Channel Capacity Calculator Updates

Enhancements to the jonsson_3cy_01_10_28_20 capacity calculator

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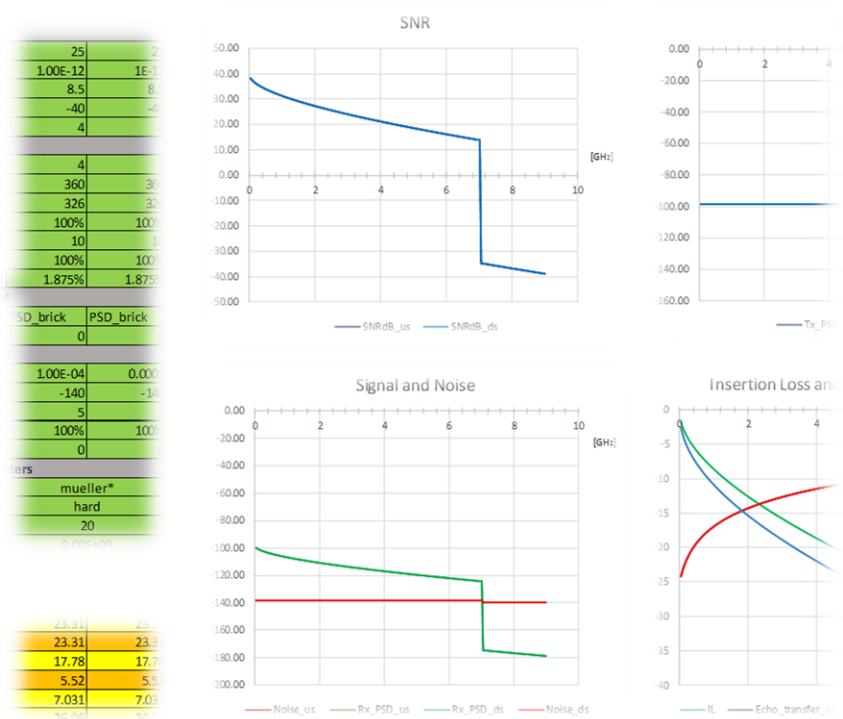
802.3cy

Introduction

- We introduced channel capacity calculation tool in jonsson_3cy_01_10_28_20
- This contribution updates the channel capacity calculator with new enhancements
- Examples are given of results for the updates



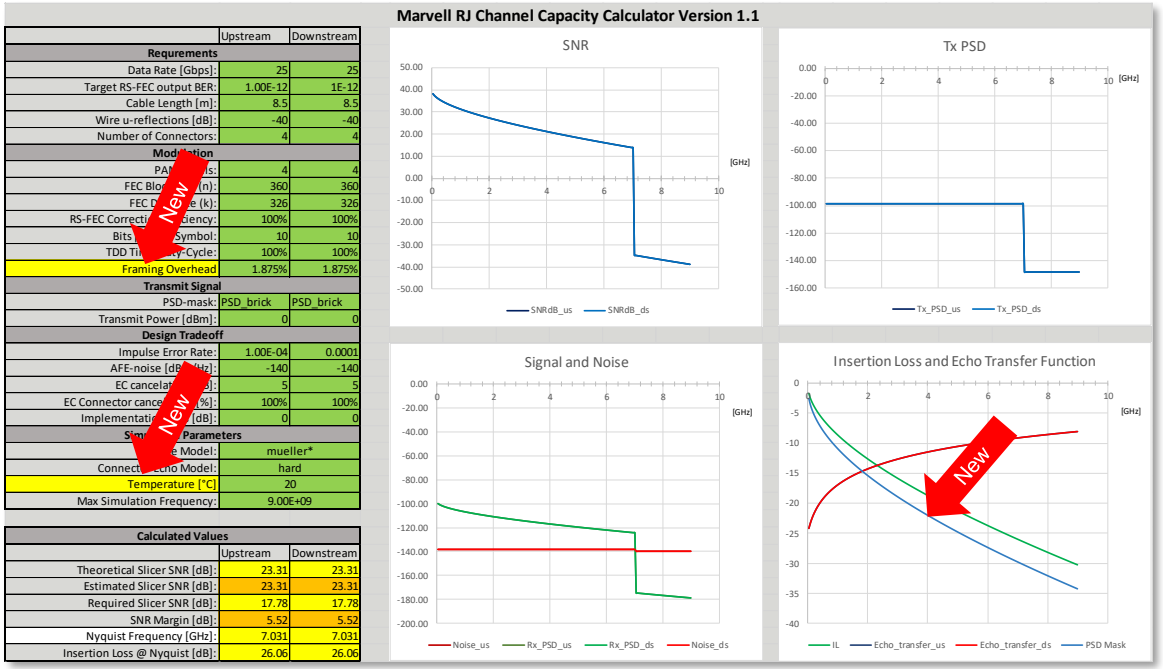
Updates In New Version

The following enhancements have been made to the Capacity Calculator:

