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Integrated Microwave Photonics chip platform using hybrid integration

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Overview

- Introduction
- Beamforming
- Microwave Photonic link
- Examples
- Experiments/results
- Conclusions
- Future

Our Mission

- LioniX International is a leading global provider of customized microsystem solutions, in particular integrated photonics-based, in scalable production volumes

Why

- Applying disruptive technologies to solve major societal challenges

Integrated Photonics is one of the key enablers

Scalable Production Volumes

The Gallery,
LioniX offices and labs

The Gallery,
Cleanroom, PIC production

High Tech Factory,
PHIX assembling & packaging Fab

Magic Micro and KANC
Cleanroom, PIC production

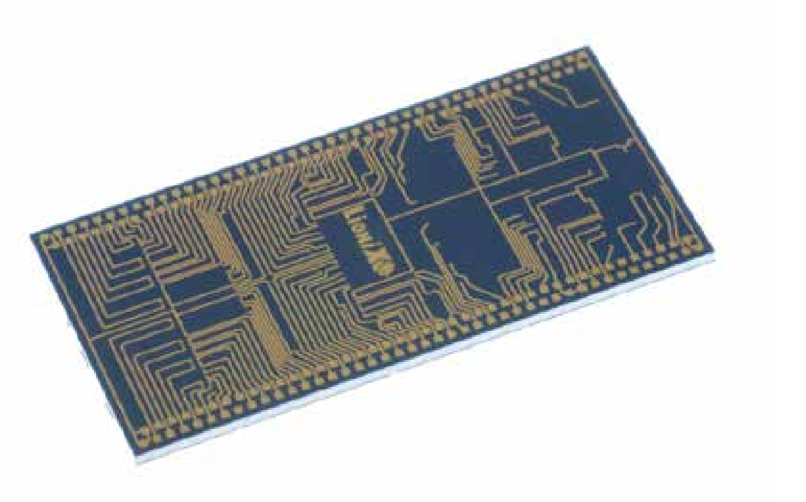
Magic Micro / KANC
Seoul,
South Korea

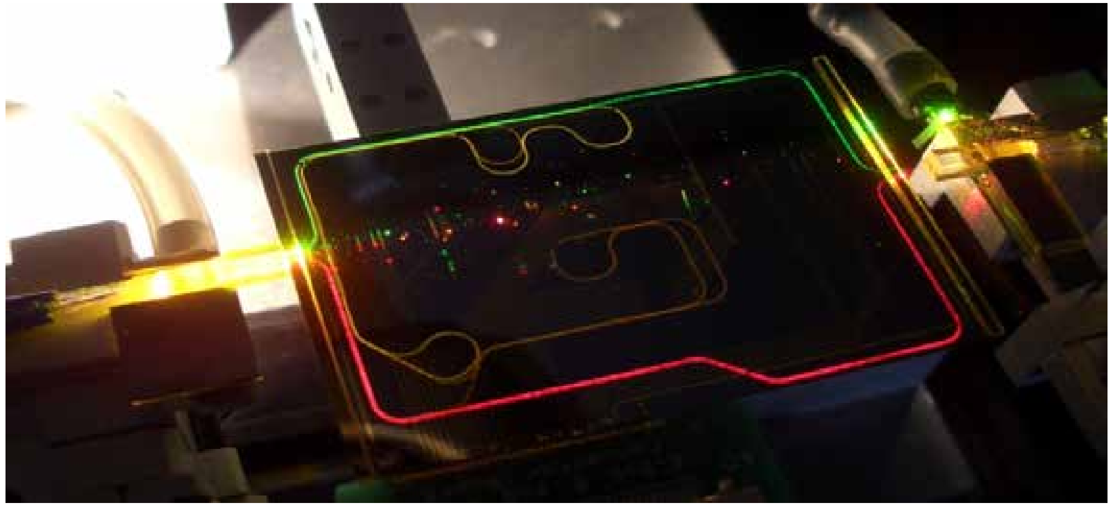
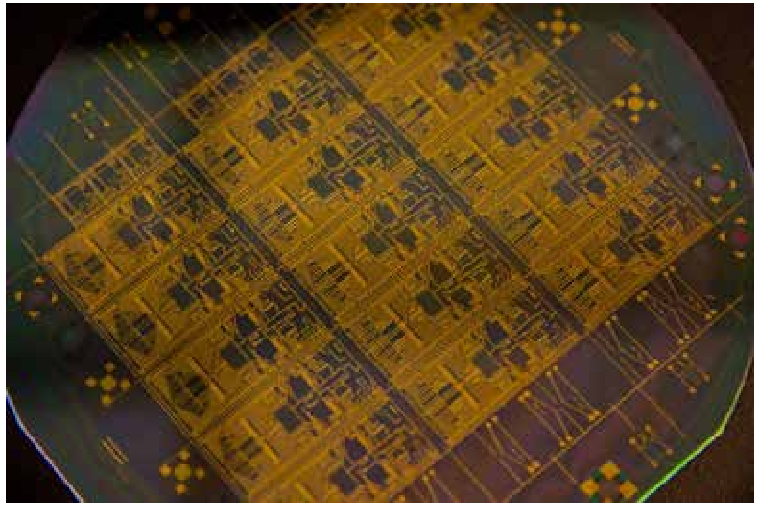
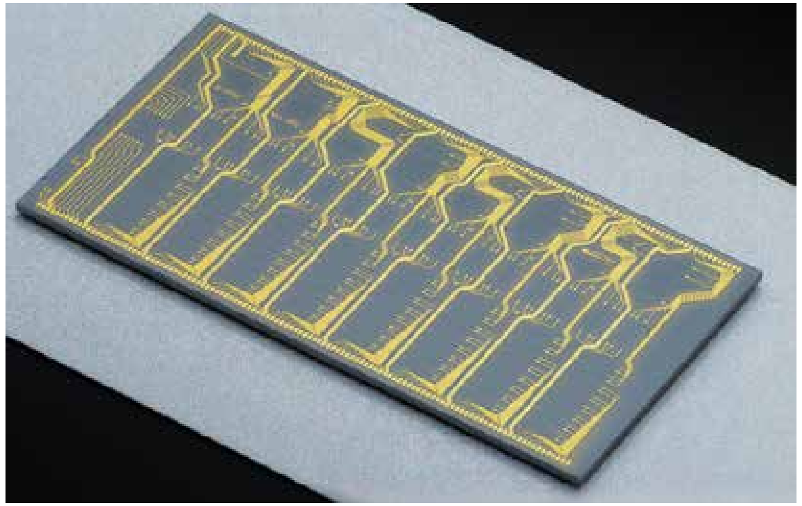
LioniX International
Enschede,
The Netherlands

Technology Leadership

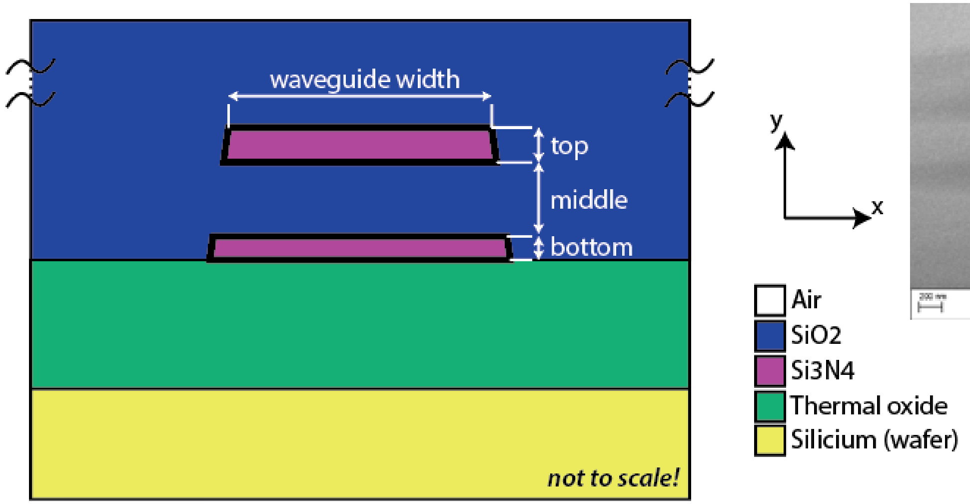


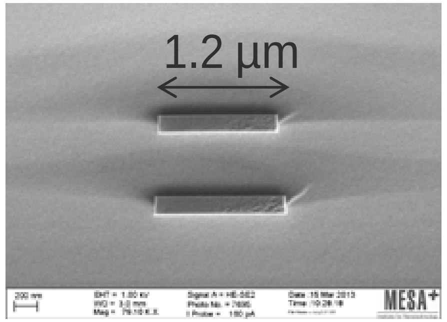




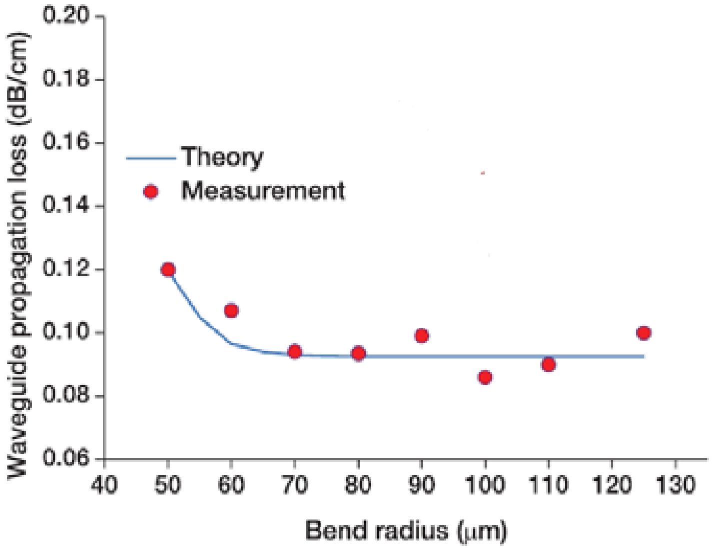




TriPleX Photonic Integrated Chip Platform

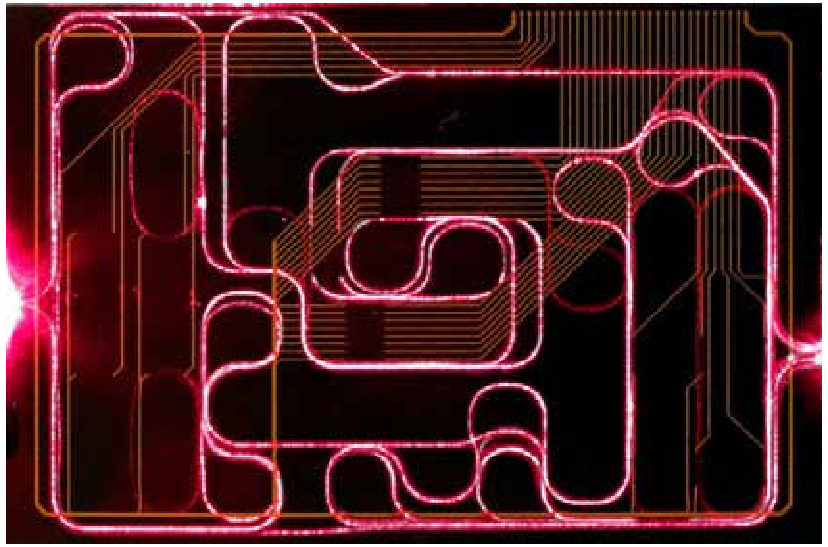




- Low waveguide loss (< 0.1 dB/cm @ 1550 nm)
- Small bend radius (< 80 µm)
- Low loss spot size converters
  - Low coupling loss to single-mode fiber (<0.5 dB)
  - Low chip-to-chip coupling loss (< 1 dB)
- CMOS-compatible fabrication process
- Complex structures
- High optical powers (watts)



L. Zhuang et al., Optics Express, 19(23), 23162-23170 (2011)

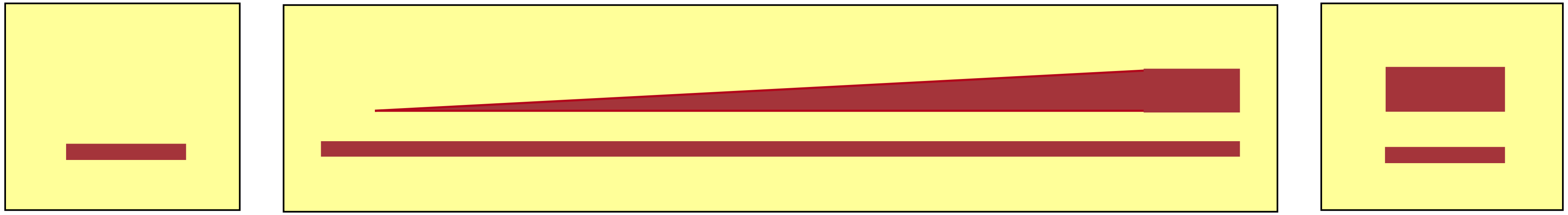


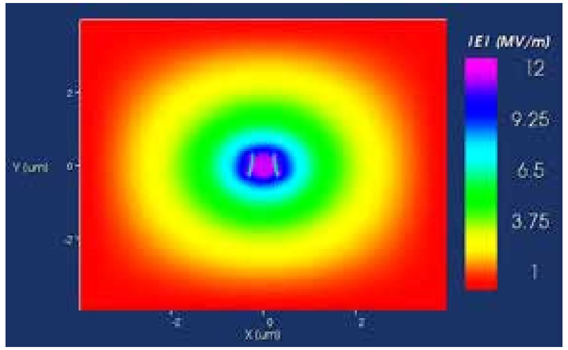
C. Taddei et al., *IEEE MWP* 2014, Sapporo, Japan

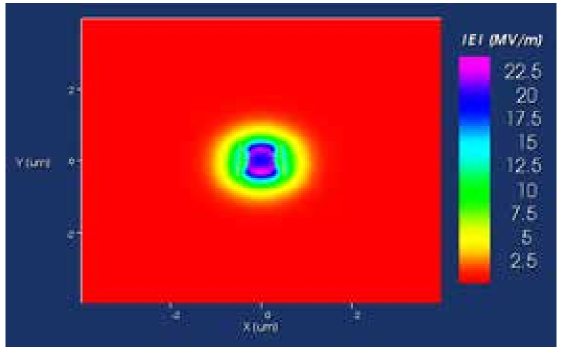
Current review: C. G. H. Roeloffzen et al., J. Sel. Top. Quant. Elec.24(4) 1-21 (2018)

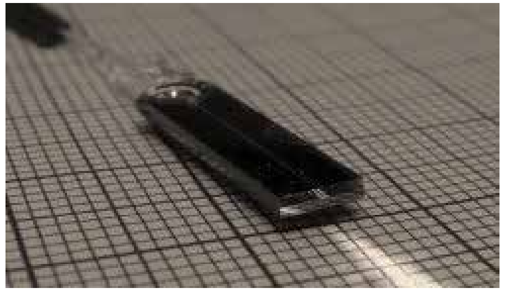
Tapering: high ó low index waveguides

Low index contrast | **High index contrast**





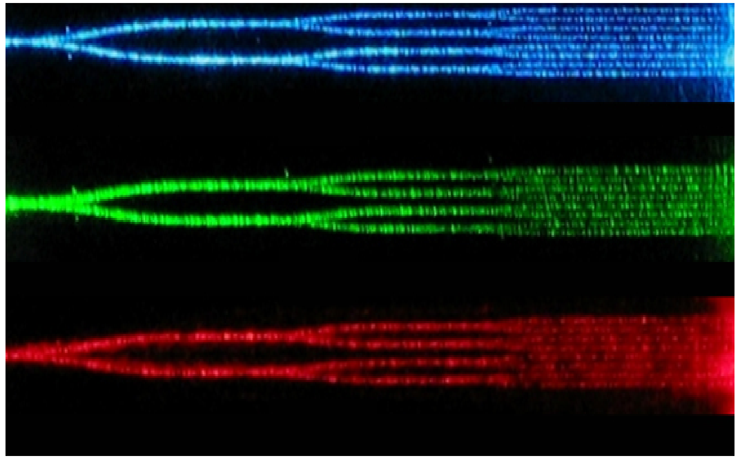


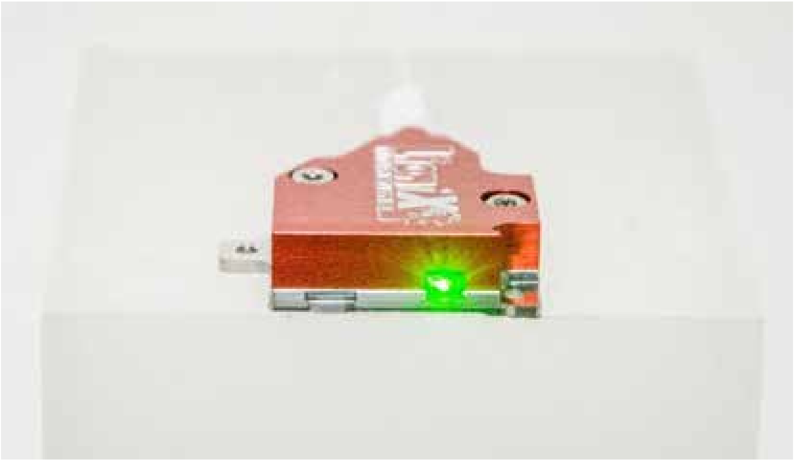


- **Mode profiles from 1 µm to > 10 µm**
- **Modefield conversion**
- **Pitch conversion**
- **Low loss coupling to almost any external component, including SM fiber, InP and Si (SOI)**

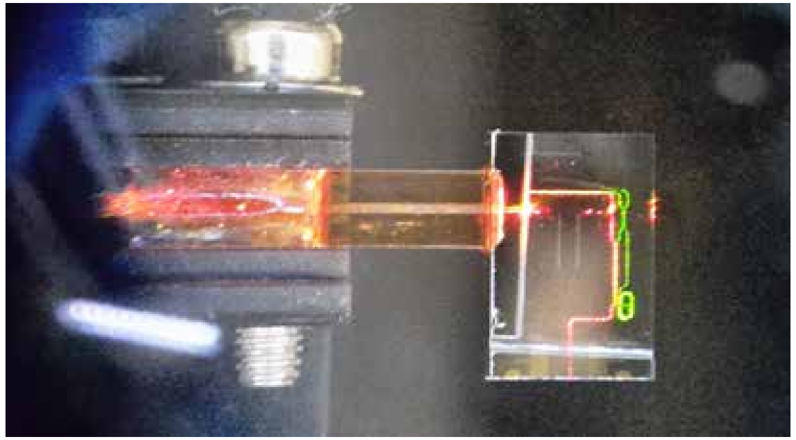
Basic examples

Wide-band power splitters





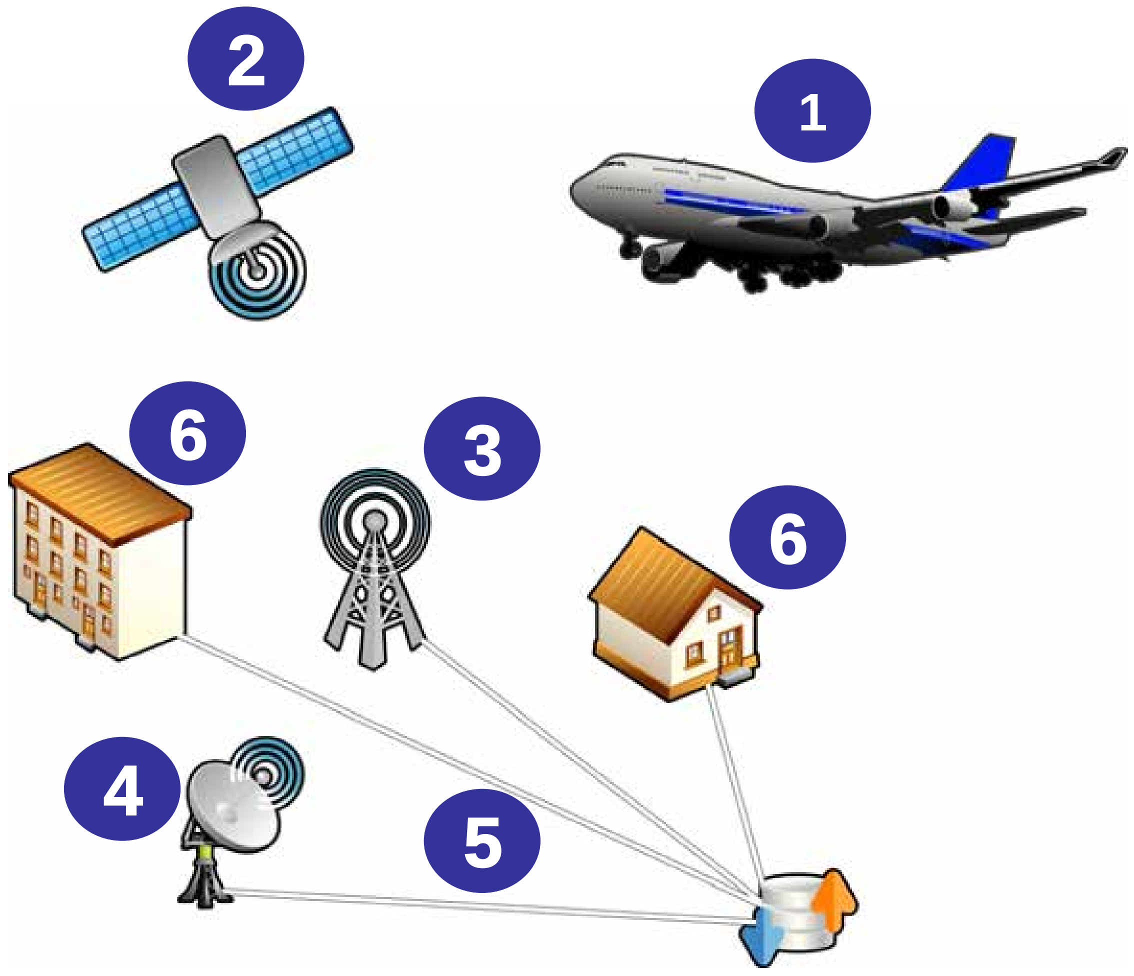
wide-band spectrometers, interferometers



