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# Integrated Microwave Photonics
## for phase array antenna systems

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Chief Scientific Officer

LioniX International

April 18th, 2018

# Our Mission

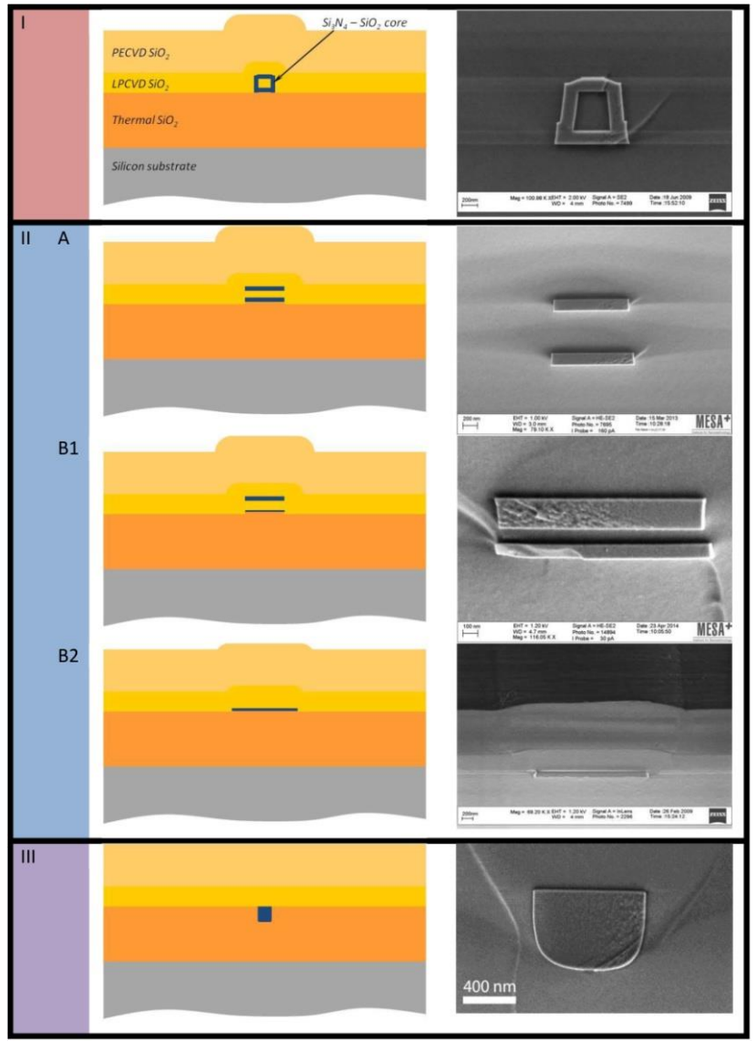
LioniX International is a leading global provider of customized microsystem solutions, in particular integrated photonics-b ed, in scalable production volume

**Why**

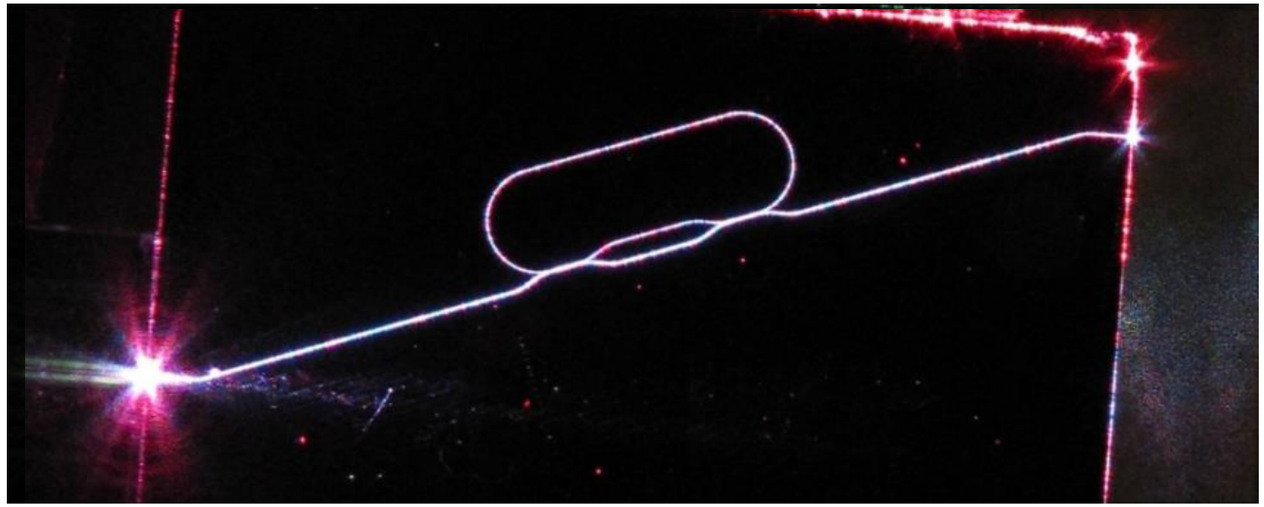
Applying dis gies to solve challenges

**Integrated Photonics is one of the key enablers for this**

# Proprietary Technology: TriPleX Platform




- Adjustable polarization properties (sensors ⇔ telecom)
- Low optical attenuation (< 0.1 dB/cm @ 1550 nm)
- Small bend radii (80 µm, small footprint!)
- High optical powers (> 1 Watt)
- Spot size converters for low loss fiber chip coupling (< 1 dB)

**Roeloffzen et al. IEEE JSTQE, 24(4), (2018)**

# Network Enhancements for 5G

mmWaves

Small Cells

Massive MIMO

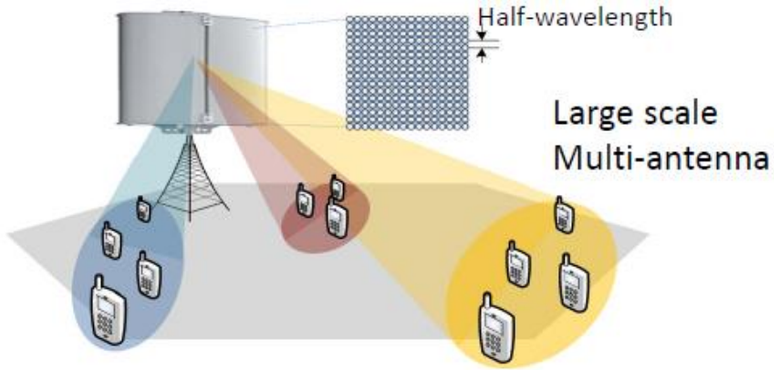
Beamforming

Full Duplex

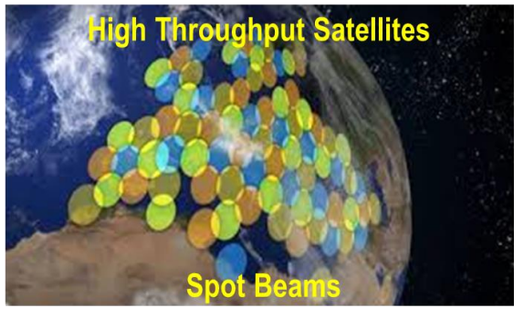
# Beamforming

Beamforming or spatial filtering is a signal processing technique used in **sensor arrays** for directional signal transmission or reception. This is achieved by **combining elements** in an antenna array in such a way that signals at particular angles experience **constructive interference** while others experience destructive interference.

