MARVELL

Evaluation of Expected Channel Performance

Calculating achievable performance for different channels

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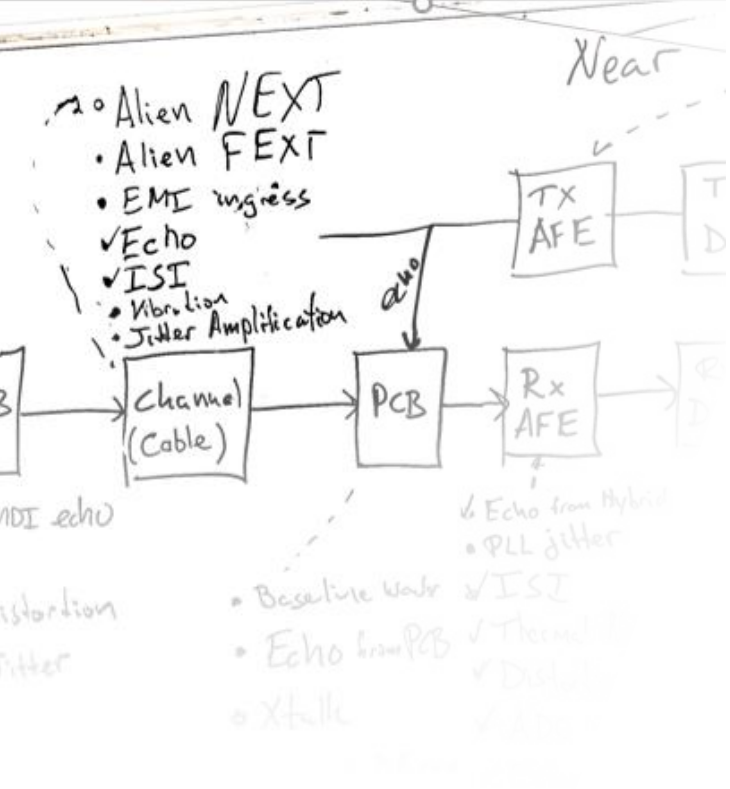


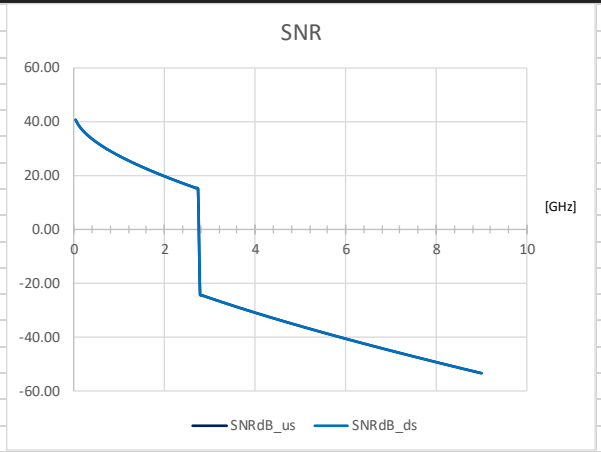
Introduction

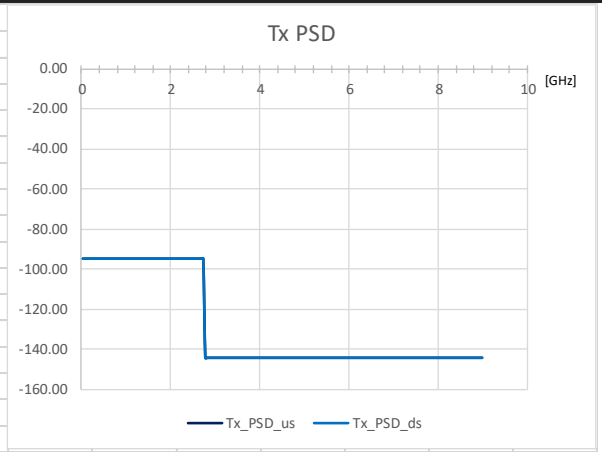
- Evaluating communication system performance is very complicated, especially in early stages of standards development where so many things are in flux
- One way to evaluate the performance is to use theoretical calculations with assumptions about the Phy implementation
- This presentation will describe how accompanying spreadsheet can be used for such theoretical calculations
- Results are presented for the theoretical calculation for some the cables that have been presented so far in the 802.3cy development