- Support for estimating impact of temperature changes on Insertion Loss
- Accounting for Framing Overhead
- Insertion Loss limit line from zimmerman_3cy_01a_1120
- Default values are more realistic for 25Gbps PHY

	Upstream	Downstream
Requirements		
Data Rate [Gbps]:	25	25
Target RS-FEC output BER:	1.00E-12	1E-12
Cable Length [m]:	8.5	8.5
Wire u-reflections [dB]:	-40	-40
Number of Connectors:	4	4
Modulation		
PAM [illegible]s:	4	4
FEC Block [illegible](n):	360	360
FEC [illegible]e (k):	326	326
RS-FEC Correcti[illegible]ciency:	100%	100%
Bits [illegible]Symbol:	10	10
TDD Ti[illegible]y Cycle:	100%	100%
Framing Overhead	1.875%	1.875%
Transmit Signal		
PSD-mask:	PSD_brick	PSD_brick
Transmit Power [dBm]:	0	0
Design Tradeoff		
Impulse Error Rate:	1.00E-04	0.0001
AFE-noise [dB[illegible]Hz]:	-140	-140
EC cancela[illegible]:	5	5
EC Connector cance[illegible]%]:	100%	100%
Implementati[illegible][dB]:	0	0
Sim[illegible] Parameters		
[illegible]e Model:	mueller*	
Connect[illegible]cho Model:	hard	
Temperature [°C]	20	
Max Simulation Frequency:	9.00E+09	

Calculated Values		
	Upstream	Downstream
Theoretical Slicer SNR [dB]:	23.31	23.31
Estimated Slicer SNR [dB]:	23.31	23.31
Required Slicer SNR [dB]:	17.78	17.78
SNR Margin [dB]:	5.52	5.52
Nyquist Frequency [GHz]:	7.031	7.031
Insertion Loss @ Nyquist [dB]:	26.06	26.06



Insertion Loss Changes with Temperature

- Temperature changes can affect the IL of a cable in several ways, including temperature variation in the conductance of the conductor and the insulator materials
- The updated Channel Capacity Calculation model only accounts for changes in IL due to changes in the conductance of the conductor
- The conductance of the insulator dielectric material can also change with temperature, but these changes are very dependent on the dielectric martial used
- For some dielectric materials, like PTFE, temperature changes have minimal impact on conductance

- The insertion loss model in the Capacity Calculator approximates the insertion loss for different cables as

$$IL(f) = a\sqrt{f} + bf$$

- Where the "$a\sqrt{f}$" term is due to skin-effect and conductor losses and the "bf" term is due to losses in the dielectric material
- The coefficient "a" scales with the square root of the conductor metal conductance and the conductance changes with temperature according to

$$\rho(T) = \rho_{ref}(1 + \Delta\rho_T(T - T_{ref}))$$

- Where $\Delta\rho_T \approx 0.004\frac{1}{°C}$ for copper
- The new insertion loss formula is

$$IL(f,T) = a_{20°C}\sqrt{1 + \Delta\rho_T(T - 20°C)}\sqrt{f} + bf$$

Framing Overhead

- The framing overhead in IEEE 802.3ch comes from three sources
  - RS-FEC overhead
  - 65/64 encoding overhead
  - OAM overhead
- The original Capacity Calculator already accounted for the RS-FEC overhead, since it is an important factor in the line code tradeoff
- The updated spreadsheet adds field to account for overhead other than RS-FEC
- For IEEE 802.3ch the 65/64 and OAM overhead is

$$\frac{65}{64} \times \frac{3260}{3250} - 1 = \frac{3}{160} = 1.875\%$$

149.1.3 Operation of 2.5GBASE-T1, 5GBASE-T1, and 10GBASE-T1

The 2.5GBASE-T1 PHY, 5GBASE-T1 PHY, and 10GBASE-T1 PHY each operate using full-duplex communications over a single balanced pair of conductors with an effective rate of 2.5 Gb/s, 5 Gb/s, or 10 Gb/s in each direction simultaneously while meeting the requirements (EMC, temperature, etc.) of automotive environments. The PHY supports operation on an automotive link segment supporting up to four in-line connectors using a single balanced pair of conductors for up to at least 15 m. The 2.5GBASE-T1, 5GBASE-T1, and 10GBASE-T1 PHYs utilize four level Pulse Amplitude Modulation (PAM4) transmitted at 1406.25 MBd, 2812.5 MBd, and 5625 MBd rates, respectively. A 33-bit scrambler is used to improve the EMC performance. XGMII TX_D, TX_EN, and TX_ER are encoded together using 64B/65B encoding. To maintain a bit error ratio (BER) of less than or equal to 10^{-12}, the 2.5GBASE-T1, 5GBASE-T1, and 10GBASE-T1 PHYs add 340 bits of Reed-Solomon Forward Error Correction (RS-FEC) parity to each group of fifty 64B/65B blocks. The PAM4 mapping, scrambler, RS-FEC, interleaver, and PAM4 encoder/decoder are all contained in the PCS (see 149.3).

