Comment #147, #169: Problems of high DFE coefficients

Yasuo Hidaka
Fujitsu Laboratories of America, Inc.

September 16-18, 2015

Comment #147

Cl **110** *SC* **110.10.7** *P* **154** *L* **21** **#** 147

Hidaka, Yasuo Fujitsu Lab. of Americ

Comment Type **TR** *Comment Status* **X**

bmax(n) is specified as 0.5 for CA-N.
This is to prevent error propagation caused by DFE.

However, a burst error does not matter for CA-N, because FEC is not used. Once there is an error, no matter whether a single-bit error or a burst error, the entire frame is dropped by a check sum error.

SuggestedRemedy

Change bmax(n) value for CA-N to 1.

Proposed Response *Response Status* **O**

Comment #169

Cl **110** *SC* **110.10.7** *P* **154** *L* **21** **#** 169

Dudek, Mike QLogic

Comment Type **TR** *Comment Status* **X**

It has been shown in sun_061015_25GE_adhoc that with the existing COM parameters and coding the mean time to false packet acceptance in the no-fec case can be shorter than the age of the universe. It has also been shown that changing bmax to 0.35 will solve this issue and will not significantly alter the worst case COM (test case 2)

SuggestedRemedy

Change bmax to 0.35 in the CA-N column of table 110-10
Also change bmax to 0.35 in table 110-7.

Proposed Response *Response Status* **O**

Abstract

- I was too optimistic in comment #147, because if we allow high DFE coefficients, we cannot meet MTTFPA (Mean Time to False Packet Acceptance) requirements at BER=1E-12 due to burst errors
  - Hence, bmax is proposed to change from 0.5 to 0.35 (comment #169)

- However, there are still serious problems with bmax = 0.35 or 0.5
  - Problem 1: COM is not accurate when bmax < 1
    - Current COM should not be used with bmax < 1
      - This may be fixed later
  - Problem 2: BER (and COM) can be drastically degraded when bmax is 0.35 or 0.5
    - Good channels can be rejected, if bmax is 0.5 or 0.35

- We have two other options to satisfy the MTTFPA requirement:
  - Option 1:
    - Revise COM criteria so that we get BER<1E-15, if we pass COM test with DER0=1E-12
    - Test Rx for BER<1E-15 with no restriction on DFE coefficients
  - Option 2:
    - Use precoding to *eliminate* burst errors due to DFE error propagation

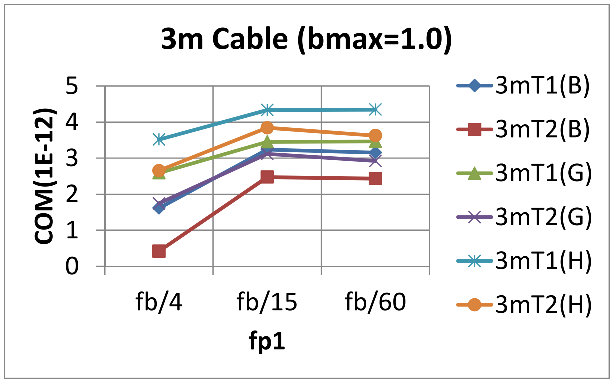
Study of bmax Effect on COM and BER

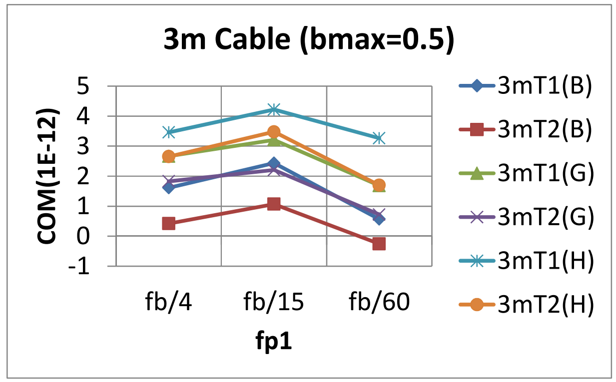
- bmax(n)
  - 1.00, 0.50, 0.35 (for all n)
- CTLE
  - fp1: fb/4, fb/15, fb/60
  - fz: same as fp1
  - DC gain:
    - min -12dB, max 0dB, step 1dB when fp1 = fb/4 or fb/15
    - min -8dB, max 0dB, step 0.5dB when fp1 = fb/60
- Channel data
  - 3m cable: B(30Q4) – fair, G(26QQ) – typical, H(26Q4) – good
  - 5m cable: Q(24QQ) – fair, N(26QQ) – typical, R(24QQ) – good
- Test conditions
  - Test 1 (PKG trace = 12mm) and Test 2 (PKG trace = 30mm)
  - DER0 = 1E-12
- Equalizer parameters: optimized by reference COM code (i.e. http://www.ieee802.org/3/bj/public/tools/ran_com_3bj_3bm_01_1114.zip)
- BER and Eye: analyzed by in-house tool
  - Parameters of statistical analysis (unless otherwise noted):
    - TX RJ = 0.01UI (rms), TX DJ = 0.15UI (δ-δ), TX EOJ = 0.035UI (p-p)
    - RX RJ = 0.005UI (rms), RX DJ = 0.075UI (δ-δ), RX EOJ = 0.0175UI (p-p)
    - TX output noise SNR_{TX} = 27 (dB)
    - RX input noise η_0 = 5.20E-8 (V^2/GHz)
    - Receiver 3dB bandwidth = 0.75 (fb)

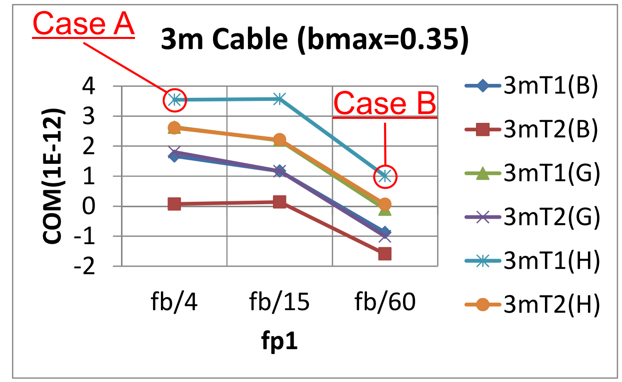
Effect of fp1 on COM and BER for 3m Cable

