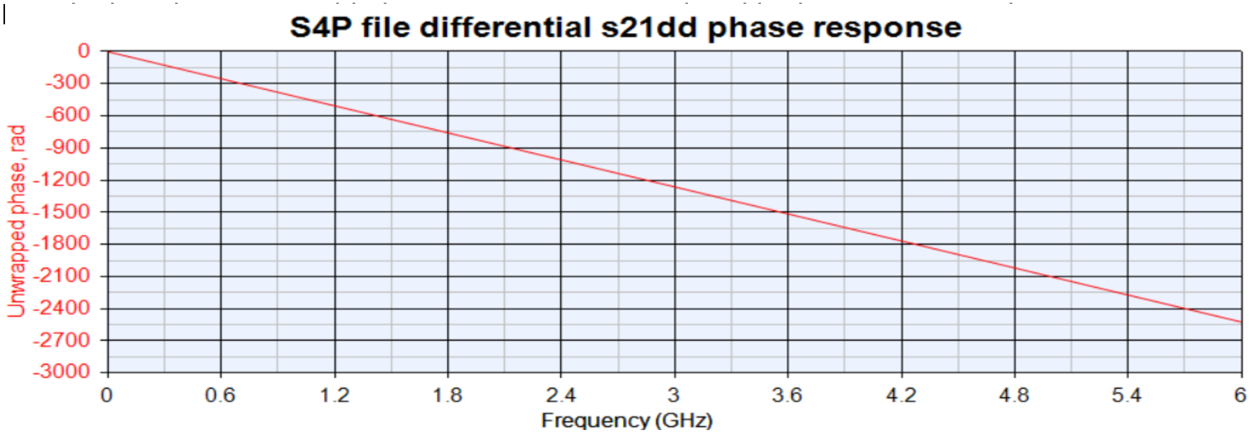


As can be seen, there is about 24 dB loss at Nyquist (6 GHz).

Here is a zoom to the Nyquist frequency.

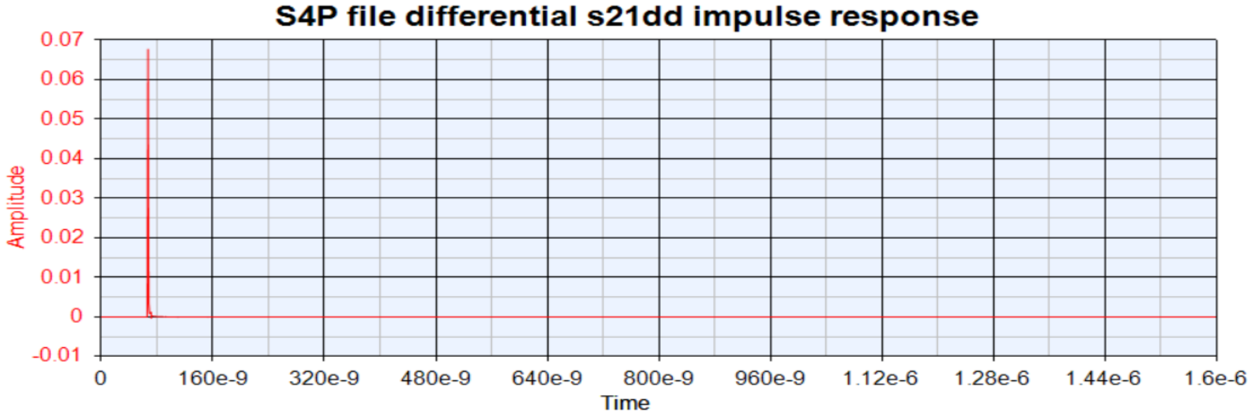


As can be seen, the low frequency loss is about 0.2 dB and there is a bit of suck out at 4.6 GHz.



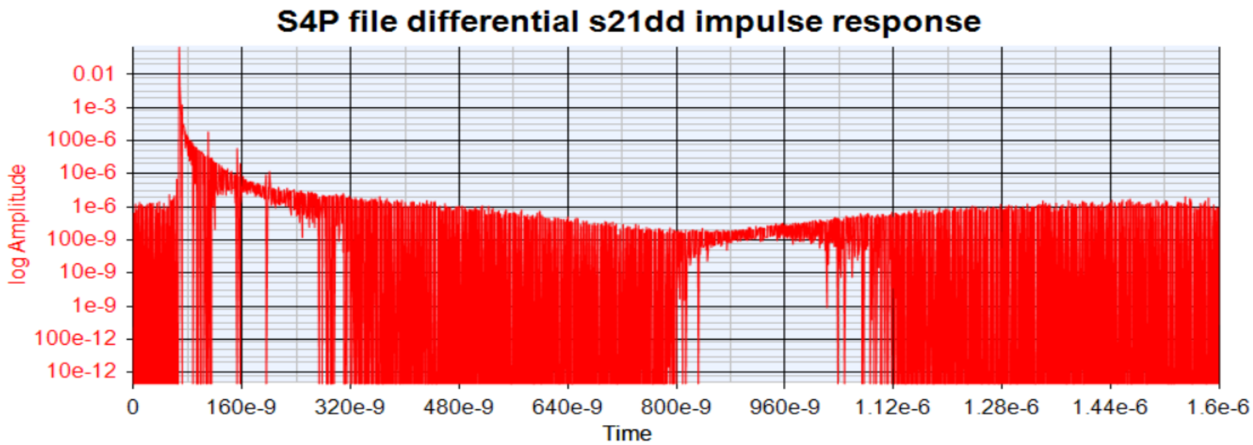
As can be seen, this phase response show a time delay (dp/dw) of 67 nsec.

