SPACEBEAM OPTICAL BEAMFORMER FOR SAR
A potential enabler for the SKADI mission

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Research and Innovation actions
H2020-SPACE-2018-2020
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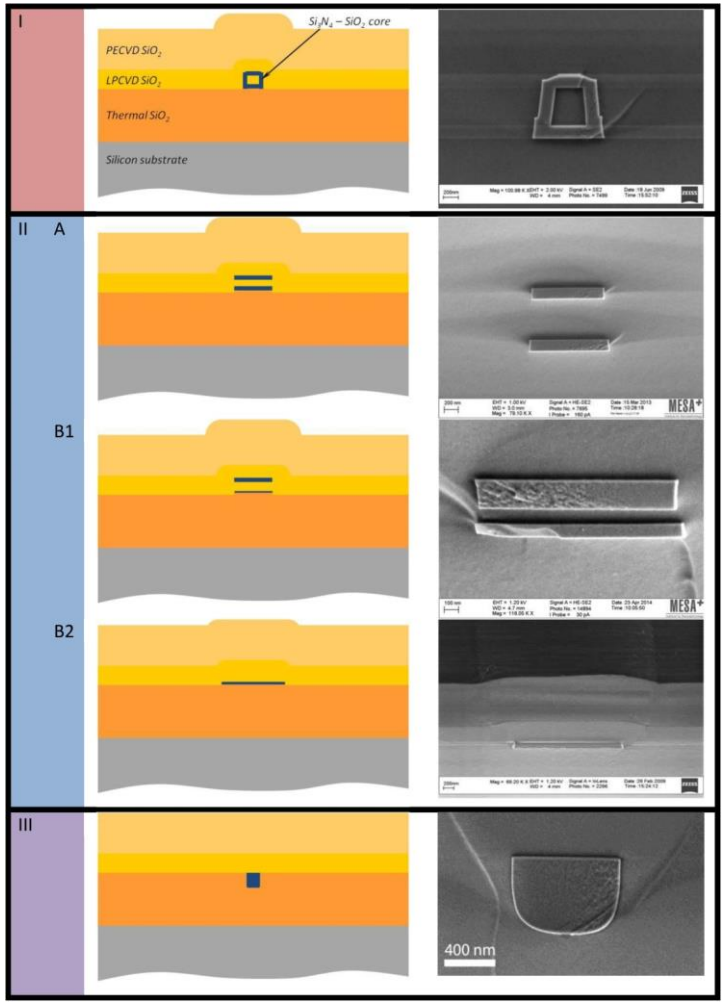
MOTIVATION

- Advanced spaceborne SAR modes require complex beamforming which is typically implemented via RF analog or digital beamforming solutions.
- MIMO beamforming, e.g. for multi-beam scan-on-receive systems, can be digitally implemented but such solutions require significant system ressources (SWaP) which hinder the implementation of these advanced modes in compact SAR payloads and satellites.
- Microwave photonics offer the potential to implement MIMO beamforming in the photonics „analog“ domain, fully integrated in compact photonics integrated circuits (PICs).



LioniX Silicon NitrideTriplex™ Sample Geometries

END-TO-END PERFORMANCE REQUIREMENTS

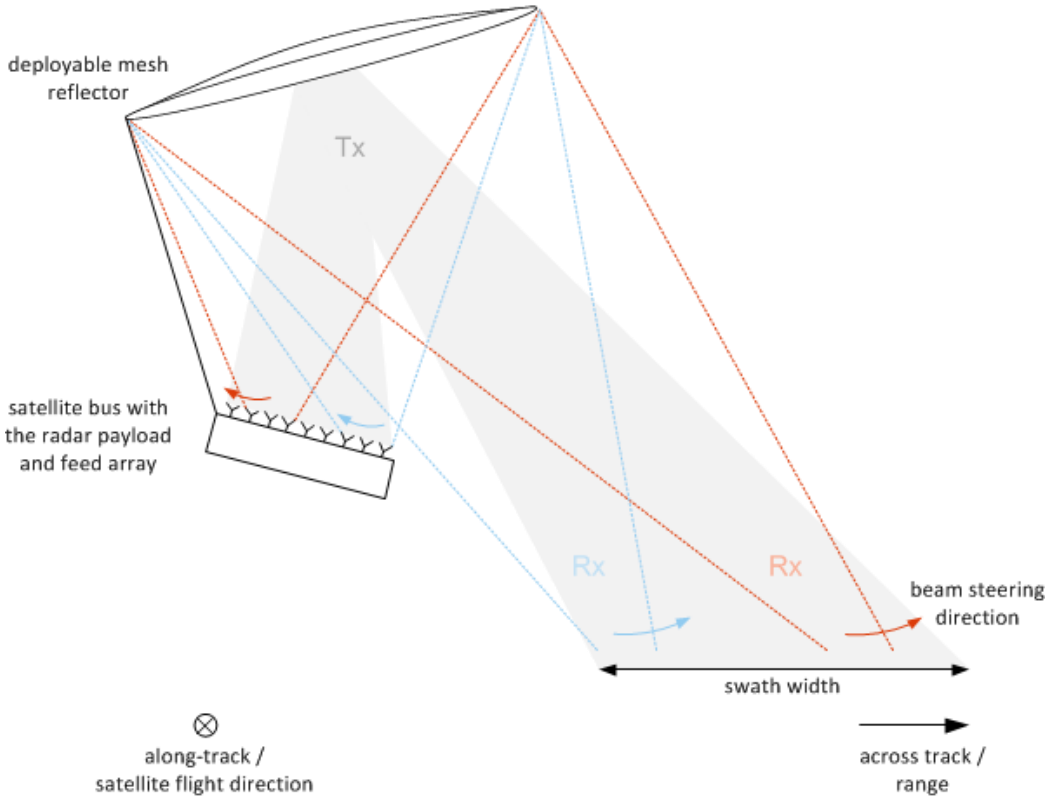
The following end-to-end performance / imaging requirements have been assumed as framework for the SPACEBEAM activities:

Parameter	Value / Range
Sensor Type	Spaceborne SAR Sensor
Frequency Band	X-Band
Swath Width (across-track)	> 50 km
Swath Length (along-track)	> 50 km
Ground Resolution	< 1.3 m × 1.3 m (along-track × across-track)
Noise Equivalent Sigma Zero (NESZ)	< -20 dB
Ambiguity to Signal Ratio (ASR)	< -20 dB
Dynamic Range	> 30 dB

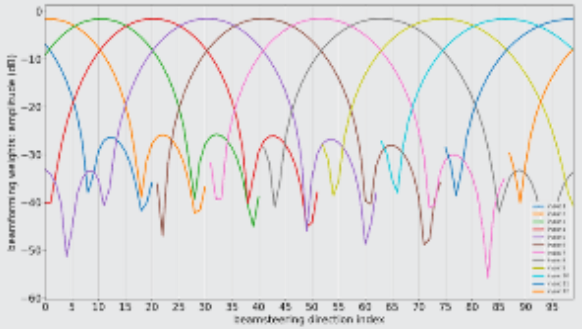
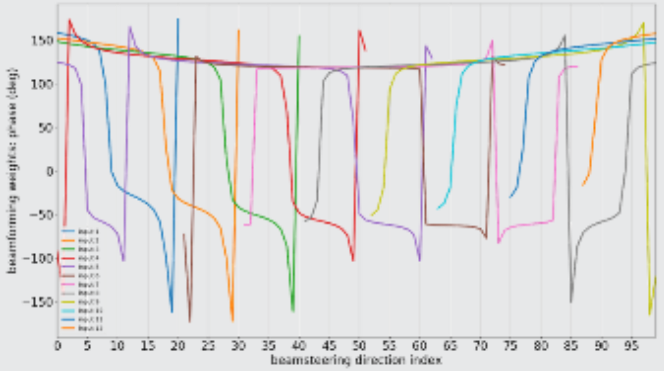
HIGH-LEVEL SYSTEM ARCHITECTURE

To derive realistic receiver and beamformer requirements, the following high-level system architecture has been derived:

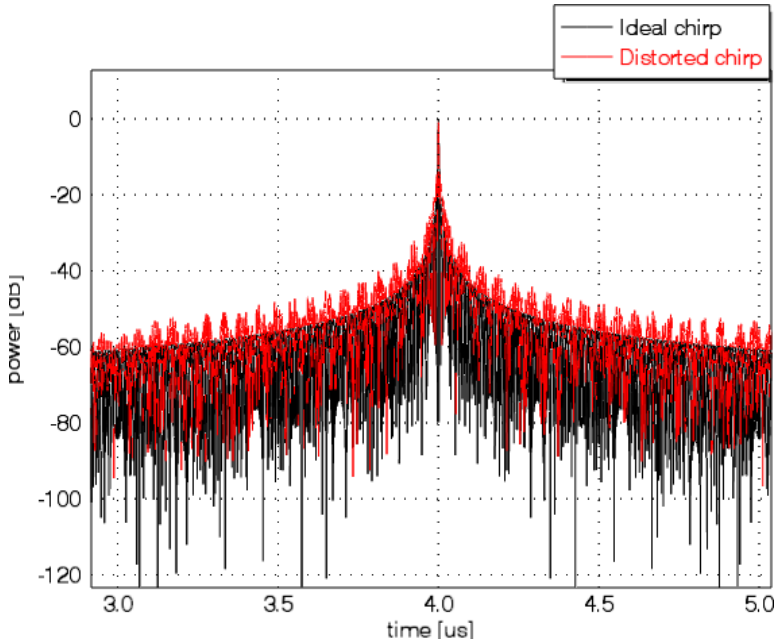
Parameter	Value
Imaging mode	Scan-on-receive to enable wide swath imaging with up to three simultaneous Rx beams
Orbit height	500 km
angle range	>4.9 deg across-track beam steering interval enabling >50 km swath width at steep incidence angles.
SAR Antenna	Array-fed reflector with ∅2.9 m Feed array with 12 independent channels along elevation
Centre frequency	9.6 GHz (X-band)
RF bandwidth	< 400 MHz
Transmitter	3 kW peak power @11% RF duty cycle