FUJITSU

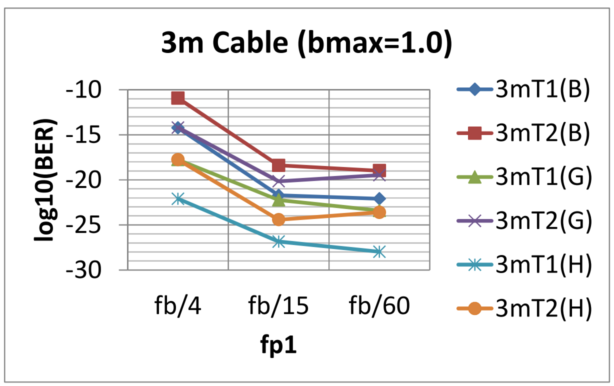
fp1 vs COM (DER0=1E-12)

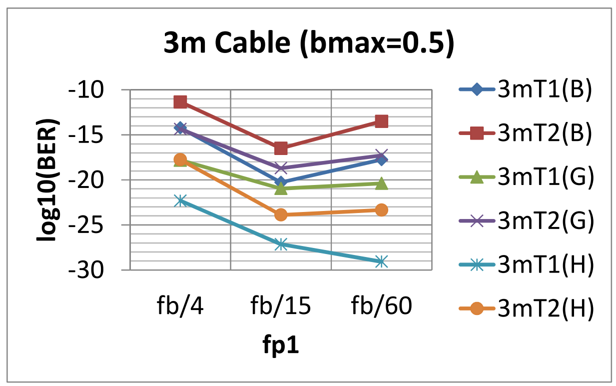


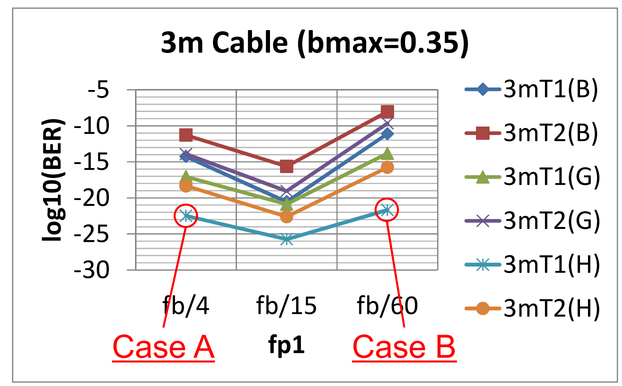




fp1 vs BER





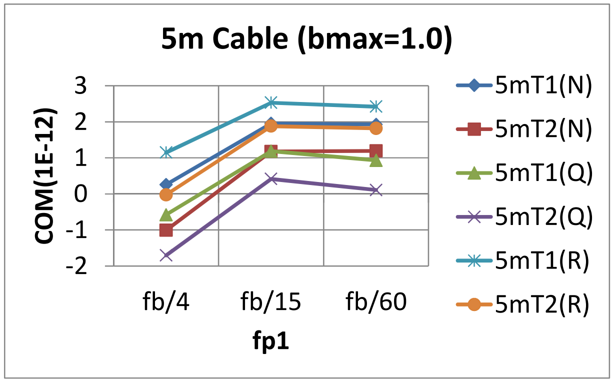


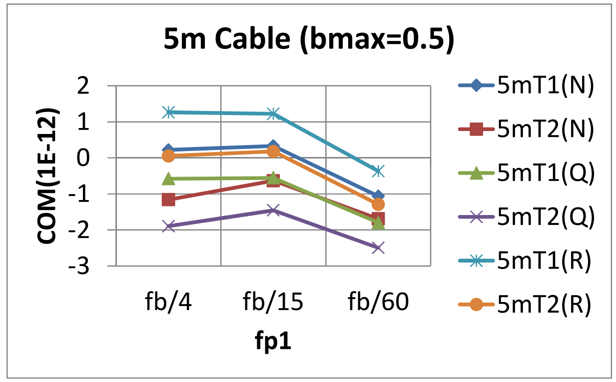
- COM and BER are roughly consistent when bmax=1.0
- COM and BER are very inconsistent when bmax=0.5 or 0.35
  - Although BER is improved or same, COM is often largely degraded

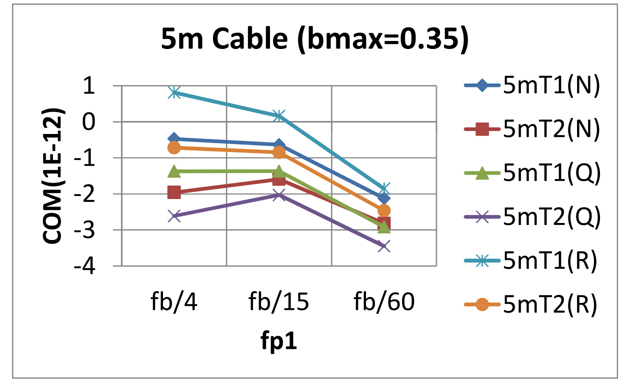
Effect of fp1 on COM and BER for 5m Cable

FUJITSU

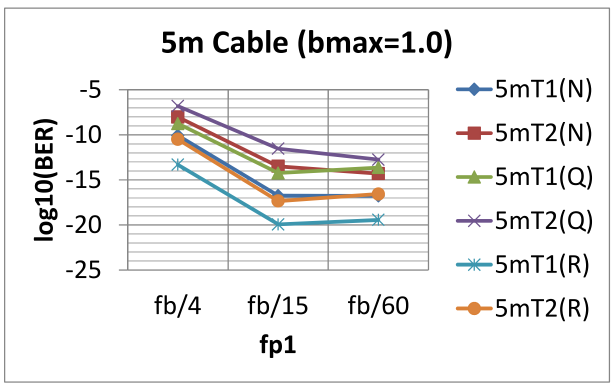
fp1 vs COM (DER0=1E-12)