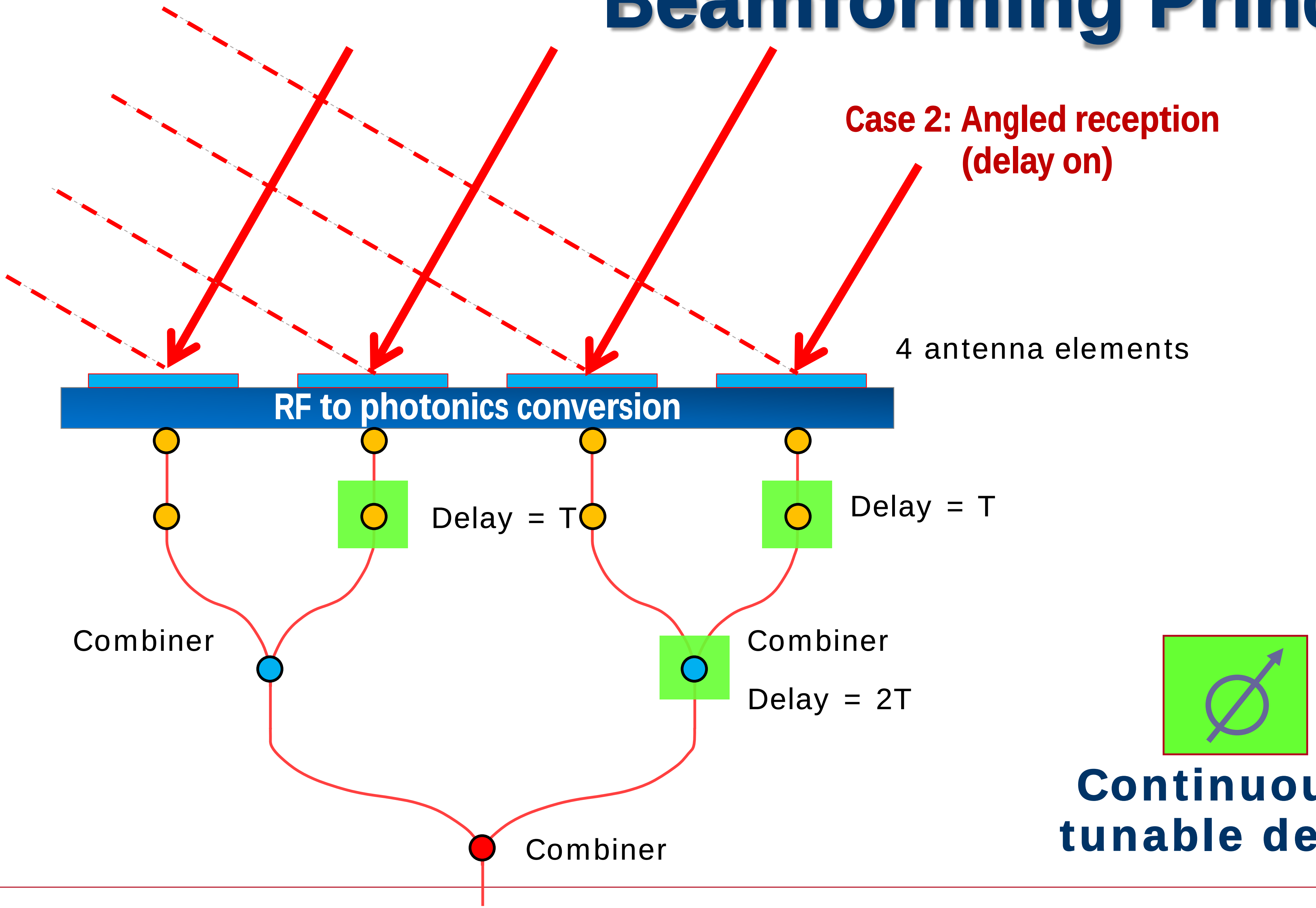
Microwave Photonic Systems Solutions

Opportunities

1. Satellite communication terminals on high speed vehicles
2. Satellite communication terminals on GEO or LO satellite
3. Directional antennas for 5G Infrastructure
4. Beam forming modules for astronomy
5. High Dynamic Range photonic link
6. High Speed Indoor solution (60 GHz)

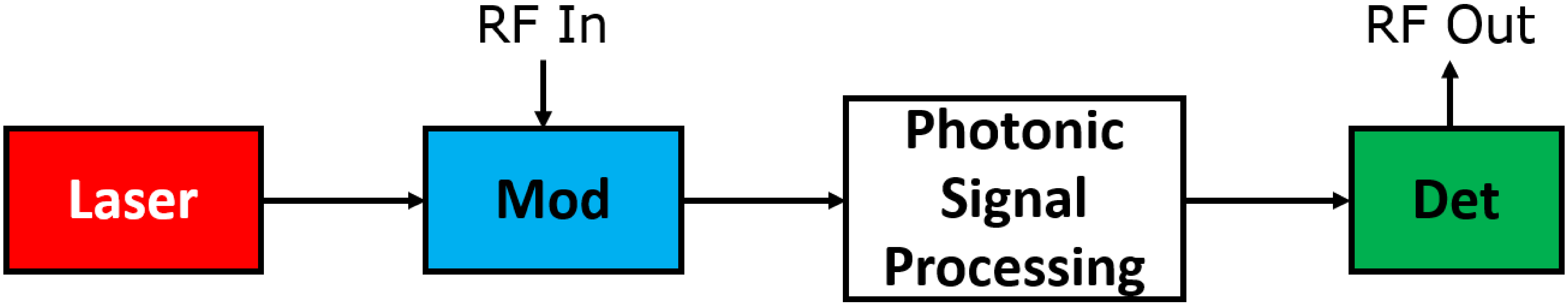


Beamforming Principle



Continuously tunable delays

Microwave Photonic Link



Analog Photonic Link

$$G_{PM\_SSBFC} = \frac{P_{RF\_out}(t)}{P_{RF\_in}(t)} = \left(\frac{\pi R_{pd} P_l R}{2LV_\pi}\right)^2 = \left(\frac{\pi I_{pd\_DC} R}{2V_\pi}\right)^2$$

$$I_{pd\_DC}(t) = R_{pd}\frac{P_l}{L}$$

P_l = Laser power (50 mW)

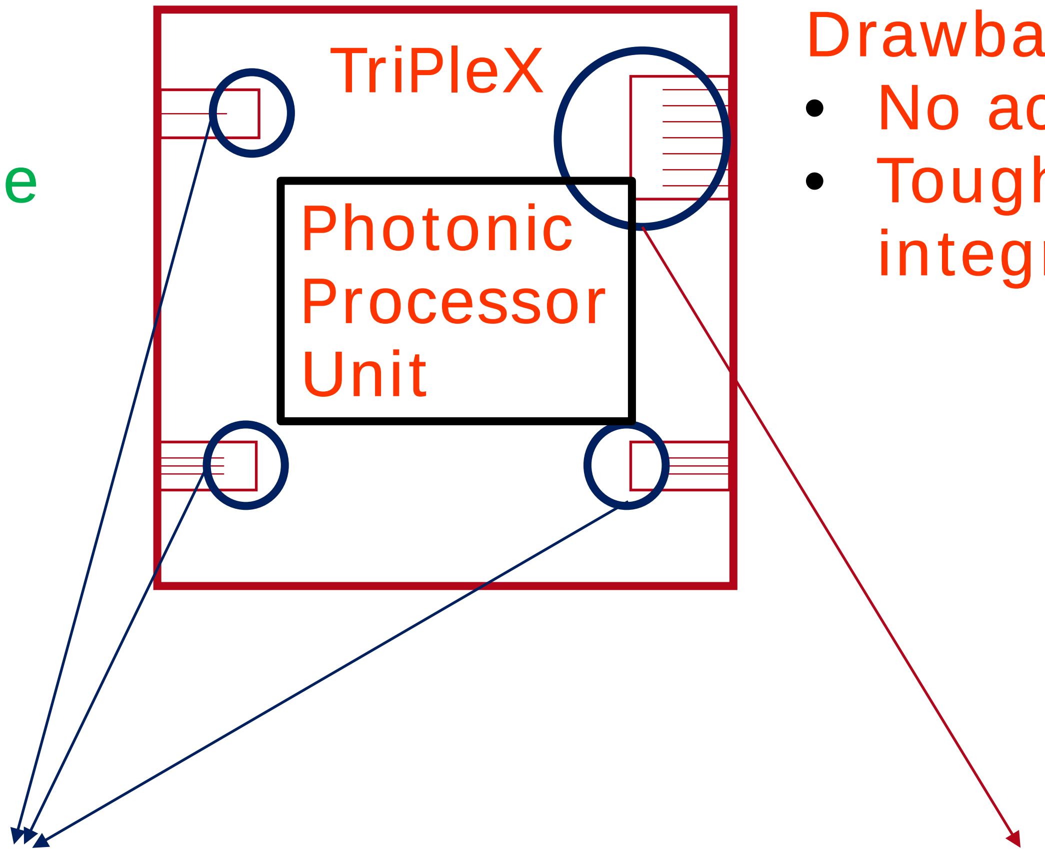
V

Needs

- Low optical propagation loss
- High performance active components
- Efficient Electrical to optical conversion
- Powerful lasers
- High power handling
- Robust processing/assembly

TriPleX Photonic Signal Processing

Strengths:
- Low loss
- Long distances possible
- Small bend radius
- Spot size converters
- Easy process
- Robust
- Capable of handling high powers



Drawbacks:
- No active components
- Tough to monolithically integrate with other platforms

Interfaces to Indium Phosfide (InP)

Interface to PM SM fiber

Needs

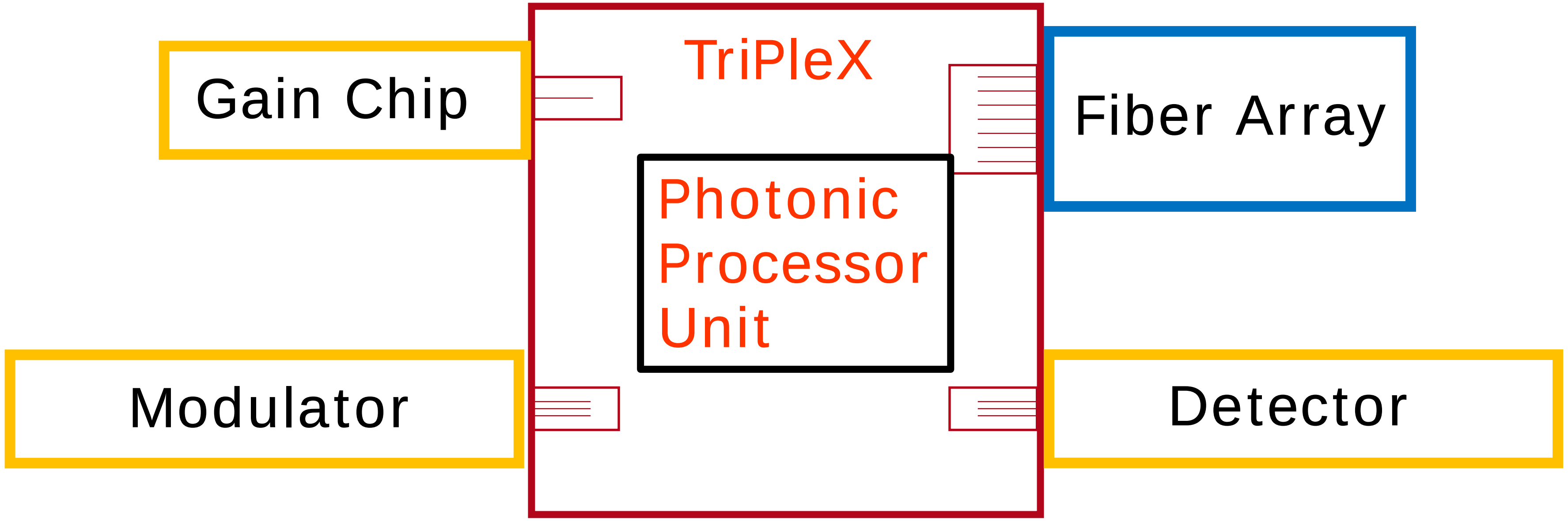
- Low optical propagation loss through the whole optical path
- High performance active components
- Efficient Electrical to optical conversion
- Powerful lasers
- High power handling
- Robust processing/assembly

Needs

- Low optical propagation loss through the whole optical path
- High performance active components
- Efficient Electrical to optical conversion
- Powerful lasers
- High power handling
- Robust processing/assembly

Hybrid assembly

- Combine the best of two platform In this case TriPleX and InP



Needs

- Low optical propagation loss through the whole optical path
- High performance active components
- Efficient Electrical to optical conversion
- Powerful lasers
- High power handling
- Robust processing/assembly

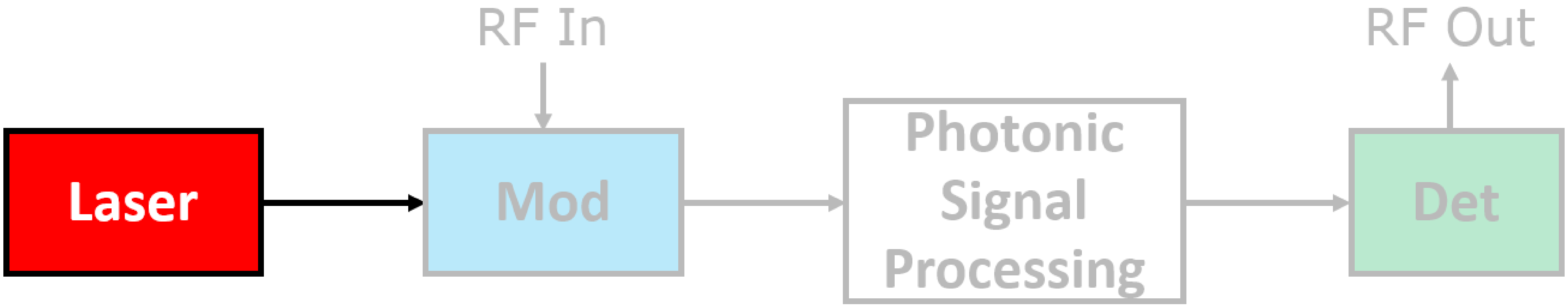
- More difficult than monolithic processing

Criteria: high performance microwave photonic link

- Multiple Indium Phosphide Chips
  - **Laser**
    - High power laser (> 50 mW)
    - High power gain (> 100 mW)
    - Small linewidth (< 10 kHz)
  - **Modulator**
    - High speed (> 40 GHz)
    - Sensitive (V < 3 V)
  - **Detectors**
    - High speed (> 40 GHz)
    - Responsivity (> 0.6 A/W)
  - Very low RF crosstalk required (< -70 dB)

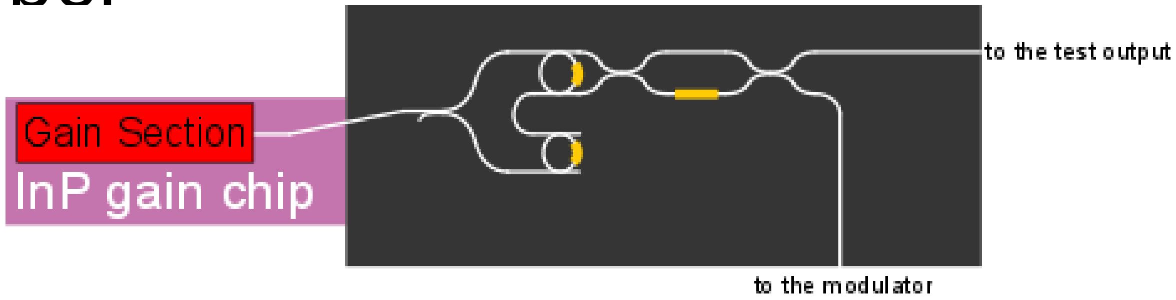
- TriPleX, Silicon Nitride chips
- High contrast, low loss optical processing
- Spot size converters for low loss interfacing
- **High integration density +**
- **Efficient, low-power tunability**
- **Drives Co$t Down**

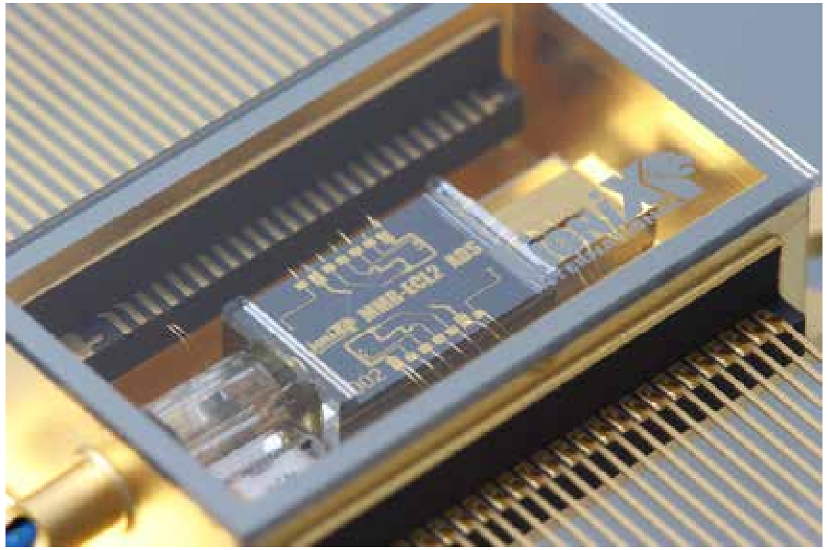
MPL: Laser



Tunable hybrid integrated laser source

- ü High optical power (>50 mW), small bandwidth (several kHz, sub-kHz)
- ü Mode matched to standard telecom fiber
- ü High side mode suppression
- ü Tunable over C-band (>80 nm)
- ü Potential to integrate other optical functions on TriPleX chip



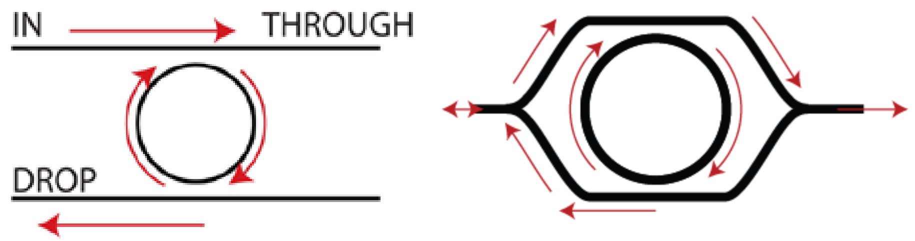


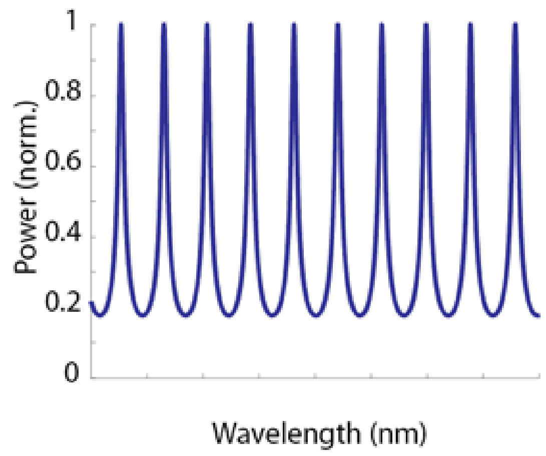
- ü Recent record performance

Oldenbeuving, et al., Laser Phys. Lett. 10 (2013) 015804
Fan, et al., CLEO 2017.

