Photonic beamforming network for multibeam satellite-on-board phased-array antennas

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Valencia Nanophotonics Technology Center

ThalesAlenia Space
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esa

PRESENTATION OUTLINE

- Beam Handling/Processing
- Optical Beamforming
- Proposed Architecture
- Implementation
- Test and Results
- Technology Comparison
- Further Developments
- Conclusions

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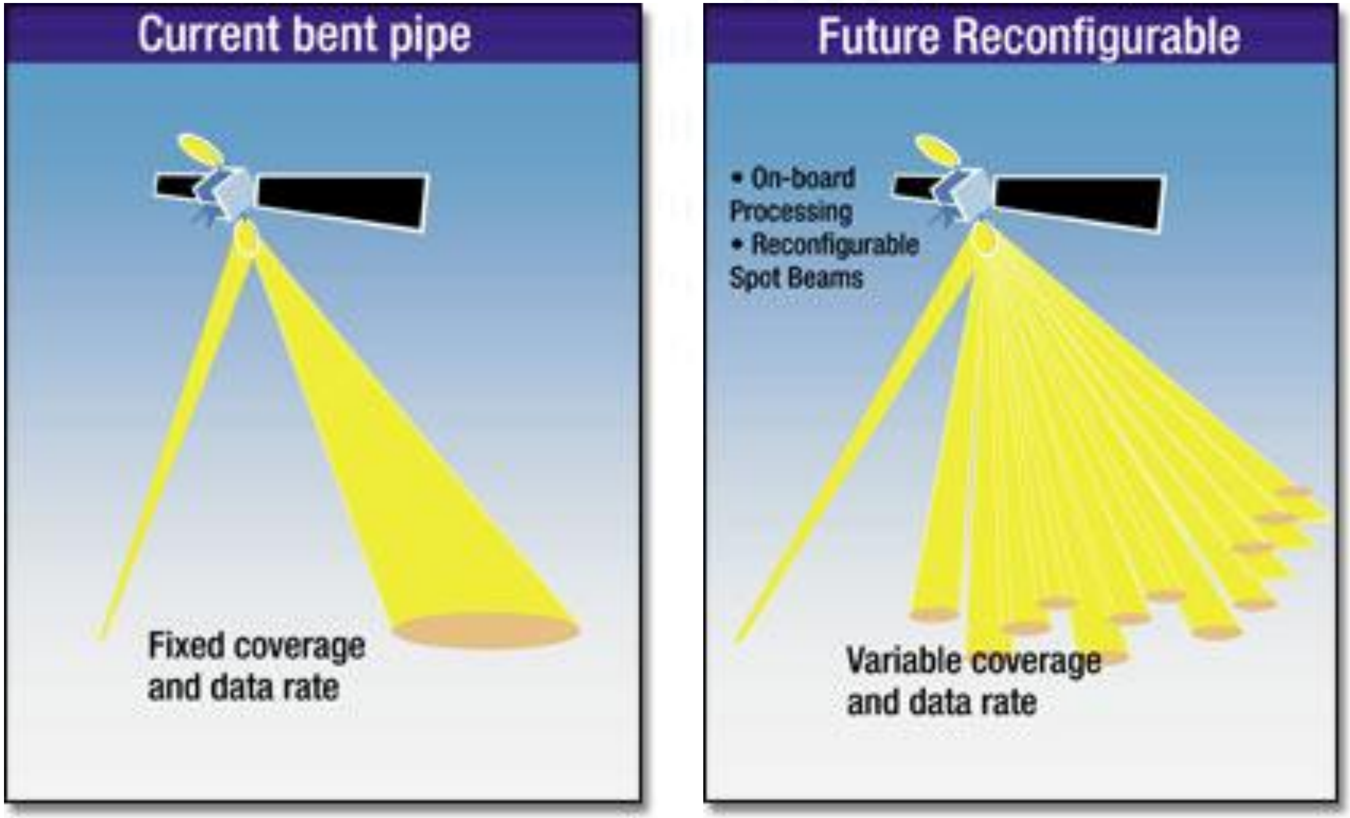
BEAM HANDLING/PROCESSING