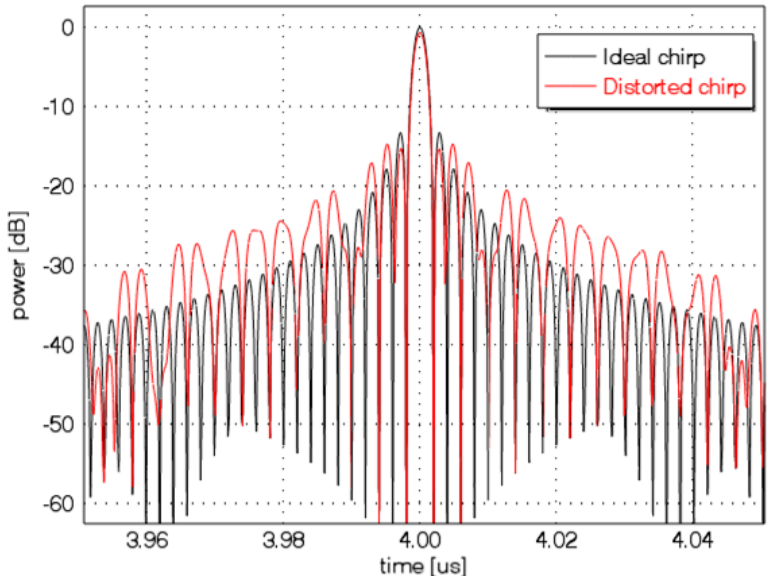
SPACEBEAM SAR RECEIVER REQUIREMENTS

Parameter	Value
Receiver RF input channels	12 at X-band centre frequency
Receiver IF output channels	3 synthesised beams at intermediate frequency of 1300 MHz
RF bandwidth	< 400 MHz
RF dynamic range at receiver input	> 32.5 dB
RF power at receiver input	between -90 dBm to -57.5 dBm
Receiver noise figure	< 6 dB (goal)
RF power at PIC input	between -53.7 dBm to -21.4 dBm
Beamforming dwell time	2 to 3 µs (incl. switching time)
Beamforming weights switching time	< 300 ns / goal < 100 ns
Beamforming weights amplitude relative error	< 5%
Beamforming weights random phase error	< 10°
Beamforming weights as function of beam	Amplitude  Phase 

