40Gbit/s Coherent Optical Receiver Using a Costas Loop

***H. Park**, M. Lu, E. Bloch, T. Reed, Z. Griffith, L. Johansson, L. Coldren, and M. Rodwell*

University of California at Santa Barbara

Amsterdam

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Introductions

Motivations

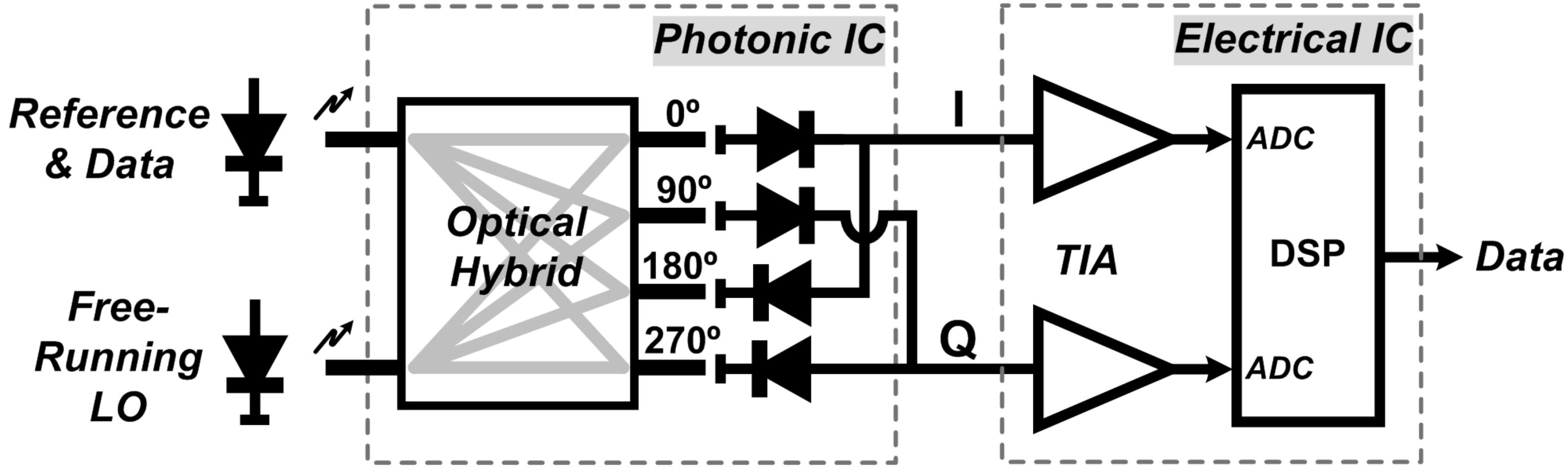
- Higher Spectral Efficiency – QPSK / multi-level QAMs
- Higher Data Rates – 40Gbit/s, 100Gbit/s, and even higher
- Higher Receiving Sensitivity

Recent Coherent Optical Communication

- Coherent detection based on DSP
  - Local oscillator (LO) laser
  - Polarization diversity 90° optical hybrid
  - Balanced detectors
  - High speed analog to digital convertor (ADC)
  - High speed digital signal processing (DSP)

Coherent Optical Communications

Coherent Optical Receiver – I



- **Advantages:**
  - Multi-level constellations
  - High data rate
  - Phase managements
  - Polarization managements
- **Dis-advantages:**
  - Electrical circuit complexity
  - Speed limitations
  - Cost issues
  - Power consumptions

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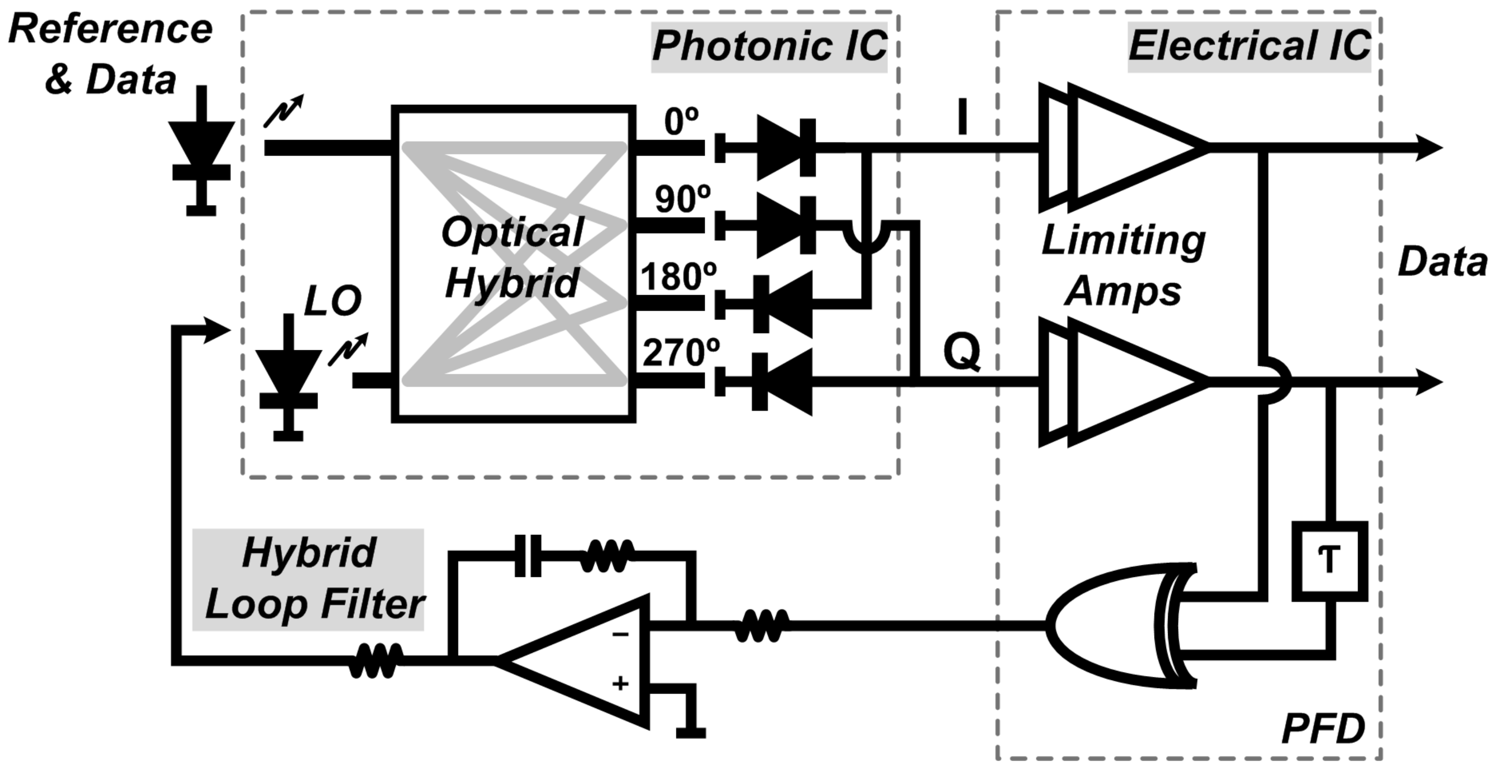
Coherent Optical Communications

