Improved Results for both 56 and 112Gb/s PAM4 Signals

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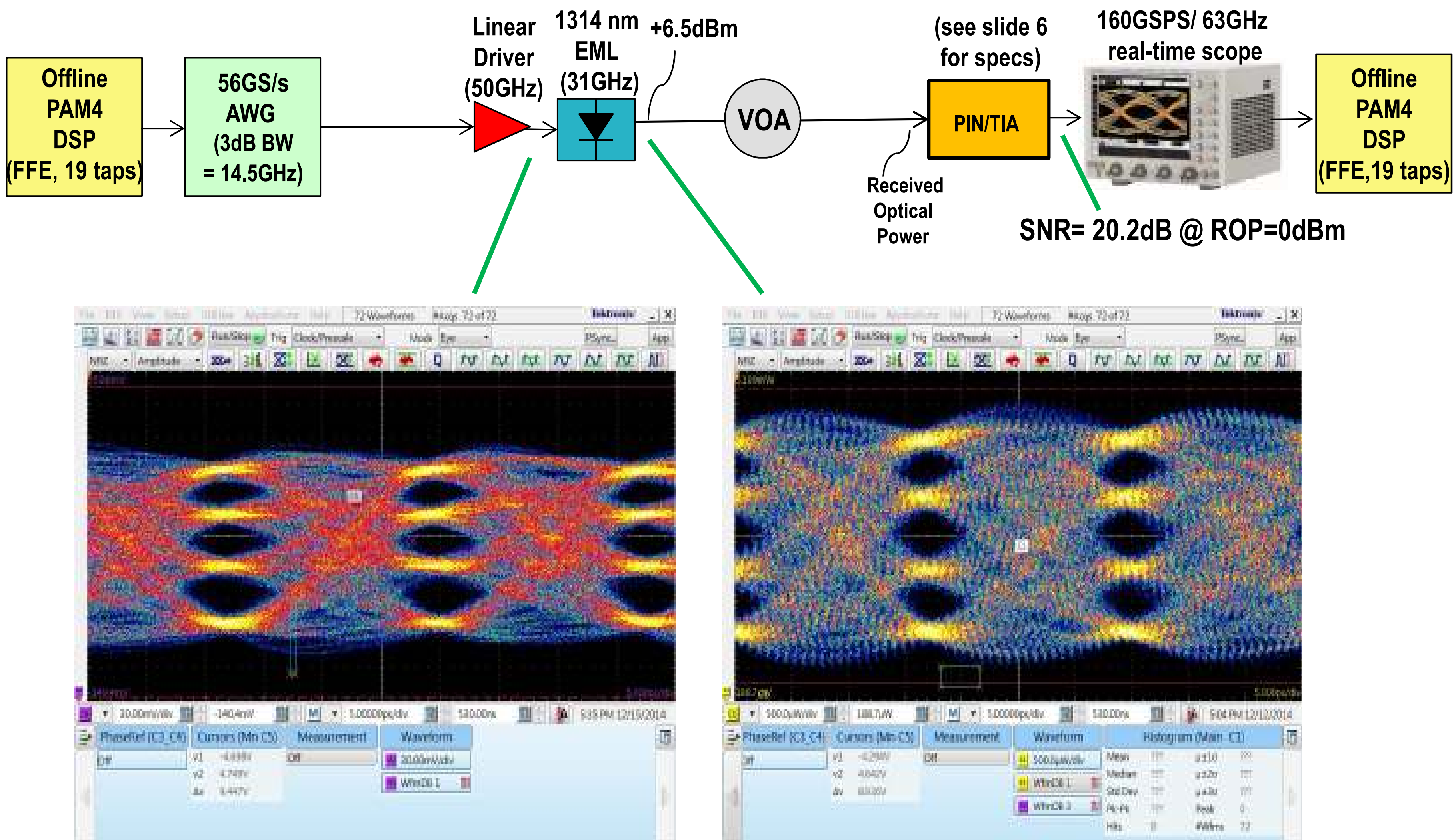
Goals

- Improve the BER vs ROP performance of 112Gb/s PAM4
- Set bandwidth requirements on electrical and optical components
- Investigate penalty caused by SSPR over PRBS15