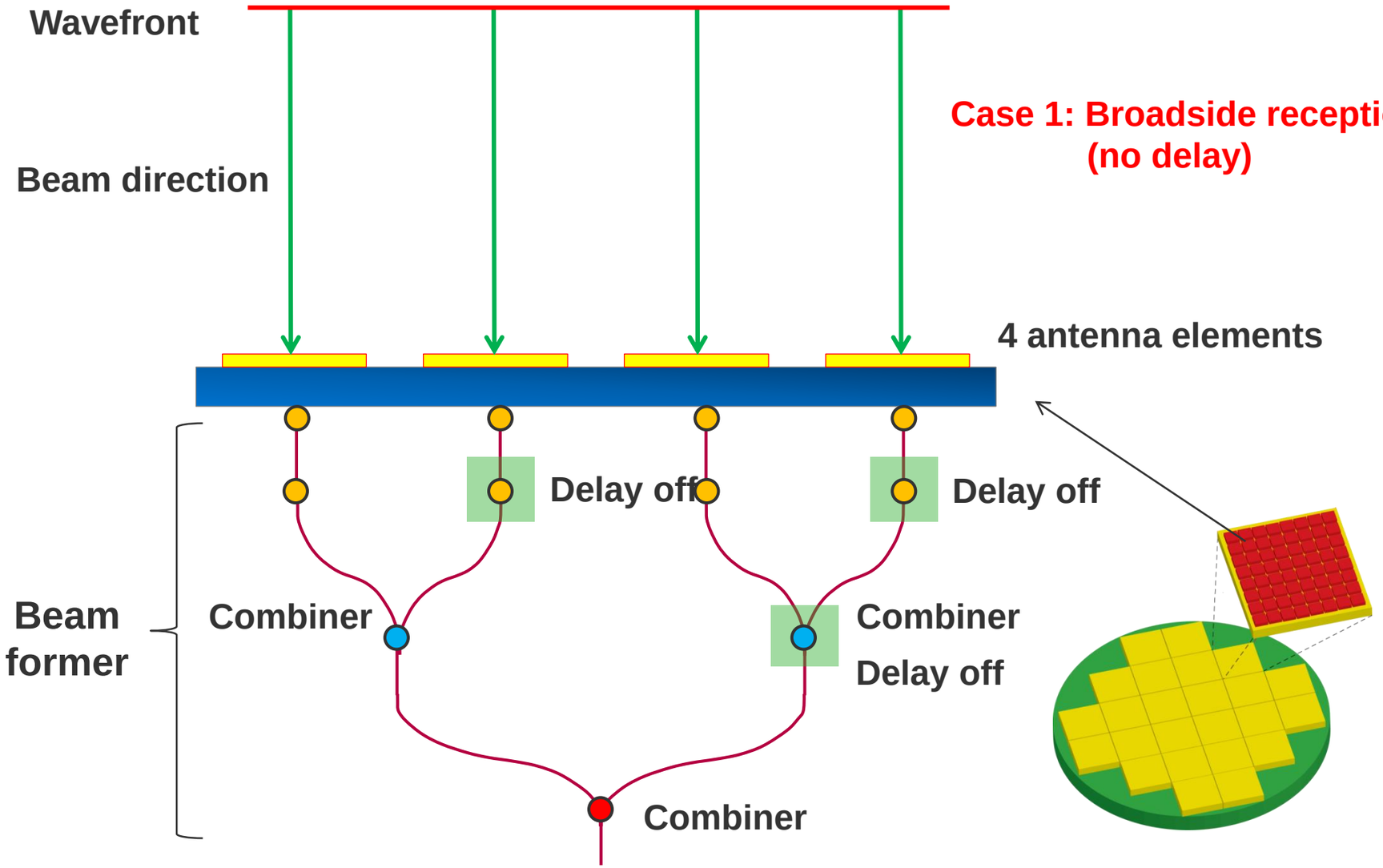
- Dynamically & continuously steerable beam
- Adjustable beam shape and beam profile (2D)
- Active interference suppression capability
- Large bandwidth achieved at large view angles
- Multiple independent beams capability
- Technology scalability, applicable for 1-100 GHz
- Low power consumption
- Mass producible





# Beamforming network



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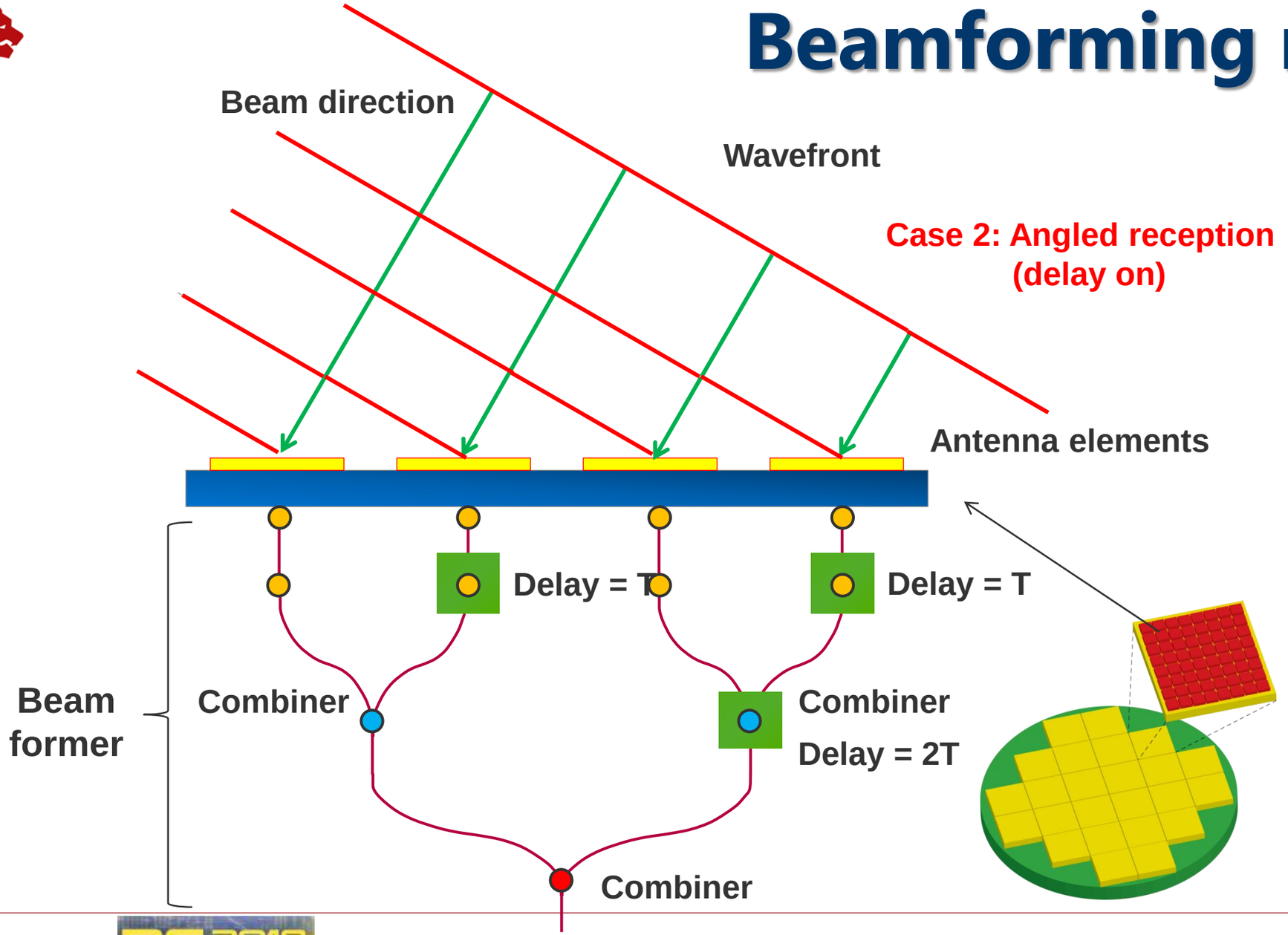
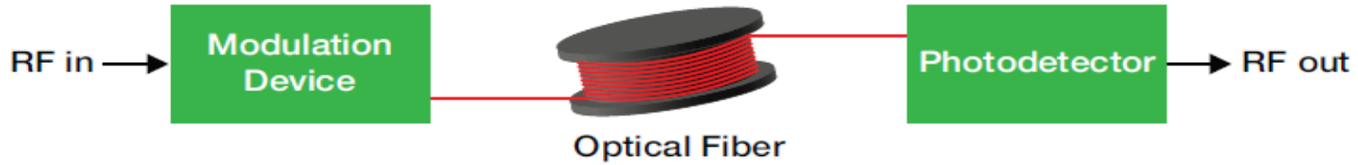
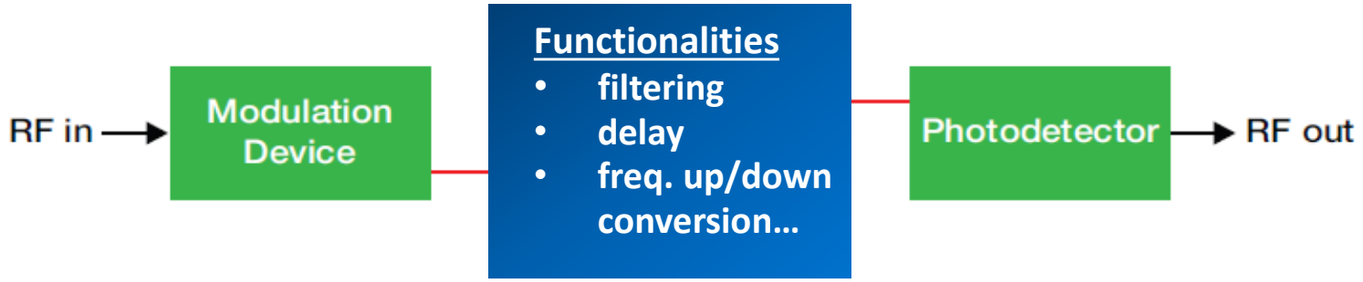