Coherent Optical Receiver – II

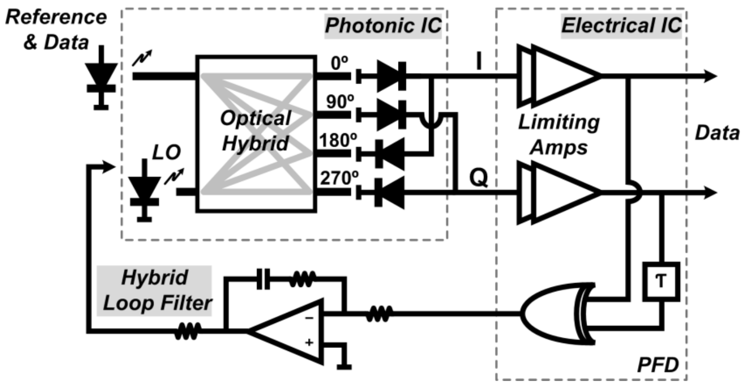


- Homodyne OPLL based coherent receiver – <u>*Costas Loop*</u>
- Optical carrier recovering technique

Requiring Stable OPLL

Coherent Optical Communications

Coherent Optical Receiver – II



- **Challenges:**
  - Long loop delays (*1ns)
  - Narrow loop bandwidth (*100MHz)
  - Transmitting and LO lasers' linewidth
  - Sensitive by external variations
- **Solutions:**
  - Integrated circuits (photonic IC, electrical IC)
  - Feed-forward loop filter topology
  - Minimizing Interconnection delays
  - Digitally operating feedback system

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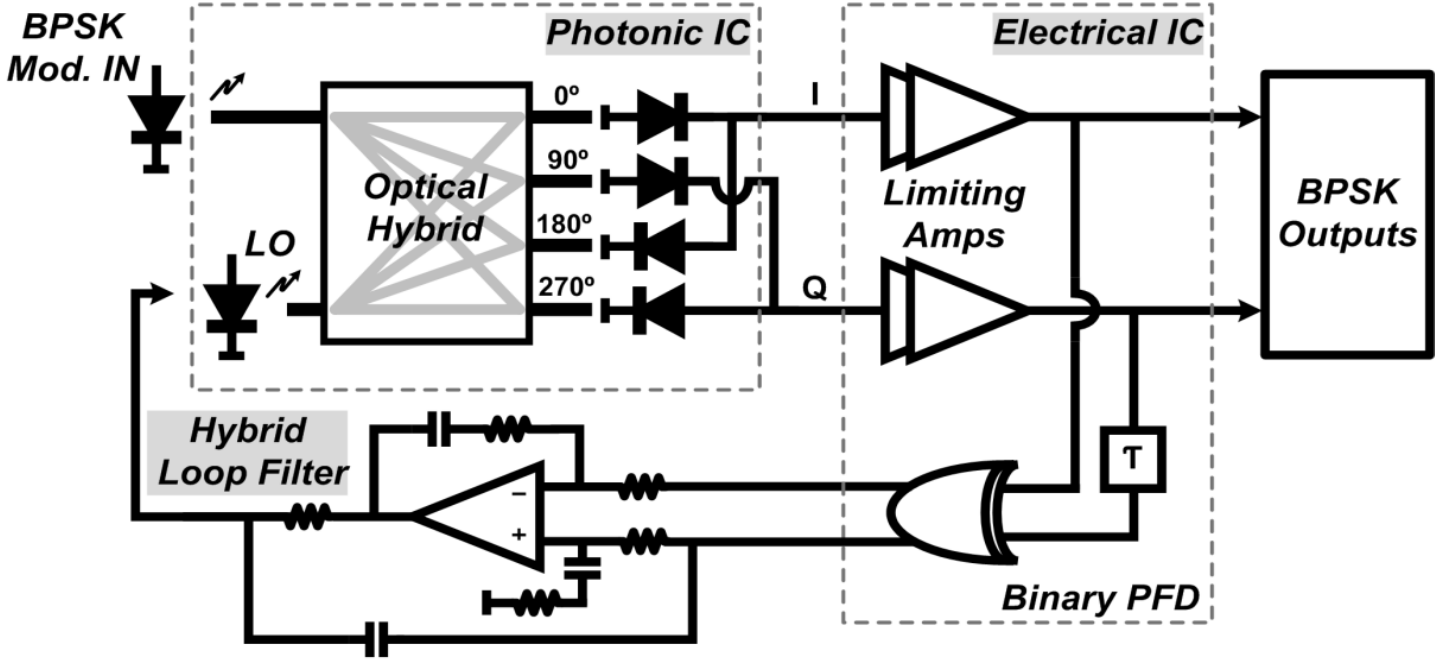
Phase Locked Coherent BPSK Receiver

Homodyne OPLL + Costas Loop



- Three blocks: photonic IC, electrical IC, and hybrid loop filter
- High speed BPSK data demodulations

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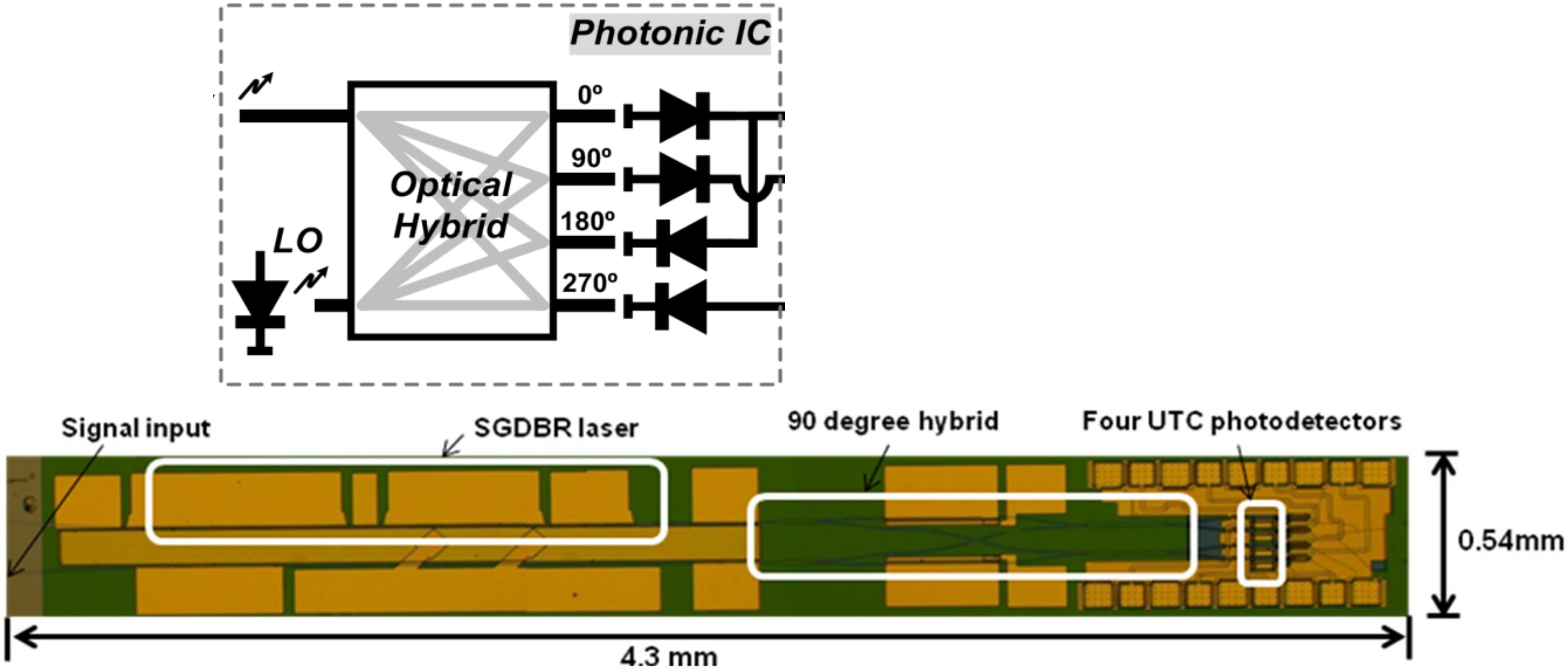
Phase Locked Coherent BPSK Receiver

