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DWDM Tb Photonics Integrated Circuit for Continuous Readout

Award DE-SC0019581

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TTDAQ Readout Network
Specifications

- Radhard tolerant;
- Triggerless, continuous readout for true SW driven detector;
- Photonic Integrated Circuit (PIC) modulator direct interface to sensor preamplifiers;
- Tb bandwidth per fiber and up to 64 DWDM channels (100G ITU grid. Currently limited to 32 by the foundry PDK FSR 3.2THz)
- Transport of both analog and digital signals;
- GTS protocol for nonintrusive, in-band timing synchronization over COTS packet networks, without HW timing distribution;
- FPGA based picosecond TDC for both detector signals and network packets, at backend electronics;
- Highest modulation power efficiency;

PIC Design

- 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.

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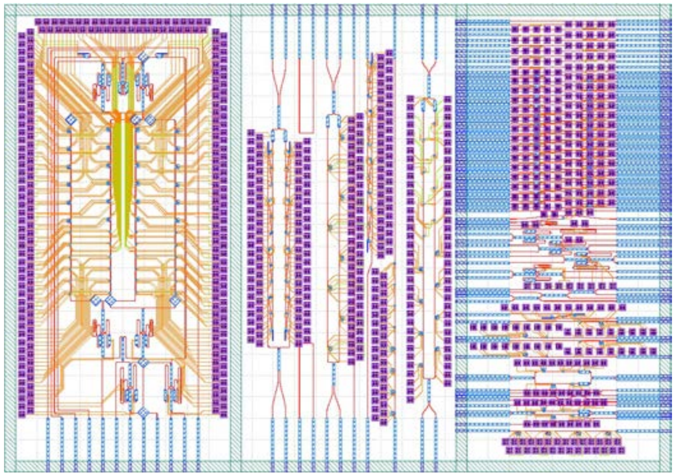
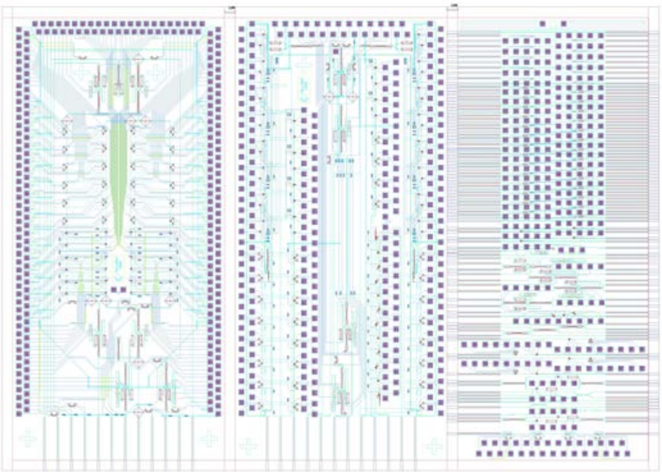
RUN 1