# Integrated Microwave Photonics

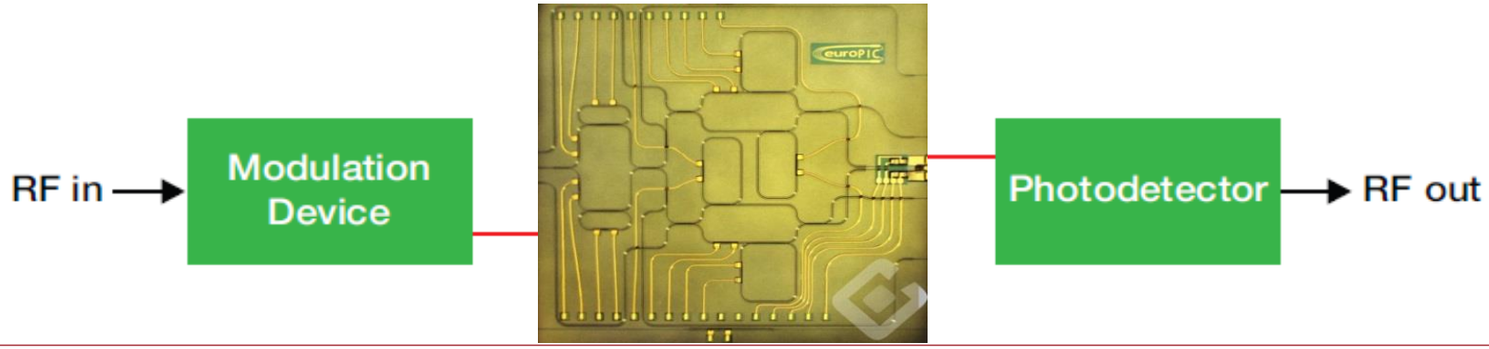
**MWP link:** low loss signal transport/distribution




**MWP system:** wideband, reconfigurable RF signal processing

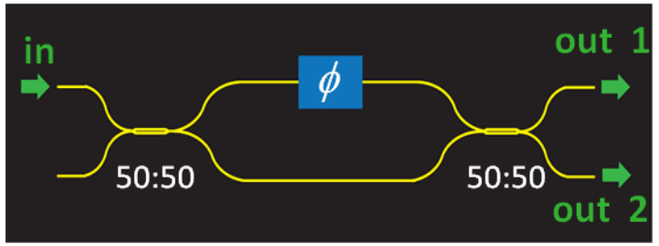



**Integrated MWP:** PICs for advantage in size, weight and power

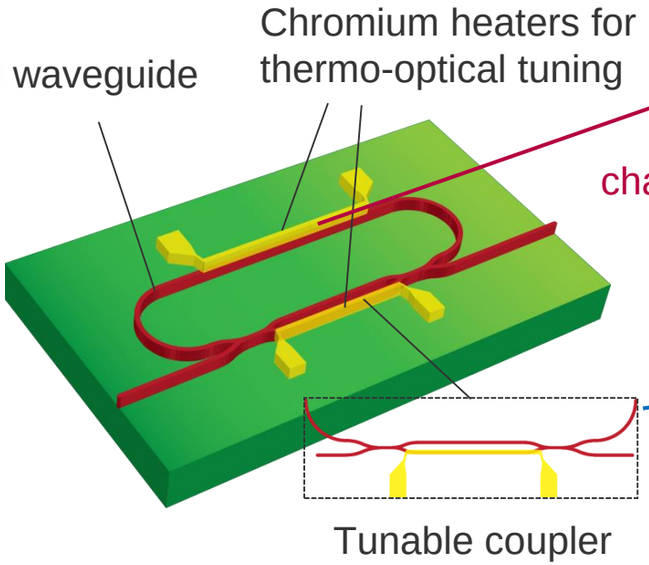


# Optical ring resonator as tunable delay

**Combiners: Tunable MZI coupler**



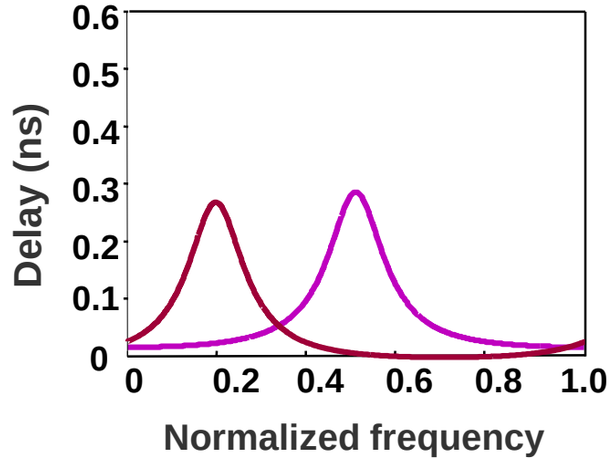

**Delay element: Optical ring resonator**

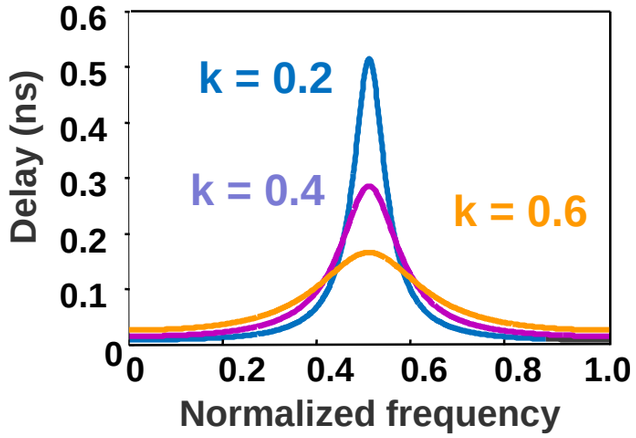



Phase shifter to change the resonance frequency

Tunable coupler to change the coupling to the ring

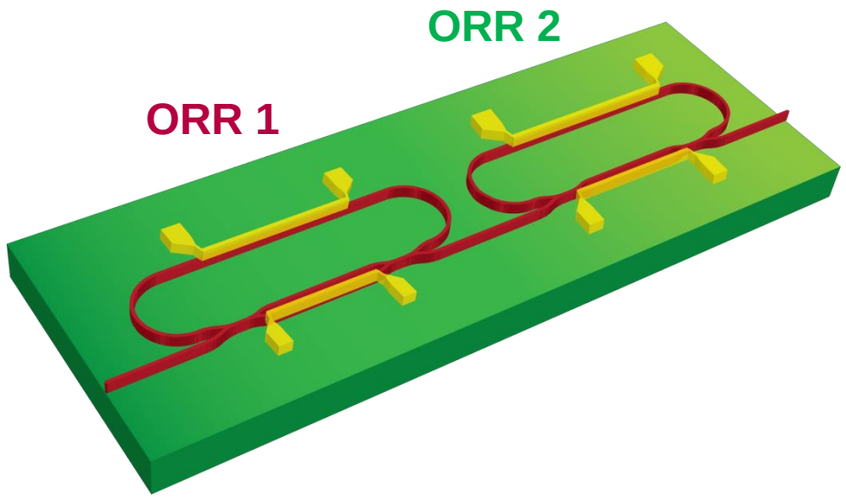
**If the directional couplers are 50:50, by changing $\phi$ (thermo–optic tuning) the optical power at the complementary outputs can be tuned from 0 to 100%**

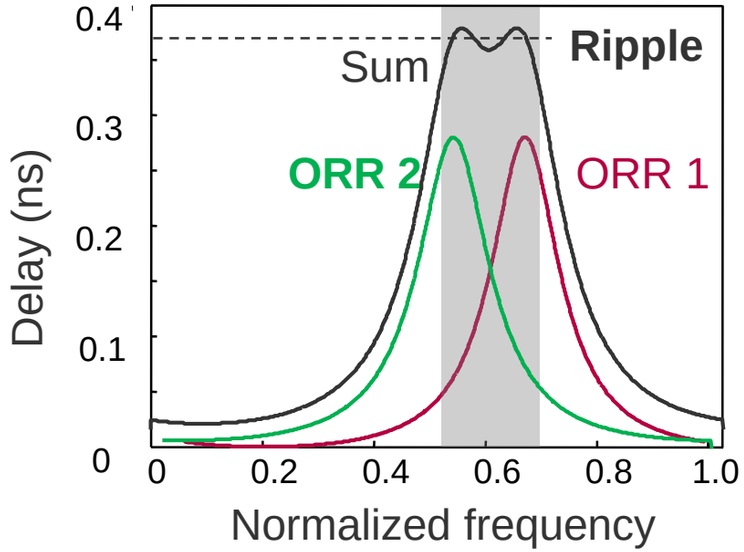


# Optical ring resonator as tunable delay

- Single ORR provides tunable delay, but it is band limited
- Trade-off between maximum delay and delay bandwidth
- Solution→ cascade more than one ORRs



