Receiver testing for PHYs based on 10GBASE-KR

Adam Healey
LSI Corporation

Richard Mellitz
Intel

John D'Ambrosia
Force10 Networks

IEEE P802.3ba Task Force Meeting
Dallas, TX
November 2008

Motivation

- Clauses 84 and 85 define multi-lane PMD sub-layers that seek to have commonality with Clause 72 (10GBASE-KR)
- In IEEE P802.3ba/Draft 1.0, both Clauses 84 and 85 reference Clause 72 receiver requirements, including the receiver interference tolerance test (72.7.2.1)
- The test methodology is defined in Annex 69A and applies to a single 10GBASE-KR receiver tested in isolation
- It is unclear how this methodology should be applied to the multi-lane PMD sub-layers in question
- Concepts may apply to XLAUI, CAUI, and PPI but these interfaces are not considered in this presentation

Citations

- 84.8.2.1 Receiver interference tolerance
  - The receiver interference tolerance tests are the same as those described for 10GBASE-KR in 72.7.2.1 and Annex 69A.

- 85.8.4 Receiver characteristics
  - Receiver characteristics are summarized in Table 85–5 and as detailed in 72.7.2.1 through 72.7.2.5 with the exception of the receiver characteristics specified in 85.8.4.1, 85.8.4.2, and 85.8.4.3.

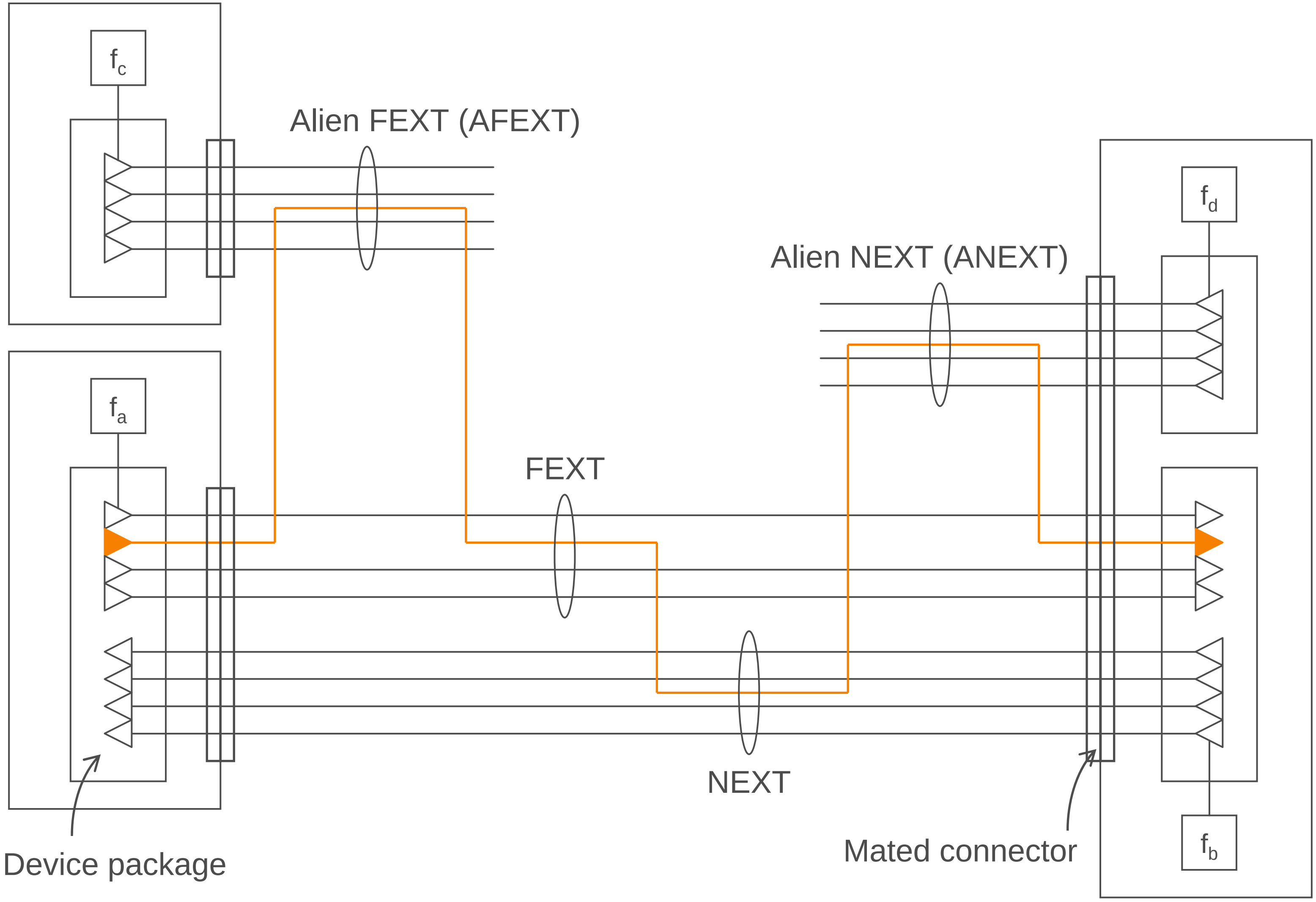
- 85.8.4.1 Bit error ratio
  - The receiver shall operate with a BER 10^{-12} or better when receiving a compliant transmit signal, as defined in 85.8.3, through a compliant cable assembly as defined in 85.9 exhibiting the maximum insertion loss of 85.9.2.