OSI

ETHERNET LAYERS

149.1.3.1 Physical Coding Sublayer (PCS)

The MultiGBASE-T1 PCS couples a 10 Gigabit Media Independent Interface (XGMII), as described in Clause 46, to the 2.5GBASE-T1, 5GBASE-T1, and 10GBASE-T1 Physical Medium Attachment (PMA) sublayer.

In addition to the normal mode of operation, the PCS supports a training mode. Furthermore, the PCS contains a management interface.

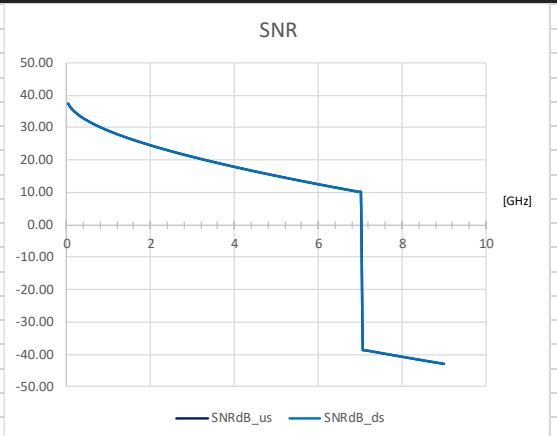
In the transmit direction, in normal mode, the PCS receives eight XGMII data octets provided by two consecutive transfers on the XGMII service interface on TXD<31:0> and groups them into 64-bit blocks with the 64-bit block boundaries aligned with the boundary of the two XGMII transfers. Each group of eight octets along with the data/control indications is transcoded into a 65-bit block. These 65-bit blocks are then aggregated into groups of 50 blocks. The contents of each group are contained in a vector tx_group50x65B. Next, a 10-bit OAM field is appended to form a 3260-bit block. A number, L, of these 3260-bit blocks are formed into a RS-FEC input superframe, then encoded by the RS-FEC (360, 326, 2^{10}) and the round–robin interleaving as described in 149.3.2.2.16. The RS-FEC output superframe consists of L × 3600 bits. The duration of the superframe is L × 320 / *S* ns. Finally these bits are exclusive OR'd with a degree 33 scrambler to create the MultiGBASE-T1 payload. PCS transmit functions are described in 149.3.2.2.

Example Calculations

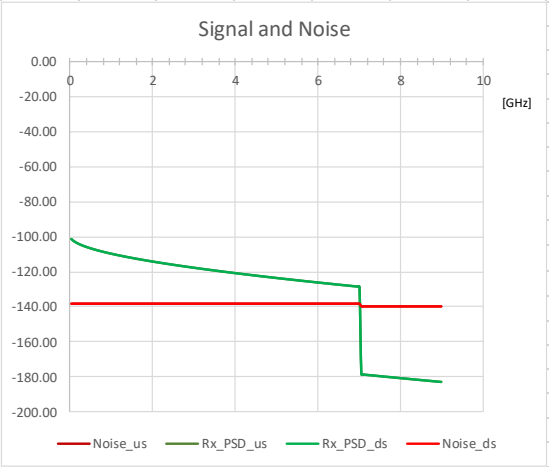
Performance of Echo Canceled System for Zimmerman Mask

