
ASTRON

RF over Fibre Solutions for the SKA

Peter Maat – ASTRON

Topics

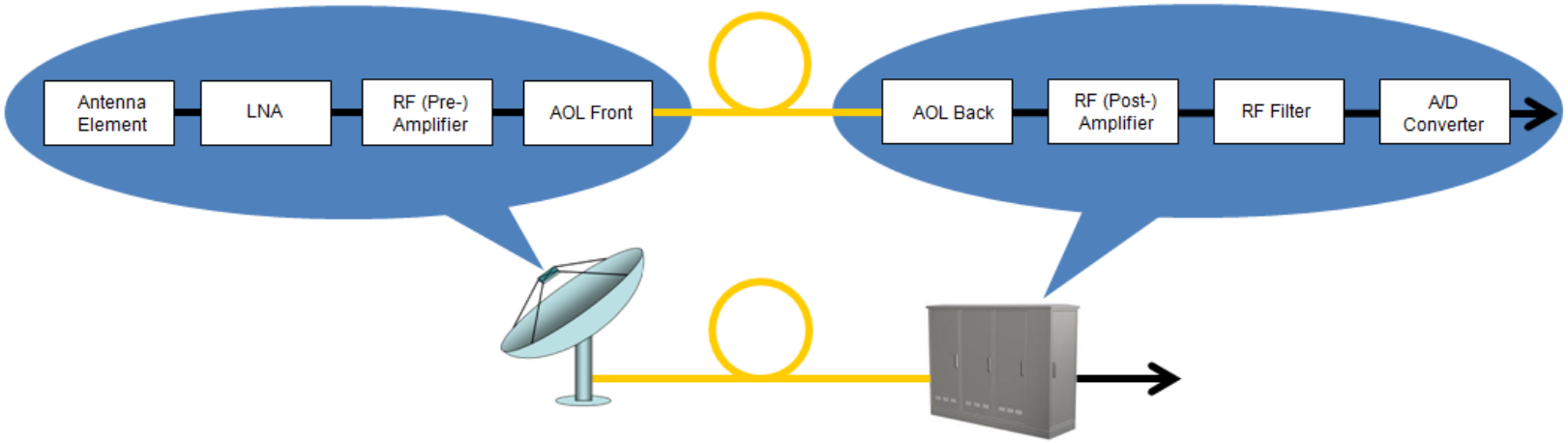
- Analog Optical Link Technology for the SKA
- Interfaces
- Functional Requirements
- Design concept
- Impact of extensibility to SKA2
- Cost and Power
- Plan

Analog Optical Link Technology for the SKA

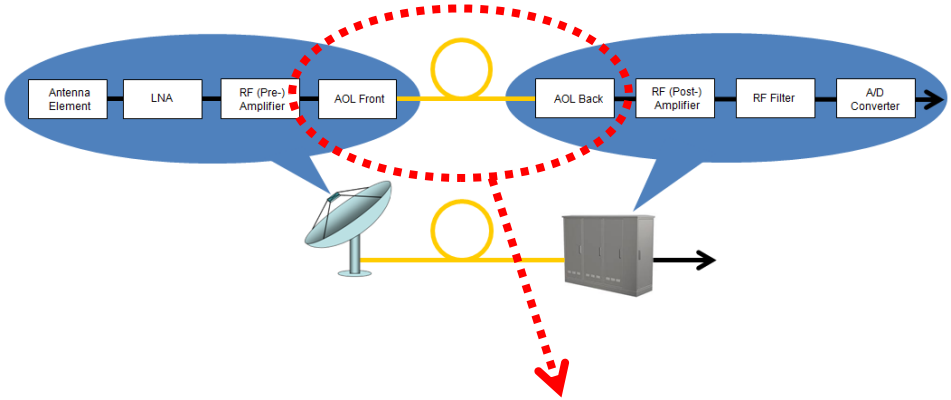
- **Analog Optical Link Application Area:**
  - Aperture Array Tile Connection
  - PAF / SPF Connection
  - PAF Antenna Element Connection

- **Why Photonic Technology?**
  - Broadband / High Frequency
  - Immunity for RFI
  - Light Weight
  - Small Space Envelope