112Gb/s PAM4

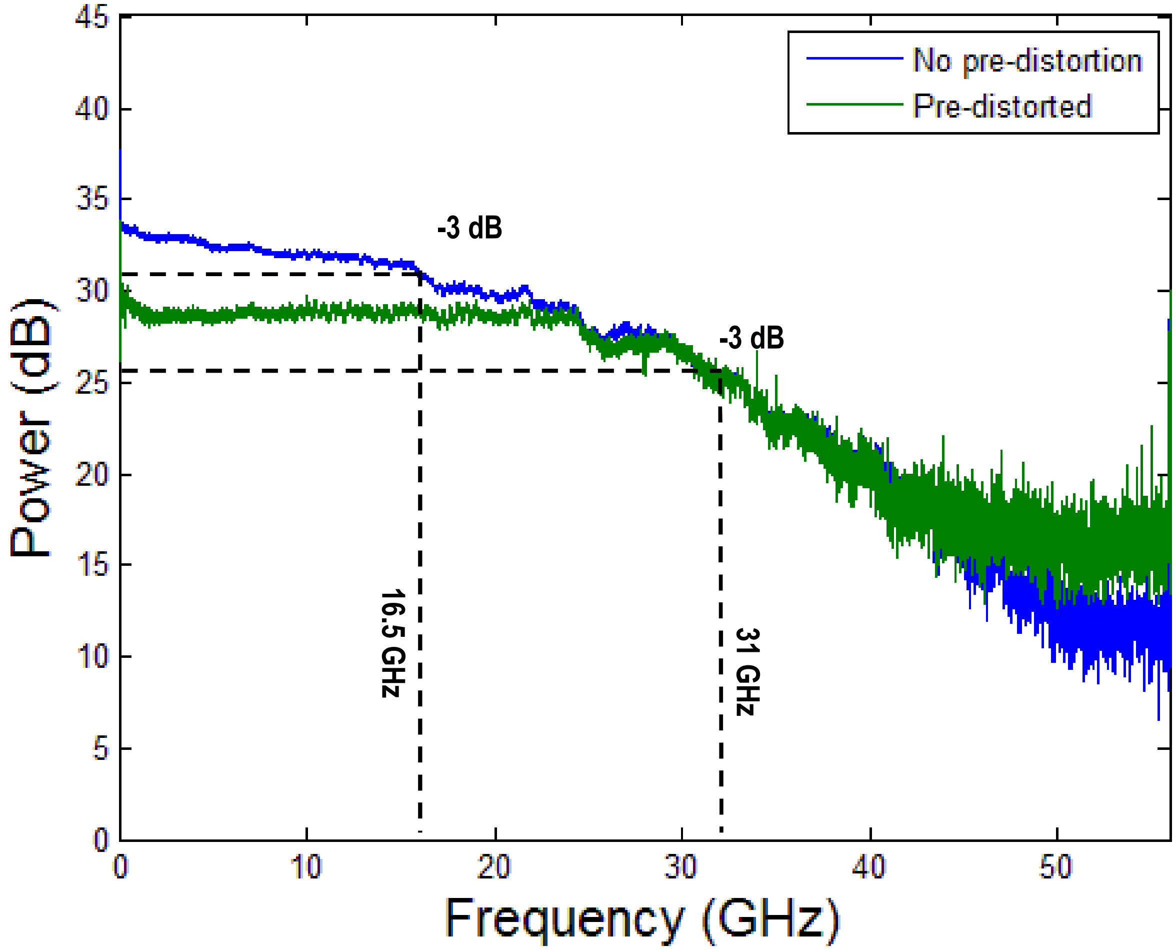
Single-wavelength 112Gb/s PAM-4 Experiment: Pre- and Post-DSP



SNR= 22.5dB

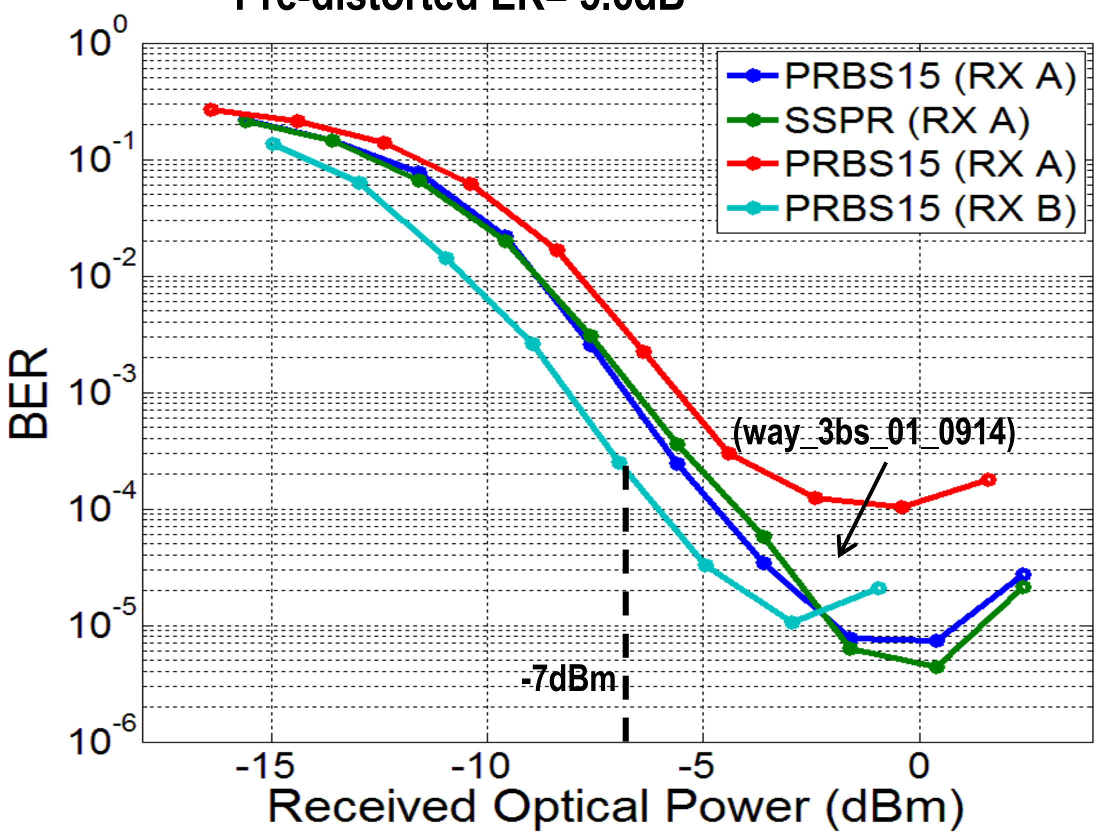
SNR= 22.0dB @ ROP= 4.5dBm

Overall Transmitter Bandwidth (DAC+Driver+EML)



