

Discussion on Error Statistics

Phil Sun, Credo Semiconductor

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Introduction

- In Long Beach meeting, we had discussions whether burst errors exist besides DFE error propagation.
- [lyubomirsky_3ck_01a_0119](#) proposed to solve burst error issue by constrain DFE tap weights or use SERDES “not prone to burst error problems” as no other burst sources found in a channel simulation.
- [he_3ck_01a_0119](#) shows burst error problems for a long-FFE receiver with two light-weight DFE taps.
- As ideal simulations may not capture system behavior, this contribution analyzes reported FEC error statistics and calls attention to burst error penalty in link budget analysis.

Sources of Burst Errors

- Correlated noise.
- Slow loops in the receiver.
- Implementation imperfection.
- May be data pattern dependent.
- Burst errors exist regardless of SERDES architecture.

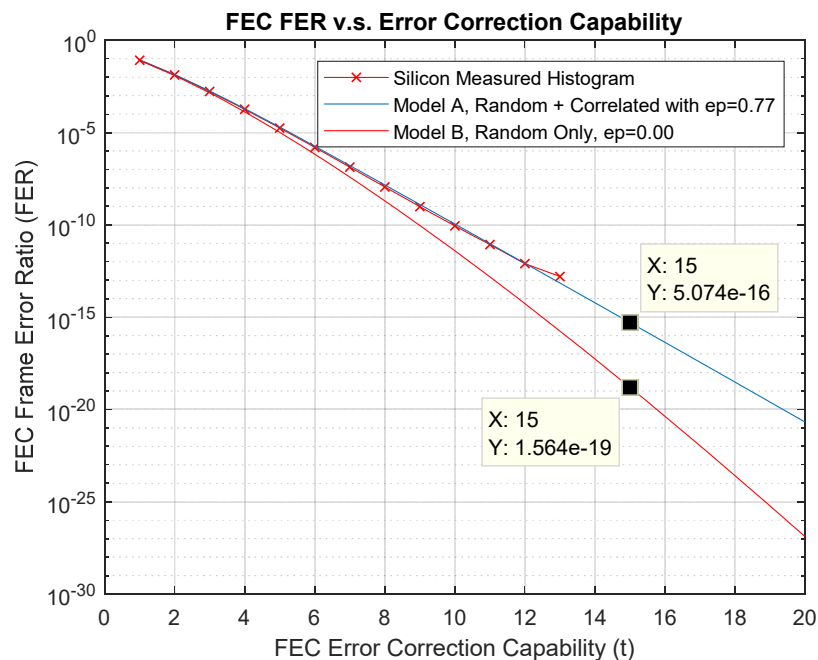
Reported FEC Statistics

- FEC statistics is reported for 400GBASE-LR8 with 27km SMF [cole_b10k_01_0718](#). RAW BER is 8.71e-5.

Symbol Errors per Codeword

No. of Symbols	Count	Percentage
1	1,829,578,729,491	77.827087
2	437,987,258,685	18.631214
3	72,660,290,732	3.090842
4	9,452,501,111	0.402093
5	1,035,966,554	0.044068
6	100,548,342	0.004277
7	8,996,715	0.000383
8	768,593	0.000033
9	64,951	0.000003
10	5,574	0.000000
11	502	0.000000
12	49	0.000000
13	4	0.000000
14	1	0.000000
15	0	*

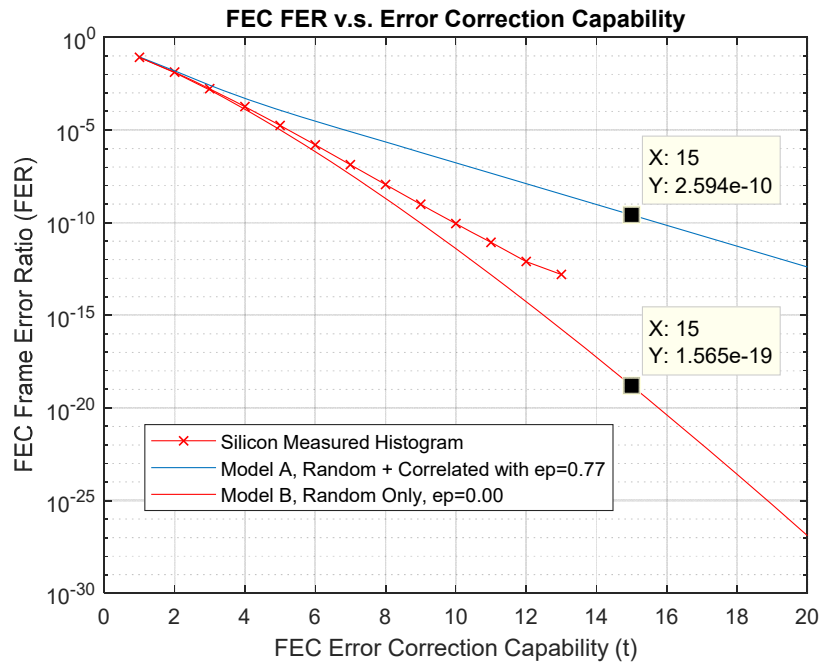
Error Histogram Analysis



Curve Fitting Results		
Component	Random	Burst
Error Propagation Rate	0	0.77
BER	8.6e-5	1e-6

