Microwave Photonic Technology for Astronomy Instrumentation

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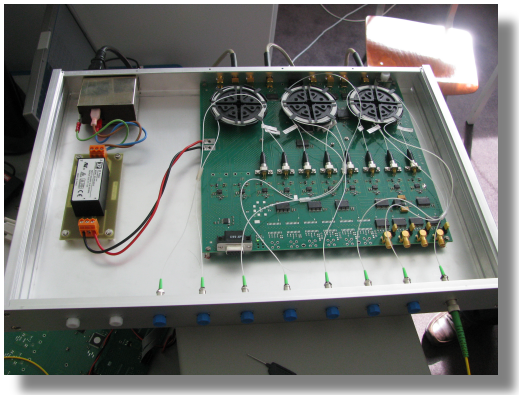
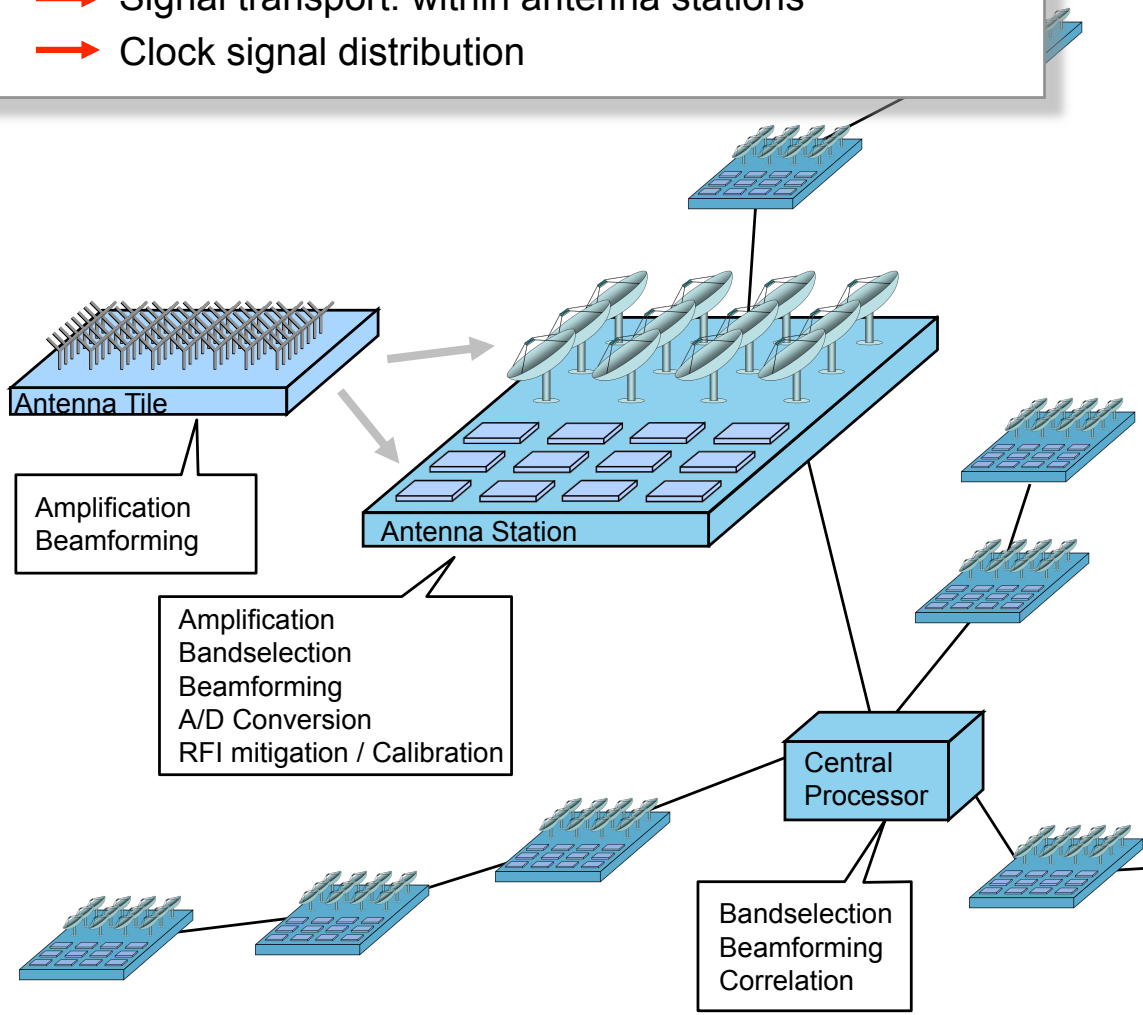
ASTRON

NWO
Netherlands Organisation for Scientific Research

AOLs for Astronomy Instrumentation

- Application areas of AOL technology
  - → Signal transport: within antenna stations
  - → Clock signal distribution

