Beta and Epsilon Point Update

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Contributors and Supporters

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Executive summary

- Proposal defines the operation of 8.5 Gb/s Fibre Channel in the server blade environment
- [Enhanced] TWDP-based transmitter device compliance methodology
- [Enhanced] WDP-based receiver device signal tolerance input
- Reference receiver with 1 feed-forward, 3 feedback taps
- Comprehensive channel analysis, loss and jitter budgets presented to support proposed specifications
- Relevant test procedures from SFF-8431, tailored to 8.5 Gb/s Fibre Channel applications, to be included in Annex A
  - Described in detail in companion document T11/07-398v1
- Additional detailed modifications to the FC-PI-4 draft also described in companion document

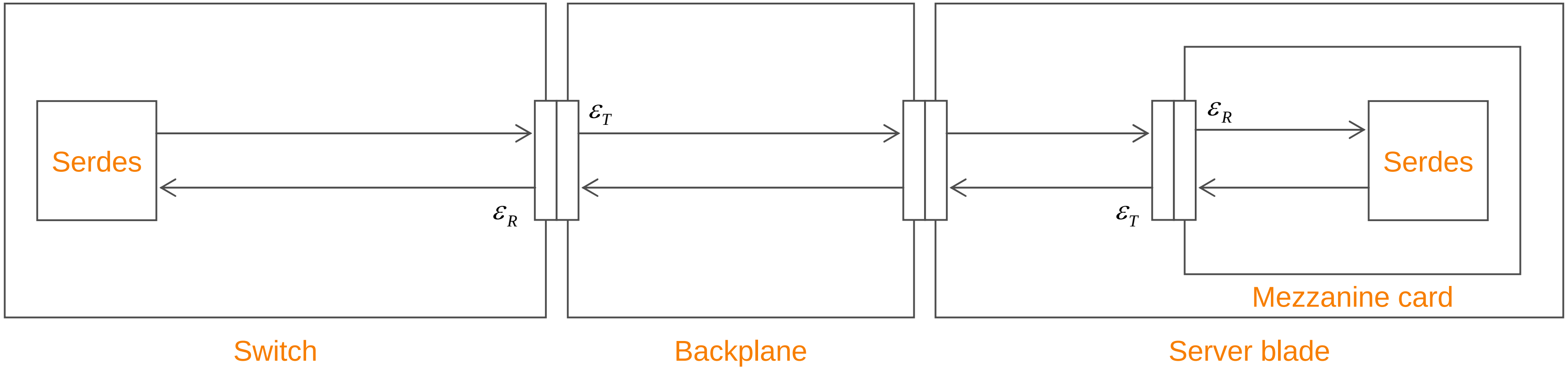
August 8, 2007 Updates

- Corrected Epsilon point reference model
- Added Beta point requirements to the specification tables
- Introduced transmitter minimum output rise/fall times as a crosstalk control measure
- Increased the VMA_T (min), which yielded a corresponding increase in the minimum receiver VMA_R (min)
  - Influences TWDP targets for the transmitter
- Updated transmitter TWDP requirements to include an allowance for transmitter duty cycle distortion
- Defined a new interference source for receiver signal tolerance test

Assumptions

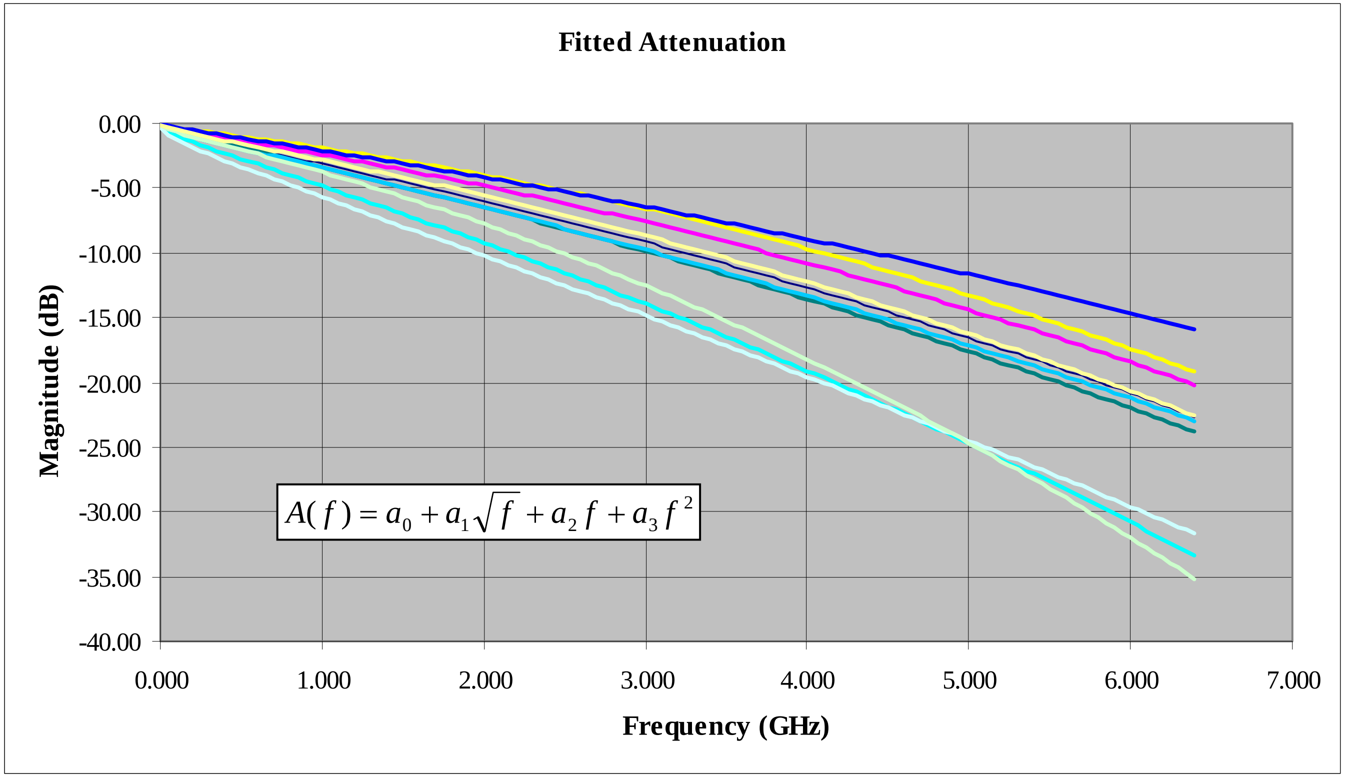
- Epsilon point specifications describe point-to-point links traversing a passive electrical backplane in a modular platform environment
- The Epsilon point differs from the Beta point in that:
  - It considers only fabric topologies (not arbitrated loop)
  - It has more aggressive performance targets (links span longer distances, include more connectors, higher density, e.g. higher loss and crosstalk)
  - Blade server versus JBOD and RAID
- It is desirable to leverage IEEE 802.3ap™-2007 (Backplane Ethernet) and OIF Common Electrical Interface
  - However, these are serdes (Alpha point) specifications
  - Work is required to project the methodologies and requirements to Epsilon point