These S-parameter can be directly converted to a time domain impulse response using an Inverse FFT as shown here. For impulse display, the impulse convention referencing unity amplitude is used. Note that the IBIS-AMI standard references unity impulse area.



First off, we can see that this impulse response has the 67 nsec time delay expected.

Let's look at more detail by using a log y axis.



Now, we can see that there is residual noise before 67 nsec and there is a non-causal re-growth of the impulse response after 400 nsec.

In general, S4P data needs corrections to be used properly in any time domain tool to remove these artifacts without introducing other artifacts.

Modeling the Channel Impulse using SerDesDesign.com

SerDesDesign.com is focused on the behavioral modeling of multi-gigabit high speed digital (HSD) integrated circuits (IC) used in high data rate serializer/deserializer (SerDes) communication channels and systems.

SerDesDesign.com features:

- free and subscription-use of on-line tools, including Channel Simulator

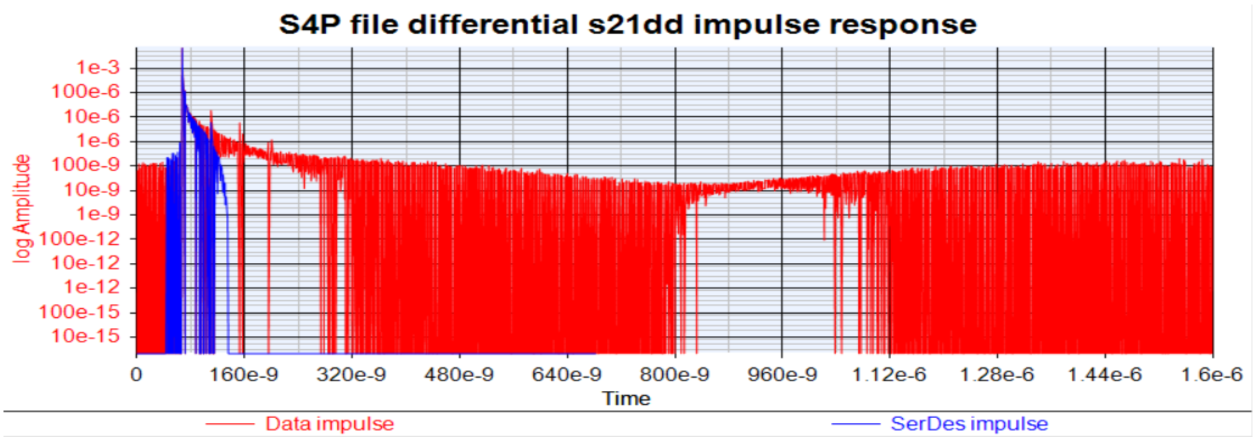
- tools for creating custom SerDes system IBIS-AMI models
- consulting and training for custom user defined IBIS-AMI models

Included in the suite of tools is:

- 1. a free tool for analyzing differential channels.
- 2. a free channel simulator using channels and Tx and Rx models.
- 3. a free channel simulator using channels with SerDes repeaters.