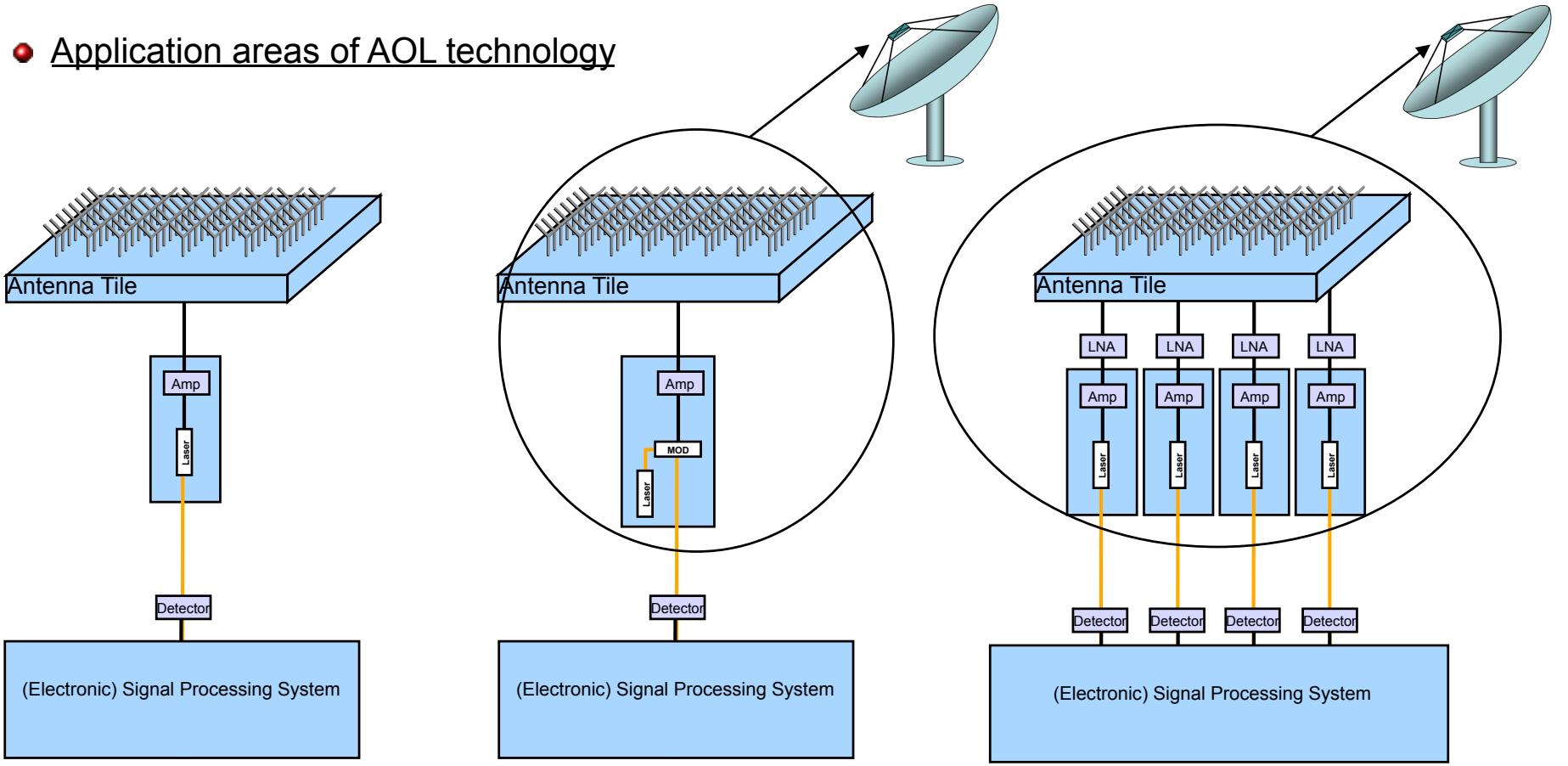




- Why Analog Photonic Links
  - Broadband / High Frequency
  - Immunity for RFI
  - Light Weight
  - Small Space Envelope

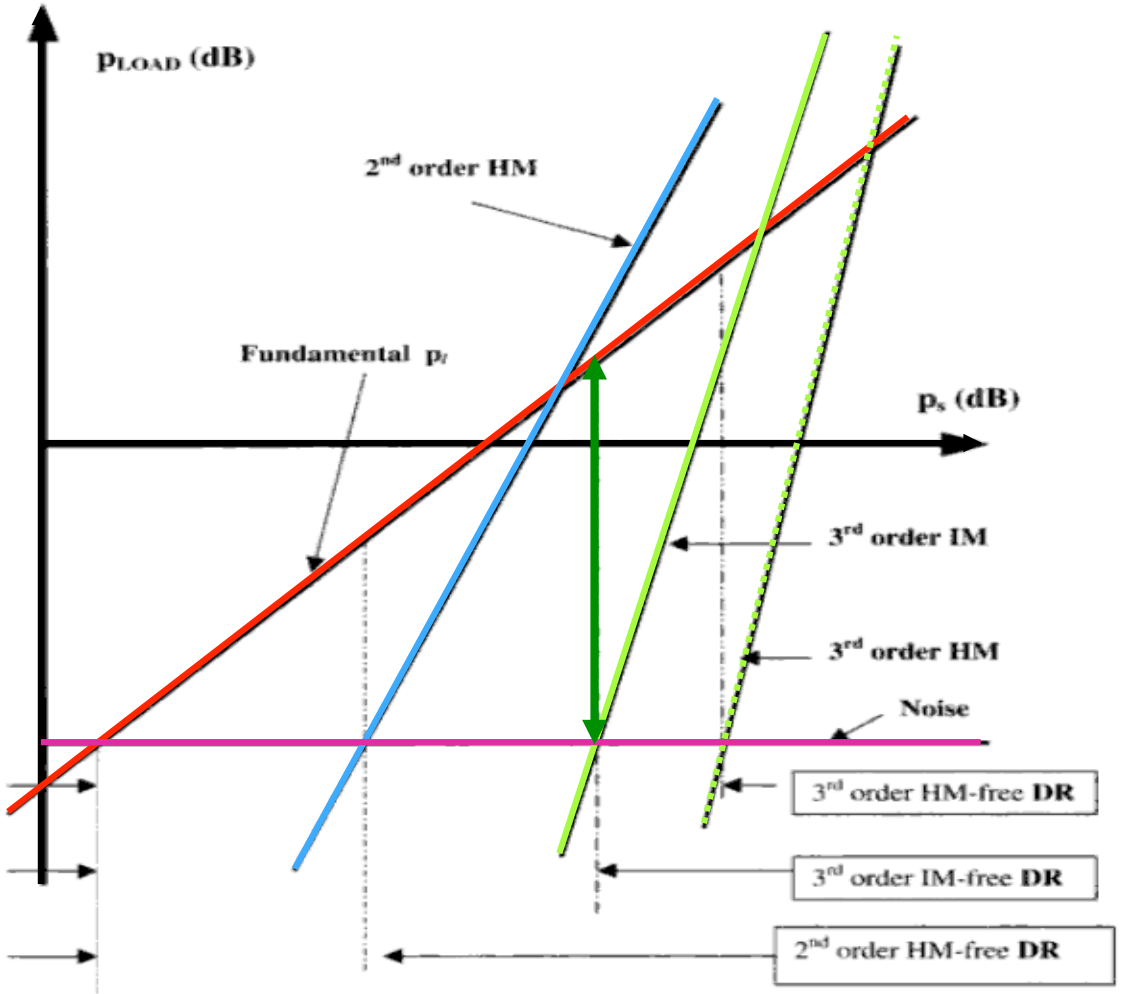
AOLs for Astronomy Instrumentation

- Application areas of AOL technology



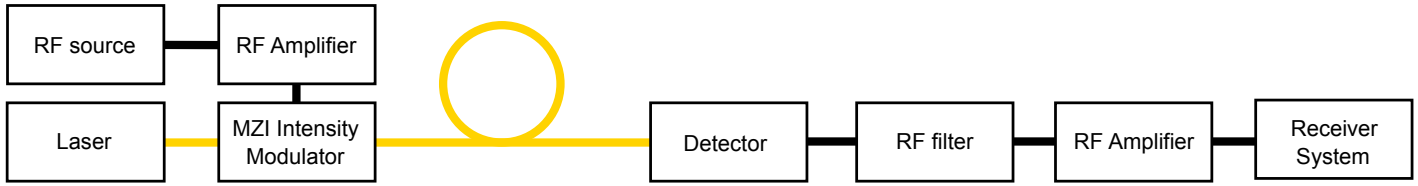
AOL Technology

- AOL Performance

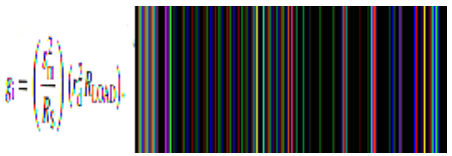


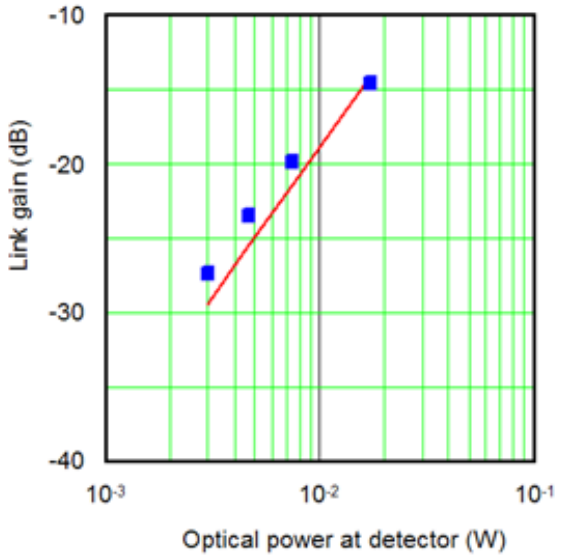
AOL Technology

- External Modulation: Link Gain



Laser		
	Type	EM4, AA1406
	Optical power	100mW
	RIN level	-170 dB/Hz
Modulator		
	Type	Photline, MXAN LN10
	Insertion loss	4 dB
	V_π at 1 GHz	5.5 V
	Input impedance	50 Ω
Detector		
	Type	Agere, R2560A
	Responsivity	0.8 A/W
	Impedance	50 Ω