Topics

- Multi-lane PMD sub-layer observations
- Review of 10GBASE-KR interference tolerance
- Applicability to Clauses 84 and 85
- Additional crosstalk considerations

Multi-lane PMD sub-layer observations

Illustration of the sources of coupled noise



Crosstalk assumptions

- Aggressors are not correlated to the victim or each other and crosstalk combines in terms of a power sum
- Aggressors are not synchronous to the victim or each other
- FEXT aggressor and victim transmitter characteristics, such as output voltage and transition time, match within some constraint
- NEXT aggressors all exhibit worst-case characteristics
- ANEXT and AFEXT aggressors, when present, also exhibit worst-case characteristics
- Alien crosstalk is not significant for a shielded copper cable assembly

Review of 10GBASE-KR interference tolerance

10GBASE-KR interference tolerance test setup

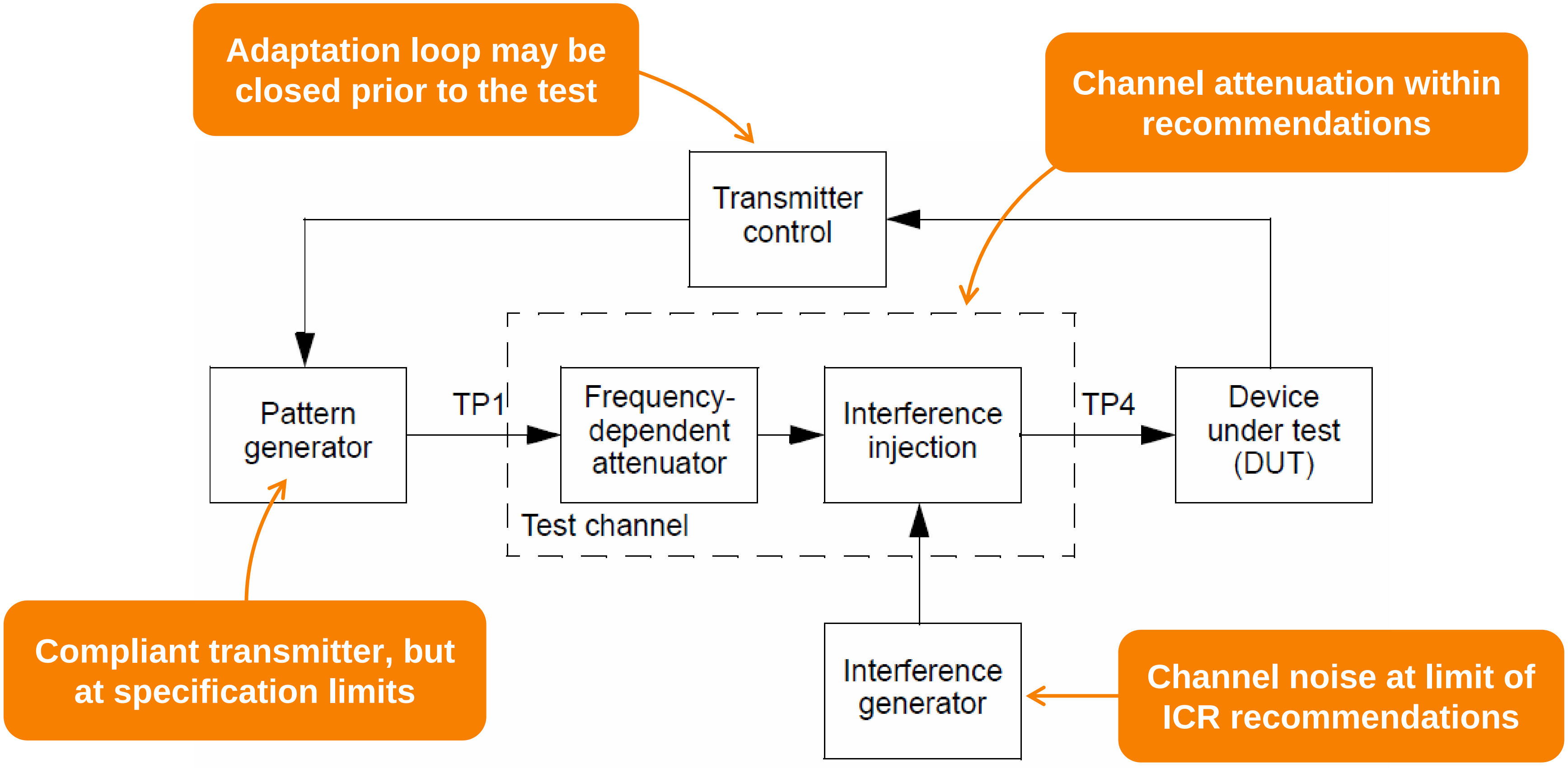


Figure 69A–1—Interference tolerance test setup

General assumptions

- Test channel insertion loss is $IL_{TC}(f)$
- Test channel return loss is better than 20 dB
- $PSXT(f) = ICR_{min}(f) + IL_{TC}(f)$
- Worst-case attenuation and noise within channel recommendations
- 3 dB margin required for reflective losses not included in test channel
- Two test cases are defined to ensure the implementation can tolerate reasonable mixtures of loss and noise permitted by the $ICR_{min}(f)$