Broadband Telecom Satellites



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Beam Handling/Processing

State-of-the-art

(Europe) French STENTOR mission
- 48 SSPAs
- 3 beams (Ku-band)

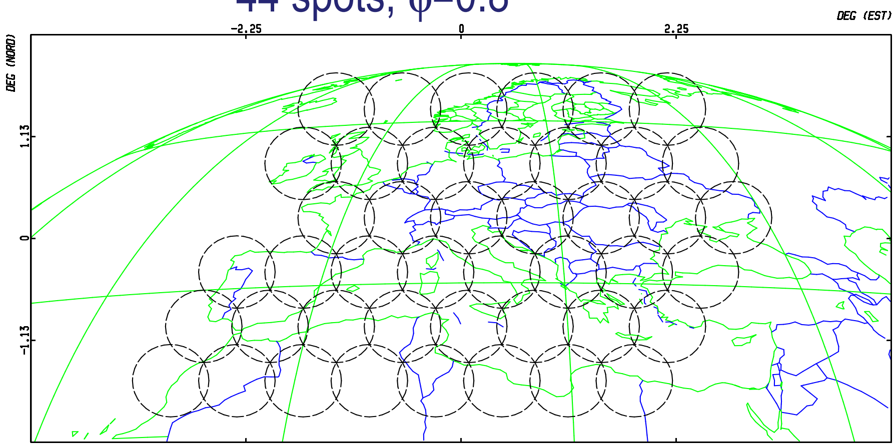
(US) SPACEWAY (Ka-band)
- 3000 SSPAs
- 24 beams (Ku-band)

DirecTV's Spaceway F1 satellite undergoes final preparations for its launch aboard a Zenit-3SL vehicle. **(Boeing photo)**

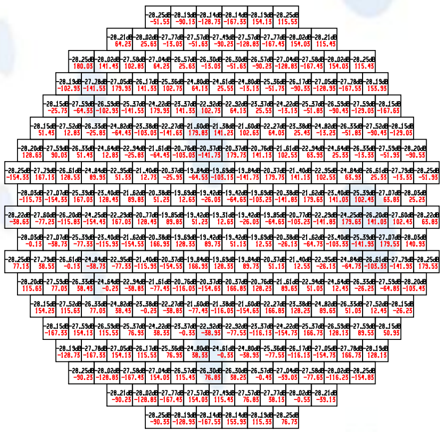
BEAM HANDLING/PROCESSING

- Problem to be addressed
  - FUTURE SCENARIOS
    - Coverage of a wide area by **multiple fixed narrow beams**
    - **Direct Radiating Array (DRA)** scheme
    - **Hundred of antenna elements to be feed**
    - **Multibeam capability**

"Europe + Maghreb" **coverage:**
44 spots, ϕ=0.8°



Antenna = 256-elements DRA



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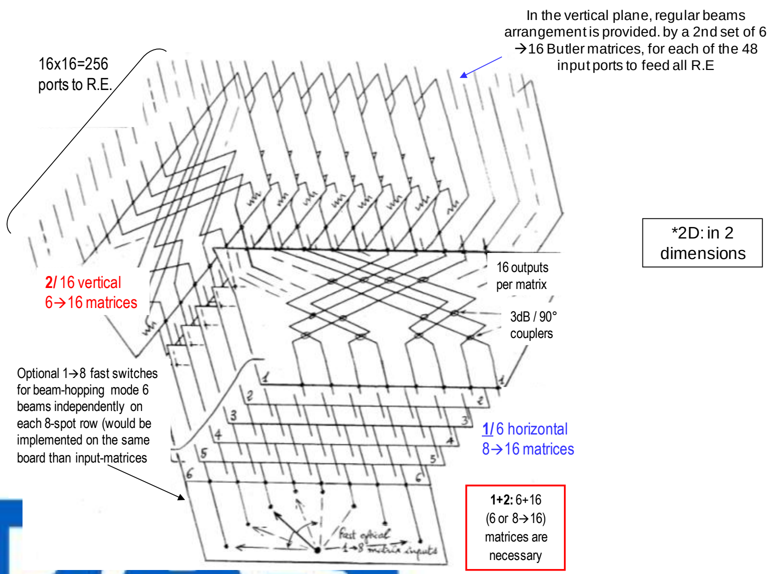
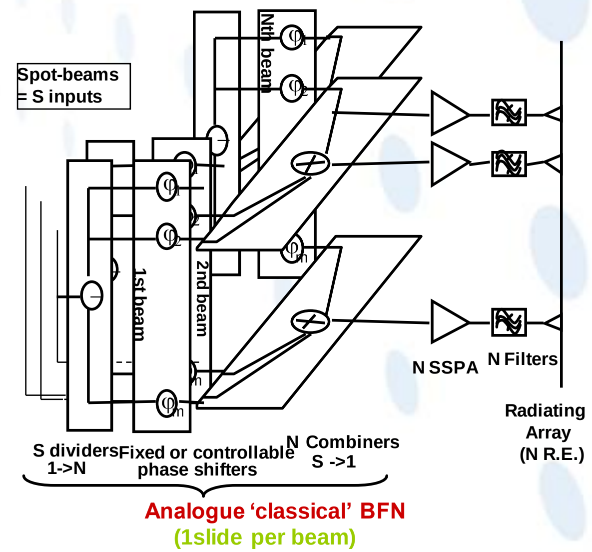
Beam Handling/Processing