Photonic IC



- SG-DBR laser – 40nm tunable ranges
- 90° optical hybrid
- 4 un-balance photodiodes – 30GHz bandwidth

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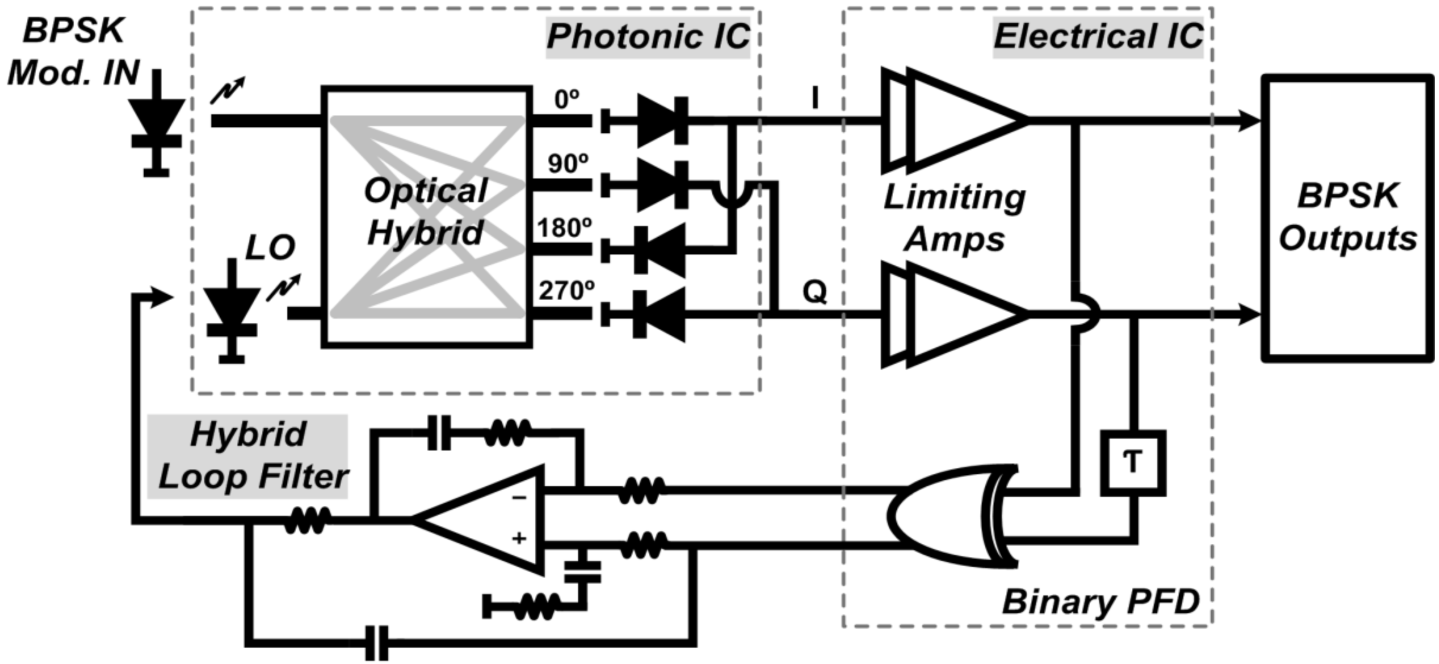
Phase Locked Coherent BPSK Receiver



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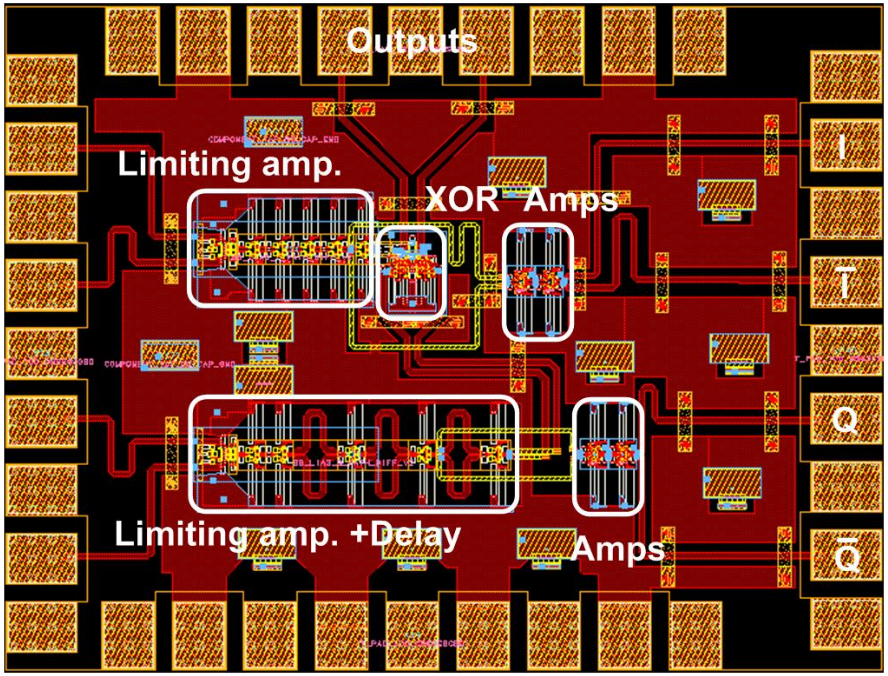
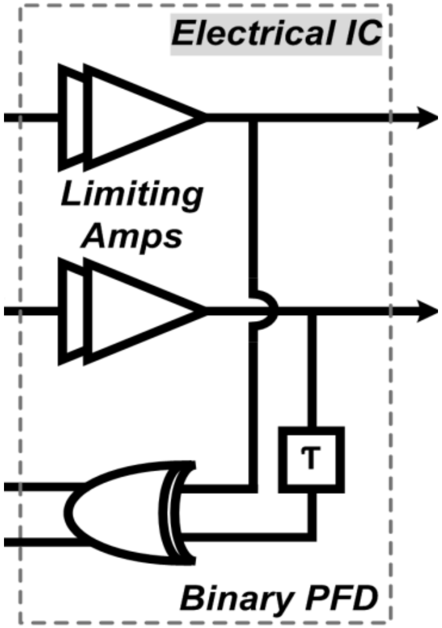
Phase Locked Coherent BPSK Receiver