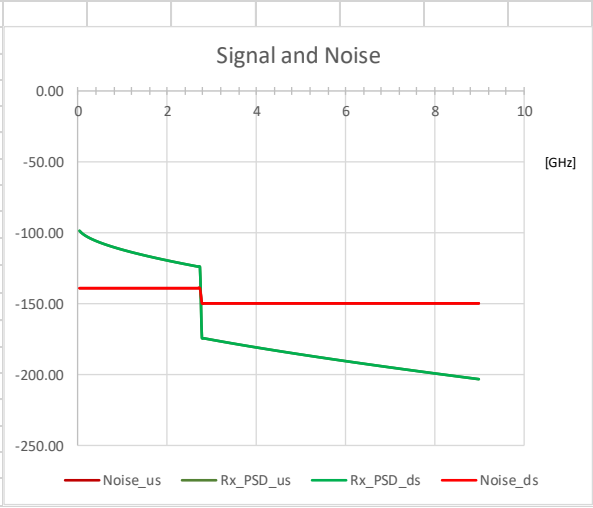
The Spreadsheet Calculates SNR Margin Based on Given Assumptions

	Upstream	Downstream
Requrements		
Data Rate [Gbps]:	10	10
Target RS-FEC output BER:	1.00E-12	1E-12
Cable Length [m]:	15	15
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%
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/Hz]:	-150	-150
EC cancelation [dB]:	5	5
EC Connector cancelation [%]:	100%	100%
Implementation Loss [dB]:	6	6
Simulation Parameters		
Cable Model:	eq149-18	
Connector Echo Model:	hard	
Max Simulation Frequency:	9.00E+09	

Calculated Values		
	Upstream	Downstream
Theoretical Slicer SNR [dB]:	24.98	24.98
Estimated Slicer SNR [dB]:	18.98	18.98
Required Slicer SNR [dB]:	17.78	17.78
SNR Margin [dB]:	1.20	1.20
Nyquist Frequency [GHz]:	2.76	2.76
Insertion Loss @ Nyquist [dB]:	29.47	29.47







Configuration Parameters

- There are separate values for Upstream and Downstream, to support modeling of asymmetric modulations
- There are five types of parameters:
  - Requirements
  - Modulation
  - Transmit Signal (PSD)
  - Design Tradeoffs
  - Simulation Parameters

	Upstream	Downstream
Requrements		
Data Rate [Gbps]:	10	10
Target RS-FEC output BER:	1.00E-12	1E-12
Cable Length [m]:	15	15
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%
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/Hz]:	-150	-150
EC cancelation [dB]:	5	5
EC Connector cancelation [%]:	100%	100%
Implementation Loss [dB]:	6	6
Simulation Parameters		
Cable Model:	eq149-18	
Connector Echo Model:	hard	
Max Simulation Frequency:	9.00E+09	

Calculated Values		
	Upstream	Downstream
Theoretical Slicer SNR [dB]:	24.98	24.98
Estimated Slicer SNR [dB]:	18.98	18.98
Required Slicer SNR [dB]:	17.78	17.78
SNR Margin [dB]:	1.20	1.20
Nyquist Frequency [GHz]:	2.76	2.76
Insertion Loss @ Nyquist [dB]:	29.47	29.47