POINT TARGET DEGRADATION DUE TO BEAM SWITCHING



Zoom in

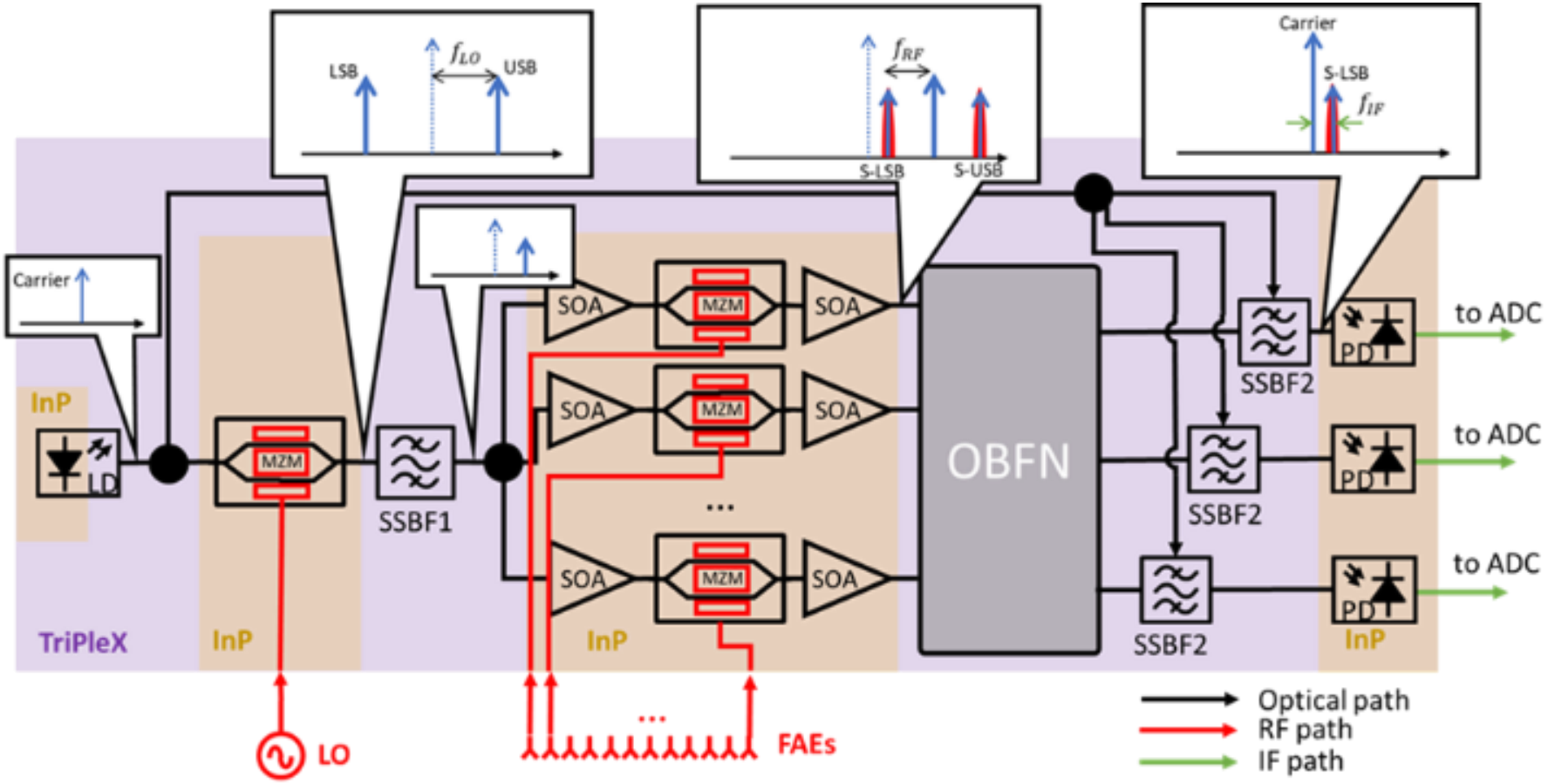


Switching Time (ns)	ISLR (dB)	Loss (dB)
0	-9.7	0
100	-8.8	-0.2
200	-7.8	-0.4
300	-7.0	-0.7

- switching time modelled as lack of data
- assumptions:
  - pulse width: 5µs
  - no. of beam directions: 50
  - dwell time: 2.6 µs
    (includes switching time)

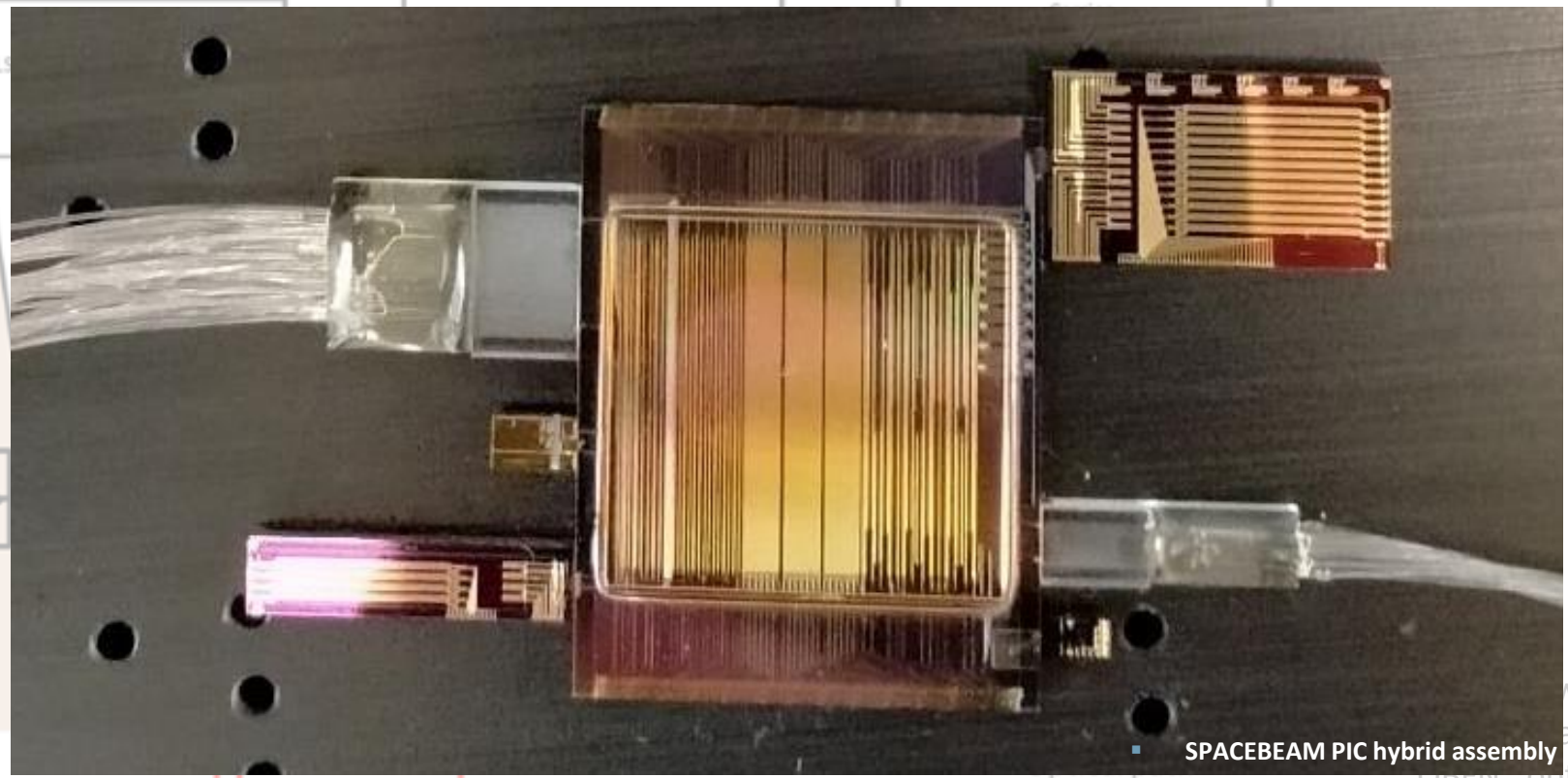
➔ **Point target response degradation for 50 beams / 300 ns is deemed acceptable and can be handled via the error budgets. This will result in a minor reduction of the gain flatness over the swath.**