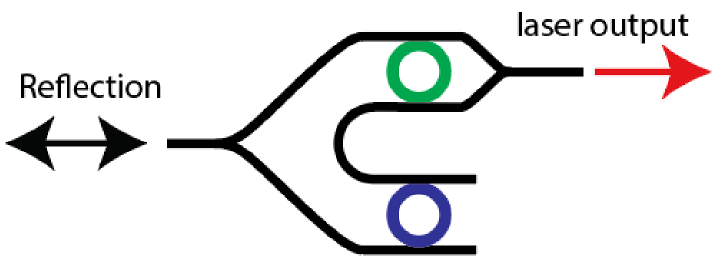
Laser working principle

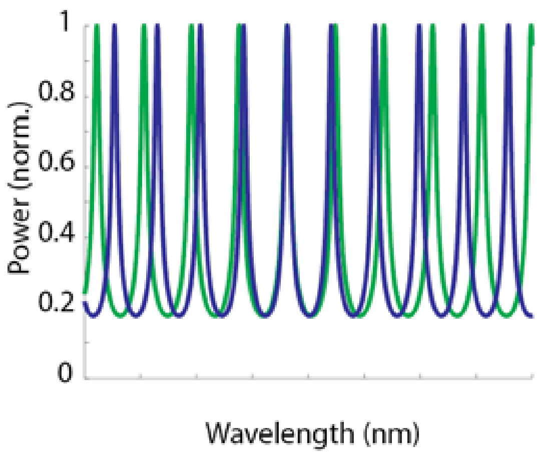
- Single ring reflector

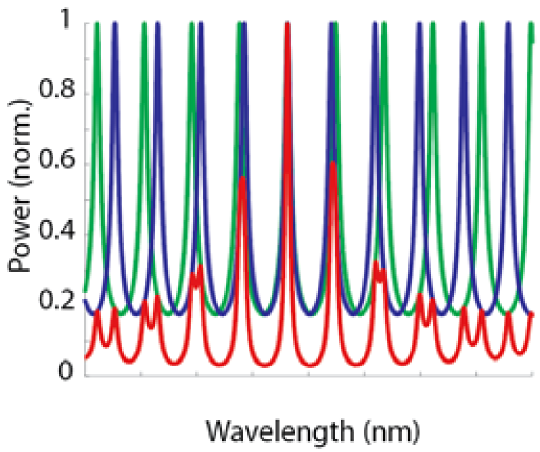


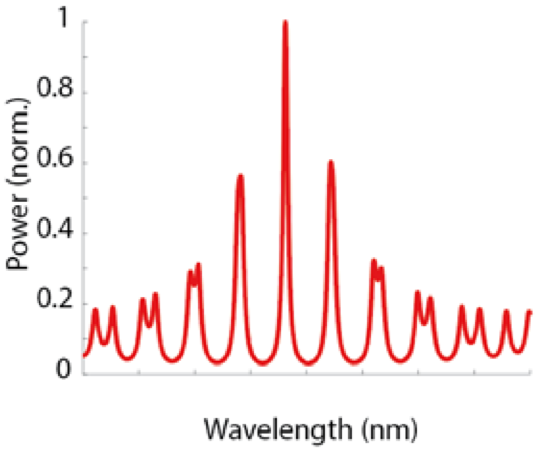


- Double ring reflector







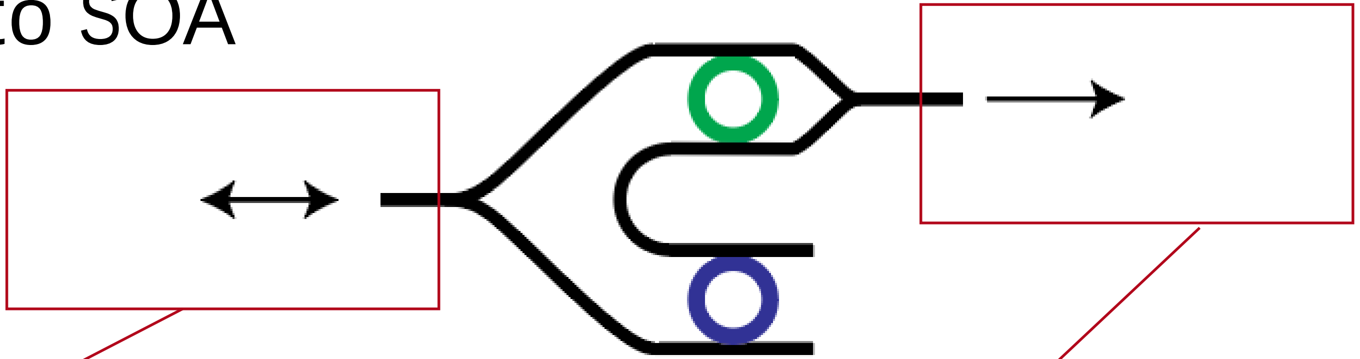


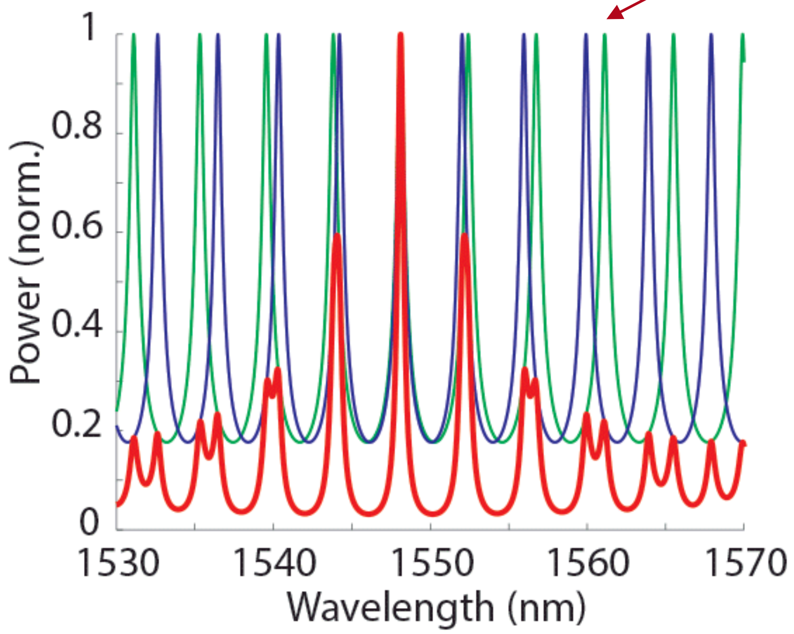
Laser working principle

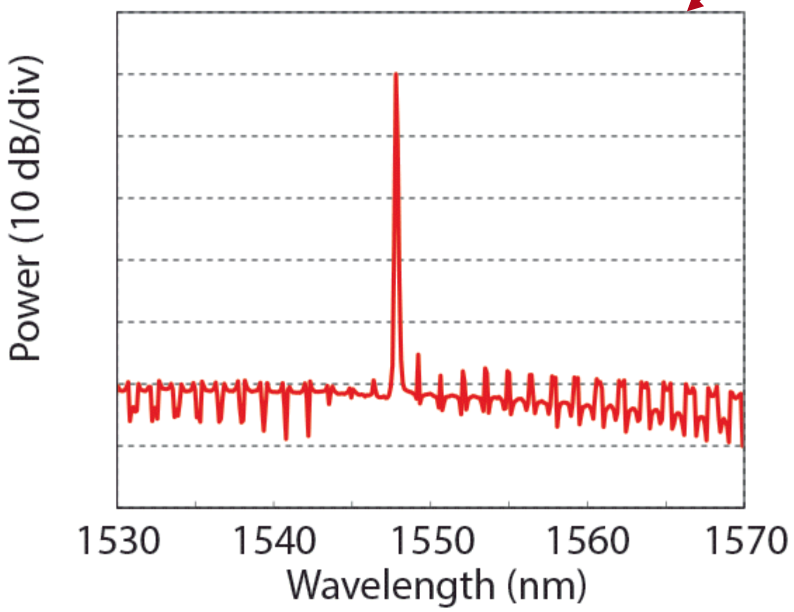
Simplified explanation

- Double ring reflector, attach to SOA

Heating 1 ring
Causes spectrum
to hop across
wavelengths

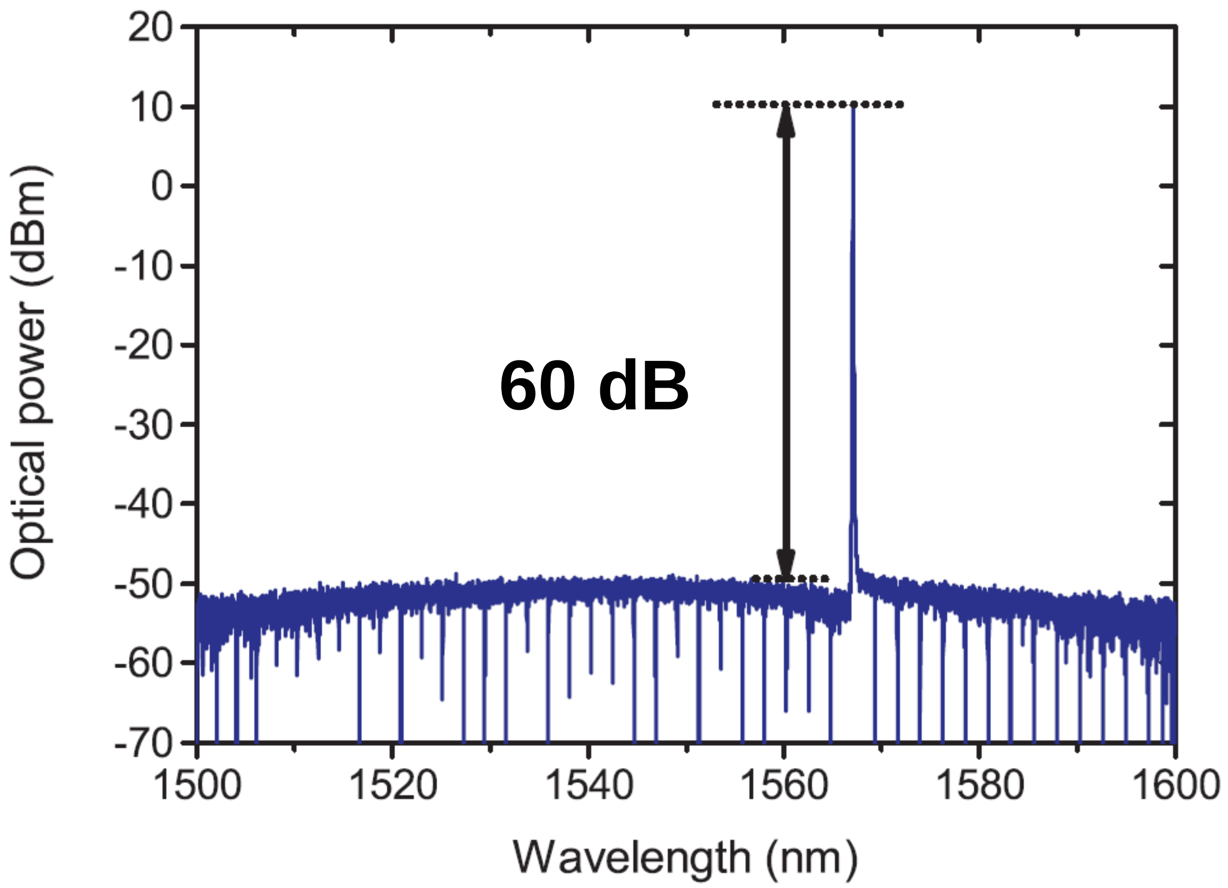




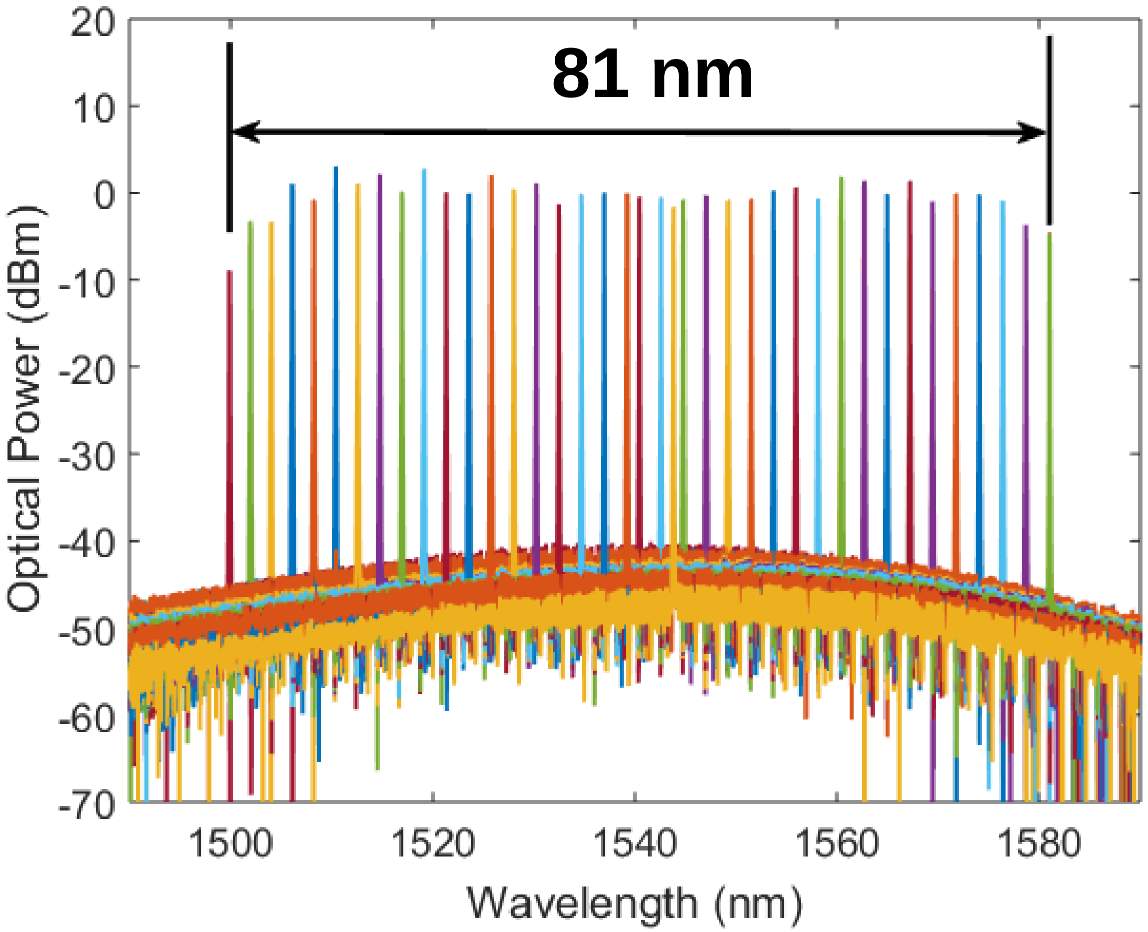


Hybrid Laser Spectral characterization

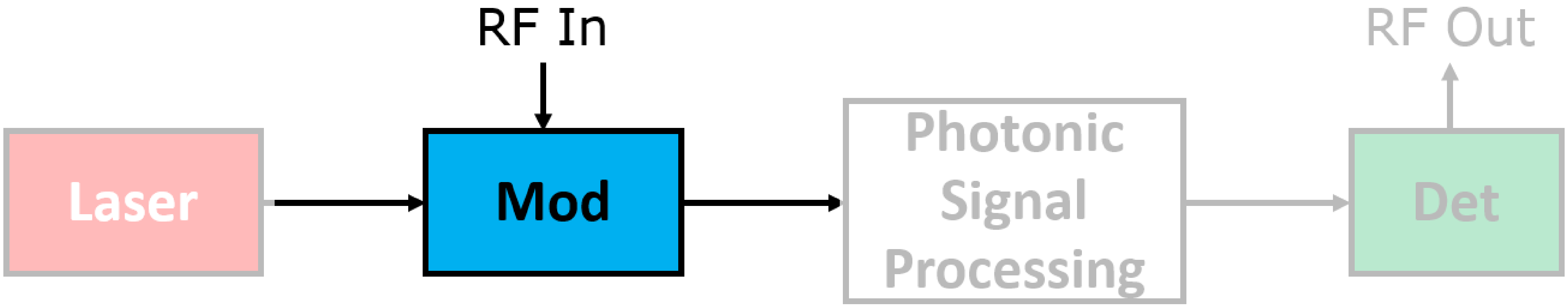
Single frequency output



Wide tuning range

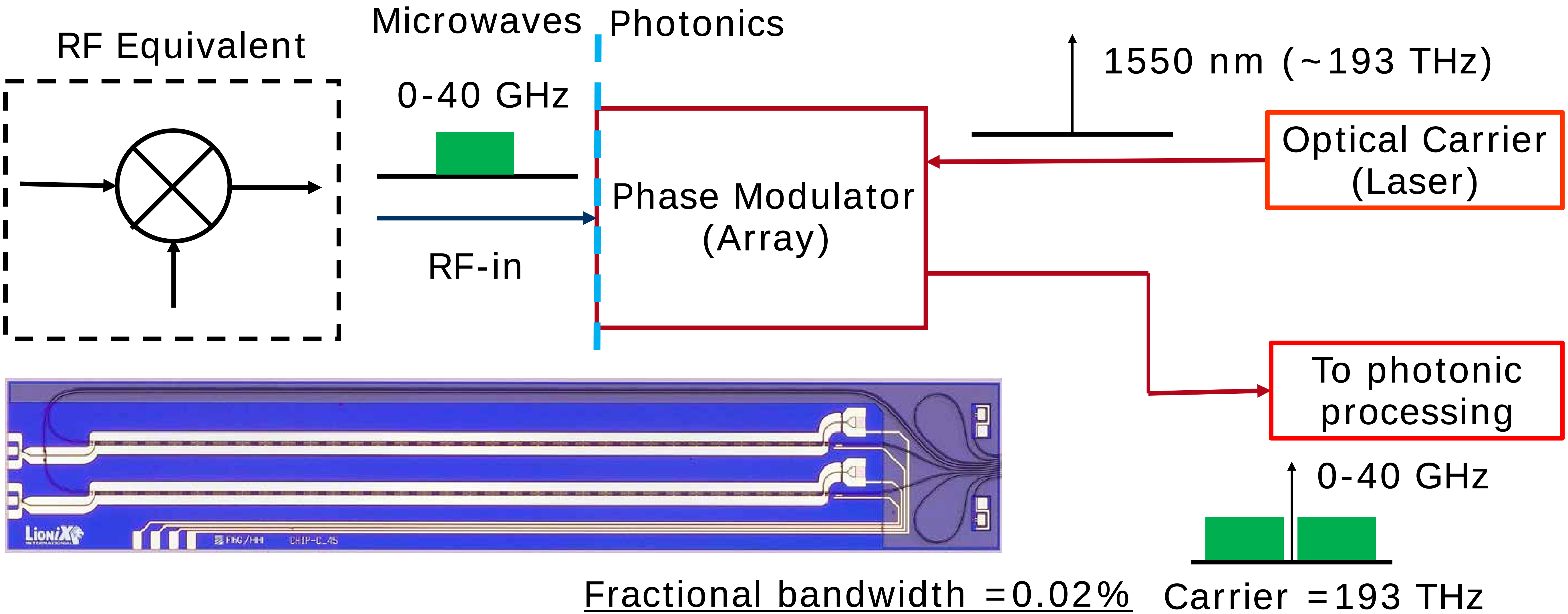


MPL: Phase modulator

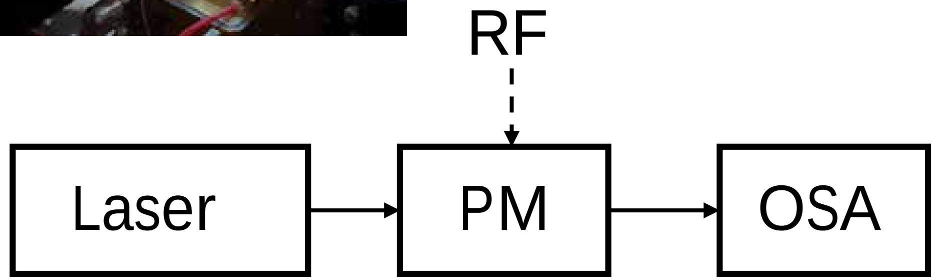


Modulator Functionality

Convert an analog microwave signal to an optically modulated signal



InP Modulator (E/O conversion)



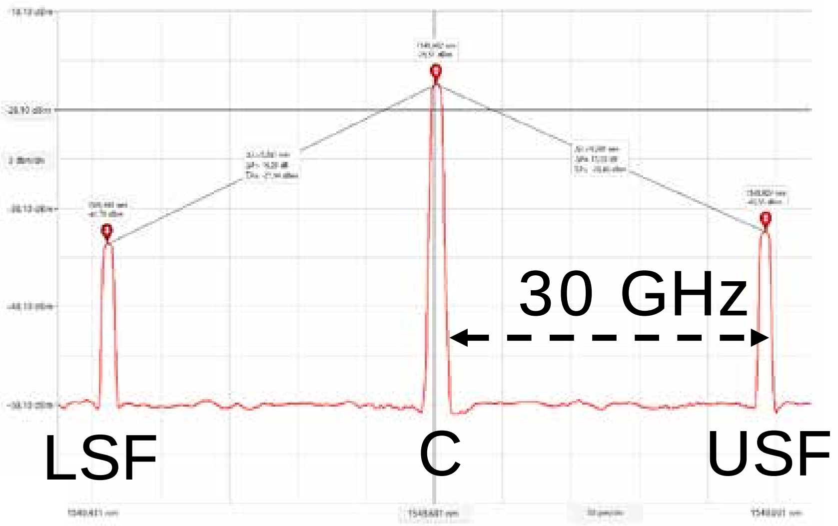
Freq (GHz)	(dB)	m	V (V)
5	10.2	0.5907	1.68
10	10.9	0.5485	1.80
20	13.2	0.4275	2.30
30	15.6	0.3275	3.00

VERY GOOD !

Increase RF power until sidebands are as high as the carrier.

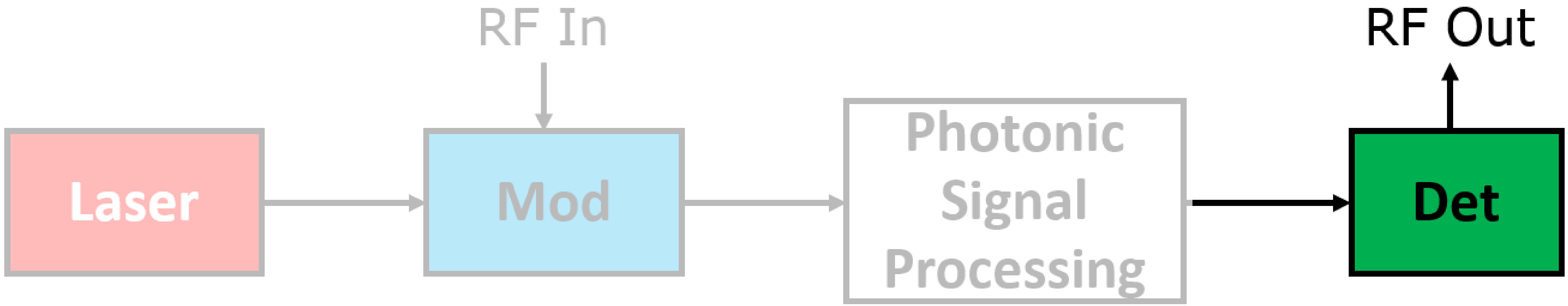
Calculate using: $$V_\pi = \frac{V_m}{0.457}$$

Where: $$V_m = \sqrt{2P_{RF}R}$$

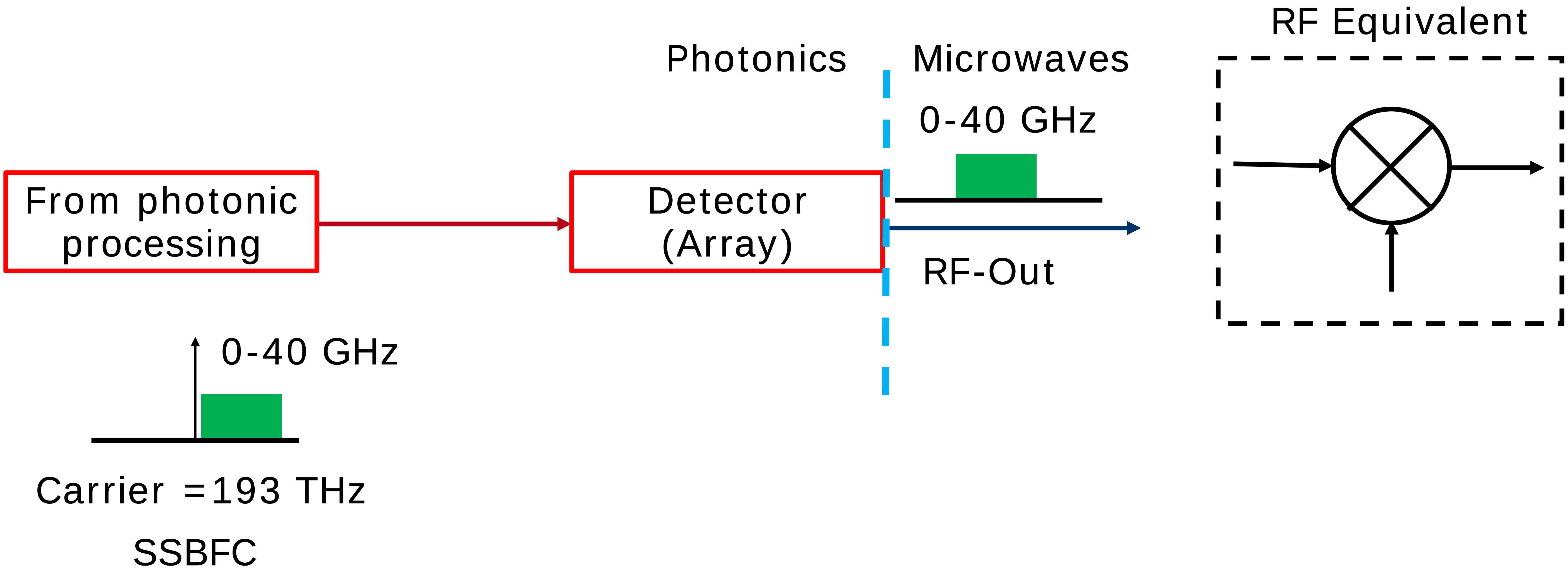


Optical spectrum analysis method (Yongqiang Shi et al., IEEE JLT 21 (10), 2003)