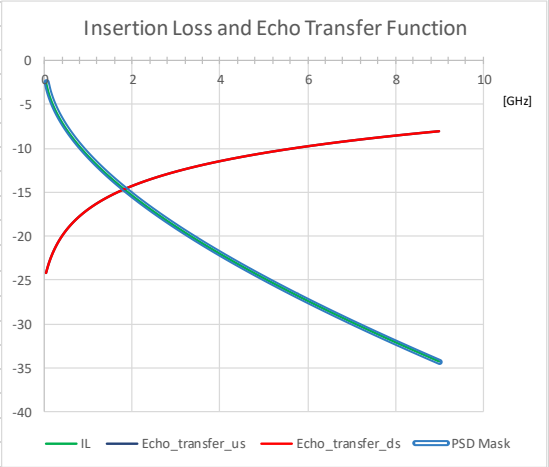
	Upstream	Downstream
Requirements		
Data Rate [Gbps]:	25	25
Target RS-FEC output BER:	1.00E-12	1E-12
Cable Length [m]:	11	11
Wire u-reflections [dB]:	-40	-40
Number of Connectors:	4	4
Modulation		
PAM Levels:	4	4
FEC Block Size (n):	360	360
FEC Data Size (k):	326	326
RS-FEC Correction Efficiency:	100%	100%
Bits per FEC Symbol:	10	10
TDD Time Duty-Cycle:	100%	100%
Framing Overhead	1.875%	1.875%
Transmit Signal		
PSD-mask:	PSD_brick	PSD_brick
Transmit Power [dBm]:	0	0
Design Tradeoff		
Impulse Error Rate:	1.00E-04	0.0001
AFE-noise [dBm/Hz]:	-140	-140
EC cancelation [dB]:	5	5
EC Connector cancelation [%]:	100%	100%
Implementation Loss [dB]:	0	0
Simulation Parameters		
Cable Model:	Zimmerman*	
Connector Echo Model:	hard	
Temperature [°C]	20	
Max Simulation Frequency:	9.00E+09	

Calculated Values		
	Upstream	Downstream
Theoretical Slicer SNR [dB]:	20.28	20.28
Estimated Slicer SNR [dB]:	20.28	20.28
Required Slicer SNR [dB]:	17.78	17.78
SNR Margin [dB]:	2.49	2.49
Nyquist Frequency [GHz]:	7.031	7.031
Insertion Loss @ Nyquist [dB]:	29.84	29.84



- The channel Insertion Loss limit proposed in zimmerman_3cy_01a_1120 has about 2.5dB margin for typical configuration

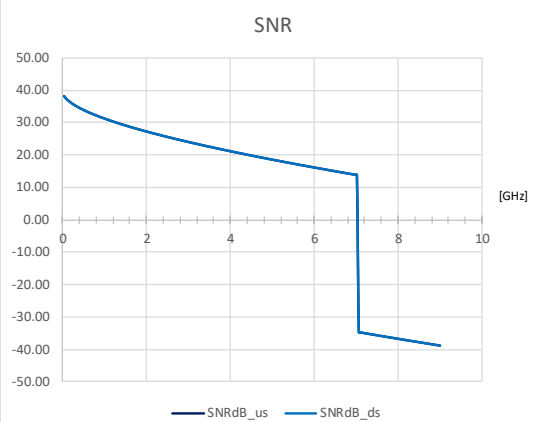




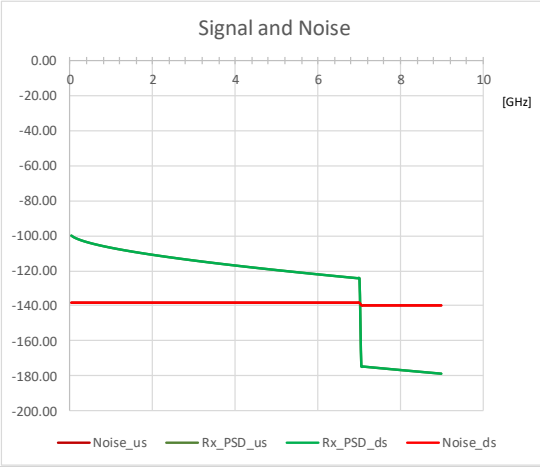
Performance for Mueller Cable (Oct 14, 2020) at T=20°C

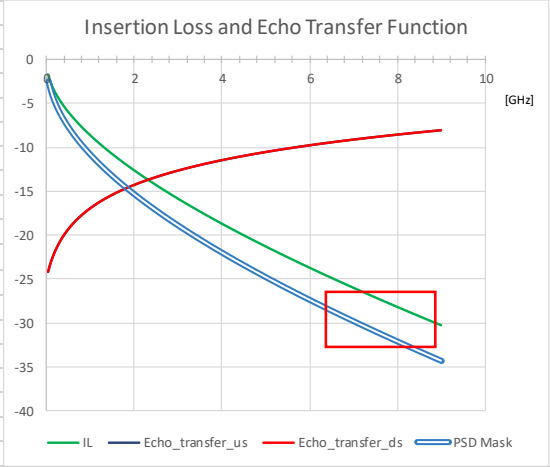
	Upstream	Downstream
Requrements		
Data Rate [Gbps]:	25	25
Target RS-FEC output BER:	1.00E-12	1E-12
Cable Length [m]:	8.5	8.5
Wire u-reflections [dB]:	-40	-40
Number of Connectors:	4	4
Modulation		
PAM Levels:	4	4
FEC Block Size (n):	360	360
FEC Data Size (k):	326	326
RS-FEC Correction Efficiency:	100%	100%
Bits per FEC Symbol:	10	10
TDD Time Duty-Cycle:	100%	100%
Framing Overhead	1.875%	1.875%
Transmit Signal		
PSD-mask:	PSD_brick	PSD_brick
Transmit Power [dBm]:	0	0
Design Tradeoff		
Impulse Error Rate:	1.00E-04	0.0001
AFE-noise [dBm/Hz]:	-140	-140
EC cancelation [dB]:	5	5
EC Connector cancelation [%]:	100%	100%
Implementation Loss [dB]:	0	0
Simulation Parameters		
Cable Model:	mueller*	
Connector Echo Model:	hard	
Temperature [°C]	20	
Max Simulation Frequency:	9.00E+09	