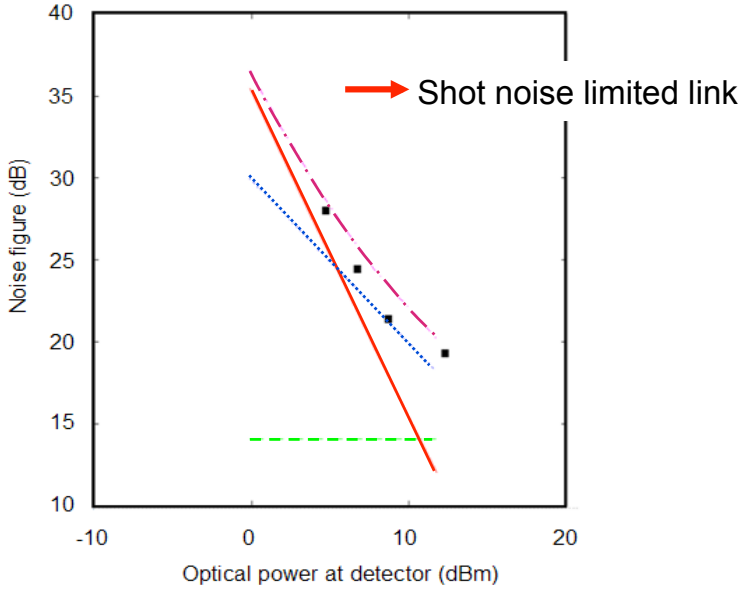
- Slope Efficiency depends on the applied optical power

AOL Technology

External Modulation: Noise

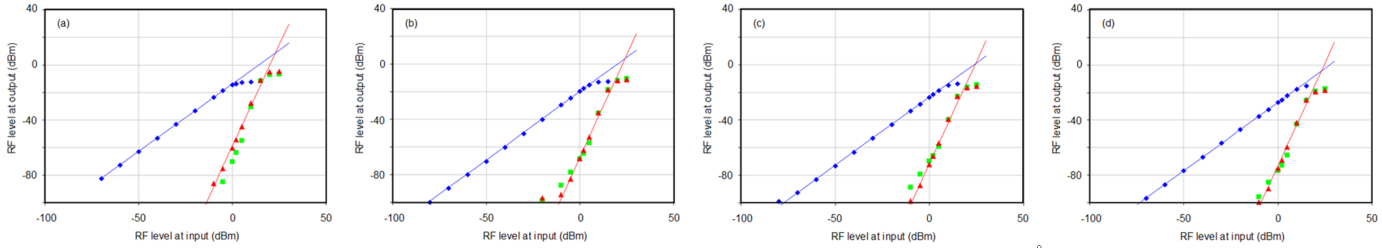
Noise sources:

- Thermal noise $p_{th} = kT$
- Shot noise $p_{shot} = \frac{1}{4} 2qI_D R_L$
- RIN $p_{rin} = \frac{1}{4} \mathrm{RIN}(I_D)^2 R_L$



External Modulation: Distortion

- Only third order spurs!



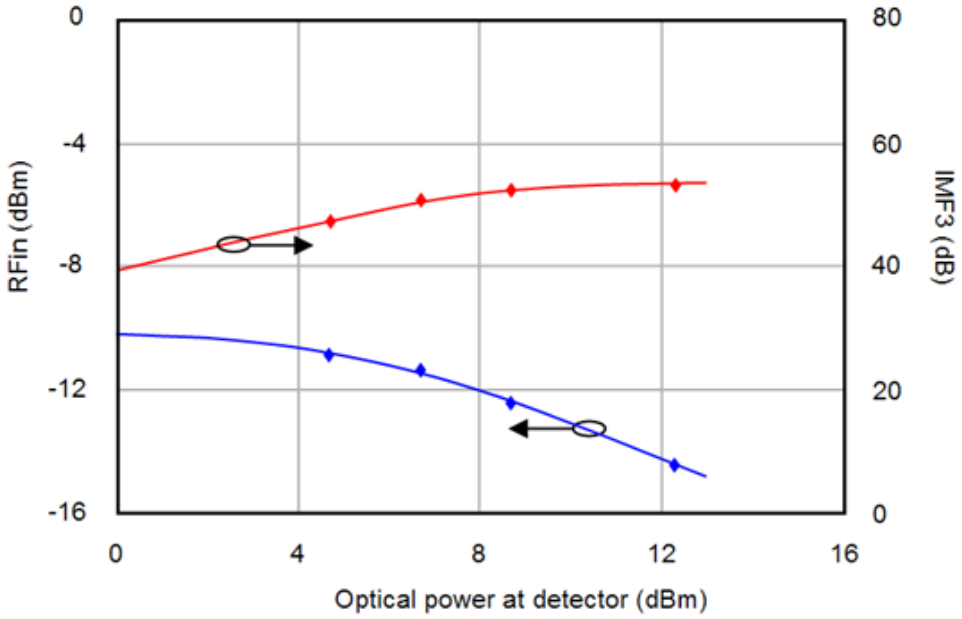
Optical power at detector (dBm)	-1 dB compression point (dBm)	-3 dB compression point (dBm)	IIP3 (dBm)	OIP3 (dBm)
4.7	10.3	15,4	23.1	-4.2
6.7	8.3	12.6	24.4	0.9
8.7	6.0	10.1	24.1	4.3
12.3	-0.7	4.0	23.0	8.4

