Experimental results on single wavelength 100Gbps PAM4 modulation

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Past Presentations

- Selection of presentations at ieee SA on 50 Gbaud PAM4 modulation
  - mazzini_02a_1215_smf
  - tipper_3bs_01a_0515
  - way_3bs_01_0515
  - welch_3bs_02a_0115
- We have improved the setup shown in the highlighted reference & show new results

Background

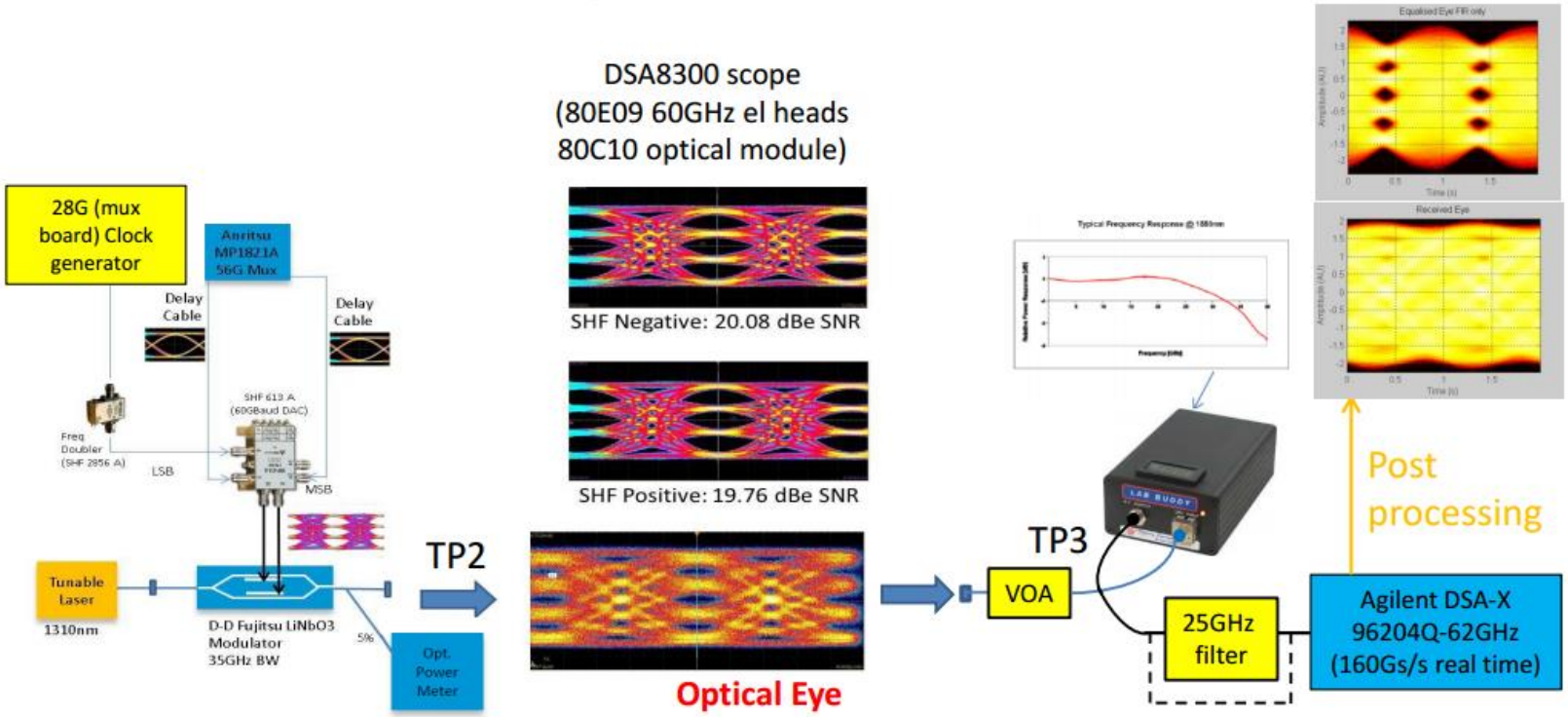
- In mazzini_02a_1215_smf, receiver sensitivities of:
  - -5.8dBm OMA w/ 9FFE Taps (2+1)
  - -7.6dBm OMA w/ 21FFE Taps (6+1)
- Concerns raised that there was insufficient margin