Calculated Values		
	Upstream	Downstream
Theoretical Slicer SNR [dB]:	23.31	23.31
Estimated Slicer SNR [dB]:	23.31	23.31
Required Slicer SNR [dB]:	17.78	17.78
SNR Margin [dB]:	5.52	5.52
Nyquist Frequency [GHz]:	7.031	7.031
Insertion Loss @ Nyquist [dB]:	26.06	26.06



- The 7m model for the grey IL curve in mueller_3cy_01_10_14_20 is well above the Zimmerman limit curve at 20°C and has SNR margin of about 5.5dB

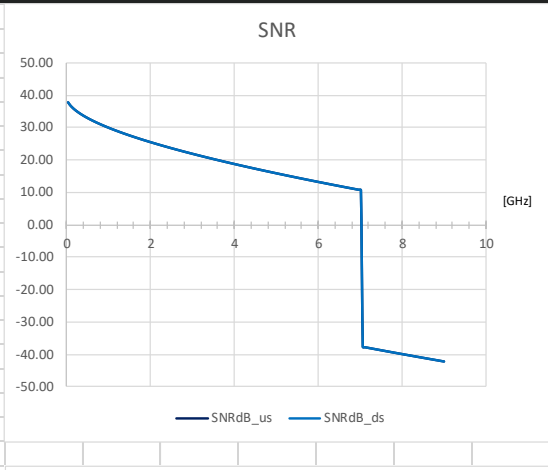




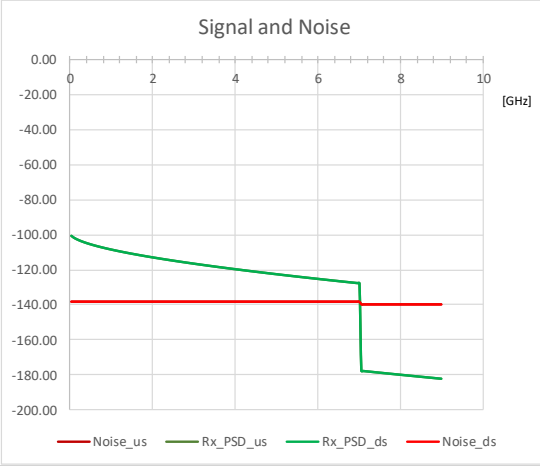
Performance for Mueller Cable (Oct 14, 2020) at T=100°C

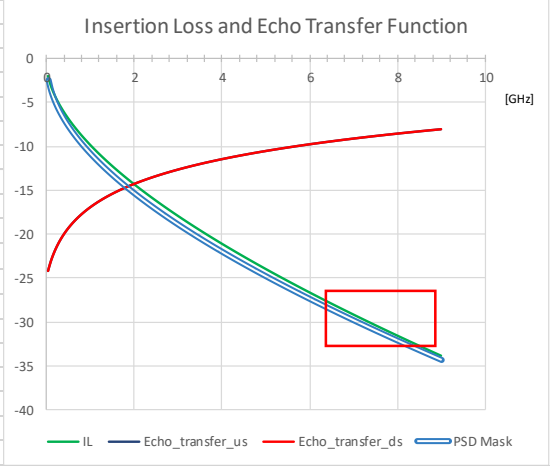
	Upstream	Downstream
Requrements		
Data Rate [Gbps]:	25	25
Target RS-FEC output BER:	1.00E-12	1E-12
Cable Length [m]:	8.5	8.5
Wire u-reflections [dB]:	-40	-40
Number of Connectors:	4	4
Modulation		
PAM Levels:	4	4
FEC Block Size (n):	360	360
FEC Data Size (k):	326	326
RS-FEC Correction Efficiency:	100%	100%
Bits per FEC Symbol:	10	10
TDD Time Duty-Cycle:	100%	100%
Framing Overhead	1.875%	1.875%
Transmit Signal		
PSD-mask:	PSD_brick	PSD_brick
Transmit Power [dBm]:	0	0
Design Tradeoff		
Impulse Error Rate:	1.00E-04	0.0001
AFE-noise [dBm/Hz]:	-140	-140
EC cancelation [dB]:	5	5
EC Connector cancelation [%]:	100%	100%
Implementation Loss [dB]:	0	0
Simulation Parameters		
Cable Model:	mueller*	
Connector Echo Model:	hard	
Temperature [°C]	100	
Max Simulation Frequency:	9.00E+09	