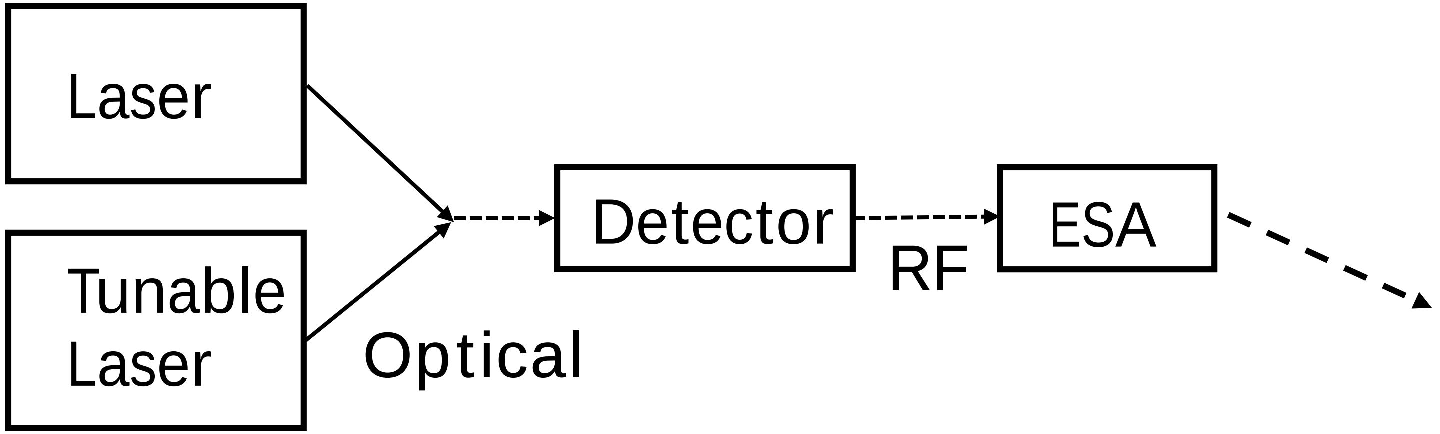
MPL: Photodiode

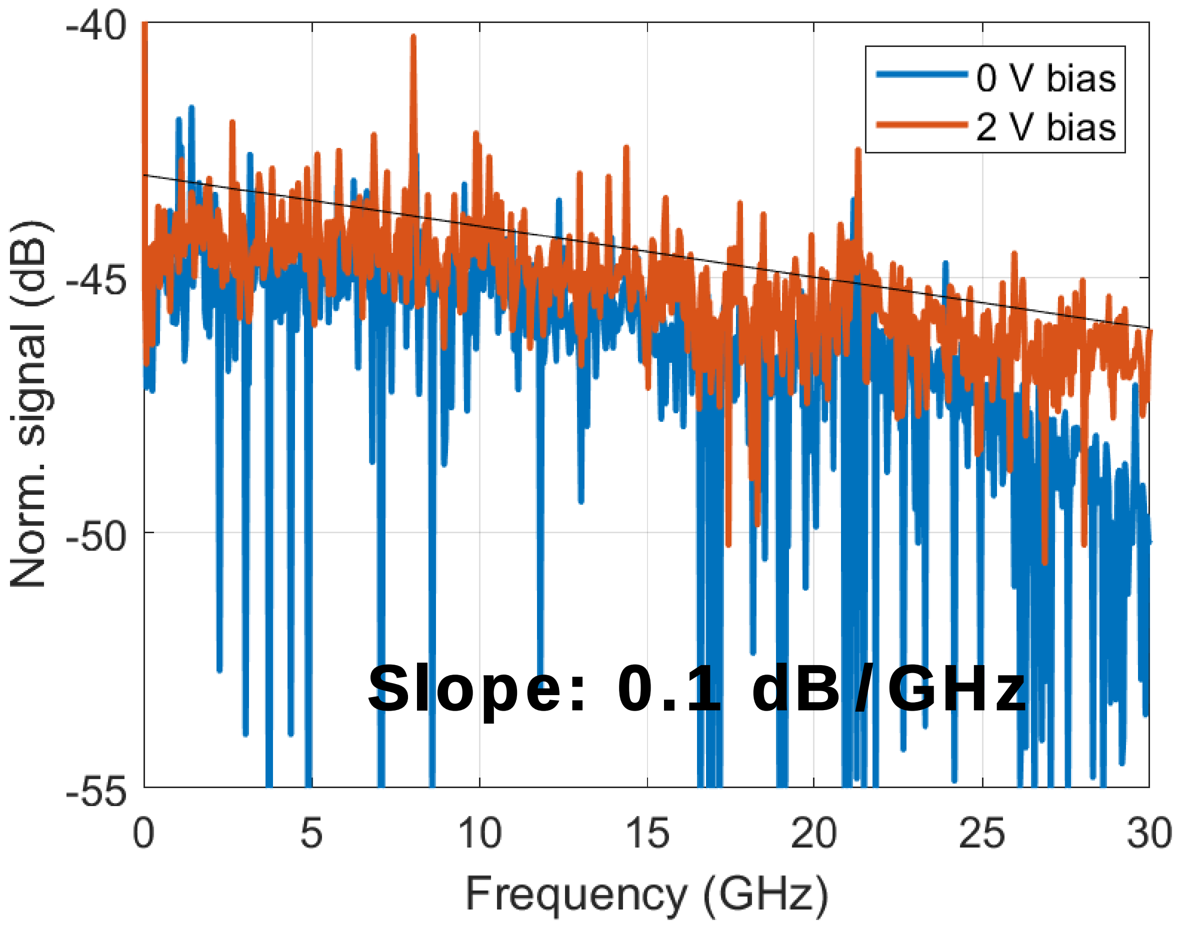


Detector functionality



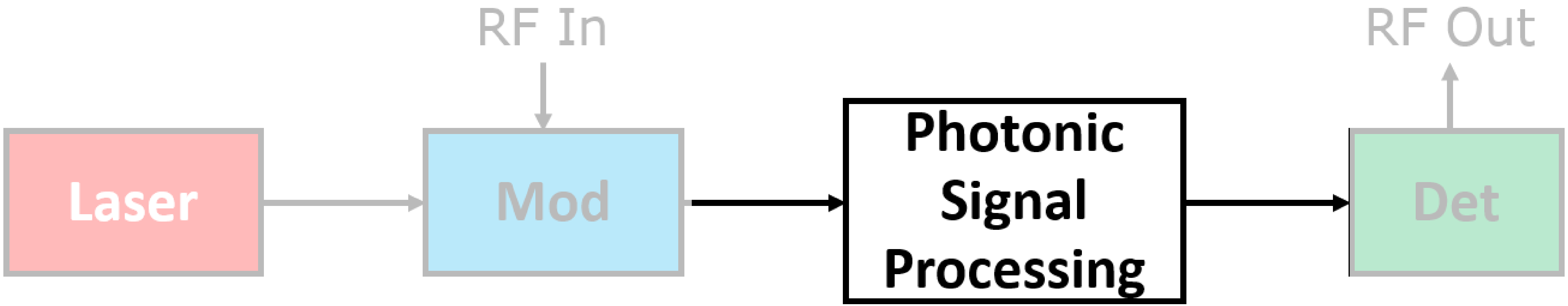
Detector responsivity/slope





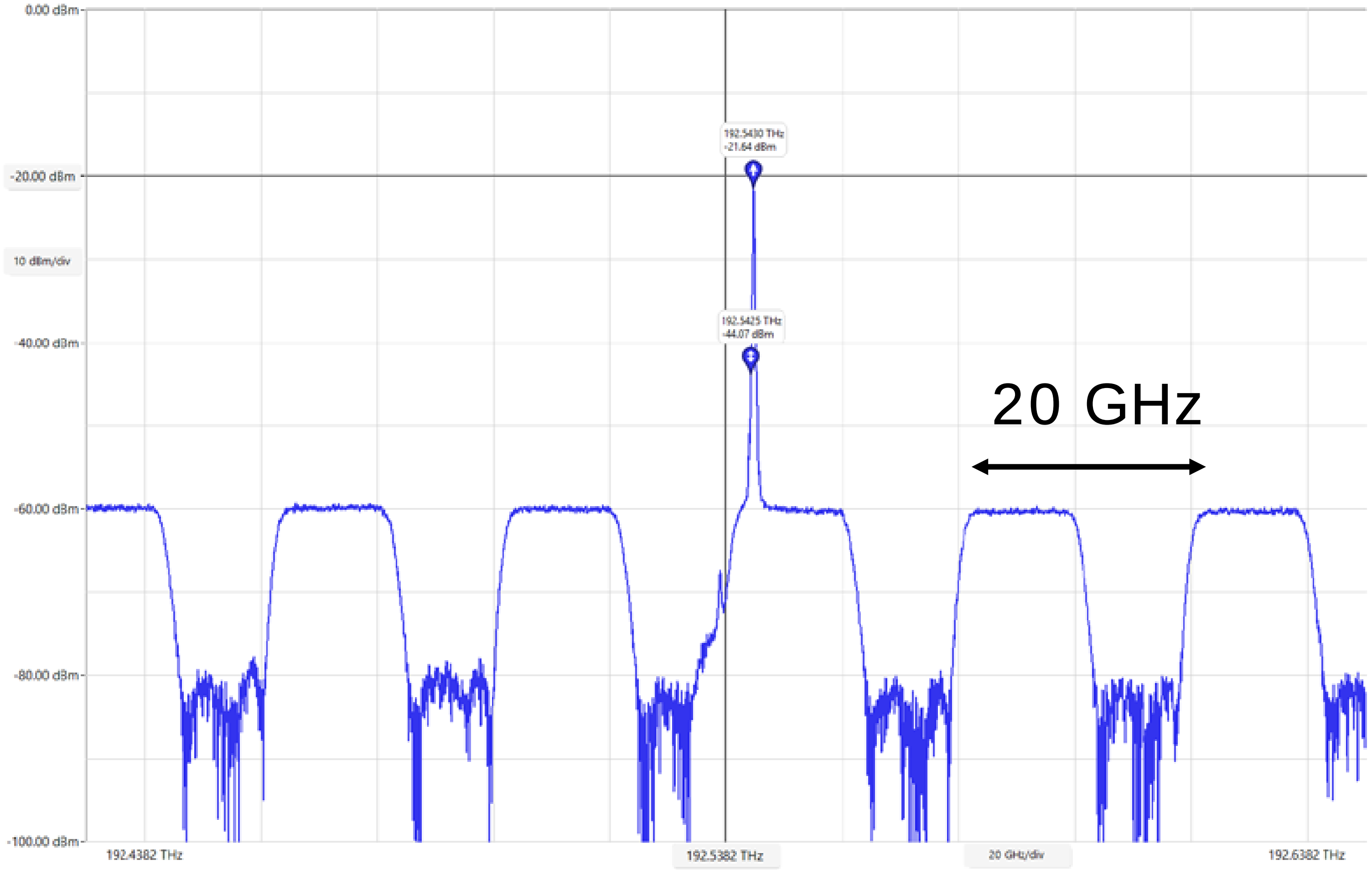
- ü High speed: > 40 GHz
- ü Responsivity > 0.5 A/W
- ü Internal Matching and biasing network

MPL: Signal processing

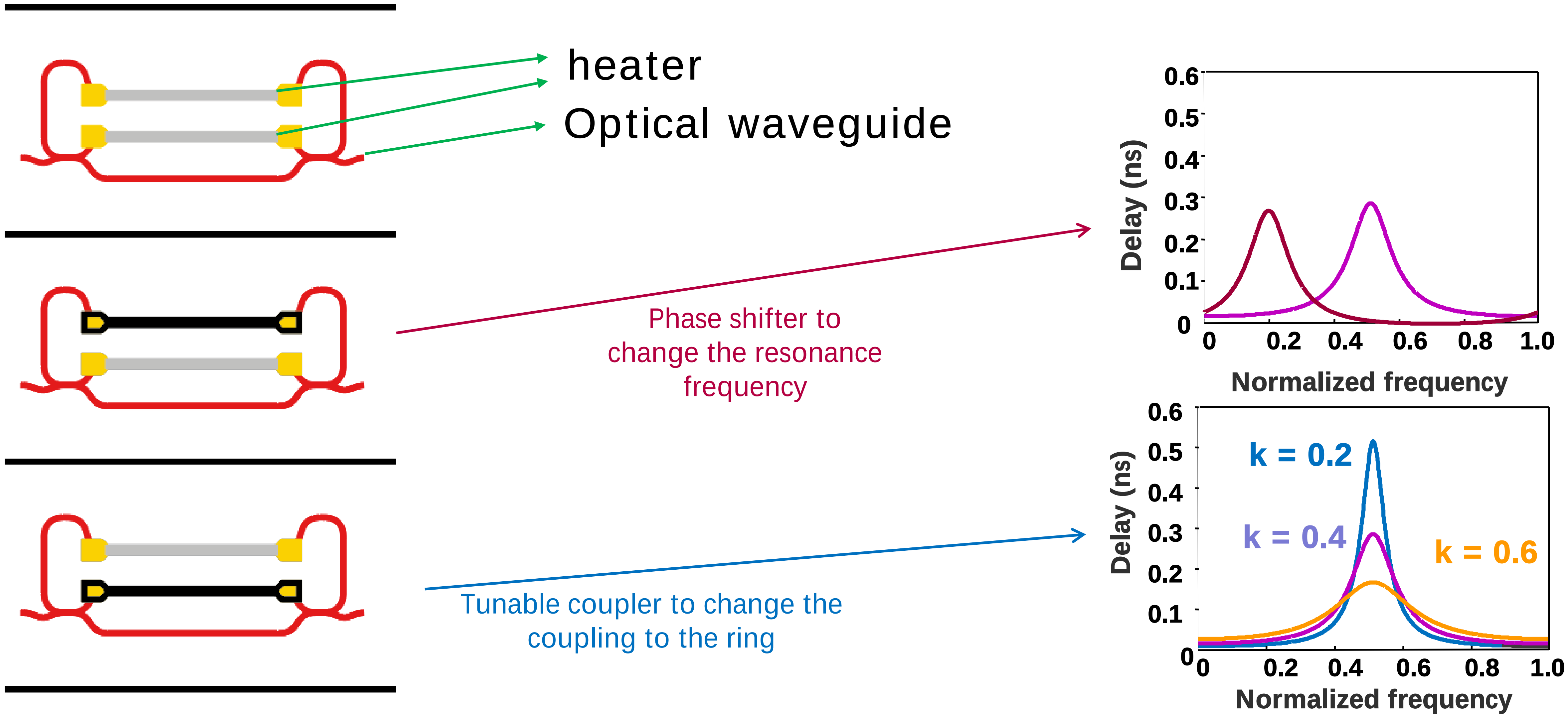


TriPleX- Filter for SSBFC processing

- Flat filter response
- Passband loss < 0.2 dB
- > 20 dB stopband rejection
- Carrier in the passband
- USB in the passband
- LSB in the stopband

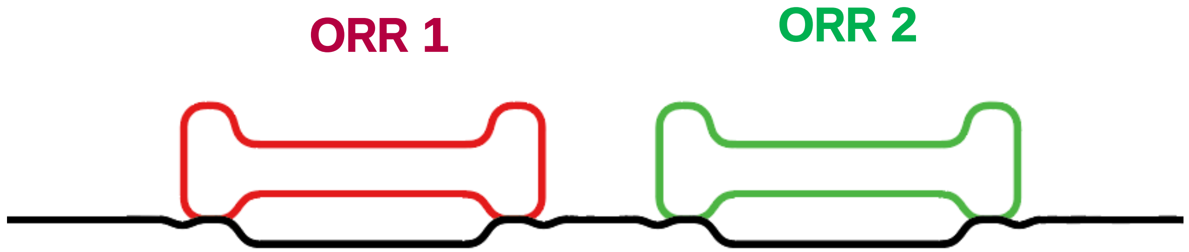


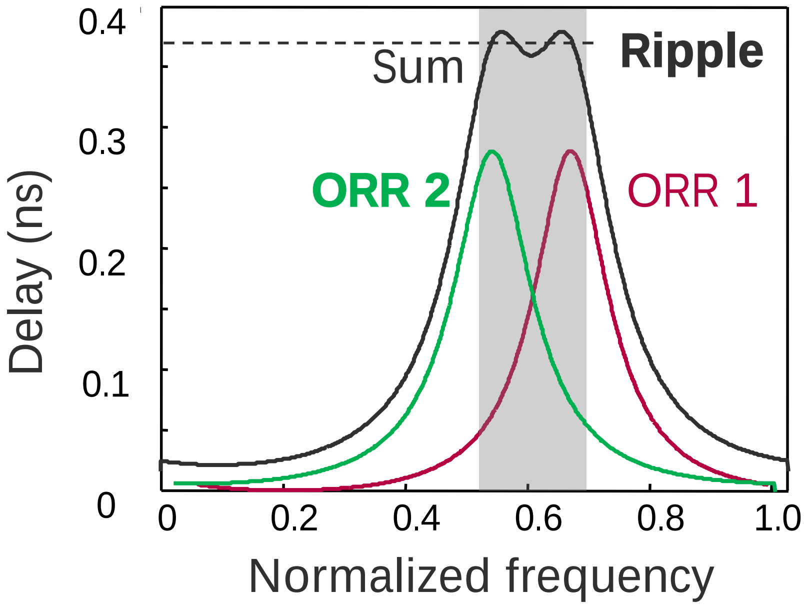
True time delay via optical ring resonator



Cascaded optical ring resonators

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



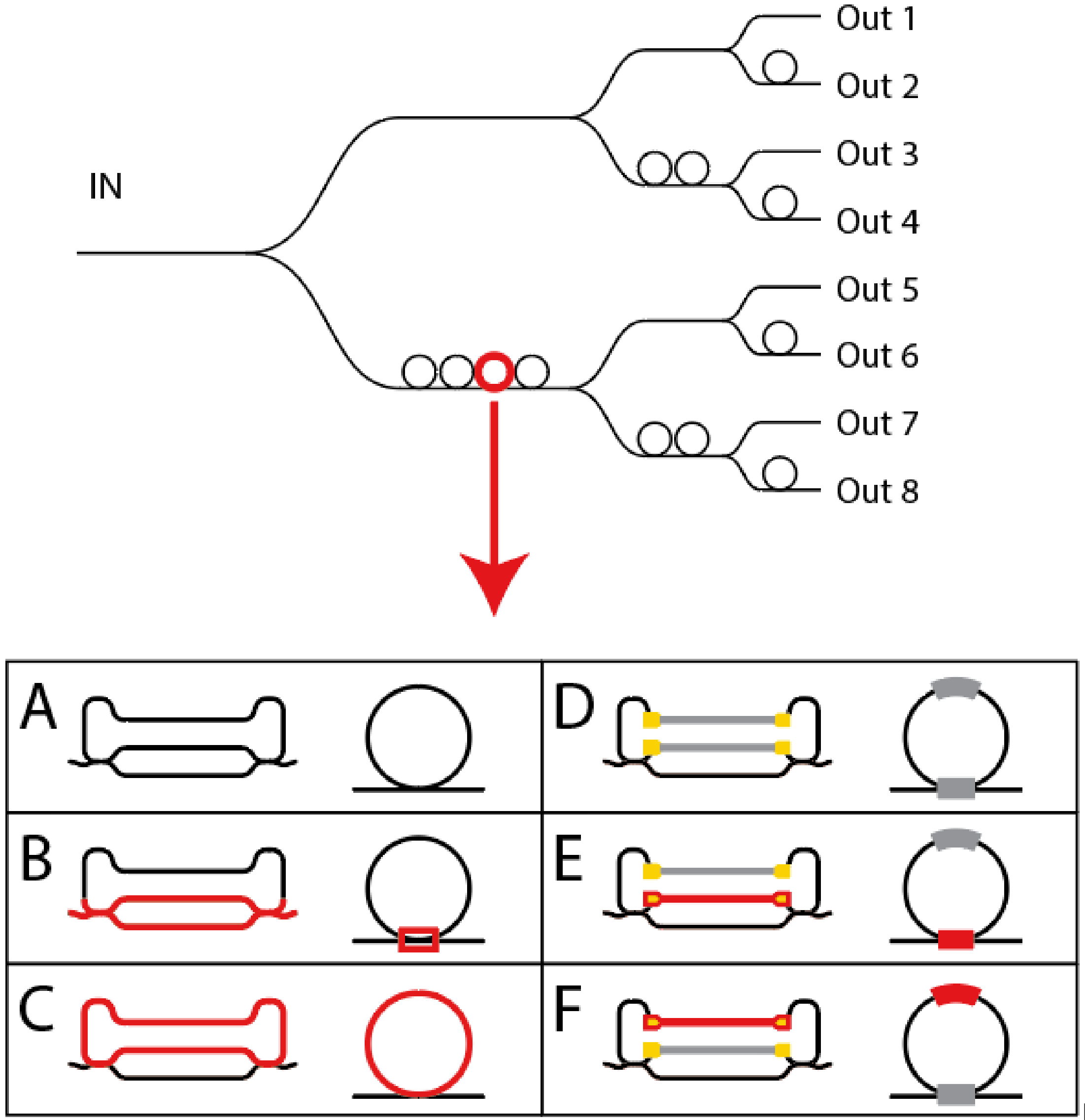


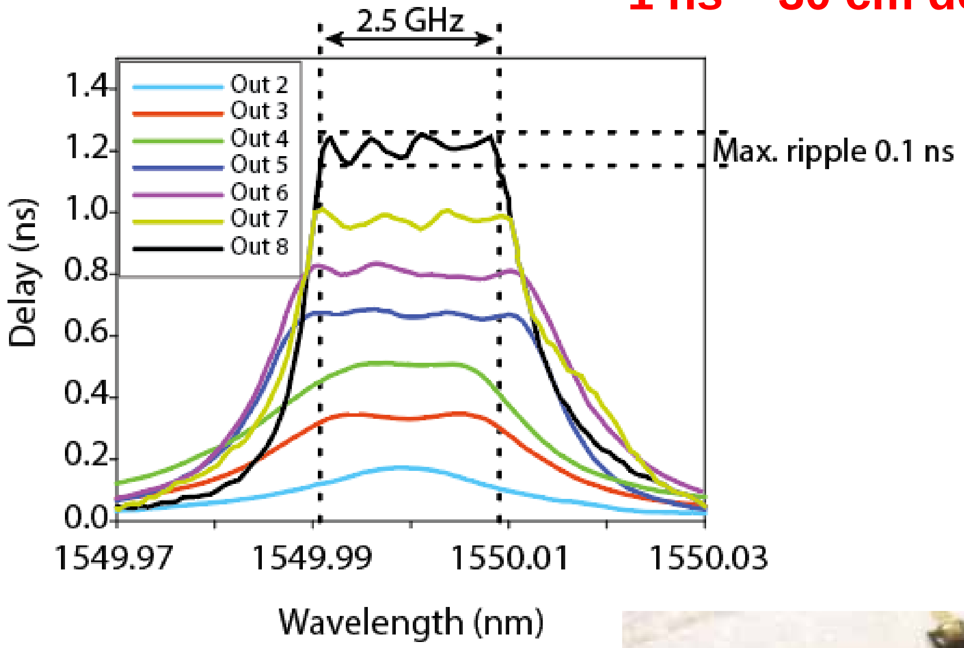
- More ORRs cascaded à more bandwidth but more ripple
- Trade-off between bandwidth, the number of ORR and the delay ripple