Transmitter assumptions

- Peak-to-peak differential output voltage is the smallest compliant value
- Transition time is the largest compliant value
- Duty cycle distortion (DCD) is the largest compliant value
- Deterministic jitter (DJ) is the largest compliant value less DCD and is modeled as sinusoidal jitter (SJ) at no less than 1/250 of the signaling speed
- Random jitter (RJ) is the largest compliant total jitter (TJ) less SJ and DCD

Noise assumptions

- All crosstalk aggressors are considered alien
- All aggressors are compliant to the 10GBASE-KR standard
- Aggressors are not synchronous or correlated to the victim
- Aggressor peak-to-peak differential output voltage is the largest compliant value
- Aggressor transition time is the smallest compliant value
- Crest factor (peak-to-RMS ratio) does not exceed 5

10GBASE-KR noise equations

Equation	Description
$H(f) = \exp\left(-\frac{1}{2}\left(\frac{2\pi f T_r}{1.6832}\right)^2\right)$	Gaussian filter with 20 to 80% transition time, T_r
$S_i(f) = V_{pk}^2 T \,\mathrm{sinc}^2(fT)\lvert H(f)\rvert^2$	Aggressor input power spectral density (PSD) with peak differential output voltage V_{pk} and unit interval T
$PSXT(f) = ICR_{min}(f) + IL_{TC}(f)$	Power sum crosstalk loss
$S_a(f) = S_i(f)10^{-PSXT(f)/10}$	Aggressor output PSD
$\sigma_a^2 = 2\int_0^{f_{max}} S_a(f)df$	Aggressor output variance
$\sigma_n = \sigma_a 10^{M/20}$	Amplitude of broadband noise (RMS)