112Gb/s PAM4 Experimental Results

Low-end cutoff frequency <50KHz
Pre-distorted ER= 5.6dB



	RX A	RX B
Responsivity (A/W)	0.4	0.7
3dB BW (GHz)	40	30
Spectral noise density (pA/√Hz)	40	35

2~3 times BER improvement can be done by further equalizing the three inner eye amplitudes

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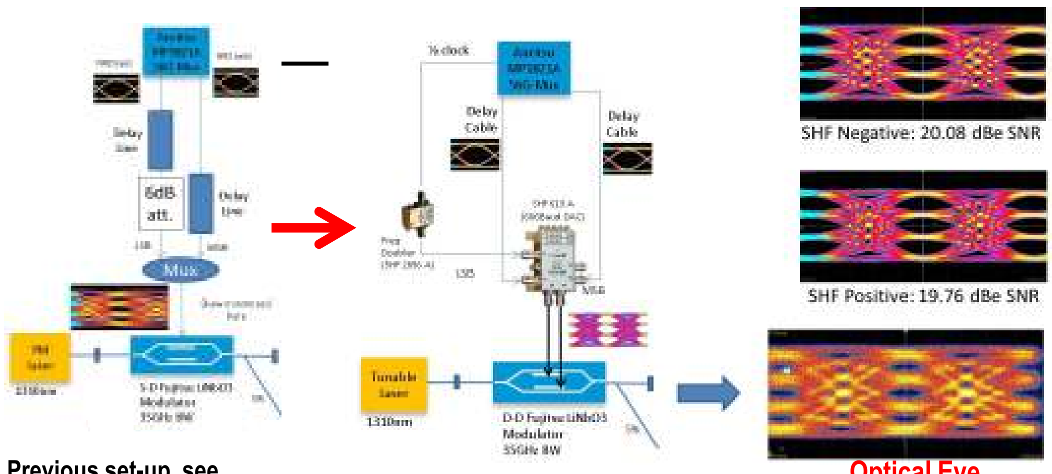
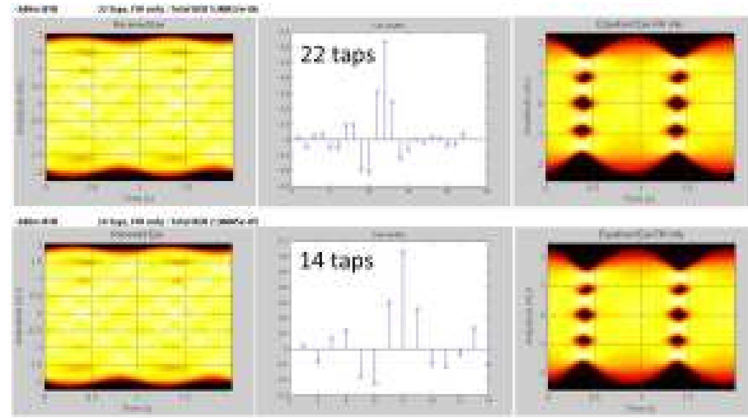
Cisco Results with LiNb03 modulator PAM 4 TX



Previous set-up, see *mazzini_01a_0814_smf.pdf*

SHF 613 A and 2856 A provided a better electrical signal and allow dual drive modulator usage to generate the 56GBaud optical signal.