Parameter Descriptions

Requirements	
Data Rate [Gbps]:	the net required data rate
Target RS-FEC output BER:	the bit error rate after Forward Error Correction
Cable Length [m]:	the length of the cable to use in the calculations
Wire u-reflections [dB]:	the gain of the return loss transfer function for the micro-reflections
Number of Connectors:	the total number of connectors, including end connectors and inline connectors
Modulation	
PAM Levels:	number of levels used in Pulse Amplitude Modulation
FEC Block Size (n):	total number of symbols in each FEC block
FEC Data Size (k):	number of data symbols in each FEC block
RS-FEC Correction Efficiency:	the efficiency of the FEC, compared to theoretical limit
Bits per FEC Symbol:	number of bits in each FEC symbol
TDD Time Duty-Cycle:	percentage of time spent in each direction in TDD
Transmit Signal	
PSD-mask:	selects one of the predefined masks for the transmit Power Spectral Density
Transmit Power [dBm]:	scales the transmit power of the mask
Design Tradeoffs	
Impulse Error Rate:	frequency of impulse events at the slicer
AFE_noise [dB/Hz];	noise floor of the Analog Front End
EC cancelation [dB]:	suppression of echo other than main connector echo
EC Connector cancelation [%]:	percentage of connector echo that is canceled by the echo cancelers
Implementation Loss [dB]:	margin loss due to imperfections in the Phy implementation, such as ADC quantization, coefficient quantization, etc.
Simulation Parameters	
Cable Model:	name of channel model selected from the tables in the Channels tab
Connector Echo Model:	name of connector echo model selected from the Mask tab
Max Frequency:	the maximum frequency used in the calculations (needs to be higher than the Nyquist frequency)

Calculations Tab

Freq	dF	IL	Tx_PSD_u	Tx_PSD_ds	Rx_PSD_u	Rx_PSD_d	Echo_tran	Echo_tran	Rx_echo_	Rx_echo_	AFE_noise	AFE_noise	EC_cancel	EC_cancel	Echo_res	Echo_res	Noise_us	Noise_ds	SNRdB_us	SNRdB_ds	SNR_us	SNR_ds	Channel_capac	Channel_capac
45,000,000	4.50E+07	-3.86098	-94.41	-94.41	-98.27	-98.27	-24.22	-24.22	-118.63	-118.63	-150.00	-150.00	5.00	5.00	-139.41	-139.41	-139.05	-139.05	40.78	40.78	11955.05	11955.05	460854307.44	460854307.44
90,000,000	4.50E+07	-5.33131	-94.41	-94.41	-99.74	-99.74	-23.42	-23.42	-117.83	-117.83	-150.00	-150.00	5.00	5.00	-139.41	-139.41	-139.05	-139.05	39.31	39.31	8521.54	8521.54	438896406.25	438896406.25
135,000,000	4.50E+07	-6.45243	-94.41	-94.41	-100.86	-100.86	-22.74	-22.74	-117.16	-117.16	-150.00	-150.00	5.00	5.00	-139.41	-139.41	-139.05	-139.05	38.18	38.18	6582.74	6582.74	422159382.62	422159382.62
180,000,000	4.50E+07	-7.3969	-94.41	-94.41	-101.81	-101.81	-22.16	-22.16	-116.57	-116.57	-150.00	-150.00	5.00	5.00	-139.41	-139.41	-139.05	-139.05	37.24	37.24	5296.14	5296.14	408064390.89	408064390.89
225,000,000	4.50E+07	-8.23021	-94.41	-94.41	-102.64	-102.64	-21.65	-21.65	-116.06	-116.06	-150.00	-150.00	5.00	5.00	-139.41	-139.41	-139.05	-139.05	36.41	36.41	4371.49	4371.49	395633200.39	395633200.39
270,000,000	4.50E+07	-8.98545	-94.41	-94.41	-103.40	-103.40	-21.19	-21.19	-115.60	-115.60	-150.00	-150.00	5.00	5.00	-139.41	-139.41	-139.05	-139.05	35.65	35.65	3673.71	3673.71	384371159.51	384371159.51
315,000,000	4.50E+07	-9.68209	-94.41	-94.41	-104.09	-104.09	-20.77	-20.77	-115.18	-115.18	-150.00	-150.00	5.00	5.00	-139.41	-139.41	-139.05	-139.05	34.95	34.95	3129.26	3129.26	373987627.93	373987627.93
360,000,000	4.50E+07	-10.3327	-94.41	-94.41	-104.74	-104.74	-20.39	-20.39	-114.80	-114.80	-150.00	-150.00	5.00	5.00	-139.41	-139.41	-139.05	-139.05	34.30	34.30	2693.89	2693.89	364294954.95	364294954.95
405,000,000	4.50E+07	-10.9459	-94.41	-94.41	-105.36	-105.36	-20.04	-20.04	-114.45	-114.45	-150.00	-150.00	5.00	5.00	-139.41	-139.41	-139.05	-139.05	33.69	33.69	2339.14	2339.14	355163825.95	355163825.95