- In this presentation, we'll review improvements to the transmitter & receiver have provided a 4-5dB improvement
  - This is a 4-5dB margin in receiver sensitivity over the proposed baseline in lewis_3cd_01_0716 and the 400GBASE-DR4 draft 1.5

53GBaud PAM 4 TX/RX : improved set-up

Setup from mazzini_02a_1215_smf

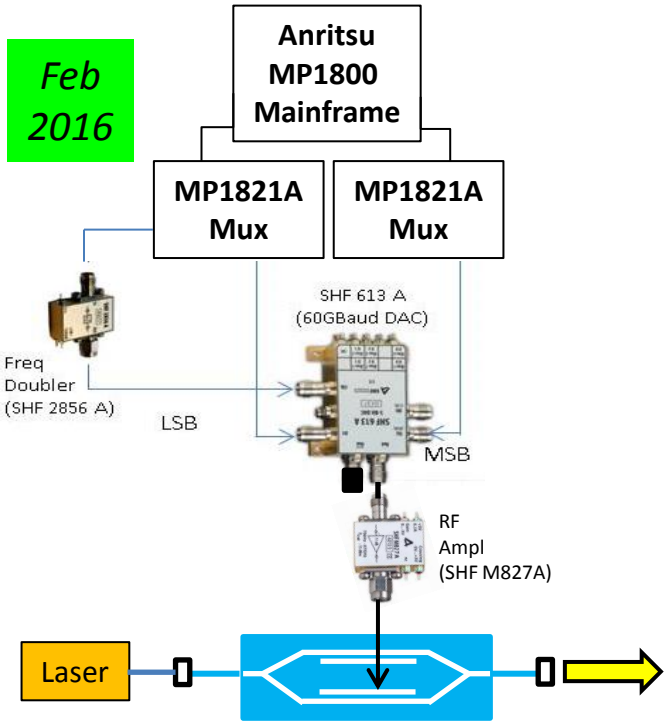
PAM 4 TX/RX : set-up with LiNb03 modulator.

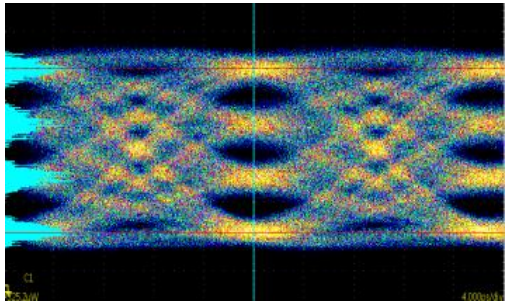


- SHF613A and 2856A provide a good electrical signal and allow dual-drive modulator to generate a 56GBaud signal.
- Clock generator was improved with respect previous tests (but limited to fixed 56GBaud).
- DSC-R409 (linear InGaAs receiver) has good frequency response but expect higher NEP (>30pa/√Hz, no AGC) w/respect new generation of linear TIAs for 53GBaud application.

We expect experimental results with discrete components to be (at this stage) worsen than any integrated implementation because the amount of optical/electrical connections in the set-up and RX limitations.

53GBaud PAM 4 TX/RX : improved set-up





Agilent DSA-X
96204Q-62GHz
(160Gs/s real time)

Optical RX Characteristics:
≈30GHz (3dB) BW
~ 13 pA/√Hz

Transmitter Improvements

- RF Amplifier improves swing yet more distortion
- Improves eye opening ~8dB ER
  - –About 1dB power penalty vs. min 5dB ER

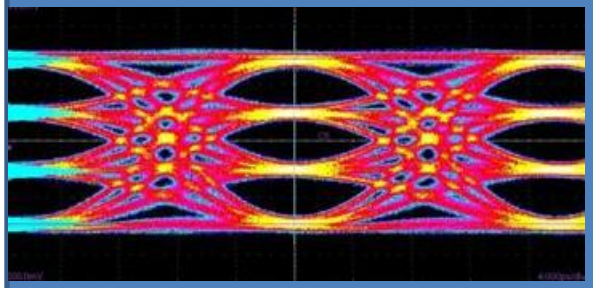
Receiver Improvements

- Macom TIA lower noise than Discovery Semiconductor used in previous setup
- Improved Gain & BW – esp higher AGC output swing