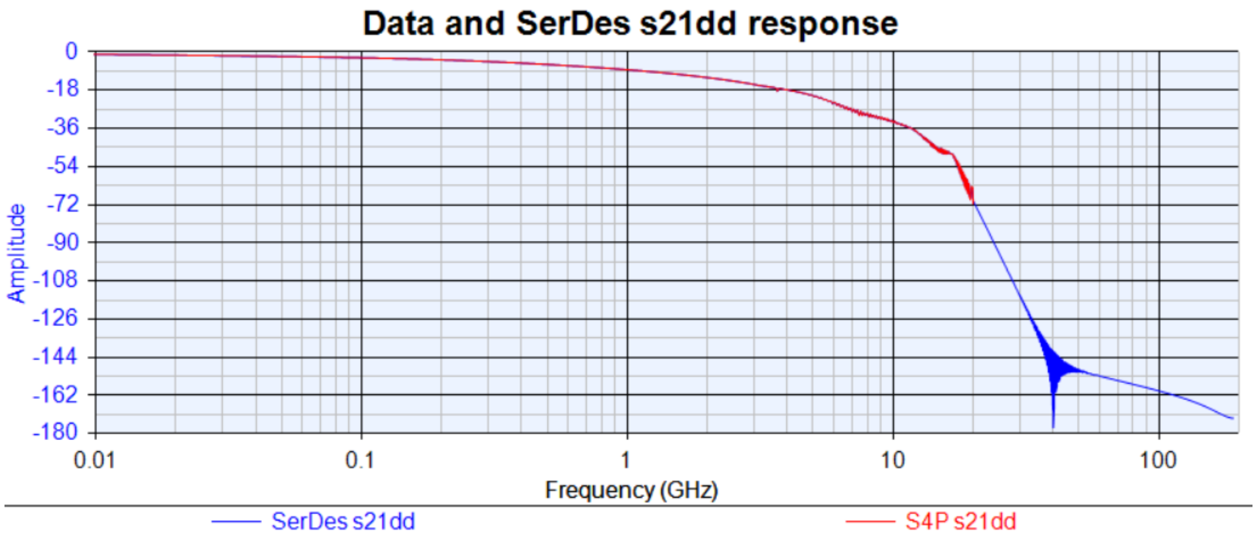
For our tests, the first tool is used to convert the S4P file to its causal s21dd impulse response (SerDes impulse).

This SerDes impulse is overlaid on the above Data impulse as shown here where scaling was made to the SerDes impulse to account for the difference in the sampling rate between the two impulses. The log Amplitude y-axis is use to better highlight the impulse differences.



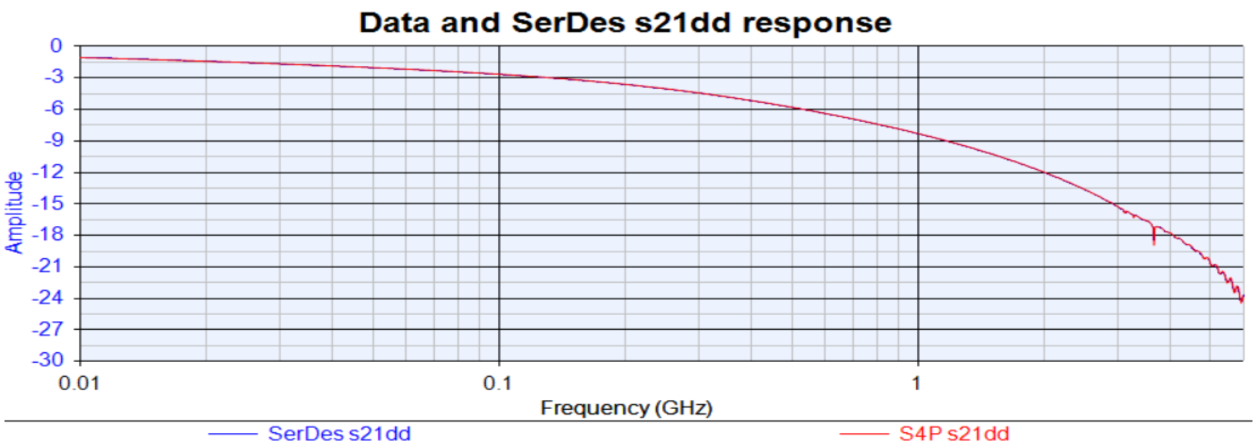
As can be seen, the SerDes impulse has less residual noise before the 67 nsec time delay and has no non-caual impulse re-growth at all.

The SerDes impulse can also be observed in the frequency domain and overlaid on the Data s21dd response as shown here. The full spectrum of the SerDes impulse is shown to frequency SampleRate/2 = BitRate*SamplesPerBit/2 = 192 GHz. The SNP Data s21dd is only up to the 20 GHz.



As can be seen, the SerDes response has no high frequency aliasing.

Let's zoom up to the Nyquist frequency.



