A Way to Evaluate post-FEC BER based on IBIS-AMI Model

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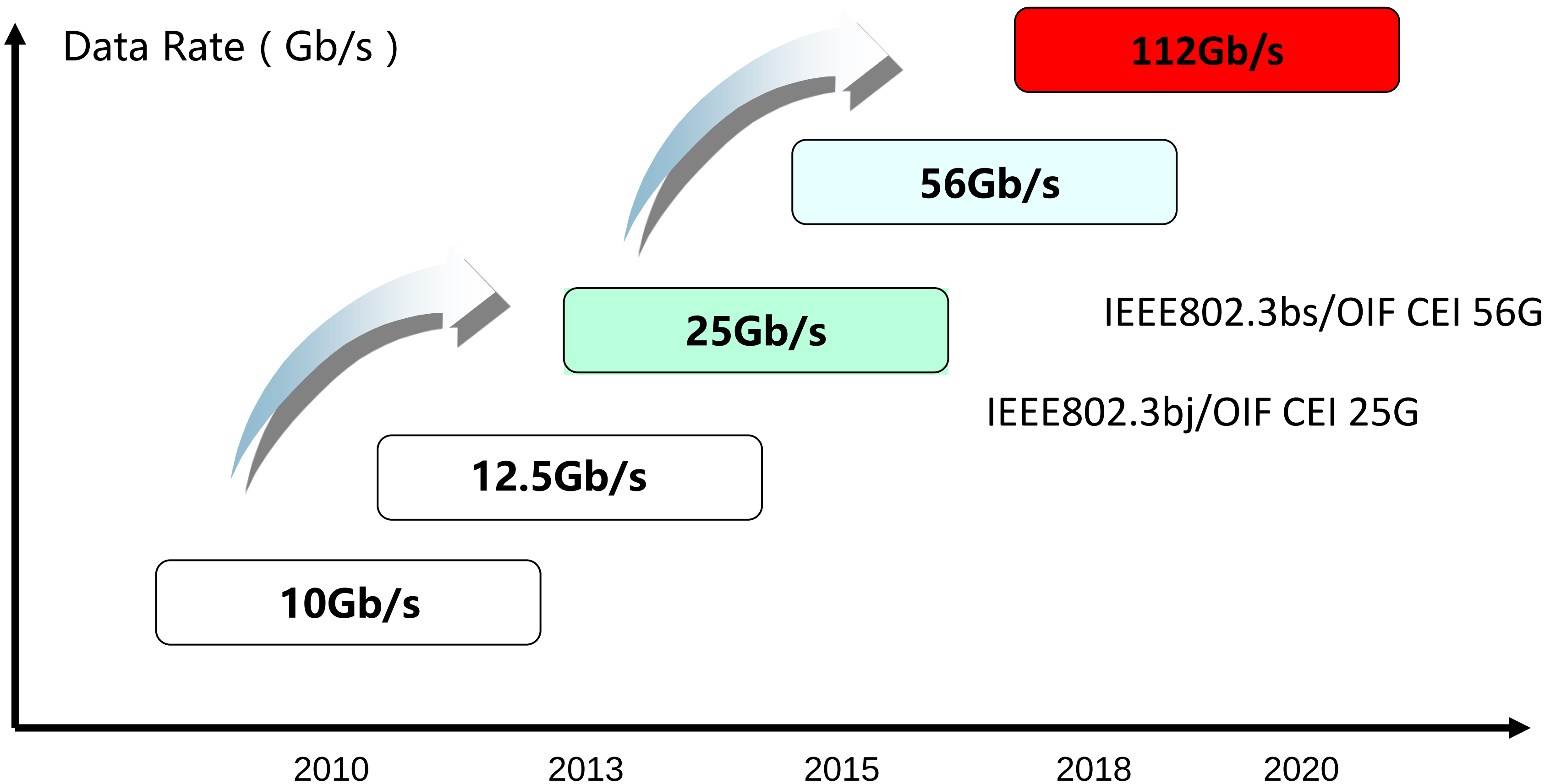
Agenda

- Introduction
- Error Propagation Theory
- A Simulation Case
- Summary

Introduction

200/400&800 Gigabit Ethernet is urgently needed in carrier network

Higher data rate requirements for 56Gb/s,even 112Gb/s



Introduction

Besides equalization techniques, some new techniques have been used for SerDes systems in order to meet 100GE- 400GE-800GE specs

Higher Data Rate： 25Gb/s to 56 Gb/s to 112 Gb/s

100GE → **400GE** → **800GE**

Equalization：
De-emphasis+CTLE+DFE

IC Architecture：
Analog based architecture
DSP based architecture

Fanny Modulation： NRZ or PAM4
Forward Error Correction： **FEC**
(optional vs. forced)

How to use it in simulation?