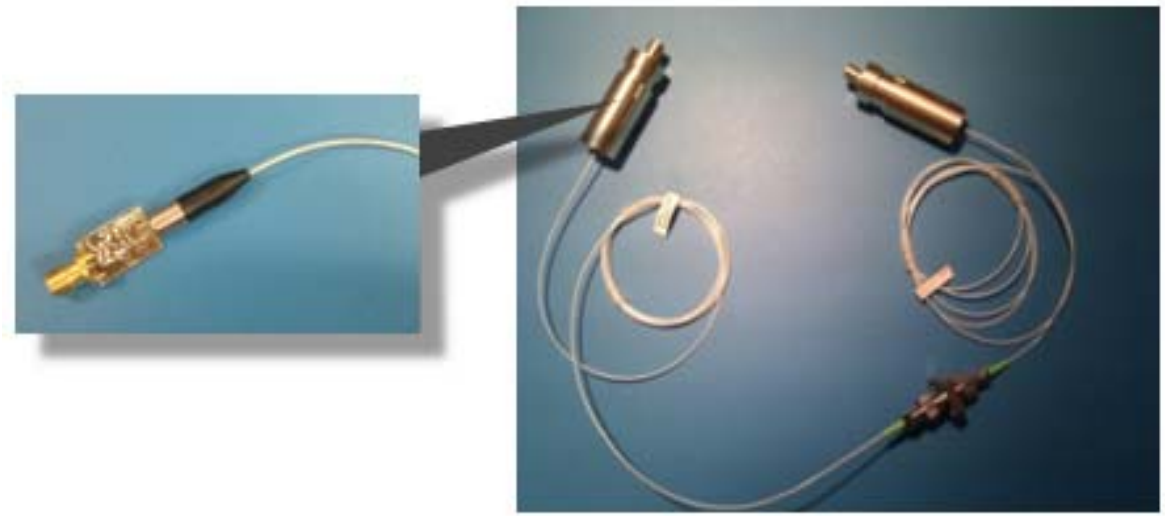
- **For SKA-1: Single Pixel Feed AOL**



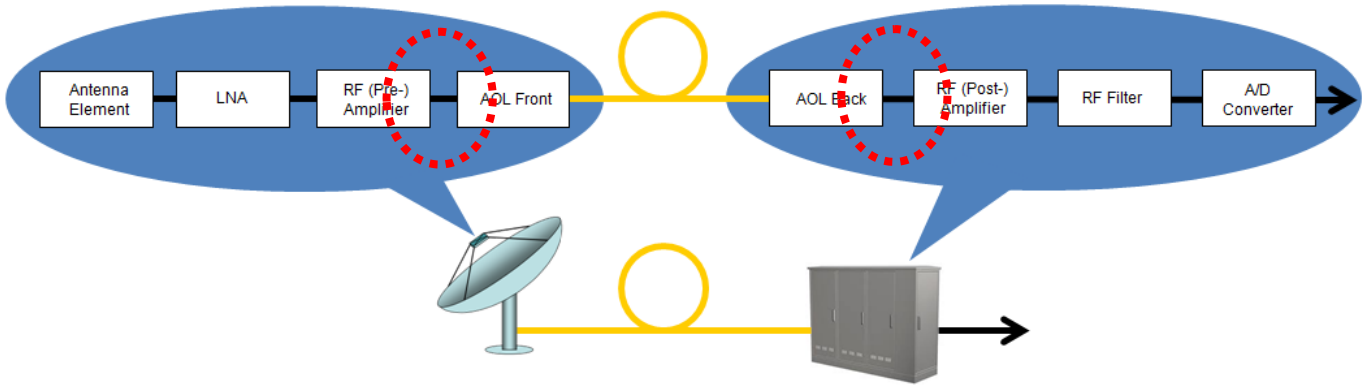
Analog Optical Link Technology for the SKA



- **Photonic Coax**



Interfaces



- Interfacing to input and output RF systems is realised via:
  - connectors (Photonic Coax)
  - on PCB level
    - transmission line
    - bond wire

Functional Requirements

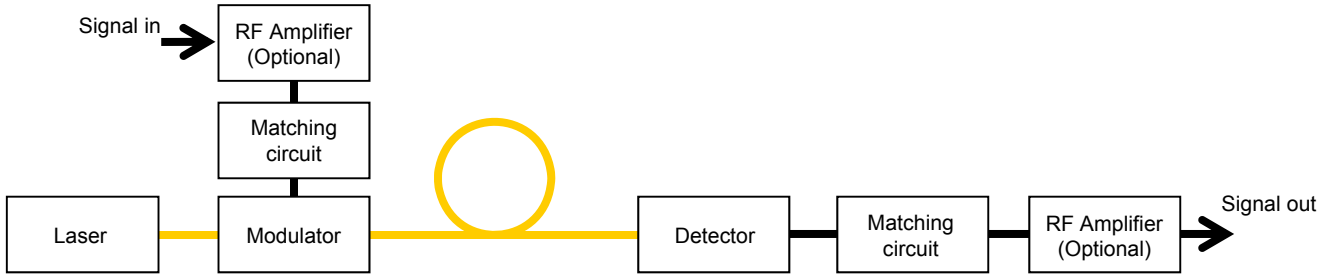
- Available Documentation:
  - Requirements Document for Signal Transport and Networks
  - Requirements Document for Antenna Networks

- Most important RF system requirements
  - Electromagnetic Frequency Range from 70 MHz to 3 GHz.
  - Spectral dynamic range
    - ≥61 dB in the band 70MHz to 240 MHz
    - ≥43 dB in the band 200 MHz to 1.4 GHz
  - Noise Figure shall be no greater than 6 dB.

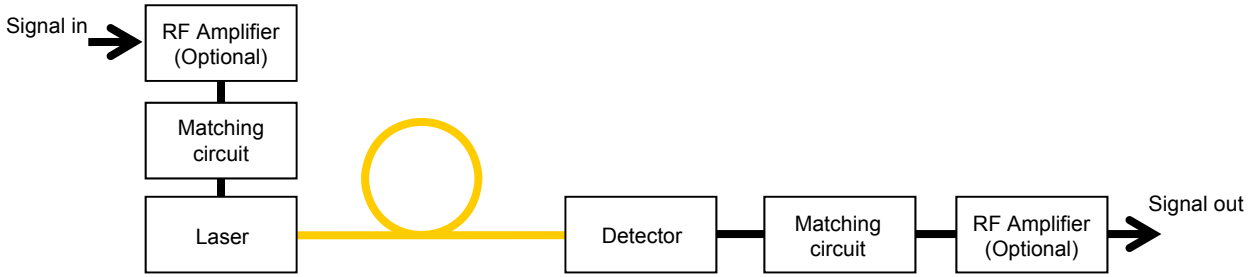
- Other important requirements concern stability, flatness and link functionality

Design Concept

- Two AOL types:
  - External modulation AOL:

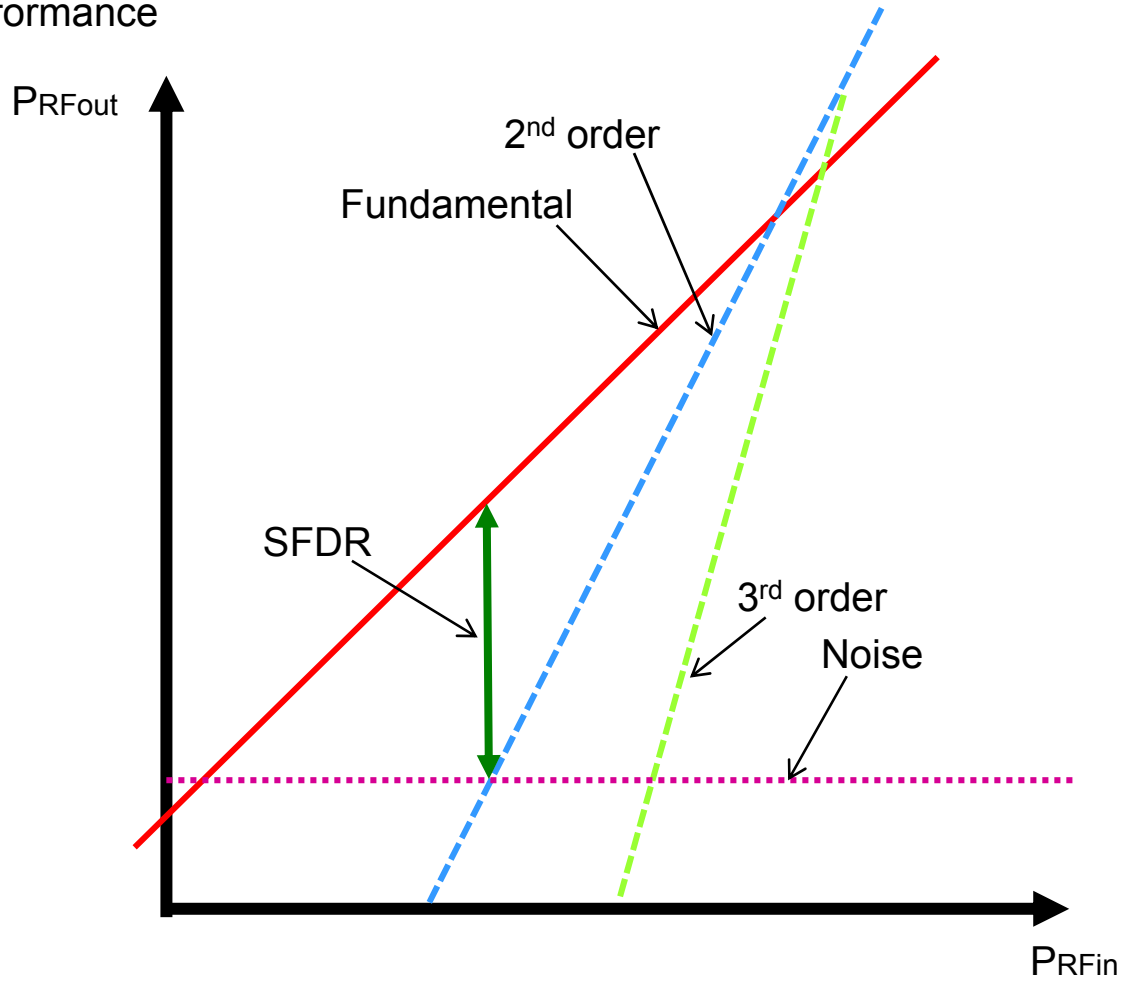


  - Direct modulation AOL:



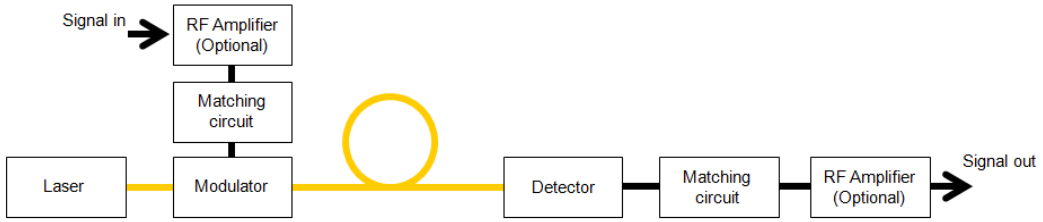
Design Concept

- AOL performance



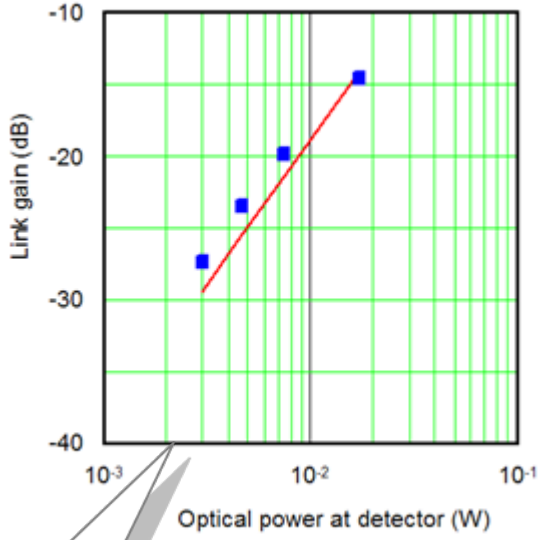
Design Concept: EM AOL

- External modulation AOL



- Cost Level: ~ 1 k€

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



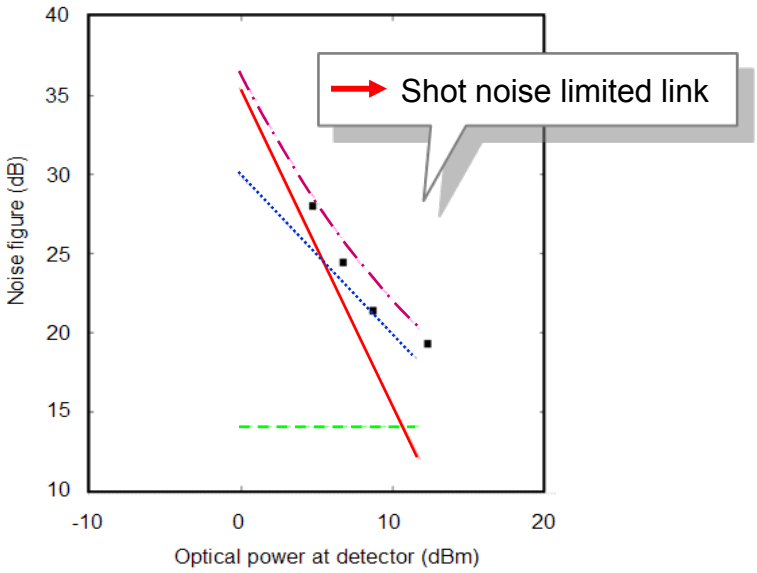
- Link Gain depends on the applied optical power level

Design Concept: EM AOL

- External Modulation: Noise

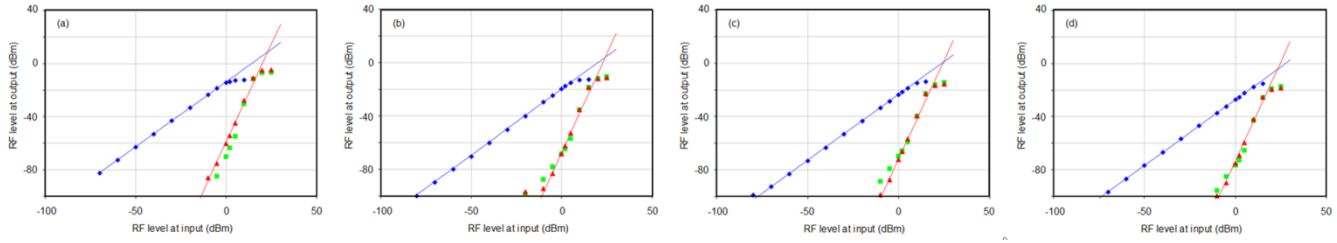
Noise sources:

- 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!



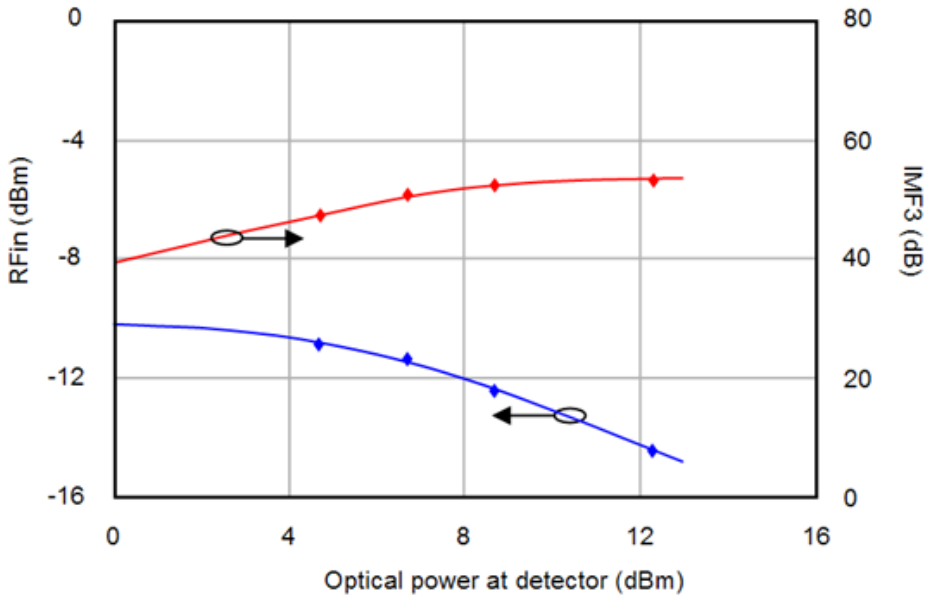
Optical power at detector (dBm)	-1 dB compression point (dBm)	-3 dB compression point (dBm)	IIP3 (dBm)	OIP3 (dBm)
4.7	10.3	15,4	23.1	-4.2
6.7	8.3	12.6	24.4	0.9
8.7	6.0	10.1	24.1	4.3
12.3	-0.7	4.0	23.0	8.4

Design Concept: EM AOL

- External Modulation: Dynamic Range

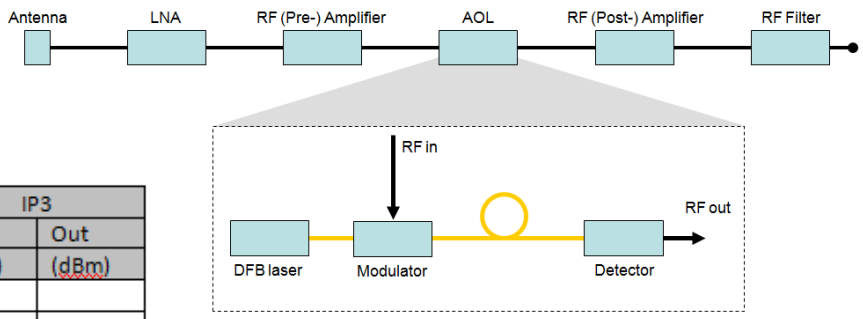
Optical power at detector	Noise level	1 Hz		1 GHz	
		IMF3	RFin	IMF3	RFin
(dBm)	(dBm/Hz)	(dB)	(dBm)	(dB)	(dBm)
4.7	-168.5	107.49	-31.06	47.49	-10.9
6.7	-166.8	110.68	-31.65	50.68	-11.35
8.7	-164.9	112.52	-32.65	52.52	-12.45
12.3	-160.8	113.22	-34.85	53.22	-14.45

