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2023 SBIR/STTR Exchange PI Meeting
Nuclear Physics

DWDM Photonics Integrated Circuit (PIC) featuring minimal detector footprint for Continuous Readout

Award DE-SC0019581

TTDAQ: A CONTINUOUS FLOW, TIMING AND TRIGGER DAQ SYSTEM.

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Telluric Labs LLC

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Background

Telluric Labs LLC was first registered in New Jersey in 2016 by its two founders Michael Ivanciu, and Radu Radulescu.

The core field of expertise is next generation photonics based readout networks integrating picosecond timing.

Develops fundamental cross-domain technologies in collaboration with research institution and industry experts.

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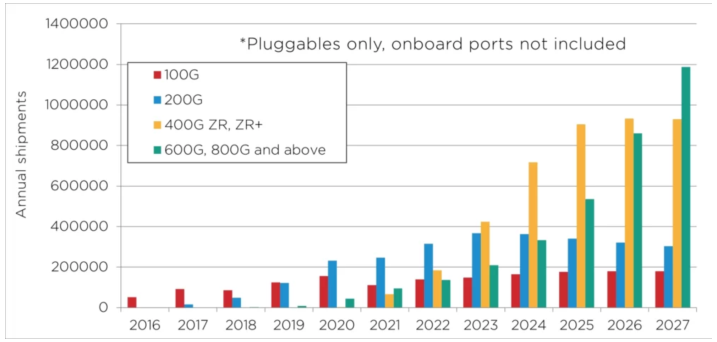
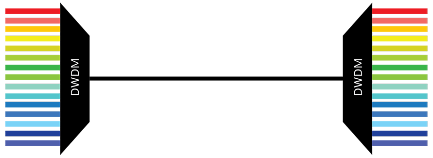
MOTIVATION

More Bandwidth, lower cost, lower power

- Current readout networks based on coax or single channel fiber increas Detectors' cost, failure rate, power consumption, experiment setup, duration, and complexity of cooling, mechanical structures, background noise cancellation algorithms, maintenance, and operation.
- Electric connections have reached their physical limit for data communications and computer systems links.
- State of the art high speed computer network links use legacy optics limited to 4 channel coarse WDM per fiber, even when using PAM4 or higher complexity modulation.
- Traditional Photonics Dense WDM systems with over 8 channels require discrete components, resulting in larger size and power consumption.
- There is significant market drive for higher data density and lower power.





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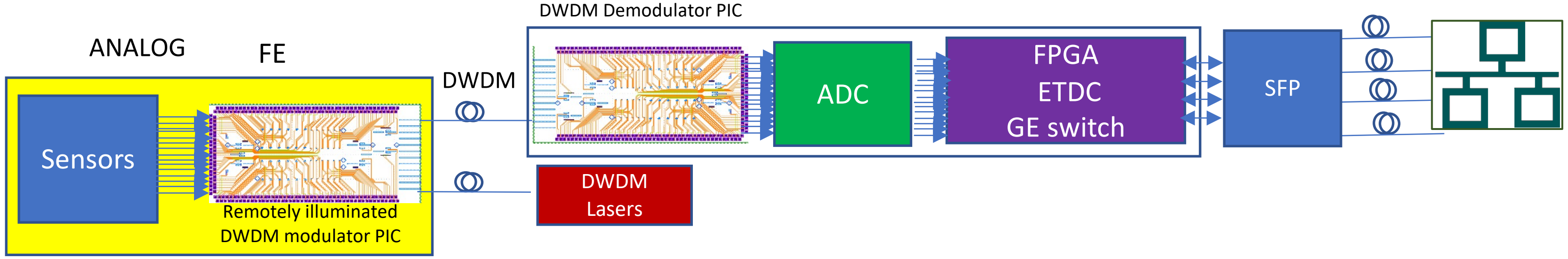
INTRODUCTION TO TELLURIC LABS PHOTONICS INTEGRATED CIRCUIT IMPACT FOR NP and HEP

The PIC Eliminates the HW trigger, coax cables and allows the transfer of most of Detector electronics to the Backend



- The DWDM Photonic Integrated Circuit (PIC) developed by Telluric Labs converts the low voltage analog signals generated by the detector into modulated optical wavelengths signals. These wavelengths are subsequently multiplexed and transmitted through a single-mode fiber to the Backend Electronics (BE), where they undergo conversion back into electrical signals. This process optimizes cost-effectiveness and enhances performance through the utilization of commercial-off-the-shelf (COTS) ADC digitizers at BE, or even lower cost PWM and TDC for a complete amplitude and timing readout. It completely eliminates digitizers (and/or coax cable drivers) on the Detector. This streamlined approach simplifies both the cryogenic setup and mechanical structure, while simultaneously improving the Signal-to-Noise Ratio (SNR).
- The PIC is designed for both digital and linear (analog) signal transmission. It is remotely illuminated by DWDM lasers external to the Detector, outside the radiation or cryogenic zone, functioning on a 200GHz ITU grid. The PIC operates on the foundation of MicroRing Resonators (MRR), configurable as differential or single-ended modulators. This provides the flexibility to balance linear characteristics, stability, and noise immunity against achieving a higher channel count.
- The PIC encompasses both modulation and demodulation capabilities. MRRs offer numerous advantages, including inherent wavelength filtering, heightened sensitivity, compact dimensions (~10um), tunability, low power consumption, and cost-effectiveness.
- The PIC has exceptional performance in laser modulation, effectively managing signals well below 1V. Its 2x4mm size ensures minimal interference with the observed particles, efficient space utilization and energy conservation, particularly beneficial for cryogenic and low-noise experiments.
- The differential Microring Modulator architecture ensures impeccable modulation linearity, enabling 16 “C” band channels per single-mode fiber.
- MRRs present a multitude of benefits, including inherent wavelength multiplexing, gradual saturation, heightened sensitivity, small dimensions (~10um), tunability, low power consumption, radiation resilience, and cost-effective manufacturing through traditional Si foundries.

Readout Topologies DWDM Tb Photonics Integrated Circuit

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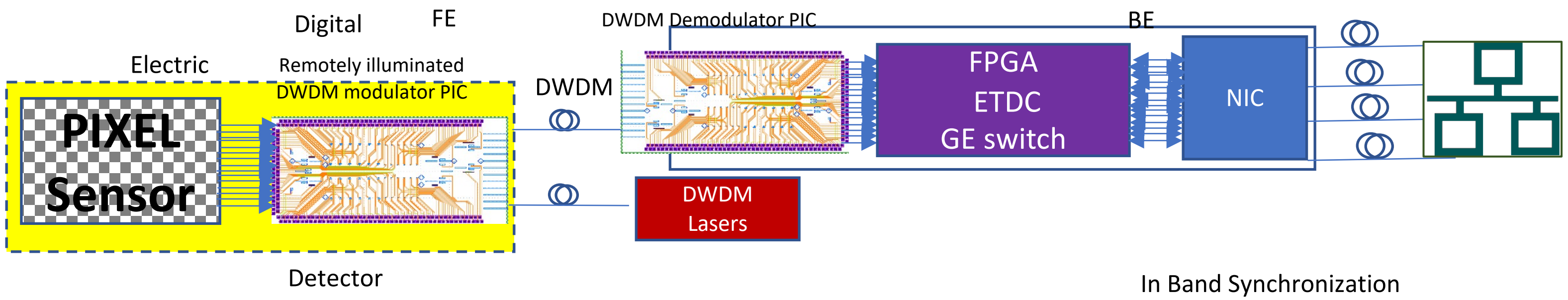
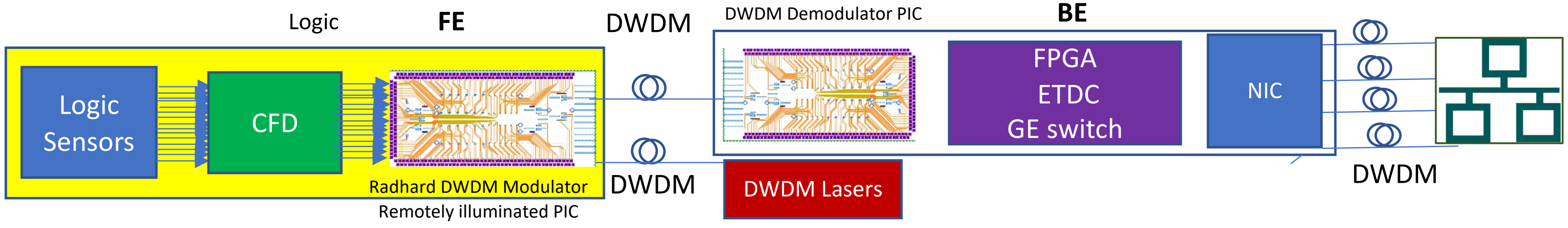
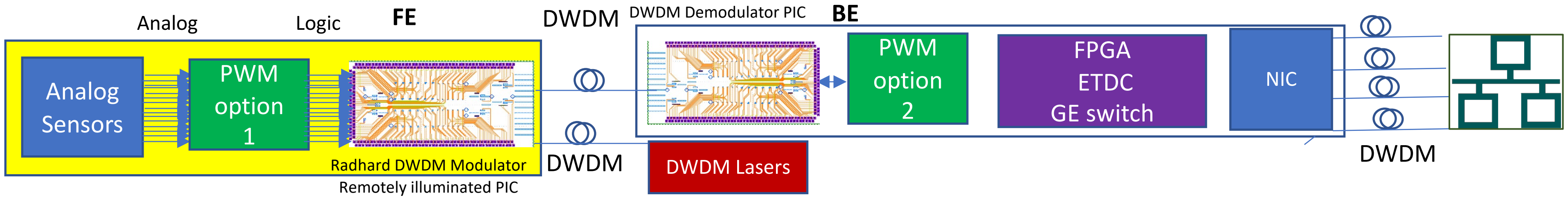
Direct connection to pixel detectors' ASIC provides 200 to 800 Gbps per fiber for digital signal