Epsilon Point Reference Model



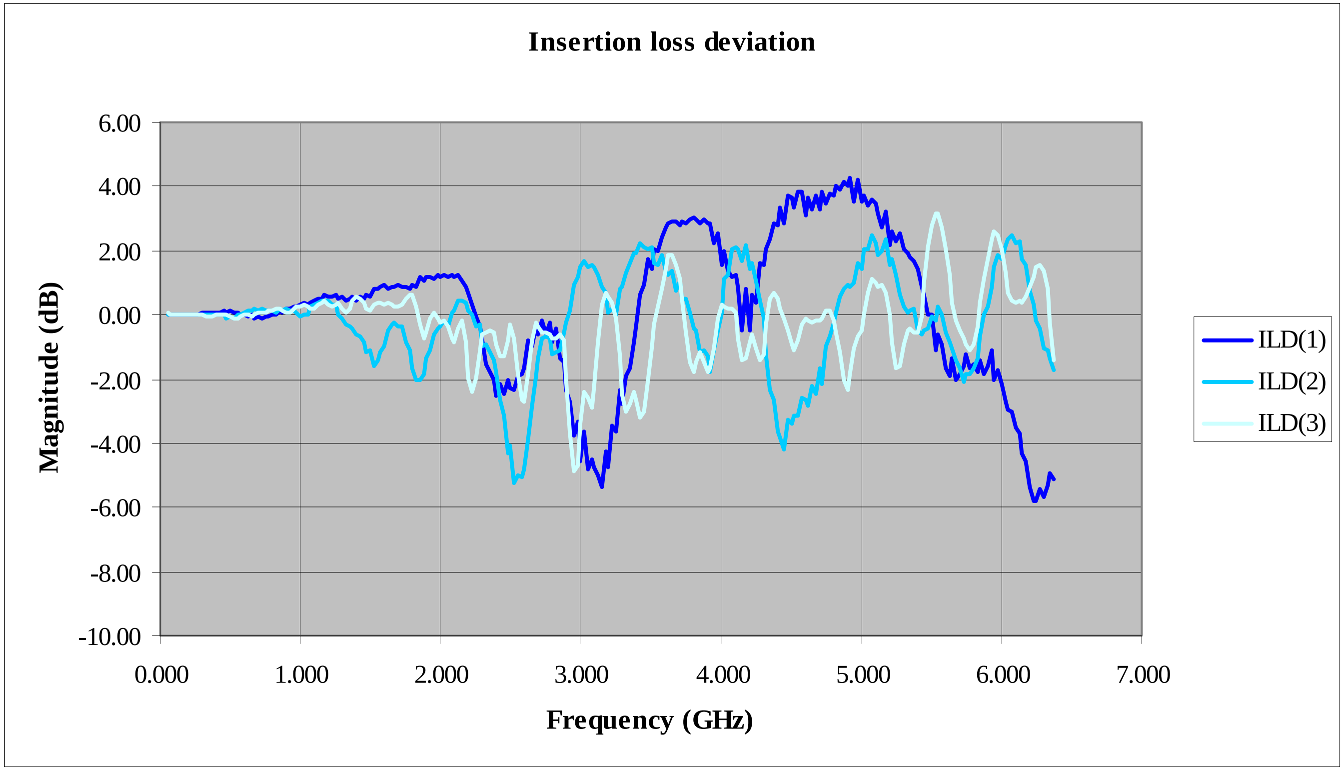
- Links spans up to 33” of differential trace on FR-4 printed circuit boards with up to three connectors [1]
  - It is an objective to support up to 20 dB of loss, at 4.25 GHz, between ε_T and ε_R [2]
- Interoperability points are the separable connectors closest to the serdes
  - A variety of connectors are currently employed at the mezzanine card and backplane interfaces, so a specific connector is not defined
- The link is assumed to be AC-coupled (may be implemented in the serdes, or on the mezzanine/switch card)