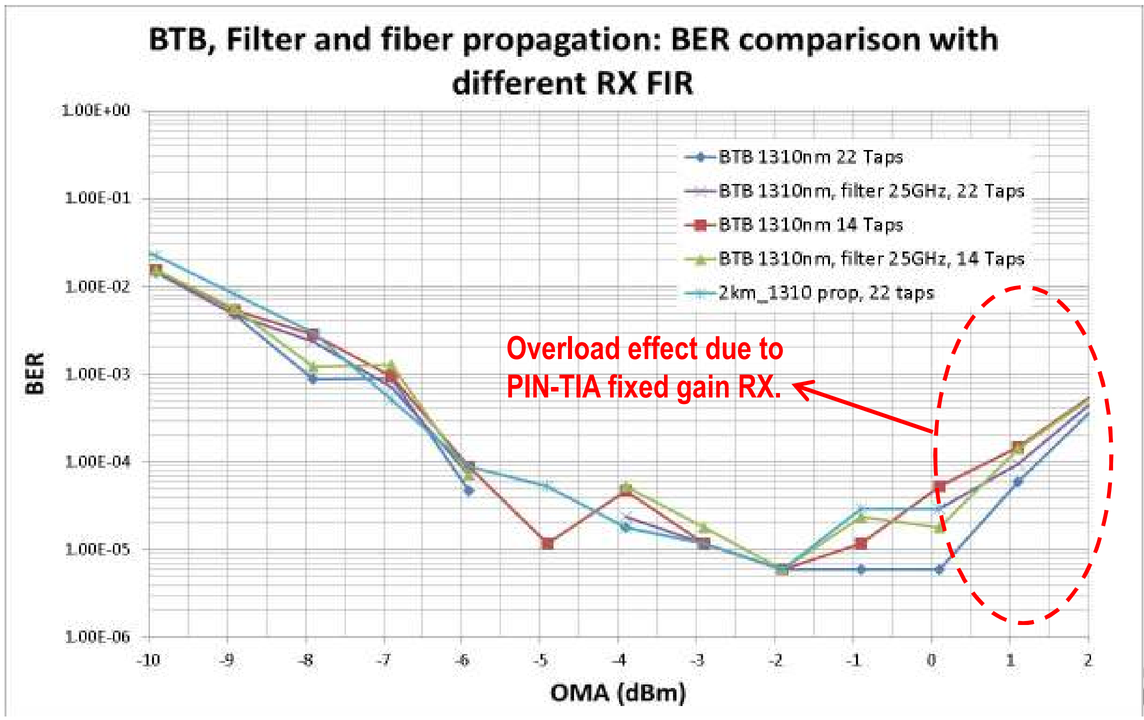


14 (T/2 spaced) RX FIR equalizer is now enough to equalize the signal.

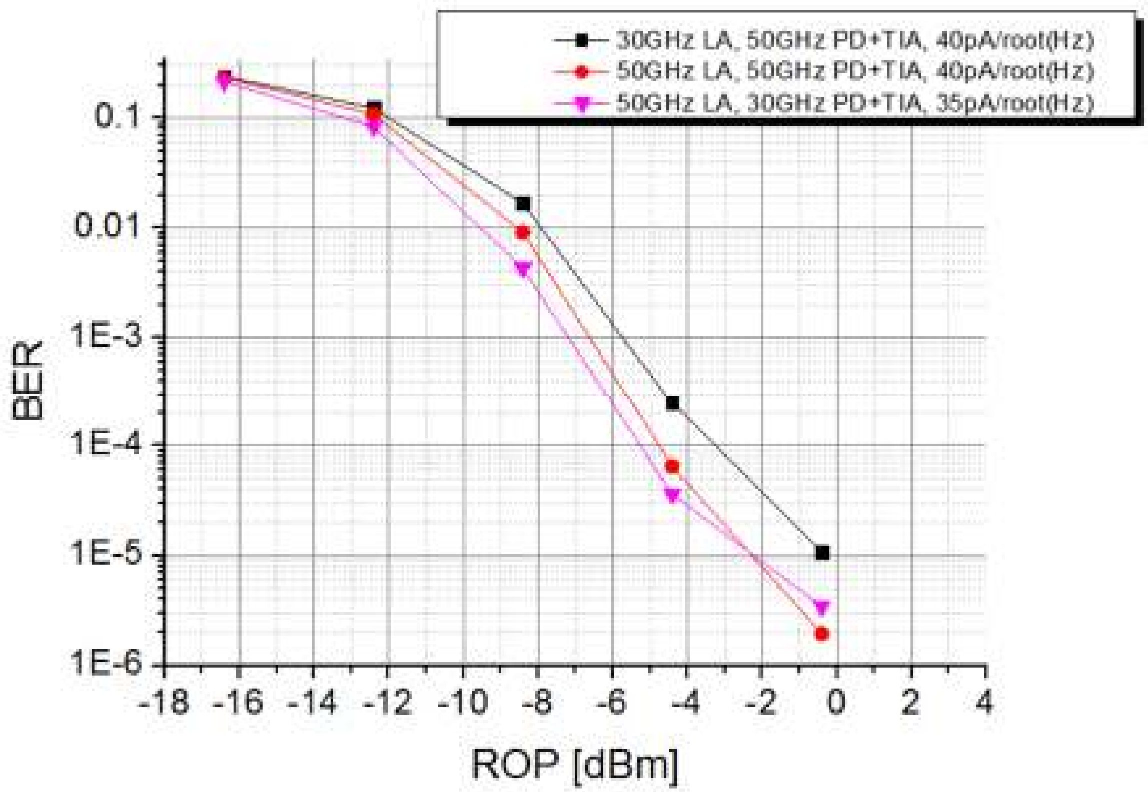
BER floor < 1E-5, one decade better than previous results, as forecasted by Alan (see tipper_01_3bs_1114), in line with Winston's results.

-6dBm OMA (ER=6dB) at 1E-4 BER.

No penalty observed between BTB and fiber propagation (≈ 1dB penalty at 50ps/nm dispersion was measured)



Simulation Match With Experimental Results



DAC 3dB BW=14.5GHz, 2nd order Bessel for DAC

TX linear AMP BW=30GHz/50GHz

EML BW=32GHz

SNR before E/O =22.5dB, ER=6dB

WL=1310nm

RIN=-145dB/Hz

RX input noise density=35/40 pa/Hz^(1/2)