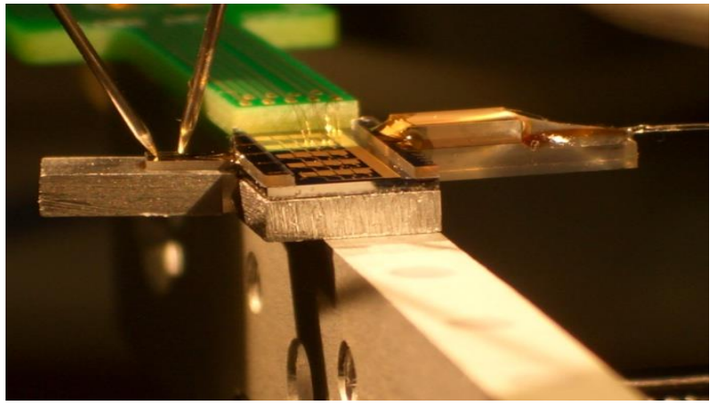

- More ORRs cascaded → more bandwidth but more ripple
- Trade-off between bandwidth, the number of ORR and the delay ripple

**Next step: to arrange the combiners and the ORRs to make a beamformer**

# Hybrid Photonic Integrated Circuits

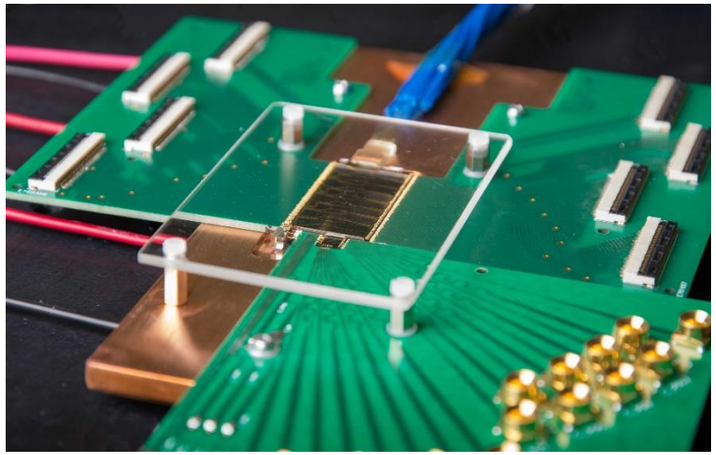
- 3 mature standardized platforms commercially available through MPW services:
  **Indium Phosphide (InP) - TriPleX ($Si_3N_4$) - Silicon Photonics (SOI)**

✓ Ultra low loss (<0.1 dB/cm)
✓ Applicable in almost all interesting wavelength regions
✓ Reliable modulators (heaters, stress modulators)
✗ But is not electro-optic, so lacks direct laser generation

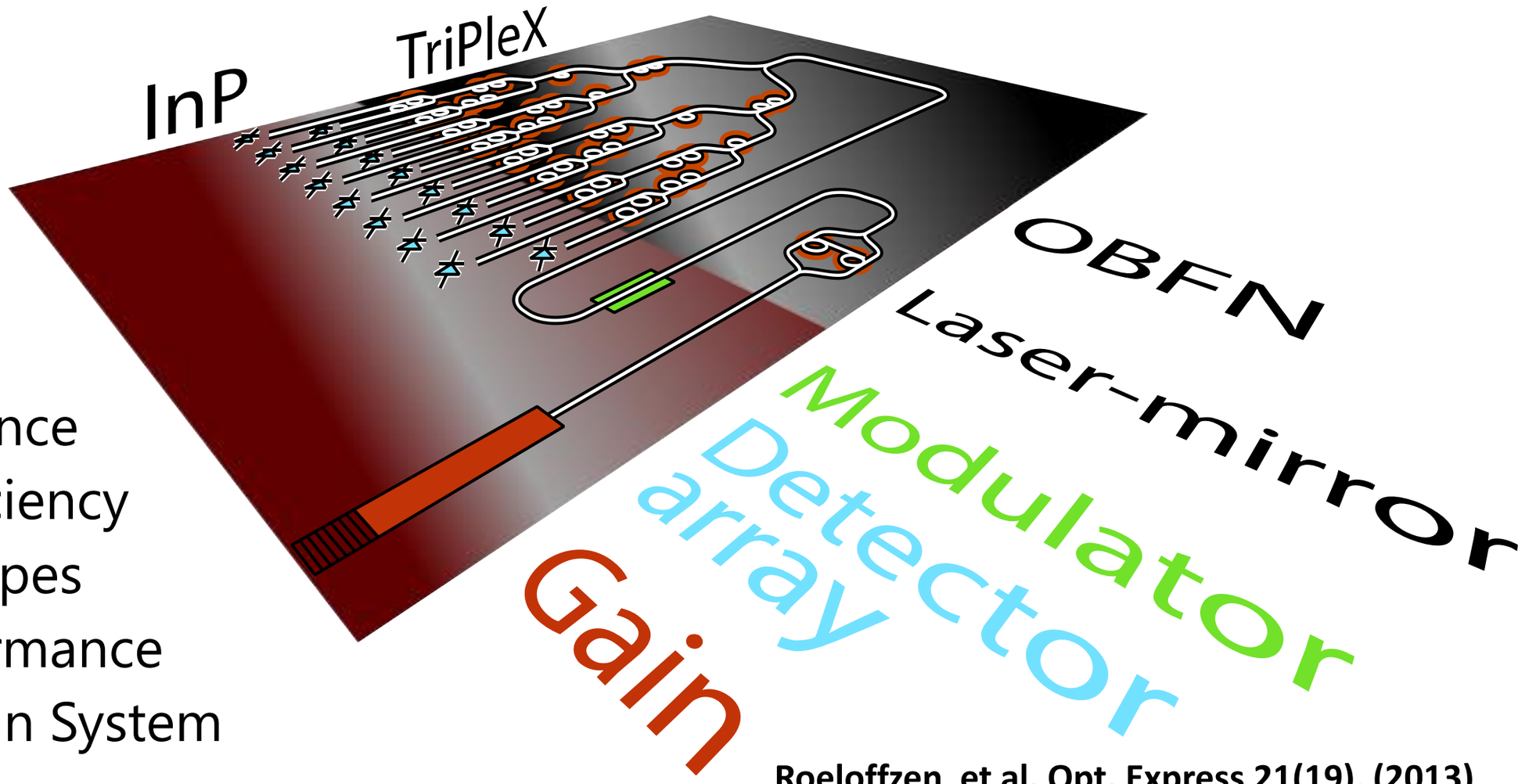


- Therefore:
  **Combine TriPleX with InP yielding:**

✓ Very high quality, widely tuneable lasers !
✓ High speed modulation (E/O conversion)
✓ High speed potodetection (O/E conversion)
✓ Also hybrid integration with other materials (AlGaAs, Si, etc.) was shown



# iMWP Beamformer



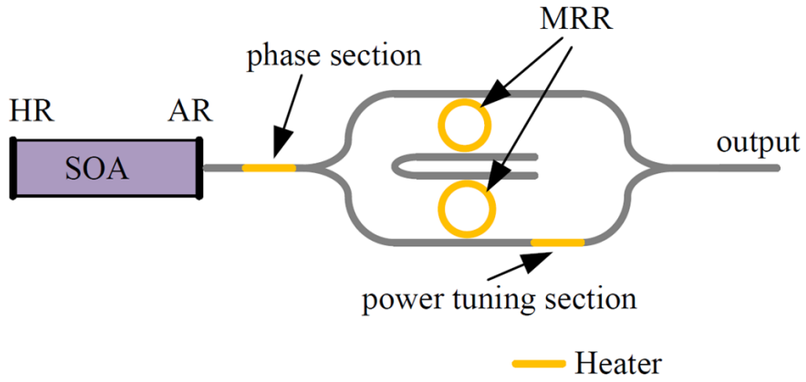

1. Laser Performance
2. Modulator Efficiency
3. Beamformer Types
4. Detector Performance
5. Optical Losses in System

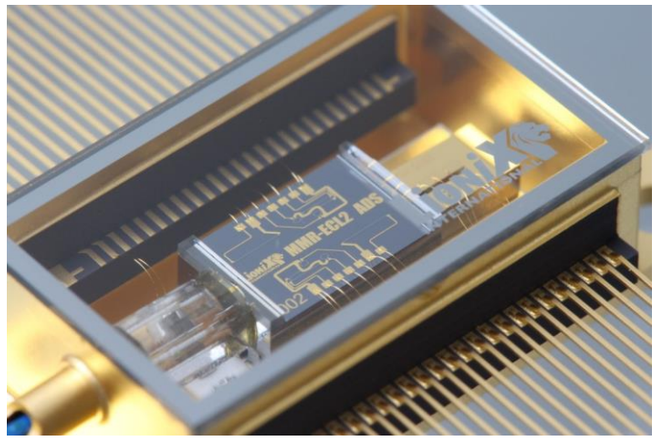
**Roeloffzen et al. Opt. Express 21(19), (2013)**

# Tunable laser source

Hybrid combination of InP gain section and TriPleX reflector chip to realize a tunable external cavity laser source with excellent specifications.