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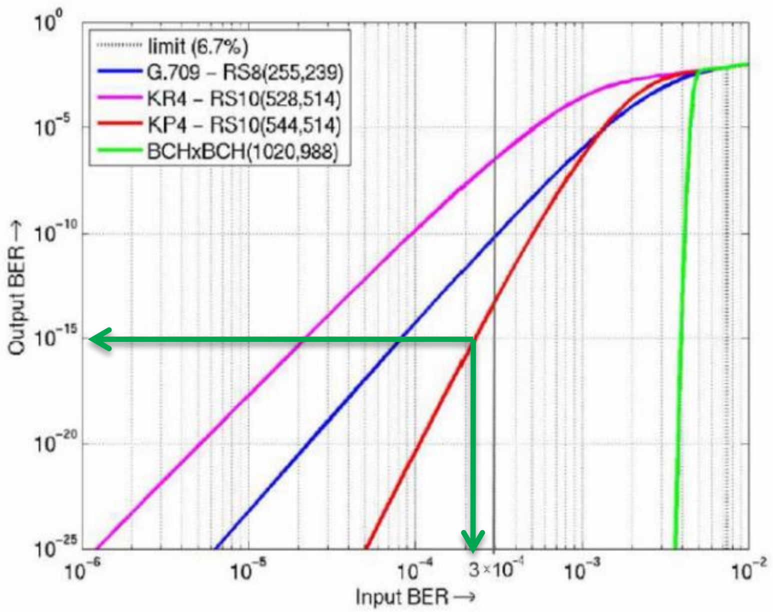
Introduction

The Forward Error Correction（FEC）has been used to Increase serial link system budgets and relaxing BER requirements

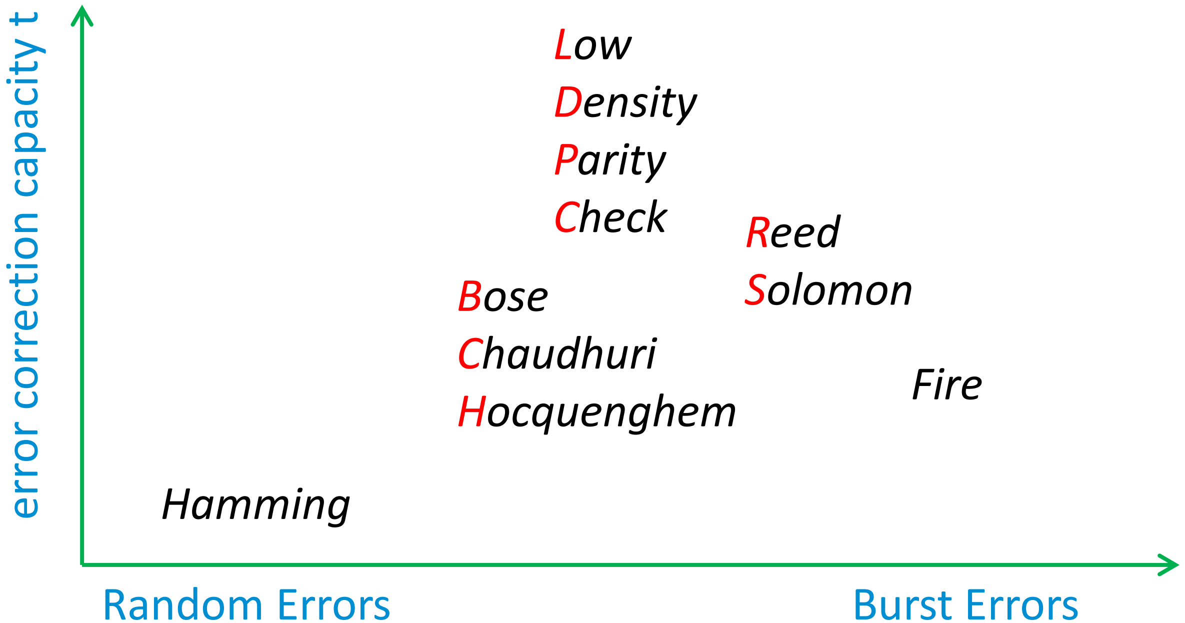
- **Code Gain**
  Gain vs Higher Frequency
- **Time**
  Serial Link Latency
- **Complexity**
  Area and Power



Target (OIF-56G-LR)
2.2e-4 without FEC
1e-15 with FEC

Introduction

- Important FEC codes



Recently adopted FEC

- Fire Code （1604, 1584） – OIF CEI-P
- QC Code （2112, 2080） – 10GBASE-KR
- RS（528, 514, 7） over GF(2^{10}) – 100GBASE-KR4
- RS（544, 514, 15） over GF(2^{10}) – 100GBASE-KP4