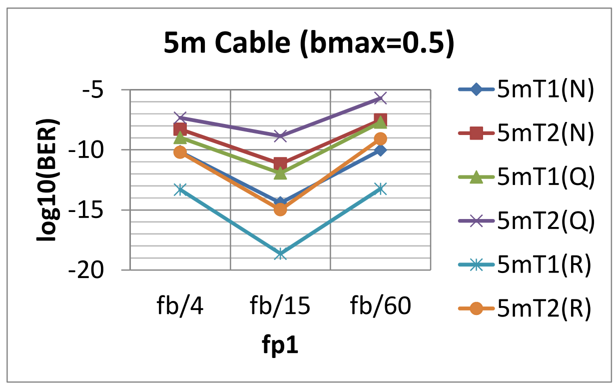


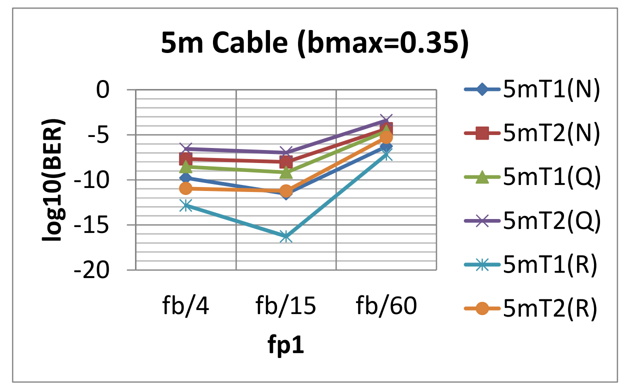




fp1 vs BER



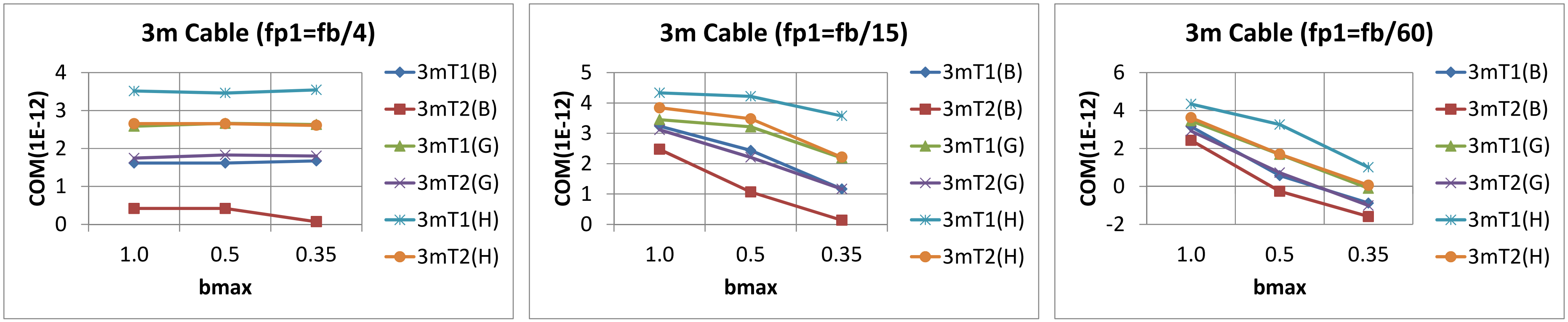




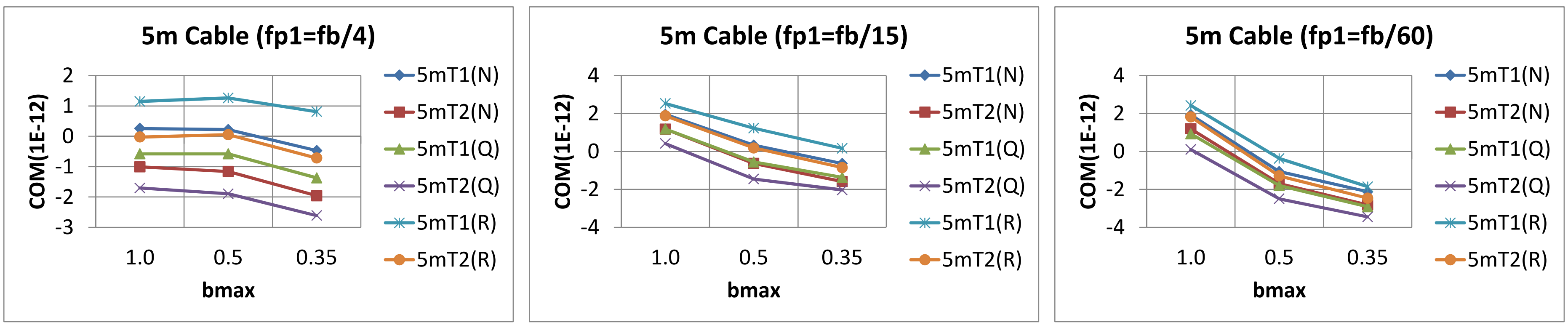
- COM and BER are roughly consistent when bmax=1.0
- COM and BER are very inconsistent when bmax=0.5 or 0.35
    - Although BER is improved or same, COM is often largely degraded

Effect of bmax on COM

- bmax vs COM (3m Cable)



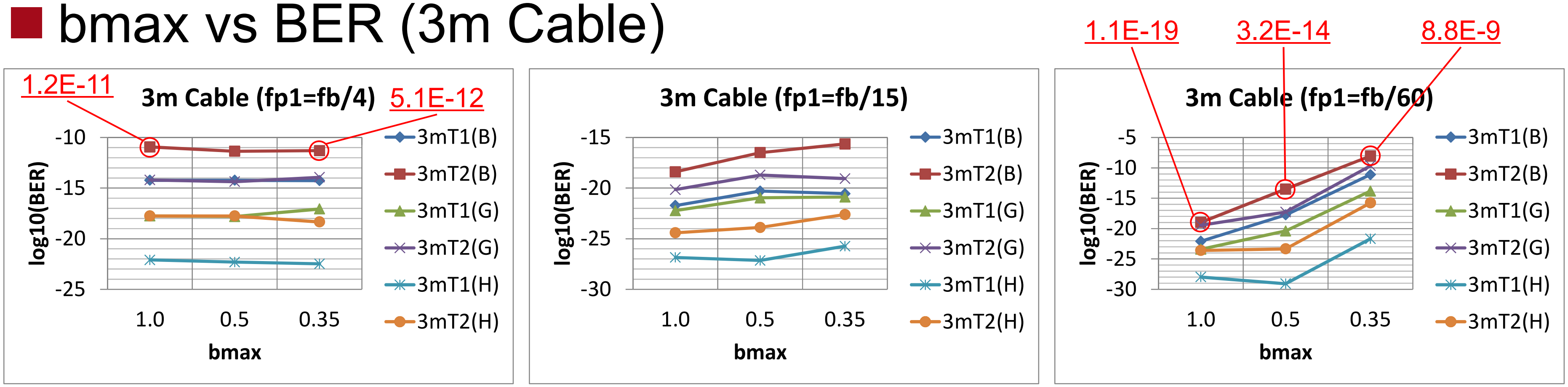
- bmax vs COM (5m Cable)