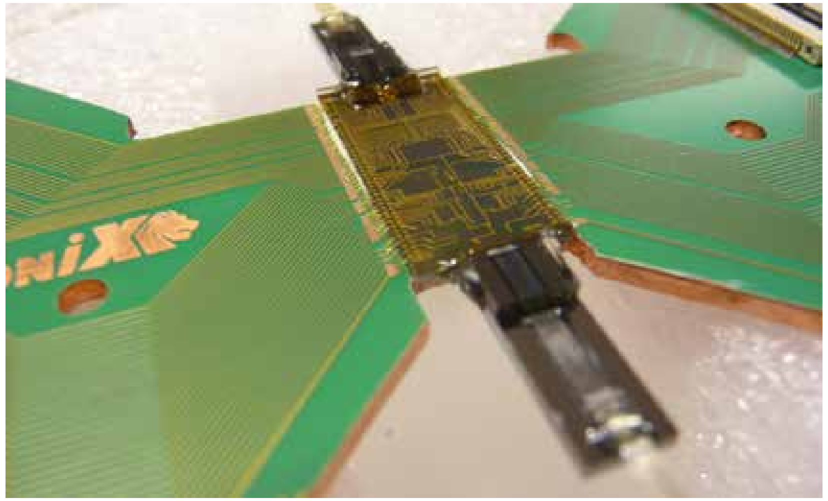
Next step: to arrange the combiners and the ORRs or spirals to make a beamformer