PHOTONICS INTEGRATED CIRCUIT BEAMFORMER



LSB	lower sideband
MZM	Mach-Zehnder modulator
OBFN	optical beamforming network
PD	photo diode
SSBF	single sideband filter
SOA	semiconductor optical amplifier
USB	upper sideband

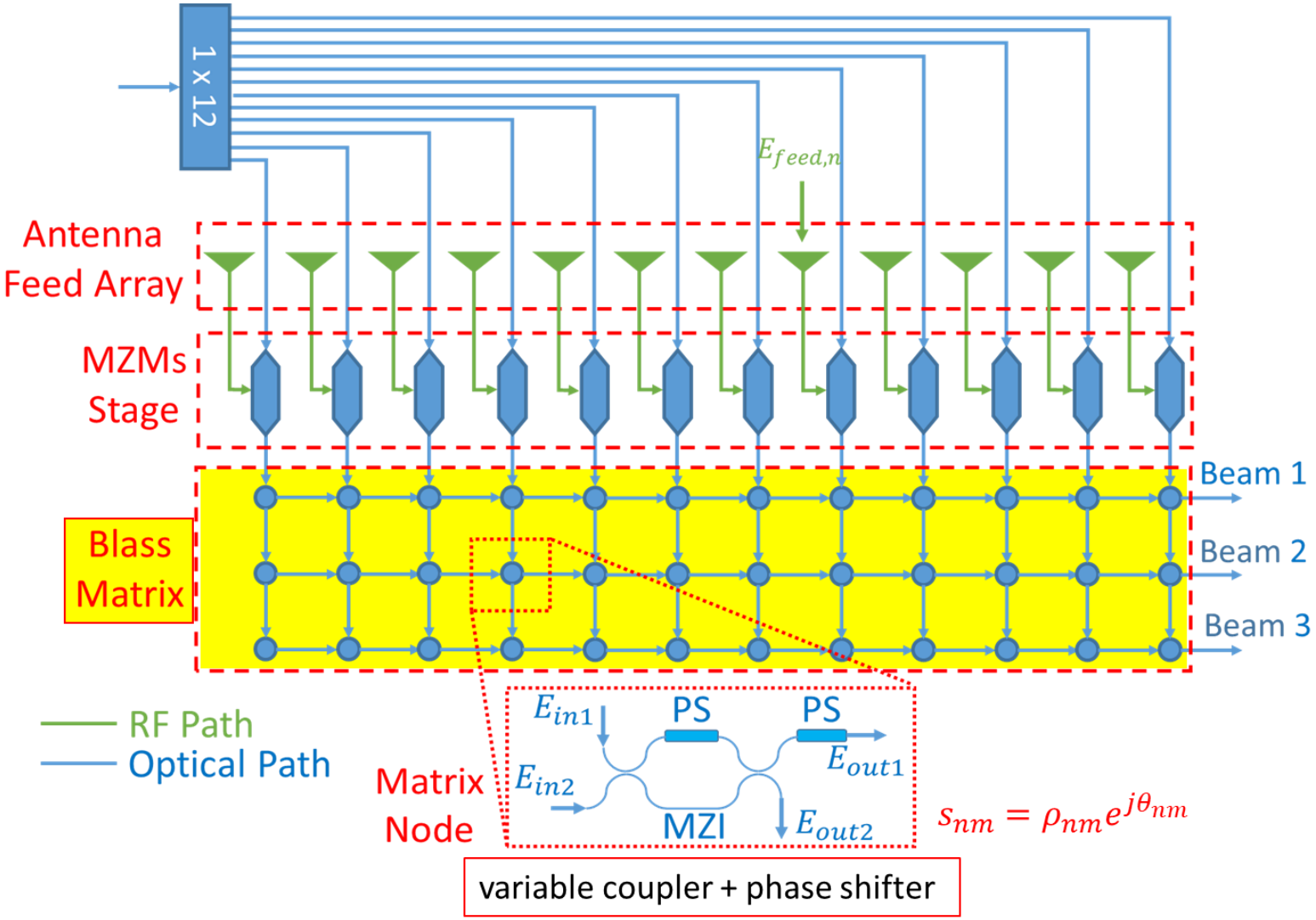
PHOTONICS INTEGRATED CIRCUIT BEAMFORMER



SPACEBEAM PIC hybrid assembly

wer sideband
ach-Zehnder modulator
OBFN optical beamforming network
PD photo diode
SBF single sideband filter
SOA Semiconductor optical amplifier
USB upper sideband