Introduction

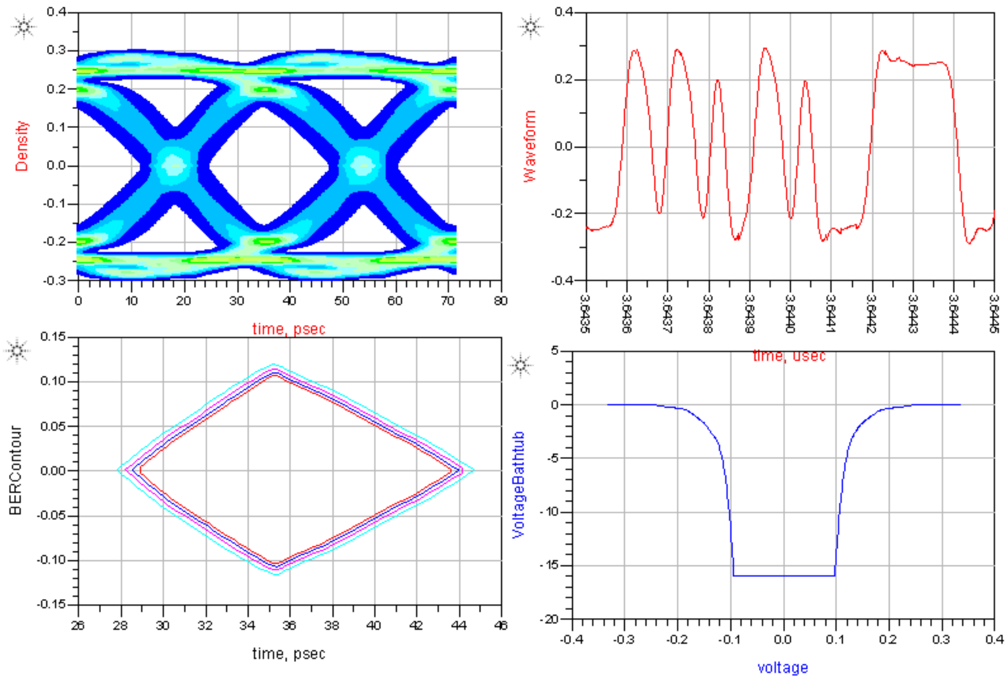
- *What can we get from simulaiton based on IBIS-AMI model?*

Available

- Eye Diagram
- Waveform
- Contour
- Bathtub

Absent

- postFEC BER



measurement	Summary
Height	0.245
Width	2.286E-11
SNR	6.811
WidthAtBER	1.482E-11
HeightAtBER	0.210

Introduction

- Current Problems

➢ FEC is a forced function in 400GE and 800GE system

➢ There is no FEC function model in the IBIS-AMI yet

- System Vendor Requirements

➢ IBIS-AMI models can be used for FEC simulations

➢ postFEC BER

We proposed a new solution evaluated the postFEC BER using FEC model

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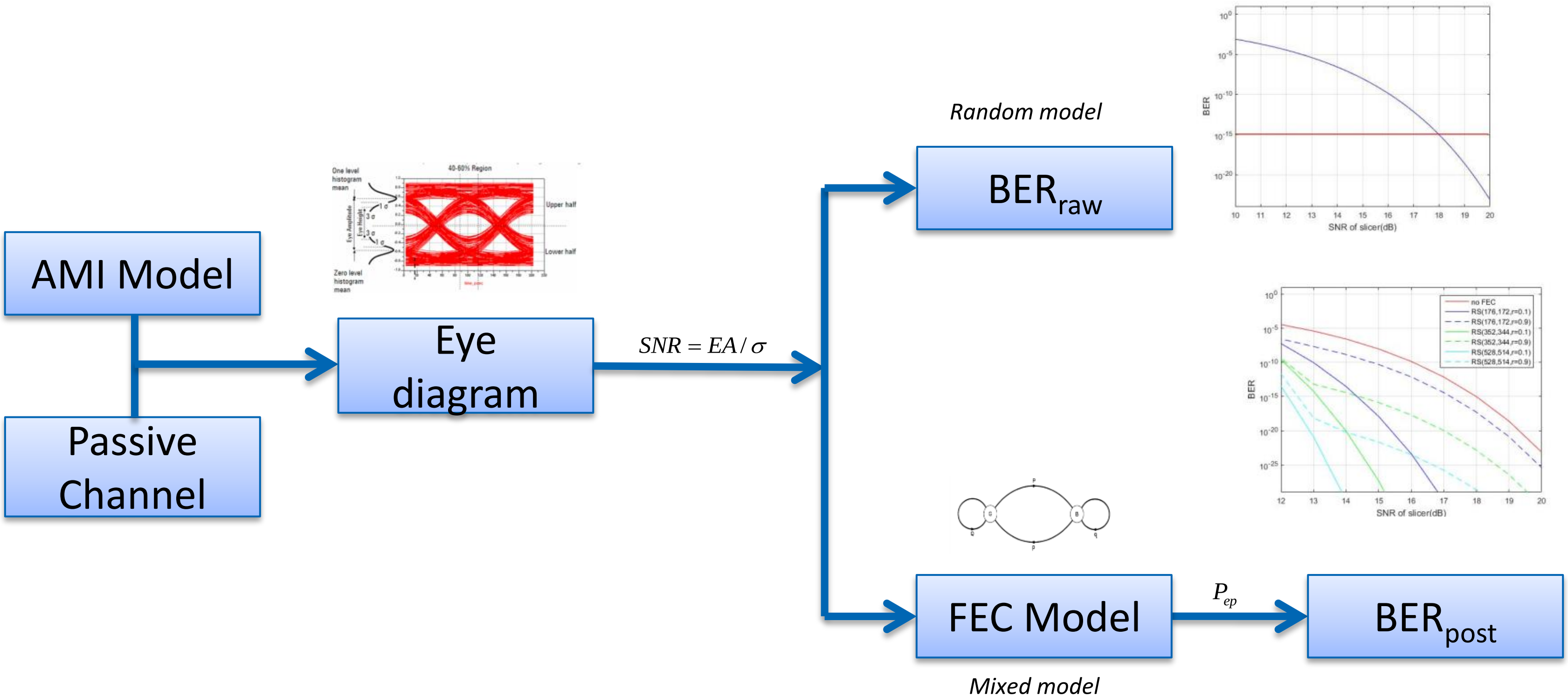
Introduction