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



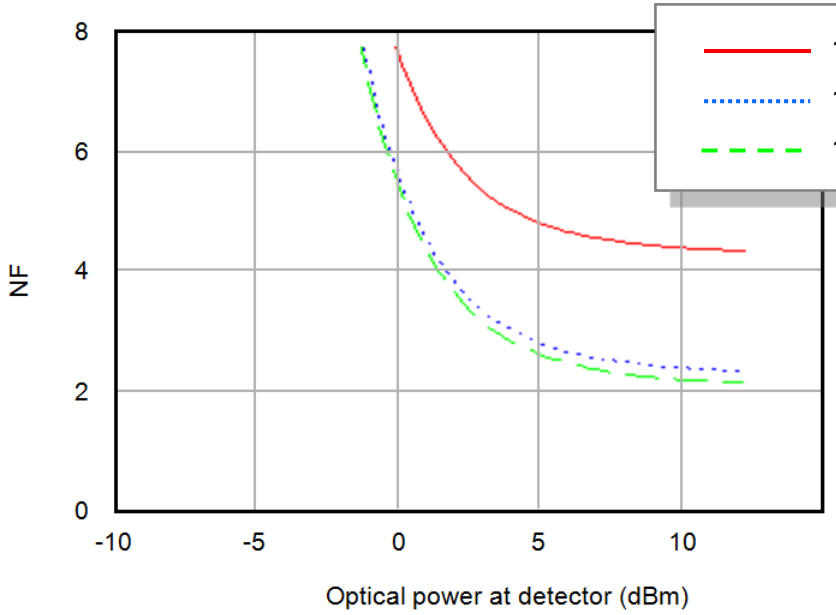
Design Concept: EM AOL

- RF system 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	25	1.1		40		40
RF Amplifier	MGA-53543	25	3.3		50		33
AOL		-17.3	19			23	
RF Amplifier	MGA-53543	17.3	3.3		50		33

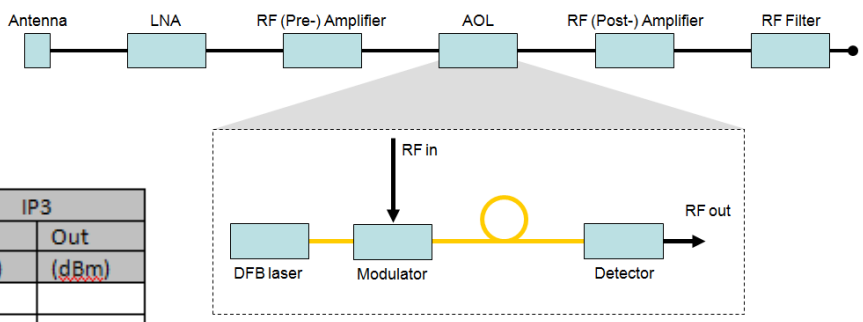
- $Pmax_{RFin}$ = -50 dBm
- $Pmax_{RFout}$ = 0 dBm



- NF < 6 dB requirement is satisfied for:
  - P_{op} > 0 dBm
  - RIN = -170 dB/Hz
  - Bandwidth of 3 GHz

Design Concept: EM AOL

- RF system with external modulation AOL



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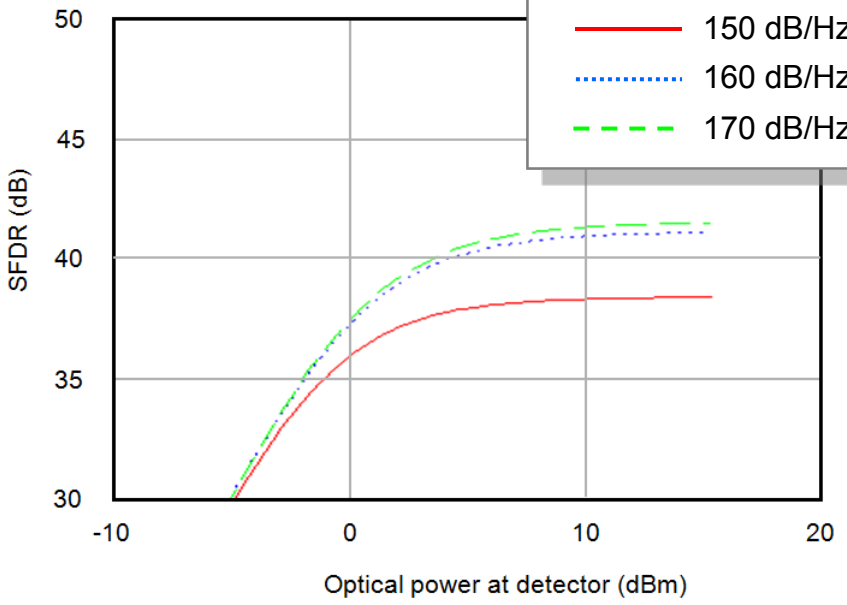