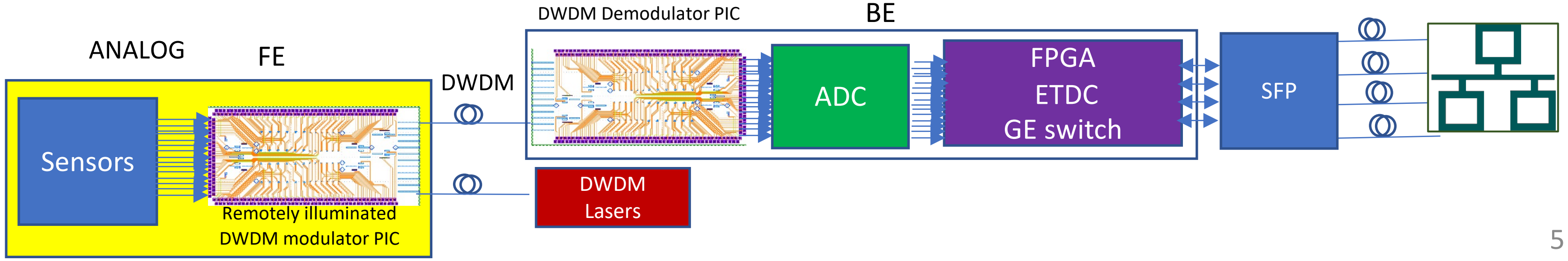
Timing Detector- provides 16 to 32 channels per fiber for digital signals



Lowest cost highest density distributed DAQ for both analog and digital signal



Lowest Detector footprint analog signal readout
Drop-in replacement of coax cables.
Analog signal transport.



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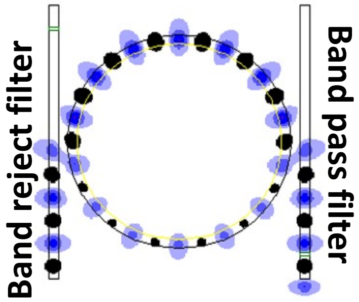
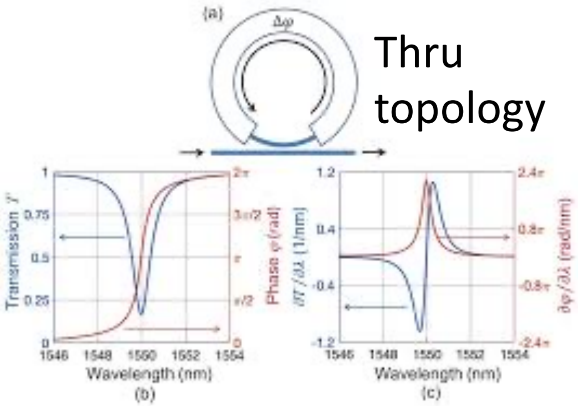
Microring Resonator Differential Modulation Principle

Add drop topology

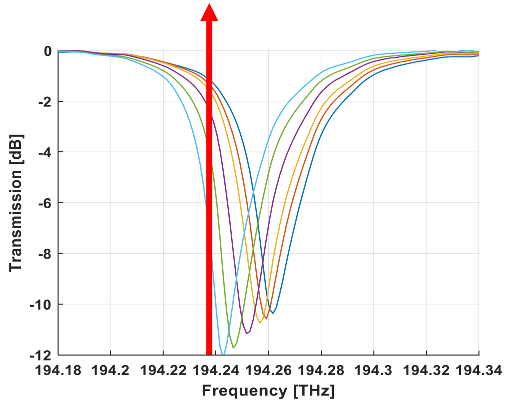


Thru topology

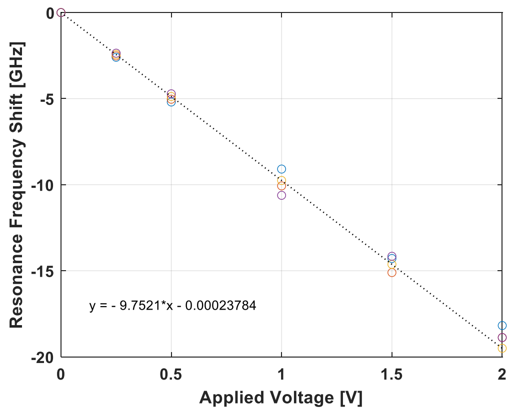


<u>Functional Control Parameters</u>

laser wavelength
laser power
Heater temperature control
DC bias
RF signal amplitude

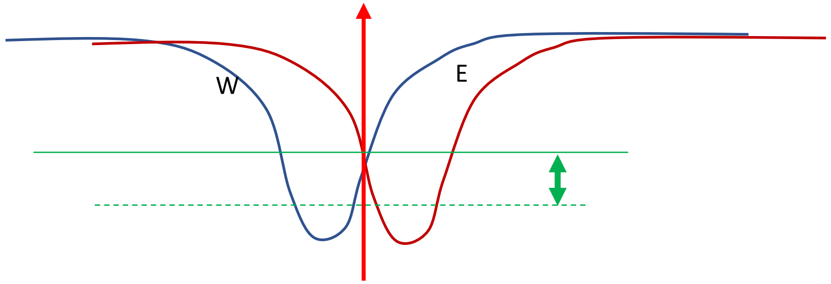


Modulation

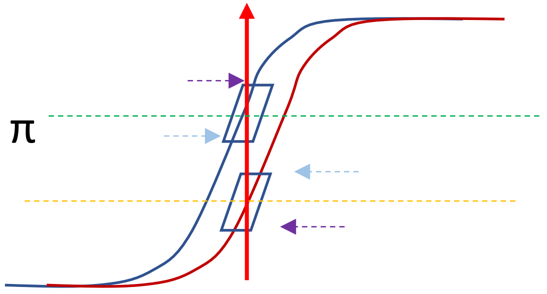


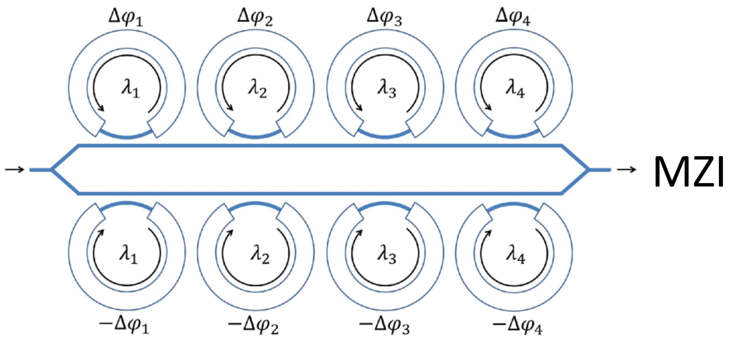
Animated RAMZI MRR modulation principle
(~10GHz/V)