- ✓ High optical power (>40 mW), small bandwidth (several kHz, sub-kHz)
- ✓ Mode matched to standard telecom fiber
- ✓ Large side mode suppression (>60 dB)
- ✓ Tunable over C-band (>80 nm)
- ✓ Potential to integrate other optical functions on TriPleX chip

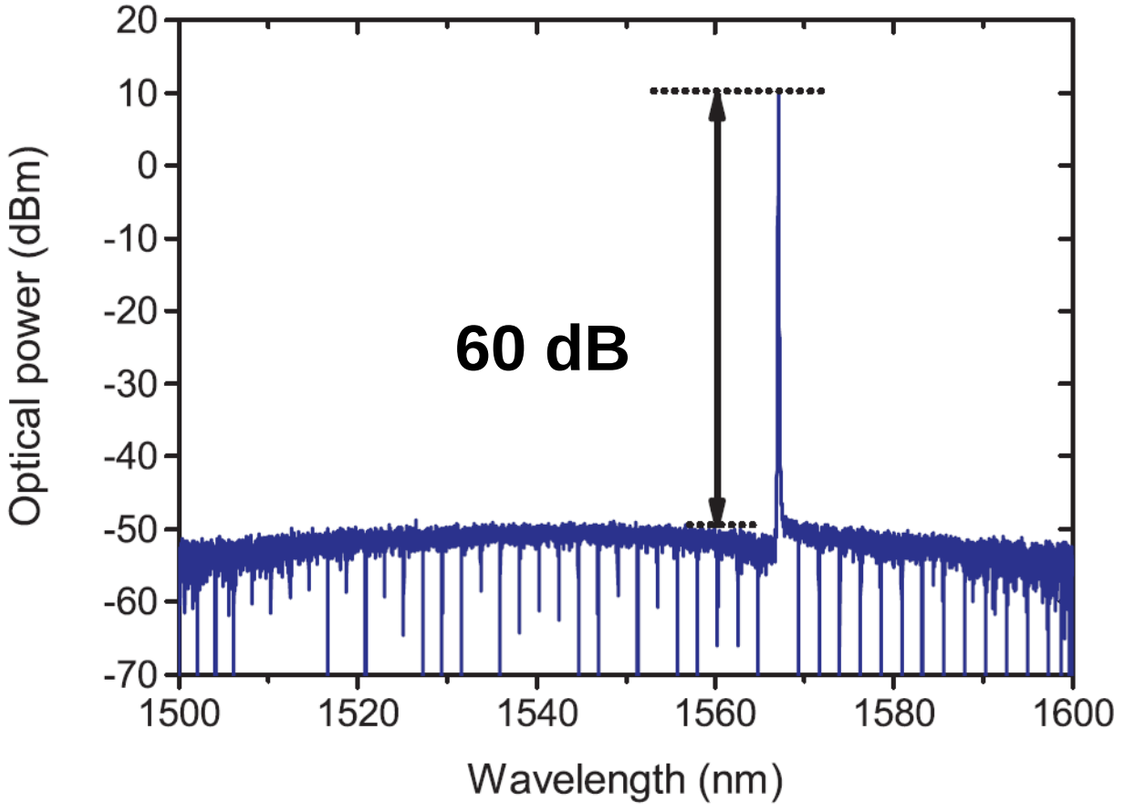


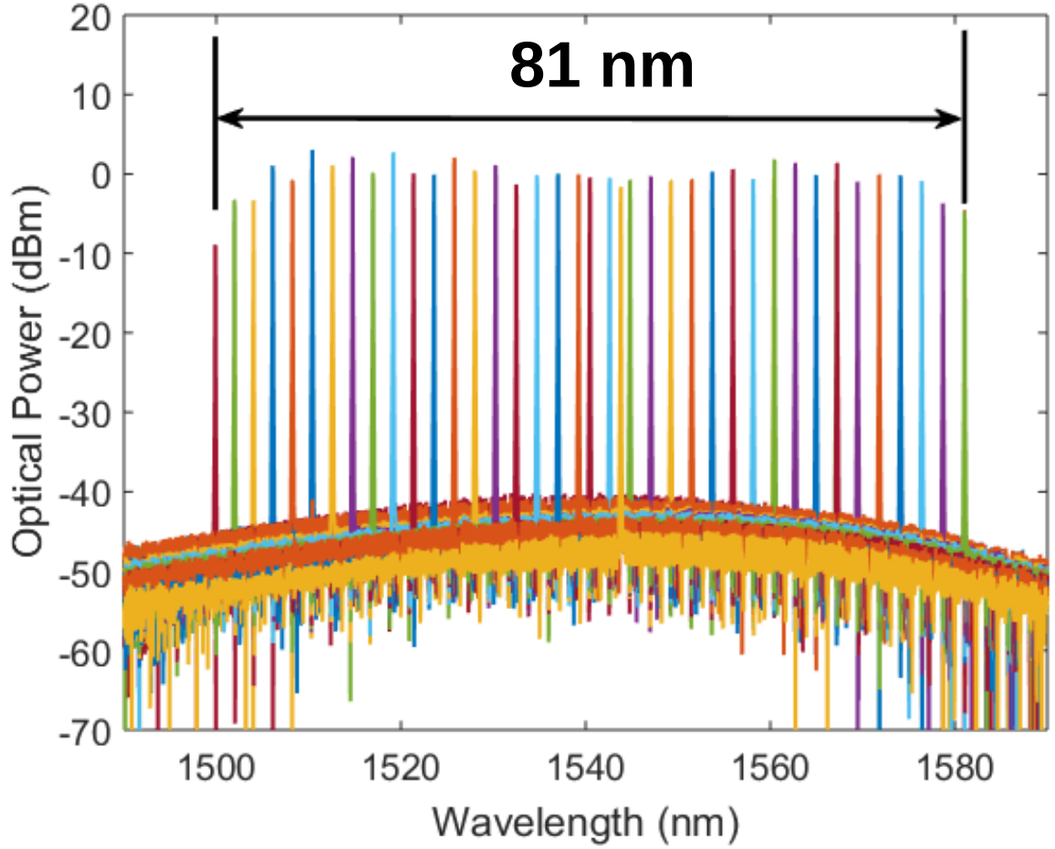
**Oldenbeuving, et al., Laser Phys. Lett. 10 (2013) 015804**