- Problem to be addressed
  - **High complexity**
  - **High mass and volume** of the classical RF implementations
  - Heavy impact in the **digital beamforming** approach.
  - **High mass** of the feeding cables (hundred of antennas)
  - **Crosstalk** and **EMI** issues





OPTICAL BEAMFORMING

- Solution proposed
  - To use photonic technology for the Beamforming Network
    - **Size reduction**
    - High **integration** of several functionalities in a **single chip**
    - High **precision** in the phase shifting (SOI technology)
    - **Mass reduction**: using **optical fiber** for the antenna feeding
    - Huge electrical **bandwidth** (typically > 40 GHz).
    - **EMI Free** technology
    - Excellent **crosstalk**
    - **Scalability with low size/mass**

OPTICAL BEAMFORMING

Optical Beam Forming

The ESA is assessing the benefits of using optical beam forming networks on Telecom and EO satellites for steerable pencil or spotlight beams, or for adjusting broadband multimedia beams.
Different scenarios:

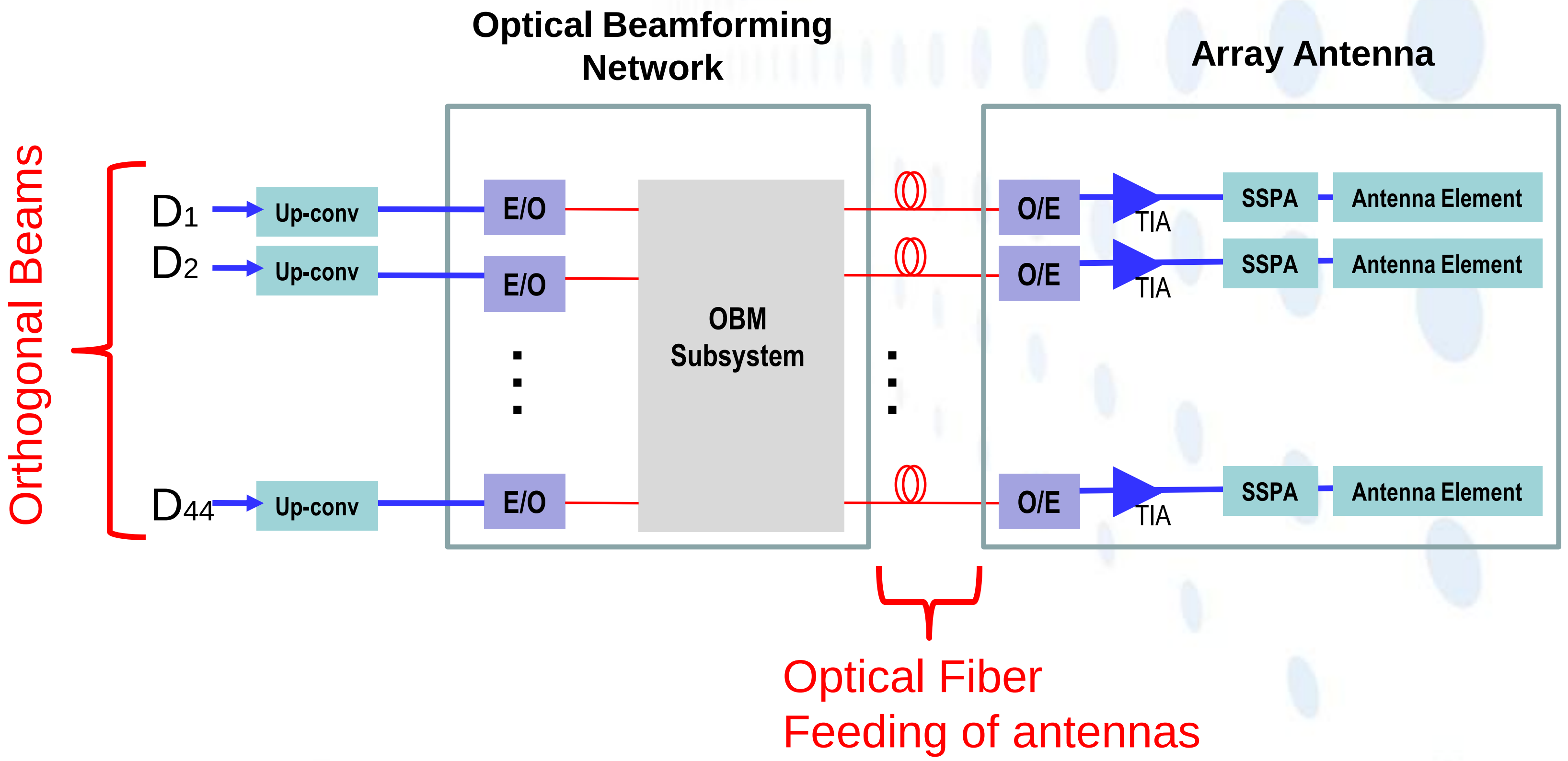
-**Wide** bandwidth requirements: True Time Delay (TTD) architectures
-**Narrow** bandwidth: no need of TTD

Broadband Telecom Satellites

•Ka band (30GHz) multimedia satellites
•Large number of beams (200)
•Small Steering Angles (few degrees)
•LC SLMs used for Amplitude and Phase control (true time delay not required)
•Integrated photonics implementing beamforming networks as Butler Matrix (true time delay not required)

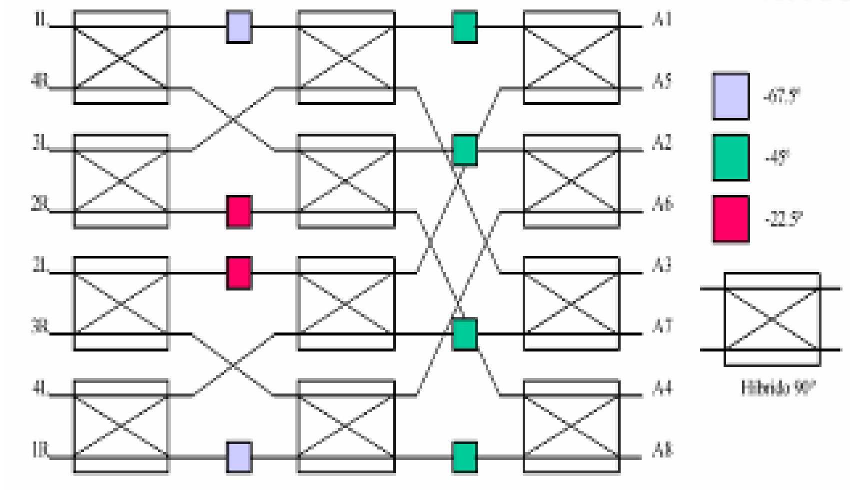
Errico Armandillo (ESA), Space Optoelectronic Day, Cork 7 April 2006