AOL Technology

- External Modulation: Dynamic Range

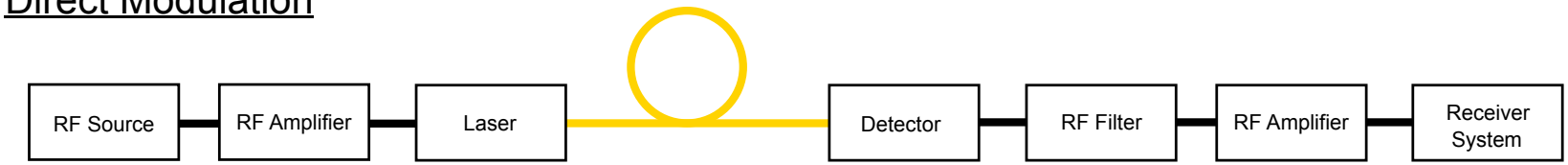
Optical power at detector	Noise level	1 Hz		1 GHz	
		IMF3	RFin	IMF3	RFin
(dBm)	(dBm/Hz)	(dB)	(dBm)	(dB)	(dBm)
4.7	-168.5	107.49	-31.06	47.49	-10.9
6.7	-166.8	110.68	-31.65	50.68	-11.35
8.7	-164.9	112.52	-32.65	52.52	-12.45
12.3	-160.8	113.22	-34.85	53.22	-14.45

$$\text{IMF3} = \frac{2}{3}\cdot\left(\text{OIP3} - P_{noise}\right)$$

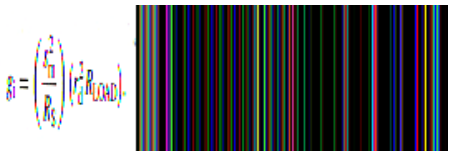


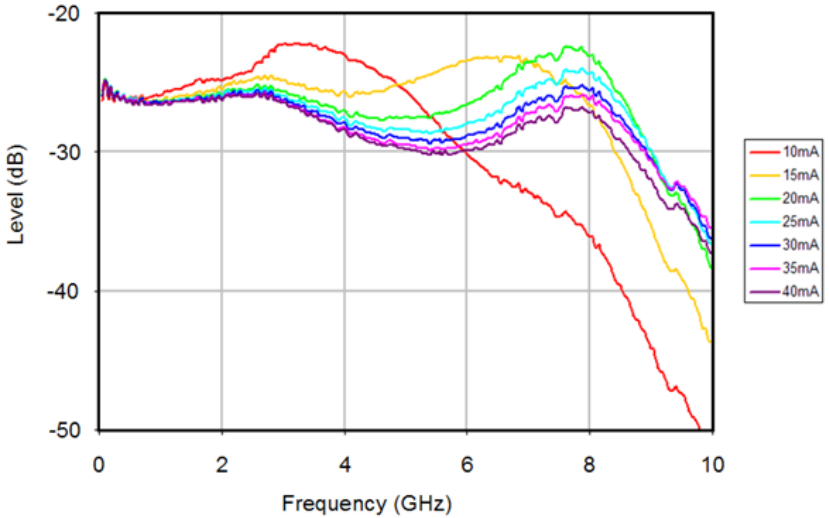
AOL Technology

- Direct Modulation



Link Gain



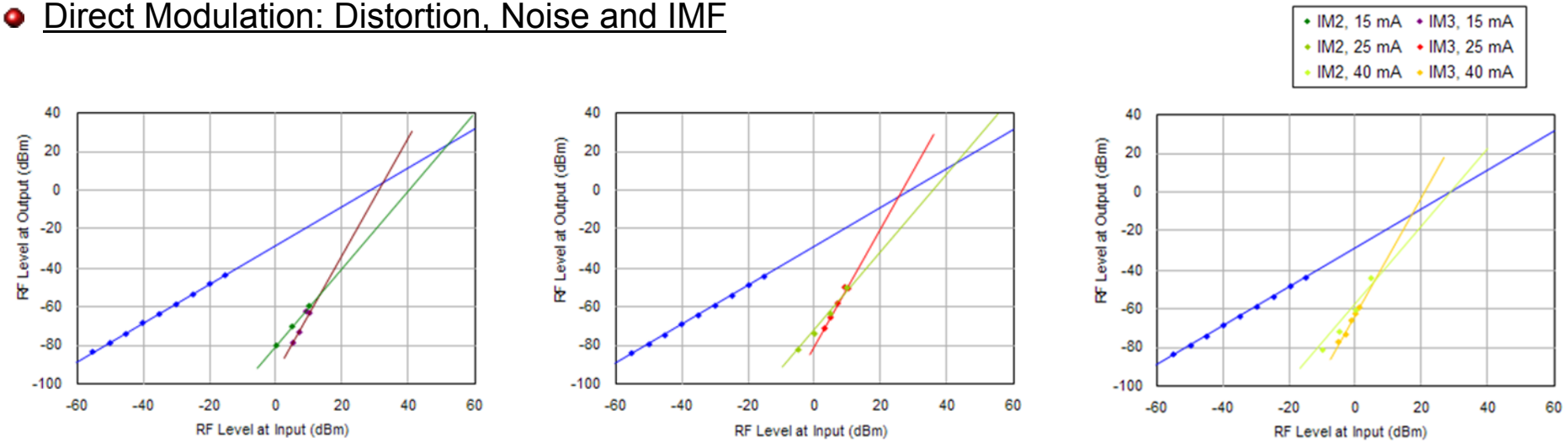


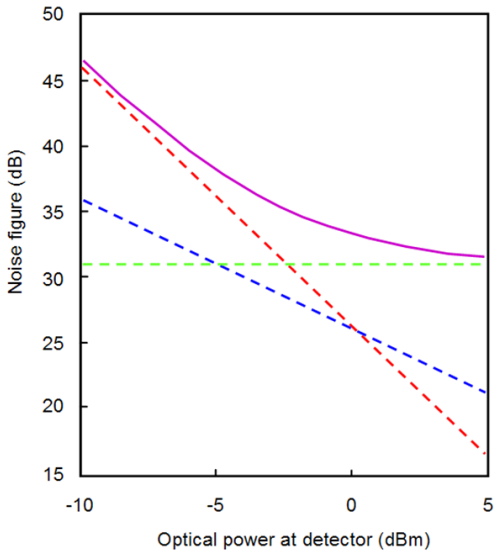
- Detector: responsivity ~ 0.9 A/W
- Laser: slope efficiency ~ 0.05 – 0.3 W/A

Laser		
	Type	Oemarket LDM1550
	Optical power	4 mW
	RIN level	-150 dB/Hz
	Slope Efficiency	0.1 W/A
Detector		
	Type	Oemarket PD-50
	Responsivity	0.8 A/W
	Impedance	50 Ω

AOL Technology

- Direct Modulation: Distortion, Noise and IMF





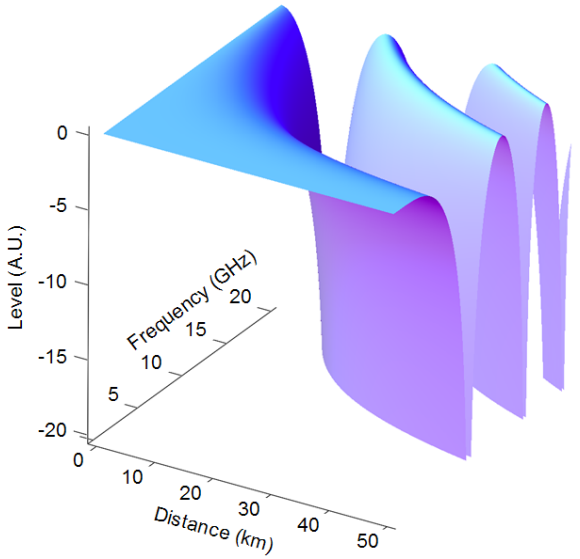
- Thermal noise $p_{th} = kT$
- Shot noise $p_{shot} = \frac{1}{4} 2qI_D R_L$
- RIN $p_{rin} = \frac{1}{4} \mathrm{RIN}(I_D)^2 R_L$