Calculated Values		
	Upstream	Downstream
Theoretical Slicer SNR [dB]:	21.24	21.24
Estimated Slicer SNR [dB]:	21.24	21.24
Required Slicer SNR [dB]:	17.78	17.78
SNR Margin [dB]:	3.45	3.45
Nyquist Frequency [GHz]:	7.031	7.031
Insertion Loss @ Nyquist [dB]:	29.15	29.15



- The 7m model for the grey IL curve in mueller_3cy_01_10_14_20 is just above the Zimmerman limit curve at 100°C and has SNR margin of about 3.35dB

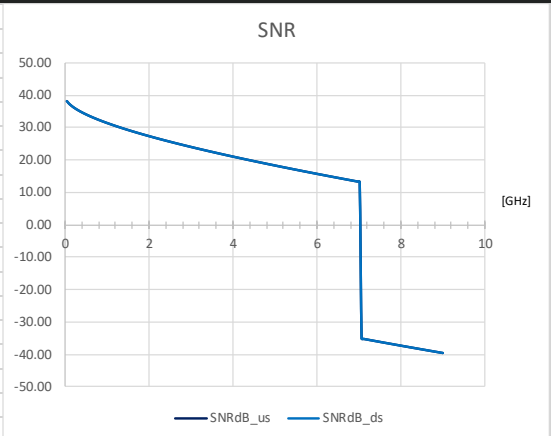


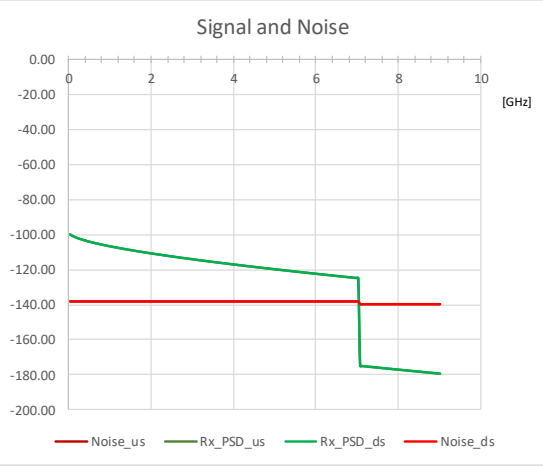


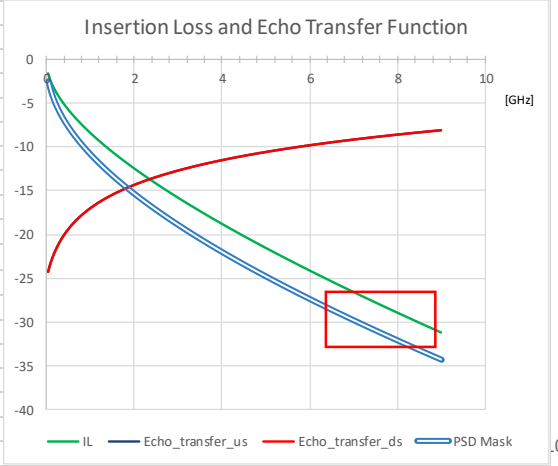
Performance for Mueller SDP Cable (Dec 1, 2020) at T=20°C

	Upstream	Downstream
Requrements		
Data Rate [Gbps]:	25	25
Target RS-FEC output BER:	1.00E-12	1.00E-12
Cable Length [m]:	11	11
Wire u-reflections [dB]:	-40	-40
Number of Connectors:	4	4
Modulation		
PAM Levels:	4	4
FEC Block Size (n):	360	360
FEC Data Size (k):	326	326
RS-FEC Correction Efficiency:	100%	100%
Bits per FEC Symbol:	10	10
TDD Time Duty-Cycle:	100%	100%
Framing Overhead:	1.875%	1.875%
Transmit Signal		
PSD-mask:	PSD_brick	PSD_brick
Transmit Power [dBm]:	0	0
Design Tradeoff		
Impulse Error Rate:	1.00E-04	1.00E-04
AFE-noise [dBm/Hz]:	-140	-140
EC cancelation [dB]:	5	5
EC Connector cancelation [%]:	100%	100%
Implementation Loss [dB]:	0	0
Simulation Parameters		
Cable Model:	mueller*sdp	
Connector Echo Model:	hard	
Temperature [°C]:	20	
Max Simulation Frequency:	9.00E+09	