Electrical IC





Teledyne's
500nm InP HBT
300GHz ft / fmax

- Limiting amplifiers
- Phase / frequency detector (PFD) – XOR + delay line

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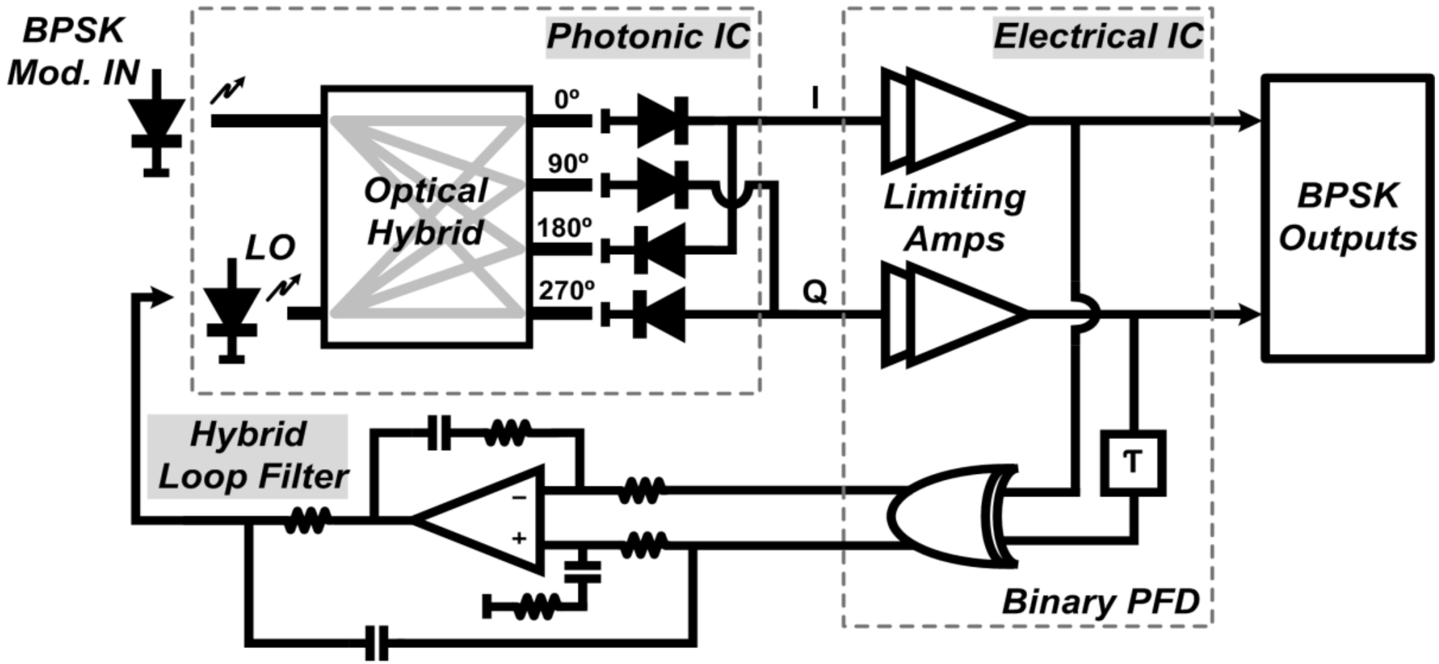
Phase Locked Coherent BPSK Receiver



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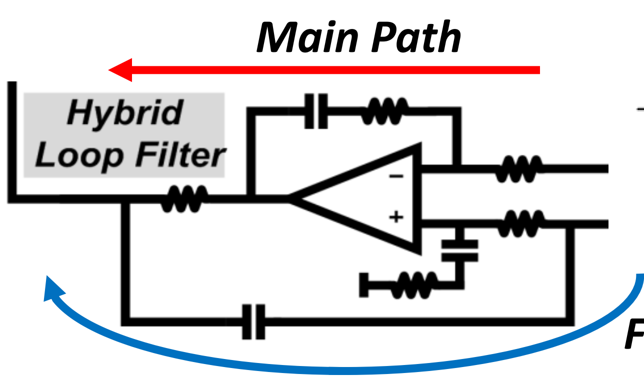
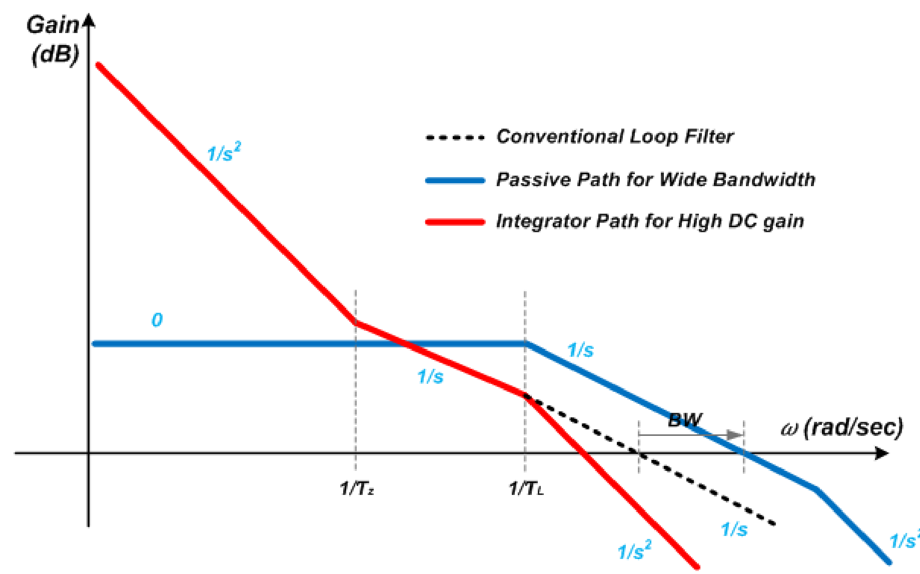
Phase Locked Coherent BPSK Receiver

Loop Filter

** Challenges:*
1. OP amp has lots of delays
2. OP amps bandwidth is limited (100MHz)



Open Loop Responses



- Main path by integrator – high gain at DC and low frequencies
- Feed-forward path – passive capacitor component

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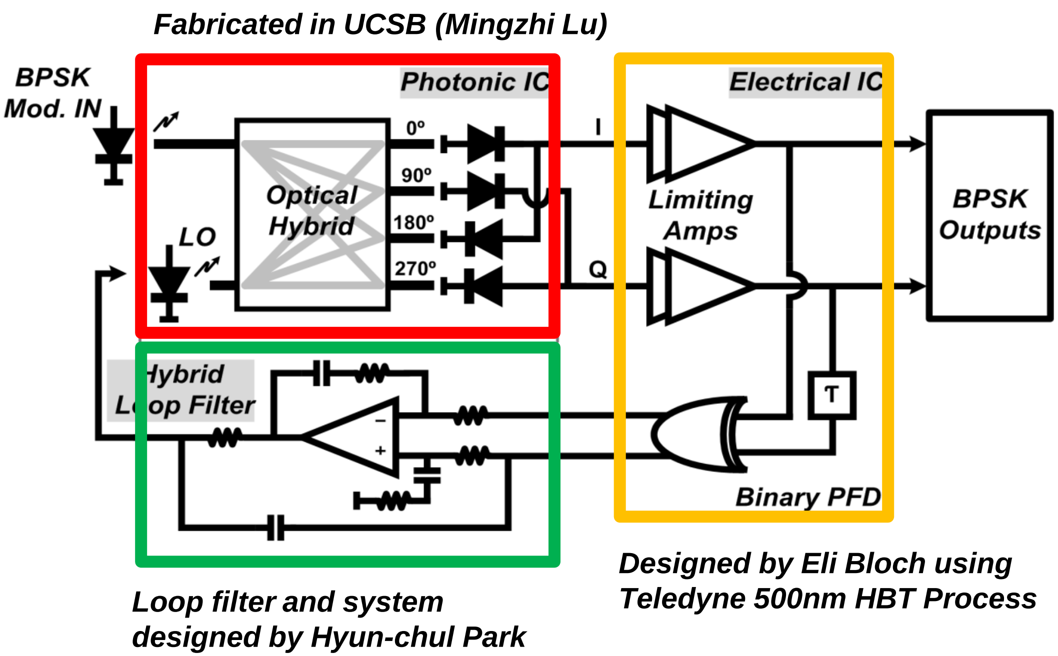
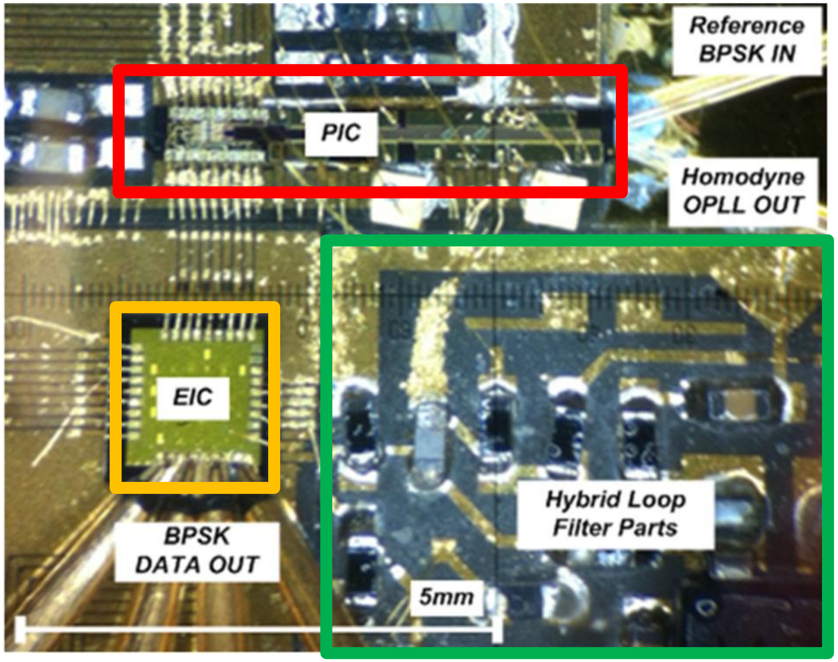
Phase Locked Coherent BPSK Receiver