Channel considerations – fitted attenuation



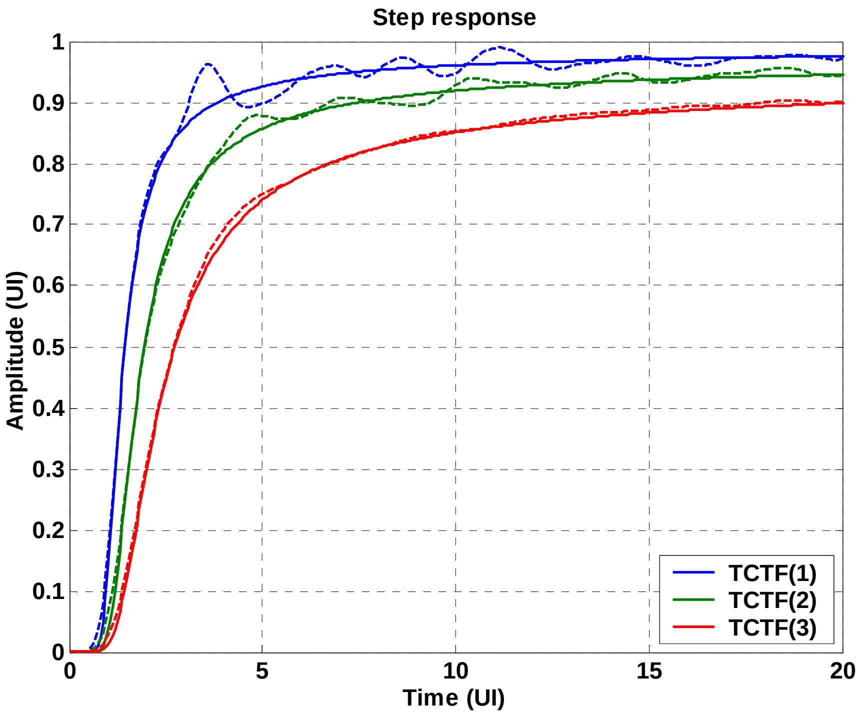
- The fitted attenuation, $A(f)$, is the least mean squares fit of the insertion loss, expressed in dB, to a polynomial function
- The fit is limited to the frequency range DC to 6.375 GHz

Channel considerations – insertion loss deviation



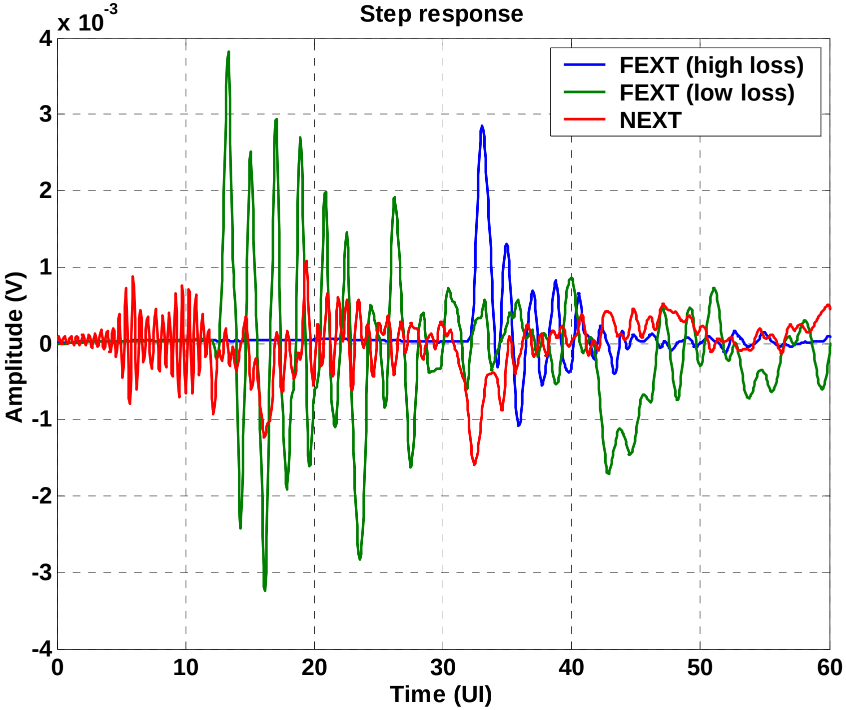
- Insertion loss deviation (ILD) is the error relative to the polynomial fit
- ILD corresponds to tail ripple in the channel impulse response
- The terminations presented by the transmitter and receiver devices will modify ILD

Channel considerations – step response



- A comparison of the step response generated from the fitted attenuation and the original step response illustrates the impact of ILD
- Much of ripple in the step response can not be compensated by the reference receiver, e.g. more than 3 UI away
- Such ripple is empirical in nature, e.g. variation in the path delay alters the arrival time of reflections and impacts the performance
- Stressors will be based on the fitted attenuation and the impact of ILD will be rendered as a term in the loss budget