Calculated Values		
	Upstream	Downstream
Theoretical Slicer SNR [dB]:	23.22	23.22
Estimated Slicer SNR [dB]:	23.22	23.22
Required Slicer SNR [dB]:	17.78	17.78
SNR Margin [dB]:	5.44	5.44
Nyquist Frequency [GHz]:	7.03	7.03
Insertion Loss @ Nyquist [dB]:	26.64	26.64





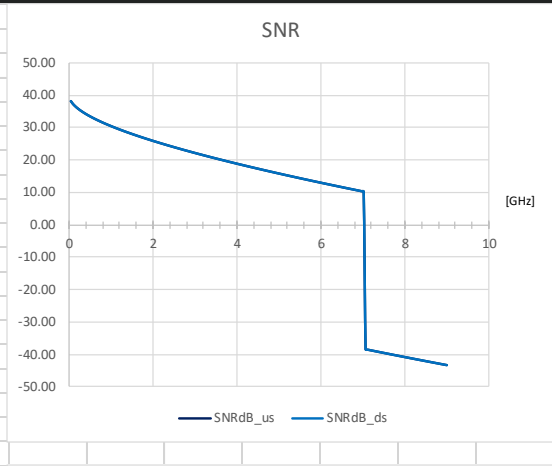


- The 11m model at 20°C for the SDP IL curve in mueller_3cy_01_12_01_20 is just above the Zimmerman limit curve at 20°C and has SNR margin of 5.44dB
- Note that PCB IL is not included in this calculation

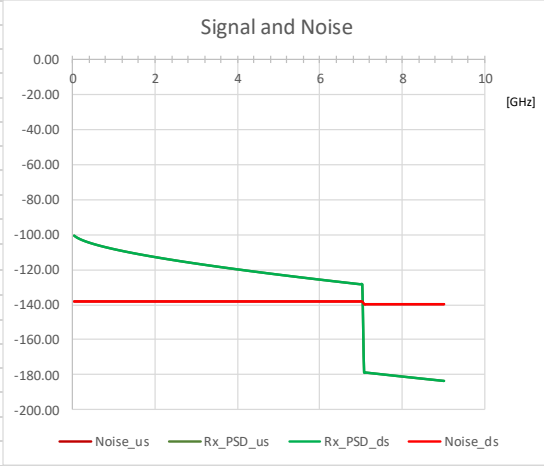
Performance for Mueller SDP Cable (Dec 1, 2020) at T=105°C

	Upstream	Downstream
Requrements		
Data Rate [Gbps]:	25	25
Target RS-FEC output BER:	1.00E-12	1.00E-12
Cable Length [m]:	11	11
Wire u-reflections [dB]:	-40	-40
Number of Connectors:	4	4
Modulation		
PAM Levels:	4	4
FEC Block Size (n):	360	360
FEC Data Size (k):	326	326
RS-FEC Correction Efficiency:	100%	100%
Bits per FEC Symbol:	10	10
TDD Time Duty-Cycle:	100%	100%
Framing Overhead:	1.875%	1.875%
Transmit Signal		
PSD-mask:	PSD_brick	PSD_brick
Transmit Power [dBm]:	0	0
Design Tradeoff		
Impulse Error Rate:	1.00E-04	1.00E-04
AFE-noise [dBm/Hz]:	-140	-140
EC cancelation [dB]:	5	5
EC Connector cancelation [%]:	100%	100%
Implementation Loss [dB]:	0	0
Simulation Parameters		
Cable Model:	mueller*sdp	
Connector Echo Model:	hard	
Temperature [°C]:	105	
Max Simulation Frequency:	9.00E+09	

Calculated Values		
	Upstream	Downstream
Theoretical Slicer SNR [dB]:	21.16	21.16
Estimated Slicer SNR [dB]:	21.16	21.16
Required Slicer SNR [dB]:	17.78	17.78
SNR Margin [dB]:	3.38	3.38
Nyquist Frequency [GHz]:	7.03	7.03
Insertion Loss @ Nyquist [dB]:	29.72	29.72