Amplitude



Phase Modulation of DT

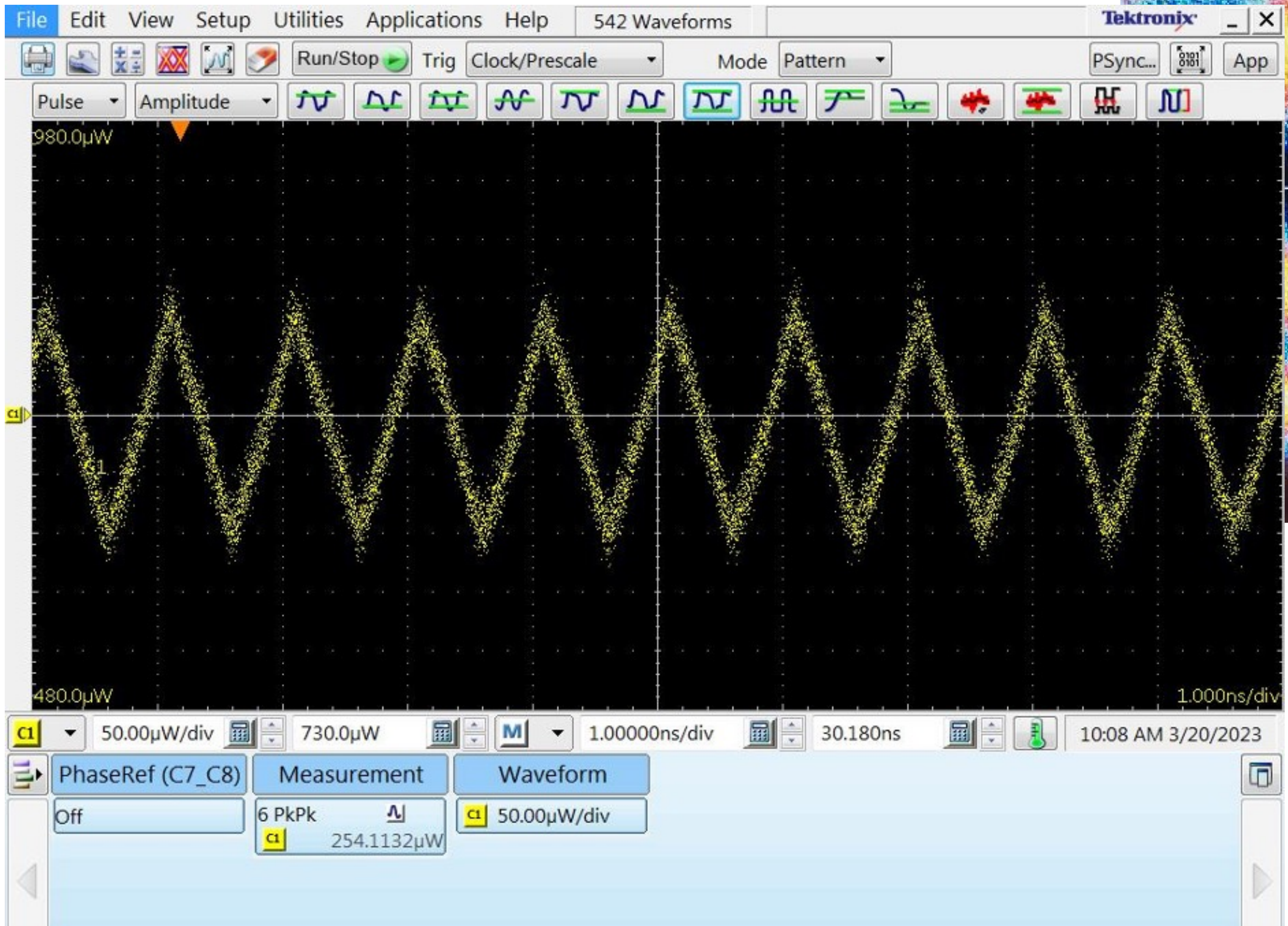




RAMZI – analog modulation
https://ieeexplore.ieee.org/document/8540485

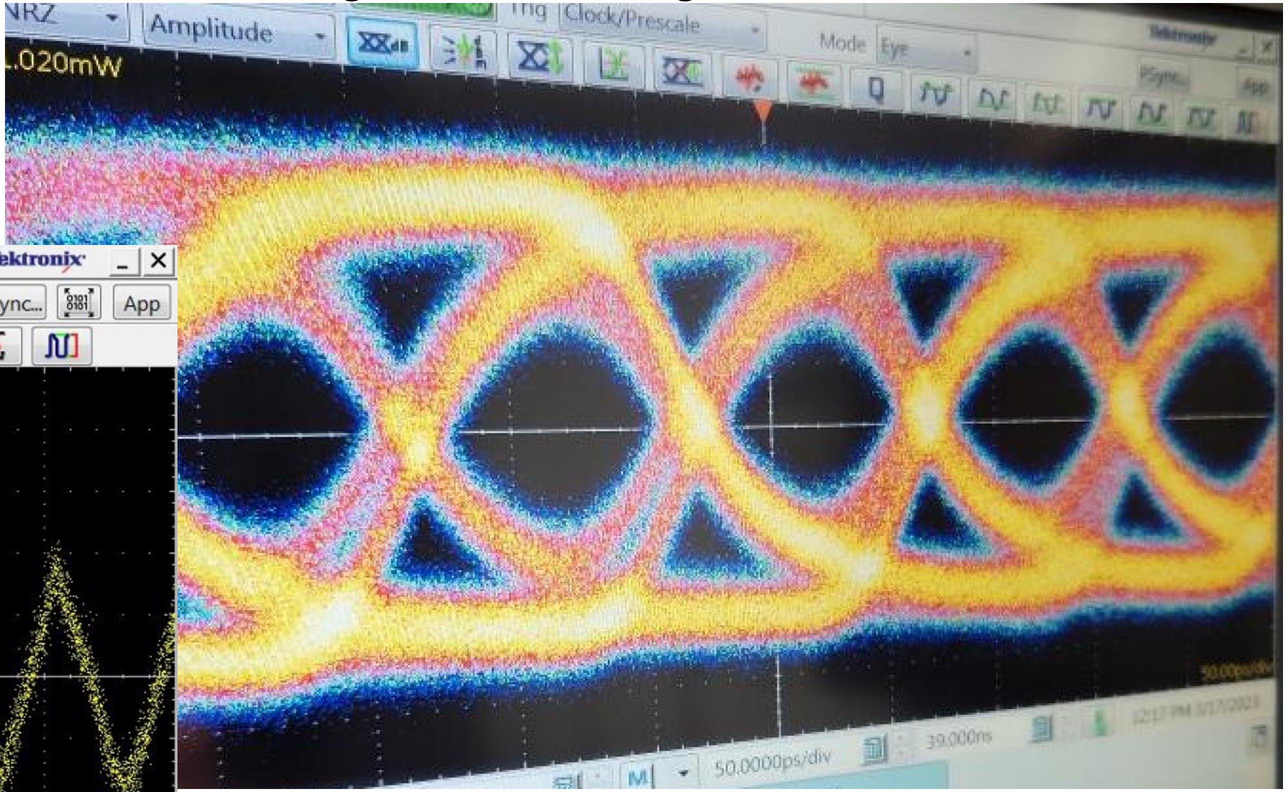
Linear v. Digital Optical Links

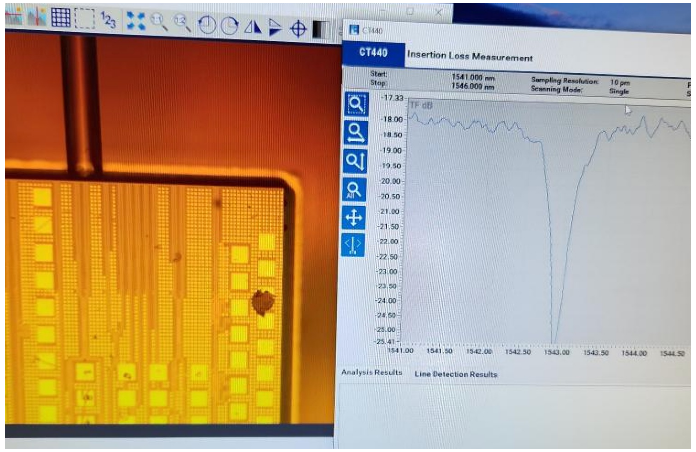
ANALOG LINEAR MODE – transport of any signal



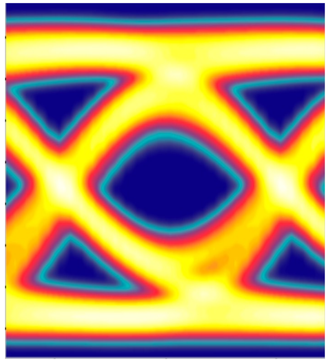
MRR Differential architecture tested with 300 mV in the figure above. It works with even at 100mV. Laser is at 10dBm 1543.65nm