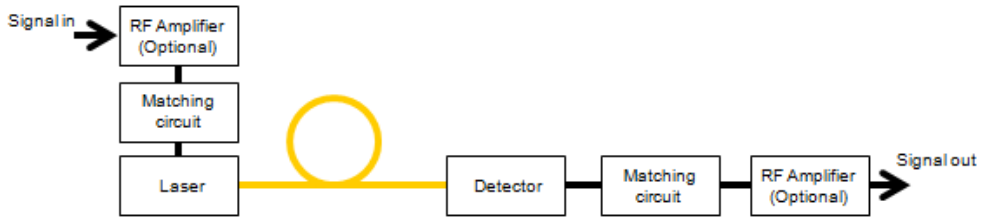
- For 200 MHz – 1.4 GHz: SFDR = 41.5 dB
- For 70 MHz – 240 MHz: SFDR = 50 dB (1)
- For $\Delta\nu$ = 3 GHz: SFDR = 37.5 dB

→ Dynamic range is limited by antenna and LNA noise

→ SFDR increase by applying an instantaneous bandwidth (for (1): 7 MHz)

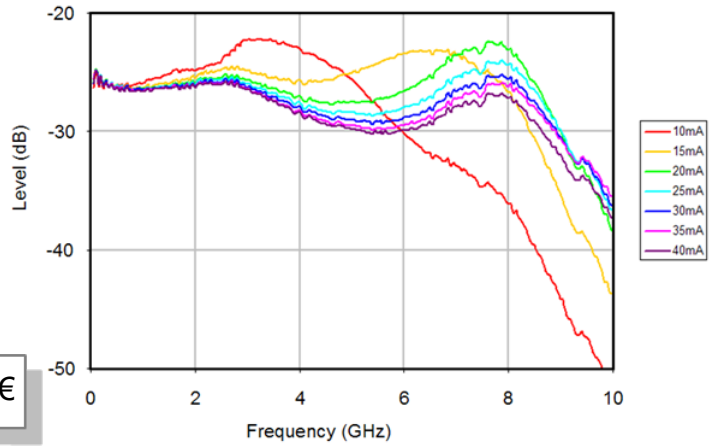
Design Concept: DM AOL

- Direct modulation AOL



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

→ Link gain ~ -25 dB



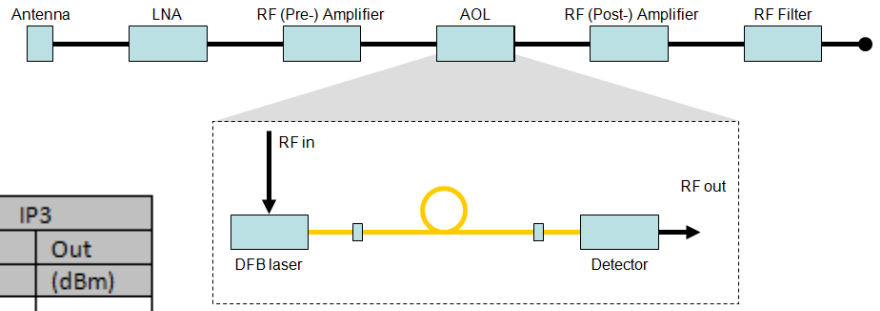
- NF = ~32 dB
- IIP2 = 52 dBm
- IIP3 = 33 dBm
- OIP3 = 6 dBm
- OIP2 = 25 dBm
- IMF2 = 47 dB (1 GHz)
- IMF3 = 49 dB (1 GHz)

- Cost Level: ~ 100 €

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

Design Concept: DM AOL

- RF systems with direct modulation AOL



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Low Noise Amplifier	ATF-54143	25	1.5	18		18	
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AOL		-27	32	52	25	33	6
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- $Pmax_{RFin}$ = -50 dBm
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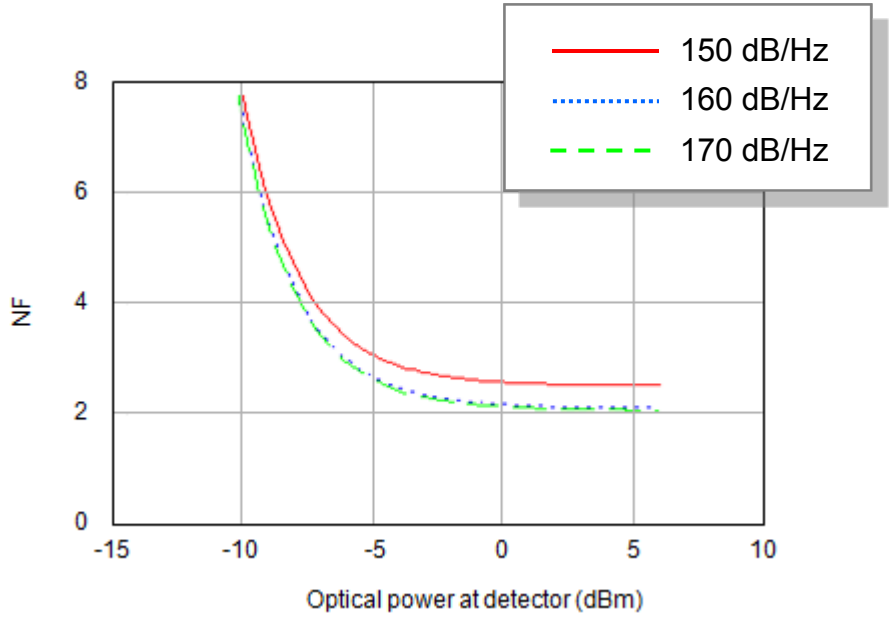
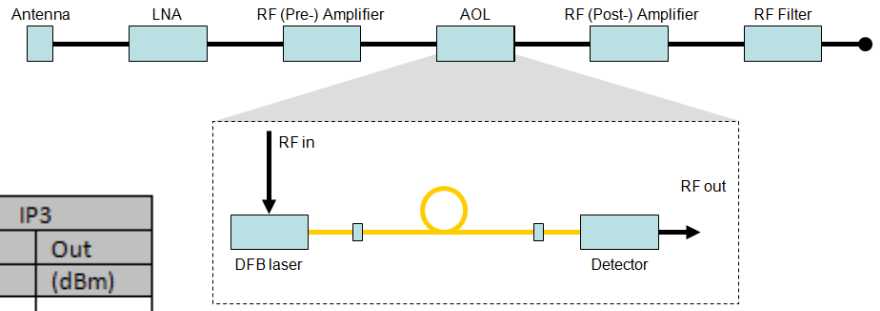