- Suggested Solution Process



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Error Propagation Theory

Random Error

- The presence and the location of the error satisfy the random distribution
- The errors are independent of each other
- Usually caused by the random noise of the channel, AWGC channel
- Random errors are generally single bit.

Burst Error

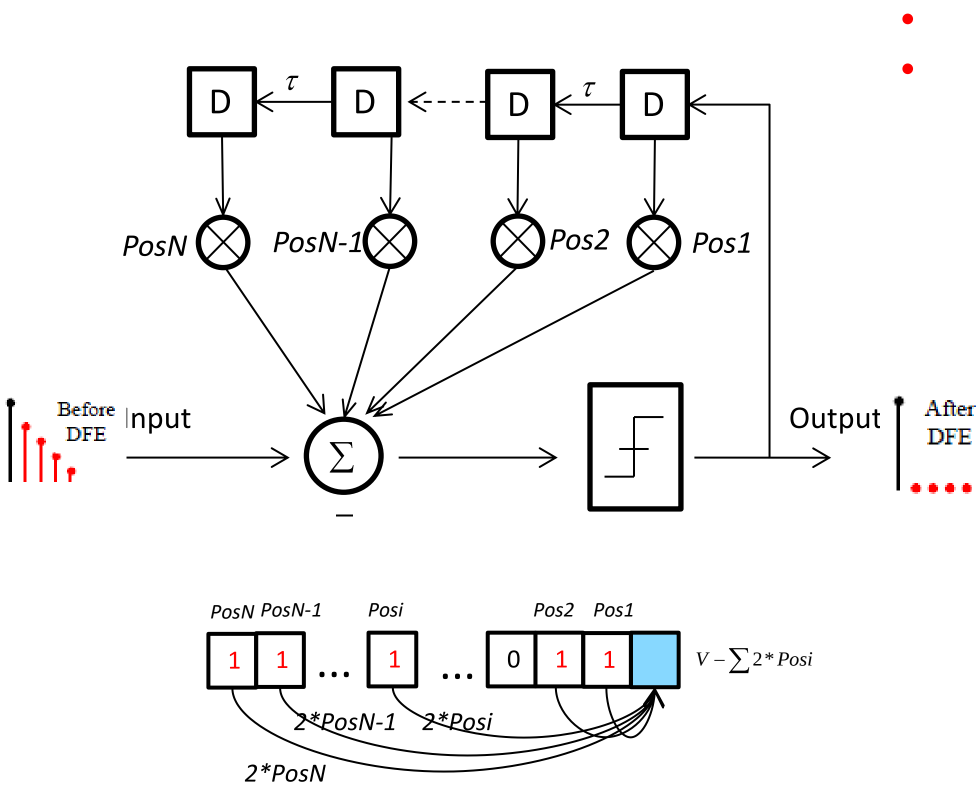
- The error contains a series of bits, the first and last bit in an error are always wrong
- There is a certain relationship between the error bits
- Caused by some structures, such as DFE, Scrambler
- The length of the error is called the burst error length

Mixed Error

- Channel contains random error and burst error
- We consider the channel as random error channel without DFE, otherwise the channel is a mixed error channel