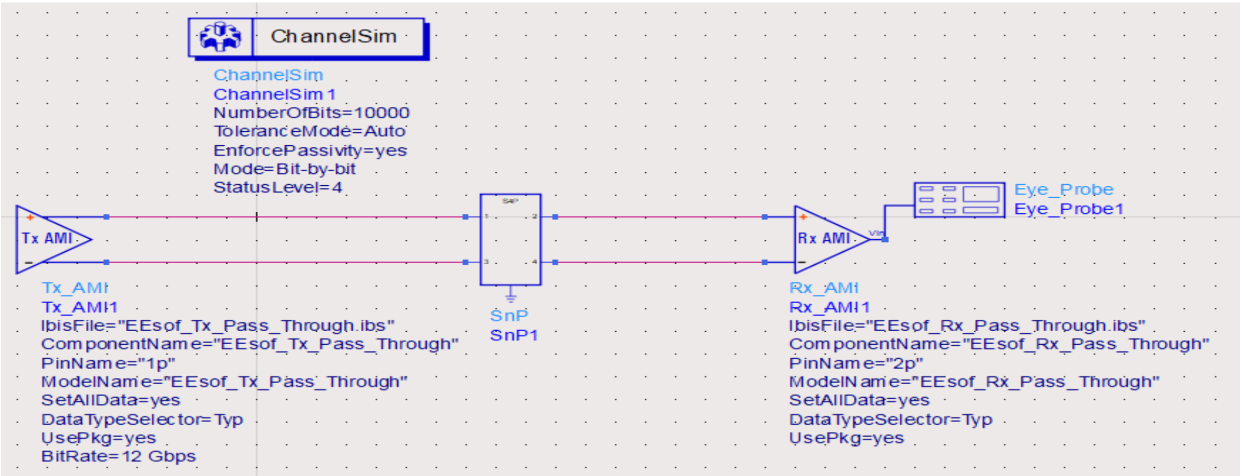
As can be seen, the SerDes and Data s21dd responses have an exact match.

Modeling the Channel Impulse using ADS

ADS is the Advanced Design System product from Keysight Technologies. ADS is the world's premier tool for high frequency design and simulation.

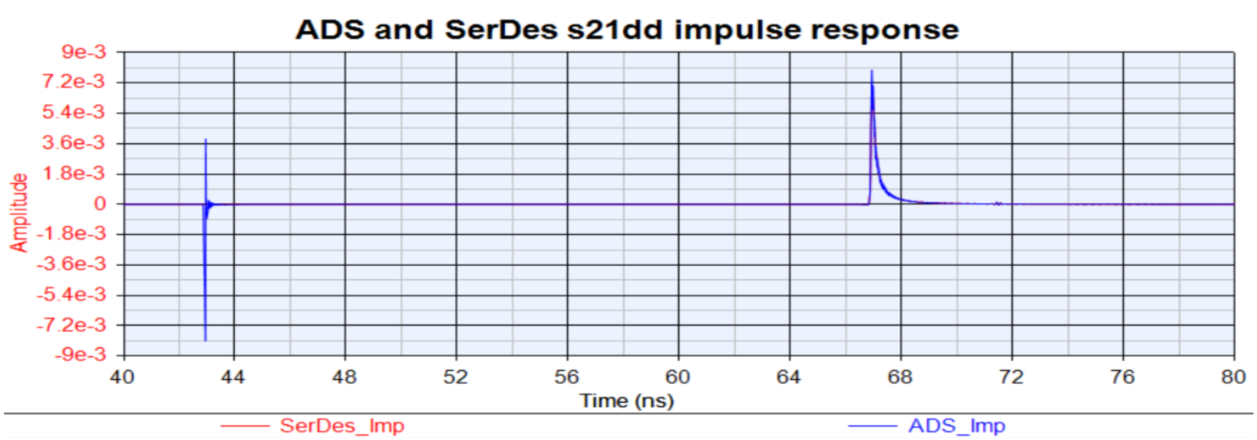
ADS includes a Channel Simulator, ChannelSim, which will be used to investigate its modeling of the S4P data in the time domain.

This following is the ADS schematic used for this test.



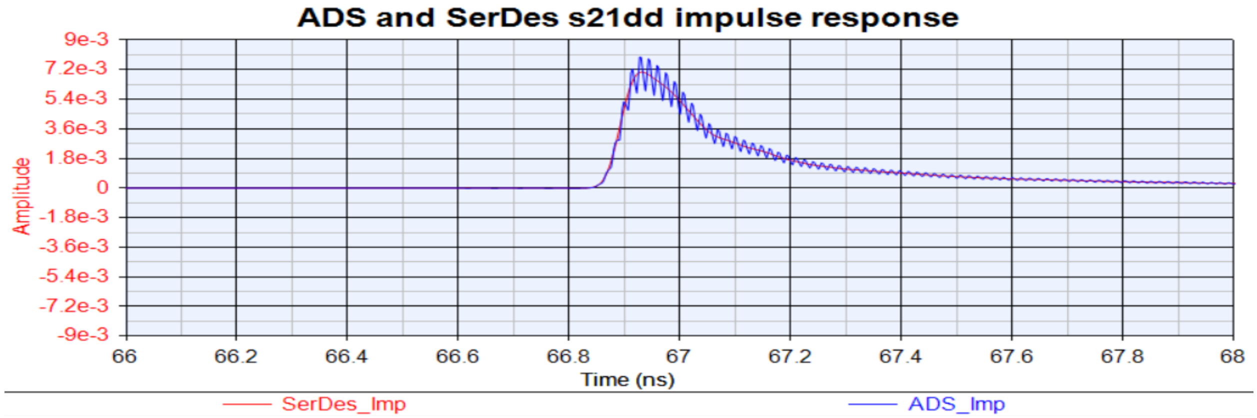
The SnP block contains the S4P file. The Tx_AMI block uses the ADS Tx pass through model. The Rx_AMI block uses the ADS Rx pass through model. The ChannelSim has StatusLevel=4 so that it prints to text file the s21dd characterization of the S4P file.