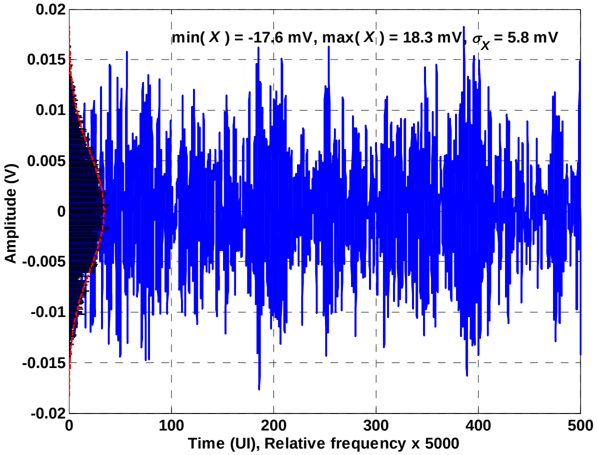
Channel Considerations – crosstalk



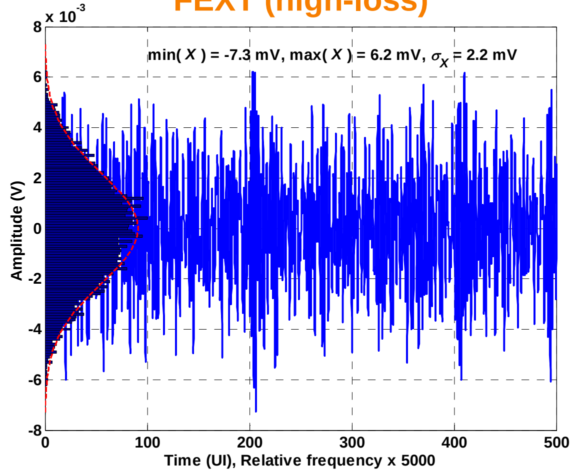
- Examination of the crosstalk step responses reveal resonances that span 10’s of symbols
- Since the crosstalk is the weighted sum of many symbol amplitudes, it tends toward a Gaussian distribution
- The addition of more aggressors reinforces this trend

Channel considerations – crosstalk from JSPAT

FEXT (low-loss)



FEXT (high-loss)



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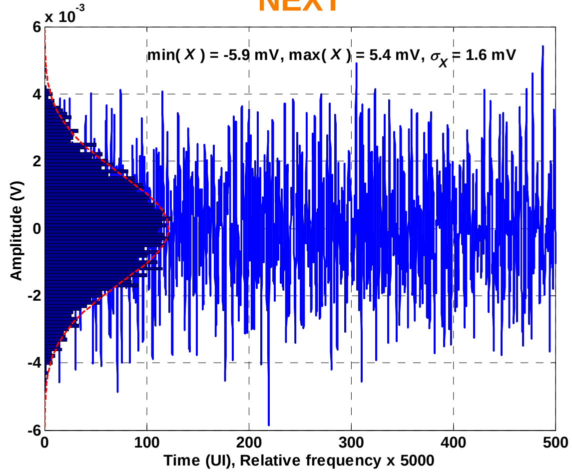
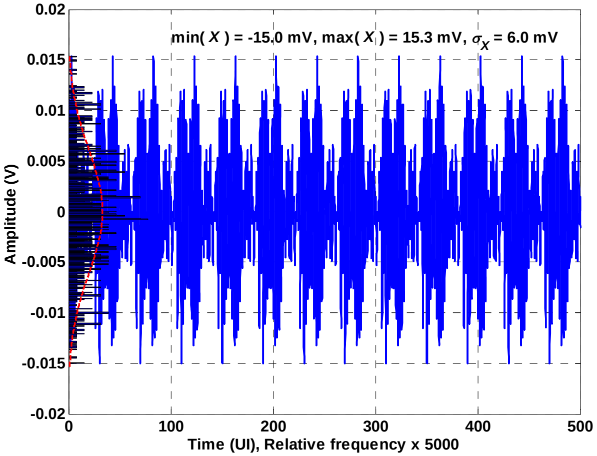


NOTE – V_{P2P} = 1200 mV, VMA_T = 1000 mV, $T_{r,f}$ (20-80%) = 40 ps

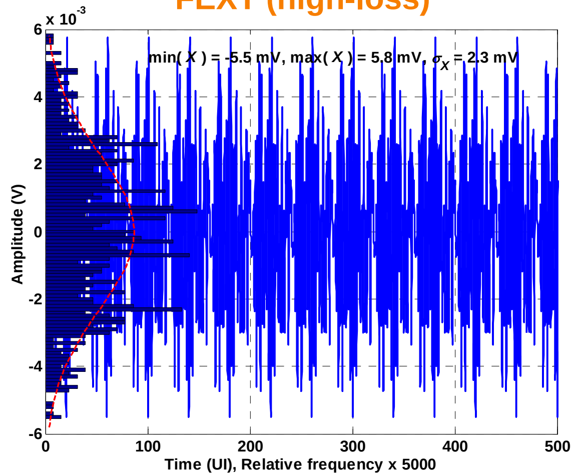
- Amplitude histograms indicate that the crosstalk amplitude may be reasonably assumed to have Gaussian statistics
  - Truncated of course, with crest factor varying per the aggressor being studied
- It can also be shown that ARBff is only weakly correlated to JSPAT, and that JSPAT itself is “relatively white”
- Observations validate the inclusion of crosstalk as an additive white Gaussian noise term in the TWDP analysis

Channel considerations – crosstalk from ARBff

FEXT (low-loss)



FEXT (high-loss)