Error Propagation Theory

- DFE diagram

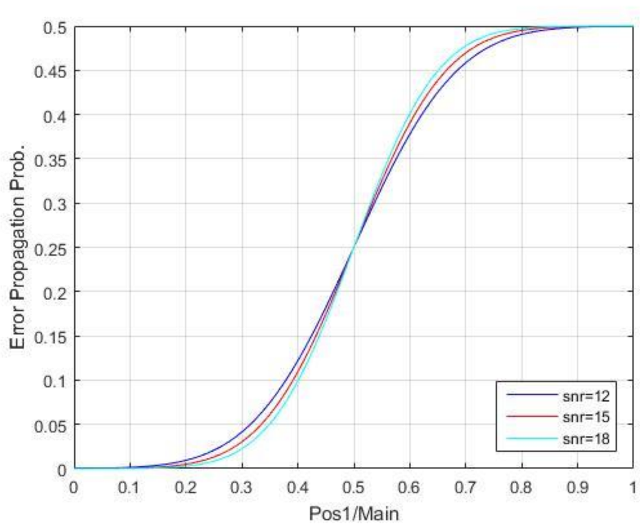


- If all DFE state registers were right, error probability is decided by slicer SNR
- If *ith*-cursor were wrong, generate a (2**Posi*) voltage deviation
- The output of DFE is associated with the previous N-bits information, where N is the number of DFE taps

Error Propagation Theory

- Many methods are used to analyse the error propagation such as
  - Monte-Carlo simulation
  - Markov chain model
  - Error Propagation theory

...



- Decision feedback equalizer (DFE) is widely used to reduce ISI
- However, this structure induces burst errors in channel
- The increased input BER performs a penalty on FEC coding gain
- Trade off between n-Tap DFE and high coding gain FEC

Error Propagation Theory

- FEC analysis for random error channel
- Raw BER is decided by the channel SNR

$$BER_{pre} = Q(\sqrt{SNR}) = \frac{1}{2} erfc(\frac{\sqrt{SNR}}{\sqrt{2}})$$

- Every RS-FEC symbol has *m*-bits, thus the error symbol rate is

$$SER_{FEC,pre} = 1 - (1 - BER_{pre})^m$$

- RS-FEC can correct *t*-symbol, the Probability of un-correction in FEC symbol is

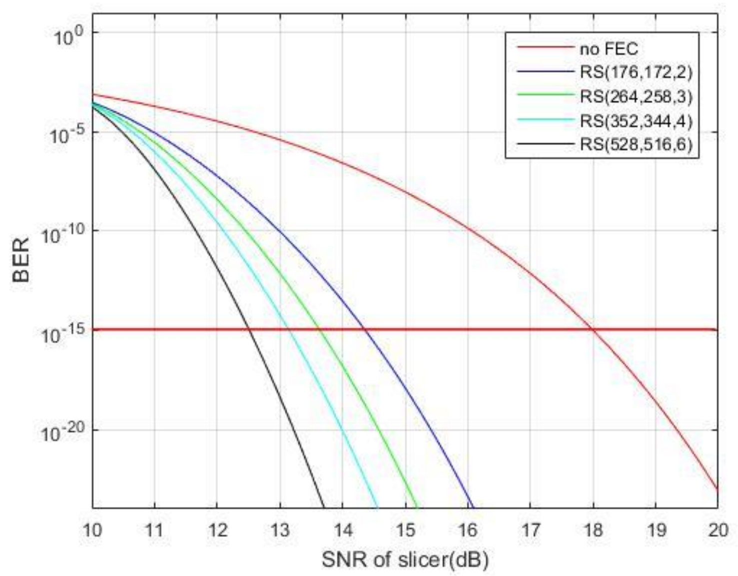
$$P_{UE} = \sum_{i=t+1}^{n} \frac{i}{n} \binom{n}{i} SER_{pre}{}^{i} (1 - SER_{pre})^{n-i}$$

- The output BER is

$$BER_{post} = 1 - (1 - P_{UE})^{1/m} \approx P_{UE} / m$$

Error Propagation Theory

- FEC Gain for Several RS Codes



- Without FEC, ~18dB SNR is needed to get 1e-15 BER
- Code with larger *t* can get higher net coding gain (NCG)
- At BER 1e-15, *t=2, 3, 4, 6* RS codes can get 3.6dB, 4.4dB, 4.8dB, and 5.5dB NCG, respectively
- The result is too idealistic because the model just considers the random error

Error Propagation Theory

- FEC analysis for 1-tap DFE channel
- Raw BER is decided by the channel SNR

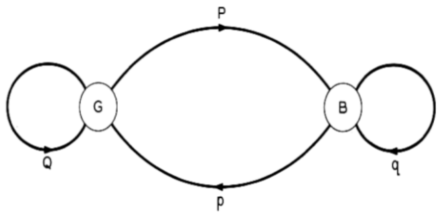
$$BER_{pre} = \frac{1}{2} erfc(\frac{\sqrt{SNR}}{\sqrt{2}})$$