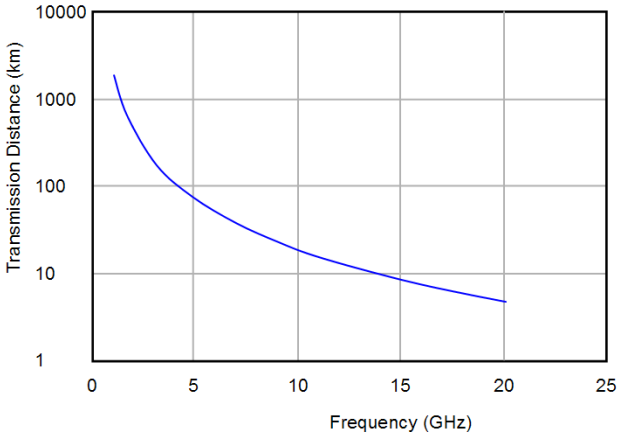
- IIP2 = 52 dBm
- IIP3 = 33 dBm
- OIP3 = 6 dBm
- OIP2 = 25 dBm
- IMF2 = 47 dB (1 GHz)
- IMF3 = 49 dB (1 GHz)

AOL Technology

- Transmission Distance

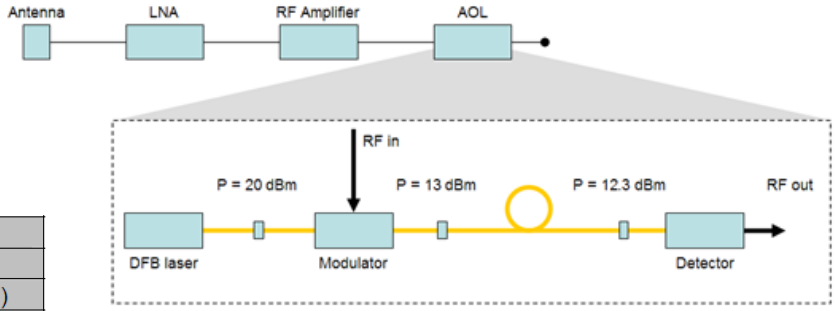
  - Optical Power
  - Dispersion
    - Modal Dispersion
    - Chromatic Dispersion
      - Carrier Suppression Effect
      - Longitudinal Mode Dispersion
      - Chirp
  - Fiber Non-Linearities



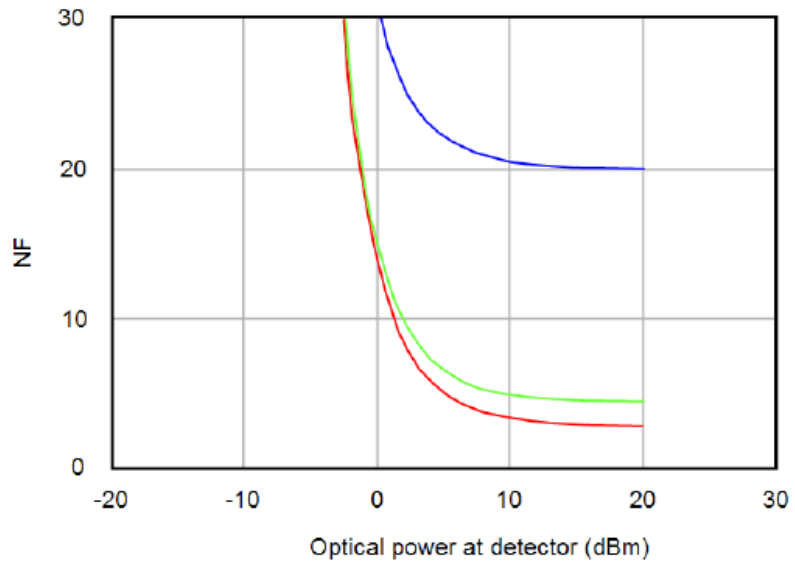


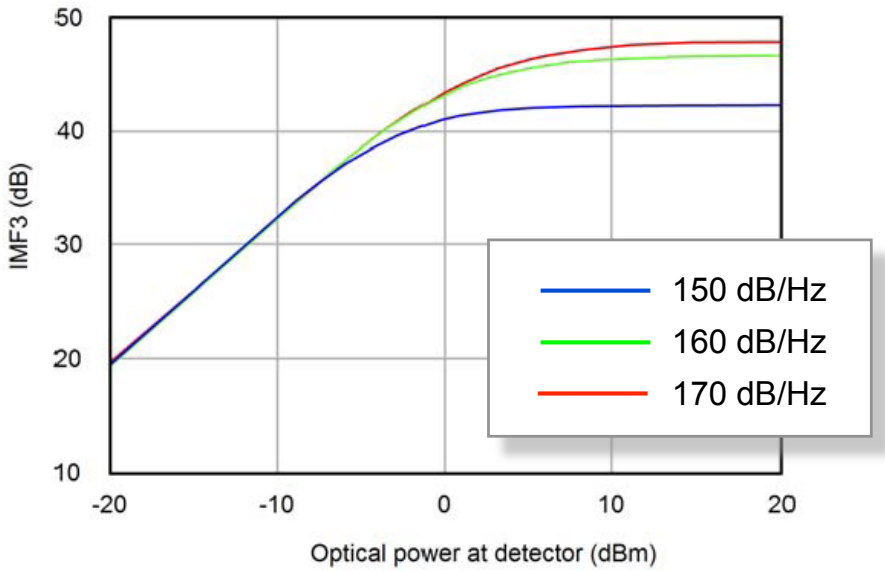
Implementation of AOLs

- RF systems with external modulation AOL



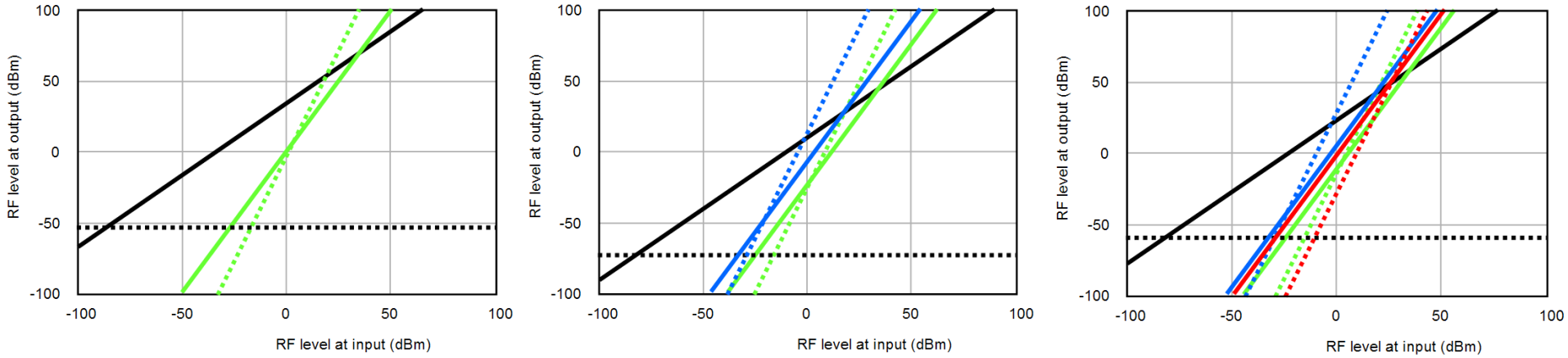
	Type	Gain	NF	IP2		IP3	
				In	Out	In	Out
		(dB)	(dB)	(dBm)	(dBm)	(dBm)	(dBm)
Antenna		-0,2					
Low Noise Amplifier	ATF-54143	16	1.5			18.0	36
RF Amplifier	MGA-53543	20	3.3			22	33
AOL		-14.6	19			23	8.4