1. Insertion Loss (IL) is calculated from IL per meter and the cable length
2. Received PSD is calculated from the channel IL and the transmit PSD
3. Received echo PSD is calculated from the return loss (RL) and the transmit PSD
4. Residual echo is calculated from the received echo and the echo cancelation (EC)
5. Noise is calculated as sum of AFE noise and residual echo
6. Signal to noise ratio (SNR) is the received PSD divided by received noise

1. $IL(f) = IL_m(f)^{length}$
2. $PSD_{Rx}(f) = IL(f)PSD_{Tx}(f)$
3. $Echo_{Rx}(f) = RL(f)PSD_{Tx}(f)$
4. $Echo_{Res}(f) = Echo_{Rx}(f) - EC(f)$
5. $Noise(f) = Noise_{AFE}\,(f) + Echo_{Res}(f)$
6. $SNR(f) = \frac{PSD_{Rx}(f)}{Noise(f)}$

Calculated Values

Calculated Values		
	Upstream	Downstream
Theoretical Slicer SNR [dB]:	24.98	24.98
Estimated Slicer SNR [dB]:	18.98	18.98
Required Slicer SNR [dB]:	17.78	17.78
SNR Margin [dB]:	1.20	1.20
Nyquist Frequency [GHz]:	2.76	2.76
Insertion Loss @ Nyquist [dB]:	29.47	29.47

The calculated values are derived from the configuration parameters

Theoretical Slicer SNR

- SNR for ideally equalized system

Estimated Slicer SNR

- theoretical SNR minus the implementation loss

Required Slicer SNR

- minimum SNR to maintain the desired bit error rate

SNR Margin

- difference of estimated SNR and required SNR

Nyquist Frequency

- half the baud rate

Insertion Loss @ Nyquist

- channel insertion loss at the Nyquist frequency

Example: 10Gbps 802.3ch

Calculated Values		
	Upstream	Downstream
Theoretical Slicer SNR [dB]:	24.98	24.98
Estimated Slicer SNR [dB]:	18.98	18.98
Required Slicer SNR [dB]:	17.78	17.78
SNR Margin [dB]:	1.20	1.20

- IEEE 902.3ch achieves symmetric 10Gbps, with BER of 10^{-12}, over 15m channel represented by equation 149-18
- The modulation is based on PAM4 modulation, (360, 326) RS-FEC, and echo cancelation
- According to the channel capacity calculations the margin for this is only 1.20dB

	Upstream	Downstream
Requrements		
Datarate [Gbps]:	10	10
Target RS-FEC output BER:	1.00E-12	1E-12
Cable Length [m]:	15	15
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 Efficency:	100%	100%
Bits per FEC Symbol:	10	10
TDD Time Duty-Cycle:	100%	100%
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/Hz]:	-150	-150
EC cancelation [dB]:	5	5
EC Connector cancelation [%]:	100%	100%
Implementation Loss [dB]:	6	6
Simulation Parameters		
Cable Model:	eq149-18	
Connector Echo Model:	hard	
Shannon Gap [dB]:	9.95	9.95
Max Frequency:	9.00E+09	