- The error propagation probability (Pep) is

$$P_{ep} = \frac{1}{4}\left[erfc\left(\frac{(1+2b_1/b_0)\sqrt{SNR}}{\sqrt{2}} \right) + erfc\left(\frac{(1-2b_1/b_0)\sqrt{SNR}}{\sqrt{2}} \right) \right]$$

b1/b0 is the ratio of Pos1 to main

- Error propagation follows the Markov chain probability of (*k+1)* consecutive errors and is

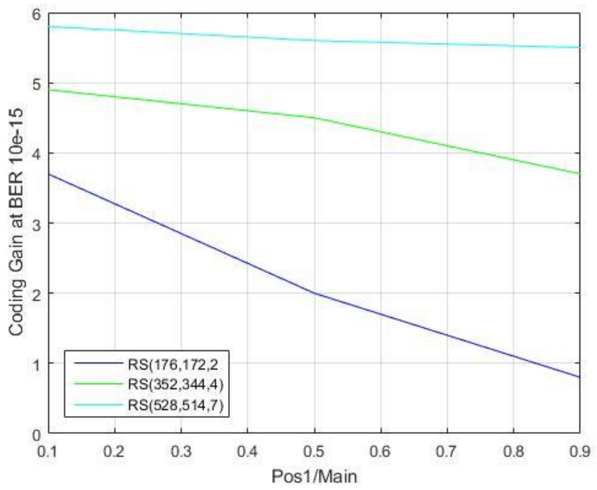


$$p(bl = k+1) = p_{ep}{}^{k}(1 - p_{ep})$$

- Calculate the postFEC BER

Error Propagation Theory

- Coding Gain Vs. Tap coefficient



- When Pos1/Main increase, FEC coding gain decreases
- RS codes with larger *t* can get higher gain
- Gain drops more rapidly for RS codes with small *t* because they cannot correct the long errors effectively
- RS(528, 514, 7) can get about 5.8dB gain for random error channel, consistent with 802.3bj ad OIF-25G standard

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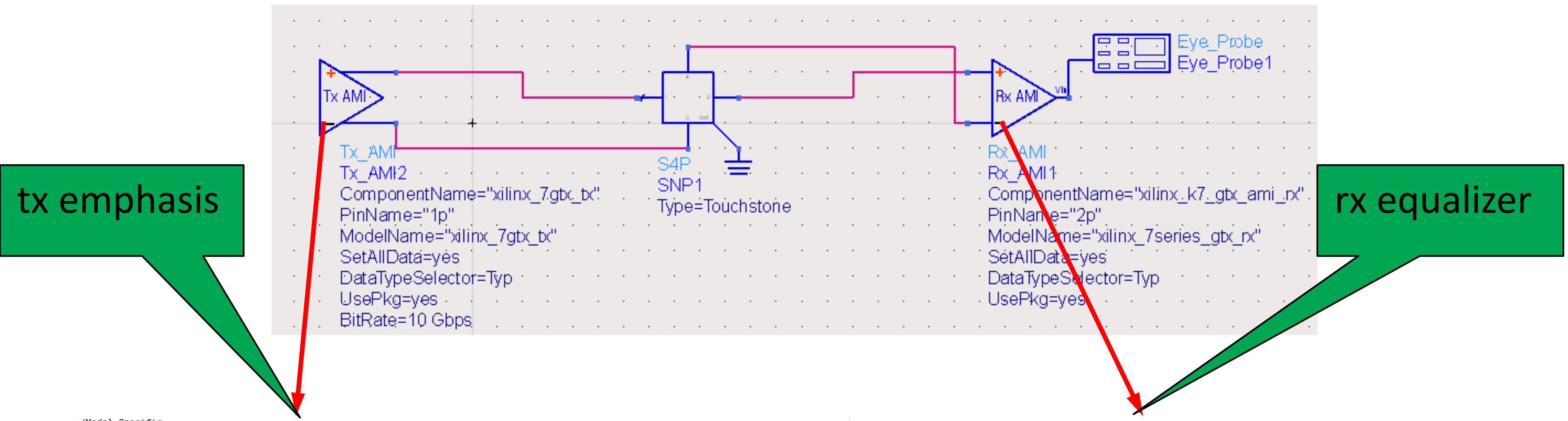
A Simulation Case