OPTICAL BEAMFORMING NETWORK

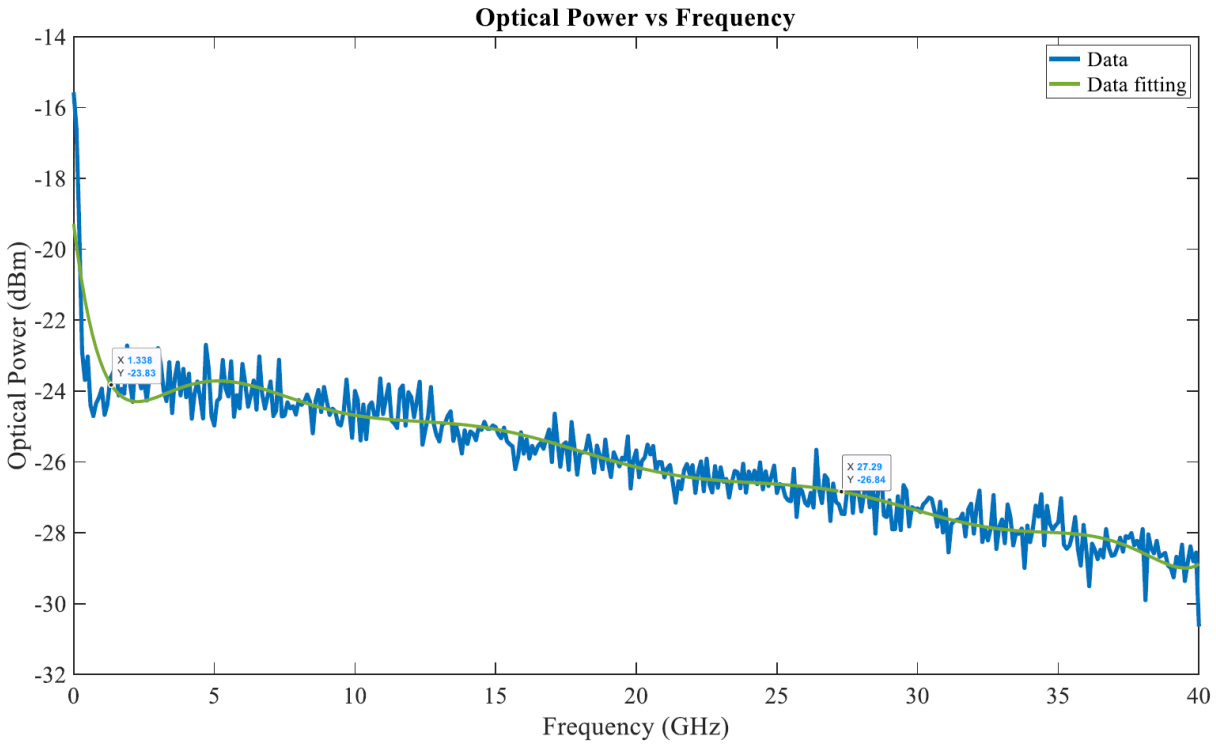


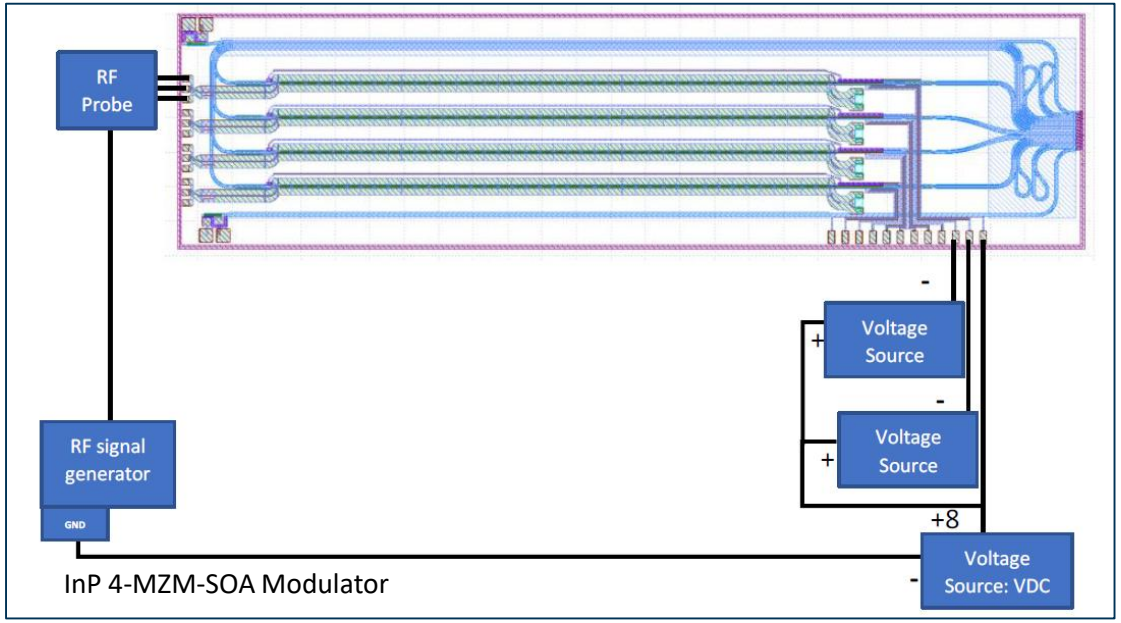
The optical beamforming network is an electrically tuneable optical Blass matrix consisting of horizontal and vertical optical waveguides which are inter-connected by reconfigurable nodes implementing tuneable optical phase shifters.