The spreadsheet can be used to evaluate the cable measurements that have been shared so far as part of the 802.3cy development

	802.3ch scaled	PAM-2	PAM-8	TDD PAM-8
Requrements				
Data Rate [Gbps]:	25	25	25	25
Target RS-FEC output BER:	1.00E-12	1.00E-12	1.00E-12	1.00E-12
Cable Length [m]:	9.5	7	8.5	8
Wire u-reflections [dB]:	-40	-40	-40	-40
Number of Connectors:	4	4	4	4
Modulation				
PAM Levels:	4	2	8	8
FEC Block Size (n):	360	360	360	360
FEC Data Size (k):	326	326	326	326
[illegible] Efficency:	100%	100%	100%	100%
[illegible] Symbol:	10	10	10	10
[illegible]	100%	100%	100%	50%
[illegible]	[illegible]	PSD_brick	PSD_brick	PSD_brick
[illegible]	0	0	0	0
[illegible]	[illegible]	1.00E-04	1.00E-04	1.00E-04
[illegible]	[illegible]	-150	-150	-150
[illegible]	[illegible]	5	5	100
[illegible]	[illegible]	100%	100%	100%
[illegible]	[illegible]	6	6	6
[illegible]	[illegible]	[illegible]	eq149-18	eq149-18
[illegible]	[illegible]	[illegible]	hard	hard
[illegible]	[illegible]	[illegible]	9.95	9.95
[illegible]	[illegible]	[illegible]	9.00E+09	9.00E+09

Evaluating Cable Measurements

- The calculations are based on the assumptions that are listed in the table (see all the green cells)
- The calculation assumed 802.3ch line modulation extended to 25Gbps
- The cable models were simple and too optimistic, assuming no suck-out, etc.
- In the real-world we need more than 0dB margin, so achievable cable length estimates in the table on the right are too optimistic

Conclusion: It is unlikely that we can achieve 25Gbps over 11m with the cables we have seen so far

	802.3ch limit	Mueller 10/14	Boyer 10/14	Patel 09/20
Requrements				
Data Rate [Gbps]:	25	25	25	25
Target RS-FEC output BER:	1.00E-12	1.00E-12	1.00E-12	1.00E-12
Cable Length [m]:	9.5	10.5	12	10.5
Wire u-reflections [dB]:	-40	-40	-40	-40
Number of Connectors:	4	4	4	4
Modulation				
PAM Levels:	4	4	4	4
FEC Block Size (n):	360	360	360	360
FEC Data Size (k):	326	326	326	326
RS-FEC Correction Efficiency:	100%	100%	100%	100%
Bits per FEC Symbol:	10	10	10	10
TDD Time Duty-Cycle:	100%	100%	100%	100%
Transmit Signal				
PSD-mask:	PSD_brick	PSD_brick	PSD_brick	PSD_brick
Transmit Power [dBm]:	0	0	0	0
Design Tradeoff				
Impulse Error Rate:	1.00E-04	1.00E-04	1.00E-04	1.00E-04
AFE-noise [dB/Hz]:	-150	-150	-150	-150
EC cancelation [dB]:	5	5	5	5
EC Connector cancelation [%]:	100%	100%	100%	100%
Implementation Loss [dB]:	6	6	6	6
Simulation Parameters				
Cable Model:	eq149-18	ueller_3cy_01_10_14_2	oyer_3cy_01_10_14_20_	patel_3cy_01_0920
Connector Echo Model:	hard	hard	hard	hard
Max Simulation Frequency:	9.00E+09	9.00E+09	9.00E+09	9.00E+09