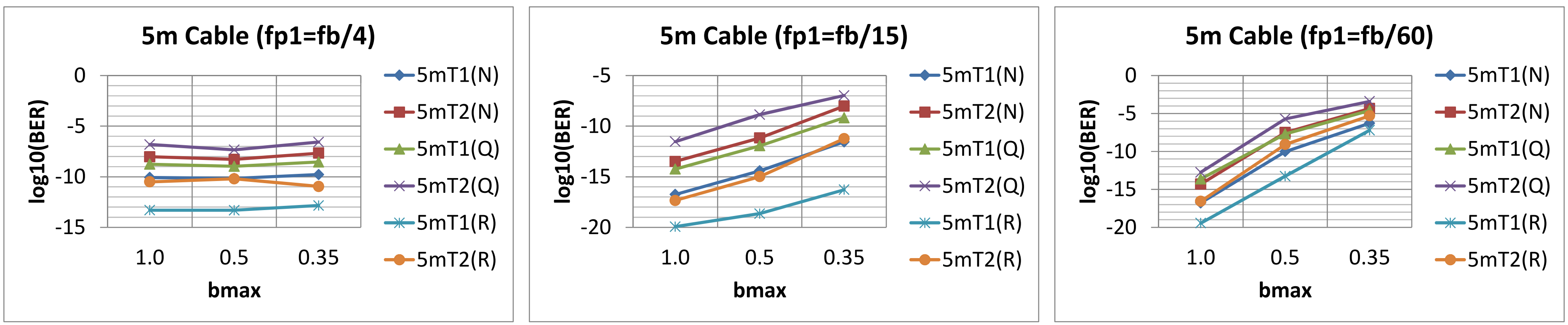
- COM is not much affected by bmax < 1 when fp1 = fb/4
- COM is largely degraded by bmax < 1 when fp1=fb/15 or fb/60

Effect of bmax on BER

■ bmax vs BER (3m Cable)



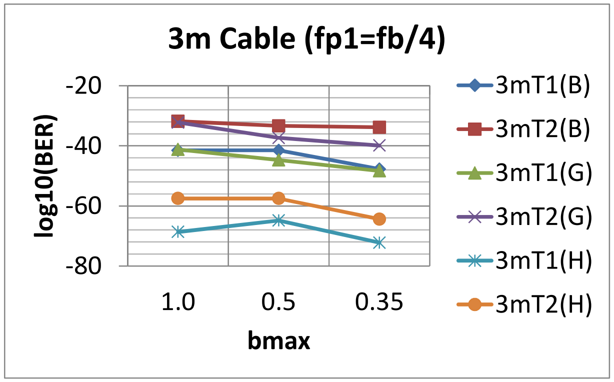
■ bmax vs BER (5m Cable)

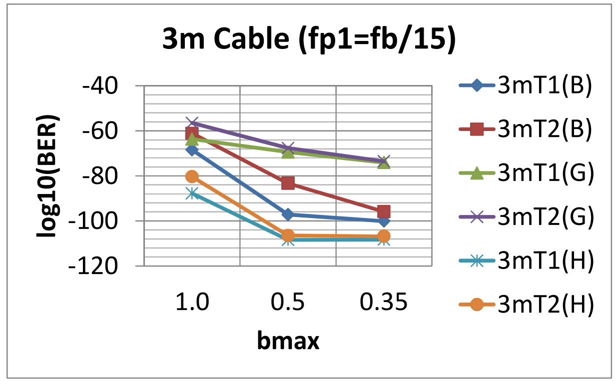


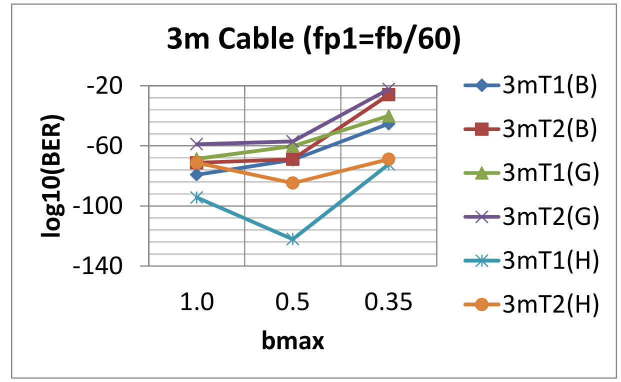
- ■ BER is not much affected by bmax < 1 when fp1 = fb/4
- ■ BER is often degraded by bmax < 1 when fp1 = fb/15 or fb/60
  - ■ 3m T2(B) is thought good, but fails for test with fp1=fb/4 or bmax=0.35

Effect of bmax on BER in Low-Noise Condition

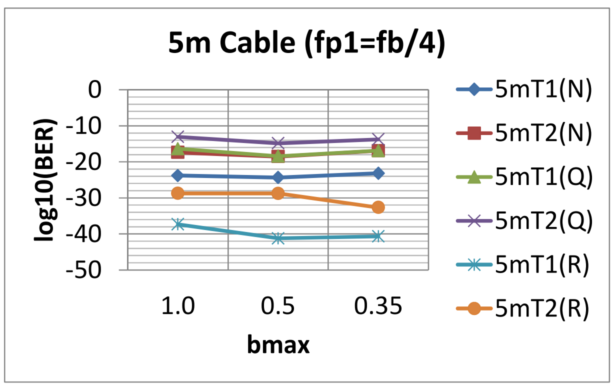
bmax vs BER (3m Cable)