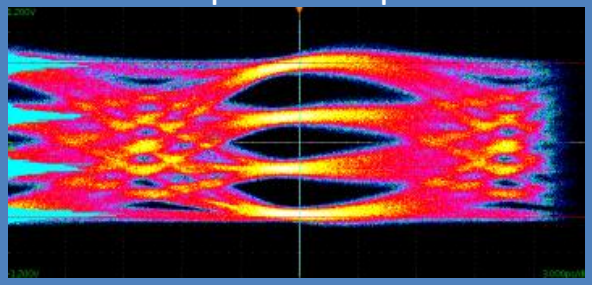
Transmitter optimization

- DAC settings were optimized (swing, Xpoint, etc)
- Waveforms were capture on sampling scope & via real time scope
- Analysis conducted on real time scope waveforms in Matlab via offline processing

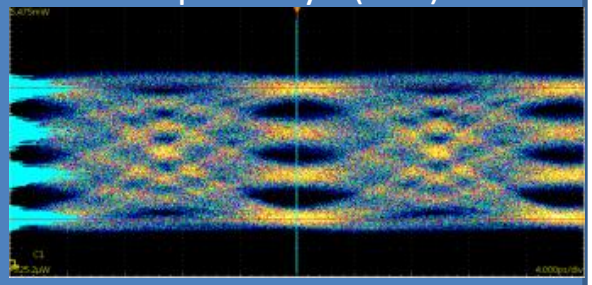
DAC output



Amplifier output

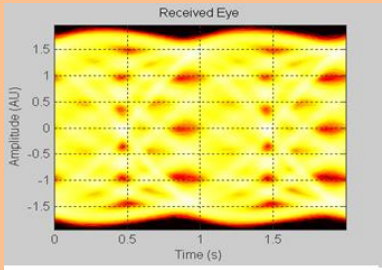


Optical eye (TP2)

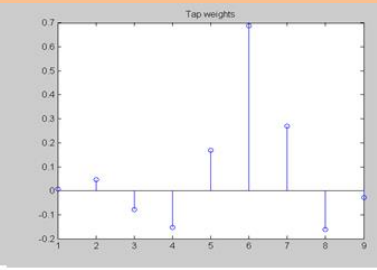


Sampling Scope

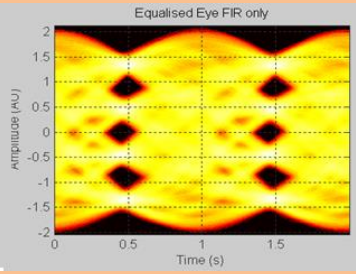
Raw Data from TIA



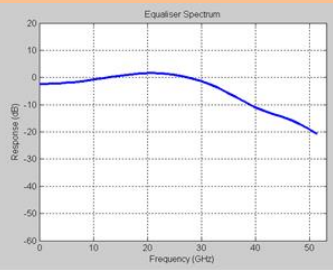
FFE Coeff.