Binary tree optical beamforming network

1 ns ~ 30 cm delay distance in vacuum

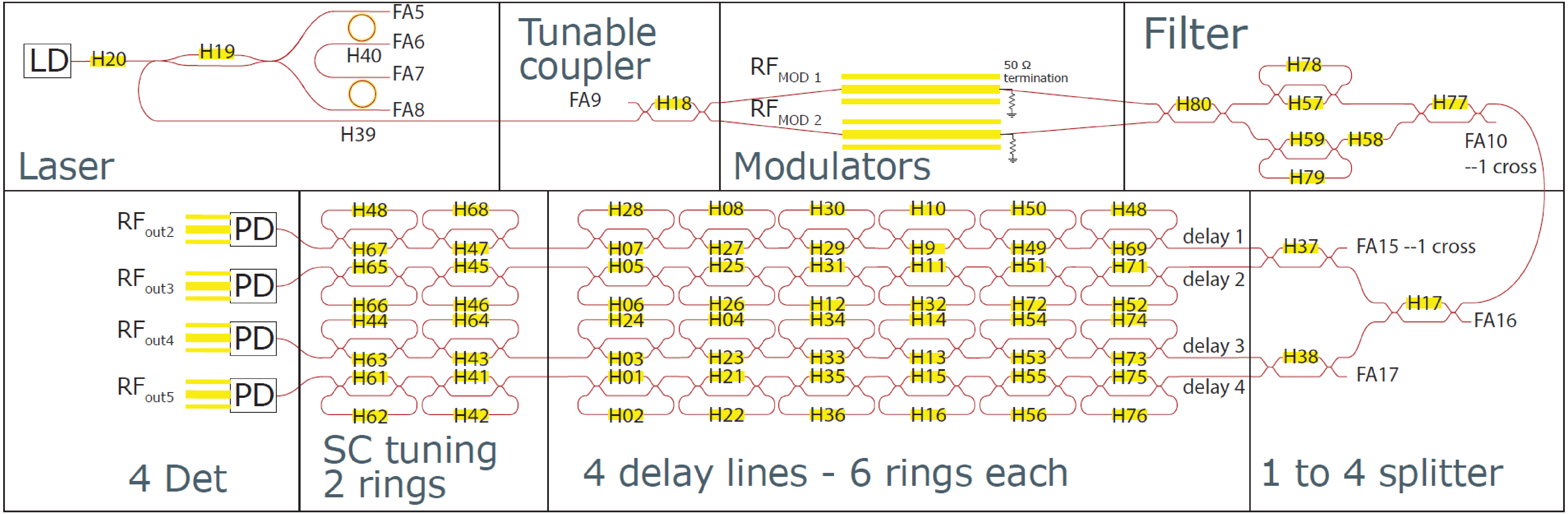




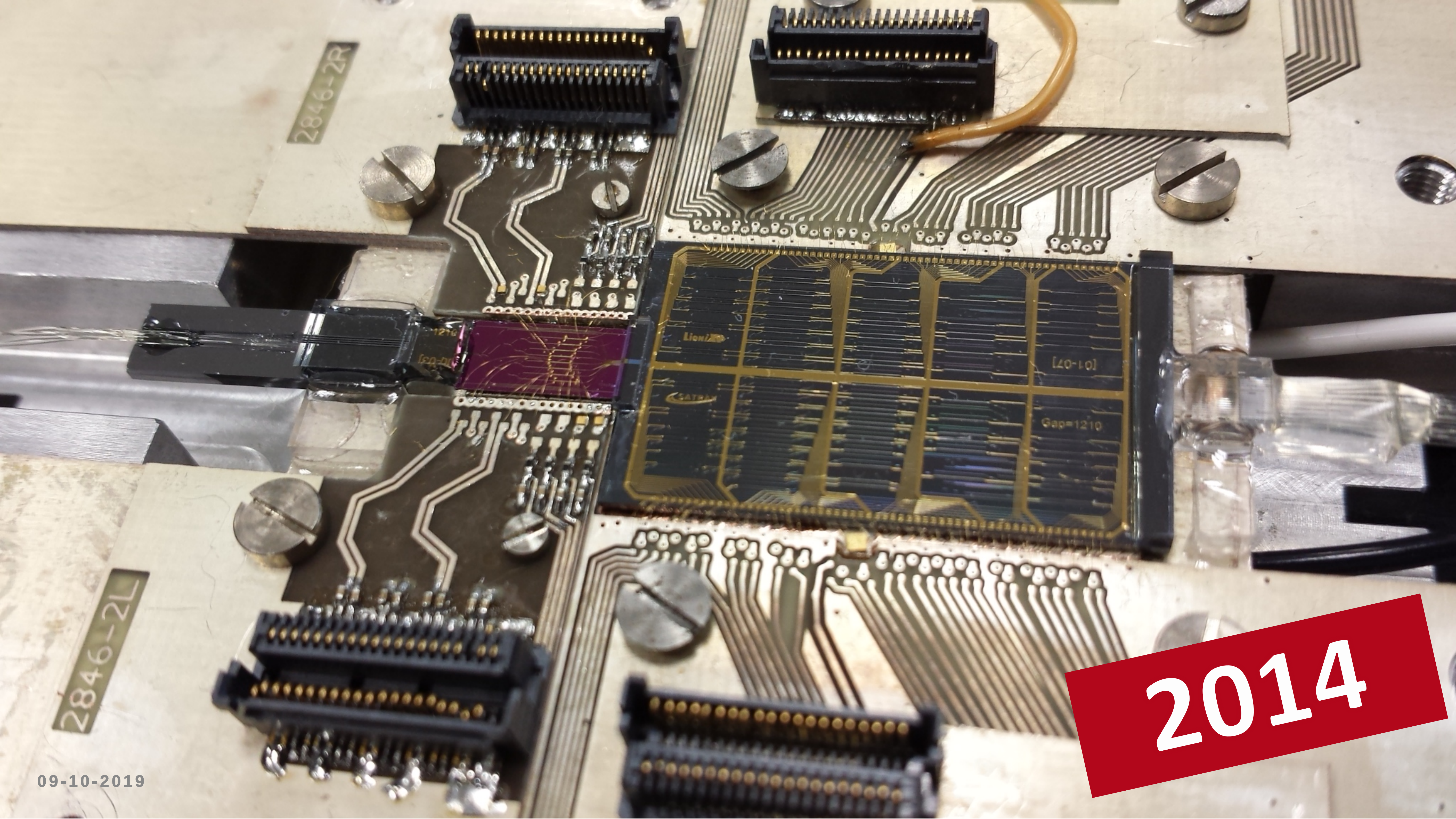


L. Zhuang et al., , vol. 19, no. 15, 2007

1xN Optical beamforming network

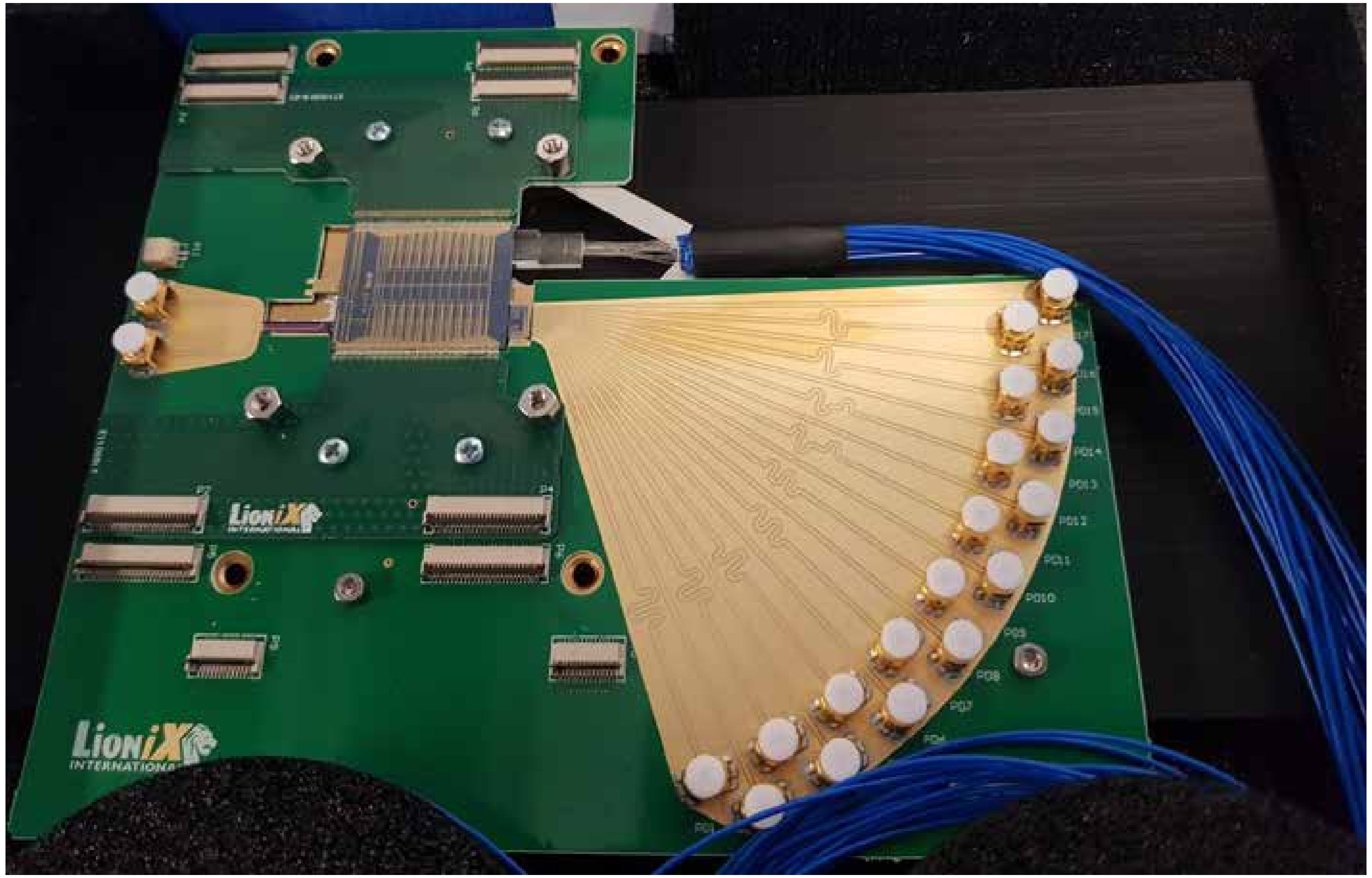


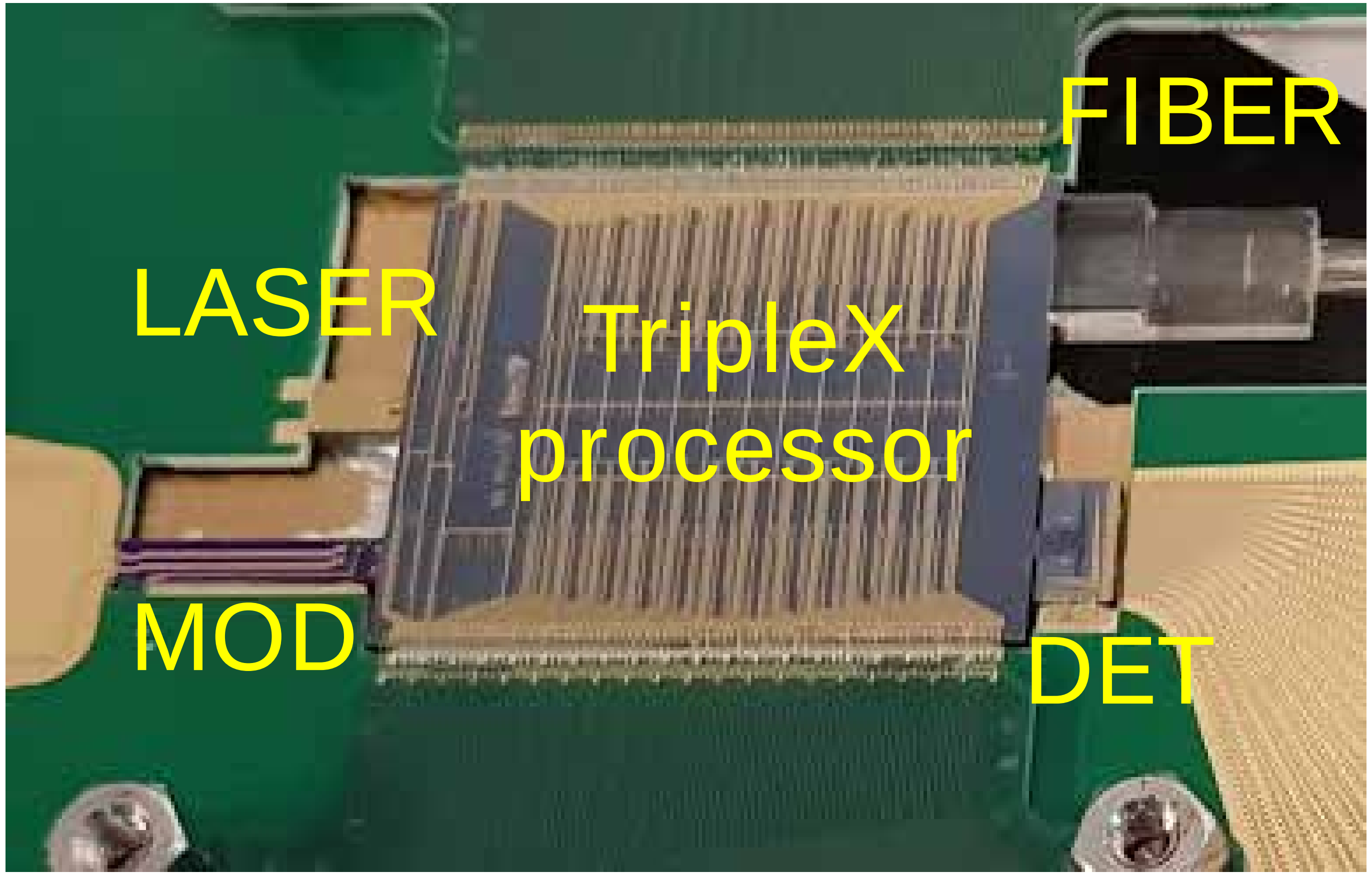
2007



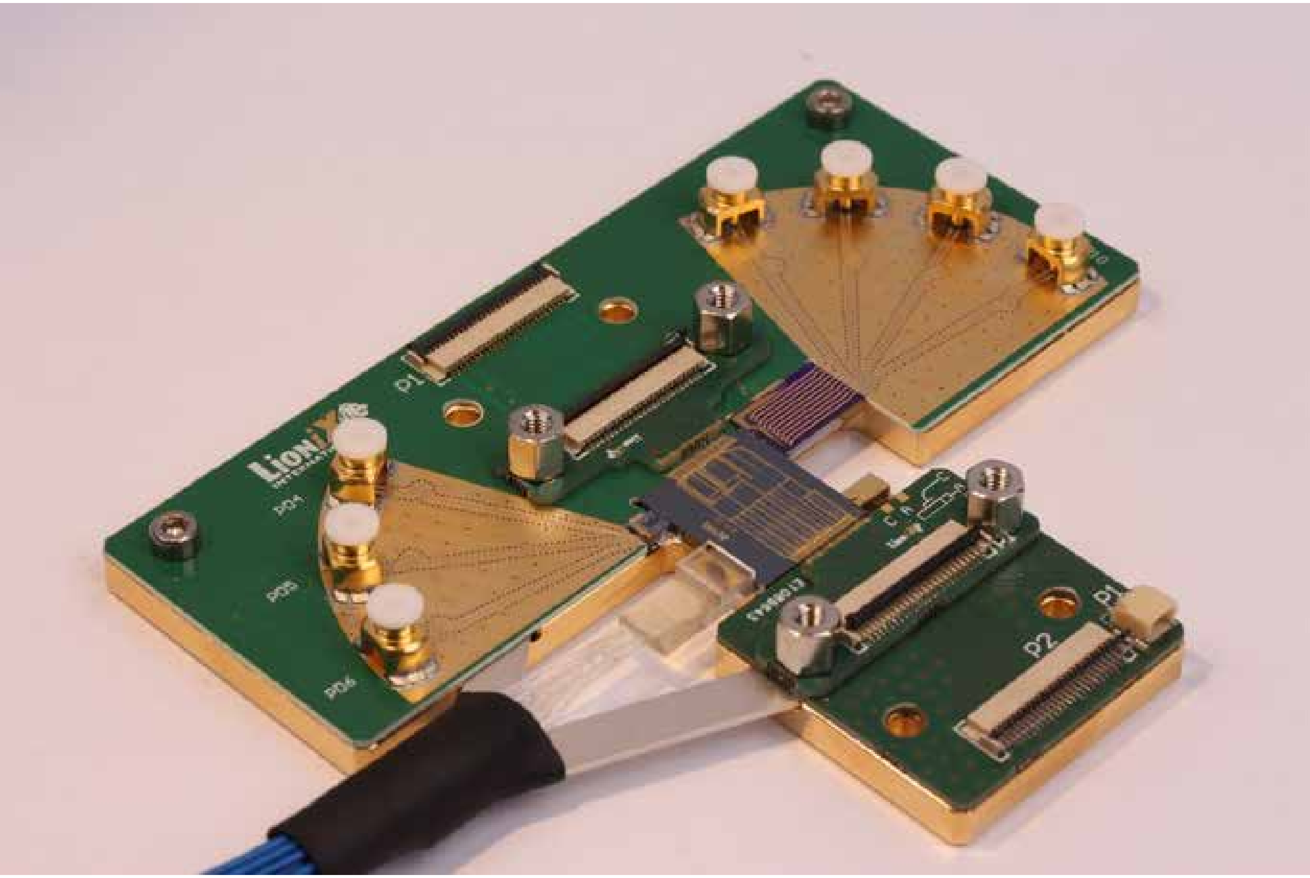
2846-2R
2846-2L
Gap=1210
2014

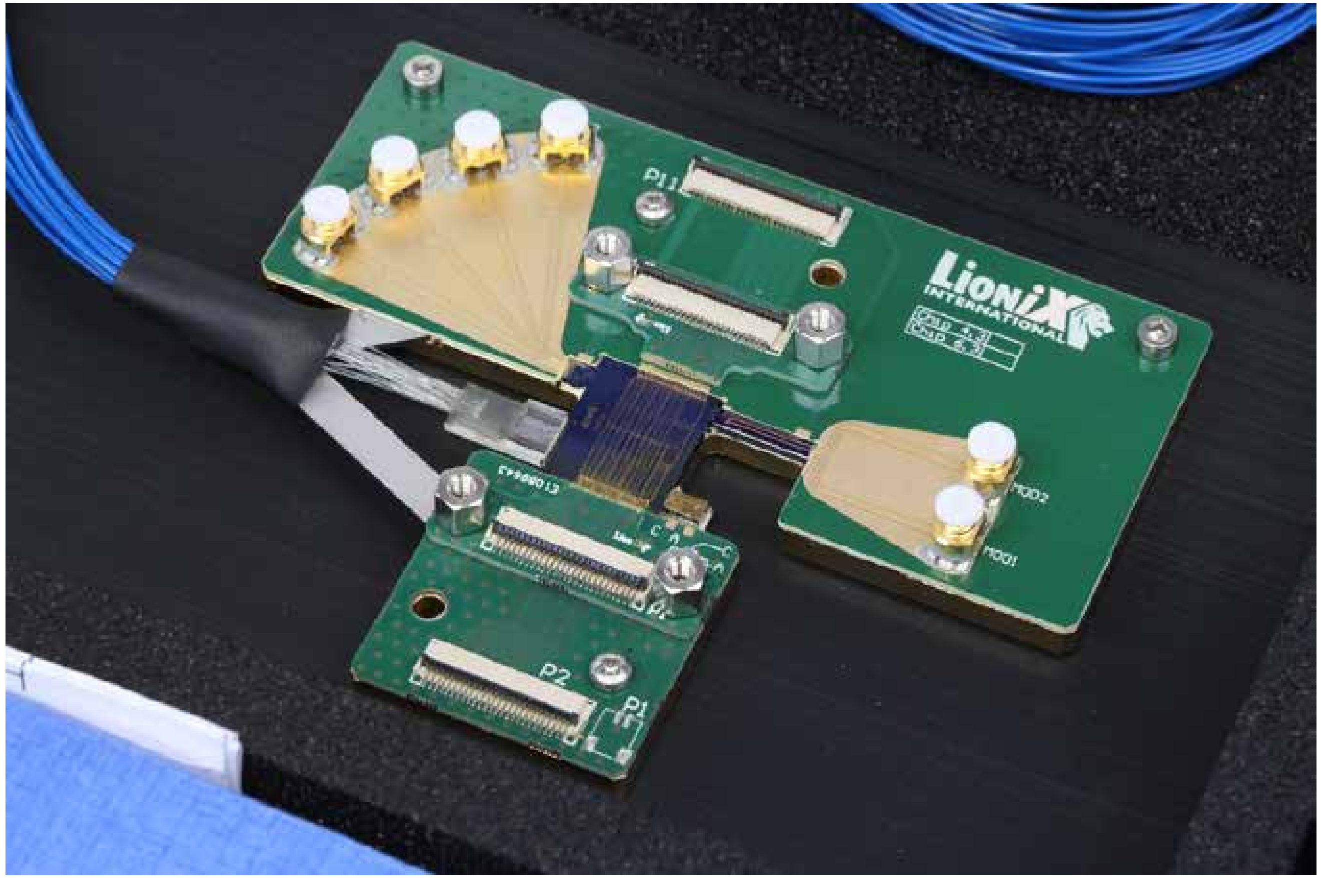
1xN Optical beamforming network



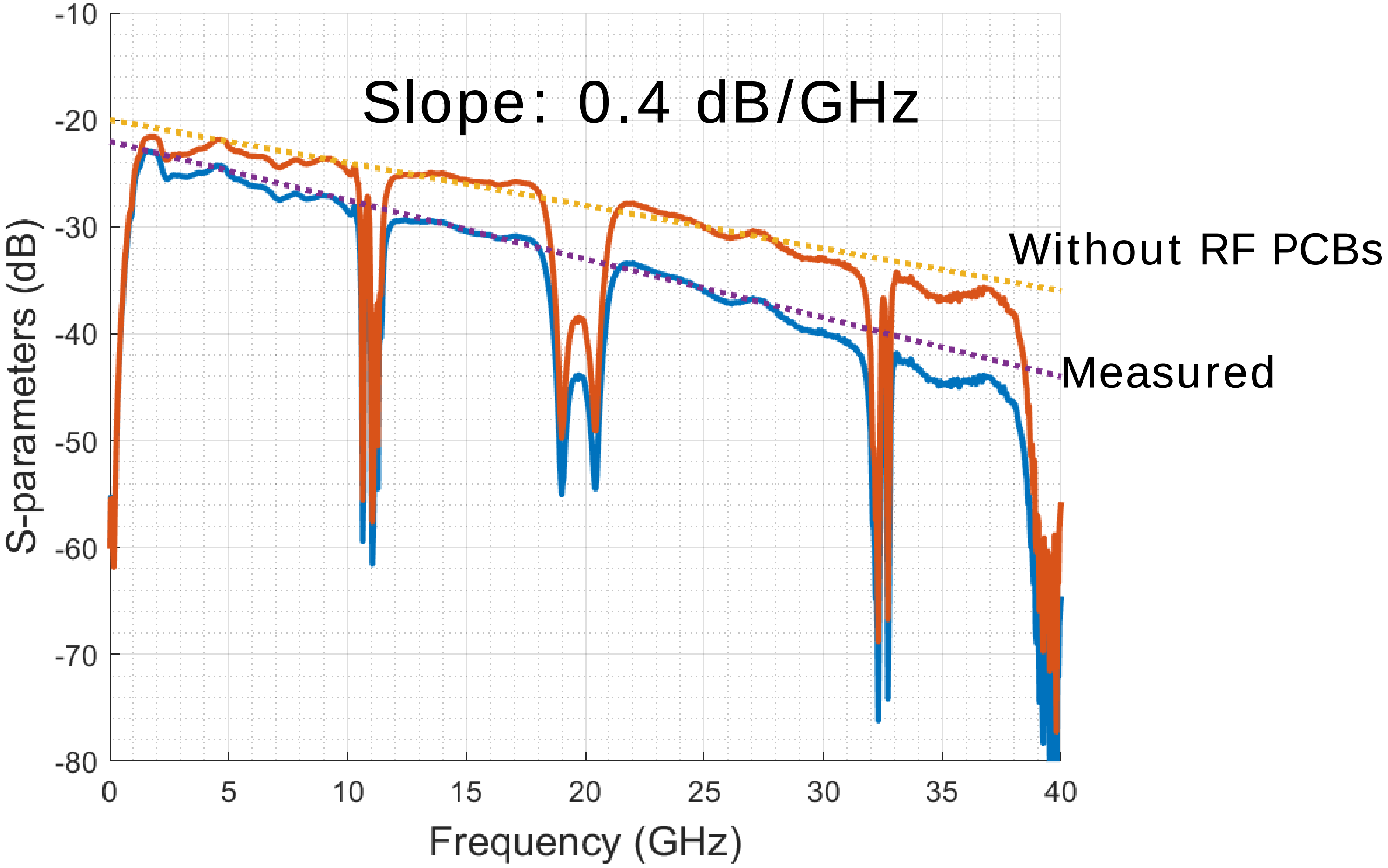


Breadboard Status





RF link gain

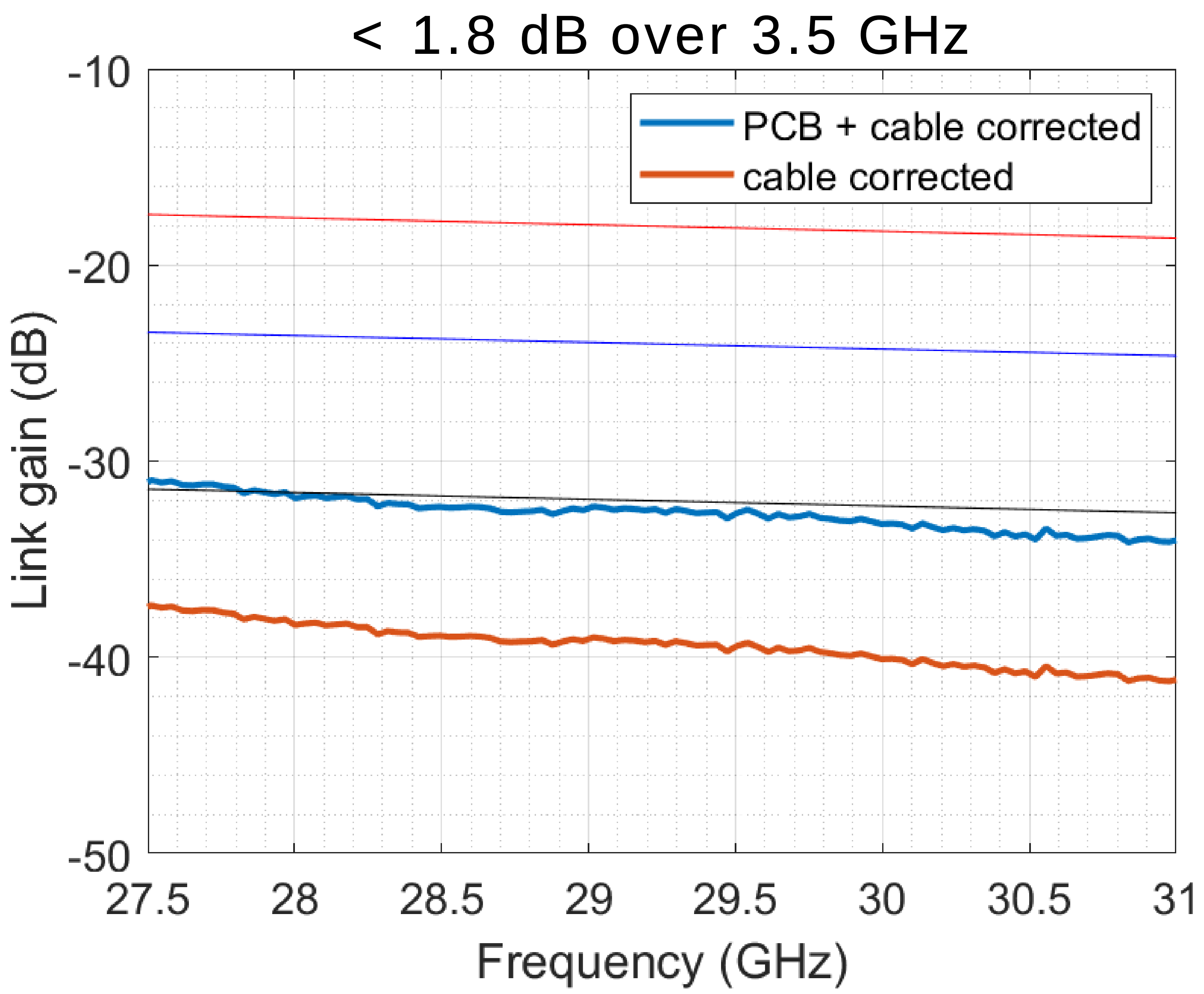


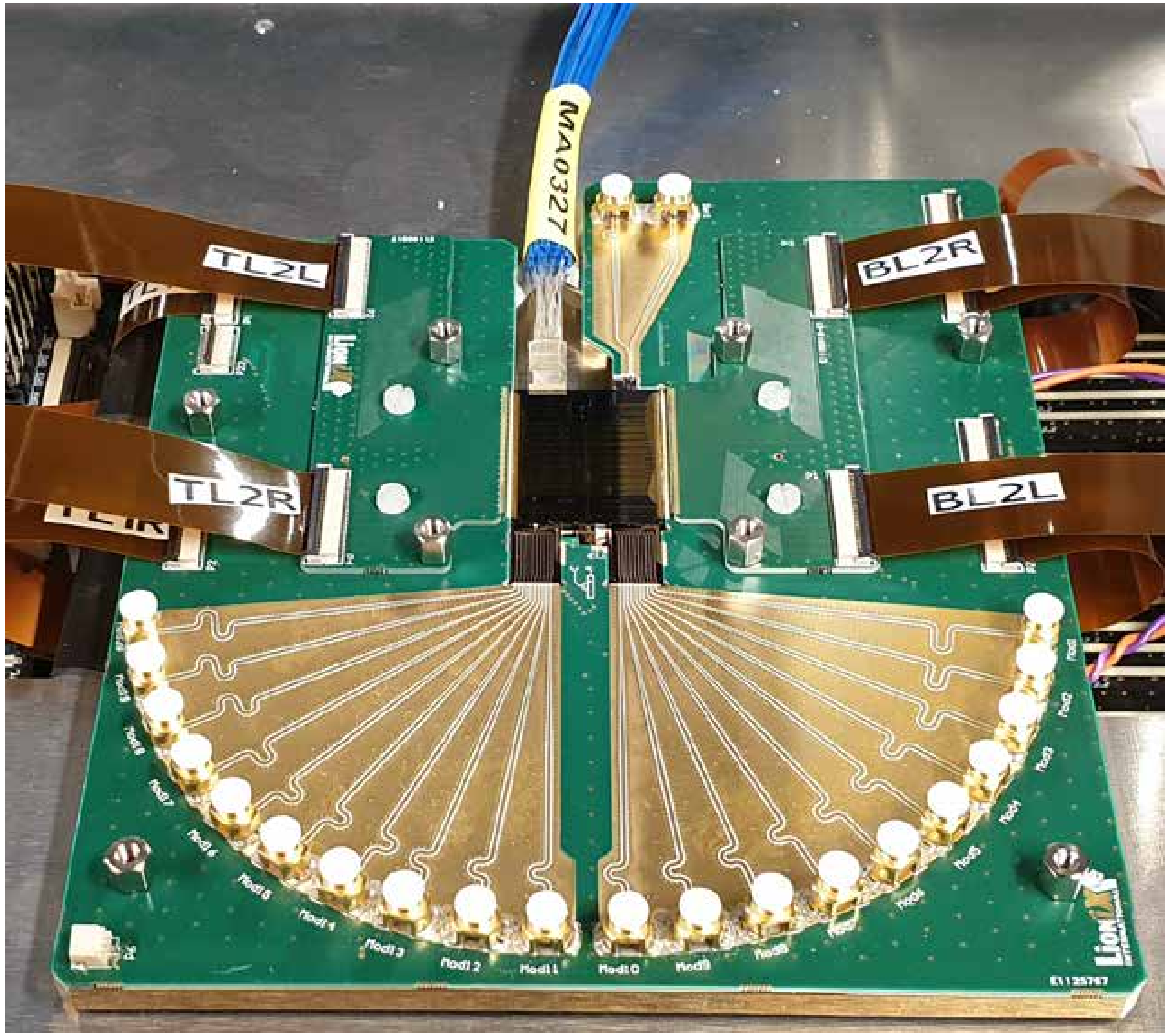
I_{PD_DC} = 3.8 mA

	Freq (GHz)	G (dB)	V (V)
Measured	5	-22	4.0
	10	-24	4.7
	20	-28	7.7
	30	-32	11.8
Expected	30	-20 ←	3
	20	-17.7 ←	2.3

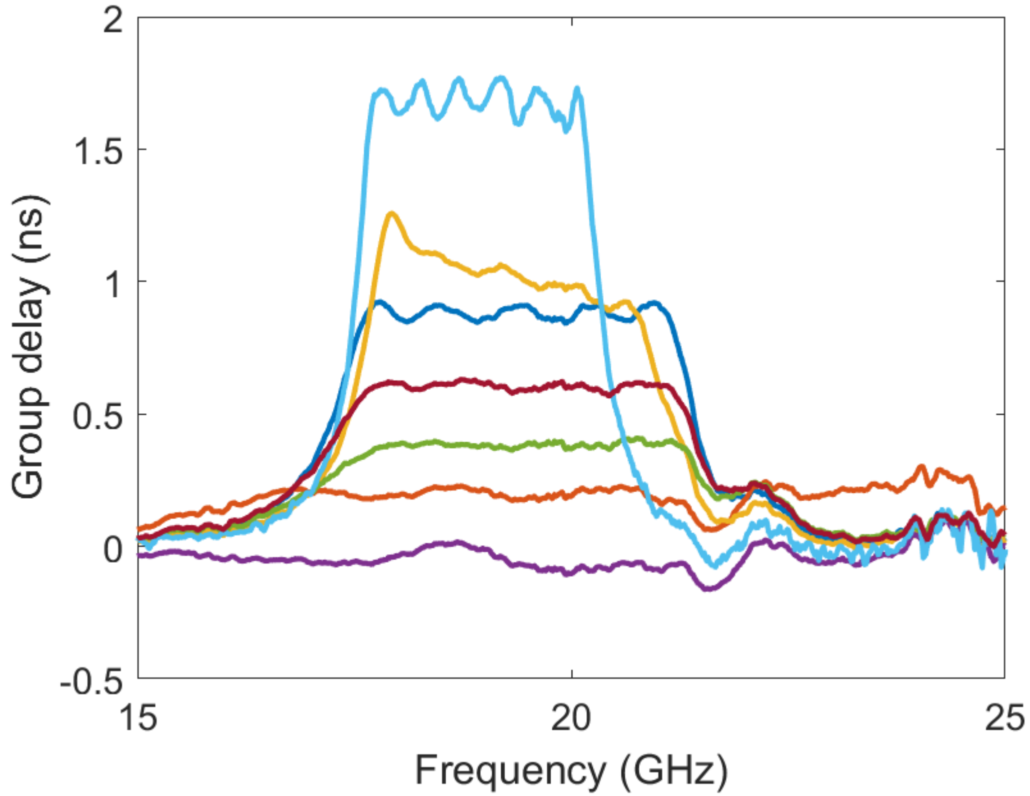
Reduced link gain is under investigation

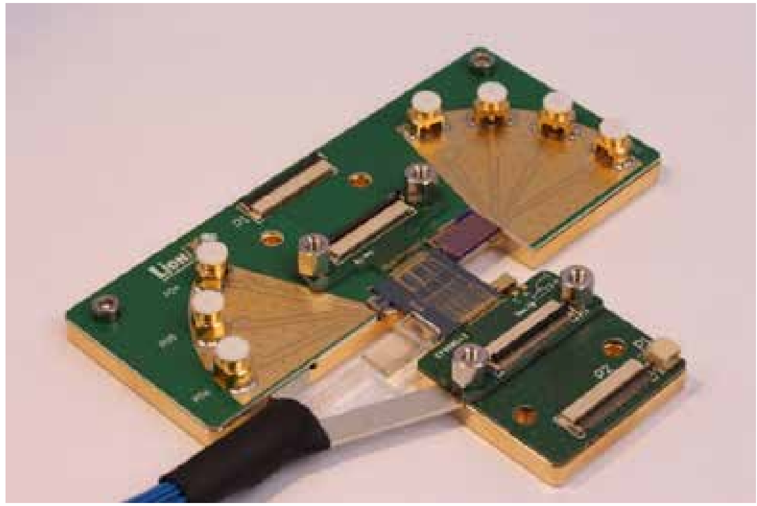
Amplitude uniformity





1x4 OBFN delay measurement

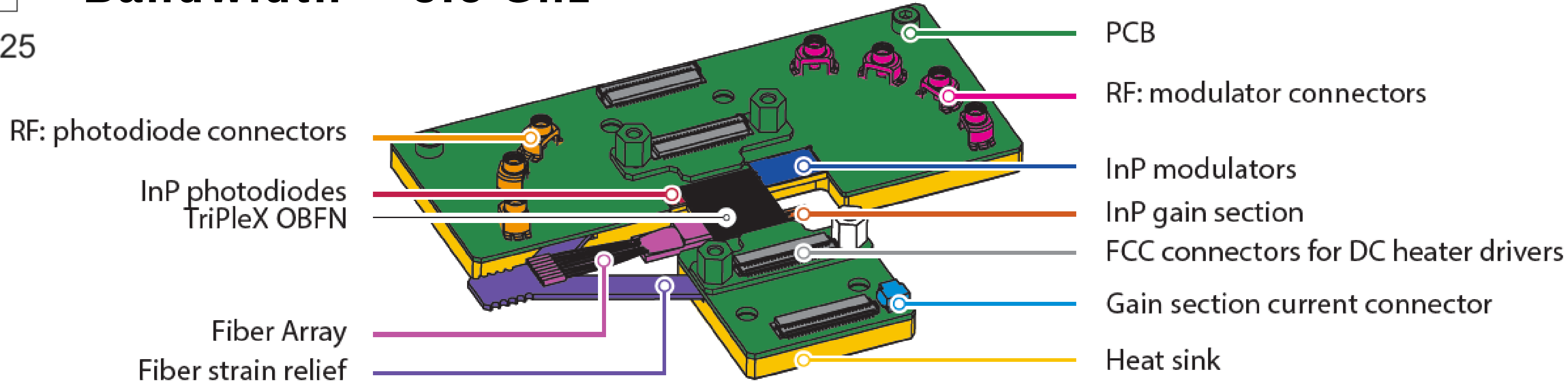




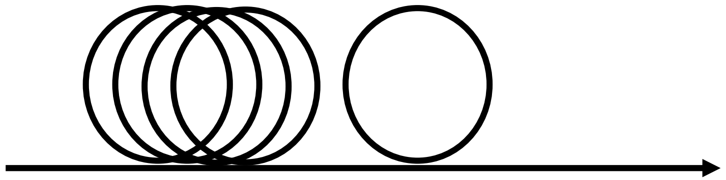
Light blue
Delay = 1.8 ns
Ripple = 100 ps
Bandwidth = 2.5 Ghz

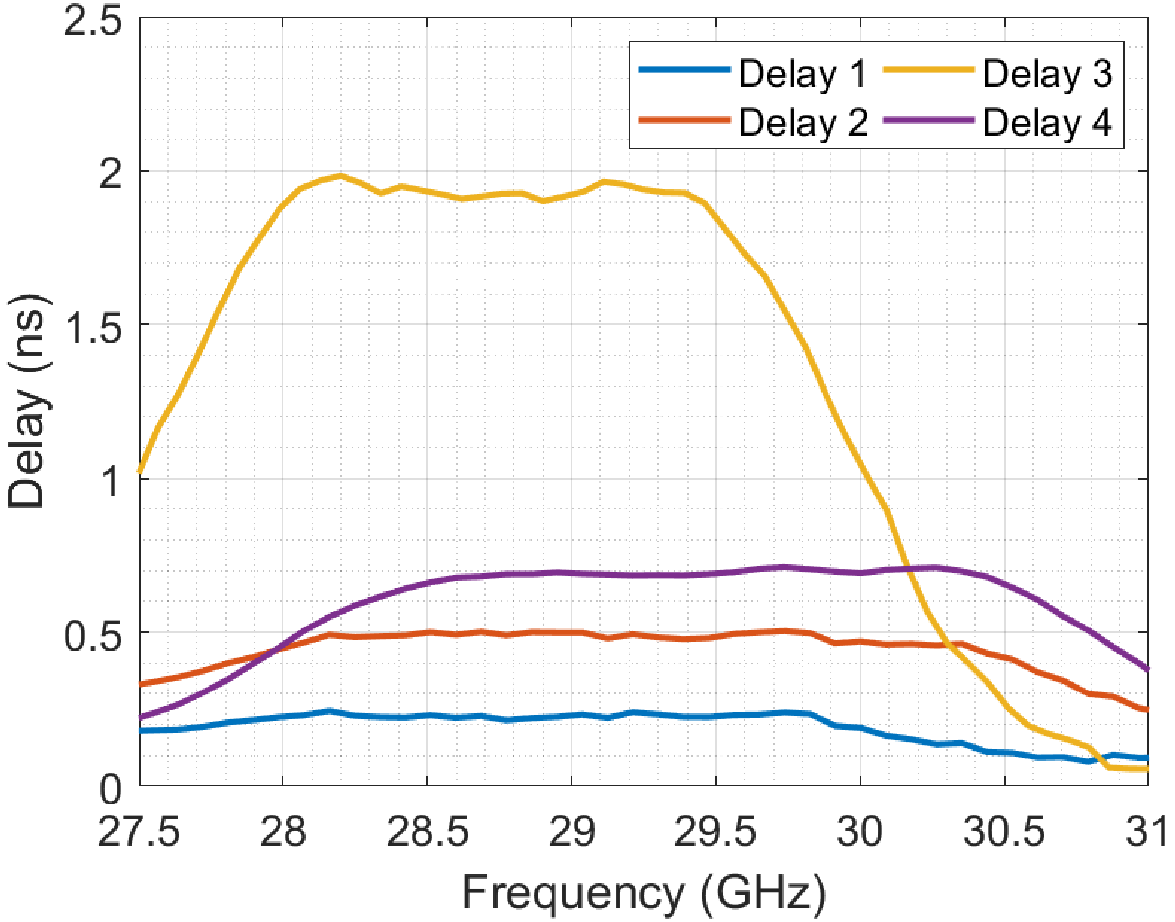
Yellow
Dispersion compensation (via slope)