PD+TIA BW=30/50GHz, PD Respons.=0.8A/W

5th-order Bessel approximation of Tx amp, E/O, PD+TIA

5 bits A/D ENOB, 5^{th} order Bessel A/D, 23GHz BW A/D

19 taps pre-correction T-spaced, 21-taps FFE Rx T/2-spaced

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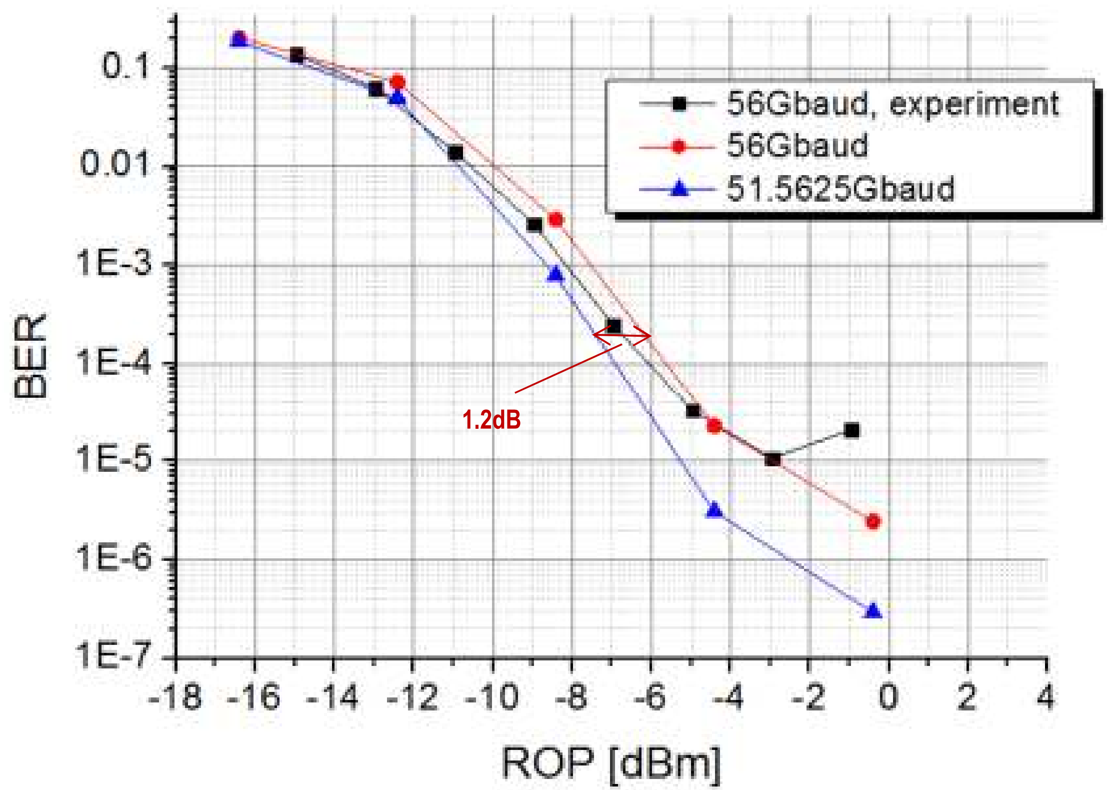
56 → 51.5625Gbaud: Receiver Sensitivity Improvement



Baud rate = 56Gbaud or 51.5625Gbaud

DAC 3dB BW=16.5GHz, 2nd order Bessel for DAC

TX linear AMP BW=30GHz

EML BW=32GHz

SNR before E/O =22.5dB, ER=6dB

RIN=-145dB/Hz

RX input noise density=30pA/Hz^(1/2)

PD+TIA BW=32GHz, PD responsivity=0.75, 400Ohm transimpedance

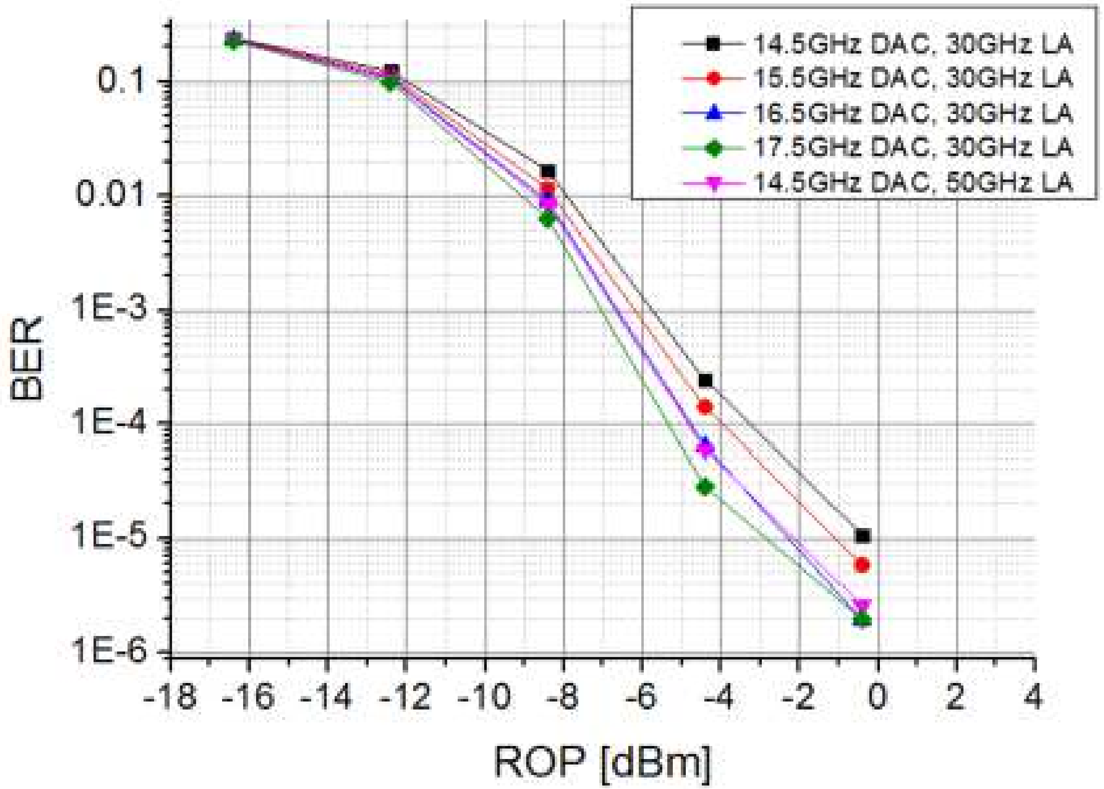
5th-order Bessel approximation of Tx amp, E/O, PD+TIA