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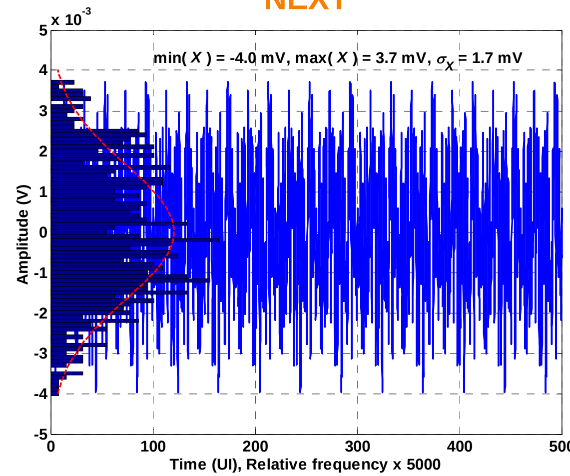
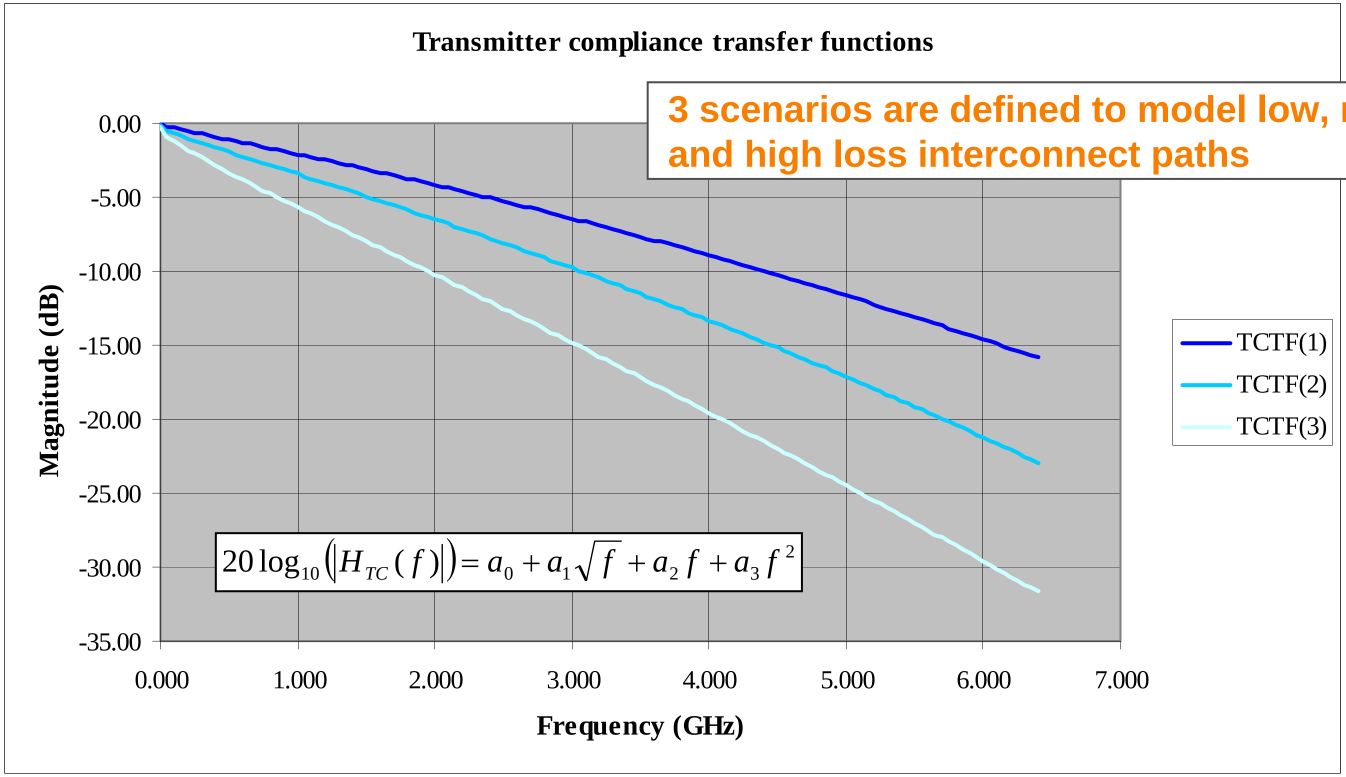


NOTE – V_{P2P} = 1200 mV, VMA_T = 1000 mV, $T_{r,f}$ (20-80%) = 40 ps

- Primitive pattern results in significant deviation from Gaussian amplitude distribution
- However, the RMS value does not significantly deviate from JSPAT derived value and peak-to-peak amplitude is less than the JSPAT case

Transmitter compliance transfer functions



3 scenarios are defined to model low, medium, and high loss interconnect paths

	Units	TCTF index		
		1	**2**	**3**
a_3	dB/GHz^2	-0.12	-0.15	-0.11
a_2	dB/GHz	-1.55	-2.26	-3.47
a_1	dB/root-GHz	-0.37	-0.85	-1.77
a_0	dB	-0.06	-0.18	-0.34

Scenario 1 – Low loss channel: Loss budget

	$[mV_{pk\text{-}pk}]$	$[mV_{rms}]$	[dB]		*Comments*
V_{P2P} (max)	1200				*Tx peak-to-peak output voltage*
			5.13	P_{TE}	*Tx maximum equalization gain*
VMA_T (max)	1000				*Tx maximum output amplitude*
VMA_T (min)	665				*Tx minimum output amplitude*
	-125		1.81	P_A (max)	*Channel VMA loss*
VMA_R (min)	540				*Rx minimum input amplitude*
			7.10	TWDP	*Tx waveform and dispersion penalty*
			4.40	P_{ILD}	*Insertion loss deviation*
			2.20	P_{UJ}	*Uncorrelated jitter*
			18.67	P_{ALLOC}	*Total allocated dispersion penalty*
			4.97	M	*Unallocated margin ($\geq$ 0, hopefully)*
VMA_{SX}	97				*Sensitivity adjusted for crosstalk*
σ_X		6.0			*Crosstalk (RMS)*
			1.96	P_{BT4}	*Matched filter vs. Bessel filter*
VMA_{MFB}	77				*Matched filter bound sensitivity*
VMA_S	48				*Rx nominal sensitivity*
		3.4			*Electronics noise and slicer uncertainty*
0					
Q_0 =	7.03	for BER 1.0E-12			*Target signal-to-noise ratio*