Integration on a Single Carrier board





- Compact chip size of 10 x 10mm^2
- Total delay (120ps)=PIC (40ps)+EIC (50ps)+Interconnection (30ps)

1GHz Loop Bandwidth is feasible

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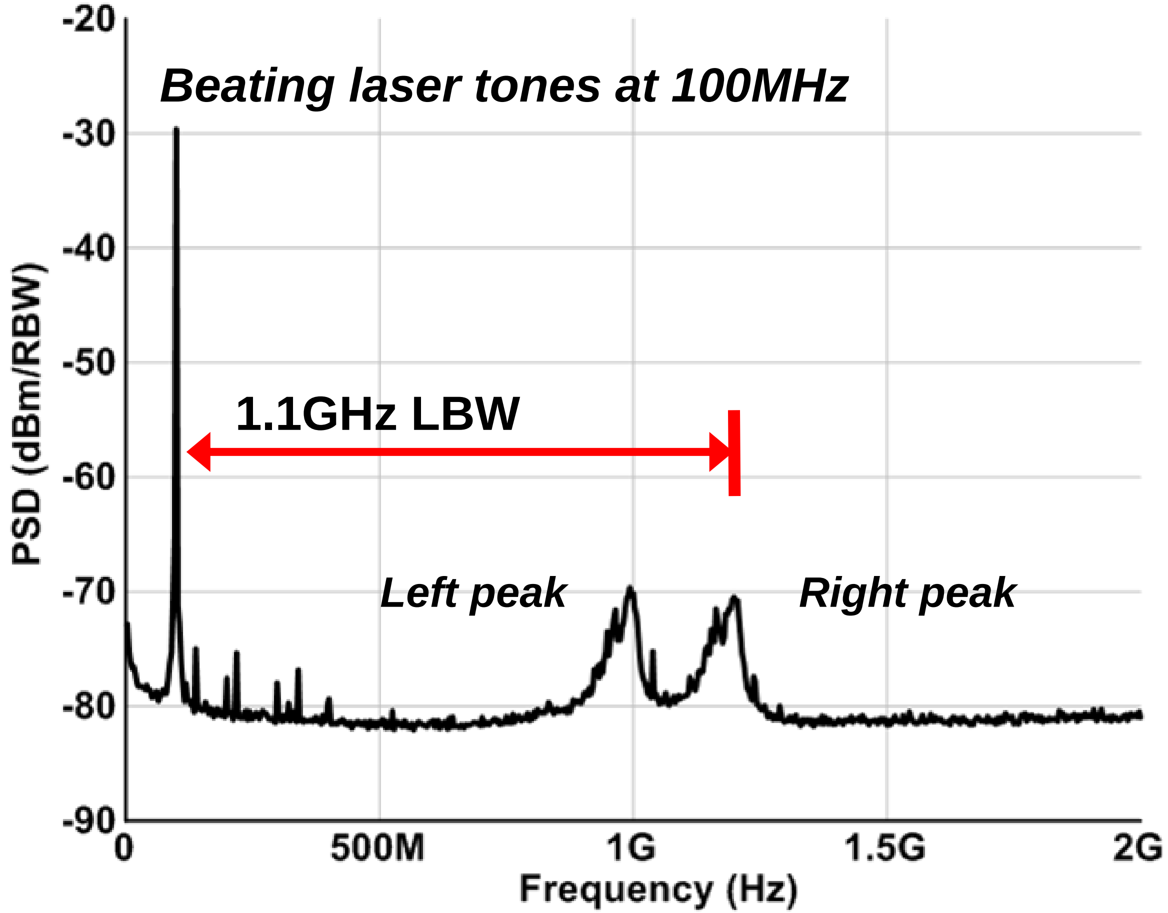
Test Results – Homodyne OPLL

Beating spectrum: locked SG-DBR + Ref. with 100MHz mod.

<u>1.1GHz closed loop bandwidth</u>



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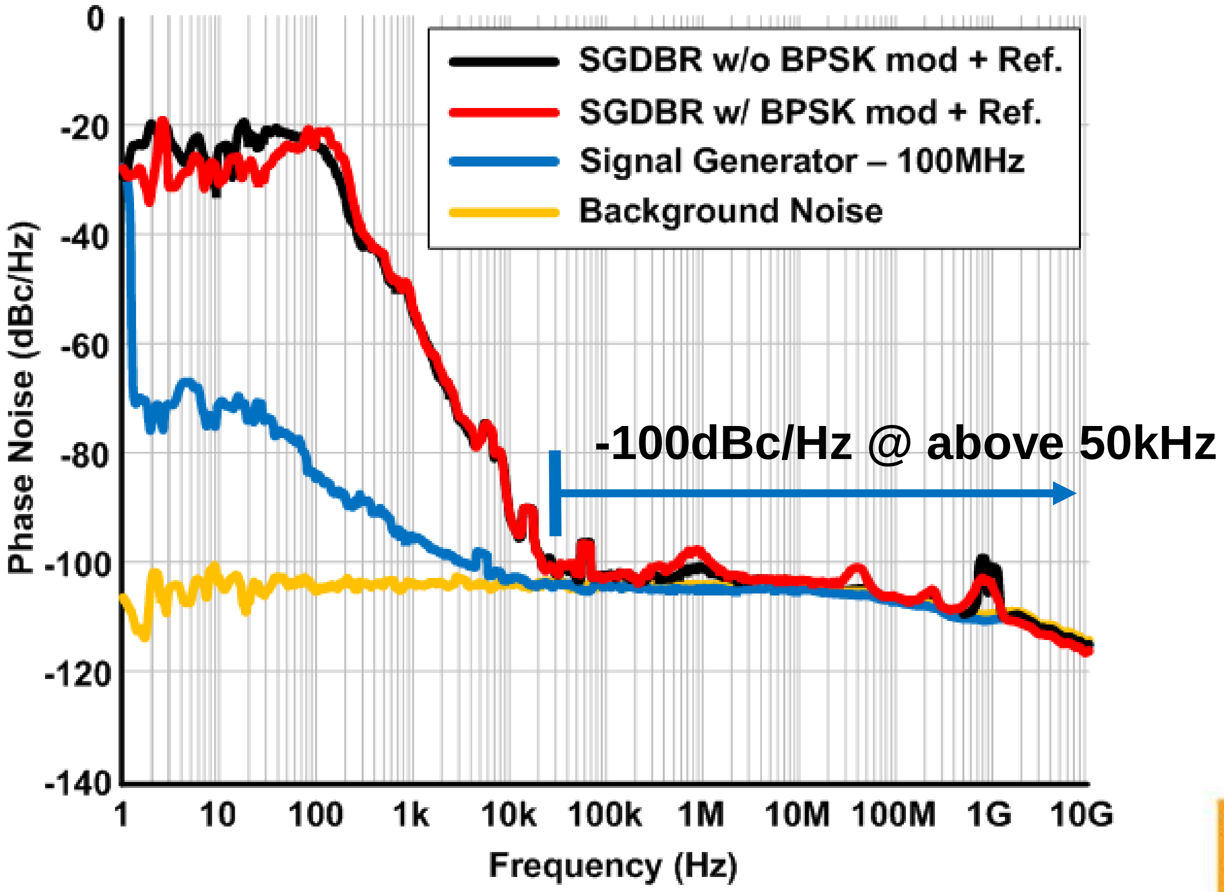
Test Results – Homodyne OPLL