RUN 2



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

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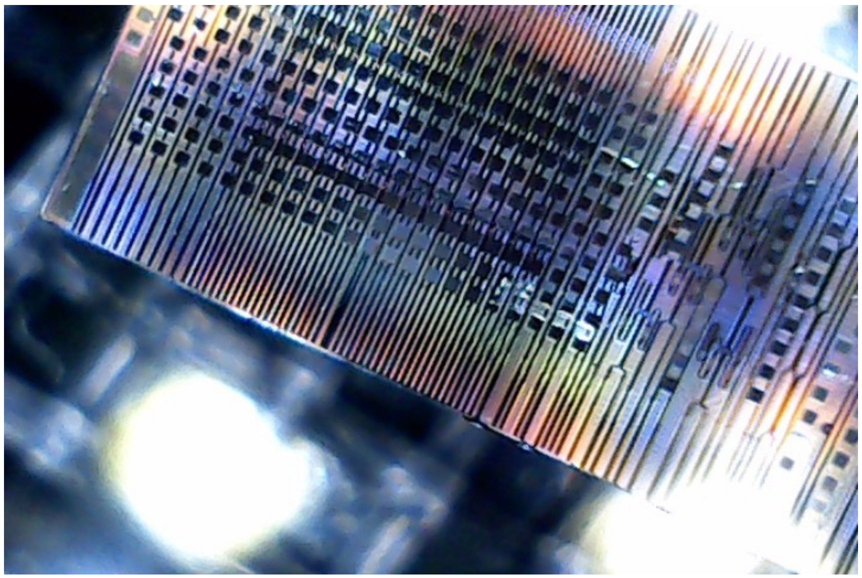
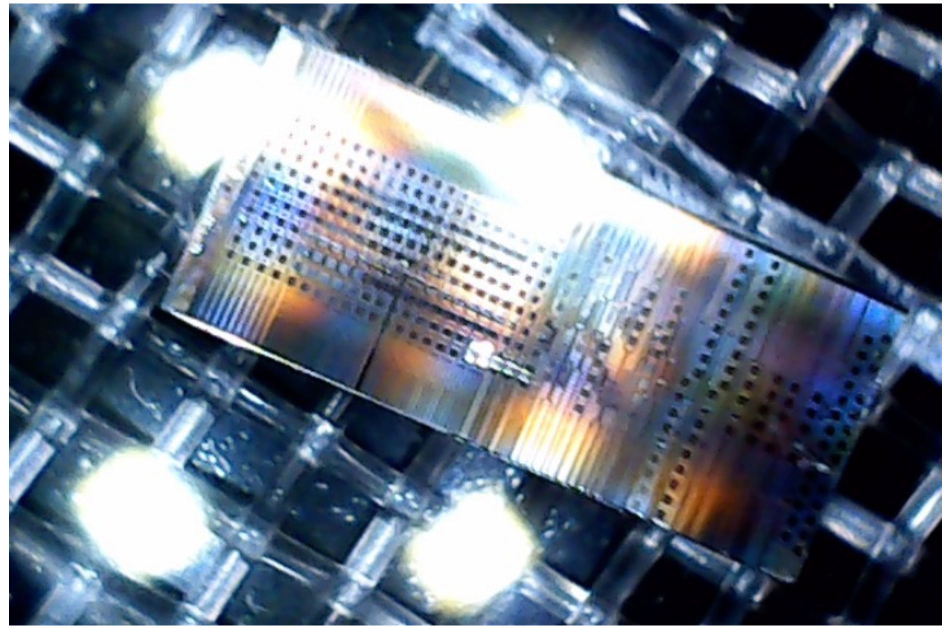
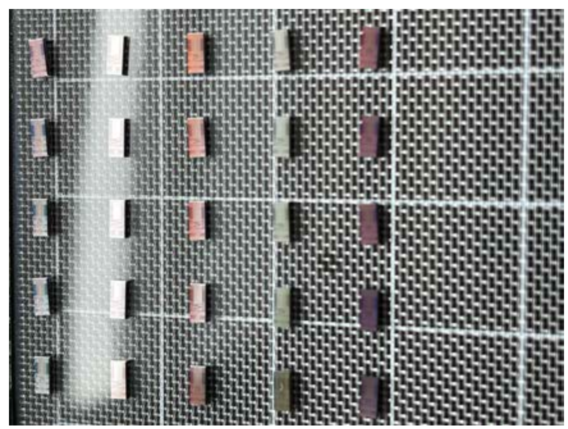
Pebbles Chiplet





Comprises basic circuits and several new MRR designs



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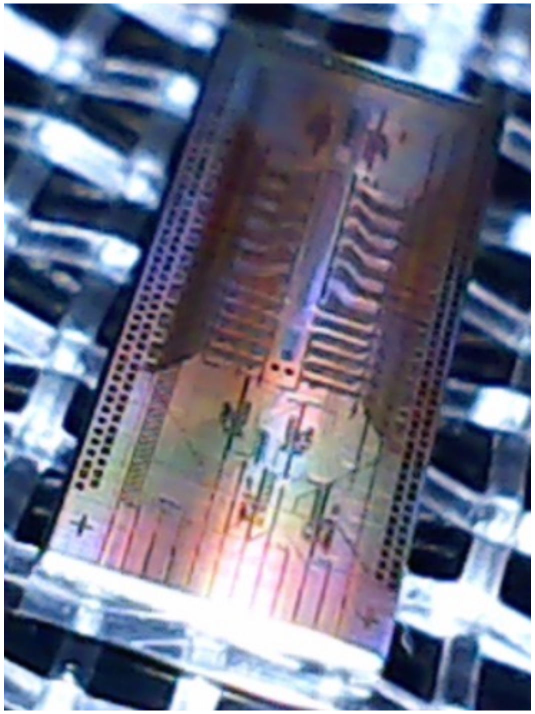
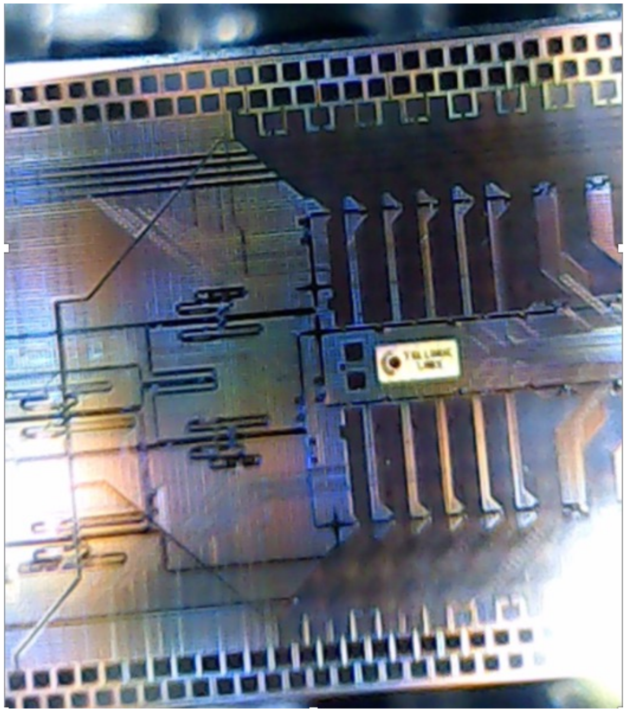
Prometheus Chiplet





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

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Tb DWDM PIC Advantages

- 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 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 of laser source;
    - External lasers provide an additional control and communication channel;
    - Physical layer measurement of propagation delay, and additional synchronization method.