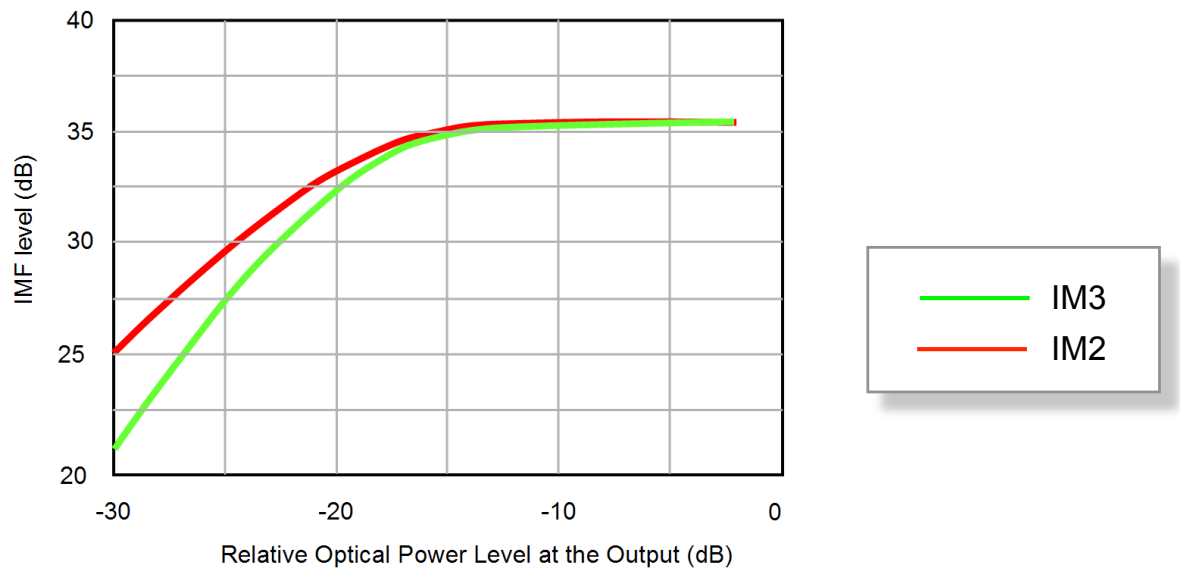




Implementation of AOLs

- RF systems with direct modulation AOL





AOL: discussion and conclusion

- Measured performance:

	Link Gain (dB)	IMF2 @ 1 GHz (dB)	IMF3 @ 1 GHz (dB)
External modulation AOL	-14.6	-	53
Direct modulation AOL	-27	47	49

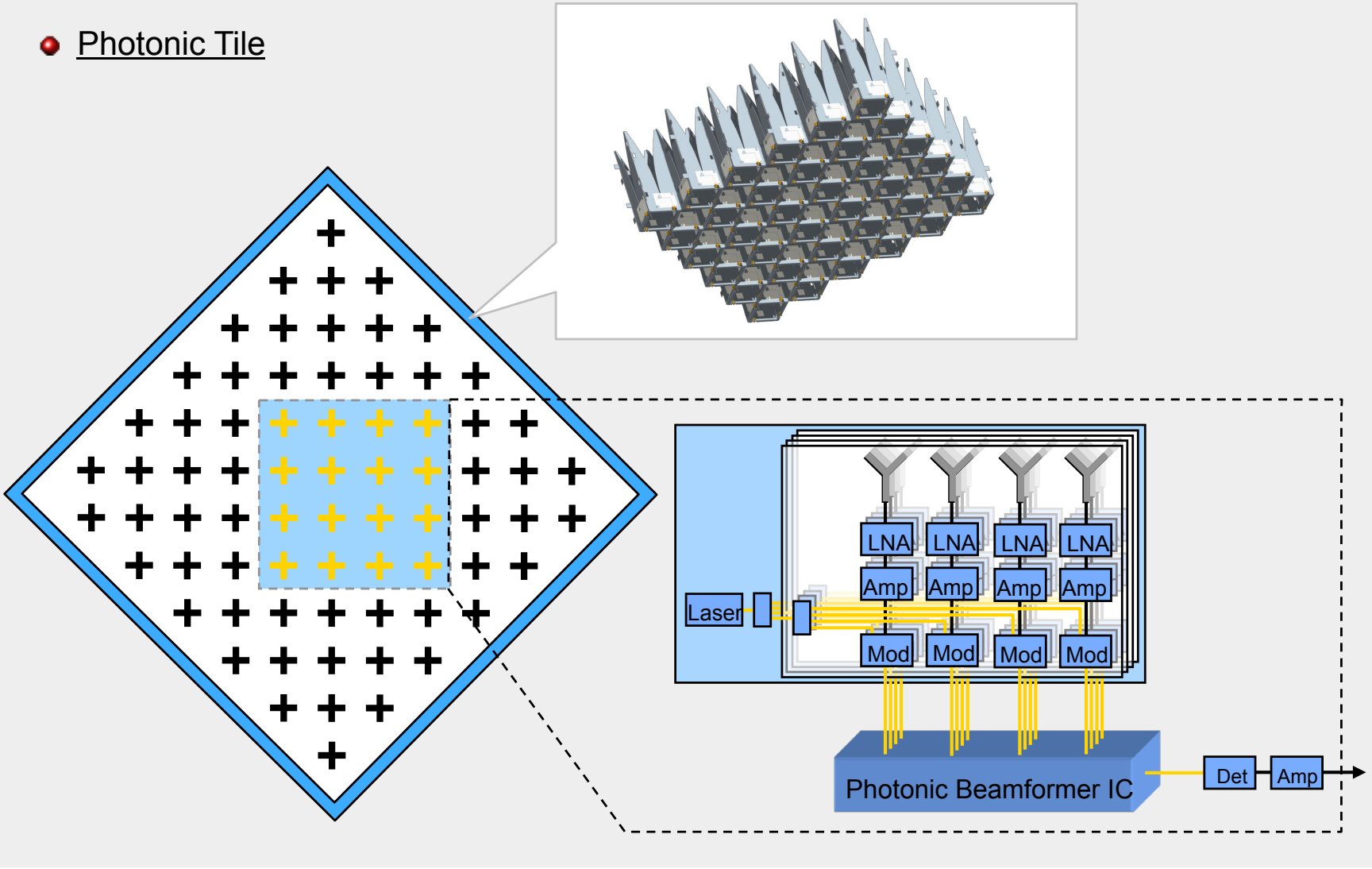
- AOLs provide broadband performance up to ~ 10 km with good performance
- Higher frequencies / longer distances: lower costs with AOLs
- AOL noise figure
  - High with respect to *kTB*
  - Thanks to the high gain in front of the AOL not a big problem (Friis)

$$F_{total} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \frac{F_4 - 1}{G_1 G_2 G_3} + \ldots$$