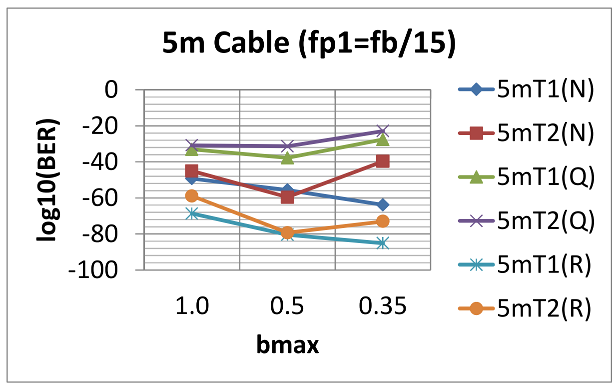


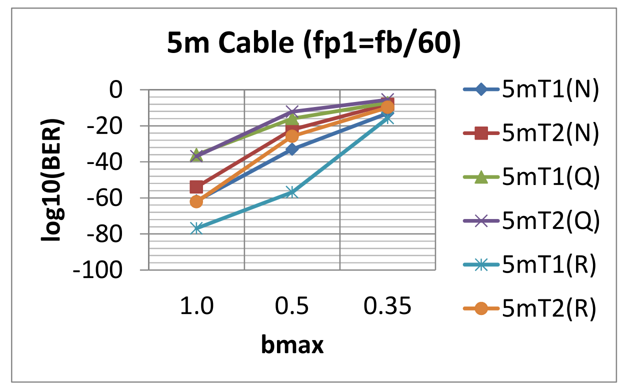




bmax vs BER (5m Cable)



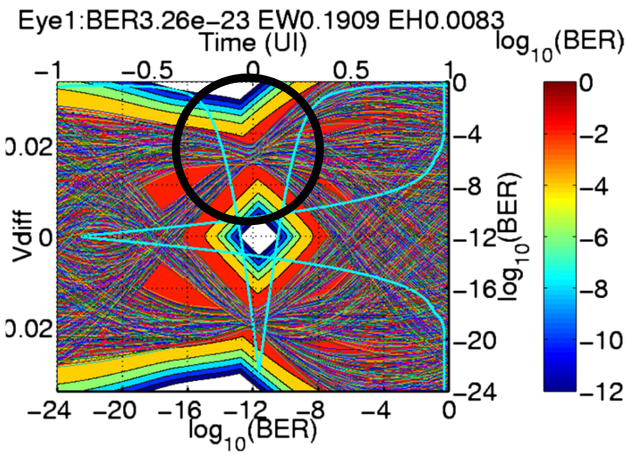


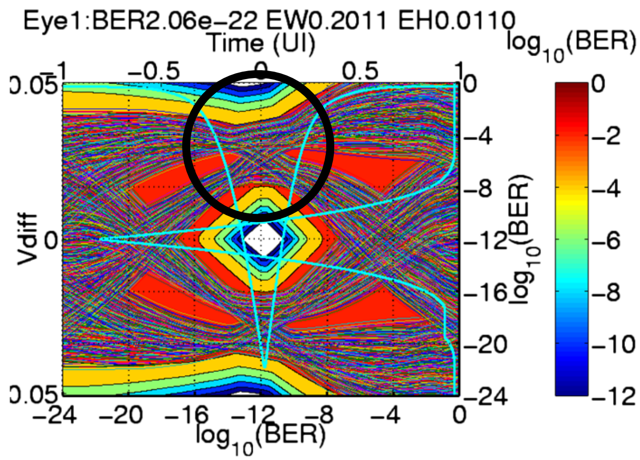


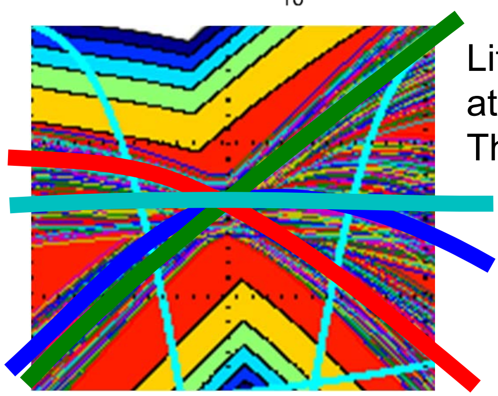
- This is simulated without Tx output noise or Rx input noise
- BER is often improved by bmax < 1 in this low-noise condition
  - However, this ultra low-noise condition is not realistic

Detail Analysis of Case A and Case B

- Channel: 3m cable H(26Q4), Test 1, bmax=0.35
- Case A (fp1=fb/4)
  - DCgain = -12 dB, b(1) = 0.337389 (not restricted)
  - COM (DER0=1E-12)
    - 3.5463 dB (reference implementation)
    - 3.71644 dB (our implementation)
  - BER = 3.26E-23
- Case B (fp1=fb/60)
  - DCgain = -6.5 dB, b(1) = 0.35 (restricted by bmax)
  - COM (DER0=1E-12)
    - 1.0056 dB (reference implementation)
    - 1.37456 dB (our implementation)
  - BER = 2.06E-22

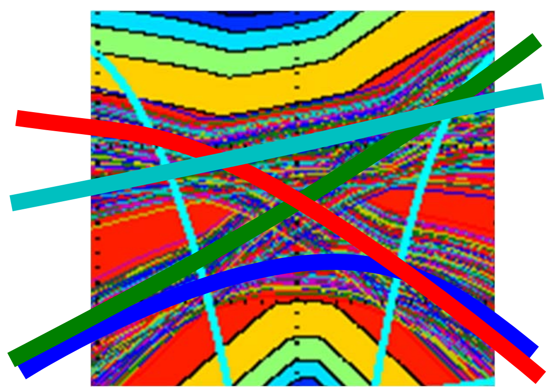






Little data dependence at the best phase.
This is OK.

- 0-1-0 (blue)
- 0-1-1 (green)
- 1-1-0 (red)
- 1-1-1 (cyan)



Large data dependence at the best phase.
This causes the problem.