5 bits A/D ENOB, 5th order Bessel A/D, 20GHz BW A/D

19 taps pre-correction T-spaced, 21-taps FFE Rx T/2-spaced

Receiver sensitivity improved by 1.2dB @ BER=2.1e-4 when the baud rate is lowered from 56 to 51.5625Gbaud

DAC and Linear Amplifier Bandwidth Tradeoff (Simulation)



DAC 3dB BW is varied, 2nd order Bessel for DAC

TX linear AMP BW=30GHz/50GHz

EML BW=32GHz

SNR before E/O =22.5dB, ER=6dB

WL=1310nm

RIN=-145dB/Hz

RX input noise density=40 pa/Hz^(1/2)

PD+TIA BW=50GHz, PD Respons.=0.8A/W

5th-order Bessel approximation of Tx amp, E/O, PD+TIA

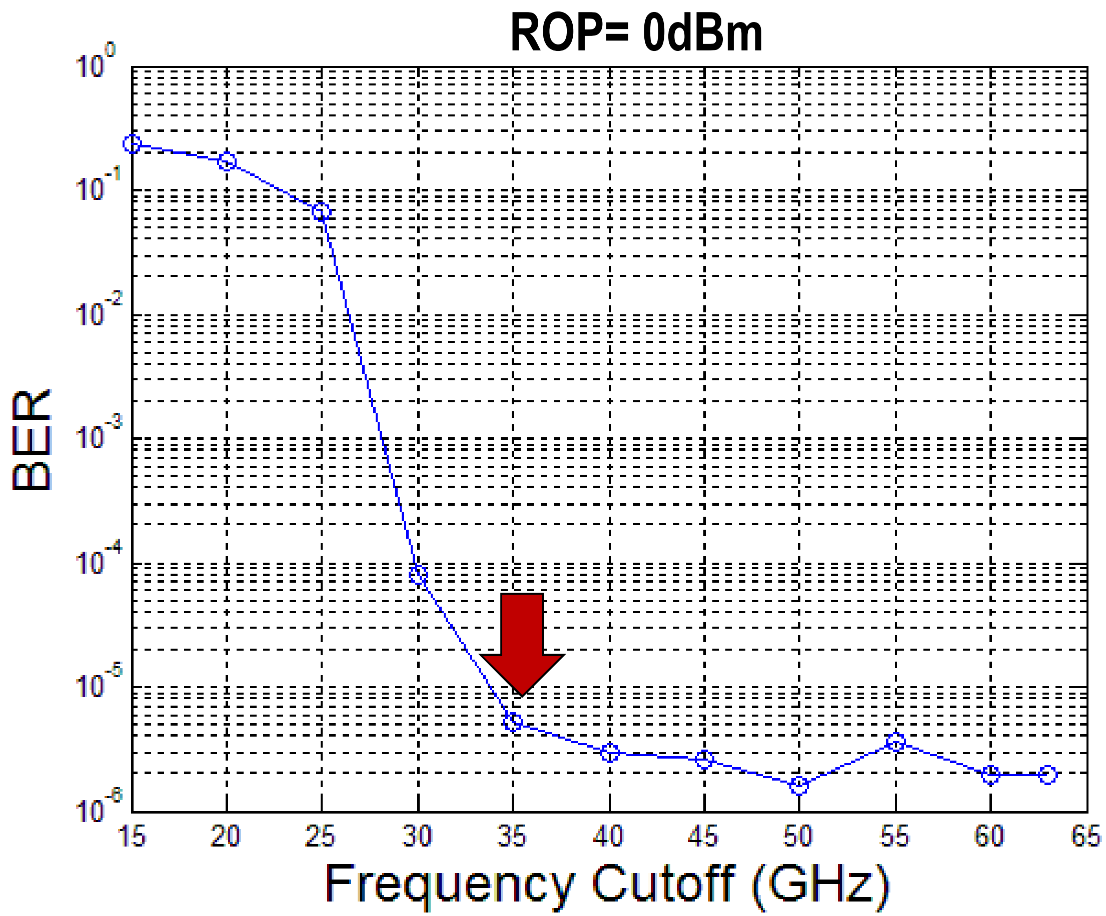
5 bits A/D ENOB, 5th order Bessel A/D, 23GHz BW A/D

19 taps pre-correction T-spaced, 21-taps FFE Rx T/2-spaced

With pre-equalization, 16.5GHz DAC + 30GHz LA can achieve the same BER performance as in the experiment