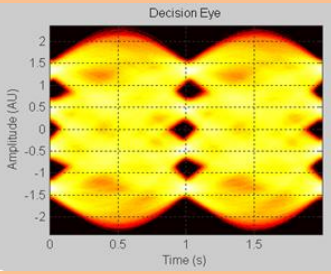
Eye - FIR only Equalized



Eq. spectrum



Decision Eye



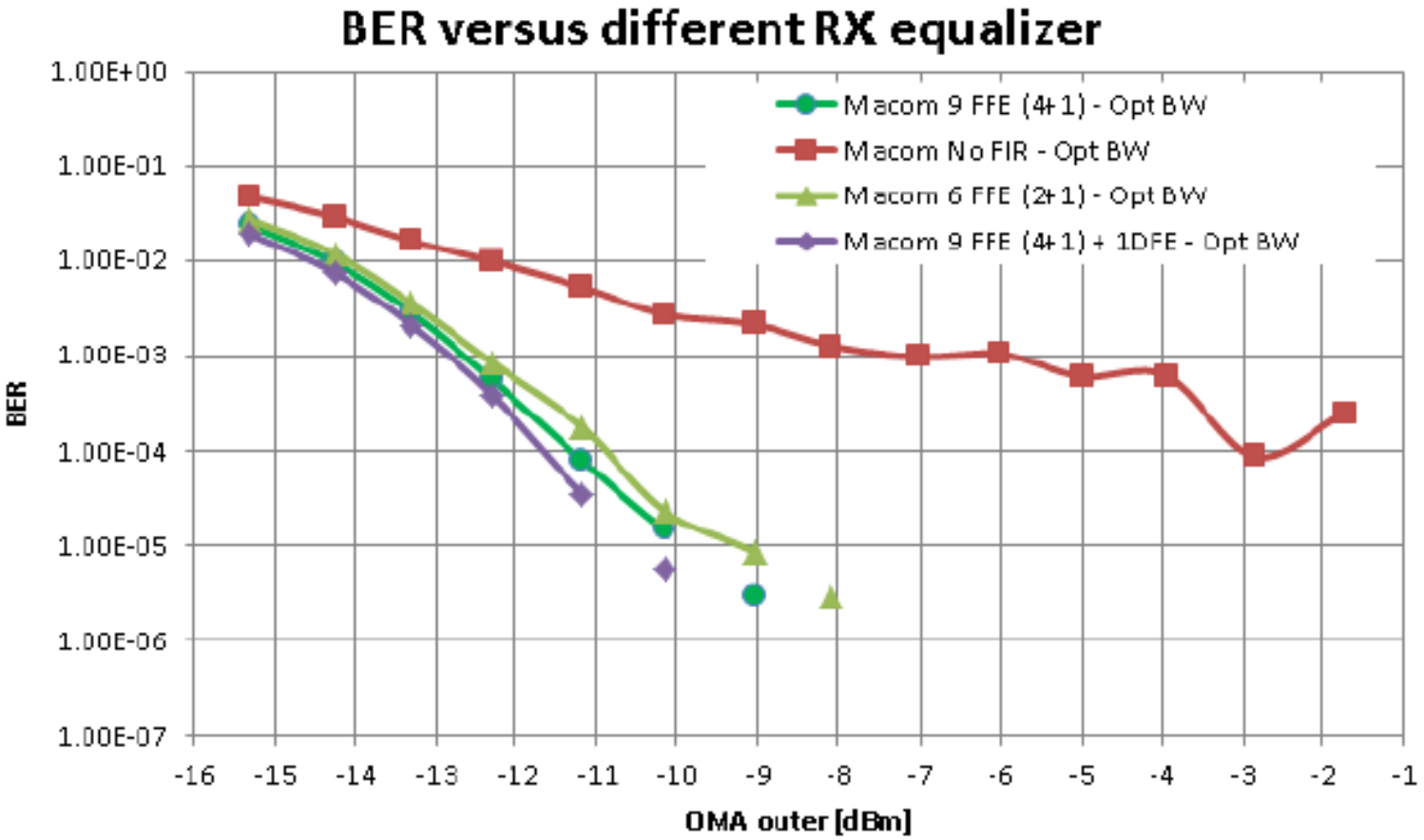
Captured/Stored Waveforms

Notes on Waveform Capture

- Raw sample asynchronous to the data stream and very few samples per baud
  - 160Gsa/s (Keysight realtime scope) was the sampling rate which is 6.25ps between samples. The nominal baud rate was 53.125Gbaud which is 18.823529ps. So samples per baud = 3.0117647
  - This raw data was first oversampled by factor of 6, thus generating samples at 960GHz using **spline**.
    - Linear, Cubic were also considered but it was shown than spline got the best results in another study.
  - Then it was linearly interpolated for 53.125 and 32 samples per baud.