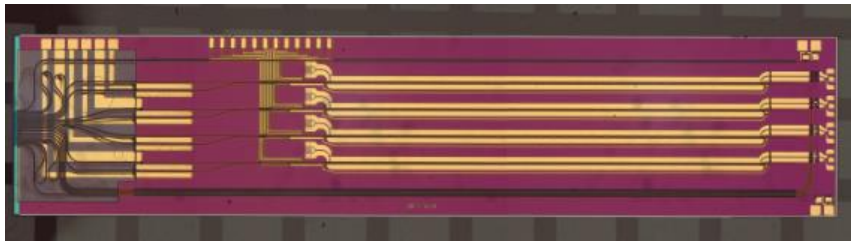
For fast phase shifting, the optical phase shifters are controlled by Lead Zirconate Titanate (PZT) piezo-electric actuators deposited on top of the TriPleX waveguides rather than conventional thermal control.

APPLICATION TO KA-BAND

The SPACEBEAM PIC technology beamforming is frequency-transparent up to 40 GHz and does not hamper the extension of the functionalities to higher frequencies.

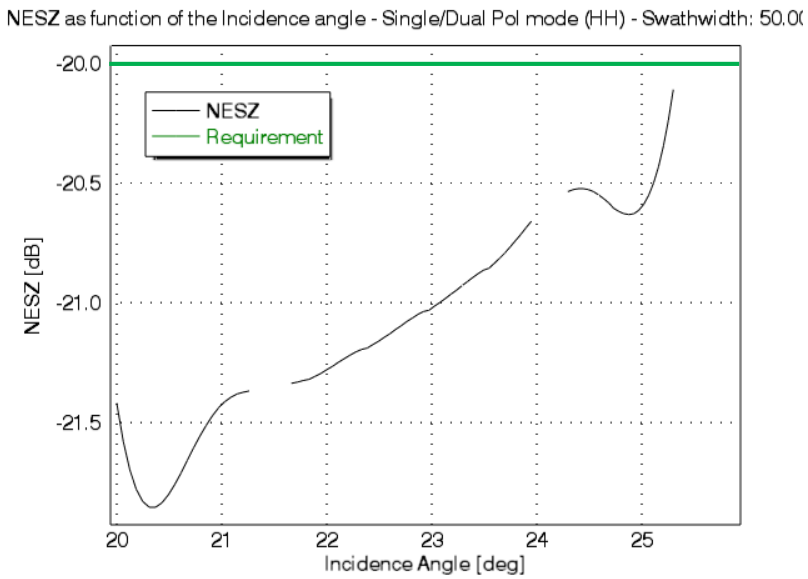






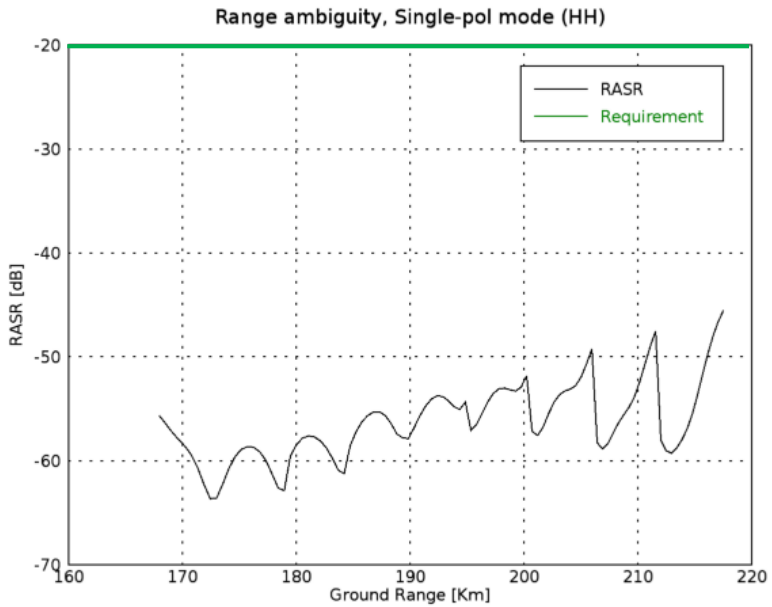
→ The SPACEBEAM PIC design can be employed at all key spaceborne Earth Observation microwave remote sensing frequencies including Ka-Band, such as for the SKADI mission.