The ADS impulse is overlaid on the SerDes impulse as shown here where ADS impulse scaling referencing unity amplitude was used.



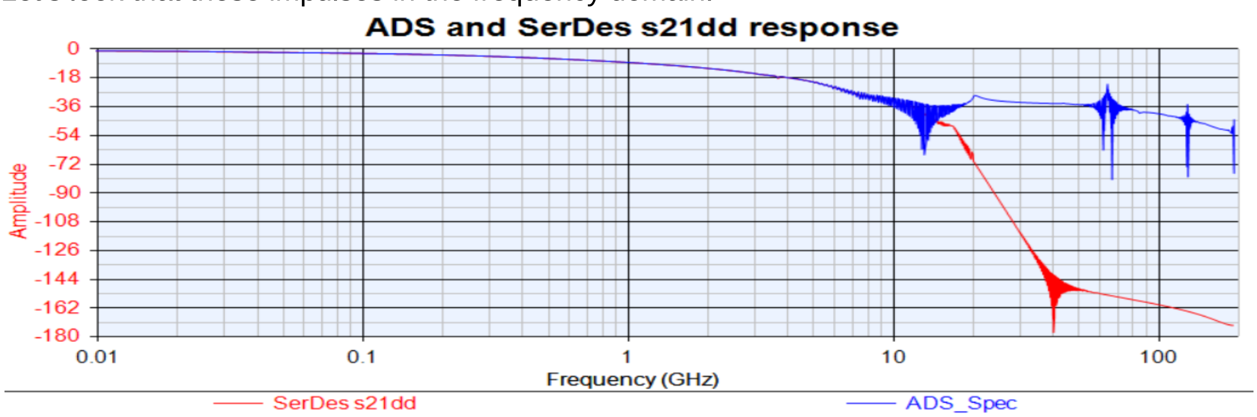
Notice that the ADS impulse has a very large impulse artifact at 43 nsec which in not present SerDes or Data impulse responses.

Let's zoom onto the impulse at 67 nsec.



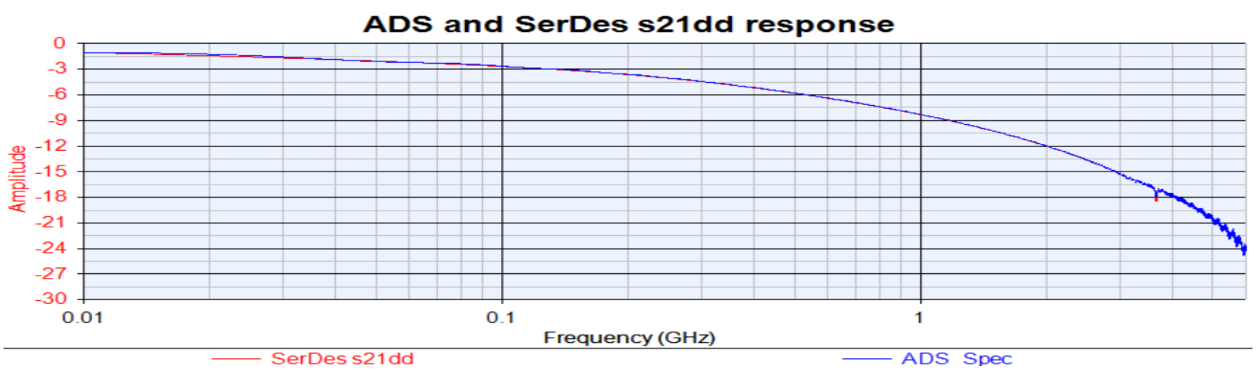
Notice that the ADS impulse has high frequency ringing in its response.

Let's look that these impulses in the frequency domain.