10GBASE-KR noise calculations

Parameter	Test 1 value	Test 2 value	Units
Test channel insertion loss, $IL_{TC}(f)$	$A_{max}(f)$	$A_{max}(f)/2$	dB
Aggressor transition time	24	24	ps
Aggressor peak differential output voltage	600	600	mV
Margin for reflective loss	3	3	dB
Amplitude of broadband noise (RMS)	5.2	11.6	mV

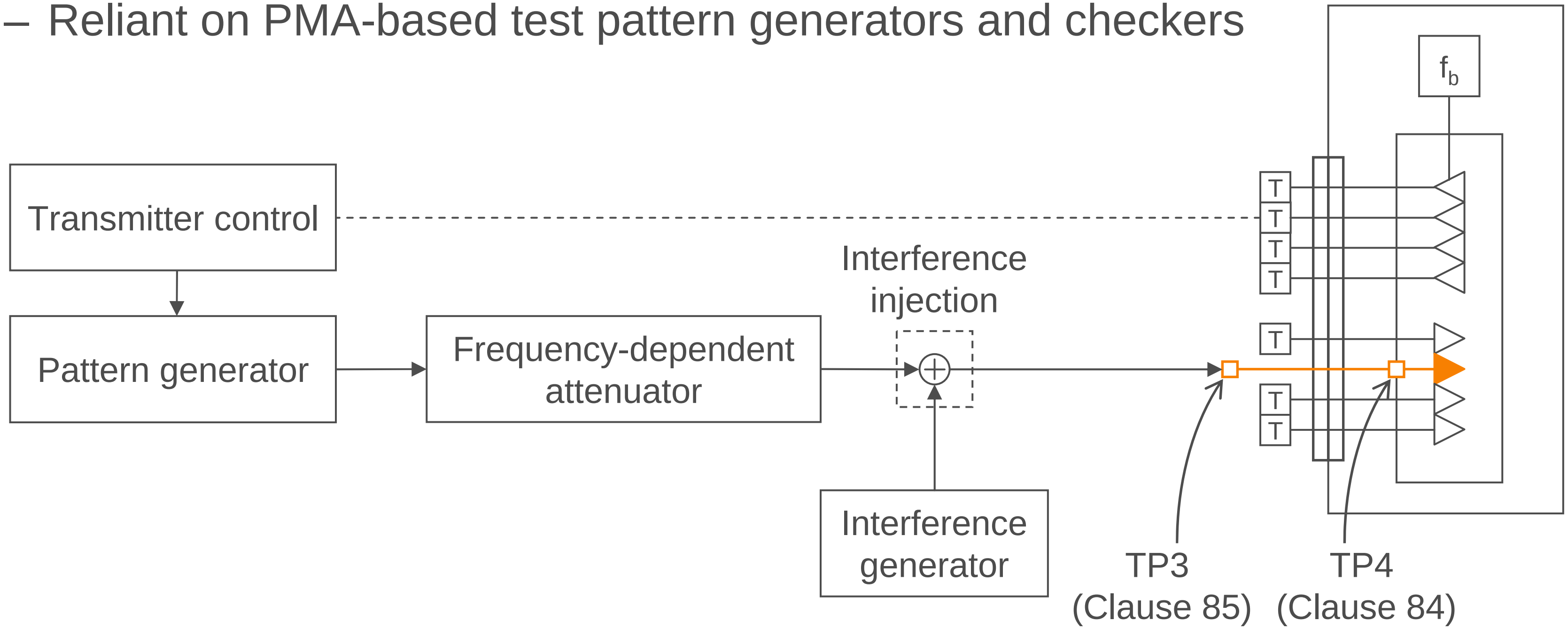
Applicability to Clauses 84 and 85

Approaches to receiver specification – 1

- Specify that the receiver shall operate at the target BER or better when connected to a compliant transmitter using a compliant channel
  - Convenient from the perspective of writing a specification
  - To ensure interoperability, the worst case must be examined as a member of the set of compliant transmitters and channels
  - Emulation of worst-case operating conditions is an exercise left to the user of the standard
  - Leads to inconsistency in verification methods, and therefore results