Scenario 1 – Low loss channel: Jitter budget

[mUI]

	NC-DDJ (pk-pk)	BUJ (pk-pk)	RJ (pk-pk)	RJ (RMS)	UJ (RMS)	TJ (pk-pk)	*Comments*
ε_T		35	140	10	**20**		*Tx output jitter*
	110						*Tx waveform and dispersion*
	280						*Insertion loss deviation*
				11			*Crosstalk*
ε_R							
		200	140	10			*Rx clock and data recovery*
Total	390	235	252	18		877	*Total jitter ($\leq$ 1 UI, hopefully)*
						943	*What if RJ = UJ (e.g. BUJ = 0)?*

NOTE – for link analysis purposes only, not intended to populate FC-PI-4 jitter output or tolerance tables

Scenario 2 – Medium loss channel: Loss budget

	$[mV_{pk\text{-}pk}]$	$[mV_{rms}]$	[dB]		*Comments*
V_{P2P} (max)	1200				*Tx peak-to-peak output voltage*
			5.13	P_{TE}	*Tx maximum equalization gain*
VMA_T (max)	1000				*Tx maximum output amplitude*
VMA_T (min)	665				*Tx minimum output amplitude*
	-194		2.99	P_A (max)	*Channel VMA loss*
VMA_R (min)	471				*Rx minimum input amplitude*
			10.50	TWDP	*Tx waveform and dispersion penalty*
			3.10	P_{ILD}	*Insertion loss deviation*
			1.20	P_{UJ}	*Uncorrelated jitter*
			18.67	P_{ALLOC}	*Total allocated dispersion penalty*
			3.87	M	*Unallocated margin ($\geq$ 0, hopefully)*
VMA_{SX}	97				*Sensitivity adjusted for crosstalk*
σ_X		6.0			*Crosstalk (RMS)*
			1.96	P_{BT4}	*Matched filter vs. Bessel filter*
VMA_{MFB}	77				*Matched filter bound sensitivity*
VMA_S	48				*Rx nominal sensitivity*
		3.4			*Electronics noise and slicer uncertainty*
0					
Q_0 =	7.03	for BER 1.0E-12			*Target signal-to-noise ratio*

Scenario 2 – Medium loss channel: Jitter budget

[mUI]

	NC-DDJ (pk-pk)	BUJ (pk-pk)	RJ (pk-pk)	RJ (RMS)	UJ (RMS)	TJ (pk-pk)	*Comments*
ε_T		35	140	10	**20**		*Tx output jitter*
	150						*Tx waveform and dispersion*
	260						*Insertion loss deviation*
				13			*Crosstalk*
ε_R							
		200	140	10			*Rx clock and data recovery*
Total	410	235	267	19		912	*Total jitter ($\leq$ 1 UI, hopefully)*
						973	*What if RJ = UJ (e.g. BUJ = 0)?*

Scenario 3 – High loss channel: Loss budget

	$[mV_{pk\text{-}pk}]$	$[mV_{rms}]$	[dB]		*Comments*
V_{P2P} (max)	**1200**				*Tx peak-to-peak output voltage*
			7.02	P_{TE}	*Tx maximum equalization gain*
VMA_T (max)	**1000**				*Tx maximum output amplitude*
VMA_T (min)	**535**				*Tx minimum output amplitude*
	-234		**5.00**	P_A (max)	*Channel VMA loss*
VMA_R (min)	301				*Rx minimum input amplitude*
			15.40	*TWDP*	*Tx waveform and dispersion penalty*
			3.10	P_{ILD}	*Insertion loss deviation*
			0.50	P_{UJ}	*Uncorrelated jitter*
			20.79	P_{ALLOC}	*Total allocated dispersion penalty*
			1.79	*M*	*Unallocated margin ($\geq$ 0, hopefully)*
VMA_{SX}	61				*Sensitivity adjusted for crosstalk*
σ_X		**2.7**			*Crosstalk (RMS)*
			1.96	P_{BT4}	*Matched filter vs. Bessel filter*
VMA_{MFB}	49				*Matched filter bound sensitivity*
VMA_S	48				*Rx nominal sensitivity*
		3.4			*Electronics noise and slicer uncertainty*
0					
Q_0 =	7.03	for BER 1.0E-12			*Target signal-to-noise ratio*

LSI

Scenario 3 – High loss channel: Jitter budget

[mUI]

	NC-DDJ (pk-pk)	BUJ (pk-pk)	RJ (pk-pk)	RJ (RMS)	UJ (RMS)	TJ (pk-pk)	*Comments*
ε_T		35	140	10	**20**		*Tx output jitter*
	330						*Tx waveform and dispersion*
	90						*Insertion loss deviation*
				9			*Crosstalk*
ε_R							
		200	140	10			*Rx clock and data recovery*
Total	420	235	235	17		890	*Total jitter ($\leq$ 1 UI, hopefully)*
						960	*What if RJ = UJ (e.g. BUJ = 0)?*

Modifications to the TWDP methodology

- Enhancements introduced in T11/07-344v0, e.g. spectral line timing recovery and horizontal eye opening evaluation (NC-DDJ) [3]
- Electrical stressors described by the transmitter compliance transfer functions
- Assignment of an independent TWDP limit for each stressor
- Assignment of an independent P_{ALLOC} value for each stressor
- Adjustment of P_{ALLOC} based on the calculated VMA
- Electrical signals vs. optical signals, e.g. dB calculated as $20\log_{10}(x)$ as opposed to $10\log_{10}(x)$
- Anti-aliasing filter bandwidth scaled to 75% of the signaling speed in contrast to the static 7.5 GHz bandwidth in the current version
- It is expected that transmitter emphasis (pre-cursor and post-cursor) will be necessary to satisfy the requirements
  - For each stressor, the corresponding TWDP limit shall be satisfied for at least one equalization setting of the transmitter device under test

Beta T and Epsilon T – signal requirements

- Section 9.3.1, modify Table 26 as shown...