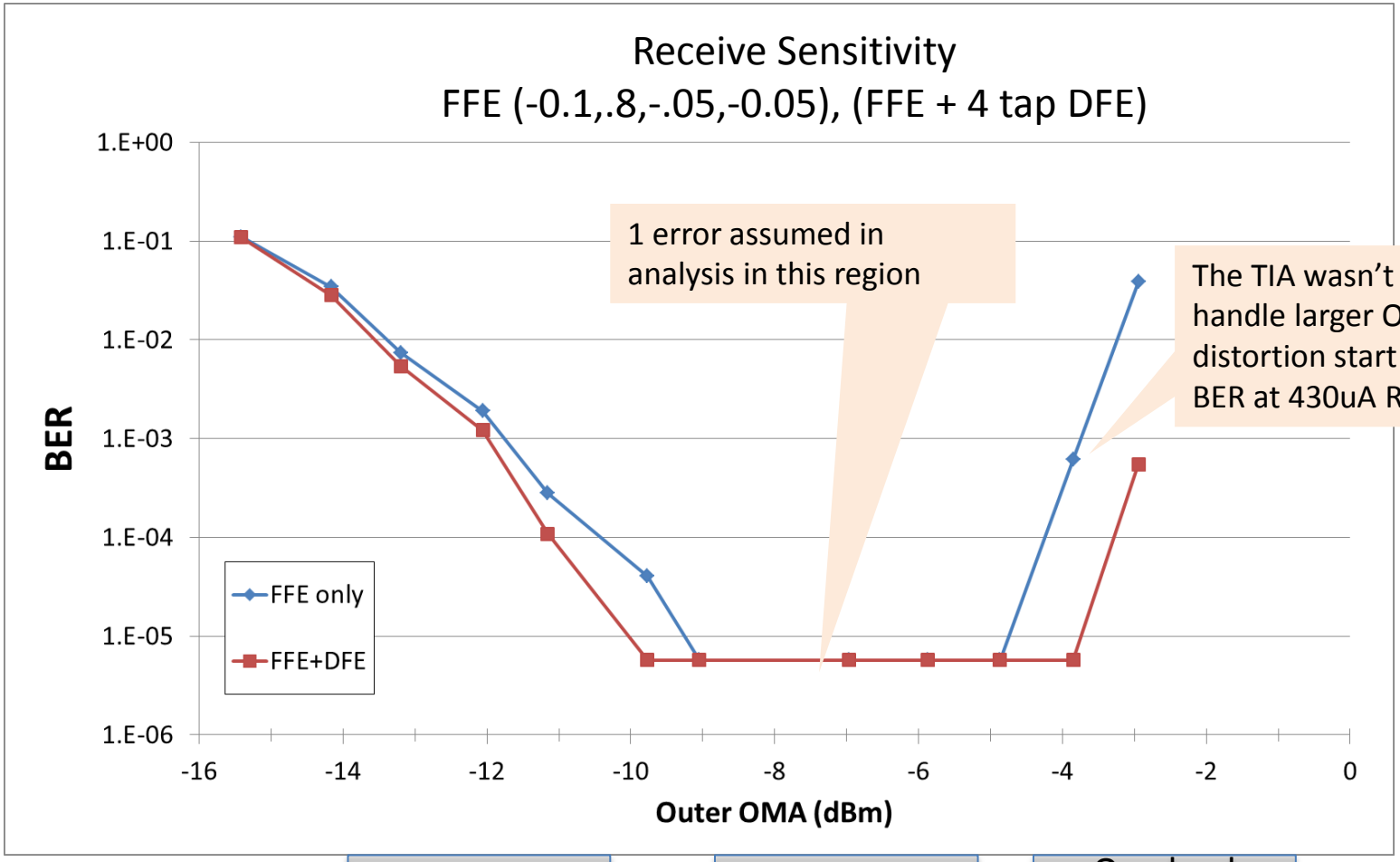
- PRBS15 pattern was used. More complex pattern might yield different results.
  - The LSB was delayed by 2 or 3 bits and then inverted.
- Memory depth was 2^19 = 524,288 samples, which covers about 174080 bits so best BER can be shown to be about 1/174080 = 5.74E-6