Approaches to receiver specification – 2

- Test each individual lane in isolation using the methodology defined in Annex 69A
  - Plus, define the state of unused lanes (e.g. terminated, transmitters active)
  - Captures impact of host and package NEXT, but not FEXT
  - Will not capture any interaction between the lanes resulting from the parallel operation of transmitter control loops
  - Reliant on PMA-based test pattern generators and checkers



Approaches to receiver specification – 3

- Define a test set-up that emulates the worst-case multi-lane transmitter and channel

- Could be an N-fold replication of the test set-up defined in Annex 69A
  – Burdensome N-fold replication of test equipment
  – Additional test coverage limited to host and package FEXT

- N instances of test channel and interference generator may be avoided if a new multi-lane test channel could be designed with the worst-case insertion loss on each lane and worst-case crosstalk coupling between lanes
  – It is not clear that this even feasible
  – If feasible, then the concern shifts to availability from a broad set of suppliers
  – There is still the need to emulate a worst-case transmitter
  – It is not clear how to guarantee margin for reflective losses or alien crosstalk

Additional considerations for Clause 85

- If the transmitter requirements apply at TP2, must loosen requirements to account for Tx_PCB, mated connector, and test fixture insertion loss between TP1 and TP2
  - Adjust emulation of worst-case transmitter accordingly
- If the receiver requirements apply at TP3, the test channel should be based on the cable assembly attenuation and not channel attenuation
  - Do not double count Rx_PCB insertion loss
  - Perhaps remove the insertion loss of one mated connector as well
  - Define new $IL_{TC}(f)$ equation(s) for Clause 85
- Adjust $ICR_{min}(f)$ for the TP2 to TP3 span
- Broadband noise amplitude may then be calculated using 10GBASE-KR formulae

Additional crosstalk considerations

Treatment of FEXT for the multi-lane case

- If individual limits were applied to the various crosstalk components…
- …and matching requirements were imposed on the transmitters in the N-lane interface…
- …some degree of pessimism could be removed from the broadband noise calculation
- Consider the example where the power-sum FEXT loss is $10\log_{10}(a)$ dB down from the power-sum crosstalk loss, PSXT(f)

Revised noise analysis

Equation	Description
$H_m(f) = \exp\left(-\frac{1}{2}\left(\frac{2\pi f T_r}{1.6832}\right)^2\right)$	Gaussian filter with 20 to 80% transition time, T_m
$S_m(f) = V_m^2 T \operatorname{sinc}^2(fT)\left\|H_m(f)\right\|^2$	Aggressor input power spectral density (PSD) with peak differential output voltage V_m and unit interval T
$PSFEXT(f) = PSXT(f) - 10\log_{10}(a)$	Far-end crosstalk loss
$S_c(f) = (1-a)\,S_i(f) + a\,S_m(f)$	Composite aggressor input PSD
$S_a(f) = S_c(f)10^{-PSXT(f)/10}$	Effective aggressor output PSD

Calculation example

Parameter	Test 1 value	Test 2 value	Units
Test channel insertion loss, $IL_{TC}(f)$	$A_{max}(f)$	$A_{max}(f)/2$	dB
$10 \log_{10}(a)$	6	6	dB
FEXT aggressor transition time[1]	41	41	ps
FEXT aggressor peak differential output voltage[1]	460	460	mV
Aggressor transition time	24	24	ps
Aggressor peak differential output voltage	600	600	mV
Margin for reflective loss	3	3	dB
Amplitude of broadband noise (RMS)	4.9	10.8	mV

[1] Assume approximately 15% spread in transmitter characteristics across the N lanes

Recommendations

- Test each individual lane in isolation using the methodology defined in Annex 69A
  - Plus, define the state of unused lanes (e.g. terminated, transmitters active)
- Adjust transmitter, $IL_{TC}(f)$, and $ICR_{min}(f)$ parameters in Clause 85 to account for the specification of receiver parameters at TP3
- Consider separate limits for PSNEXT and alien crosstalk (if applicable) in addition to ICR
  - PSFEXT contribution may be derived from these parameters
- Consider matching requirements for the multi-lane transmitter
- Recalculate equivalent broadband noise for the interference tolerance test considering the new requirements