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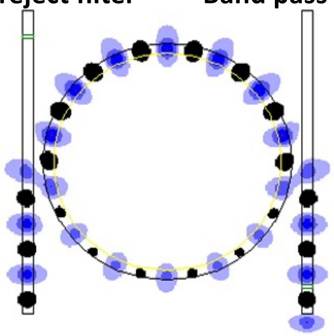
MICRORING RESONATORS FUNCTIONAL PRINCIPLES

Add drop topology

Band reject filter **Band pass filter**



Functional Control Parameters

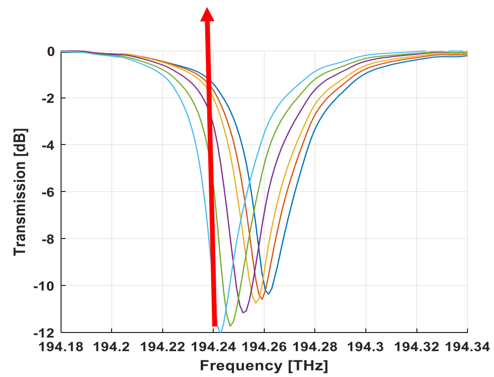
laser wavelength

laser power

Heater temperature control

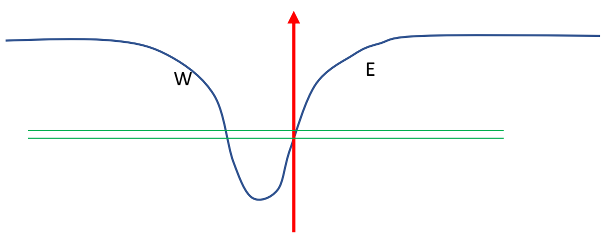
DC bias

RF signal amplitude

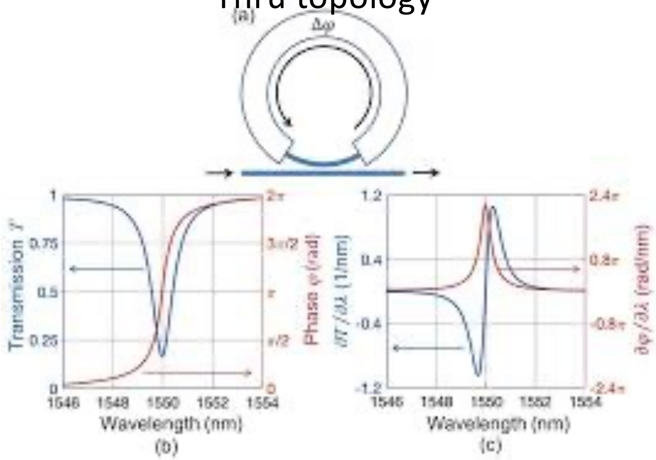


RAMZI MRR modulation principle (~10GHz/V)