Cross correlation between SG-DBR and reference lasers

-100dBc/Hz @ above 50kHz



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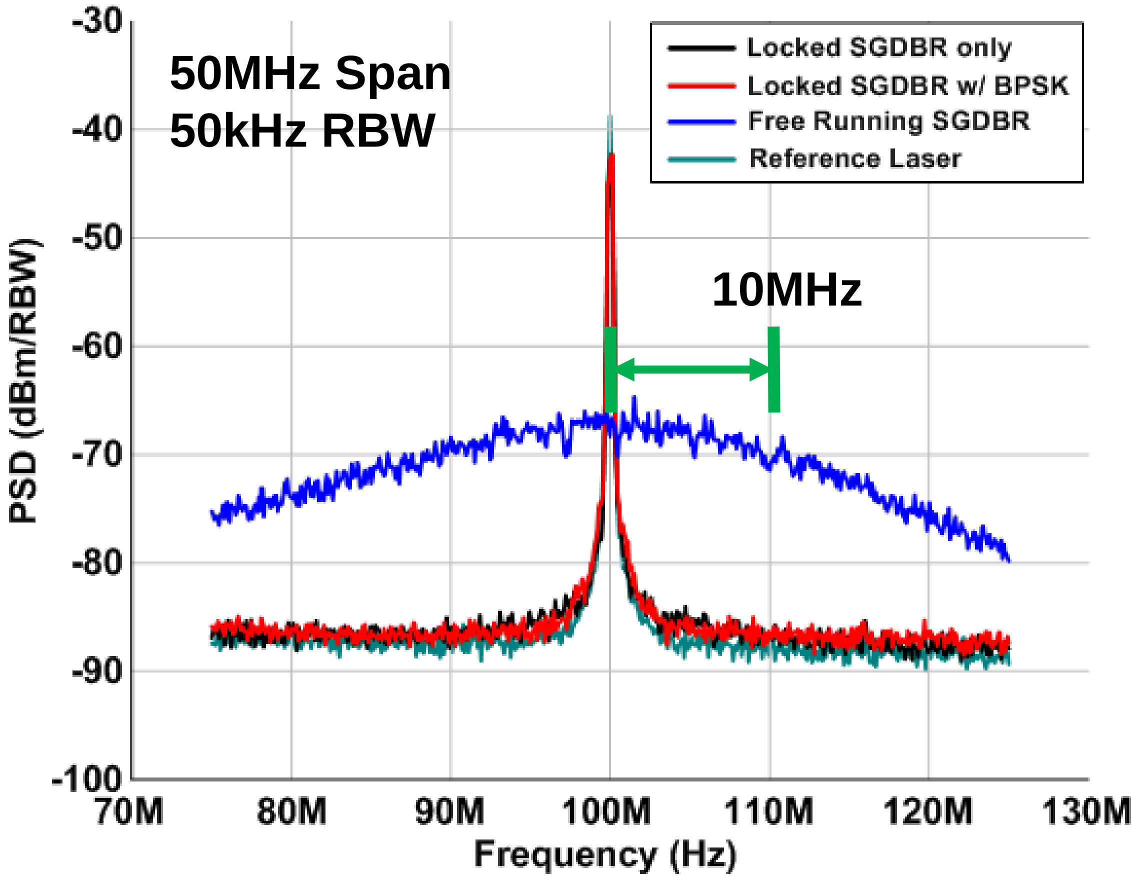
Test Results – Homodyne OPLL

Linewidth using self-heterodyne with 25km optical fiber

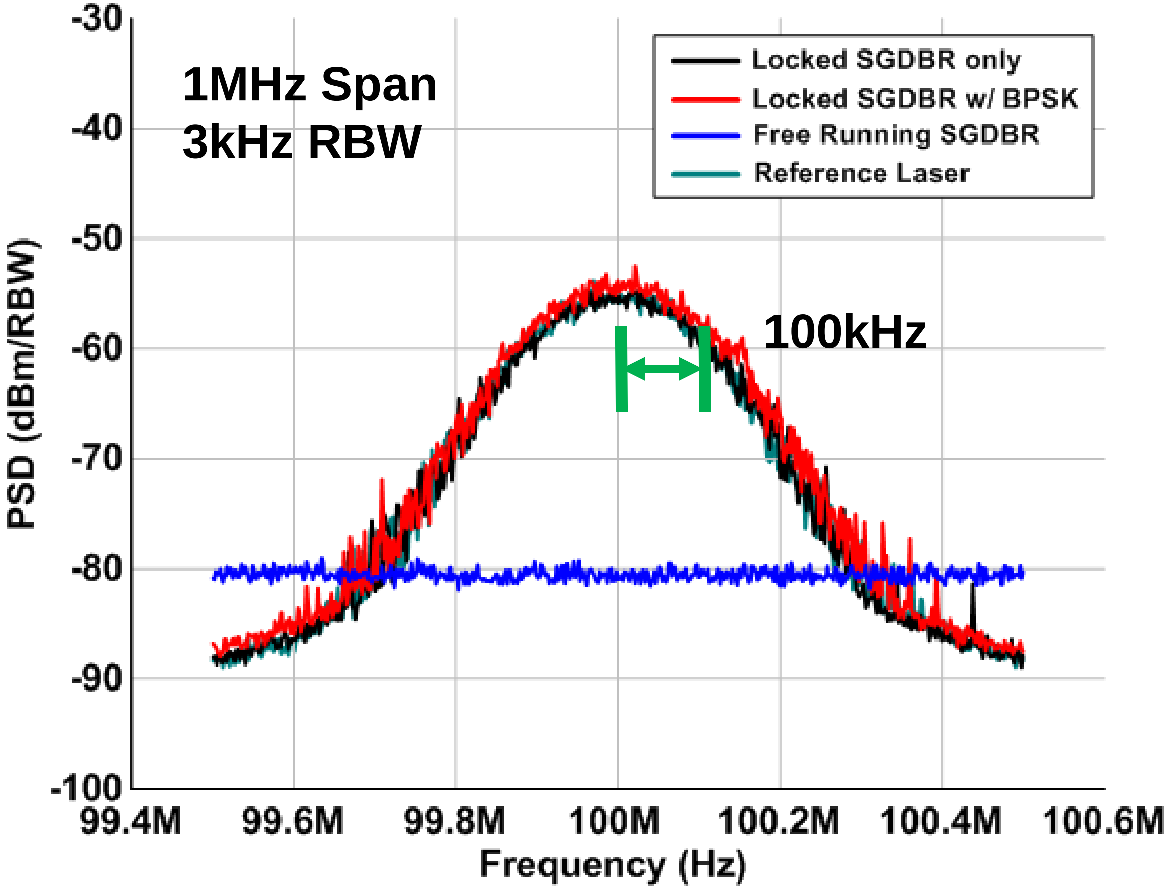
<u>10MHz linewidth</u> for free-running SG-DBR