- Acquisition of SNR




```
(Model_Specific

  (TXPRECURSOR  (Usage In)
         (Type Integer)
         (Default 0)
         (Format List 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20)
         (Description "Pre Cursor Tap Weight Index.")
  )

  (TXPOSTCURSOR  (Usage In)
         (Type Integer)
         (Default 0)
         (Format List 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31)
         (Description "Post Cursor Tap Weight Index.")
  )

  (TXDIFFCTRL (Usage In)
          (Type Integer)
          (Default 12)
          (Format List 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15)
          (Description "Tx swing code: 0 is the smallest Tx swing ")
  )
```

```
(LPM_KL_OverWrEn (Usage In) (Type Integer)  (Format List 0 1) (Default 0)
     (Description "0-adaptive, 1-fixed at initial code")
)

(RX_DFE_GAIN_CFG_bit12_to_8 (Usage In) (Type Integer)  (Format Range 15 0 31) (Default 15)
     (Description "AGC code")
)
(RXDFEAGCOVRDEN (Usage In) (Type Integer)  (Format List 0 1) (Default 0)
     (Description "0-adaptive, 1-overwrite to initial value")
)

(RX_DFE_KL_CFG2_bit8_to_5 (Usage In) (Type Integer)  (Format Range 1 0 15) (Default 1)
     (Description "CTLE1 and CTLE2 code: suggest range is from 0 to 5")
)

(RX_DFE_KL_CFG2_bit23_to_26 (Usage In) (Type Integer)  (Format Range 5 0 15) (Default 5)
     (Description "CTLE3 code: suggest range is from 0 to 7")
)
```

- Simulation with IBIS-AMI model
- Using the optimal tx emphasis parameters
- Using the optimal rx equalizer parameters
- Getting the best eye diagram

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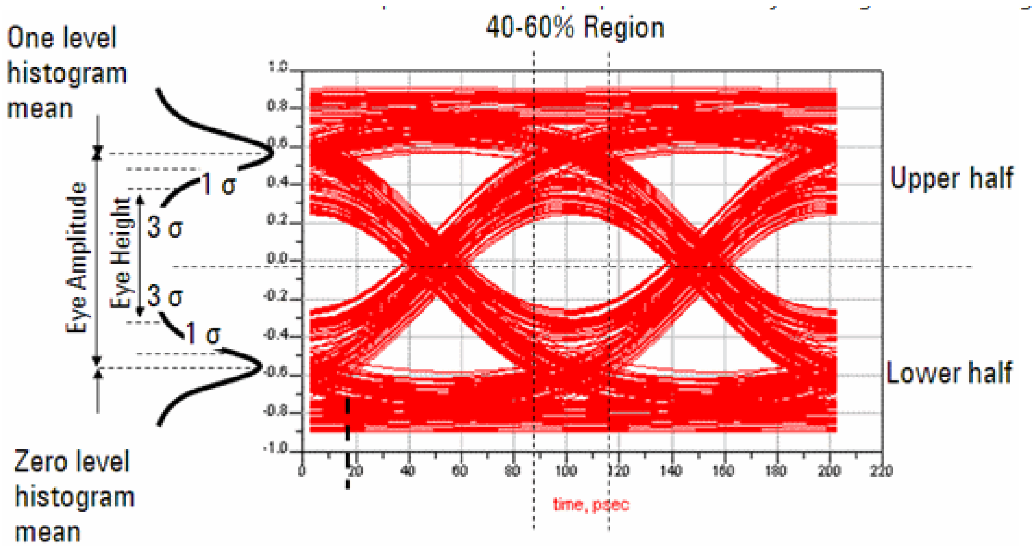
A Simulation Case

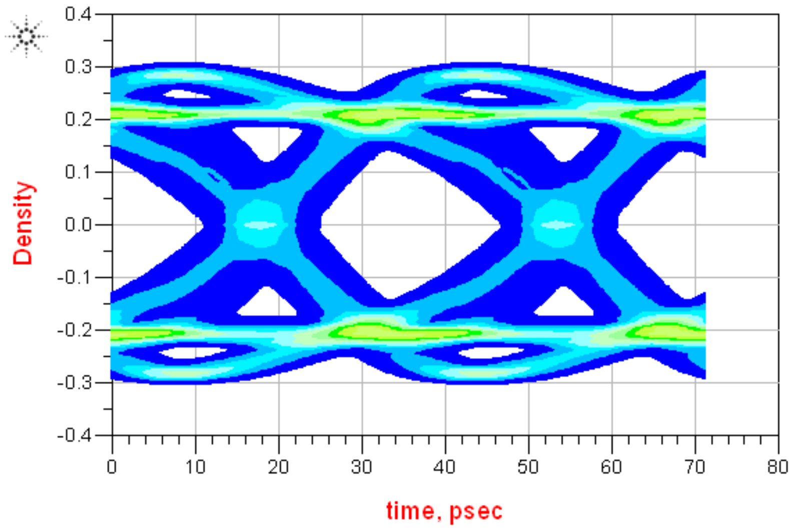


- SNR=S/N=S_amp/(N_sigma1+N_Sigma0), where S_amp=signal amplitude
- S_amp: 1 level histogram mean - 0 level histogram mean
- N_sigma: 1 sigma value