# Laser spectrum

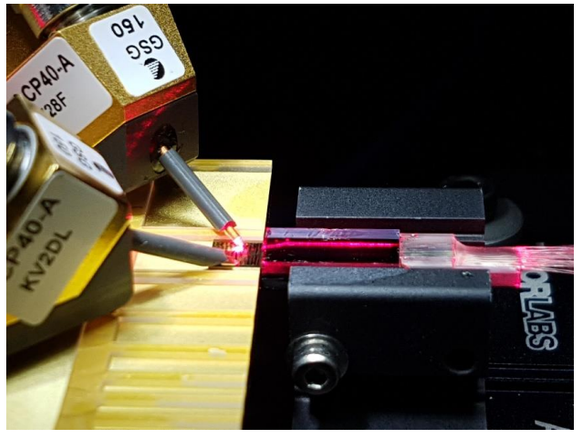
## Single frequency output

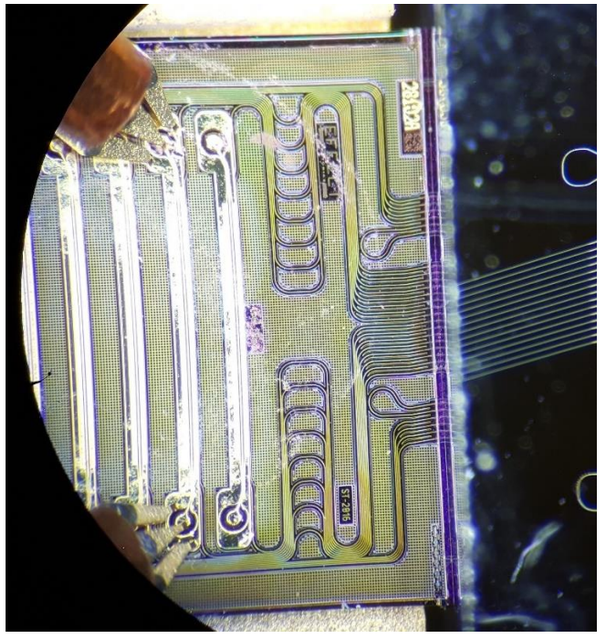


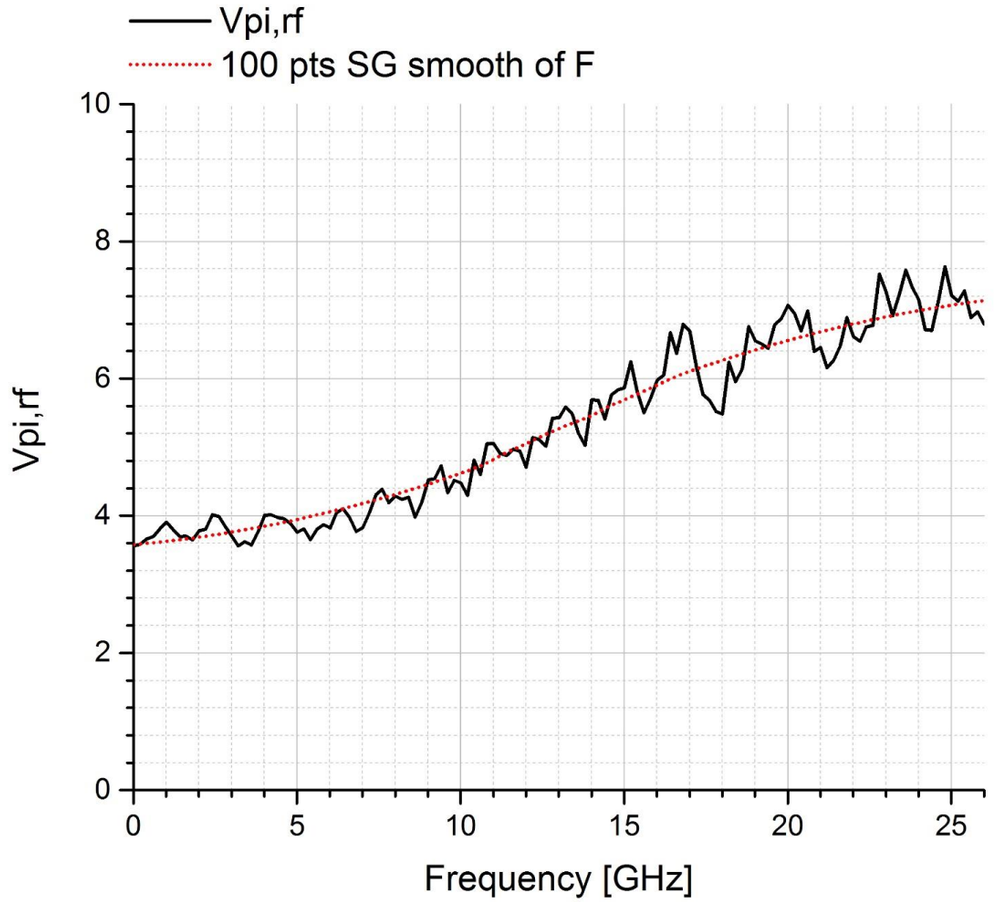

## Wide tuning range



# Modulators (E/O conversion)

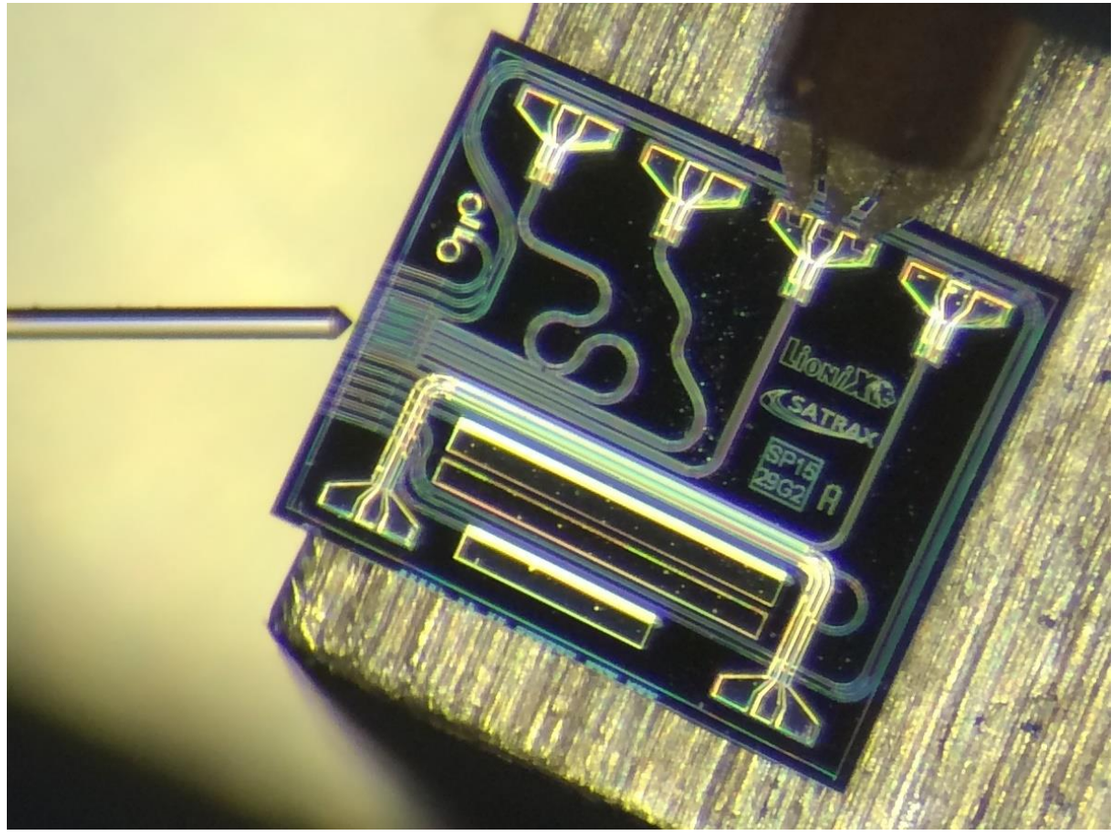