Measured 112Gb/s PAM4 BER vs ADC bandwidth (brick-wall)

- Pre-compensated SSPR
- Real-time scope frequency cutoff



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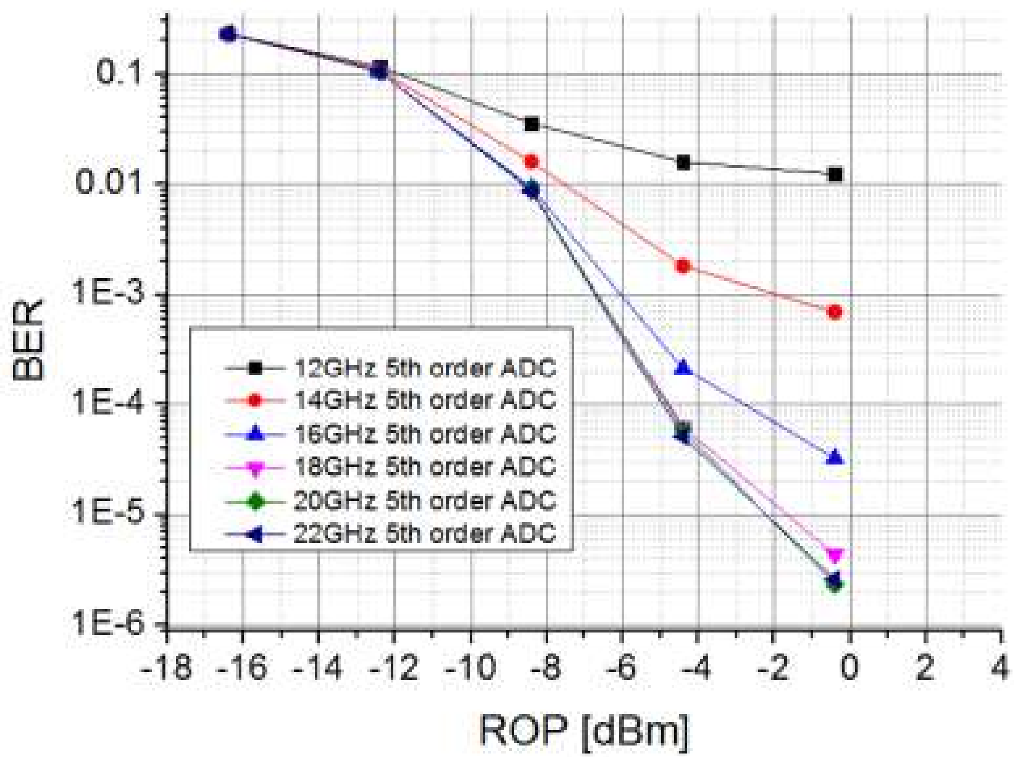
112Gb/s PAM4 BER vs ADC bandwidth (Bessel 5th-order, Simulation)



DAC 3dB BW=16.5GHz, 2nd order Bessel for DAC

TX linear AMP BW=30GHz

EML BW=32GHz

SNR before E/O =22.5dB, ER=6dB

WL=1310nm

RIN=-145dB/Hz

RX input noise density=40 pa/Hz^(1/2)

PD+TIA BW=50GHz, PD Respons.=0.8A/W

5th-order Bessel approximation of Tx amp, E/O, PD+TIA

5 bits A/D ENOB, 5th order Bessel A/D, A/D BW is varied

19 taps pre-correction T-spaced, 21-taps FFE Rx T/2-spaced

Unlike brick-wall shaped, 5th-order Bessel-shaped ADC with a bandwidth >18GHz is sufficient

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56Gb/s PAM4

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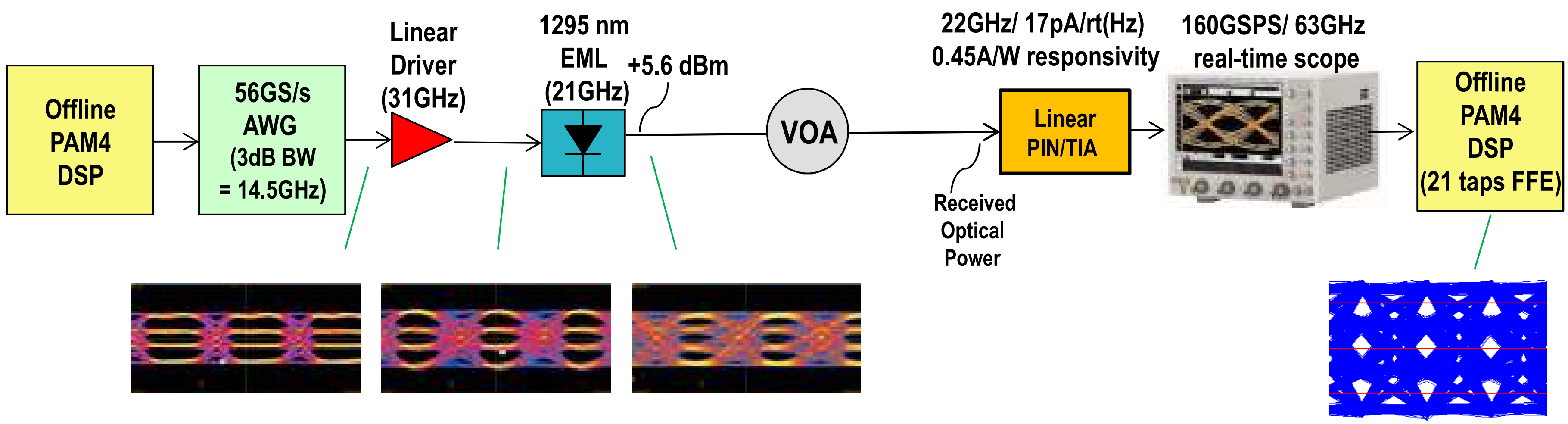
Experimental Setup