Two Options to Solve the MTTFPA issue

- Option 1
  - Use precoding to *eliminate* burst errors due to DFE error propagation
- Option 2
  - Revise COM criteria to have channel good enough to meet BER < 1E-15
  - Test Rx for BER<1E-15 with no restrictions on DFE coefficients

Precoding (review)

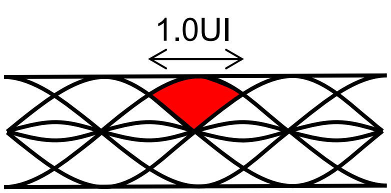
FUJITSU

- Tx: encode the transmitting data sequence by b(k) = b(k-1) ^ a(k)
- Rx: decode the received data sequence by a'(k) = b(k) ^ b(k-1)

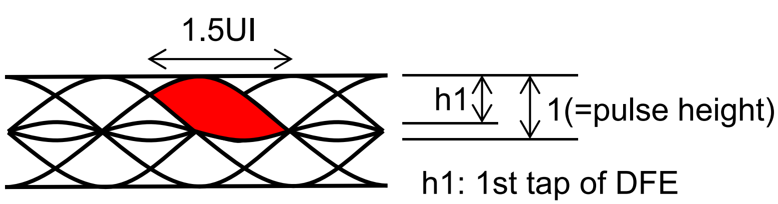
  a(k): original data sequence, b(k): transferred data sequence (NRZ),
  a'(k): recovered data sequence, ^ : exclusive-OR operator

- Any burst error on b(k) is converted to two errors on a'(k)
  - Burst error from b(k1) through b(k2) (k1<=k2) is converted to two errors, one error at a'(k1) and another error at a'(k2+1)
- Unlike Duobinary, we should not omit DFE in order to keep BER low
  - If we omit DFE, BER of a'(k) drastically goes up

Ideal eye of Duobinary w/o DFE:



Ideal eye of 1-tap DFE:



  - If we keep DFE, BER of b(k) is same as BER without precoding
  - Use precoding just to avoid burst errors on a'(k), not to avoid DFE

Minor Problems of Precoding

FUJITSU

- It increases latency
  - The extra latency is shorter than FEC latency
  - If extra latency is not acceptable, we can make use of precoding optional
    - Implementing encoder & decoder of precoding should be mandatory
- Error occurs always twice, even if error does not propagate
  - Detecting one error or two does not matter for FCS (frame check sum)
    - As long as an error is detected, the entire frame is dropped
- Precoding helps only if burst error is on consecutive bits
  - For high-loss channels, the most significant tap is always the first tap
    - Hence, burst error always occurs on consecutive bits
- If Rx does not have a DFE, unnecessary logic is required
  - It is OK for NRZ, because DFE is commonly used for NRZ

Summary

FUJITSU

- Change bmax to 1.0 in the following tables:
  - Table 110-10 COM parameter values
  - Table 110-7 interference tolerance test parameters, no FEC mode
  - Table 110-6 interference tolerance test parameters, BASE-R FEC mode

See slide 15 for change of text

- Take one of the following options for the MTTFPA issue:
  - Option 1
    - Add precoding as outlined in slide 12
    - Make no changes on target BER
  - Option 2
    - Reduce target BER as follows:
      - Meet BER < 1E-15 for no FEC mode
      - Meet BER < 1E-10 for BASE-R FEC mode
    - We may have to earn extra margin such as using LF-CTLE
    - See hidaka_3by_03_0915 for more detail

Change of Text (Revised Comment #147)

- Table 110-10 COM parameter values
  - Change values of $b_{max}(n)$ to 1 in columns of CA-N and CA-S
- Table 110-7 test parameters, no FEC mode
  - Change value of b_{max} used in COM calculation to 1
- Table 110-6 test parameters, BASE-R FEC mode
  - Change value of b_{max} used in COM calculation to 1

Appendix

Difference between COM and our BER analysis

FUJITSU

- COM
  - Directly calculate a single probability distribution (i.e. PDF or CDF)
  - Jitter is added at all ISI locations
- Our BER analysis
  - Calculate multiple (4 for NRZ, 32 for PAM4) probability distributions for all the combinations of prior, next, and cursor symbol levels
    - # of cursor symbol levels is half, because of vertical symmetry
    - Jitter is added differently for each distribution, taking account of each transition
      - Jitter at 010 is smaller than at 011 or 110, because derivative is cancelled and small
      - No jitter is added for distribution at 111 sequence, because there is no transition
  - Final CDF is the worst case that is the max value of multiple CDFs:

$$P_{worst}(y) = \frac{1}{2}\max_k[P_k(y)] = \frac{1}{2}\max_k\left[\int_{-\infty}^{y} p_k(y)dy\right]$$

    - Here, $P_{worst}(y)$ and $P_k(y)$ are CDFs and $p_k(y)$ are PDFs.
    - Coefficient $1/2$ is for the fact that this is only for lower side of the entire final CDF:

$$P_{final}(y) = \max[P_{worst}(y), P_{best}(y)] = \max\left[P_{worst}(y), \min_k[P_k(y)]\right]$$

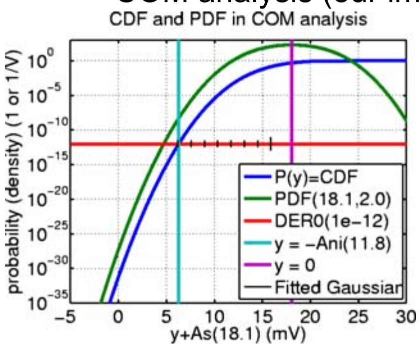
  - Jitter is not added at ISI locations other than before or after cursor
    - Due to this difference, estimated BER is a little lower than DER0 when COM is 0dB

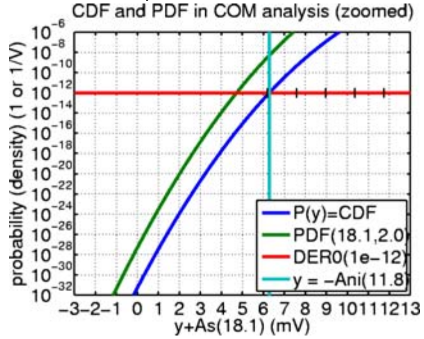
Very Detail Analysis of Case A and Case B