Digital Mode: for Signals from the Detector's ASICs





Digital mode tested with 1Vpp signal



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Tb DWDM PIC Advantages (simplified analog or digital FE)

- The Readout based on PIC allows SW driven functionality with much lower installation, commissioning, operations, and maintenance costs for NP experiments.
- Parallel experiments with independent filtering / SW trigger using COTS FPGA accelerator boards;
- Lower cost for simpler FE, simpler cooling system, lighter detector structures;
- Passive Optical Networks (PON) provide scalability and flexibility;
- The PIC uses microring resonators coherent photonics technology;
    - Can be tuned on specific wavelength, implicitly multiplexing channels;
    - Lowest power consumption – can work in vacuum without heatsink;
    - Below 1Vpp modulation signal amplitude;
    - DWDM signal distance reaches miles over single mode fiber without amplification;
    - Double and multiple redundancy against failure of laser or resonators;
    - Minimal Si surface ensures lower PIC price - microring modulator size is ~ 10 micrometers; Current PIC size is 4x2mm;
    - Can be stacked to or integrated into the ASIC attached to the pixel array sensors;
    - Each channel potential bandwidth is over 30 Gbaud/s rate;
    - Can be manufactured in regular Si foundries;
    - Reduces electric cables resulting in lighter detector structure;
    - Inherently radiation tolerant (there are no lasers directly attached to the PIC);
    - Better control of stability, power, and spectral parameters for external laser sources;
    - Higher spectral purity and power of external laser source;
    - External lasers provide an additional control and input communication channel;
    - Physical layer measurement of propagation delay, and additional synchronization method.

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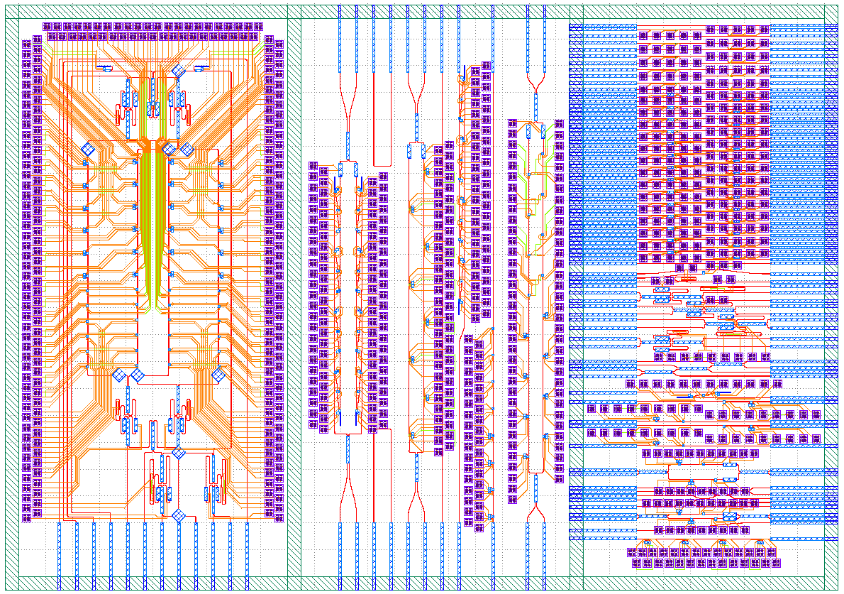
IMPLEMENTATION

Tapeout 1

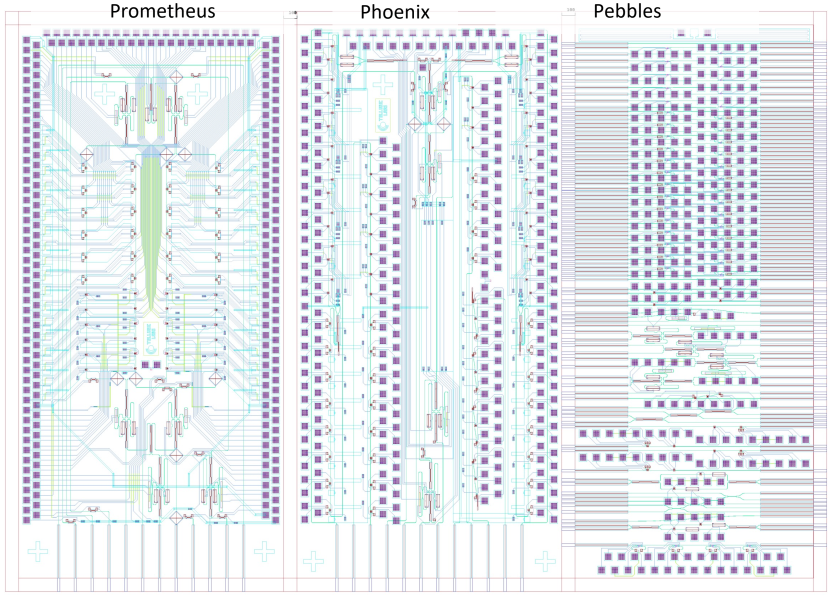


Tapeout 2

Chiplet 1
Prometheus

Chiplet 2
Phoenix

Chiplet 3
Pebbles

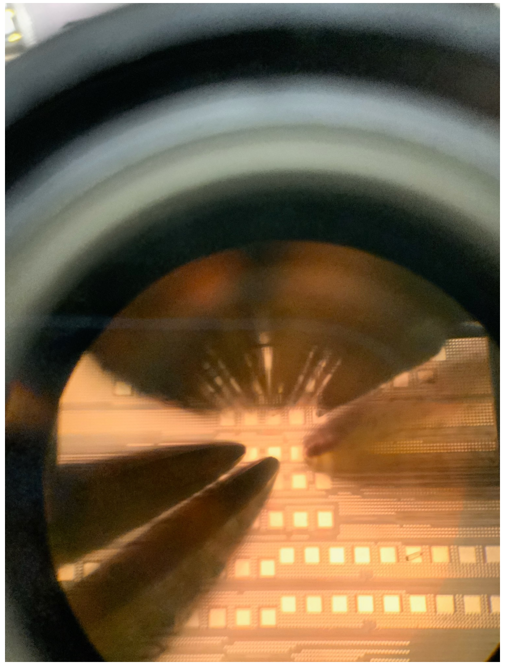


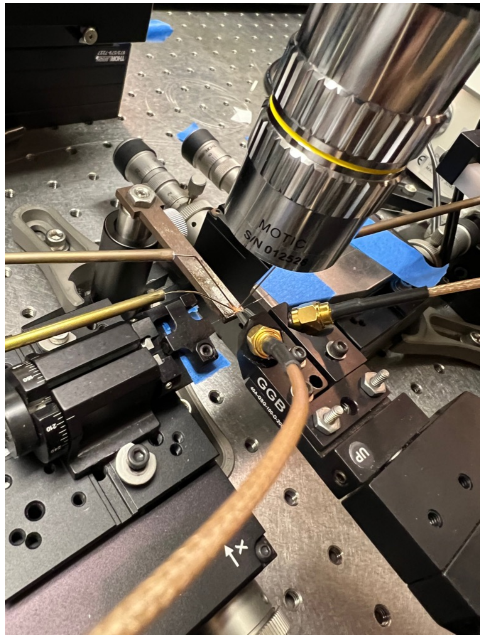
The PIC devices were developed in partnership with MIT LL and manufactured at AIM Photonics

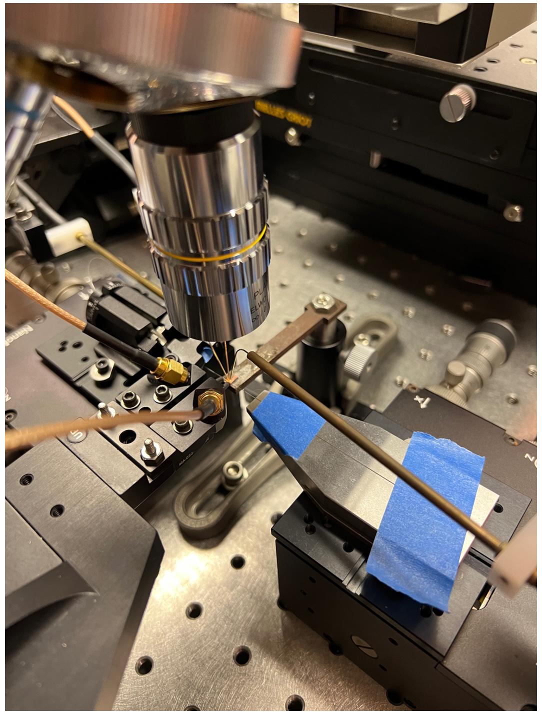
- 3 Chiplets
- Prometheus – intended for analog, 12 differential channels, or 24 single ended. Can be daisy chained for 24/48 channels.
- Phoenix – intended for 16, 25GE, differential channels. Can be daisy chained for 32 channels
- Pebbles – for test of individual subsystems.