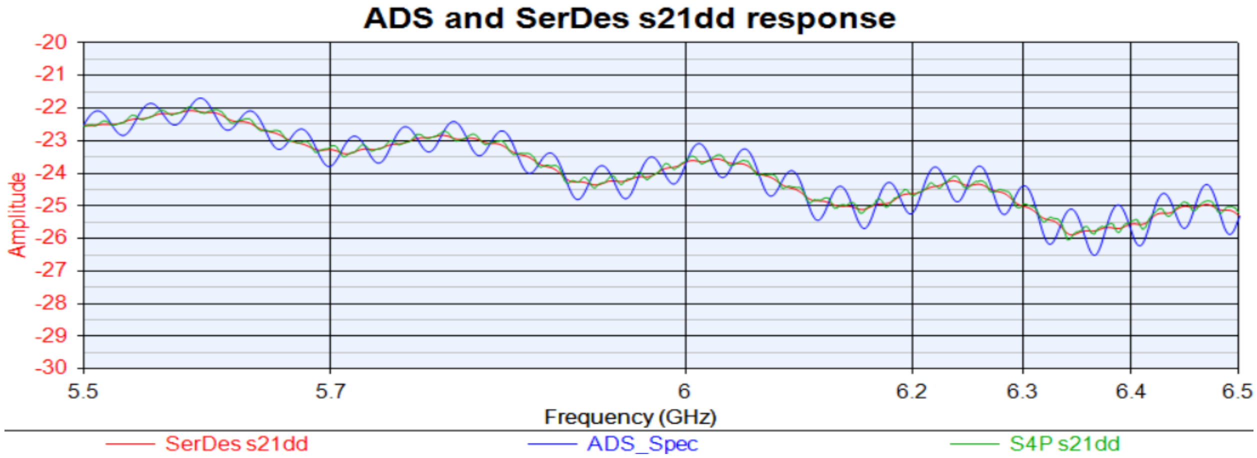
Notice that the ADS response has a lot of high frequency aliasing and a lot of ringing below the Data maximum frequency of 20 GHz.

Let's zoom on the area up to Nyquist.



As can be seen, the ADS and SerDes impulses have close match.

Let's zoom on the area at Nyquist with the Data response included.



The SerDes and Data have a close match. However, the ADS response has additional ringing.

From the above, we see the following in the ADS impulse response for the S4P file.

- The ADS impulse has a large artifact at 43 nsec that was not present SerDes or Data impulse responses.
- The ADS impulse has high frequency ringing in its response at 67 nsec.
- The ADS impulse frequency domain response has a lot of high frequency aliasing above the maximum data frequency of 20 GHz.
- The ADS impulse frequency domain response is a reasonable representation up to the Nyquist frequency, but does have additional ringing at the frequency region at Nyquist.

Fortunately, there is a work around to enable ADS to have a better impulse response for this S4P data.

The solution is to first convert the S4P file into what is called a Causal S-Parameter file. at SerDesDesign.com.

Converting S-Parameters to Causal S-Parameters

S-parameters for SnP files can be converted to Causal S-parameters files using tools on the web site: https://www.serdesdesign.com.

See discussion at **About the Generate Causal SParameters Tool...** and **Typical Causal SParameters Characteristics and Displays...** to understand the problem inherent in using S-parameter files with time domain simulations and the benefits of using causal S-parameters and associated causal impulse response for portable and consistent S-parameter simulation results across different time domain simulation tools.

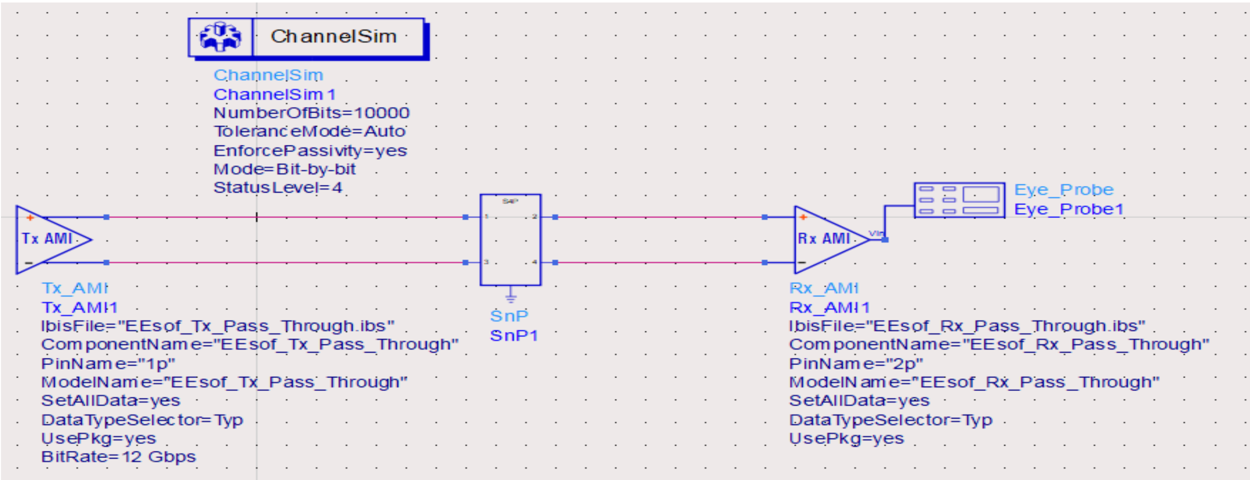
Using www.serdesdesign.com/home/generate-causal-sparameters, the s4p file listed above was converted to a causal s4p files using BitRate = 12 Gbps.