- AOL improvements:
  - Improved matching
  - Linearisation of modulator / laser
  - Optical amplification
  - Increase of slope efficiency (component improvement / laser cascading)
  - Higher optical power level

Microwave Photonic Signal Processing

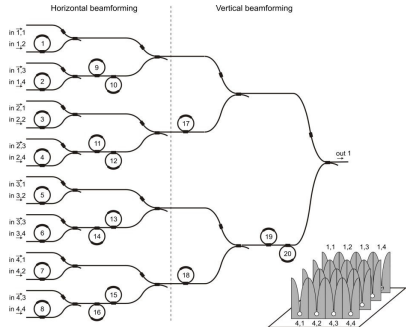
- Photonic Tile



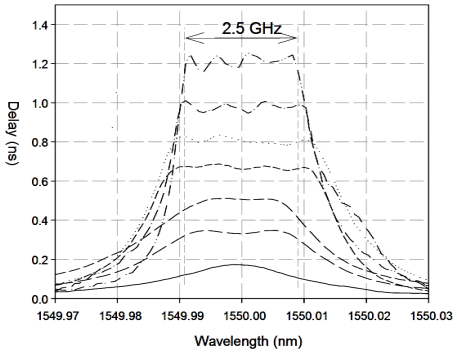
Microwave Photonic Signal Processing

- Photonic Beamformer IC

- Design

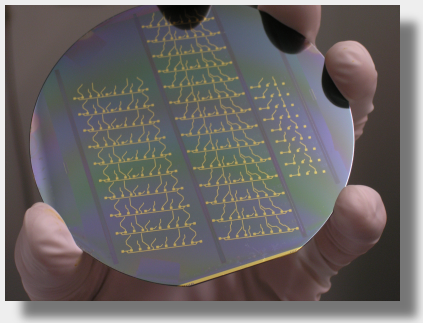


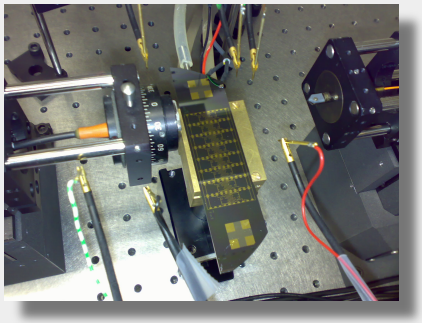
- Broadband Performance



- Ring resonator based beamforming
  - → Nano-second range delays
  - → Broadband
  - → True time delay

- IC on TriPleX platform
  - → Low loss & large time delays
  - → Polarisation insensitive
  - → Wide wavelength transparency window
  - → CMOS compatible