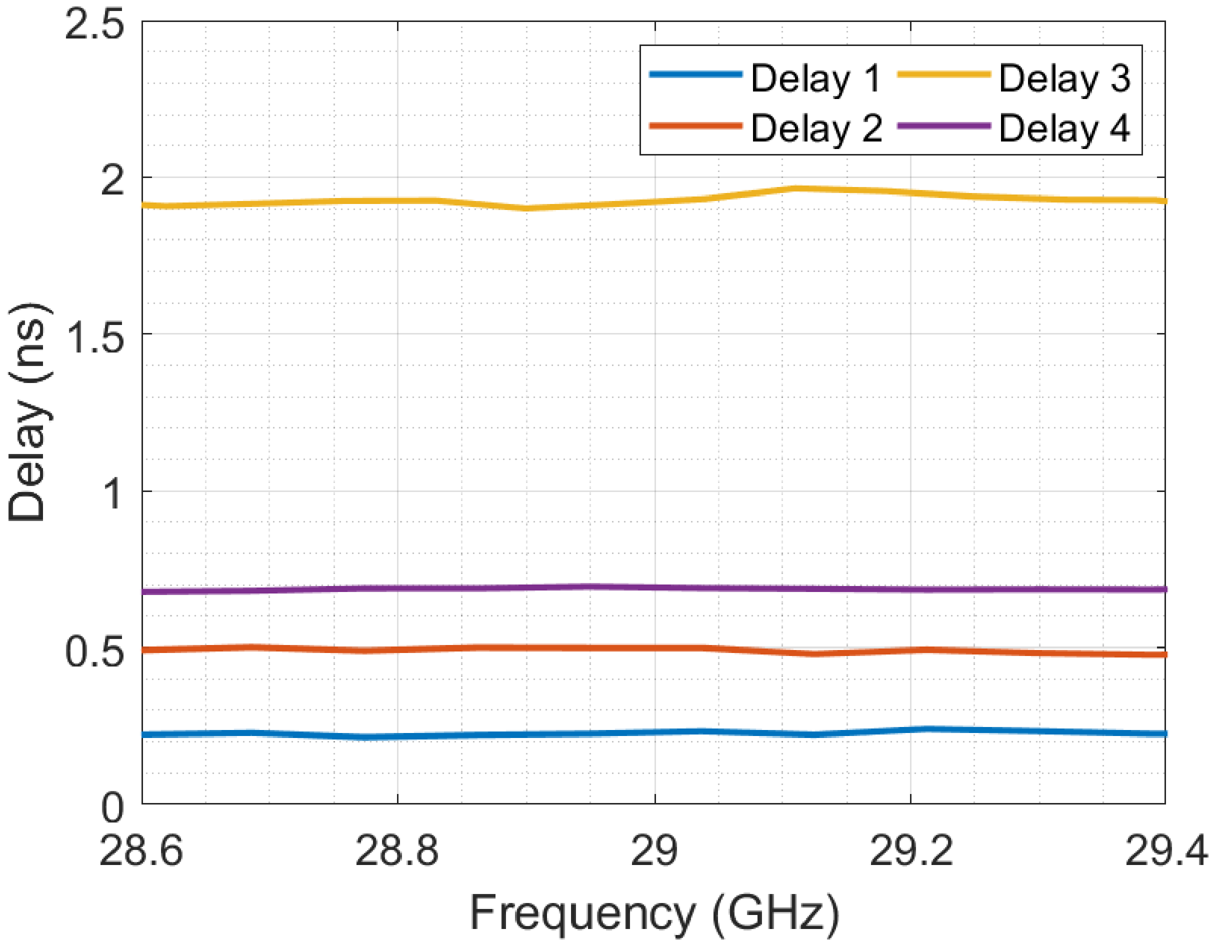
Other:
Delay = 0-1 ns
Maximum ripple = 50 ps
Bandwidth = 3.5 Ghz



Tunable delays





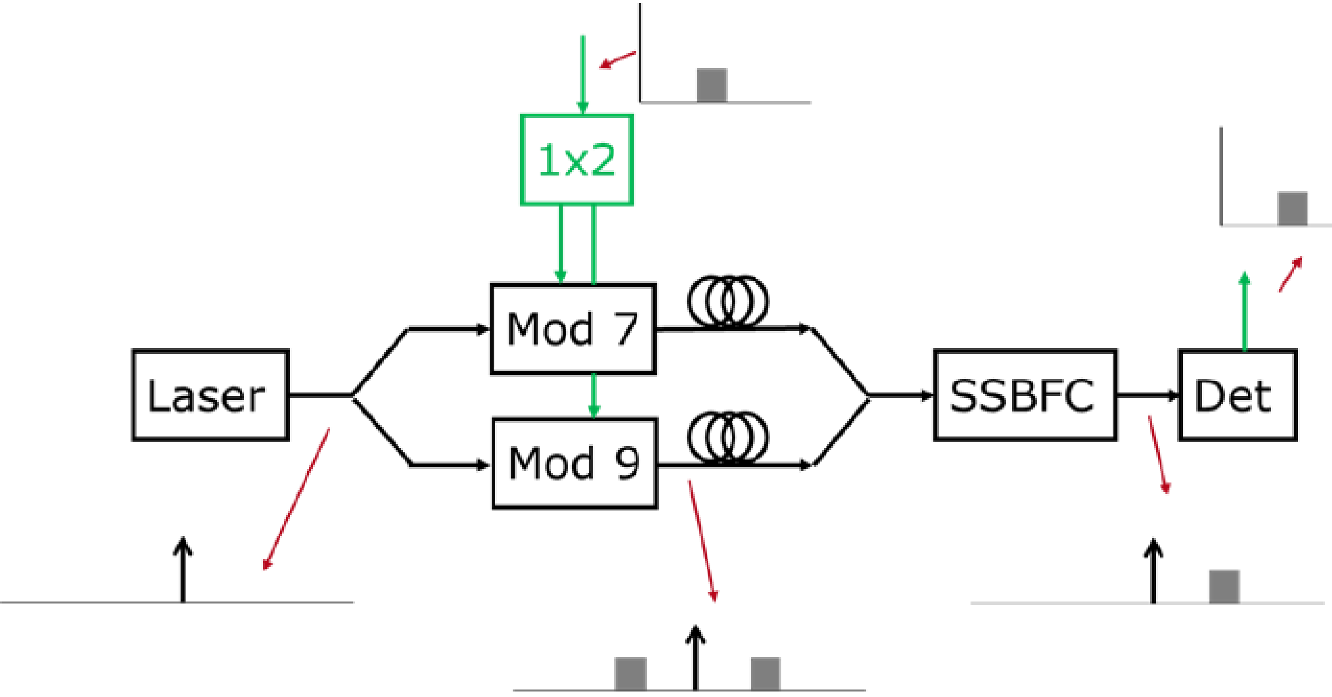


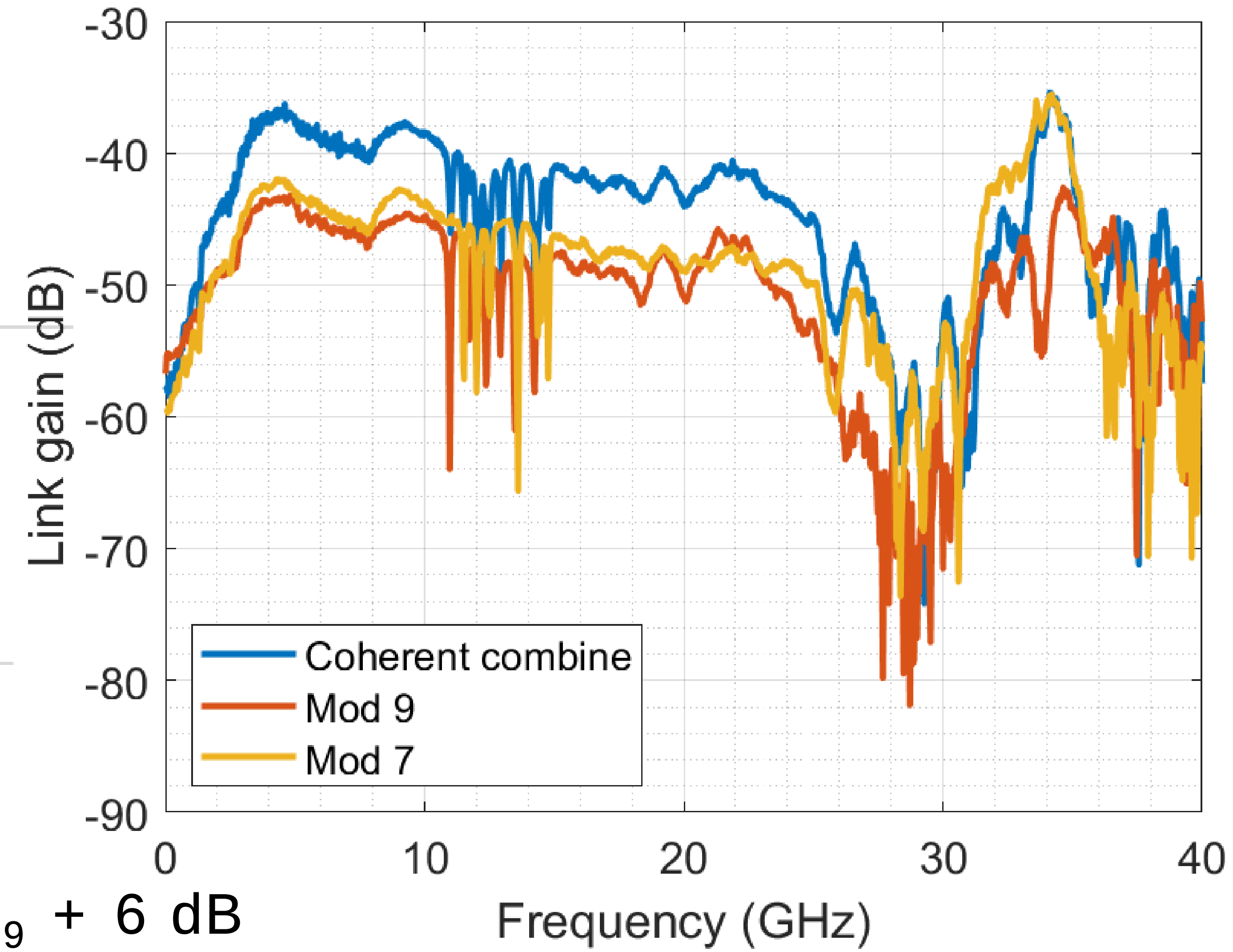
Tunable delay: 0 – 2 ns

Variation < 20 ps in 800 MHz

2x1 Coherent combining

~ I_{max_PD}

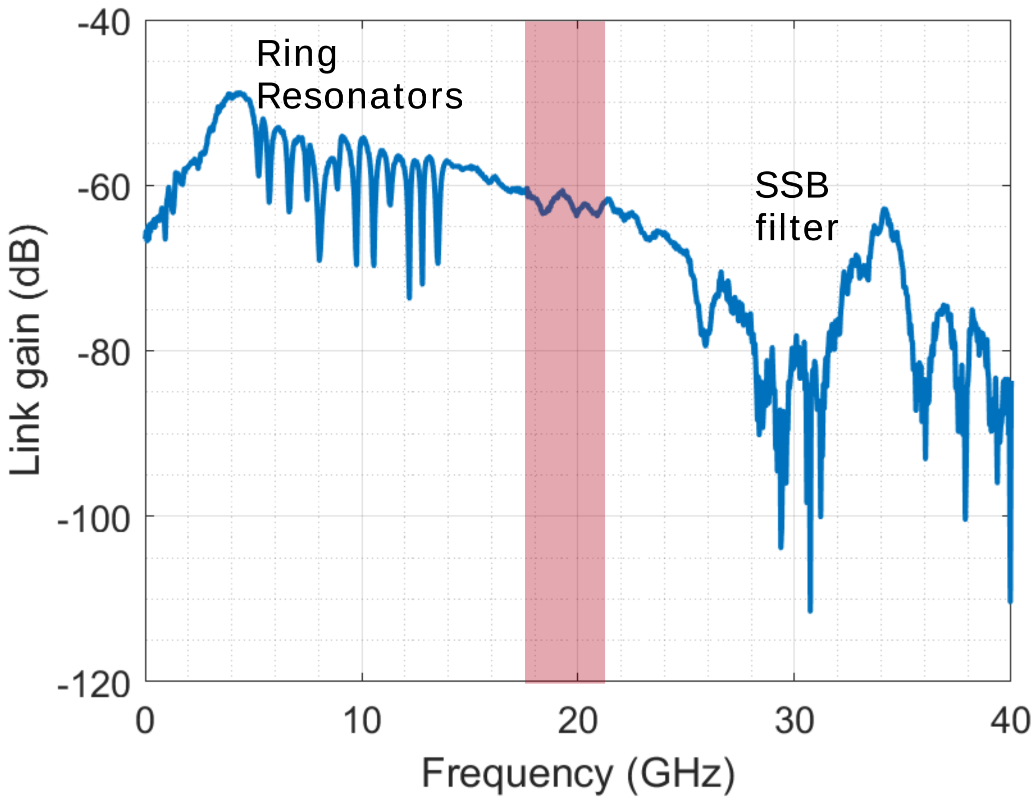




$$G_{\text{Coherent Combine}} = G_{\text{MOD 7}} + 6\text{dB} = G_{\text{MOD 9}} + 6\text{ dB}$$

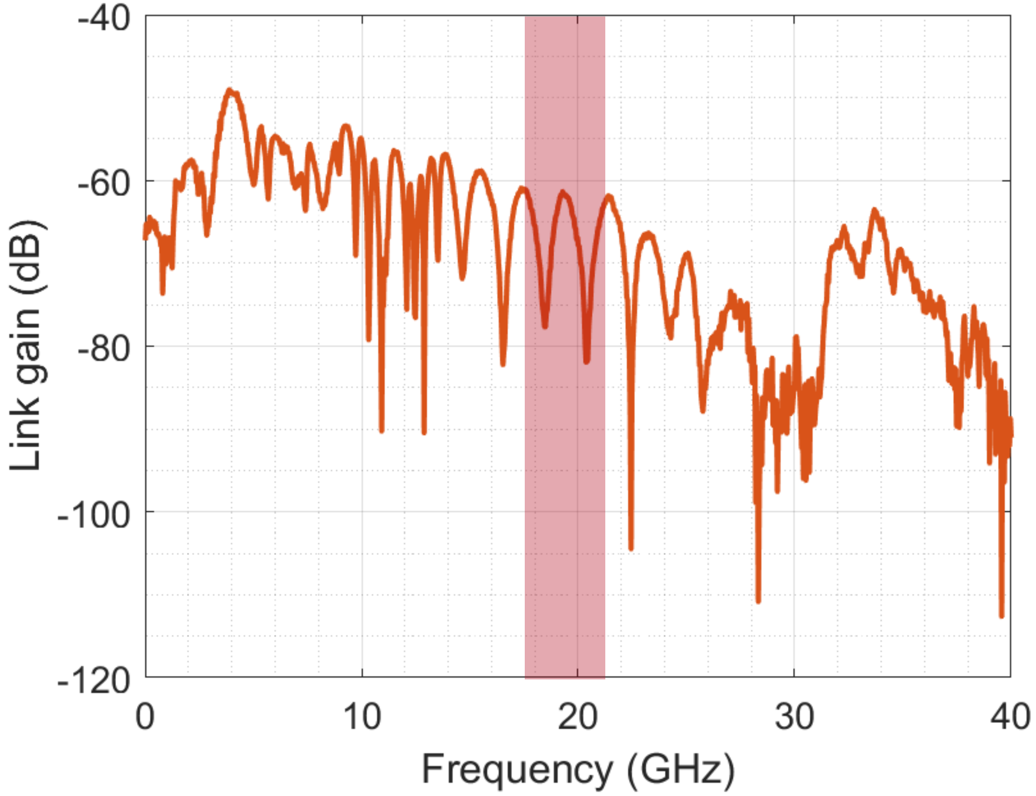
2x1 no delay

- No calibration
- $I_{PD\_Avg} = 0.5$ mA



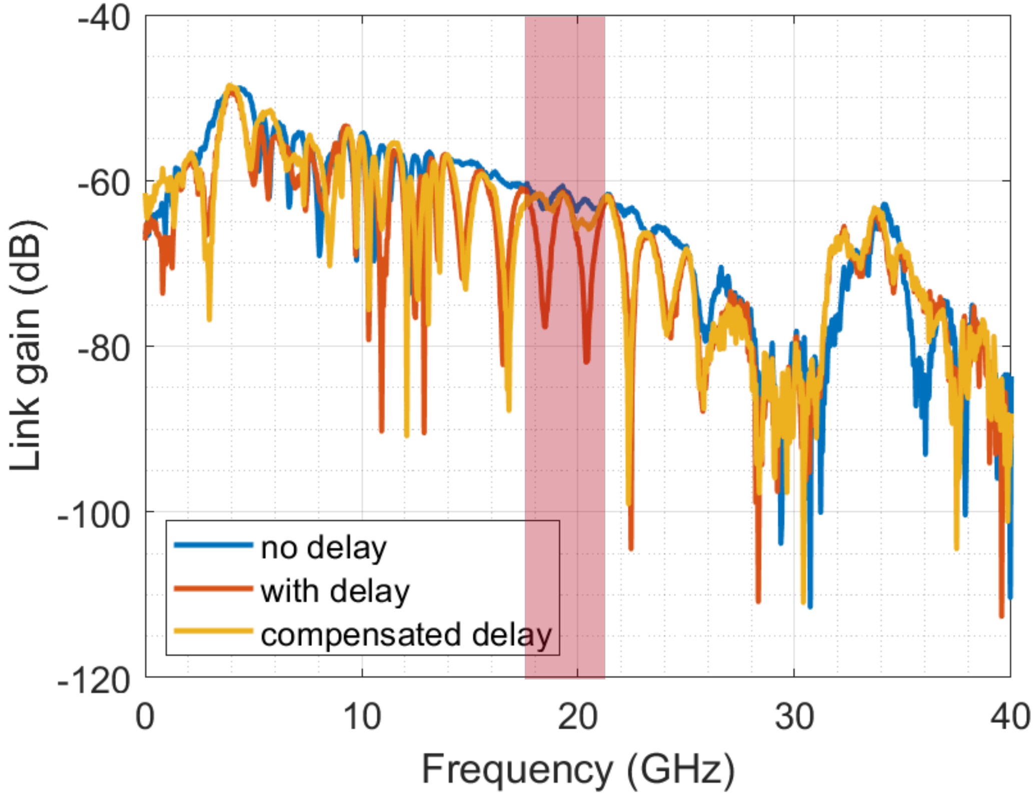
2x1 with 10 cm delay

- No calibration
- $I_{PD\_Avg} = 0.5$ mA
- $f_{FSR} = 1.9$ GHz



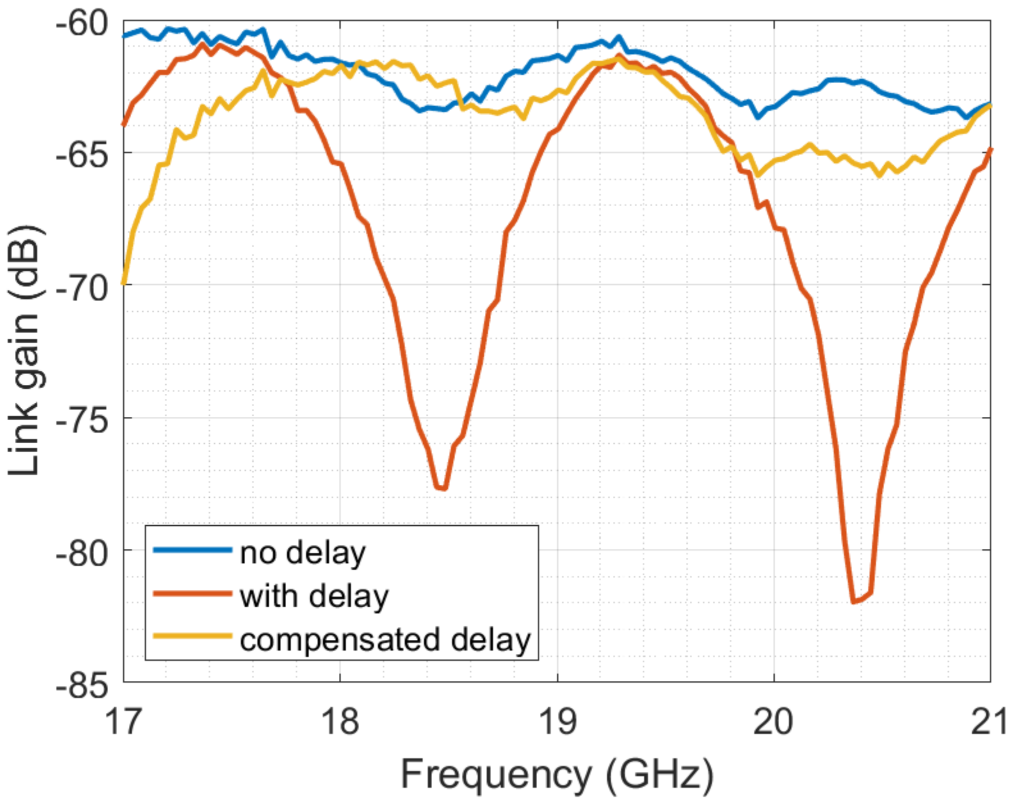
2x1 with delay compensation

- 2 Ring resonators moved to signal band



Zoom Ka Band


1
2
KRYTAR


-60
-65
-70
-75
-80
-85
Link gain (dB)
17
18
19
20
21
Frequency (GHz)
no delay
with delay
compensated delay