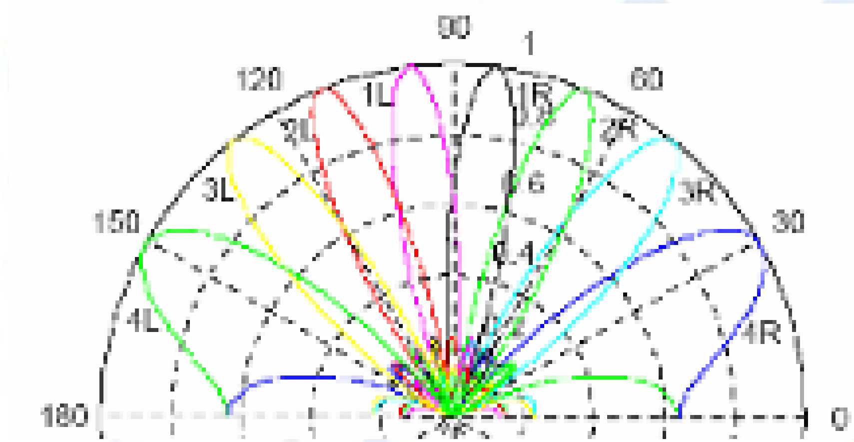
PROPOSED ARCHITECTURE



PROPOSED ARCHITECTURE

Butler Matrix: Principle of Operation

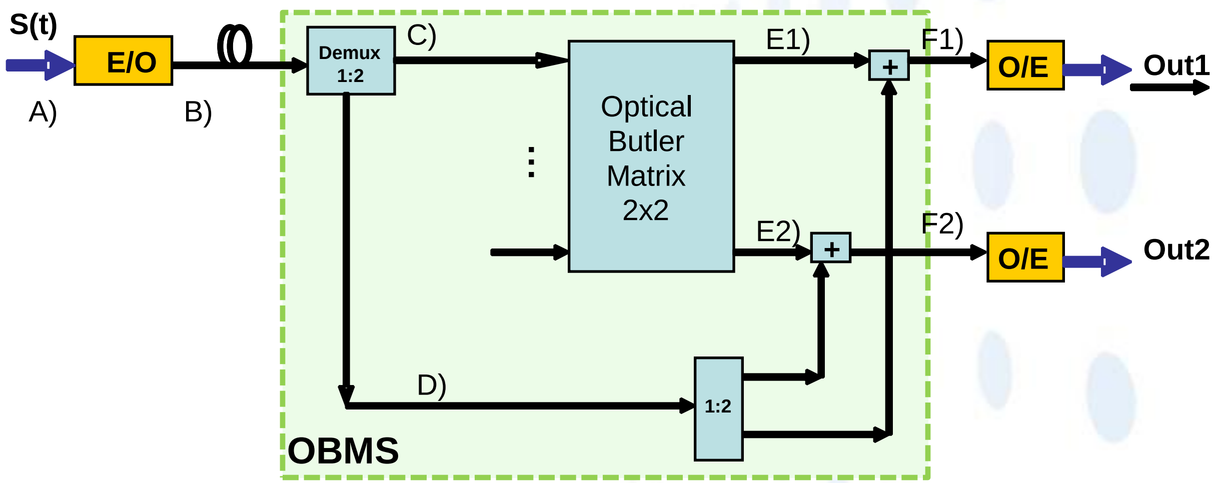




- Orthogonal beams
- Passive structure: couplers and phase shifters
- Scalable solution (FFT structure)
- Very well known solution

