120Gb/s/Lambda PAM4
2km MZM Experimental Results

IEEE P802.3bs 400Gb/sTask Force Meeting
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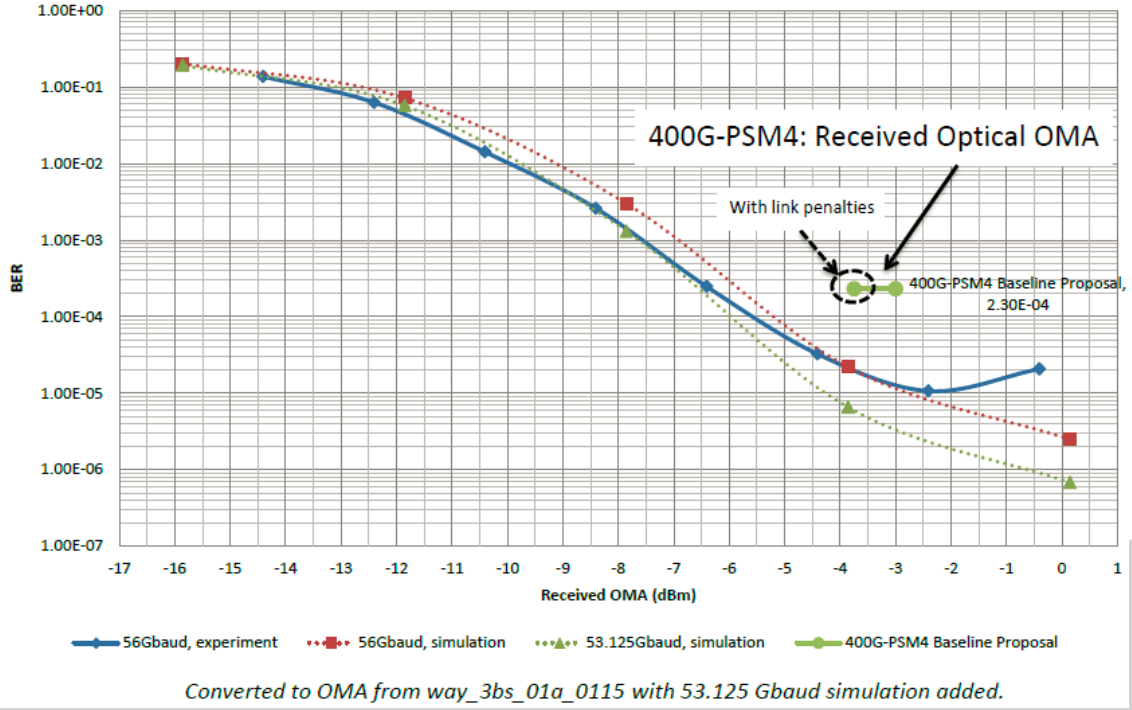
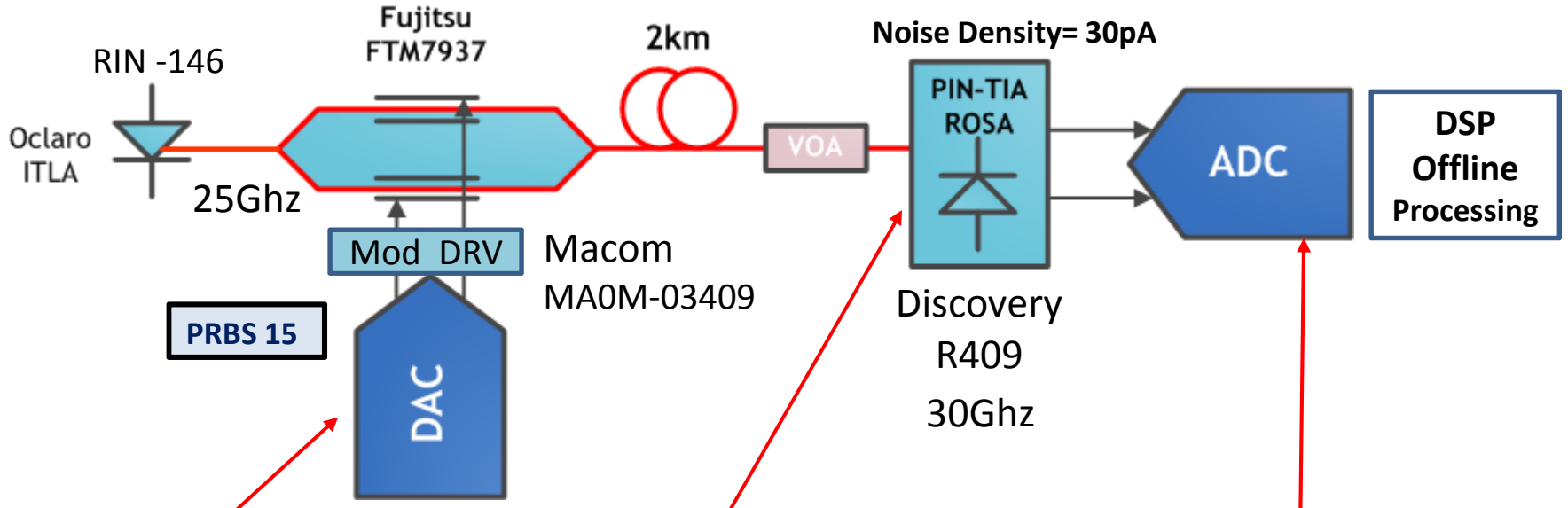
Objective