FUJITSU

Notation: PDF(μ,σ), μ=mean, σ=RMS

- Case A (fp1=fb/4)
  - COM analysis (our implementation)



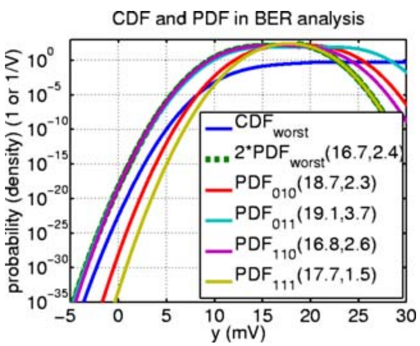


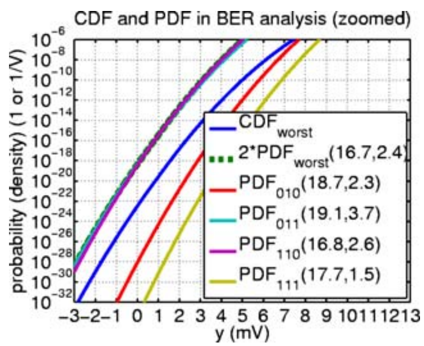
PDF: As=μ=18.1mV, σ=2.0mV, Ani=11.8mV~5.9σ

COM=20*log10(18.1mV/11.8mV)=3.72dB

BER=P(-As)=5.3E-32

  - BER analysis (vertical PDF/CDF at the best phase)



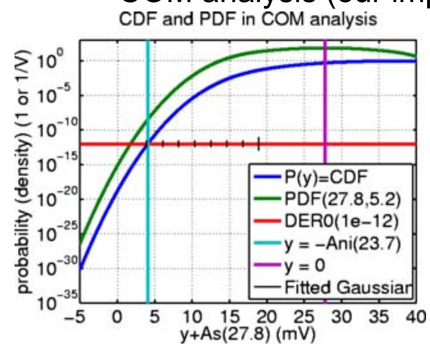


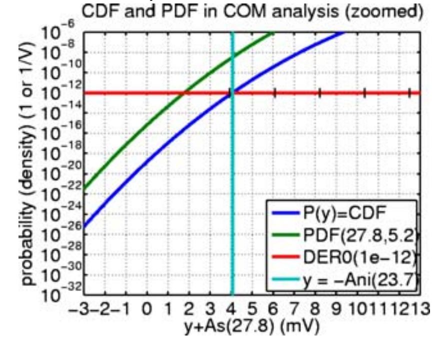
2*PDF_{worst} (μ=16.7,σ=2.4) follows PDF_{110} (μ=16.8,σ=2.6)

σ of PDF_{010} & PDF_{111} is smaller than PDF_{011} & PDF_{110}

μ is similar between PDFs with respect to σ value

- Case B (fp1=fb/60)
  - COM analysis (our implementation)





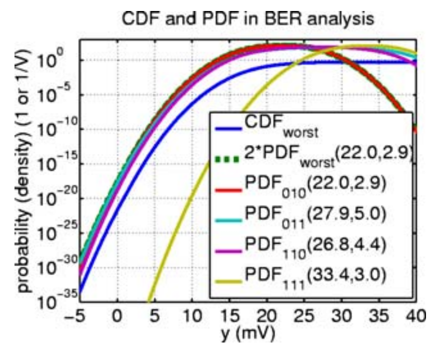
PDF: As=μ=27.8mV, σ=5.2mV, Ani=23.7mV~4.6σ

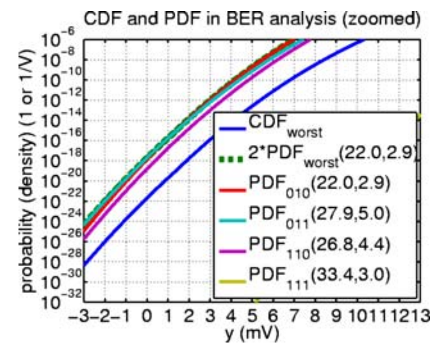
COM=20*log10(27.8mV/23.7mV)=1.38dB

BER=P(-As)=1.51E-19

σ and BER are much larger (COM is smaller) than Case A

  - BER analysis (vertical PDF/CDF at the best phase)





2*PDF_{worst} (μ=22.0,σ=2.9) follows PDF_{010} (μ=22.0,σ=2.9)

σ of PDF_{010} & PDF_{111} is smaller than PDF_{011} & PDF_{110}

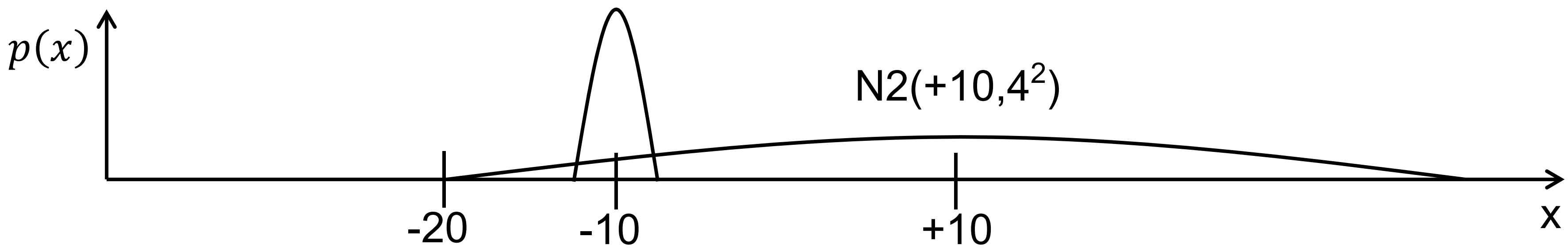
μ of PDF_{010} and PDF_{111} are quite different w.r.t. σ value

σ of 2*PDF_{worst} and BER are similar to Case A

Multiple Distribution vs Single Distribution

FUJITSU

- Multiple Distribution (two separate normal distributions)