The SamplesPerBit setting is increased as needed to get the desired fidelity in the Causal S-Parameters. For this test case, the Causal S-Parameters used SamplesPerBit = 64.

The resultant causal s4p file is named: two_coax_parallel_2.s4p.causal.s4p

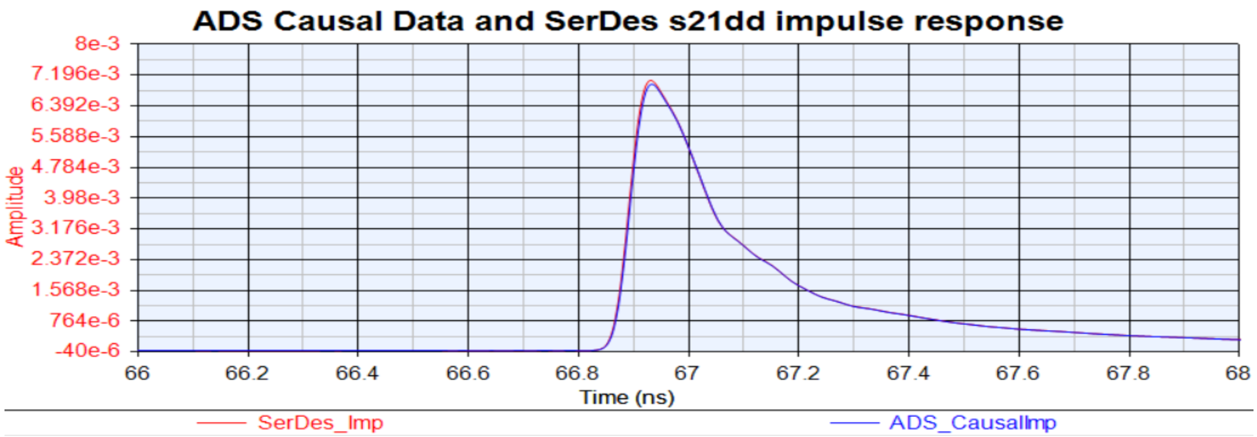
Using the Causal S-Parameters in ADS

This same ADS schematic as before is used for this test.



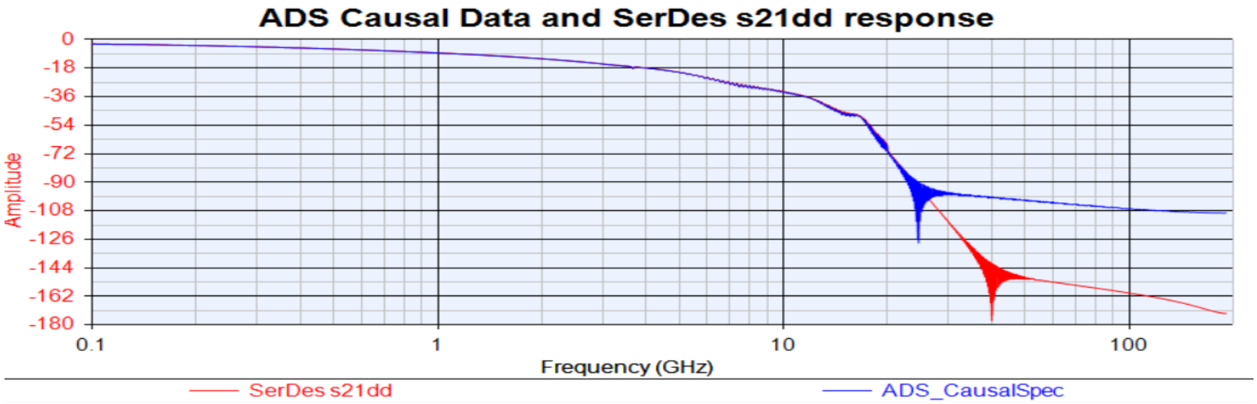
The SnP block uses the Causal S-Parameters file two_coax_parallel_2.s4p.causal.s4p.

The resultant ADS impulse is overlaid on the SerDes impulse as shown here. Only the time domain area at the 67 nsec peak is displayed since these is no longer any artifact at 43 nsec.