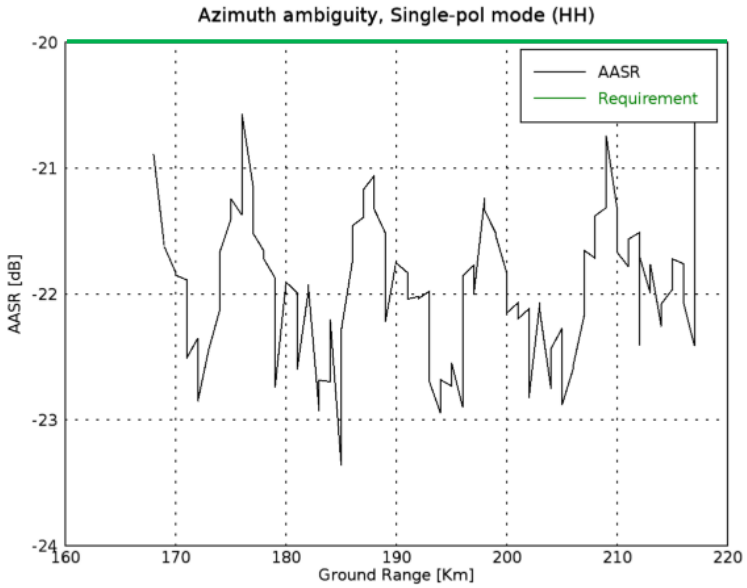
SAR INSTRUMENT PERFORMANCES



Noise Equivalent Sigma Zero (dB)

Range Ambiguity to Signal Ratio (dB)

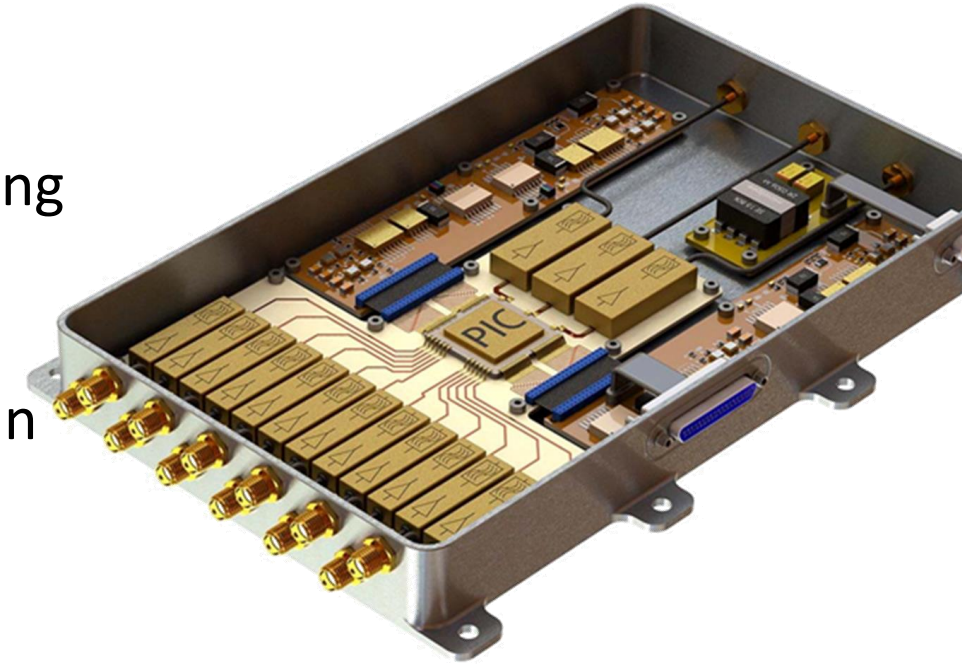




Azimuth Ambiguity to Signal Ratio (dB)

CONCLUSIONS

- Technological solution: **Hybrid PIC** based on SiN and InP including active and passive functions
- **Precise**, continuous, wideband, reconfigurable beamforming from an array of 12 antenna inputs into one, two or three simultaneous beams
- **Frequency-agnostic** photonic down-conversion of signals in the range from 5 to 40 GHz, down to IF
- Novel PIC **actuation technique** based on low-power consuming piezo elements (100x less consuming than std)
- **Space-compliant packaging** targeting TRL 6 maturity
- Specifically designed SCORE-SAR receiver module to test the performance of the entire system



SPACEBEAM artist impression by Antwerp Space

THANK YOU!

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