Probes on optical test table. In and out fiber aligned to the Pebbles chip

IR image of the Pebbles under GSGSG and DC probes.







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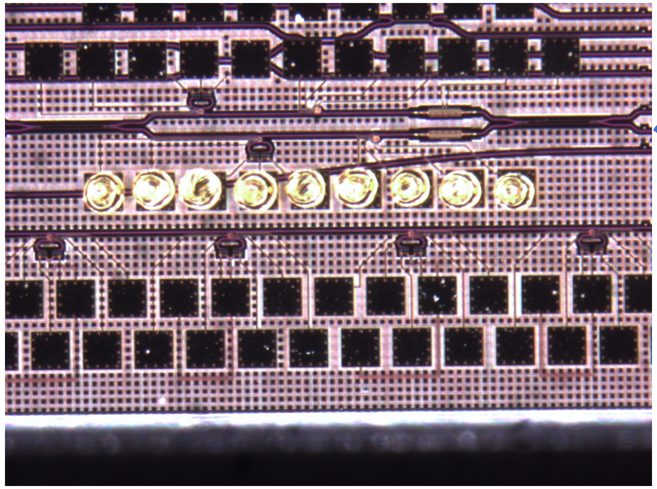
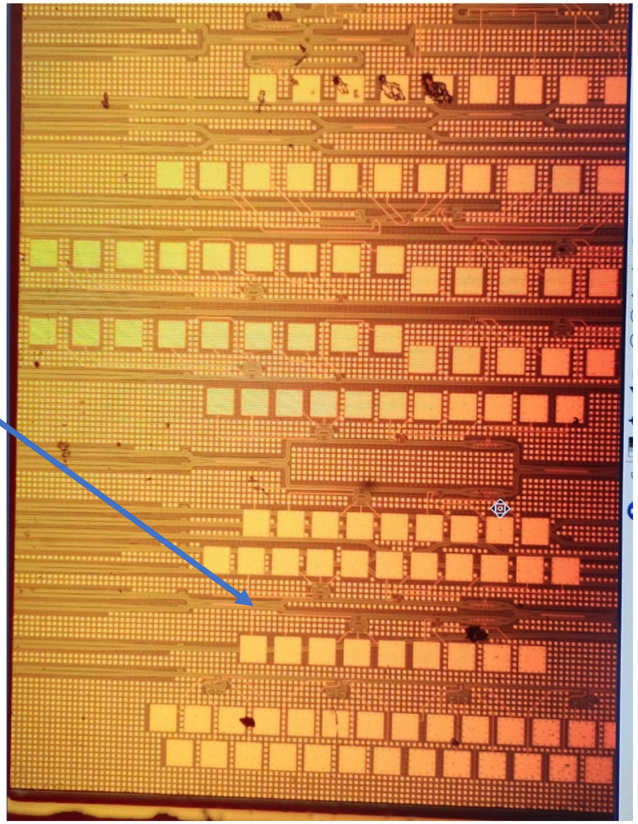
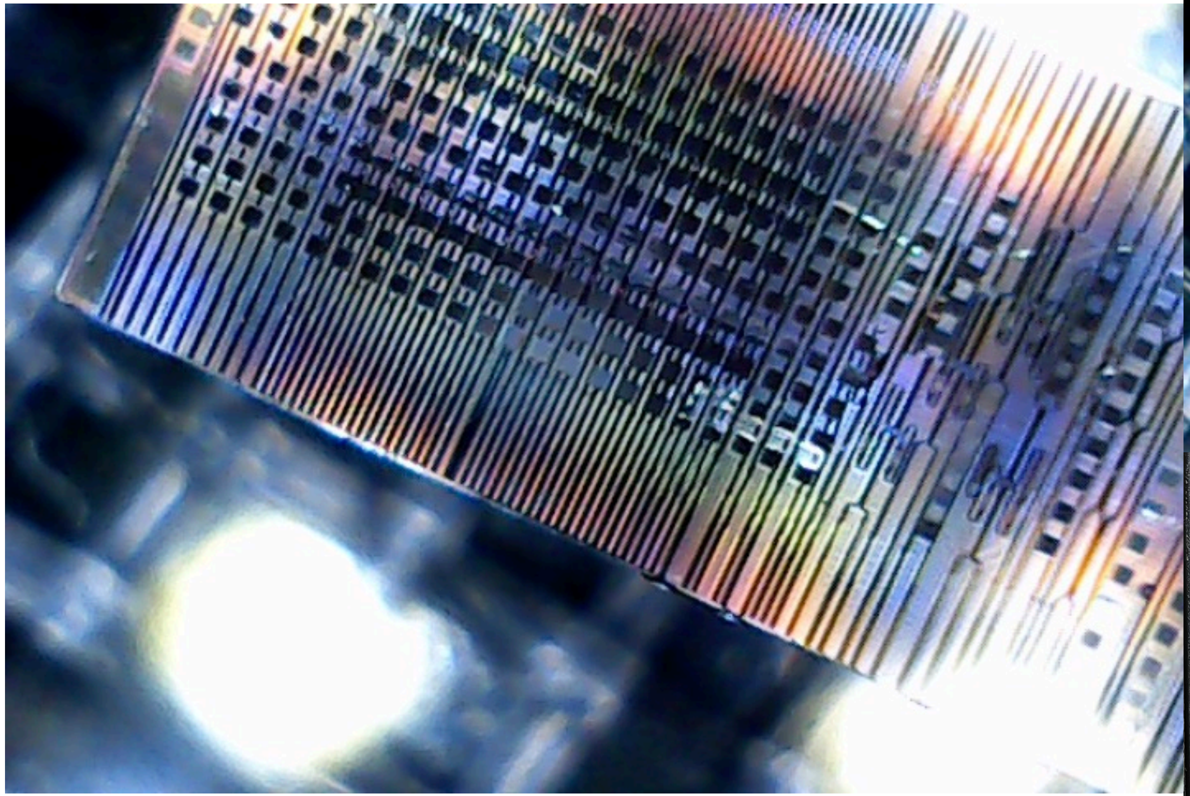
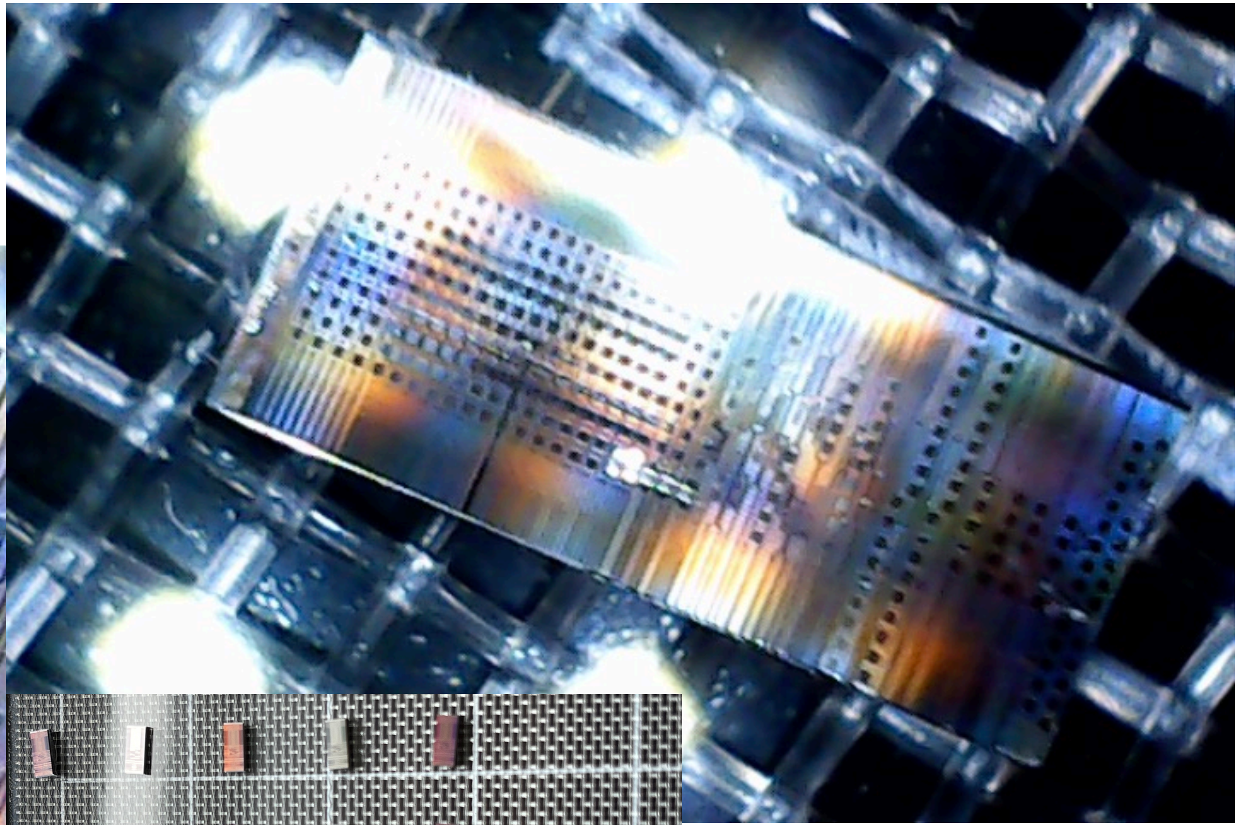
Pictures taken during evaluation of packaging tests and probing basic structures