- **Address the Error Floor at High Optical Power**
  - Experimental 2km Data with CD Impairment
  - Show no error floor down to 2e-6 BER
    - Two decade margin over KP4 preFEC (2e-4)
- **Study root cause for Fish Hook pattern at high optical power.**



Converted to OMA from way_3bs_01a_0115 with 53.125 Gbaud simulation added.

60GB PAM4 - 2km Short Reach Setup
Offline Experiment Measurements

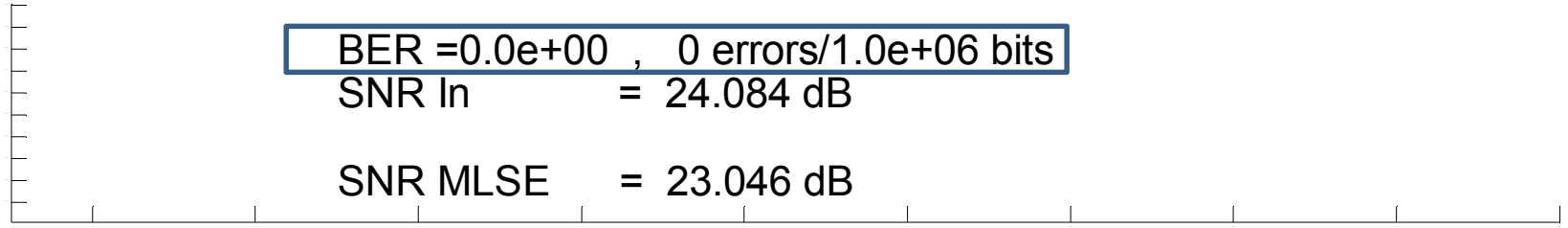


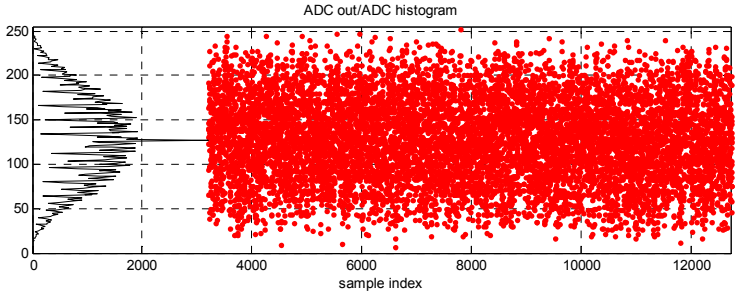
- DAC Bandwidth
  - 16Ghz
- ENOB 5.5b

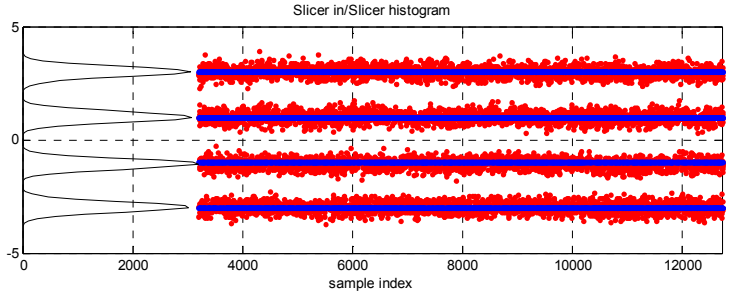
- 30pA/sqrt (Hz) – Measured using DCA
- 30Ghz BW (-3dB)
- Low Frequency Cutoff 50Khz
- Responsivity ~ .70 A/W
- Differential Transimpedance
  - Gain = 500ohms
- TIA Linearity supports +2dBm
  - 1dB Gain Compression
- AOP -1dm (-.5dBm OMA)
  - OMA Average power = 9.2e-4 W
  - .7 * 9.2e-4* 500 = 325mVpk-pk