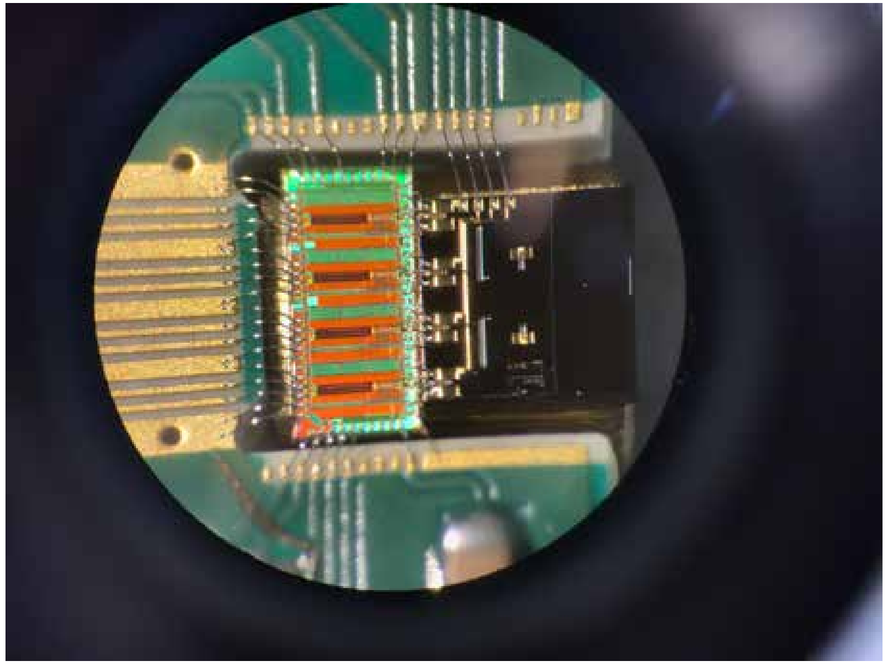

1
2
KRYTAR

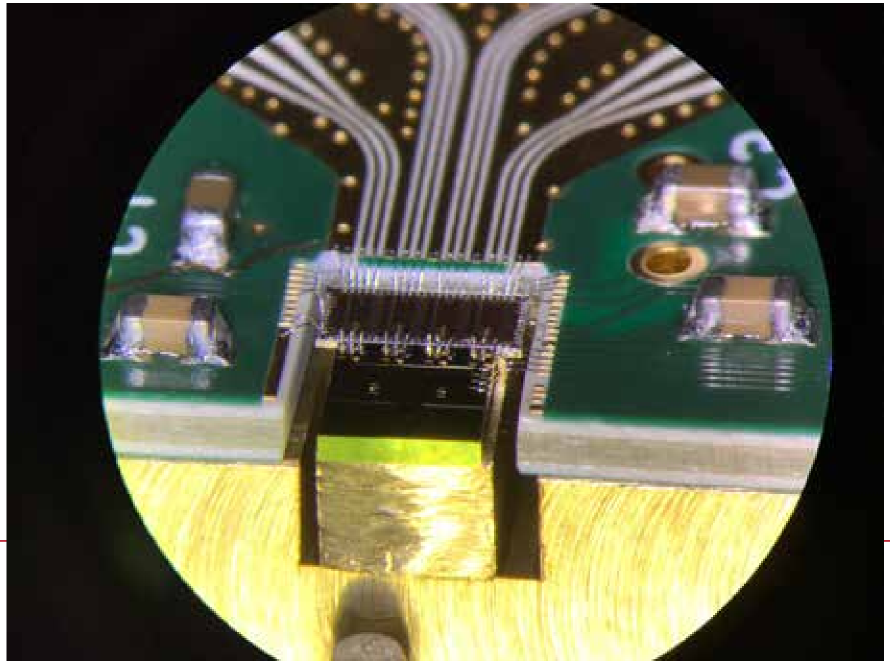
Conclusions

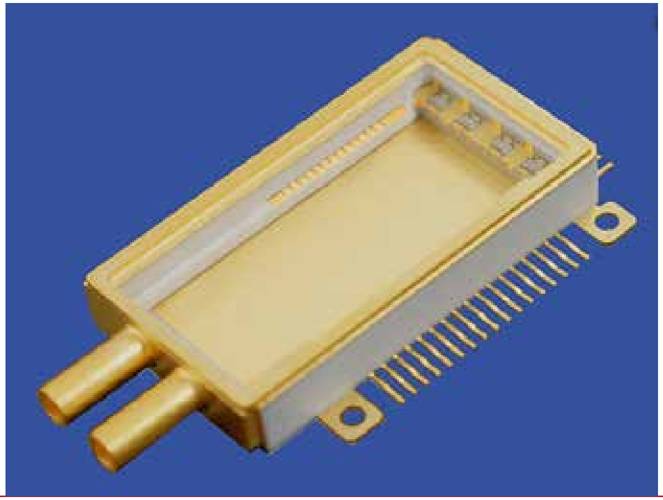
- TriPleX™ quality is excellent resulting in low loss OBFN structures. The typical waveguide propagation losses are 0.05 dB/cm.
- Laser performance is excellent with a laser power of 50 mW and RIN < -165 dB/Hz and there is an ability to further increase laser power to 100 mW.
- Modulator performance is not according to specification, resulting in higher insertion loss. This issue can be solved by having a new InP Run
- Detector performance is not according to specification, resulting in higher insertion loss of the MWP link. This issue can be solved by changing diode types with new InP run and.
- Assembly procedures giving good results. Upscaling and improvement towards reproducibility and automation and production can continue to move forward. The fiber to chip coupling losses are 0.5 dB and the InP to TripleX coupling losses are 1 - 1.5 dB.
- The OBFNs are operating as expected. Phase, delay and amplitude can be controlled independently for each path
- The system is time stable. Settings did not change over the period of testing (days to weeks).
- Broadband microwave beamforming has been achieved using photonics.

Future improvements

- Miniturise (package design)
- Integrate more electronics
- Use trans impedance amplifiers
- Scale up (develop assembly procedures)
- Improve Active components

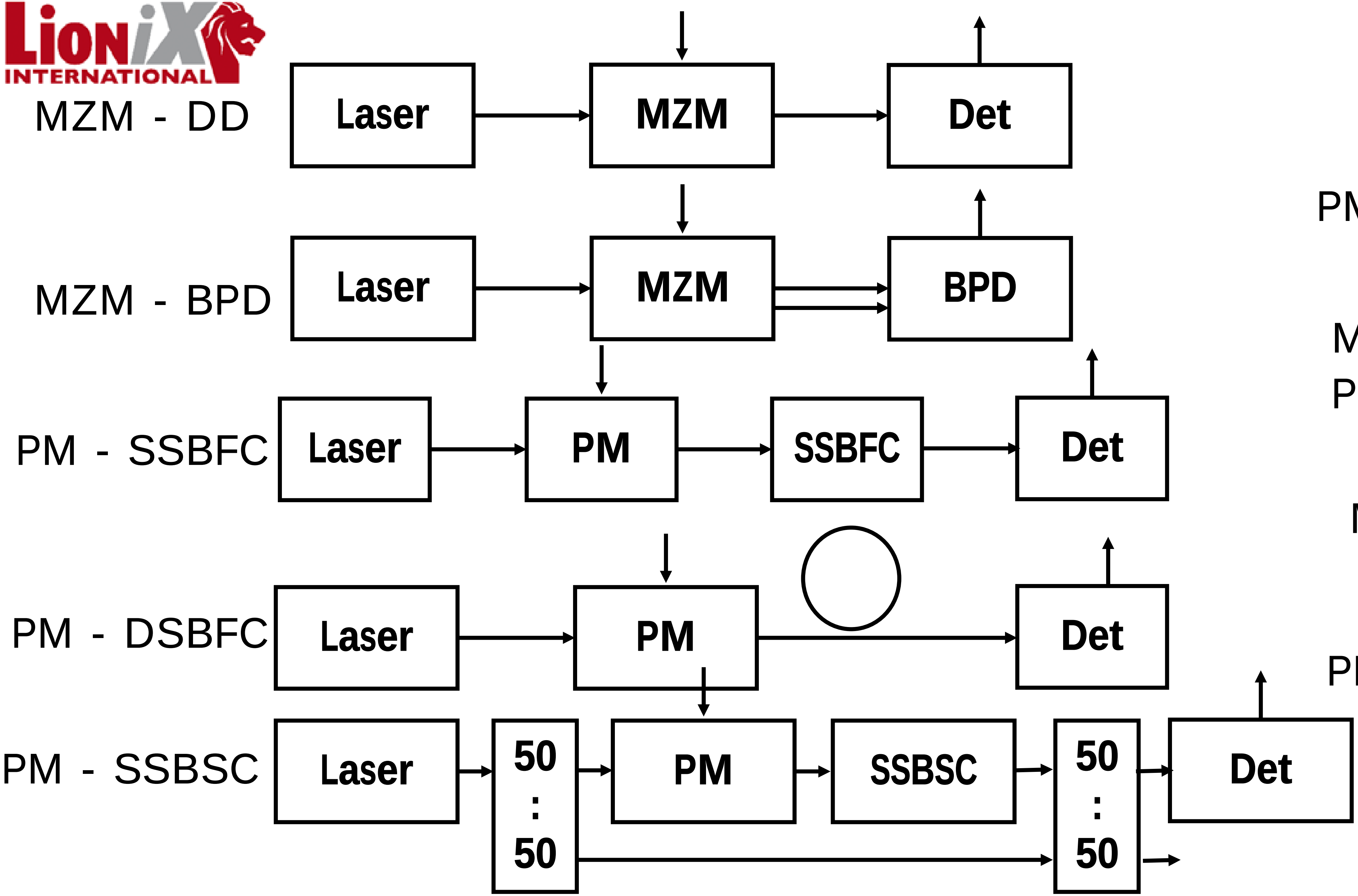




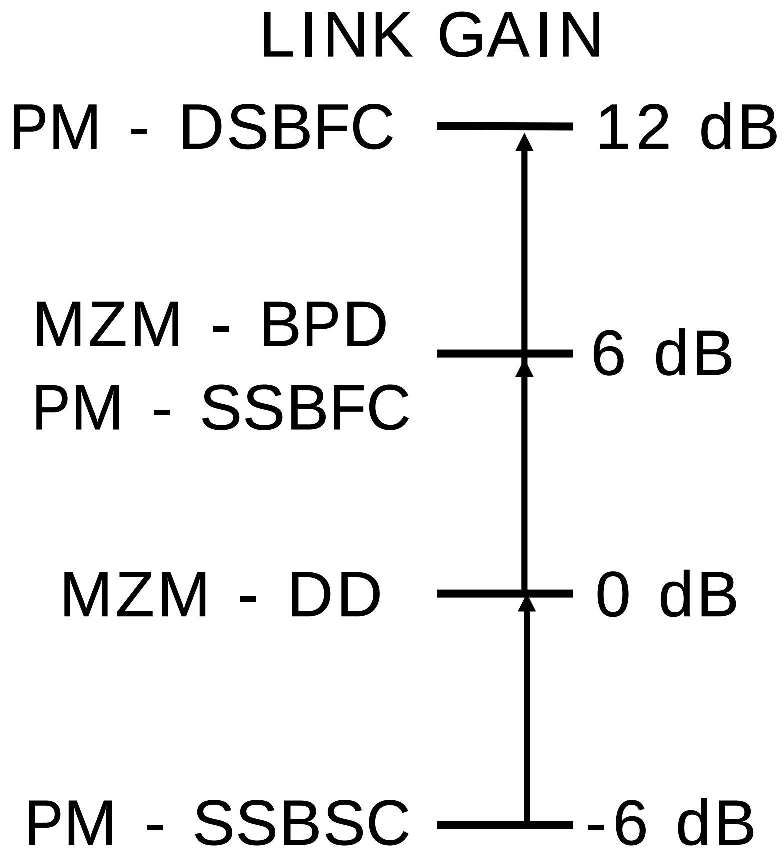


Questions

AOL Cases

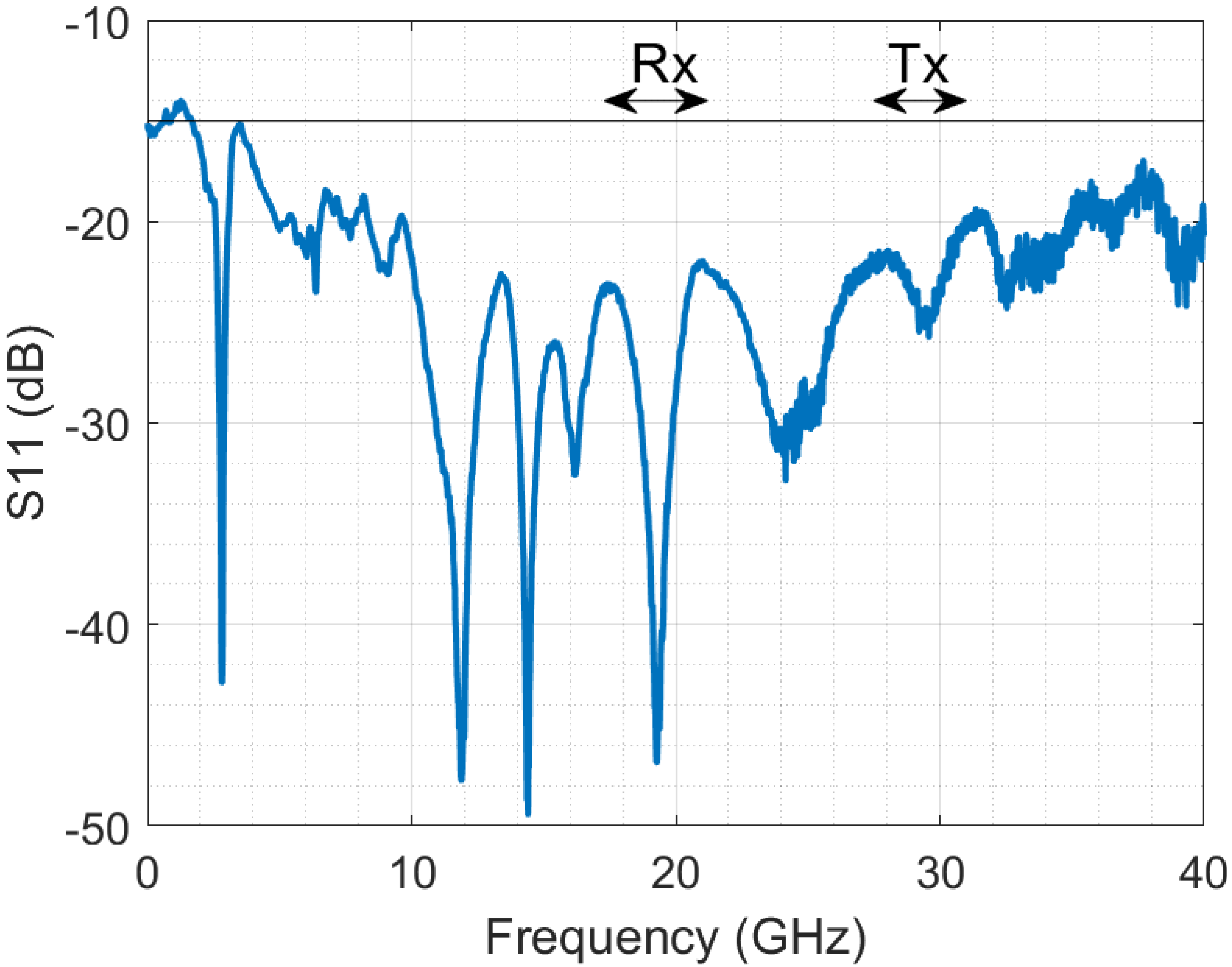


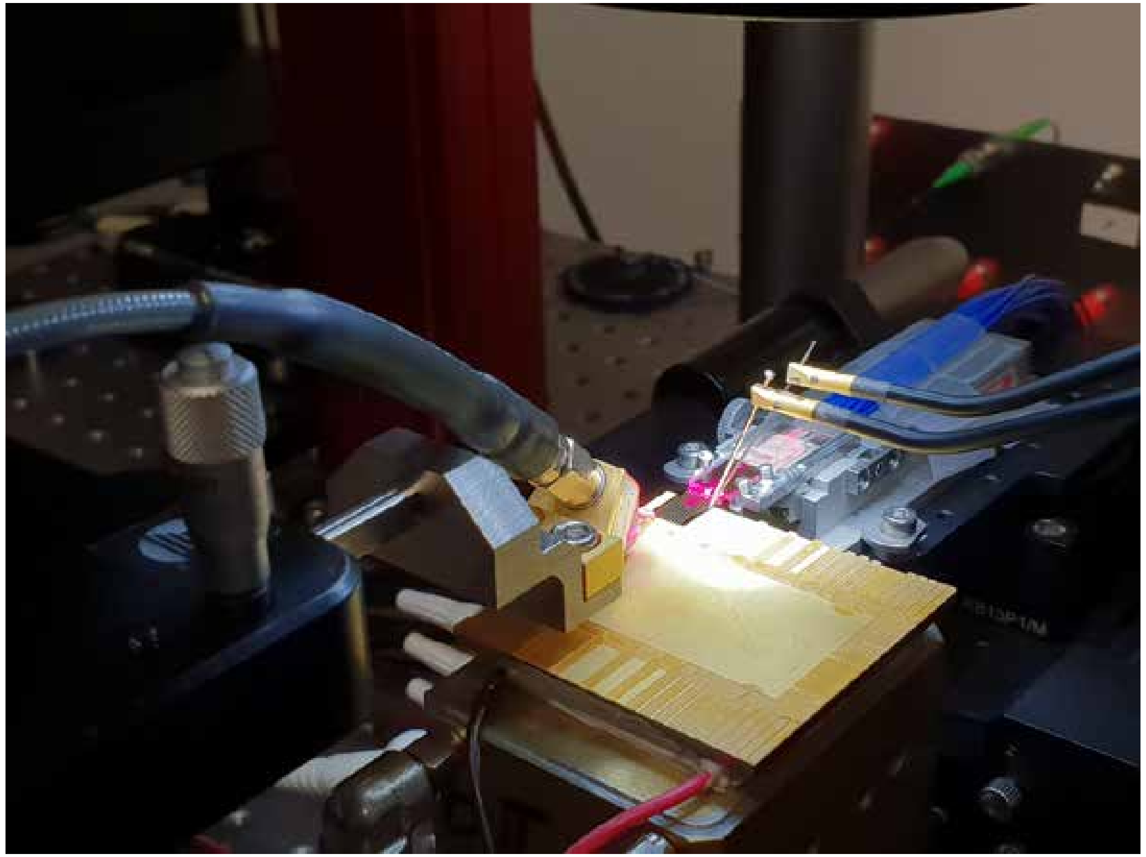
MZM - DD
Laser
MZM
Det
MZM - BPD
Laser
MZM
BPD
PM - SSBFC
Laser
PM
SSBFC
Det
PM - DSBFC
Laser
PM
Det
PM - SSBSC
Laser
50 : 50
PM
SSBSC
50 : 50
Det



LINK GAIN
PM - DSBFC
12 dB
MZM - BPD
PM - SSBFC
6 dB
MZM - DD
0 dB
PM - SSBSC
-6 dB

Modulator Return Loss

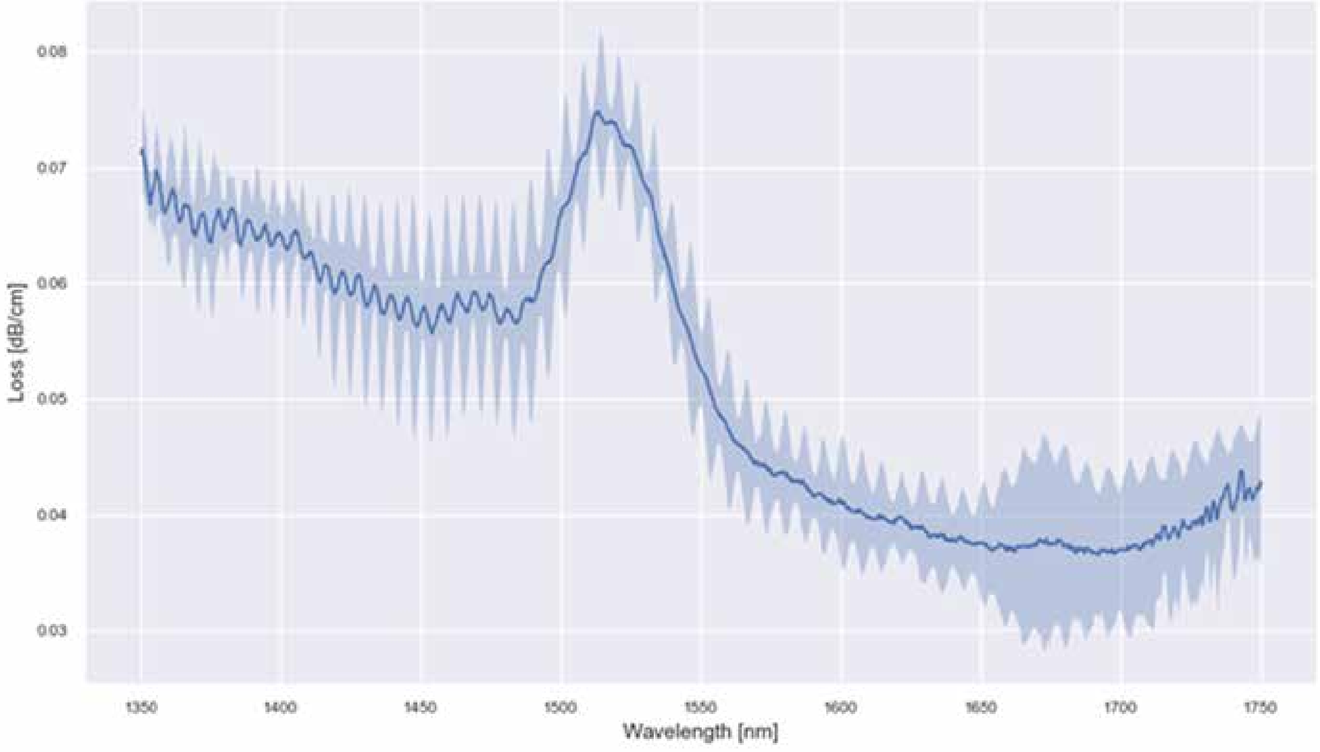


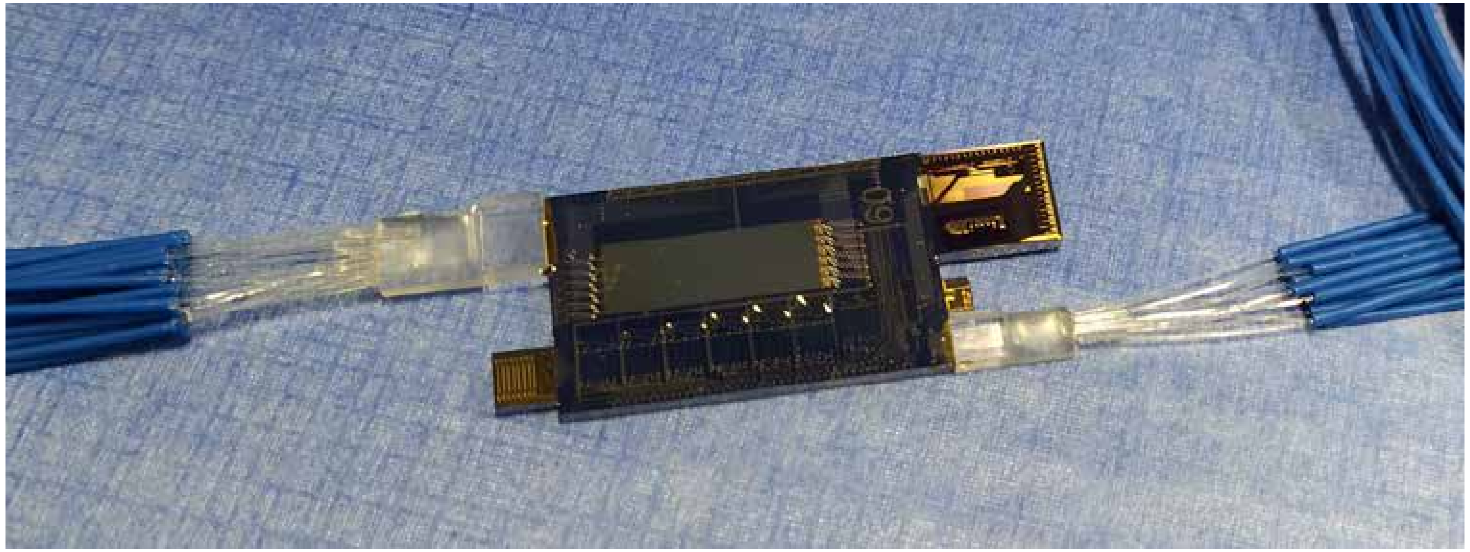


Measurement setup: VNA

~ ADS PZT compatible waveguide loss measurement (< 0.1 dB/cm)

~ **Total**
detector measured)





PZT