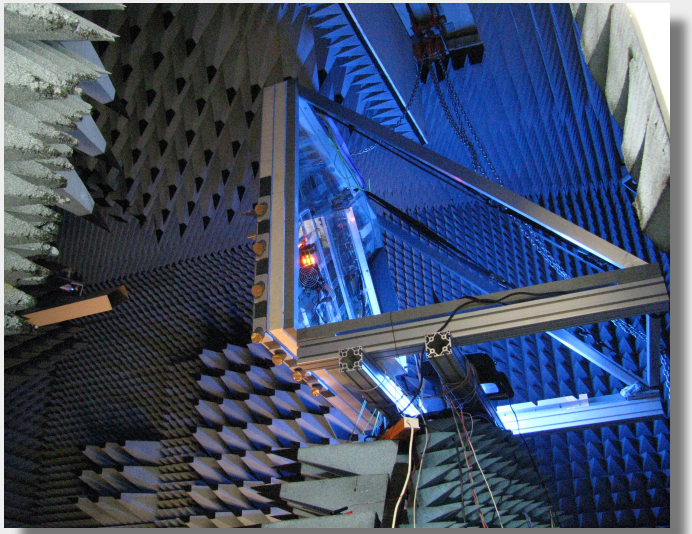


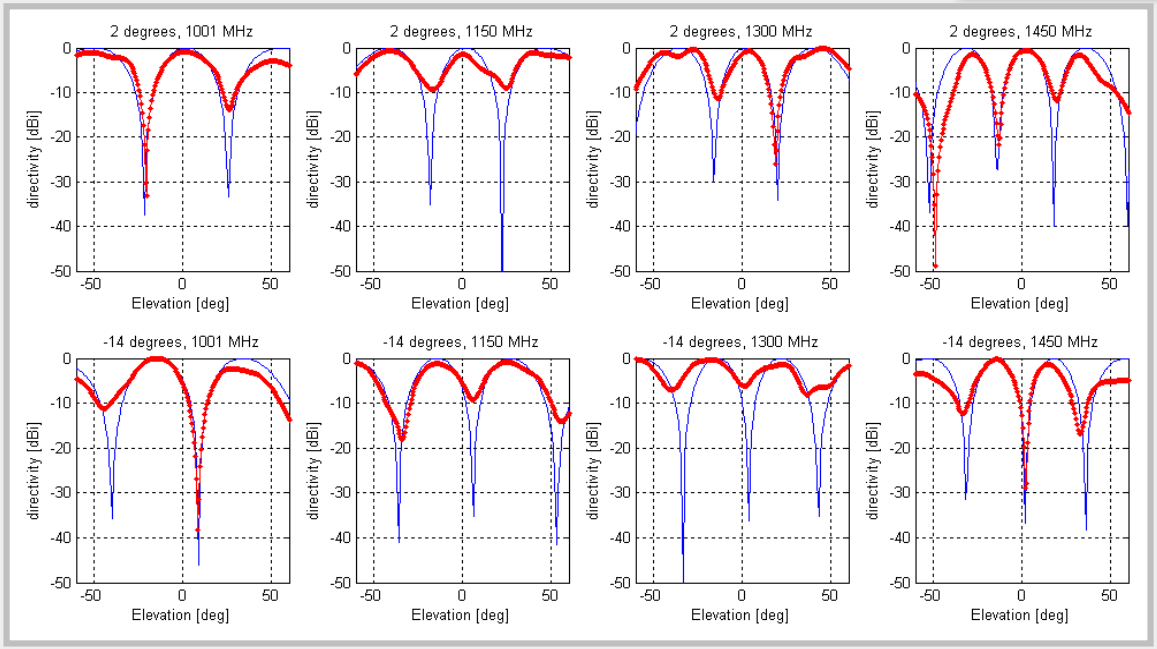
Microwave Photonic Signal Processing

- Performance of the Photonic System

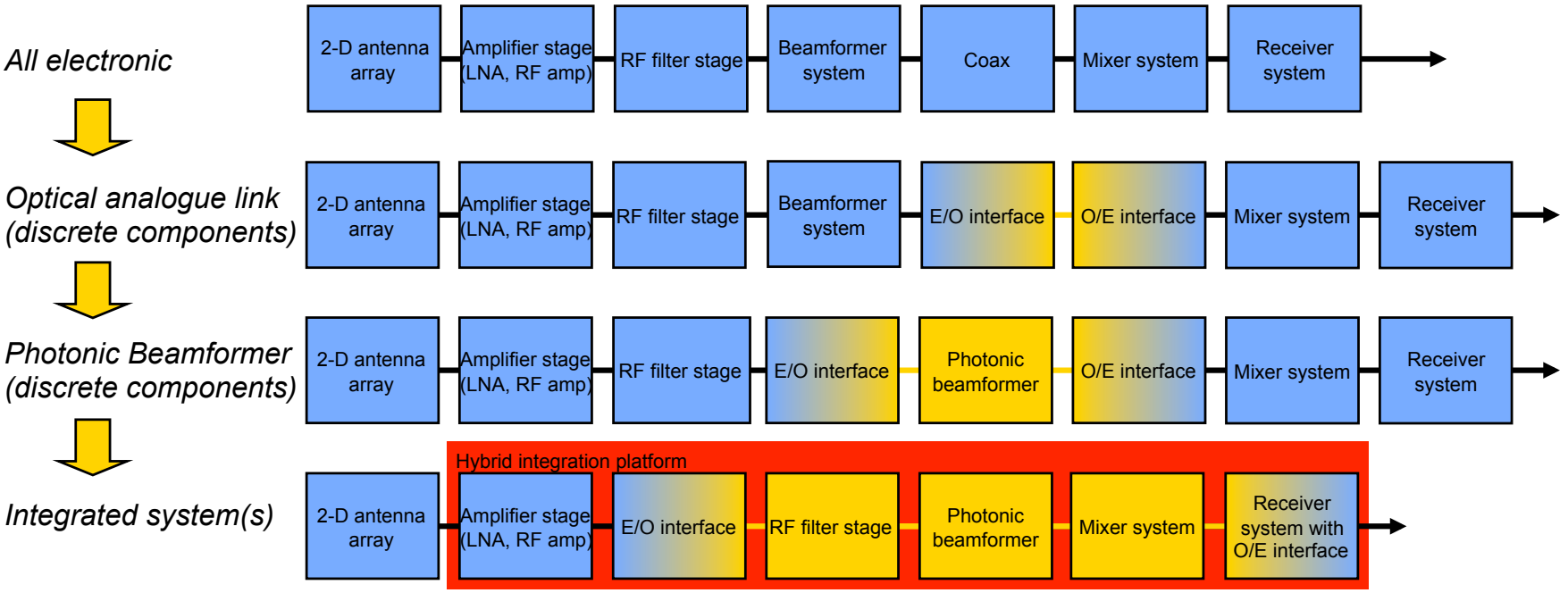
  - Analog Optical Links
    - Dynamic range: 50 dB
    - Frequency band: 500 MHz – 1.5 GHz

  - Photonic Beamformer
    - 4-channel beamforming demonstrated
    - True time delay: 1.0 GHz – 1.5 GHz

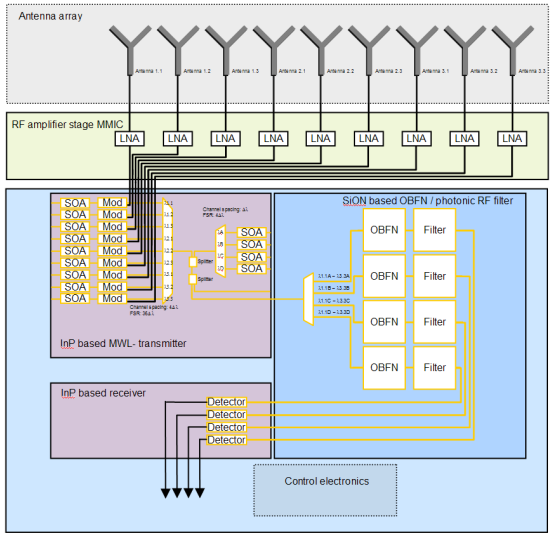


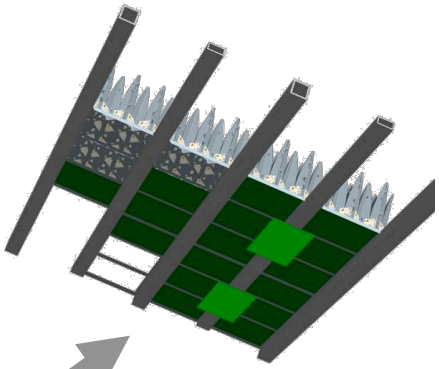


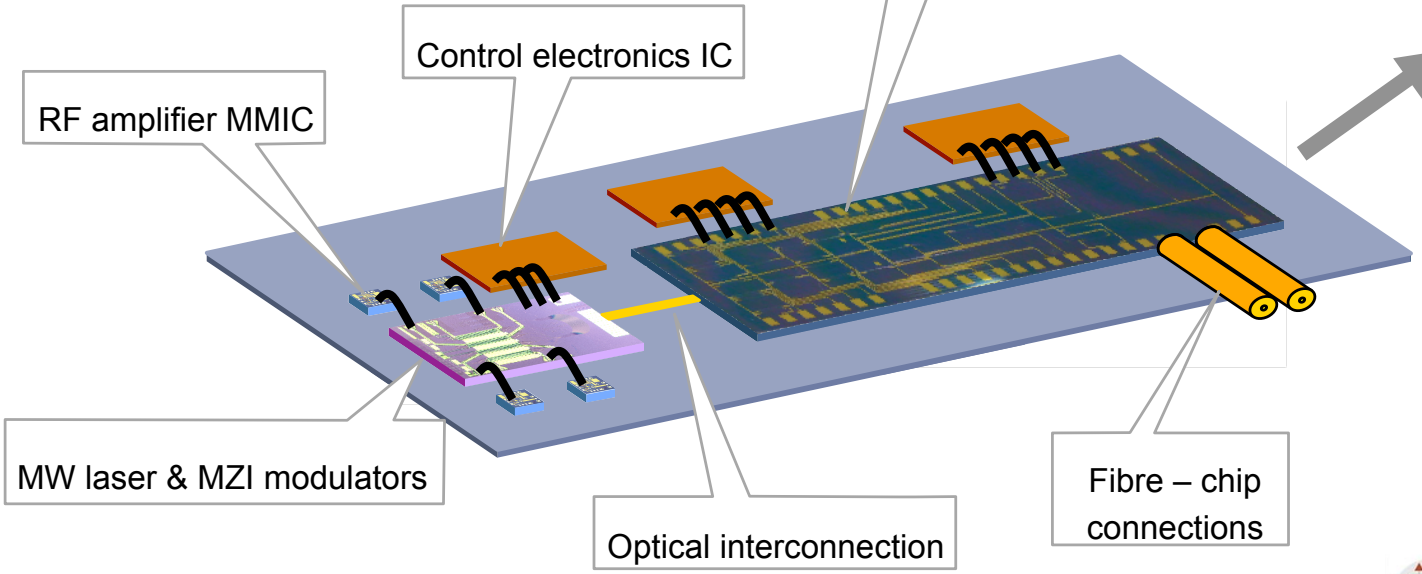
Microwave-Photonics Development Track



Integrated Microwave - Photonic System





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