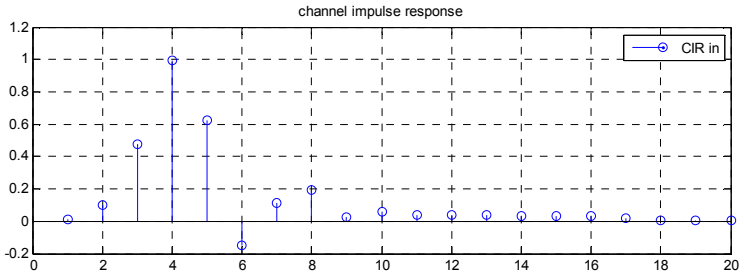
- ADC Max Memory
  - 1056k bits
  - Lowest BER @ 1e-6
- ADC Max Differential Swing
- Measured using 2GHz Sine Wave
  - ~ 300mVpk-pk Diff
- BW = 18GHz
- ENOB=5.5b

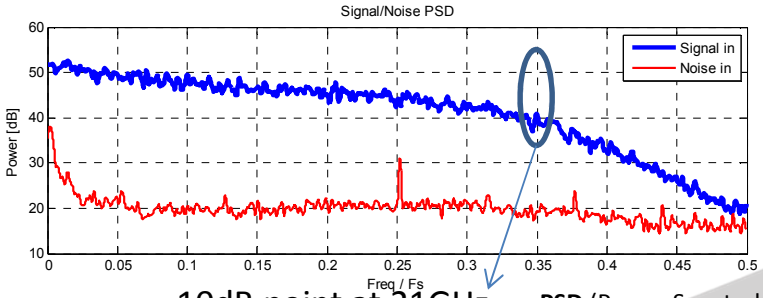
Recorded Electrical Signal (measured after the ADC)











10dB point at 21GHz

PSD (Power Spectral Density)
- Noise Estimated using Analytical Channel Model

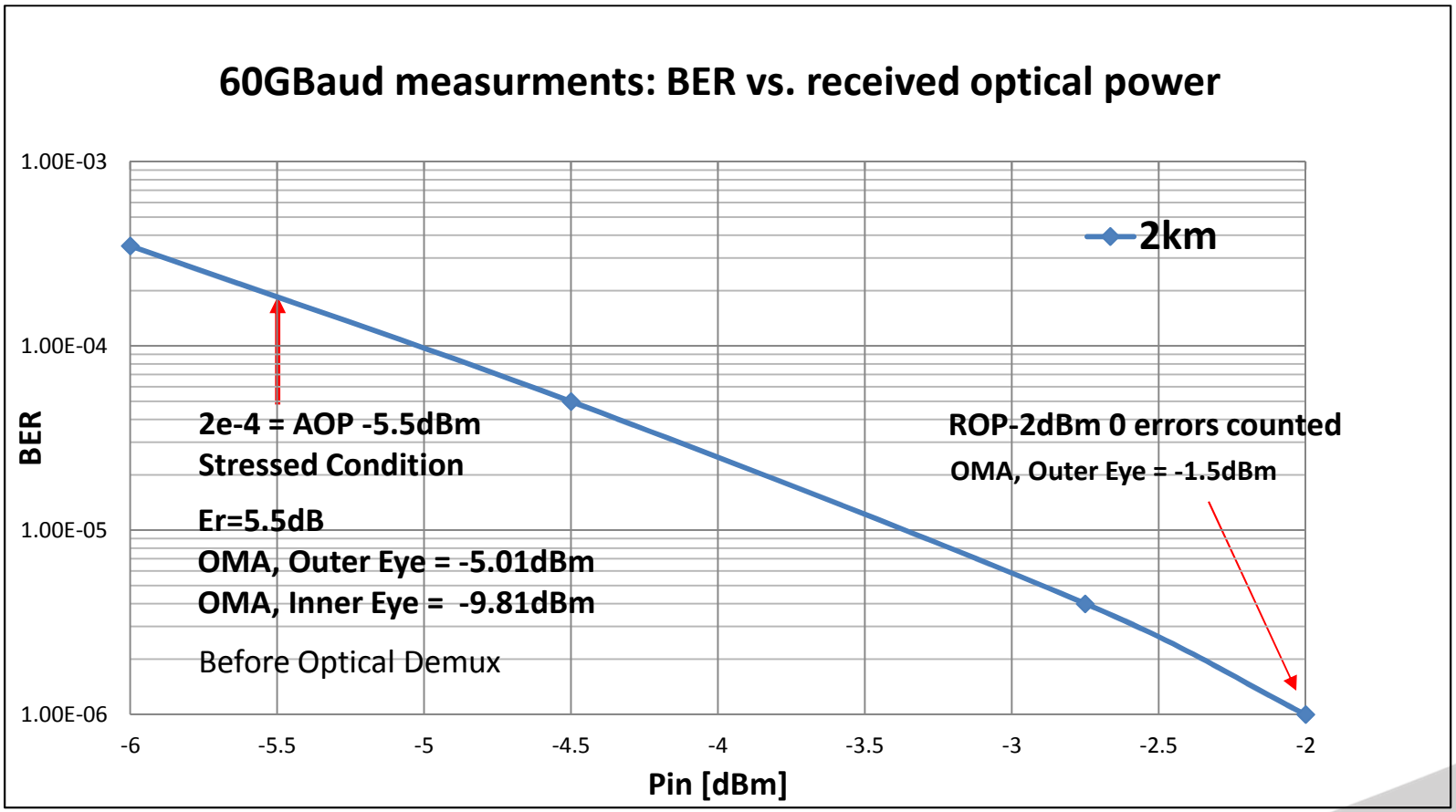
Figures, from top left clockwise:

Recorded signal and PDF >> Post-processed signal at mid-stage point of the DSP >>

PSD recorded signal single-side spectrum and estimated noise spectrum >> Channel Impulse Response (CIR)

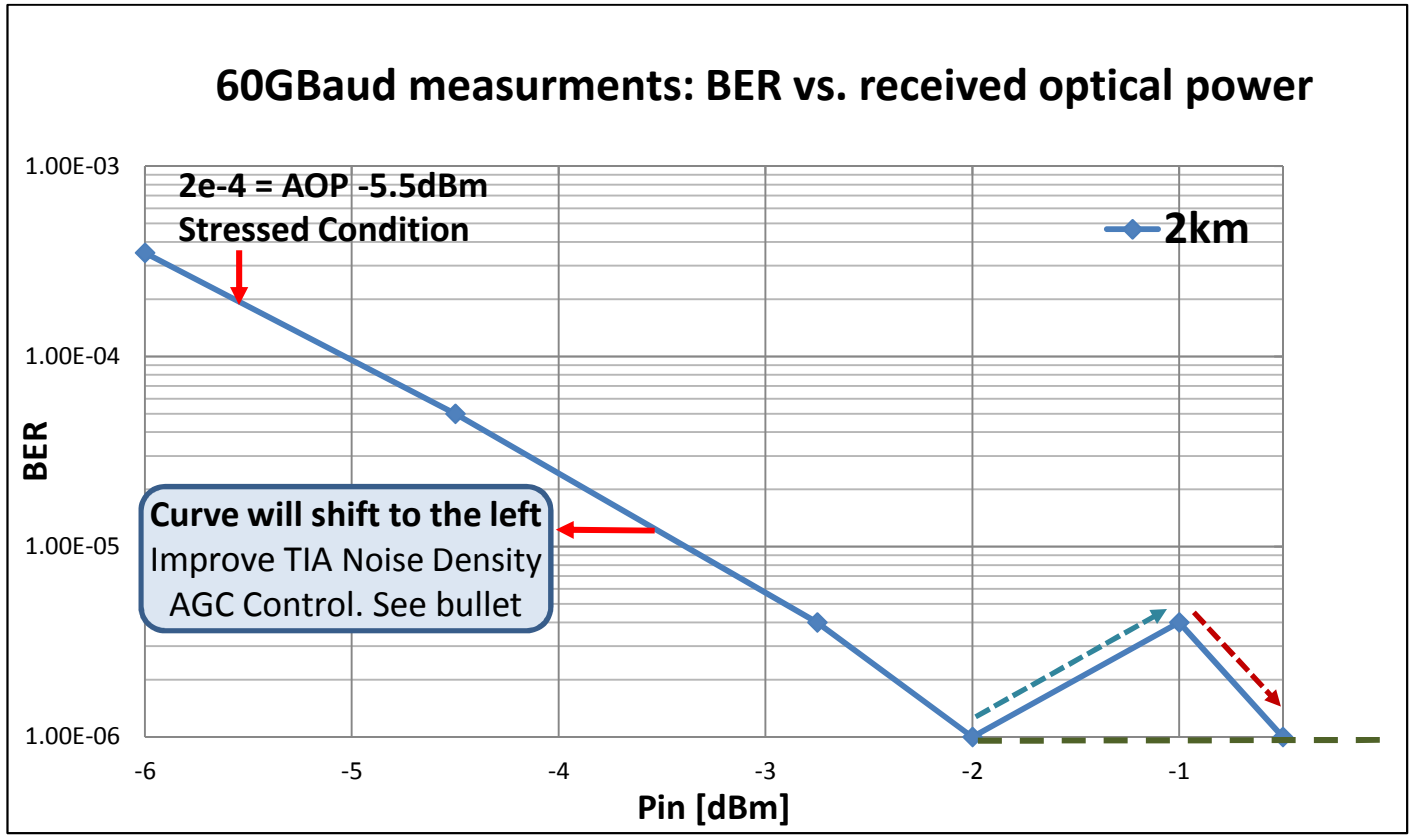
Measured BER vs. RX AOP – MZM 1550nm
RX AOP Range (-2dBm to -6dBm)