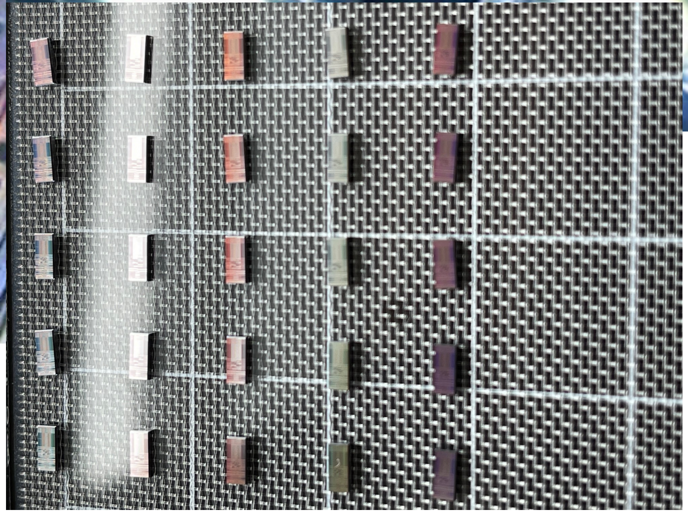




Pebbles caplet images

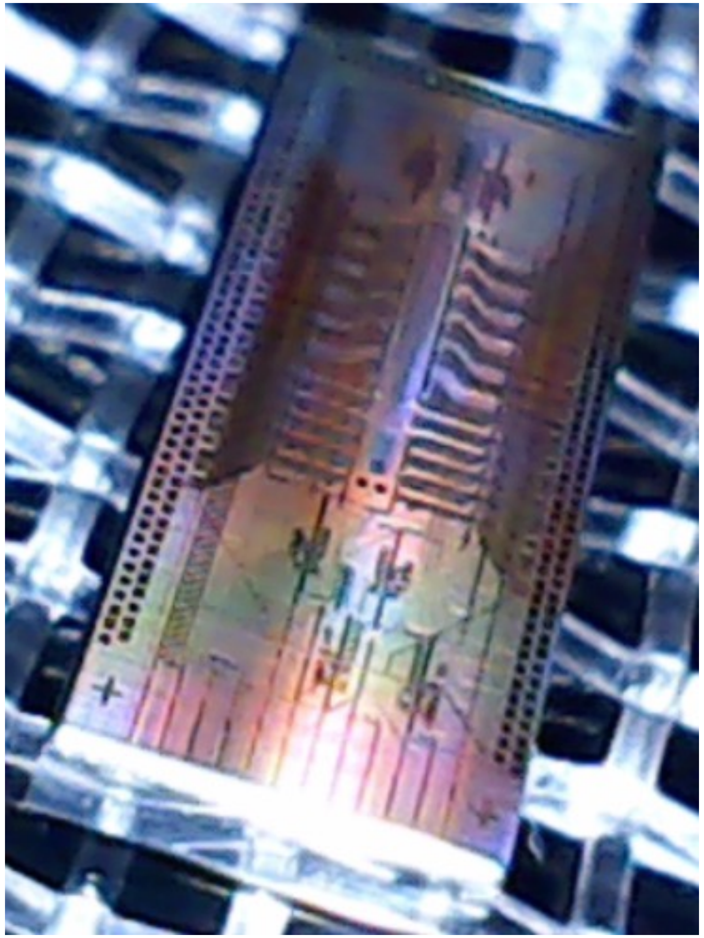


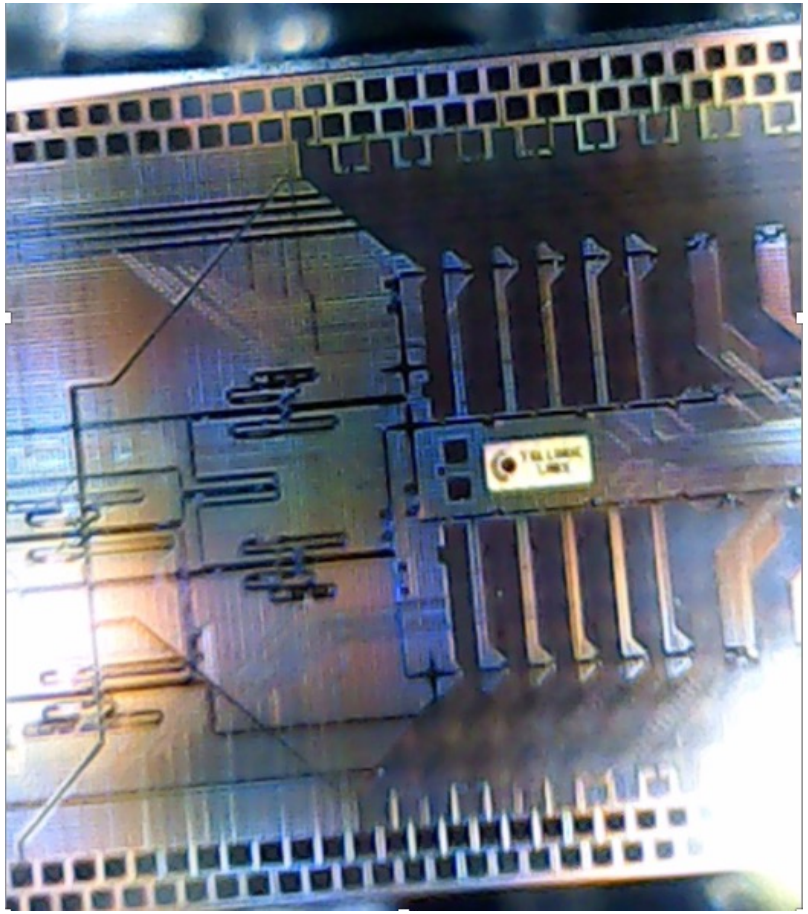




Comprises basic circuits and several new MRR designs

Prometheus chiplet images





Comprises 12 differential channels on 200G ITU grid. Can pair with another PIC for 24, 100G ITU grid channels

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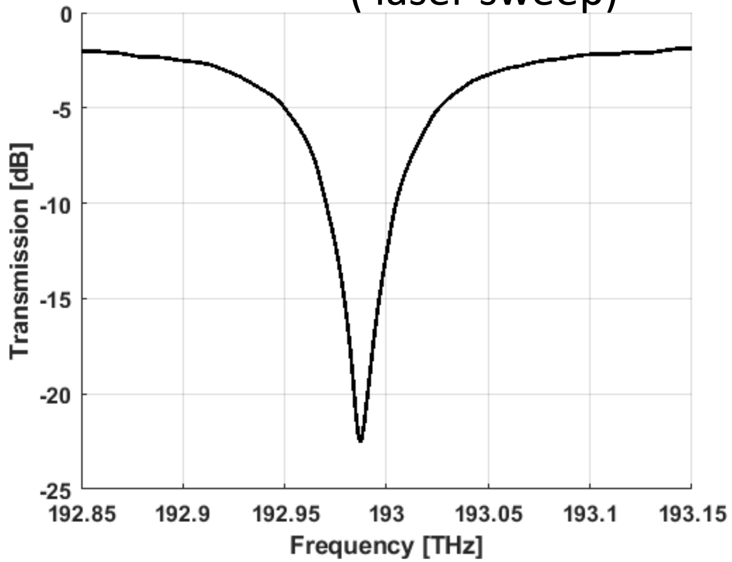
BENCH MEASUREMENTS RESULTS
DWDM Tb PIC Tapeout 1