		Units	**...**	**800-DF-EA-S**
Beta T Point				
Rise / Fall Time 20-80% Notes 6, 9	Max	ps	...	N/A
	Min	ps	...	40
Epsilon T Point				
Rise / Fall Time 20-80% Notes 6, 9	Max	ps	...	N/A
	Min	ps	...	40

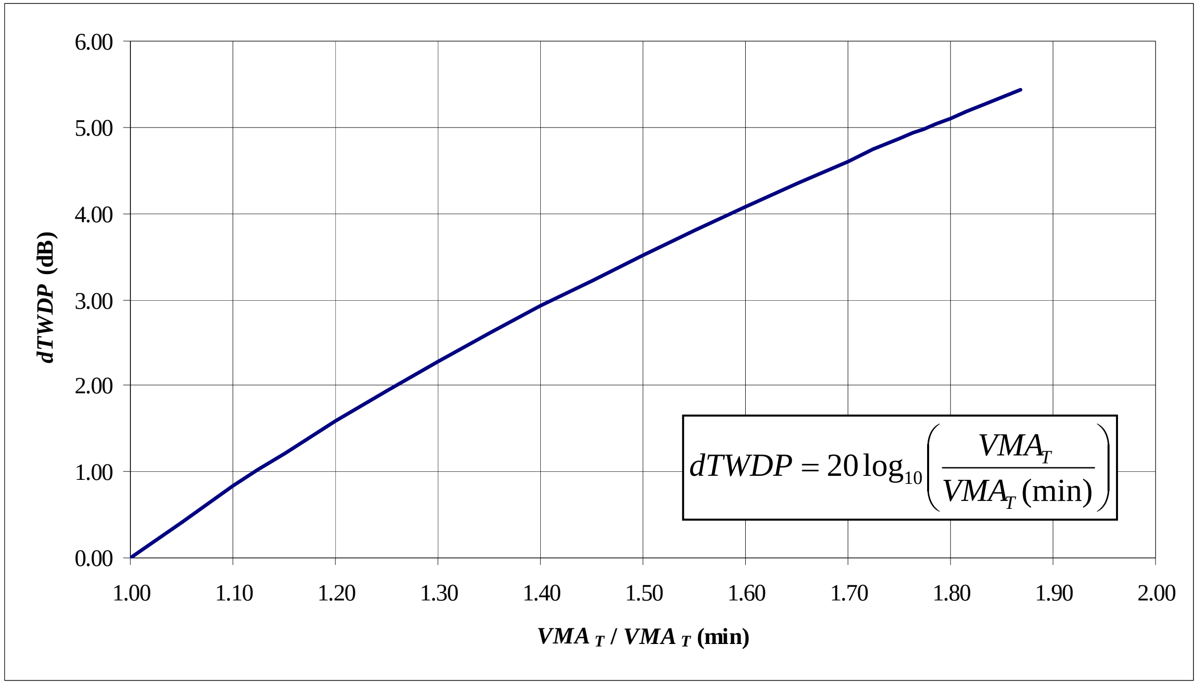
Beta T and Epsilon T – signal requirements

- Section 9.6, add Table XX - Signal requirements at Epsilon T for 800-DF-EA-S variants

		Units	Beta T Point		Epsilon T Point		
			TCTF index		TCTF index		
			1	2	1	2	3
Peak-to-peak differential output voltage	Max	mV	1200		1200		
VMA (note 1)	Max	mV	1000		1000		
	Min	mV	665		665	665	535
UJ, RMS (note 2)	Max	UI	0.020		0.020		
P_{ALLOC} (note 3)	–	dBe	18.6		18.6	18.6	20.7
TWDP (note 3)	Max	dBe	7.1	10.5	7.1	10.5	15.4
NC-DDJ (note 3)	Max	UI	0.110	0.150	0.110	0.150	0.330

Notes:
1 Voltage modulation amplitude is measured using the procedure described in annex A.x.
2 Uncorrelated jitter is measured using the procedure described in annex A.y.
3 TWDP and NC-DDJ are measured using the procedure described in annex A.z and defined using a reference receiver with 1 feed-forward and 3 feedback taps.