Test Results – Homodyne OPLL

Reference laser (Koshin) linewidth 100kHz

<u>100kHz linewidth for locked SG-DBR laser</u>



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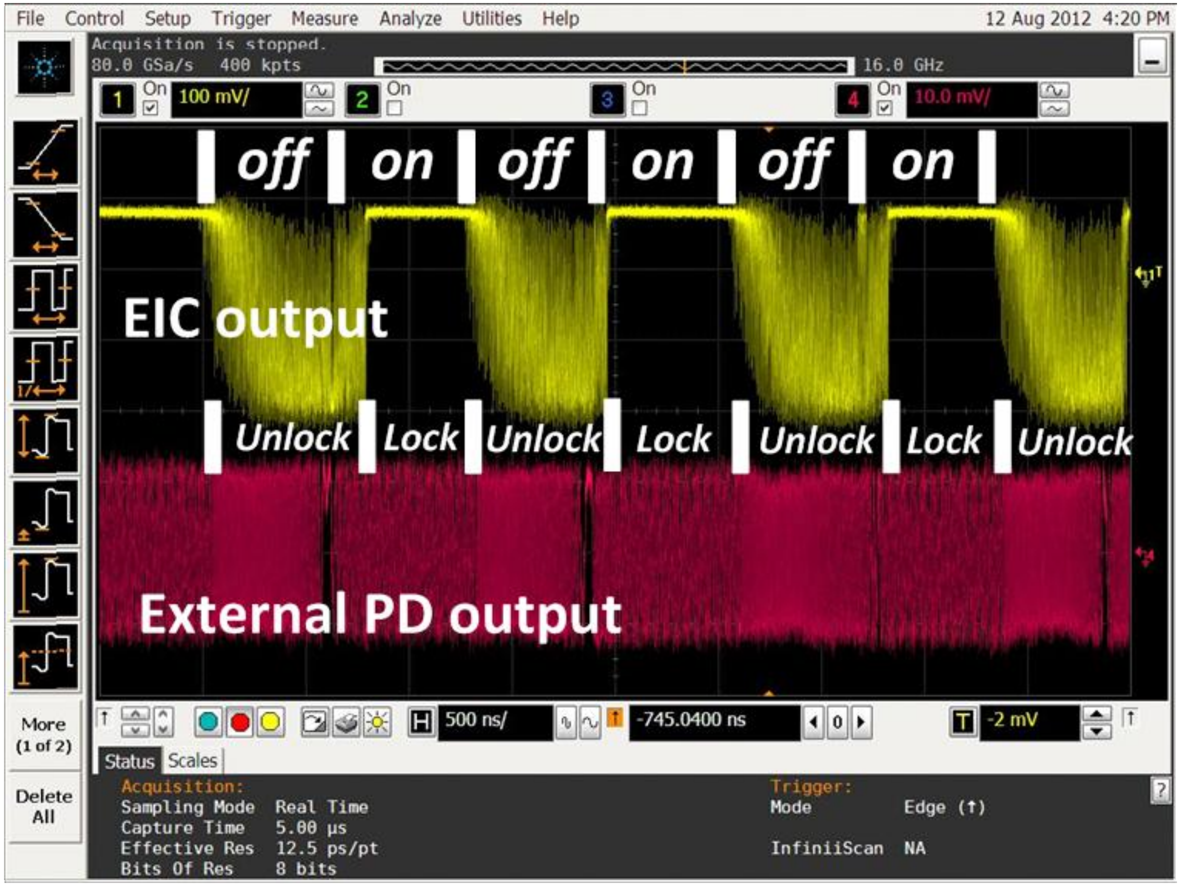
Test Results – Homodyne OPLL

400MHz/512bits ON-OFF laser

Locking conditions: EIC output – <u>DC</u>, External PD output – <u>100MHz</u>



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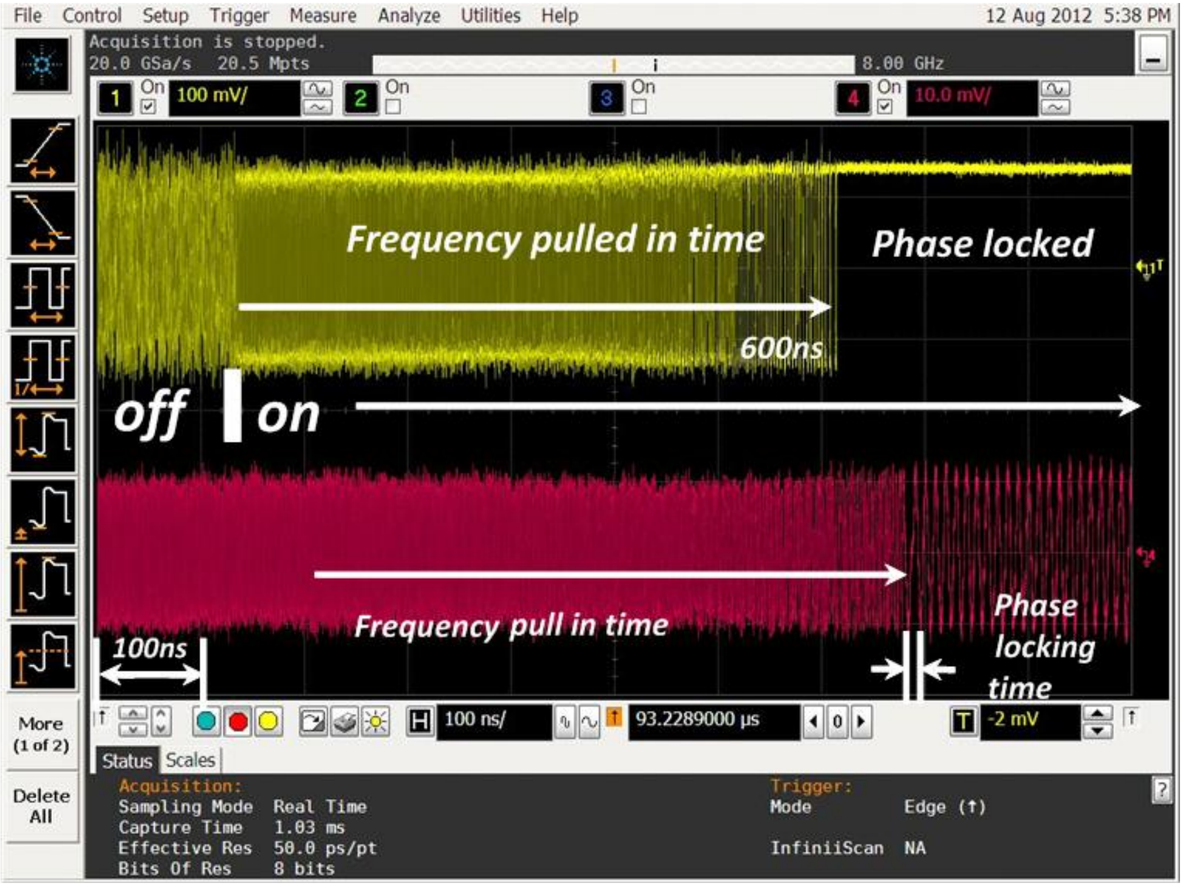
Test Results – Homodyne OPLL