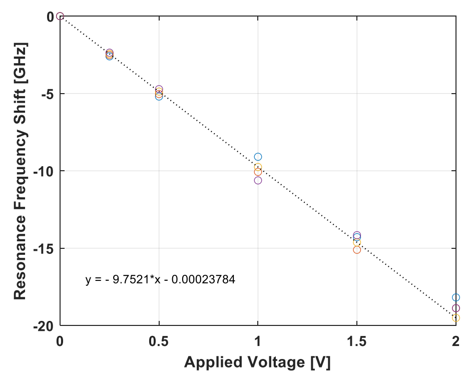
Amplitude Modulation



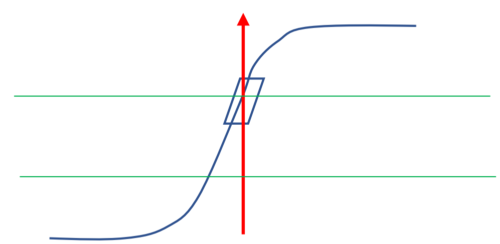
Thru topology



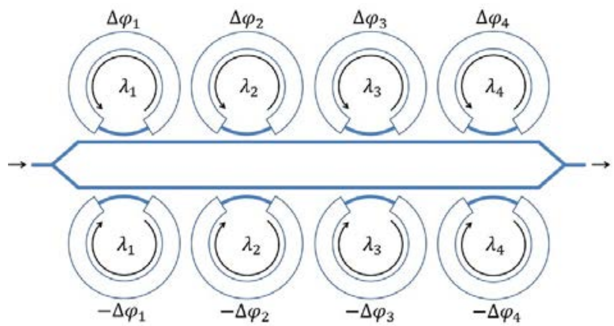
Modulation



Phase Modulation



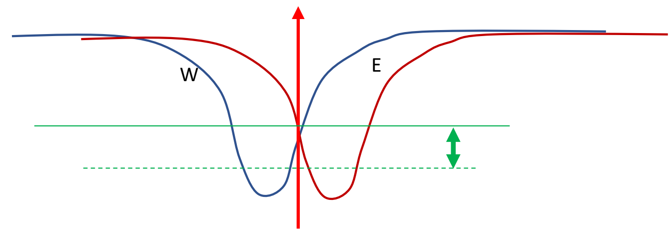
Differential modulation



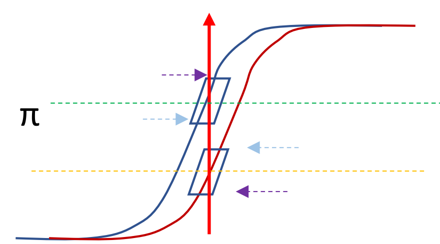
RAMZI – analog modulation
https://ieeexplore.ieee.org/document/8540485

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

Amplitude



Phase Modulation of DT



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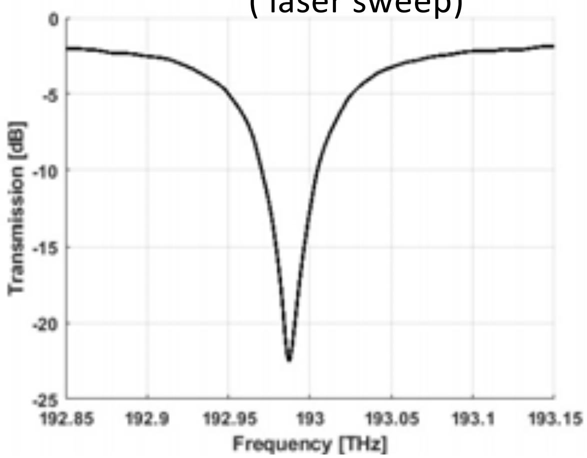
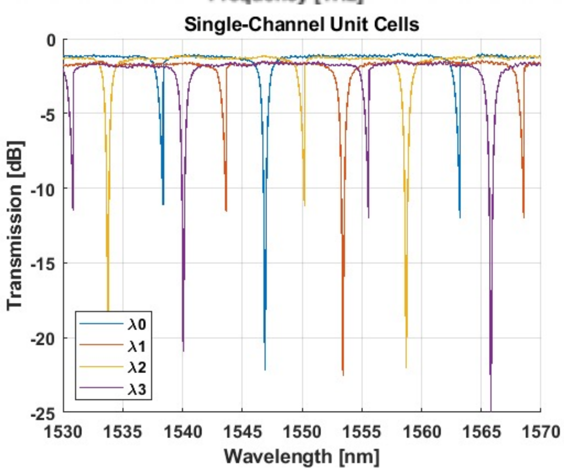
BENCH MEASUREMENTS RESULTS
DWDM Tb PIC Run1

Detail MicroRing optical characteristic (laser sweep)





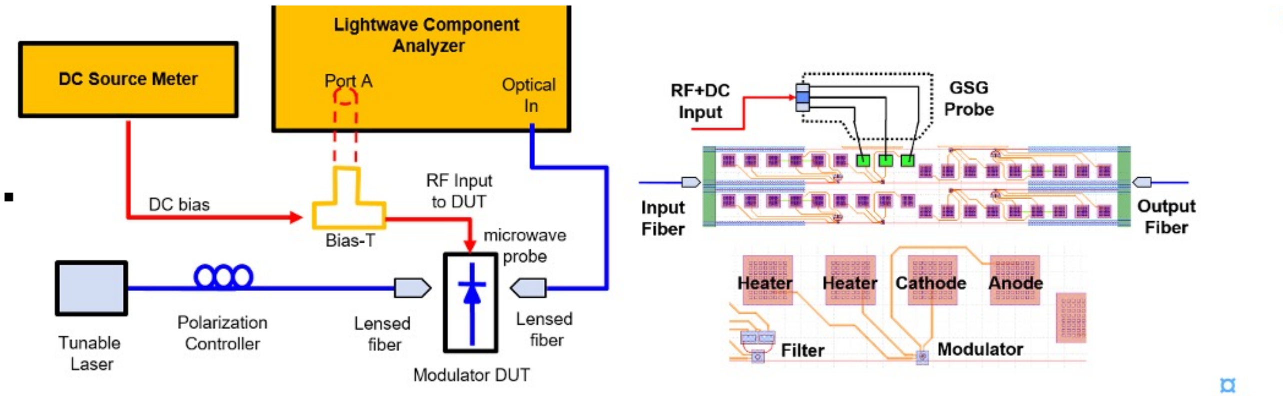


Figure 1. (Left) Experimental setup for characterizing the RF transfer function (S11 and S21) of modulator components. (Right) Detail illustration of the interface to the PIC, including the layout of a typical modulator device under test.