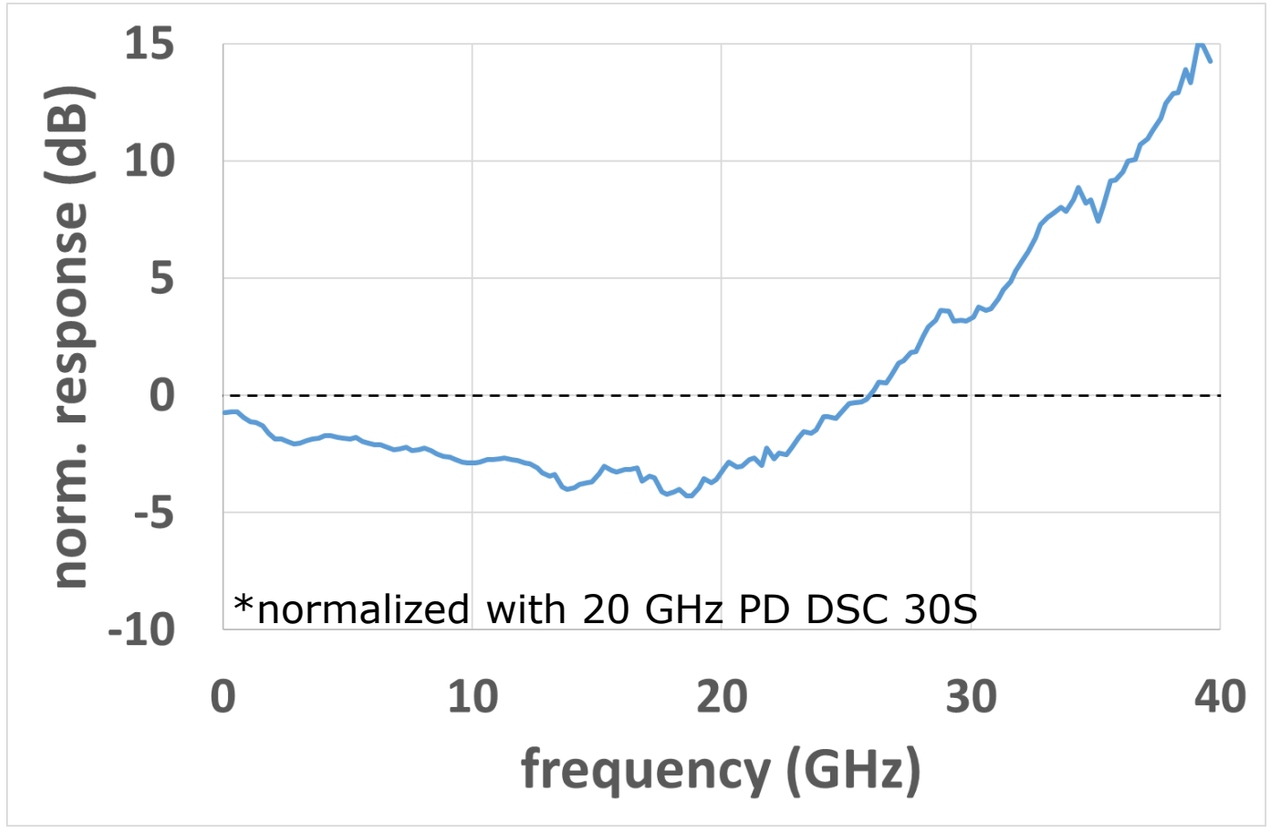





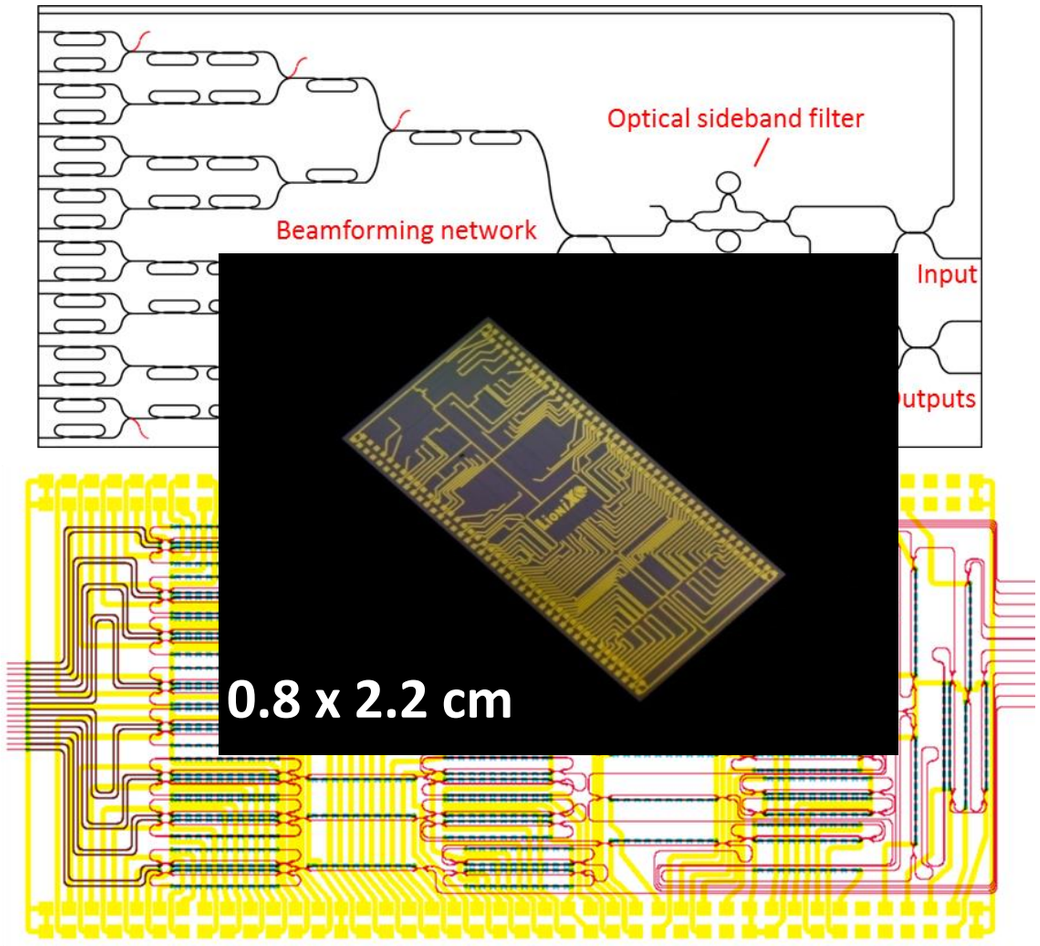
# InP Photodiodes (O/E conversion)

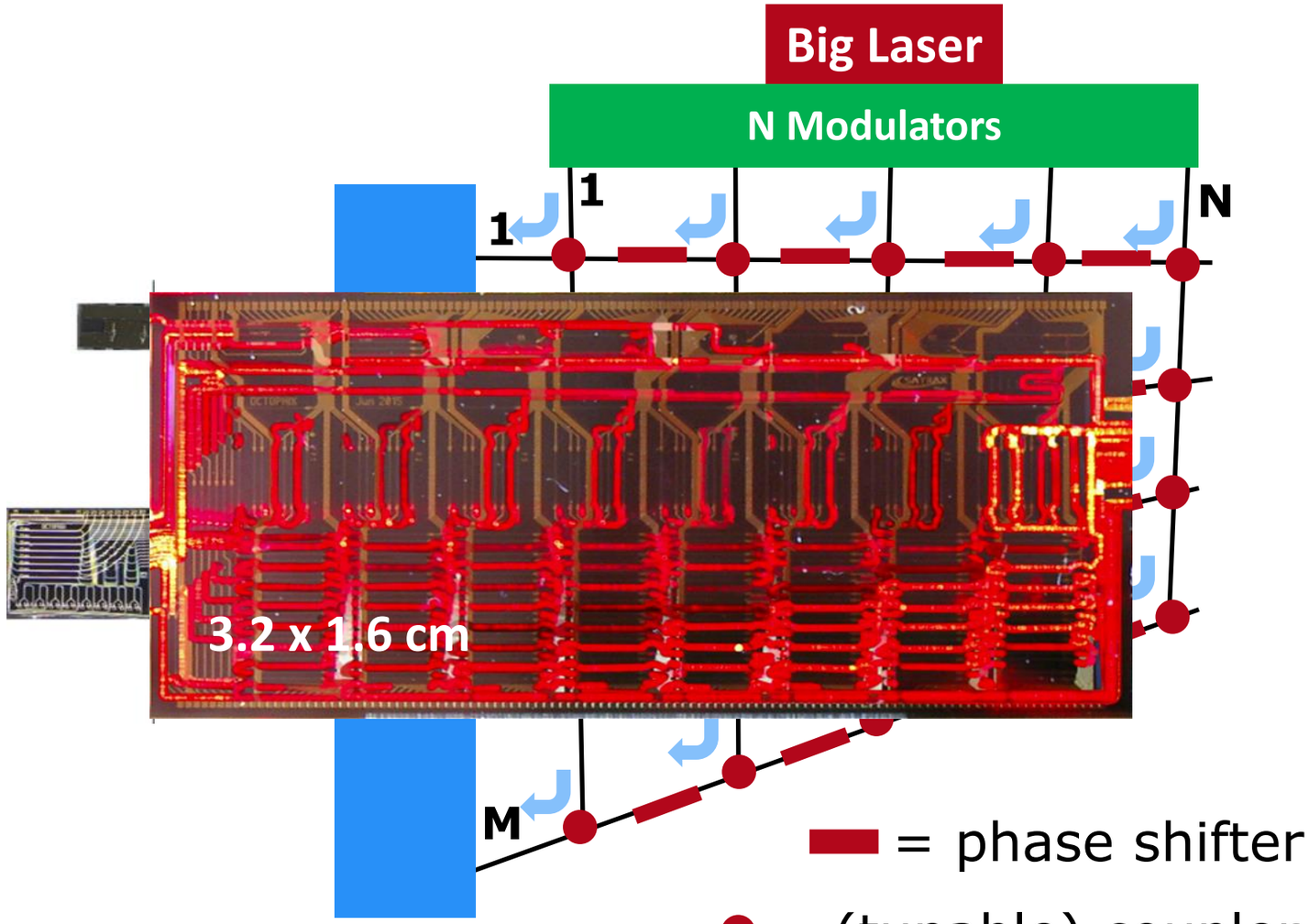
- RF-response using GSG semi-insulating InP chip + RF probe