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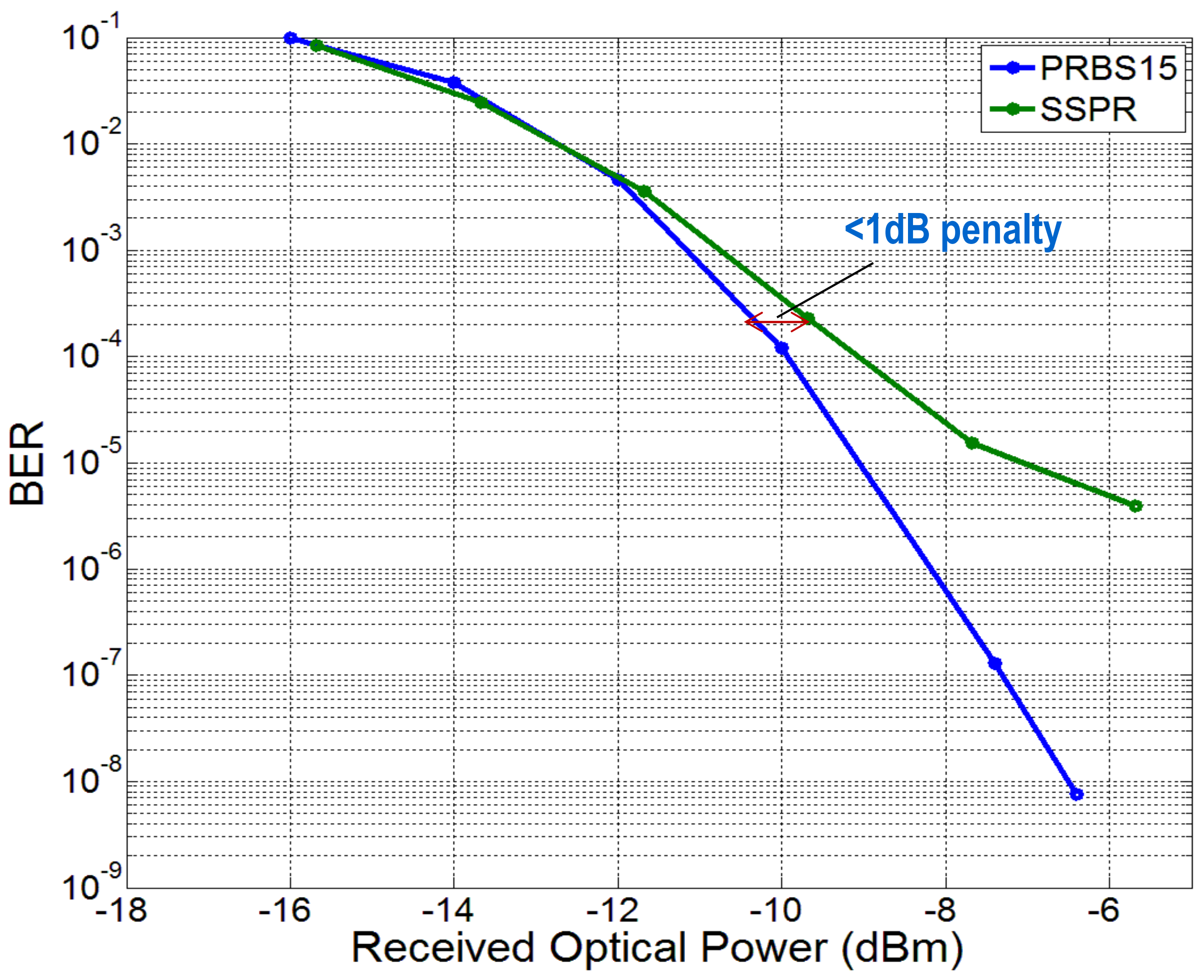
56Gb/s PAM4 BER vs ROP



TX
Extinction Ratio = 6.5 dB

RX
Low-end cutoff< 50KHz
Responsivity=0.31 A/W

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Summary

- **112Gb/s PAM4**
  - – Using practical electrical and optical components, an error floor < 1e-5 and a receiver sensitivity of -7dBm (average power @ BER=2.1e-4) can be achieved by using pre- and post-FFE equalizations
  - – Pre-equalized TX bandwidth is ~30GHz, and receiver bandwidth is ~30GHz
  - – DAC bandwidth >16.5GHz, ADC bandwidth >18GHz
  - – No BER penalty is observed for SSPR over PRBS15 using components with < 100KHz cutoff frequencies

- **56Gb/s PAM4**
  - \- < 1dB ROP penalty is observed at a BER of 2.1e-4 comparing SSPR with PRBS15 for components with <100KHz low-end cutoff frequencies

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