- NF < 6 dB requirement is satisfied for:
  - P_{op} > -8 dBm
  - RIN = -150 dB/Hz
  - Bandwidth of 1.2 GHz

Design Concept: DM AOL

- RF systems with direct modulation AOL



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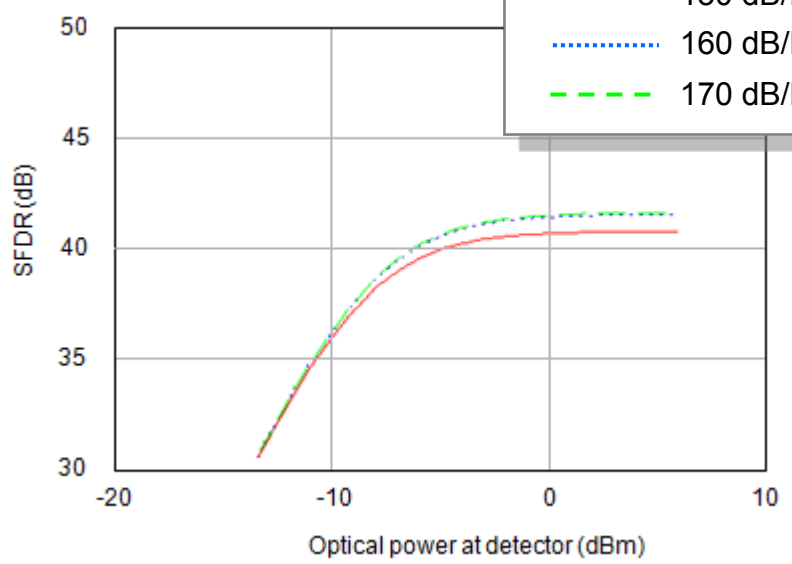

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- For $\Delta\nu$ = 3 GHz: SFDR = 37.5 dB

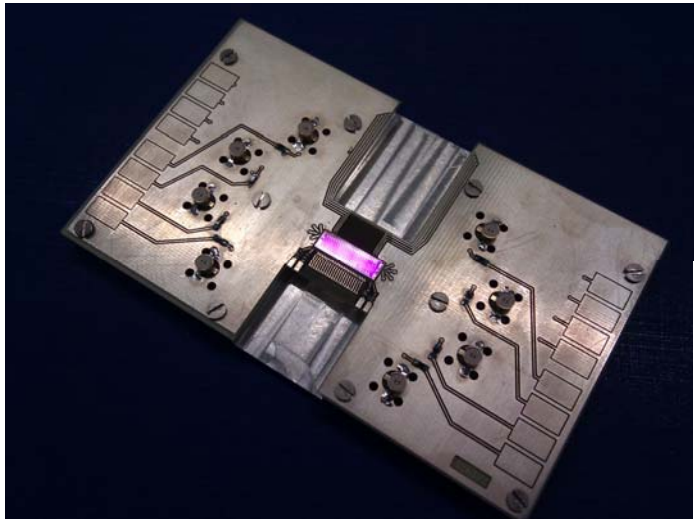
→ Dynamic range is limited by antenna and LNA noise

→ SFDR increase by applying an instantaneous bandwidth (for (1): 7 MHz)

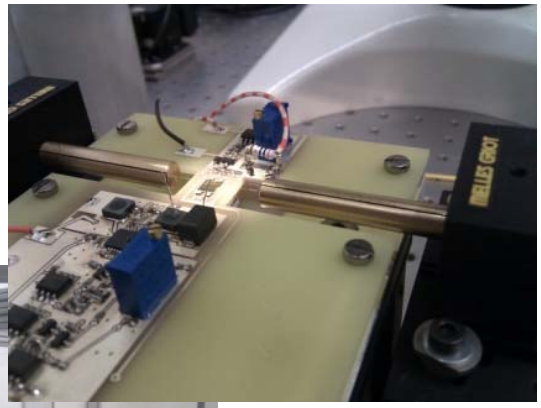
AOL technology for SKA2

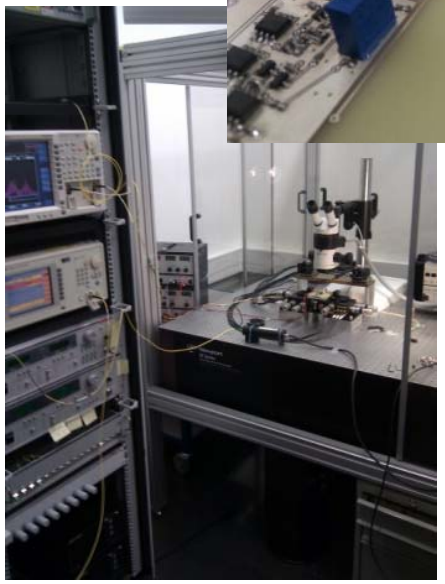
- Application of AOL technology in PAF antenna element connections
  - Cost level reduction via:
    - RF/Photonic integration
    - Array technology