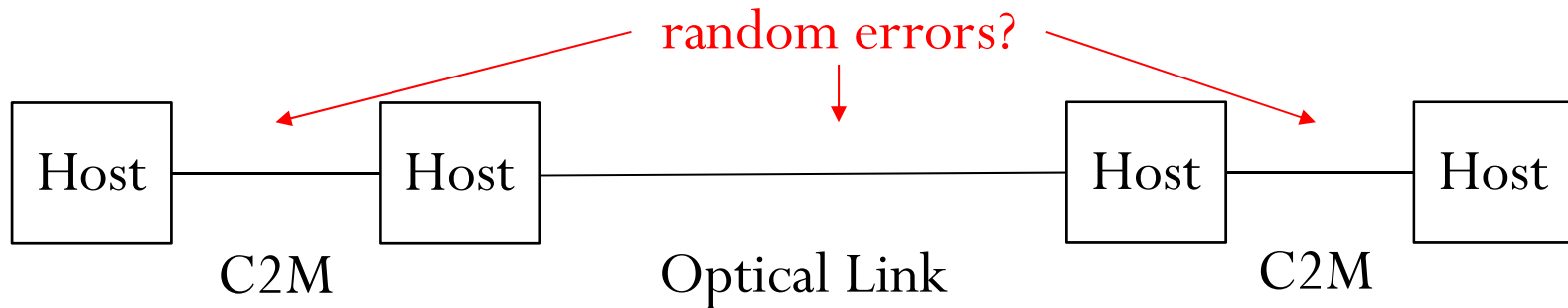
- If errors are random, post FEC BER is better by more than three orders.
- The measured error statistics can be fitted by random error + correlated error.

Performance of Non-interleaved FEC



- If non-interleaved FEC is used for this link, FER is predicted to be 2.59×10^{-10} (BER after FEC is likely worse than 1×10^{-12}).

100G C2M Interface



- 100G C2M may have 22dB insertion loss, severe reflections, and bad XTK.
 - Challenging to C2M receivers which has tight power constraints.
- 100G C2M link budget is currently studied in 802.3ck project by assuming optical link errors are random, and burst errors exist in C2M interface if DFE is used.
 - Correlated errors exist regardless whether there is DFE. Burst errors caused by DFE tail acts as a proxy of other burst errors. Extra burst error model is needed if C2M reference receiver has no DFE tails.
 - Ignoring burst error penalty may result in low-quality C2M link which will consume link budget of optical segment in the field.

Discussion on Interleaved FEC

- [gustlin_3ck_01_0119](#) proposes:
 - 2-way Interleaved FEC for 200GbE and 400GbE
 - 2-way Interleaved FEC for 100GbE KR and CR
 - Non-interleaved FEC for 100GbE C2M and C2C
- Extra latency for 2-way interleaving is 50ns for 100GbE.
 - Interleaving can be defined as optional
 - Low latency FEC modes can be defined
- Optional Interleaved FEC for 100G C2M and C2C?
 - Non-interleaved FEC is needed for backward compatibility, e.g. 100GBASE-DR.
 - Optional interleaved FEC relaxes budget of C2M and optical link when both ends are new host devices.
 - New PMD can define interleaved FEC mode for better performance without much cost.
 - 50ns extra latency is negligible for optical links.

Conclusions and Suggestions

- Correlated errors are observed in PAM4 optical links.
 - Proper modeling of correlated errors helps to optimize link budget and control link quality.
- Call for FEC statistics data for further study:
 - FEC histogram as on page #3.
 - DFE on/off status. DFE weight if it is ON.
 - Total test time.
 - Better to have data with both 100G and 400G FEC.
 - Any PAM4 link measurement is OK.
- Possible actions if burst errors generally exist:
 - Include burst error effect in modeling. Recently long DFE model is being used for burst error analysis. It might be a good proxy for other sources to avoid being too optimistic about error randomness.
 - Stronger FEC schemes. Interleaved FEC relaxes link budget for C2M, optics, and KR/CR. It can be specified as optional for backward compatibility or low latency.
 - Allocate link budget for burst errors.