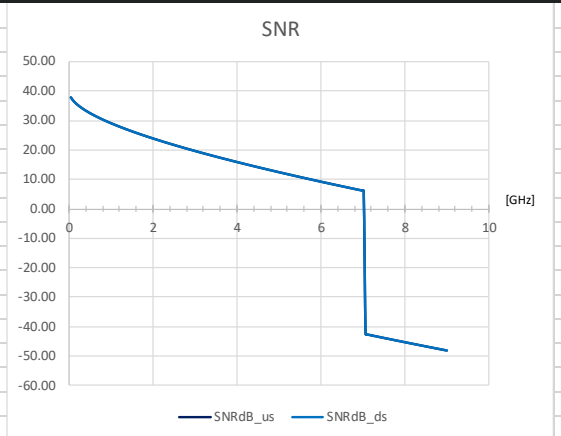
- The 11m model at 105°C for the SDP IL curve in mueller_3cy_01_12_01_20 is just above the Zimmerman limit curve and has SNR margin of 3.38dB
- Note that PCB IL is not included in this calculation

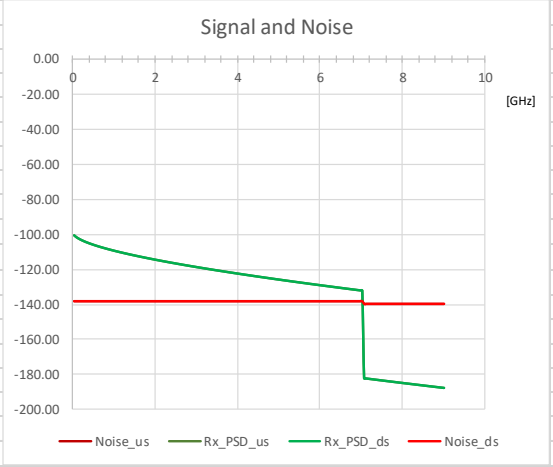


Performance for Mueller SDP Cable (Dec 1, 2020) at T=105°C

	Upstream	Downstream
Requrements		
Data Rate [Gbps]:	25	25
Target RS-FEC output BER:	1.00E-12	1.00E-12
Cable Length [m]:	12.5	12.5
Wire u-reflections [dB]:	-40	-40
Number of Connectors:	4	4
Modulation		
PAM Levels:	4	4
FEC Block Size (n):	360	360
FEC Data Size (k):	326	326
RS-FEC Correction Efficiency:	100%	100%
Bits per FEC Symbol:	10	10
TDD Time Duty-Cycle:	100%	100%
Framing Overhead:	1.875%	1.875%
Transmit Signal		
PSD-mask:	PSD_brick	PSD_brick
Transmit Power [dBm]:	0	0
Design Tradeoff		
Impulse Error Rate:	1.00E-04	1.00E-04
AFE-noise [dBm/Hz]:	-140	-140
EC cancelation [dB]:	5	5
EC Connector cancelation [%]:	100%	100%
Implementation Loss [dB]:	0	0
Simulation Parameters		
Cable Model:	mueller*sdp	
Connector Echo Model:	hard	
Temperature [°C]:	105	
Max Simulation Frequency:	9.00E+09	

Calculated Values		
	Upstream	Downstream
Theoretical Slicer SNR [dB]:	18.62	18.62
Estimated Slicer SNR [dB]:	18.62	18.62
Required Slicer SNR [dB]:	17.78	17.78
SNR Margin [dB]:	0.83	0.83
Nyquist Frequency [GHz]:	7.03	7.03
Insertion Loss @ Nyquist [dB]:	33.77	33.77





- The 12.5m model at 105°C for the SDP IL curve in mueller_3cy_01_12_01_20 is below the Zimmerman limit curve and has SNR margin of 0.83dB
- Note that this corresponds roughly to 11m cable + PCB IL

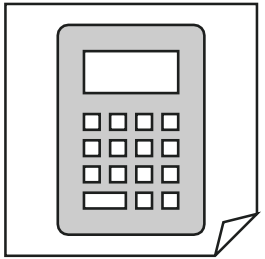
Some Follow-up Questions

Is the 2.5dB SNR Margin for the Zimmerman DSP mask sufficient?

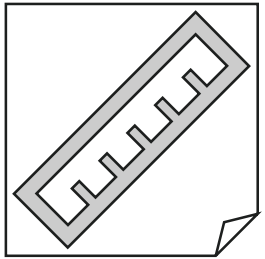
What is the cable operating temperature range needed for 802.3cy?

Will the whole length of the cable be exposed to maximum temperature, or only limited segments of the cable?

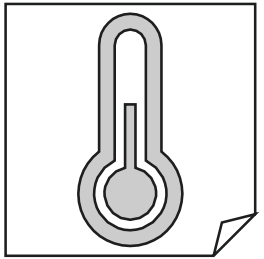
Summary



We described updates to the channel capacity calculation tool that was originally introduced in jonsson_3cy_01_10_28_20



For typical model parameters, the IL limit introduced in zimmerman_3cy_01a_1120 has SNR margin of 2.5dB



Temperature has significant impact on the Insertion Loss and the SNR margin

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