Trade-off between TWDP and VMA_T



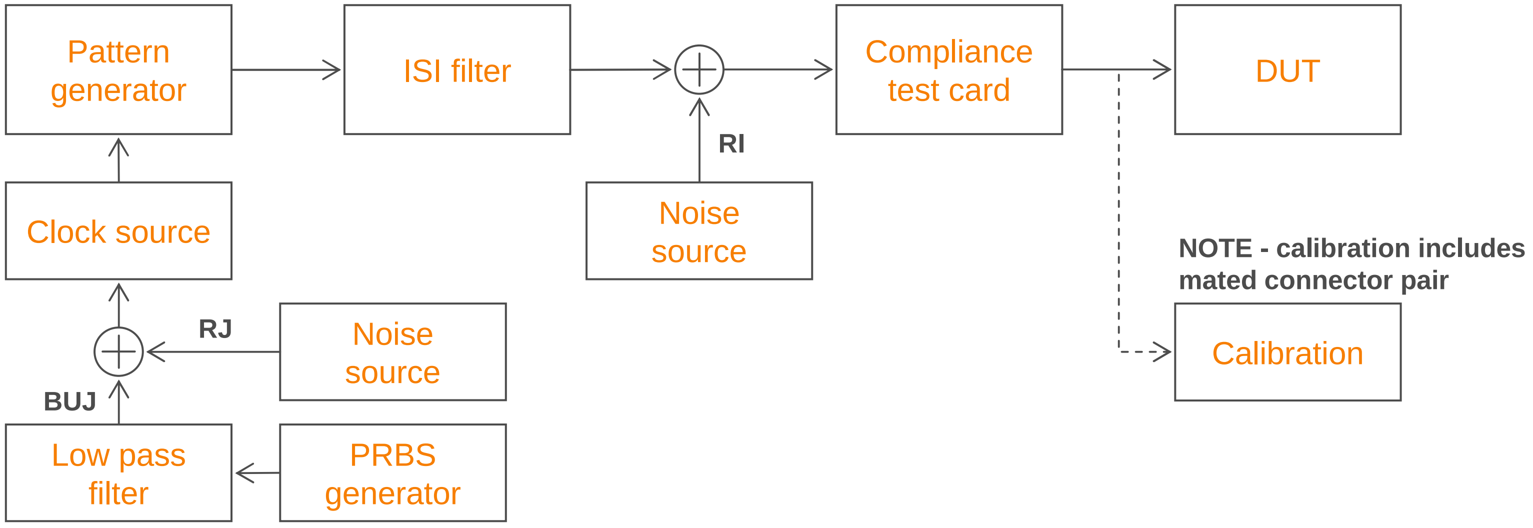
- Since the noise environment is not a function of VMA_T, VMA_T in excess of the minimum results in a larger P_{ALLOC}
  - An increase in P_{ALLOC} implies an increase in the permissible TWDP
- Given the measured (estimated) VMA_T, P_{ALLOC} may be adjusted in the TWDP test script, and the TWDP result compared to a limit adjusted by the function shown above

Beta R and Epsilon R – jitter tracking

- Section 9.4.1, modify table 30 as shown...

		Units	...	800-DF-EA-S
Beta R Point				
Rx jitter tracking test, VMA (note 6)	Max	mV	...	300
Rx jitter tracking test, jitter freq. and pk-pk amplitude (note 6)		(kHz, UI)	...	(510, 1) (100, 5)
Epsilon R Point				
Rx jitter tracking test, VMA (note 6)	Max	mV	...	300
Rx jitter tracking test, jitter freq. and pk-pk amplitude (note 6)		(kHz, UI)	...	(510, 1) (100, 5)

Beta R and Epsilon R – signal tolerance



- The ISI filter shall be constructed in such a way that it accurately represents the insertion loss and group delay characteristics of differential traces on an FR-4 printed circuit board
- Random interference (RI), formerly bounded uncorrelated interference (BUI) is added to emulate the Gaussian amplitude distribution observed from crosstalk analysis
- Block diagram intended for illustrative purposes and other implementations possible

Random interference (RI)

- Defined to be broadband additive noise
- Power spectral density shall be flat to within ±3 dB from 100 MHz to 4.25 GHz
- Power spectral density shall have a 3 dB bandwidth of 4.25 GHz
- Specified in terms of the peak-to-peak voltage applied to Epsilon R point, with includes all but 10^{-12} of the amplitude population

Beta R and Epsilon R – signal tolerance requirements

- Section 9.6, add Table YY - Signal requirements at Epsilon R for 800-DF-EA-S variants

	Units	Beta R Point		Epsilon R Point		
		Test index		Test index		
		1	2	1	2	3
VMA (note 1)	mV	540	470	540	470	300
BUJ (note 2)	UI	0.035		0.035		
RJ, peak-to-peak (note 2)	UI	0.140		0.140		
RI, peak-to-peak (note 3)	mV	187	109	187	109	50
P_{ALLOC} (note 4)	dBe	16.8	15.7	16.8	15.7	15.7
WDP (note 4)	dBe	7.1	10.5	7.1	10.5	15.4
NC-DDJ (note 4)	UI	0.110	0.150	0.110	0.150	0.330

Notes:
1 Voltage modulation amplitude is measured at the input to the receiver device under test using the procedure defined in annex A.x.
2 Bound uncorrelated jitter (BUJ) and random jitter (RJ) are measured at the input to the ISI filter per the procedure defined in annex A.y. Peak-to-peak RJ includes all but 1E-12 of the amplitude population.
3 Random interference (RI) is applied at the receiver device input per the signal tolerance procedure defined in annex A.z. Peak-to-peak RI includes all but 1E-12 of the amplitude population.
4 WDP and NC-DDJ are measured using the procedure described in annex A.z and defined using a reference receiver with 1 feed-forward and 3 feedback taps.

Conclusions

- Loss and jitter budgets close for each scenario with significant margin
  - Budgets linked through P_{UJ} and “enhanced” TWDP via NC-DDJ
- A portion of this margin will be consumed by the enhancement of ILD caused by the imperfect terminations presented by the transmitter and receiver devices
  - An effect not explicitly included in this study due to time constraints

Future work

- Channel requirements not included, but implied by the TCTF, following the example provided by legacy Beta point specifications
  - However, guidelines on how to verify that a channel has P_{ILD} within the link budget, insertion loss vs. crosstalk trade-offs, etc. may be useful

References

1. Koenen, "Channel Model Requirements for Ethernet Backplanes in Blade Servers", May 2004
   http://ieee802.org/3/ap/public/may04/koenen_01_0504.pdf
2. Wallace et al., "Epsilon Point Document", T11/07-312v1, April 2007
3. Healey and Marlett, "Enhancing WDP", T11/07-344v0, April 2007