Free Spectral Range (FSR) = 3.2 THz

MRR S parameter RUN 1

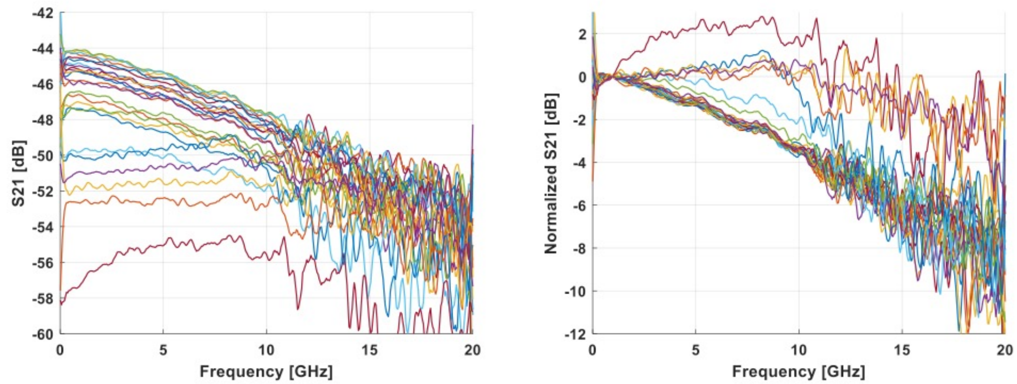


Figure 2. (Left) Measured S21 power as a function of RF modulation frequency, for a fixed bias voltage of 1.0V and at several different input laser frequencies. (Right) S21 data normalized to the value at 1GHz modulation frequency.

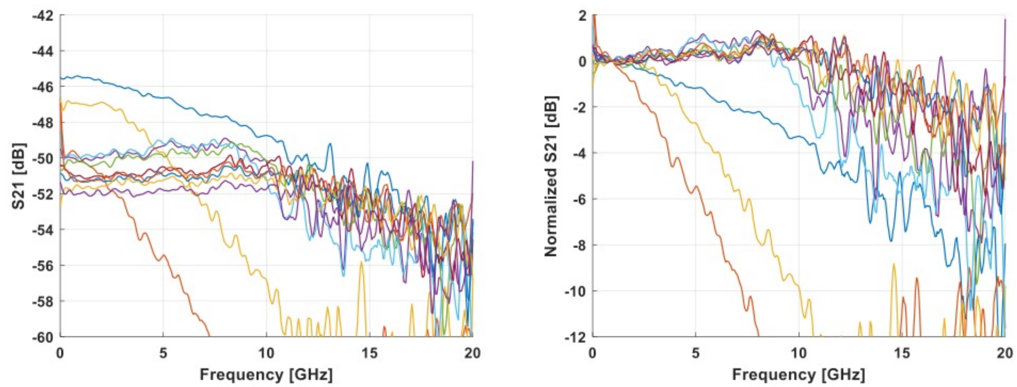


Figure 3. (Left) Measured S21 power as a function of RF modulation frequency, for a fixed bias voltage of 1.2V and at several different input laser frequencies. (Right) S21 data normalized to the value at 1GHz modulation frequency.

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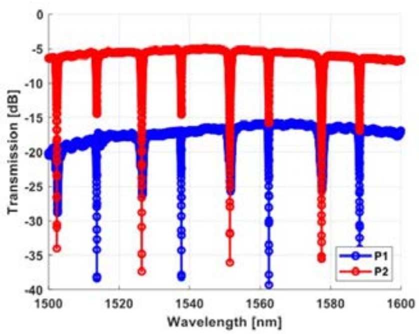
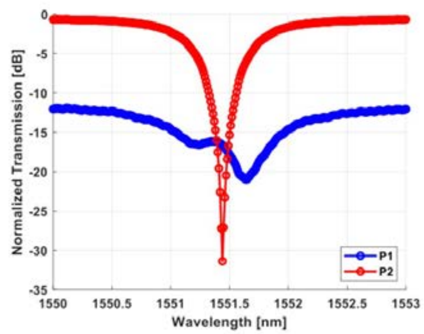
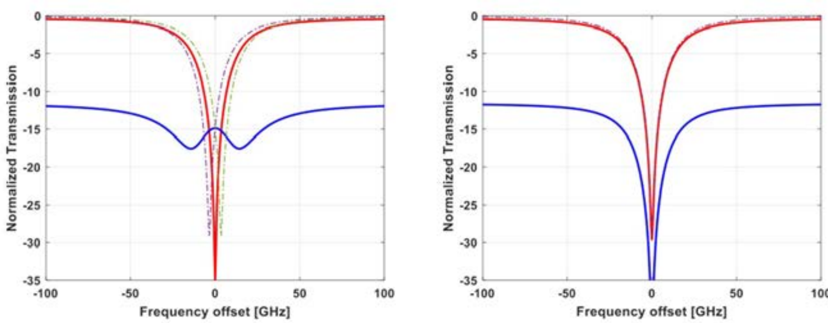
Measurement of differential modulator v. simulation



Measured transmission at the output of the interferometer .