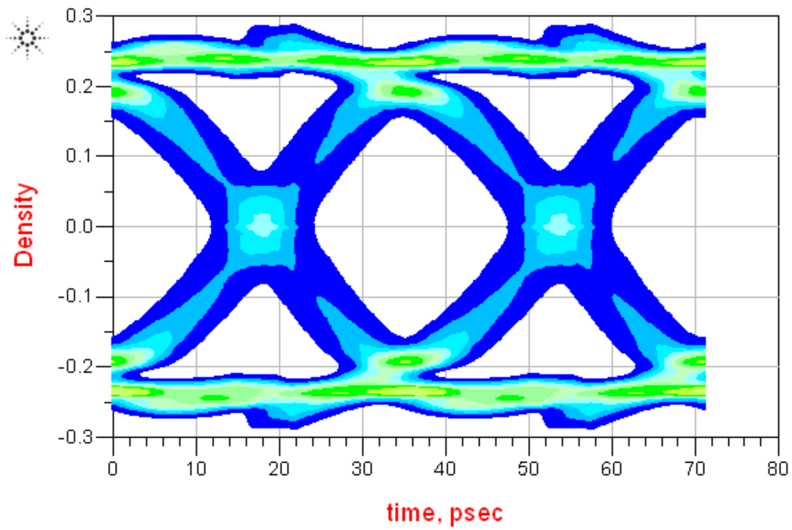
A Simulation Case

- Comparison

DFE OFF



DFE ON



- DFE impacts are obvious on eye diagram quality

A Simulation Case

- Results for RS(528, 514, 7)

	SNR=12dB	SNR=13dB	SNR=14dB	SNR=15dB
	BER_{post}			
BER_{pre}	3.43e-5	3.97e-6	2.70e-07	9.36e-9
Random (Pos1/main=0)	3.53e-14	1.30e-21	5.98e-31	1.27e-42
Pos1/main=0.5	3.82e-14	1.41e-21	6.48e-31	1.70e-42
Pos1/main=1	5.29e-14	2.06e-21	7.13e-24	2.48e-25

- The error propagation probability increases while the DFE tap coefficient becoming larger
- The BER increases with the tap coefficient
- Larger SNR shows more obvious change as shown by the relatively low BER and the effect of error floor

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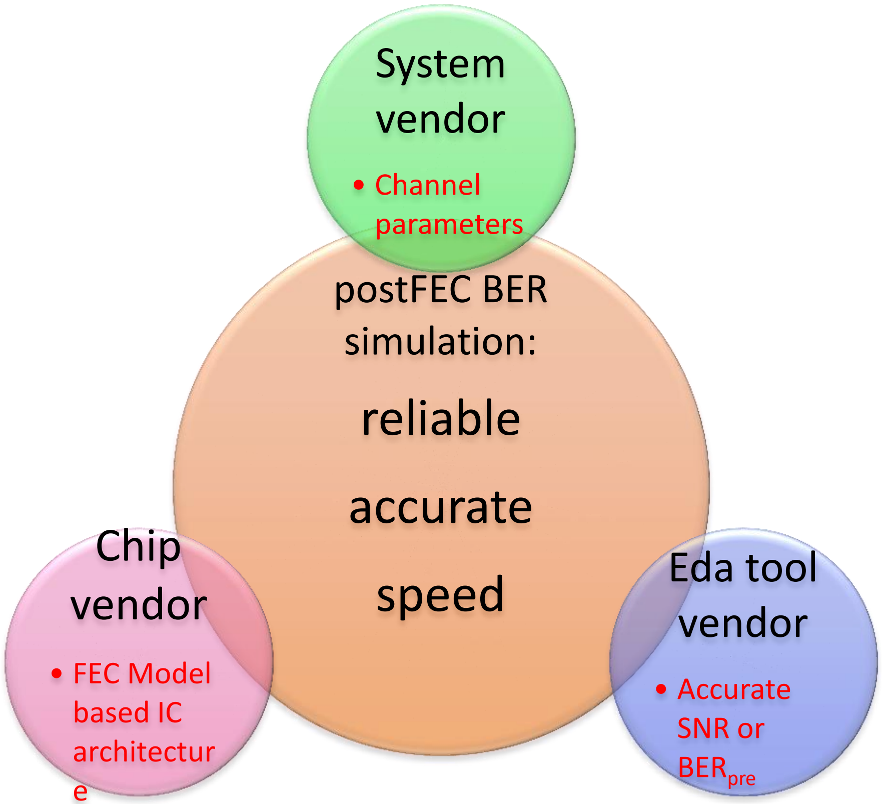
Summary

- We proposed a method to evaluate the postFEC BER for a system
- To achieve the simulation in the common **EDA Tool** based on **IBIS-AMI** model, we appeal to all the members to solve the problem together.



Summary

- An analysis method is performed combining AMI model and FEC function
- FEC function modeled based on error propagation theory
- SNR calculated through EDA tool with IBIS-AMI model
- Calculate the postFEC BER
- Advantages: SNR contains multiple effects of chip and channel; each part can be optimized separately
- We appeal to all the members to solve the problem together

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Thank you

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