Detail MicroRing optical characteristic (laser sweep)



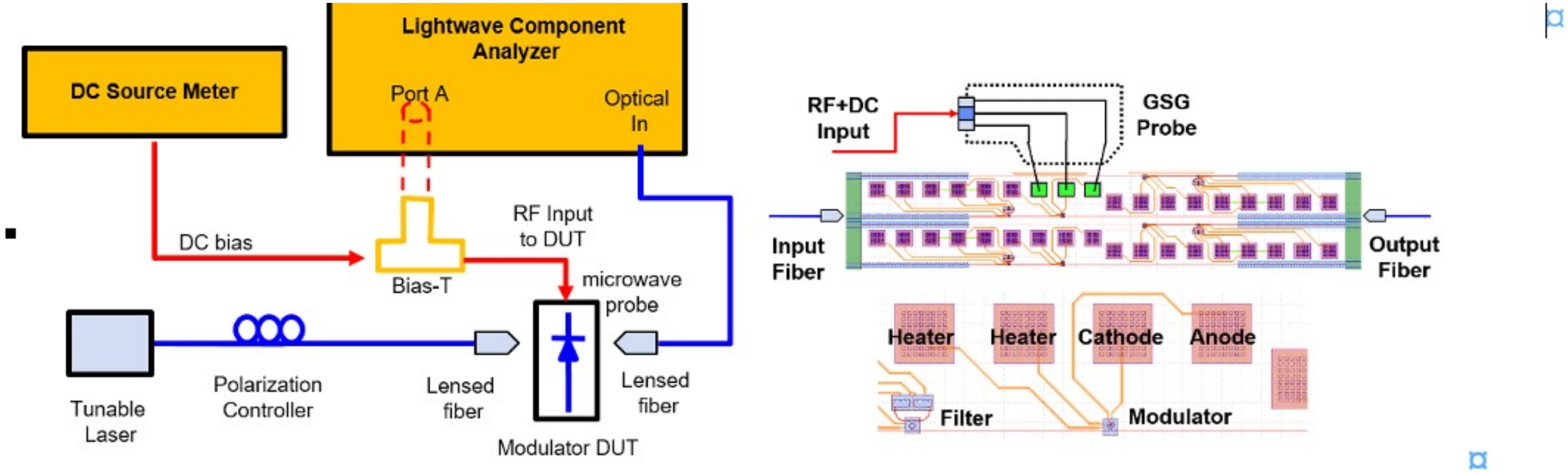
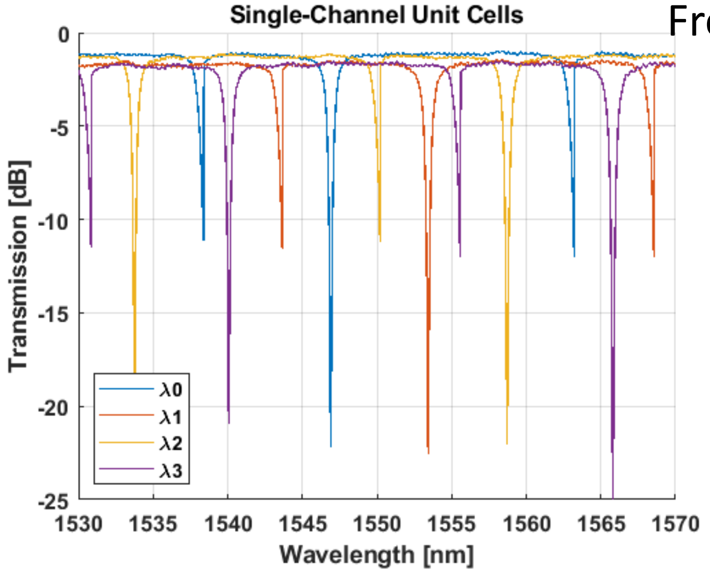
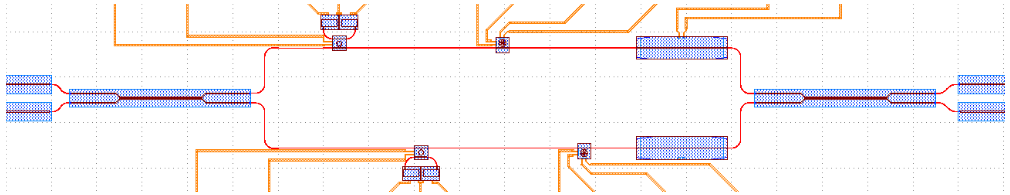


Figure 1. (Left) Experimental setup for characterizing the RF transfer function (S11 and S21) of modulator components. (Right) Detail illustration of the interface to the PIC, including the layout of a typical modulator device under test.



Free Spectral Range (FSR) = 3.2 THz

Differential RAMZI Cell



For comparison: Intel single ended 8 channel MRR single ended solution used for chip to chip communications

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Measurement of differential modulator v. simulation

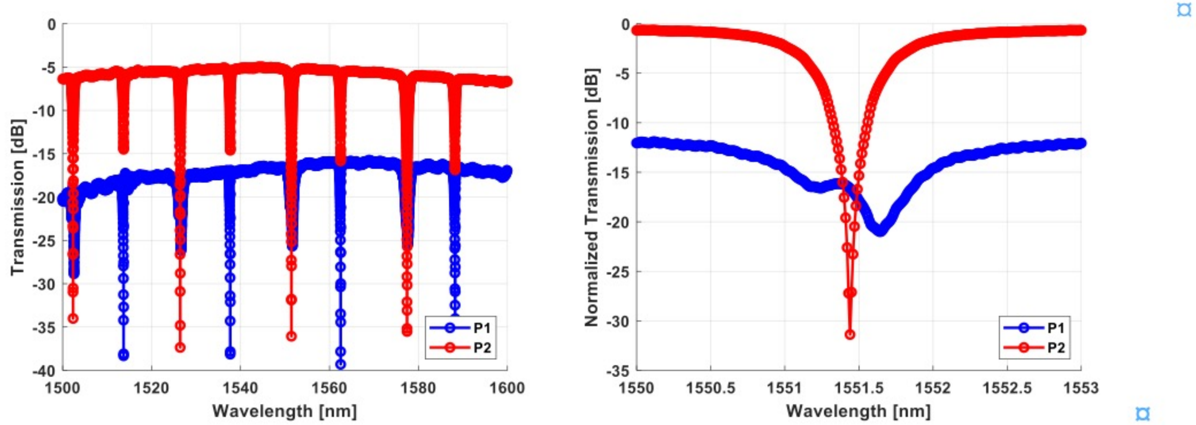


Figure 8. (Left) Measured transmission at the outputs of the interferometer. (Right) Normalized transmission in the region of one of the filter resonances.