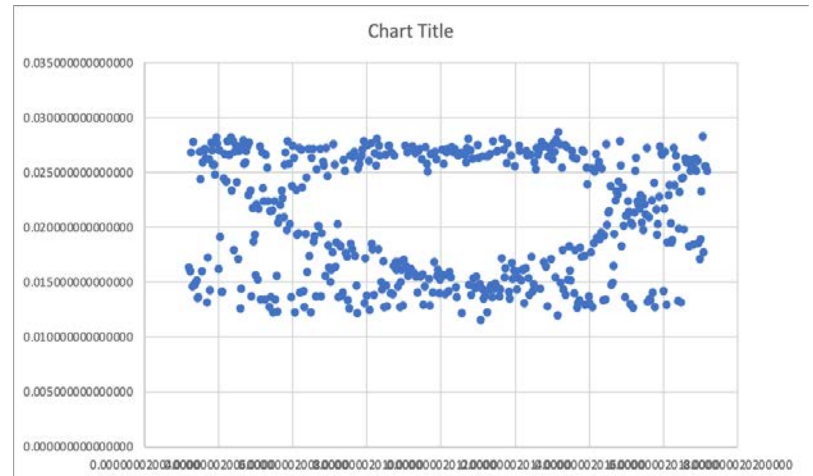


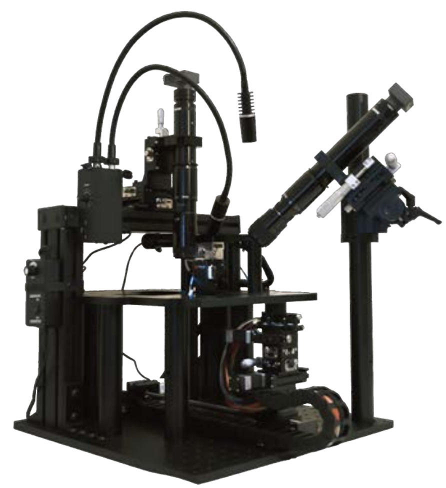
Normalized transmission in the region of one of the filter resonance.

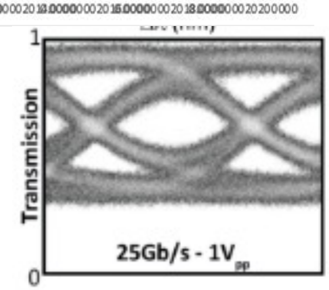


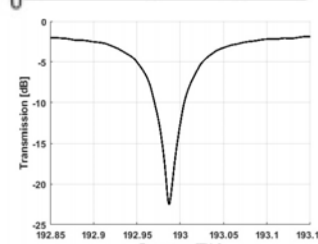
Simulated transmission at the outputs of the interferometer. Dashed lines show the positions of the simulated resonators in isolation, and the red and blue lines show the transmission at the bottom and top ports of the interferometer. Left: The result when the two resonators are mismatched in frequency. Right: the result for perfect frequency overlap.