Calculated Values				
	802.3ch limit	Mueller 10/14	Boyer 10/14	Patel 09/20
Theoretical Slicer SNR [dB]:	23.78	23.84	23.70	23.63
Estimated Slicer SNR [dB]:	17.78	17.84	17.70	17.63
Required Slicer SNR [dB]:	17.78	17.78	17.78	17.78
SNR Margin [dB]:	0.00	0.05	-0.09	-0.16
Nyquist Frequency [GHz]:	6.90	6.90	6.90	6.90
Insertion Loss @ Nyquist [dB]:	31.69	31.81	32.98	34.26

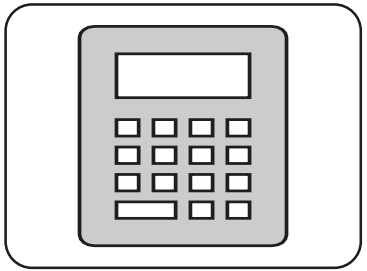
What About Other Modulation Options?

- The table on the right shows cable length estimates for some candidate modulations
- The calculations used length scaled version of the 802.3ch channel limit line to compare the modulations
- The 802.3ch modulation extended to 25Gbps has the best performance at 9.5m
- It is not likely that other modulation schemes will significantly improve the achievable cable length

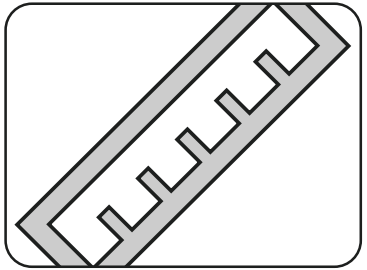
Conclusion: It is unlikely that we can achieve 25Gbps over 11m with the cables we have seen so far

	802.3ch scaled	PAM-2	PAM-8	TDD PAM-8
Requrements				
Data Rate [Gbps]:	25	25	25	25
Target RS-FEC output BER:	1.00E-12	1.00E-12	1.00E-12	1.00E-12
Cable Length [m]:	9.5	7	8.5	8
Wire u-reflections [dB]:	-40	-40	-40	-40
Number of Connectors:	4	4	4	4
Modulation				
PAM Levels:	4	2	8	8
FEC Block Size (n):	360	360	360	360
FEC Data Size (k):	326	326	326	326
RS-FEC Correction Efficiency:	100%	100%	100%	100%
Bits per FEC Symbol:	10	10	10	10
TDD Time Duty-Cycle:	100%	100%	100%	50%
Transmit Signal				
PSD-mask:	PSD_brick	PSD_brick	PSD_brick	PSD_brick
Transmit Power [dBm]:	0	0	0	0
Design Tradeoff				
Impulse Error Rate:	1.00E-04	1.00E-04	1.00E-04	1.00E-04
AFE-noise [dB/Hz]:	-150	-150	-150	-150
EC cancelation [dB]:	5	5	5	100
EC Connector cancelation [%]:	100%	100%	100%	100%
Implementation Loss [dB]:	6	6	6	6
Simulation Parameters				
Cable Model:	eq149-18	eq149-18	eq149-18	eq149-18
Connector Echo Model:	hard	hard	hard	hard
Max Simulation Frequency:	9.00E+09	9.00E+09	9.00E+09	9.00E+09
Calculated Values				
	802.3ch limit	PAM-2	PAM-8	TDD PAM-8
Theoretical Slicer SNR [dB]:	23.78	16.95	29.82	29.76
Estimated Slicer SNR [dB]:	17.78	10.95	23.82	23.76
Required Slicer SNR [dB]:	17.78	10.51	24.12	24.12
SNR Margin [dB]:	0.00	0.43	-0.30	-0.35
Nyquist Frequency [GHz]:	6.90	13.80	4.60	9.20
Insertion Loss @ Nyquist [dB]:	31.69	27.50	22.33	31.42

Summary



We described calculations that can be used to evaluate the expected achievable performance



It is unlikely that 802.3cy will achieve 25Gbps over 11m using the cables that have been presented so far

Essential technology, done right™