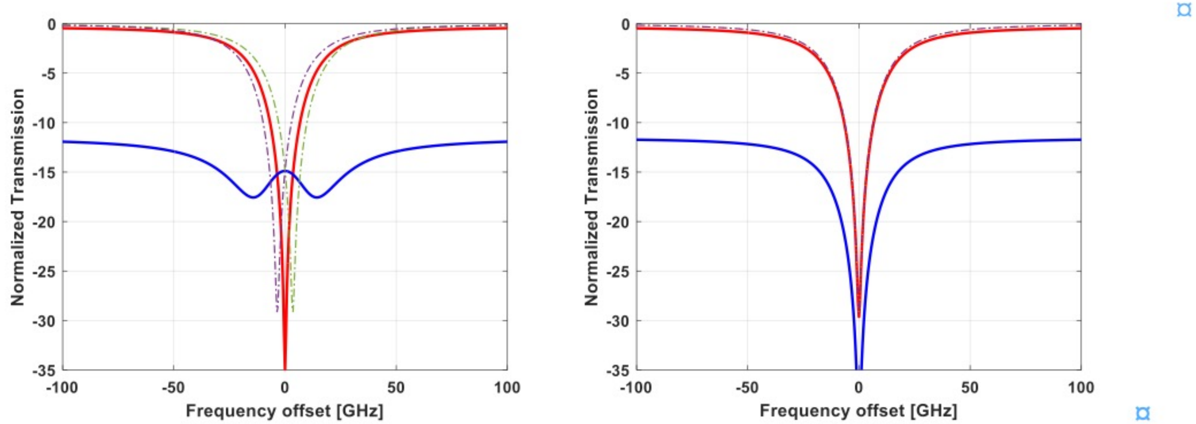
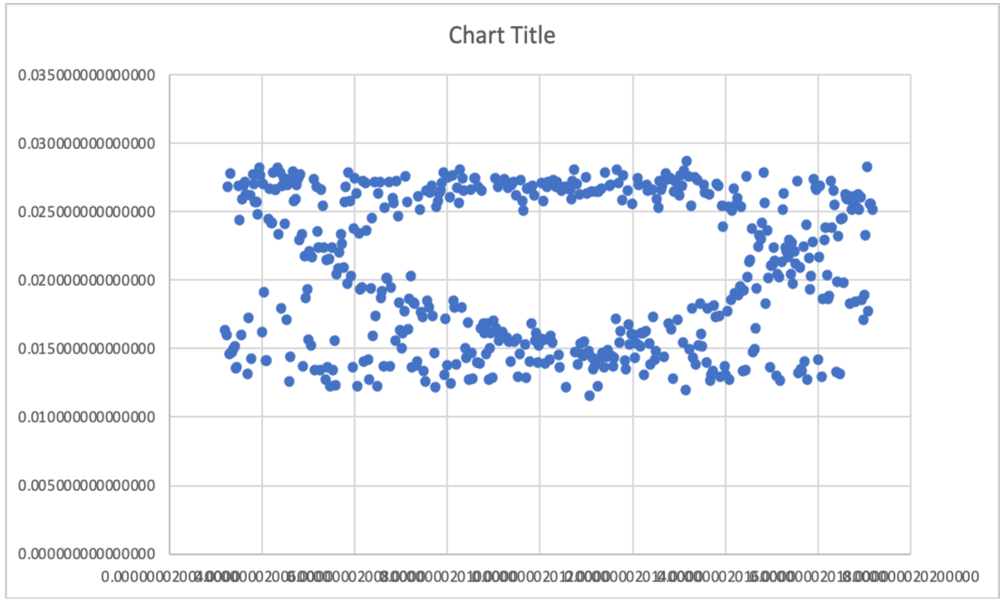
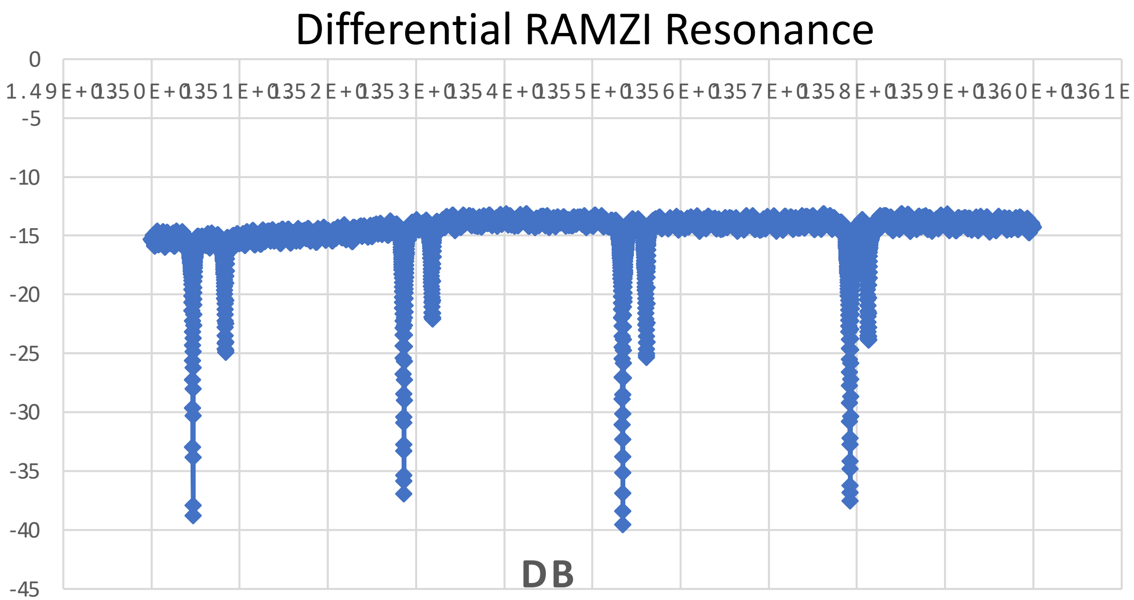


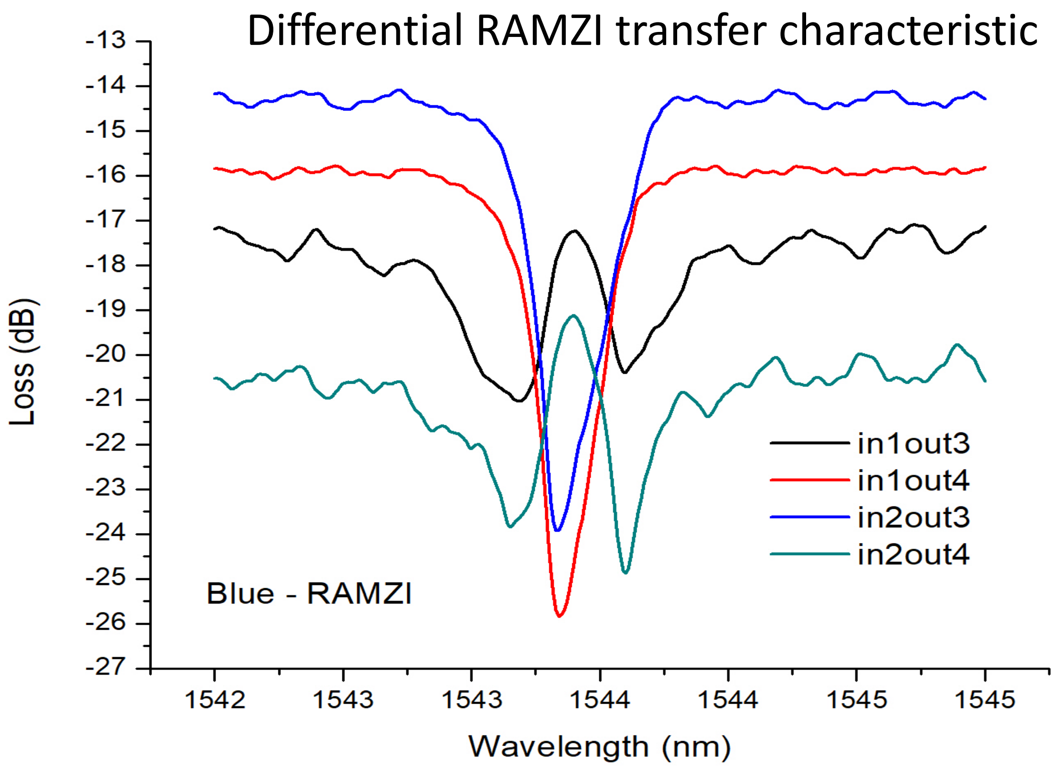
Figure 9. Simulated transmission at the outputs of the interferometer. Dashed lines show the positions of the simulated resonators in isolation, and red and blue lines show the transmission of the bottom and top ports of the interferometer, respectively. (Left) The result when the two resonators are mismatched in frequency, and (right) the result for perfect frequency overlap. Both simulations assume a phase imbalance in the interferometer of -0.17π.

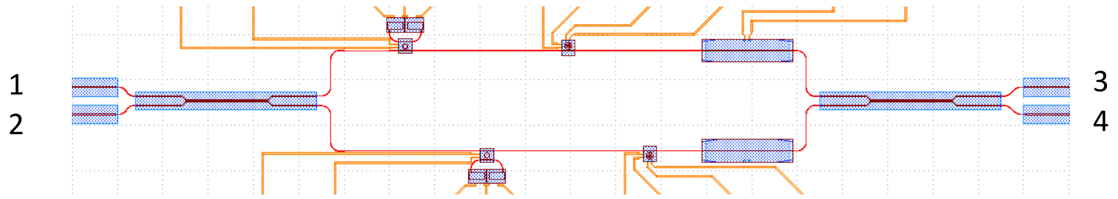
This is an eye diagram measured on the Run 1 of a single MRR – at the top corner of the curve.



GSGSG probes measurements







CONCLUSION

Differential MRRs present a multitude of benefits, including

- inherent wavelength multiplexing,
- gradual signal saturation,
- heightened sensitivity,
- higher bandwidth,
- small dimensions (~10um),
- tunability,
- low power consumption,
- readout system simplicity,
- radiation resilience, and
- cost-effective manufacturing through traditional Si foundries.

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Collaborations

FRIB

MICHIGAN STATE UNIVERSITY

MIT Lincoln Laboratory

ANALOG PHOTONICS

Brookhaven National Laboratory

AIM photonics

NJIT

Stony Brook University

Massachusetts Institute of Technology

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Thank you !

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