Eye diagram measured on the Run 1 of a single ended microring resonator

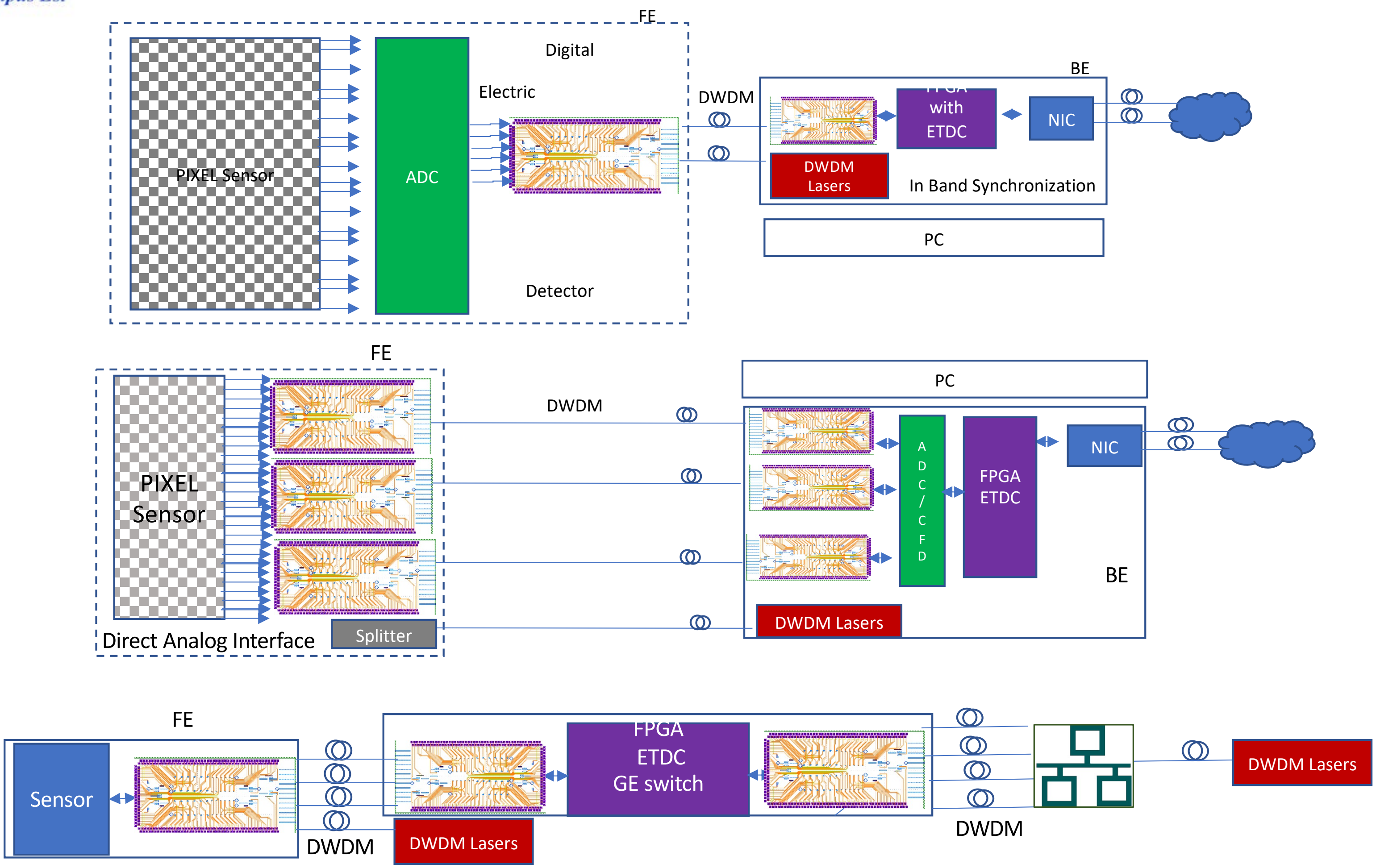








DWDM Tb Photonics Integrated Circuit for continuous readout



Packaging technologies

Multiple challenges

- optical alignment
  - Fiber array (12 fibers) for testing several entry / exit points from the PIC
- electrical contacts
  - at 100um pitch, double row pads
- Could not use traditional interposers due to cost and fabrication time
- Direct to PCB technology requires new solutions
  - Precision feature - PCB fabrication and PIC placement
  - assembly temperature
  - stability in time of bonding
  - rework
- Impedance matching (including embedded resistors)
  - > 15GHz
- Cross talk
  - RF and thermal

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Project impact on electro optics technologies

- Highest density of active components – push of PIC technology – very promising development.
- Direct fine pitch PCB bonding – replacing wire bonding for higher frequency
  - improve new materials: Anisotropic Conductive Adhesives – with tuned composition
  - Aluminum to PCB bonding technologies
  - Fine pitch RF PCB