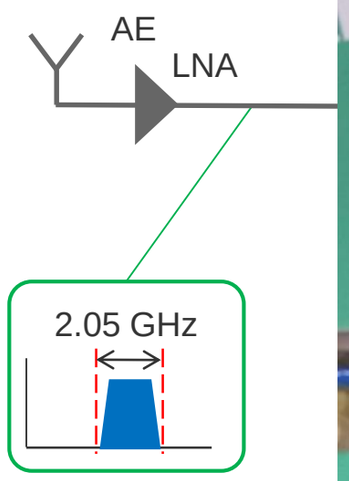



# Optical Beamforming Architectures

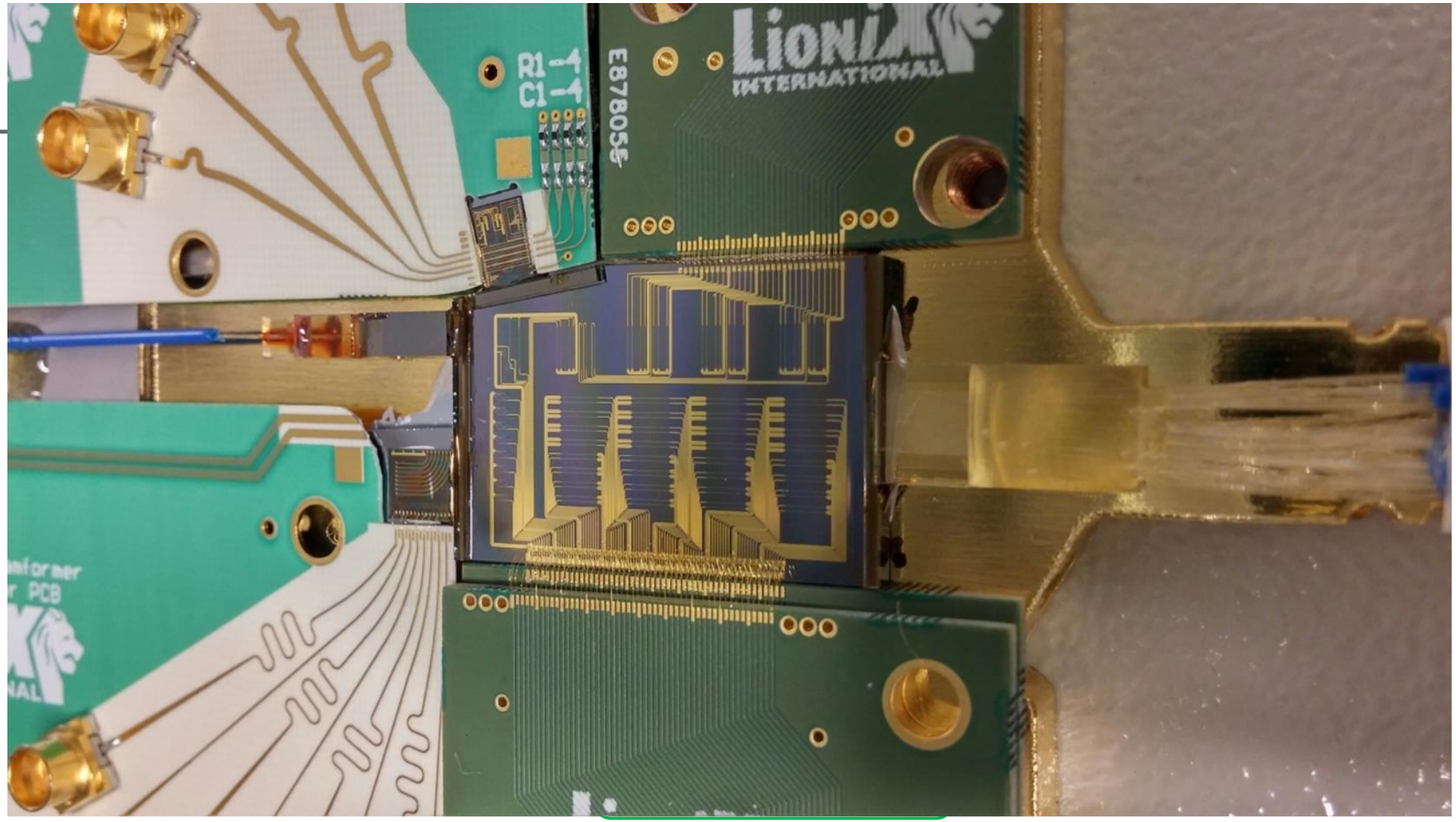


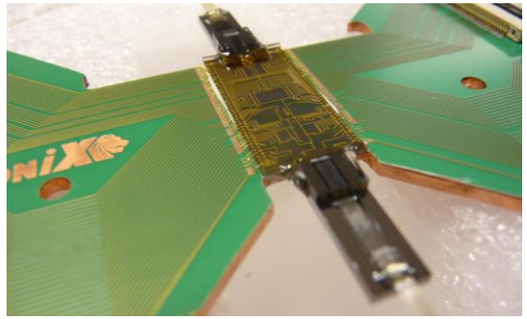
# Optical beamforming network

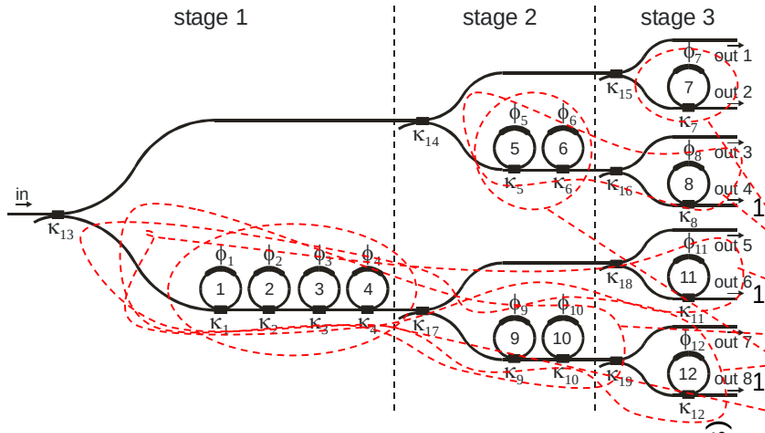



Input signal
10.7-12.75 GHz



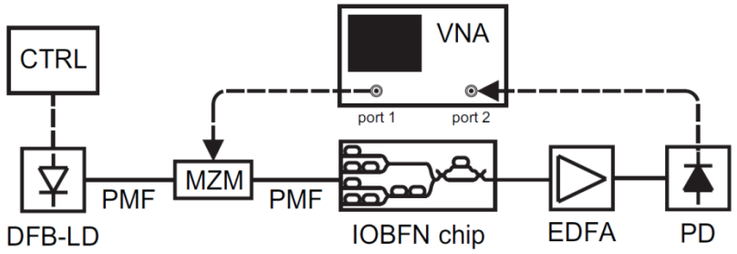
# Optical beamforming network

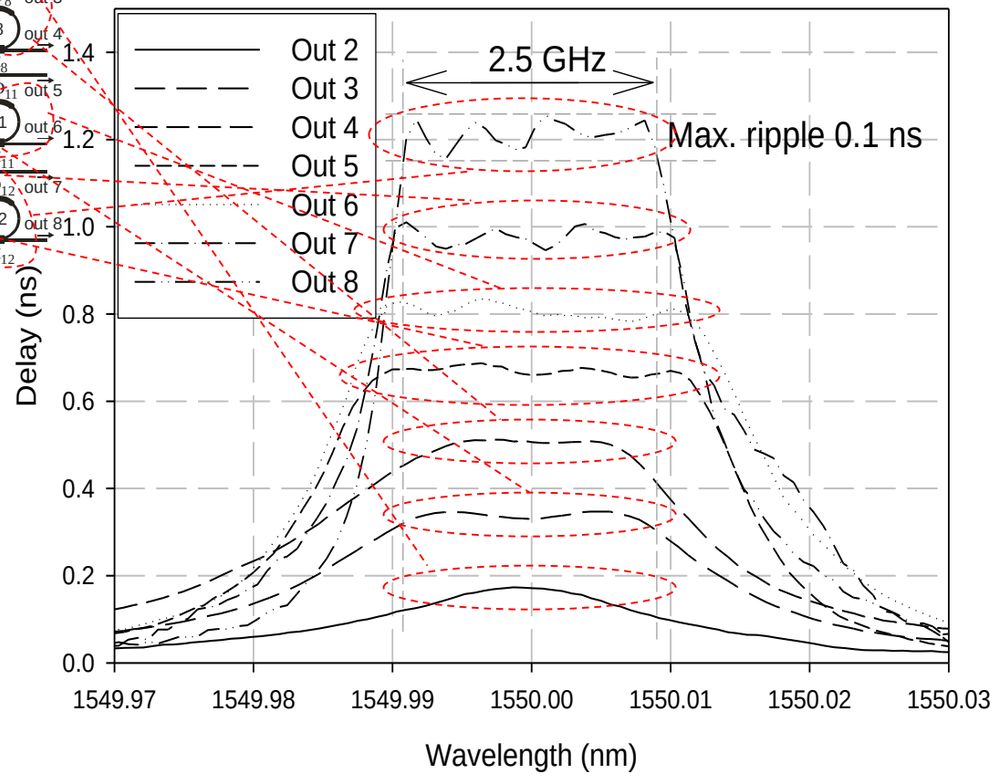





**1 ns ~ 30 cm delay distance in vacuum**

**Linearly increasing delay for a 2.5 GHz bandwidth was demonstrated**




**1 ns ~ 30 cm delay distance in vacuum**

L. Zhuang et al., *IEEE Photonics Technology Letters*, vol. 19, no. 15, 2007

# iMWP a disruption in RF technology !!

- **Vision:** Towards iMWP (10-300 GHz, Phase shifting, True time delay, Multi-beam beamforming, Combining, Splitting, Filtering, RF-in, RF-out)

- RF-Photonic integration is imperative to yield  reliable processing
  - **TriPleX™ $Si_3N_4/SiO_2$** waveguide technology enables low loss, compact, stable, mass producible MWP signal processors with **low power tuning**
  - InP enables integration of, **narrow-band lasers, high-speed modulators** and **high-speed detectors**

- **Next step:** Address assembly challenges for hybrid integration of InP and TriPleX™ $Si_3N_4/SiO_2$

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# Questions ???