Frequency pull-in time ~600ns

Phase lock time <10ns

*** Worst conditions***



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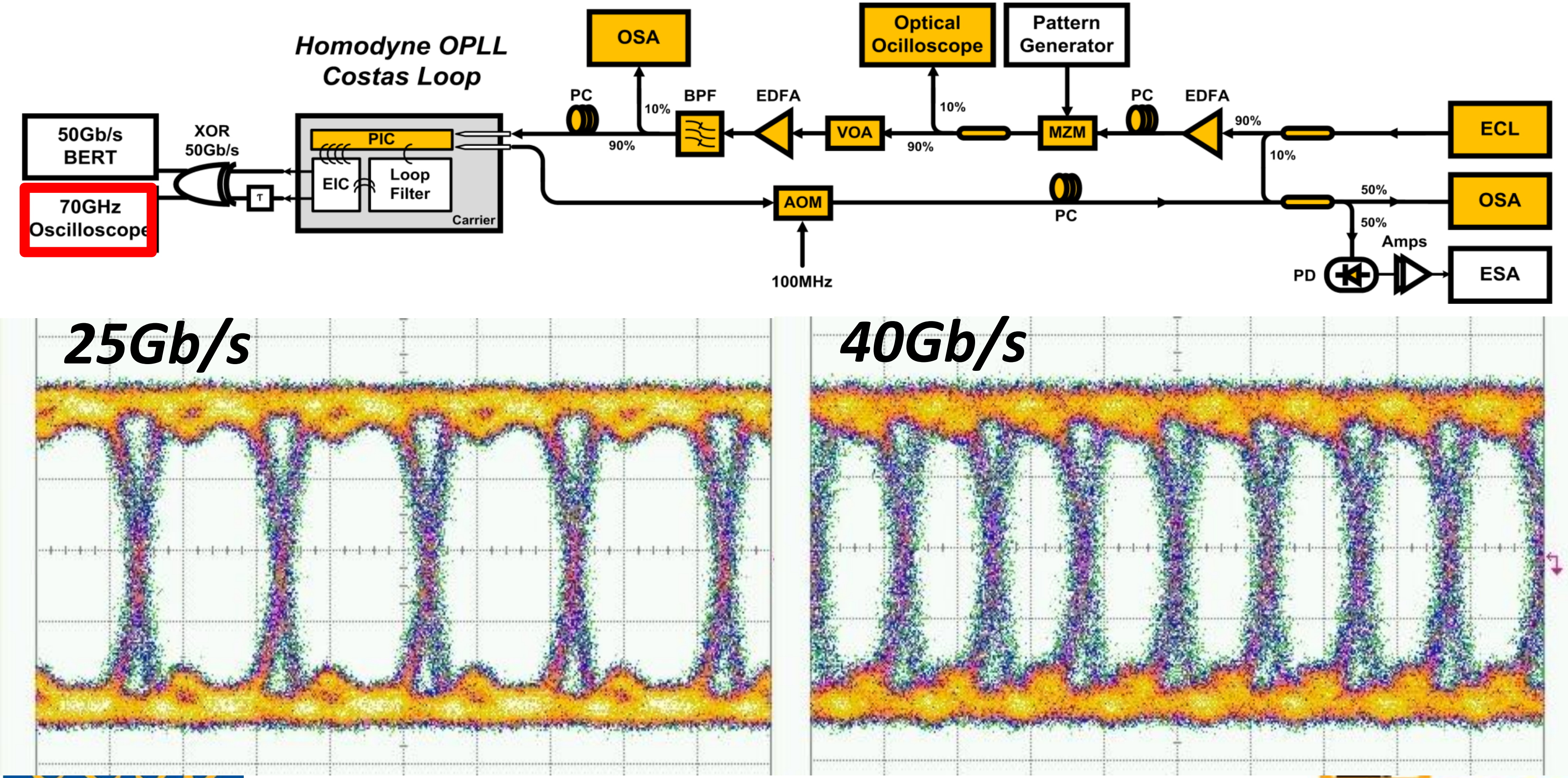
Test Results – BPSK Receiver

PRBS 2^{31}-1 signals – up to 40Gb/s BPSK data

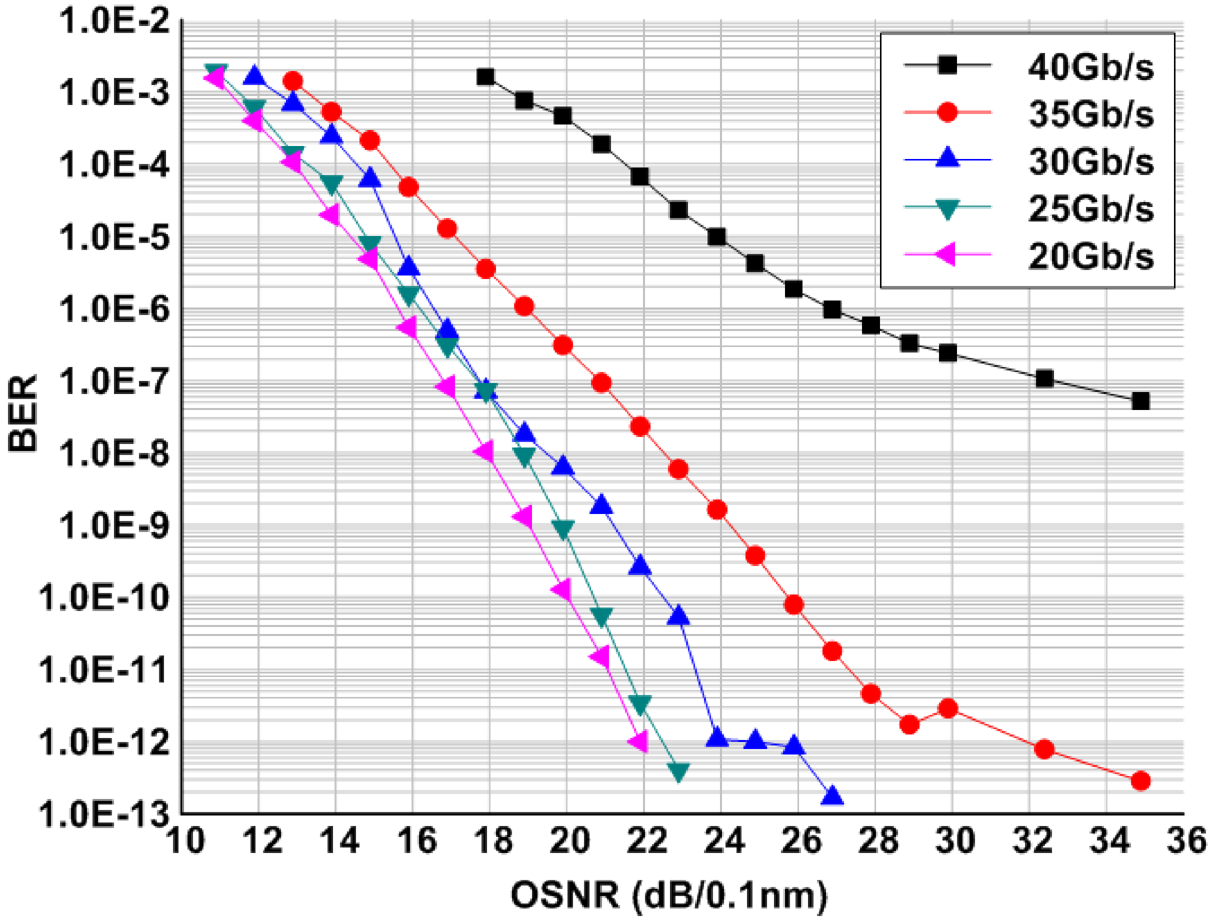
<u>Open eye diagrams for 25Gb/s and 40Gb/s</u>



Test Results – BPSK Receiver

BER vs. OSNR (20Gb/s to 40Gb/s)

<u>Error-free up to 35Gb/s , < 1.0E-7 @ 40Gb/s</u>



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Conclusions

- The first demonstration highly integrated optical Costas loop receiver
- Integrated PIC, integrated EIC, and feed-forward loop filter
- The receiver is Integrated within 10x10mm^2
- A stable homodyne OPLL by 120ps delay and 1.1GHz loop bandwidth
- 40Gbit/s BPSK coherent optical receiver (BER < 1.0e-7)
- Error-free (BER < 1.0e-12) up to 35Gbit/s

- Future works: QPSK receivers / long haul tests / dispersion compensations / polarization managements

Thank you for your attention !

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