Er = 5.5dB
Measure @1/4BR



Noise Density = 30pA, CD =34ps/nm and Baud Rate =60GB

Measured BER vs. AOP – MZM 1550nm
RX AOP Range (-0.5dBm to -6dBm)



No PAD

Added 3dB Electrical PAD

(-2.0 to -0.50dBm) Zero Errors with 3dB Pad At 1e-6

- **AGC Control Loop is needed to improve the overall Dynamic Range**
- **Sensitivity Improvement (TIA Noise Density, TX Pre-Emphasis, AGC CTL)**
  - Plus Baud Rate Improvement from 60GB to 53GB
  - Plus lowering the CD from 34ps/nm down to 11.9ps/nm per stassar_3bs_01a_0315

Summary of Experimental Data

- **Shown experimental data for a 2km Link (Receive AOP -2dBm to -6dBm)**
  - Baud rate 60GB > DAC > MZM Modulator >2km link 1550nm > ROSA > ADC
  - CD = 34ps/nm
  - Test pattern PRBS 15
    - SSPR pattern vs. PRBS15
    - No SSPR pattern penalty experimentally confirmed for LF cut < 100kHz, way_3bs_01a_0115
  - ROSA with 30pA/sqrt (Hz)
    - -5.5dBm RX AOP at 2e-4 BER
    - High RX AOP -2dBm @ 1e-6
- **Shown experimental data for 2km 1550nm Link at -0.5dBm Receive AOP**
  - Fish Hook occurred at -1dBm RX average optical power
  - After further investigation the cause was the incompatibility between the Discovery ROSA Differential Output swing vs. ADC Diff input requirement
  - Added a 3dB electrical pad between the ROSA and ADC
    - Achieved 1e-6 BER at -0.5dBm AOP
  - Adding a simple AGC control loop will improve the overall dynamic range and eliminate this issue.
- **RX AOP Sensitivity will improve with lower noise density receivers..**
  - 30GHz TIA feasible based on industry trends tipper_3bs_01_0315
  - Reference tipper_3bs_01a_0515- Latest May 2015 presentation
- **Slope response and Sensitivity will improve using 53GB vs 60GB**
  - Plus Next Generation technology will improve the BW to provide greater margin
    - ADC / DACs, MOD Driver etc…

Conclusion

- **Showed experimental data down to 2e-6**
  - Objective of the 400G Task Force
- **Lab Data presented showed the root cause for fish hook at high optical power was due to the Dynamic range of the ADC.**
  - A simple AGC control loop with a Dynamic Range of 10dB optical (20dB Electrical) would resolve the fish hook condition
  - This AGC control loop would provide optimum voltage levels into the ADC for both Low optical Power (Sensitivity) and High optical power levels. It will improve both cases..
- **Improved RX sensitivity would be accomplished by the Following:**
  - Baud rate reduction from 60Gb to 53GB
  - Lowering the CD from 34ps/nm to 11.9ps/nm (stassar_3bs_01a_0315)
  - TX Pre-Emphasis
    - way_3bs_01a_0115 showed an improvement in RX sensitivity
  - Improved Noise Density from 30pA/sqrt (Hz) to 23pA/sqrt (Hz)
    - tipper_3bs_01_0315
  - AGC Control loop with a Dynamic range of 20dB will maximize ADC performance for Low and High RX optical power.

Thank you