Post Processed Results by Cisco



no errors observed over the 174000 symbols

Post Processed Results by Macom

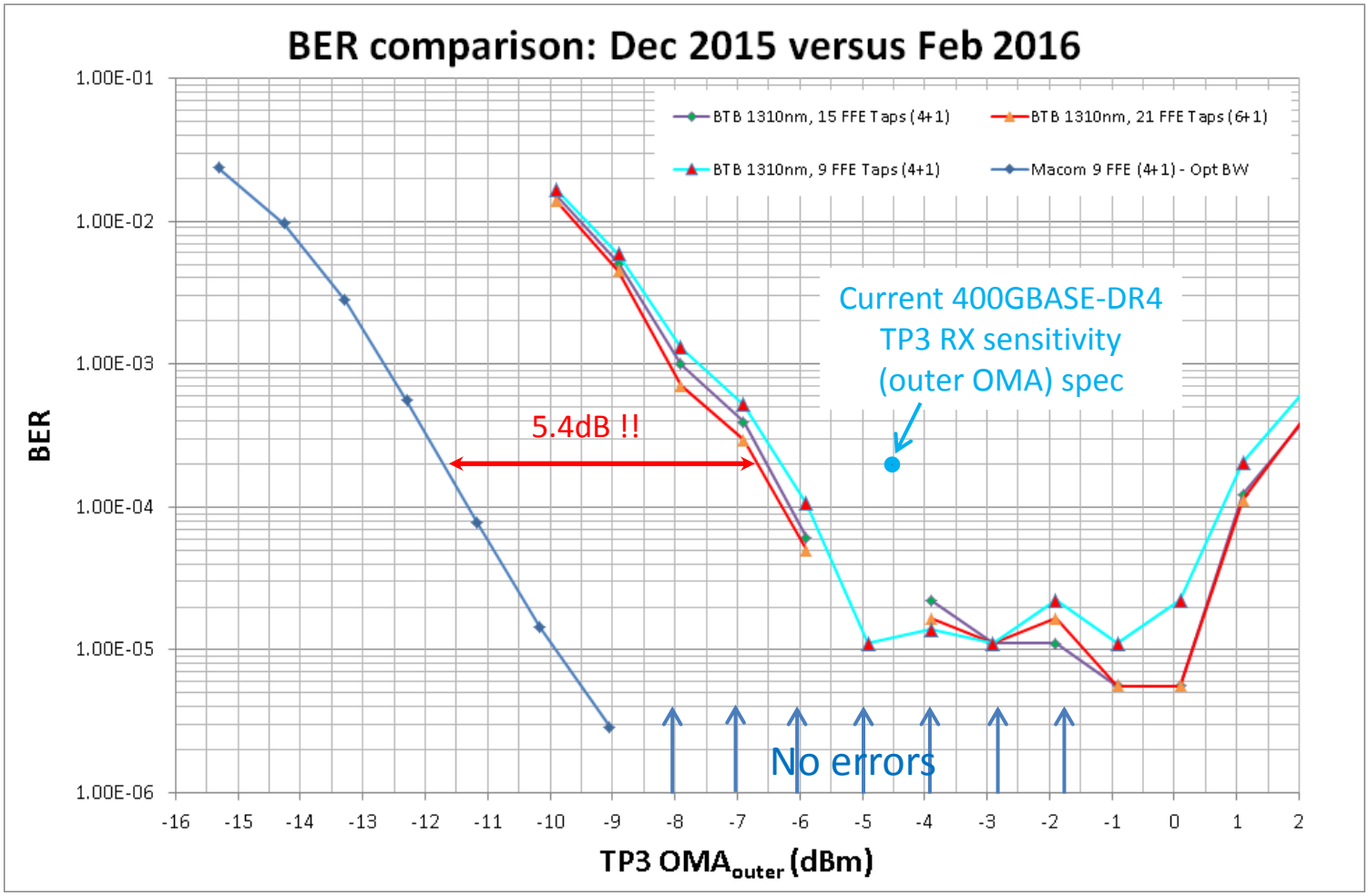


Conclusion

- New components (TX, low NEP of RX, AGC voltage swing) provide improvement to RX sensitivity
- RX sensitivity has margin compared to 100GBASE-FR proposal & 400GBASE-DR4 specification
- Waveform data can be made available for others to analyze & assist in identifying reference equalizer
- Target to acquire longer patterns consistent with ieee reference patterns

BACKUP

53.1Gbaud: OMA_{outer} sensitivities comparison with previous experiments.



Measured more than 5dB OMA_{outer} RX sensitivity improvement with same equalization and PRBS !

Post Processed Results by Macom w/ Cisco data overlaid