# Miniaturised photonic front-end for the next generation of space SAR applications

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## Introduction:

There is a natural trade-off between spacecraft size and functionality in all current satellite applications. In case of the next generation of Earth Observation satellites, one of the key development areas is synthetic aperture radar (SAR) antennas, where expected progress will be to increase the operating bandwidth and miniaturization. In this scenario, the use of photonic integrated circuits (PIC) technology in the beamforming network, in combination with an optical fibre harness, are obvious key enabling technologies for future SAR instruments.

Optically implemented true time delay (TTD) beamforming structures achieve orders-of-magnitude improvements in size and mass, provides easy routing thanks to wavelength-division multiplexing, antenna and RF system integration due to the EMI-free characteristic of the optical fibre and a reduction of the risks associated with the in-orbit antenna deployment. Additionally, the inherent broadband characteristic of photonic technology, related to the transport and processing of RF signals, simplifies the beamforming network and signal distribution design for different frequencies, applications and missions.

## 1. Application scenario

Three missions that that could benefit from the proposed technology have been identified which are based on reduction of mass and volume achievable with PIC TTD technology.

| Parameter | Mission #1 (small platforms) | Mission #2 (satellites in formation) | Mission #3 (large platforms) |
|---|---|---|---|
| Operating frequency | X-band, 9.6 GHz | X-band, 9.6 GHz | X-band, 9.6 GHz |
| Signal bandwidth | 500 MHz | 400 MHz | 800 MHz |
| Relative Signal Bandwidth | 5.2% | 4.2% | 8.3% |
| Instrument Mass (including antenna) | 30 kg | 30 kg | 250 kg |
| Peak Transmitted Power | 1 kW | 30 W | 2.8 kW |
| Access Area | 20° - 45° | 20° - 45° | 15° - 55° |
| Spatial Resolution | 1 m - 3 m | 1 m - 3 m | 0.5 m |
| Swath width | 5 km - 8 km | 5 km - 8 km | 5 km - 8 km |
| Noise Equivalent σ0 | - 20 dB @ 1m res.<br>-30 dB @ 3m res. | - 25 dB | - 15 dB |

Table1. Reference requirements for the proposed application scenario missions.

## 2. Architecture description

Multi-beam photonic beamformer sub-populated demonstrator sufficient to assess the main technical functionalities:

- RF to optical (E/O) conversion
- A PIC implementing TTD
- Optical to RF (O/E) conversion
- Associated optical distribution
- Antenna elements

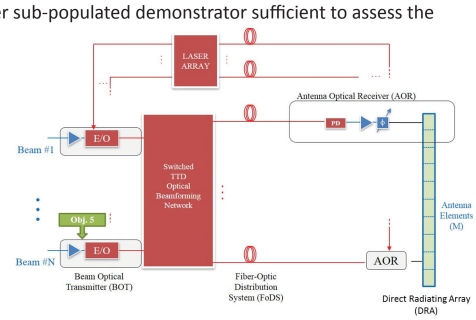



Figure 1. Scheme of the photonic beamformer. RF elements are shown in blue, optical in red.

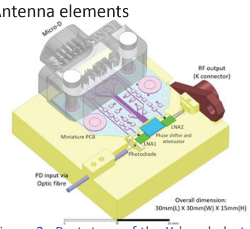


Figure 2. Prototype of the X-band photoreceiver module

## 3. Photonic integrated circuit implementing TTD lines

The proposed optical beamforming network with TTD characteristic is constructed by aggregating elementary PIC-based 8x8 beamforming network which can control the delay of up to eight signals simultaneously and to route and combine them to a specific beamforming port .

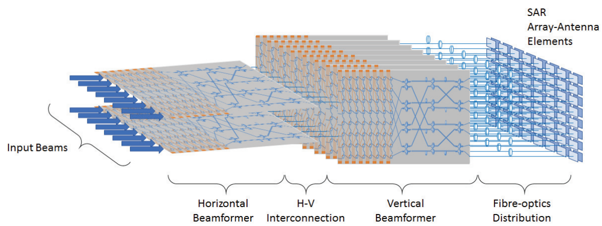
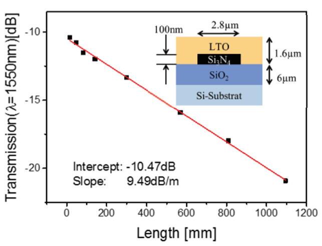



Figure 3. 3D aggregation of elementary 8x8 beamforming network PICs to construct the complete SAR beamformer




- Designed and validated a PIC manufacturing process based on low loss $Si_3N_4$ technology.
- An efficient fibre-to-chip assembly process, required for a high number of input/output ports, has been developed.
- The different photonic integrated building blocks (BB) required to implement the elementary PIC have been designed.

Figure 4. Measured transmission vs waveguide length (at wavelength of 1550nm). Fitted line, red, has a slope of 9 dB/m (propagation losses). The intercept with the y-axis yields a loss of 5.2 dB per fiber-chip coupler. Inset: Ultra-low loss photonic waveguide cross-section

## 4. Sub-array antenna element

An antenna array module in X band, whose electrical requirements will be satisfied over the whole operating frequency range, has been designed.

| Item | Requirements |
|---|---|
| Operative Frequency | X-band (9.6 GHz) |
| Frequency Bandwidth | 600 MHz |
| Polarization | Dual orthogonal linear (H, V) |
| Sub-array onfiguration | Linear (8 elements) |
| Element Spacing | 0.85 $\lambda_0$ @ 9.9 GHz |
| Subarray Spacing | 0.70 $\lambda_0$ @ 9.9 GHz |
| Return Loss | > 18 dB (Target) |
| Insertion Loss | < 1.6 dB (Target) |
| Power handling | Compatible with SAR mission |

Table2. Antenna requirements

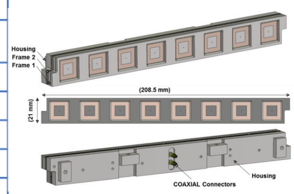



Figure 5. 3D sketch of the sub-array antenna element

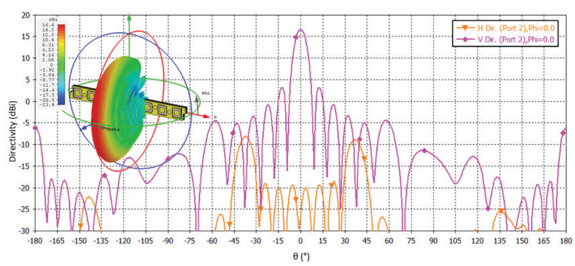



Figure 6. Simulated radiation patterns (directivity) of the AES shown in Figure 5 at 9.6 GHz in the horizontal plane, port H excited. Inset: 3D views of the radiation patterns.

## CONCLUSIONS:

The advances in design and fabrication of a miniaturised photonic front-end for the next generation of space SAR applications has been reported which incorporates new features such as, centralised signal processing and a truly broadband frequency operation approach thanks to the multi-beam TTD reconfigurable beamforming architecture.

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