- Modulator array with RF interconnects



- Laser array with control electronics



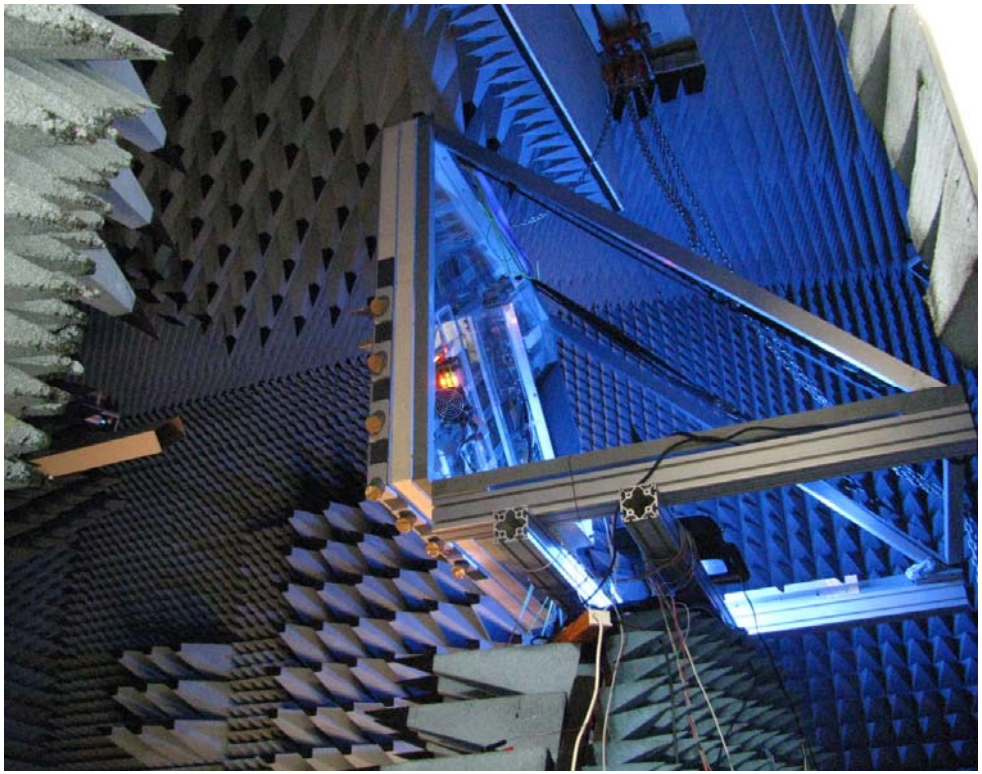


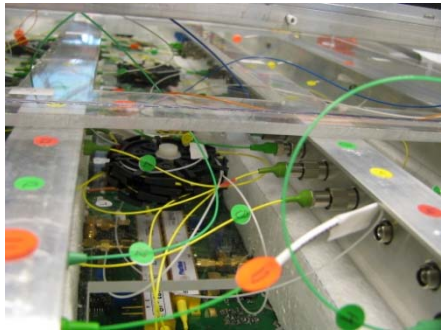
Memphis
Merging Electronics and Micro & Nano-Photonics in Integrated Systems

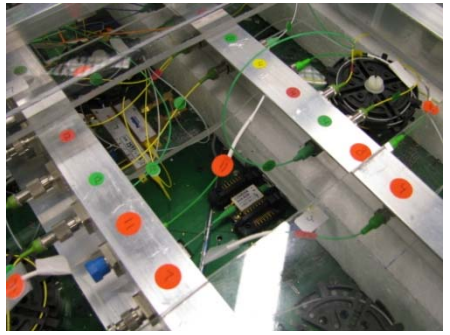
AOL technology for SKA2

- Application of AOL technology and photonic signal processing

  - Photonic receiver tile with AOLs and photonic beamformer







- True time delay beamformer
- 16 receiver system
- 500 MHZ – 1.5 GHz

Cost and Power

- EM AOL system cost: 3293 Euro / Power: 8.8 W

Component	Type	Subsection	Voltage (V)	Current (A)	Power (W)	Comment
CW Laser	EM4, AA1406					
		Laser Chip	1.2	0.55	0,66	
		TEC	< 5	< 1.5	7.5	
		Thermistor	< 5	< 0.0005	< 0.0025	
Modulator	Photline, MXAN LN10					
		Modulator Chip	< 20	< 0.0002	< 0.0004	
		Monitor Diode	< 5	< 0.0035	< 0.02	
Detector	Agere, R2560A		15	< 0.013	0	
RF amplifier	MGA-53543		5	0.05	0.1	Two amplifiers are needed

- DM AOL system cost: 255 Euro / Power: 0.62 W

Component	Type	Subsection	Voltage (V)	Current (A)	Power (W)	Comment
Laser	LDM1550		1	0.02	0.02	
Detector	PD-50		3	0.001	0	
RF amplifier	MGA-53543		5	0.06	0.3	Two amplifiers are needed

Plan

- Apply lower cost components and lower cost AOL technology
- Development of low cost array technology
- Development of low cost RF/Photonic integration technology
- Investigation of phase and amplitude stability in a field test
- Development of higher bandwidth (10 GHz) AOL technology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