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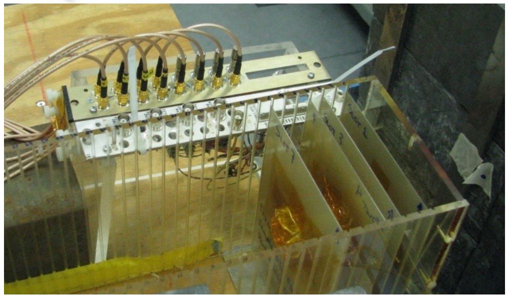
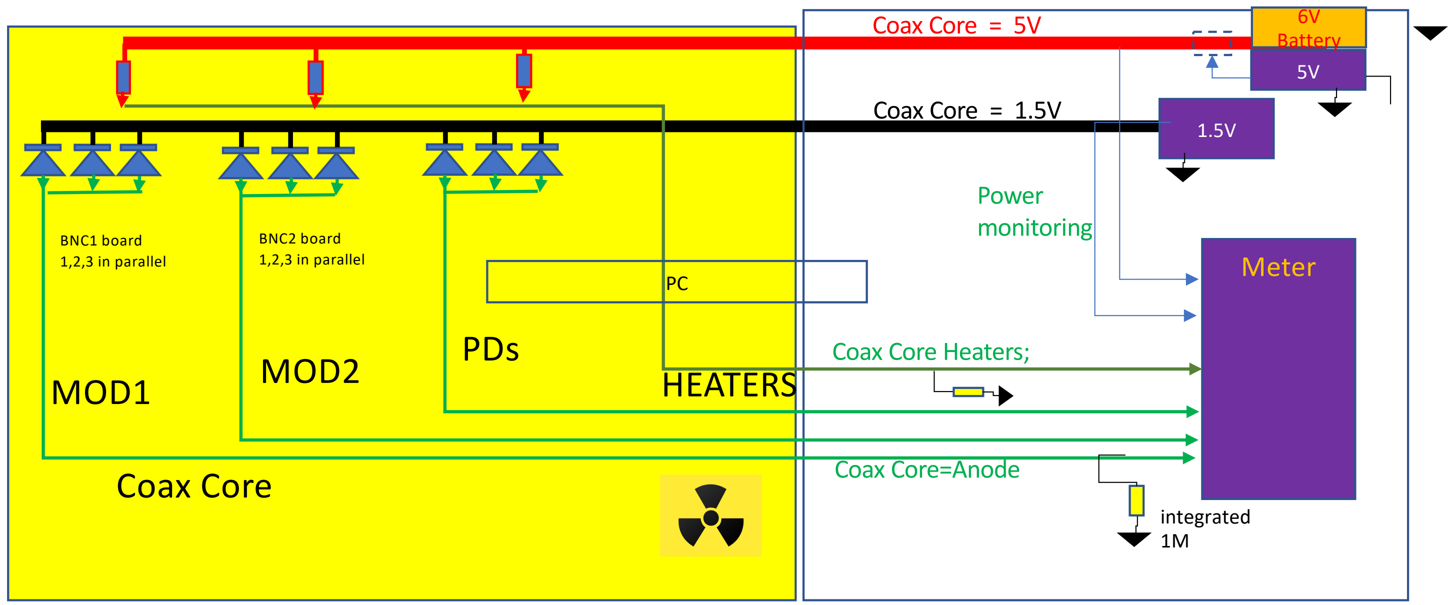
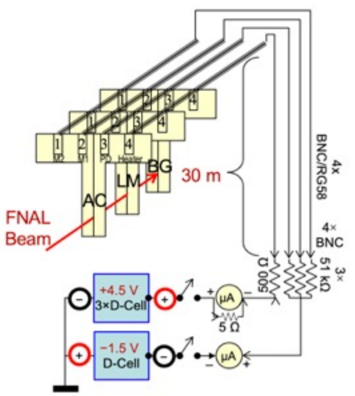
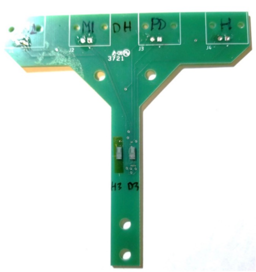
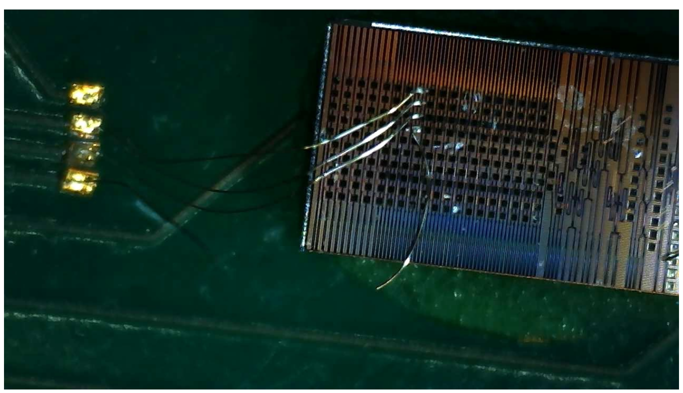
Radhard tests

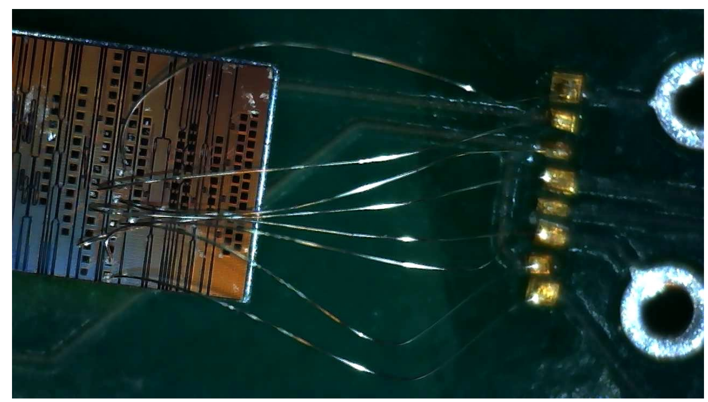












Next steps

- Comparative tests of radiation impact on the PIC
- Pebbles components test with GSGSG probes
- Build the Test PCB for Phoenix
- Package of Phoenix (PCB, fiber array, TEC)
- Test individual Phoenix channels
    - wavelength tuning
    - eye diagram
- Automatic AI test and control Phoenix multiple channels
    - wavelength tuning
    - eye diagram
    - cross talk
- Build Electronics TIA and Driver. VITA 57.4 board
- Test board with FPGA BERT and AI controls.

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Thank you !

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