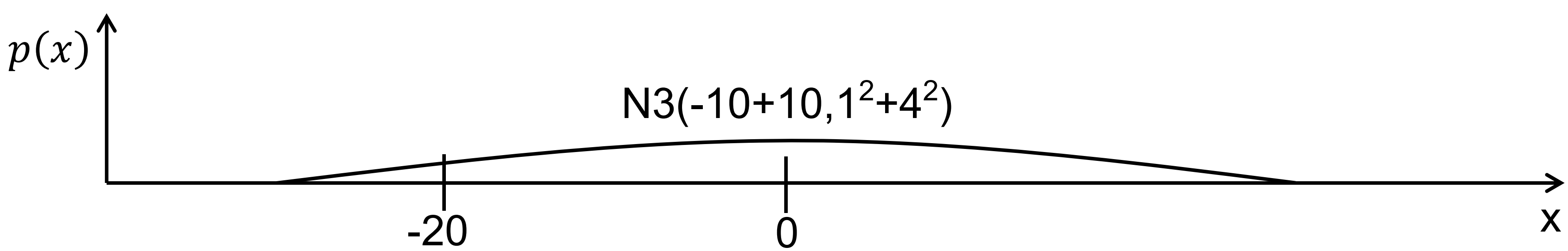


$$P_{N1}(-20) = 7.62 \times 10^{-24}$$
$$P_{N2}(-20) = 3.19 \times 10^{-14}$$

$$P_{worst}(-20) = \frac{1}{2}\max[P_{N1}(-20), P_{N2}(-20)] = 1.60 \times 10^{-14}$$

At –20, N2 is dominant, and N1 does not contribute to error at all.

- Single Distribution (if we merge different μ and different σ)

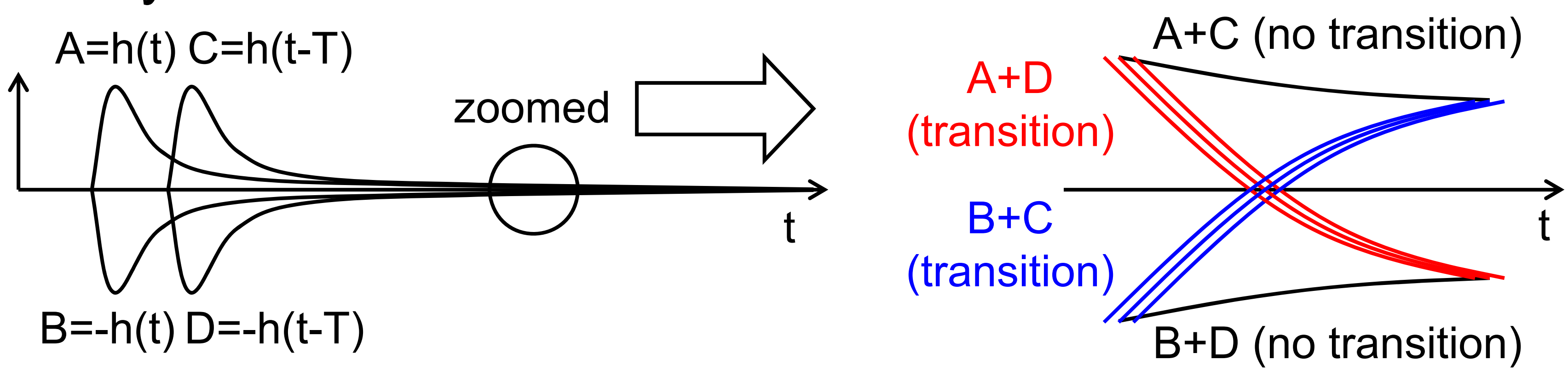


$$P_{N3}(-20) = 6.15 \times 10^{-7}$$

N3 is different from N1 and N2

Jitter at ISI locations not before or after cursor

- Jitter is not added at ISI locations other than before or after cursor symbol



- Where sign of ISI does not change
  - Envelope is covered by no transition cases (A+C, B+D)
  - Jitter affects transition cases (A+D, B+C) which are covered by envelope
  - Since ISI covers no transition cases, addition of jitter is not needed
- Where sign of ISI changes
  - Since magnitude is close to zero where sign changes, effect is minor
  - Number of sign changes is rather small

Suggestions for COM

FUJITSU

- In our experience, use of multiple distributions was the key to obtain satisfactory results for test cases where a single large ISI (i.e. the largest ISI) is *close to the RSS value of all ISIs*
  - Our scheme is not necessarily the best, but probably better than COM

- COM is very likely inaccurate when a DFE coefficient is restricted by bmax < 1, because restriction of a DFE coefficient causes the single large residual ISI close to the RSS value

- We may fix the COM formula in a similar way to our BER analysis, but I have not come to a complete suggestion yet
  - I may provide it later, but it takes some time

- In the mean time, it is OK to use the current COM with bmax = 1 and high tap-count DFE, because no single large ISI is left after DFE cancels major ISIs
  - In fact, I do not see a large discrepancy between COM and BER as long as I use bmax = 1

References

[1] http://grouper.ieee.org/groups/802/3/by/public/May15/
sun_3by_01_0515.pdf

[2] http://www.ieee802.org/3/by/public/adhoc/architecture/
sun_061015_25GE_adhoc.pdf

References of Channel Data

- ~ = http://www.ieee802.3.org/3/
- 3 meter cable assembly
  - B: ~/by/public/channel/TE_QSFP_4SFP_3m_30AWG.zip (TE_3m30AWG_QSFP_4SFP_P1_TX1_P2_RX1_THRU.s4p)
  - G: ~/100GCU/public/ChannelData/Molex_11_0516/bugg_02_0511.zip (3m 26AWG leoni/P1 RX1/TX1.s4p)
  - H: ~/by/public/channel/TE_QSFP_4SFP_3m_26AWG.zip (TE_3m26AWG_QSFP_4SFP_P1_TX1_P2_RX1_THRU.s4p)
- 5 meter cable assembly
  - N: ~/100GCU/public/ChannelData/Molex_11_0516/bugg_02_0511.zip (5m 26AWG Leoni/P1 RX1/TX1.s4p)
  - Q: ~/100GCU/public/ChannelData/Molex_11_0210/5m/5m_all.zip (P1 RX0/TX0.s4p)
  - R: ~/100GCU/public/ChannelData/molex_12_0310/cableb_bugg_03_0312.zip (P1RX1/P2TX1.s4p)

Thank you