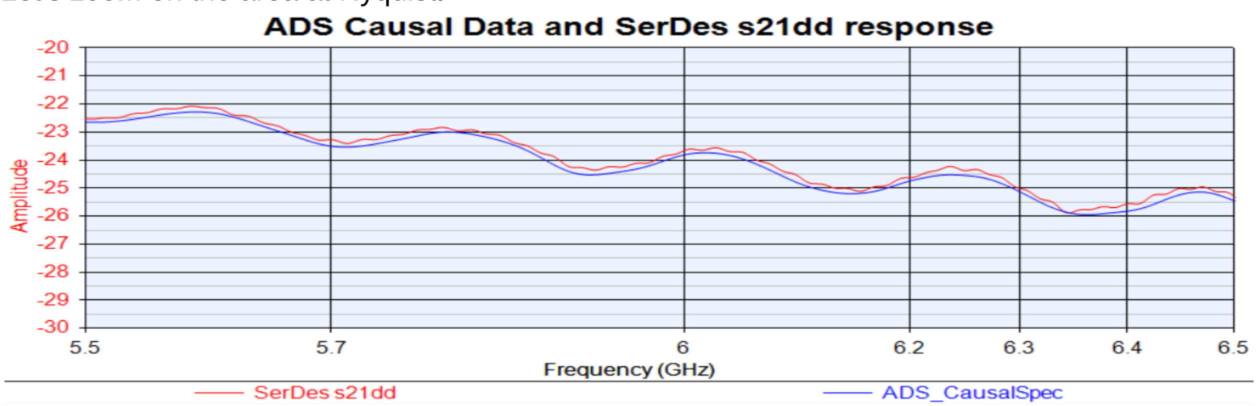
Notice that the two impulses are nearly identical. The ADS response no longer has the high frequency ringing on this peak.

Let's look that these impulses in the frequency domain.



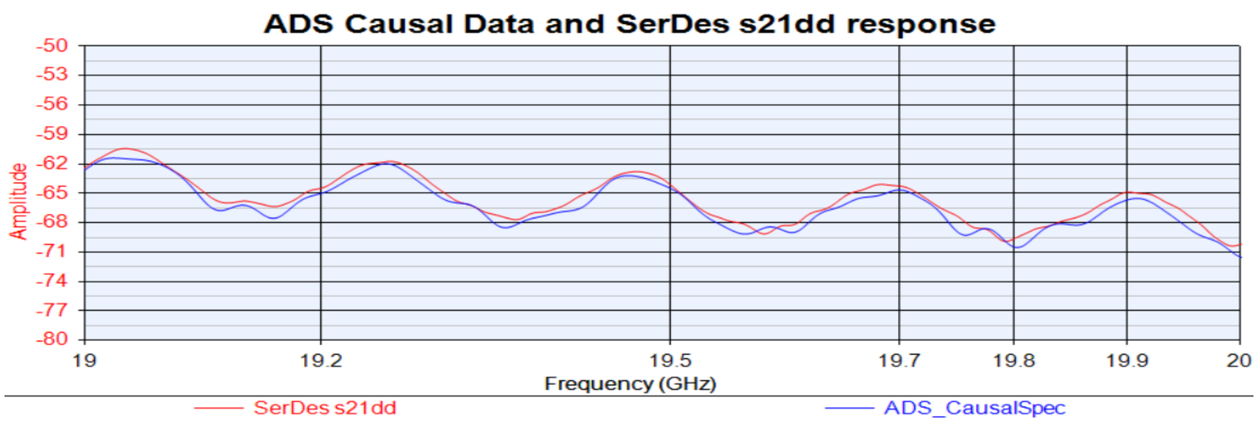
Notice that the ADS response does not have the high frequency aliasing as before and drops off above the 20 GHz maximum frequency in the original data.

Let's zoom on the area at Nyquist.



Notice that the ADS response does not have the high frequency ringing and is now very close to the SerDes data, with only a small amount of fidelity lost.

Let's zoom on the area from 19 to 20 GHz.



Notice that the ADS response is now very close to the SerDes data, with only a small amount of fidelity lost.

From the above, we see that by converting an SnP file to Causal S-Parameters and using the Causal S-Parameters in ADS, the original data is more accurately represented in ADS.

Summary

This document reports on SerDes channel impulse modeling. A channel was defined using an S-parameter file based on hardware measurements.

Such S-parameters, though measured on physical devices, inherently have non-physical distortions due to frequency band limiting, non continuous frequency domain characteristics, non reciprocity, non passivity, non causality and noise. Such distortions must be corrected when using S-parameters in the time domain such as with SerDes system Channel Simulators.

The time domain impulse response from SerDesDesign.com was shown to accurately represent the S4P data.

The time domain impulse response from ADS was shown to not accurately represent the S4P data.

When the S4P data was converted to a Causal S-Parameter data file (using tools at SerDesDesign.com), and that file was then used in ADS, the time domain impulse response from ADS was now an accurate representation of the original S4P data.

Acknowledgment

Thanks to Charles Razzell of Maxim Integrated for his collaboration in the work leading to this paper. Charles provided the measured channel S-parameter files used in this work along with some example results from running the Keysight ADS channel simulator.