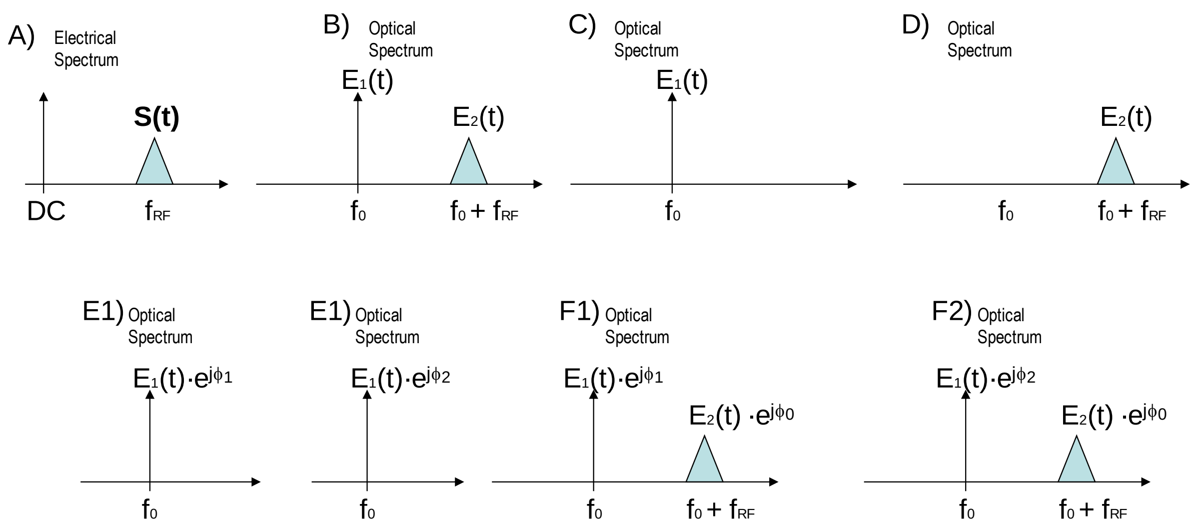
PROPOSED ARCHITECTURE

OPTICAL Butler Matrix: Heterodine Generation



$$Out1 = S(t) \cdot e^{j(\phi_1 - \phi_0)}$$

$$Out2 = S(t) \cdot e^{j(\phi_2 - \phi_0)}$$



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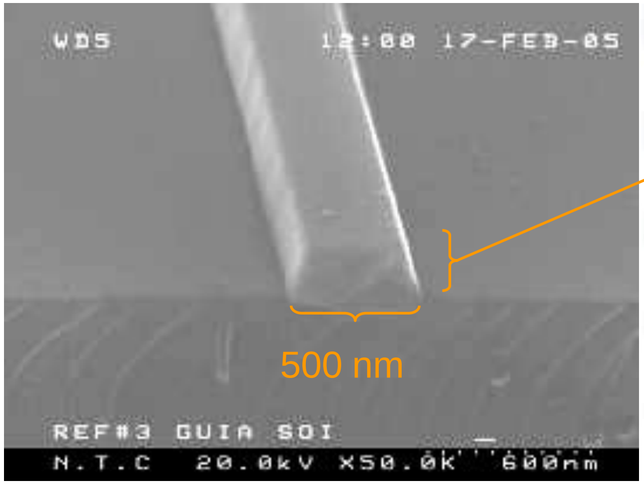
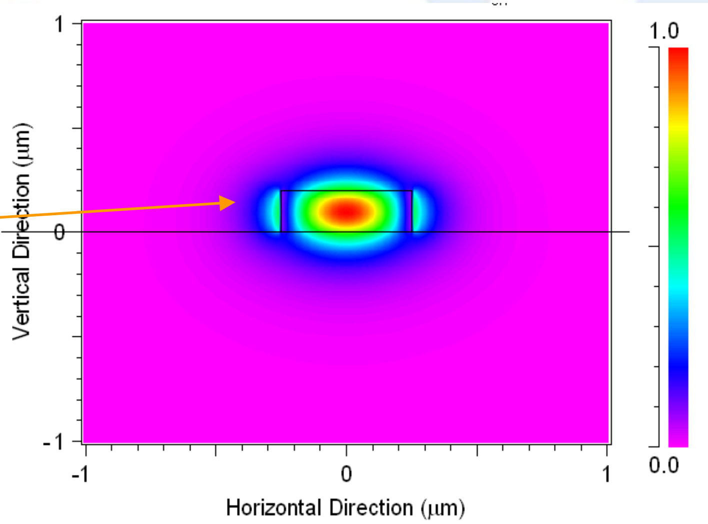
IMPLEMENTATION

SOI TECHNOLOGY



- CMOS compatible tech.
- Thin silicon (Si) layer on top of an Oxide (SiO_2) cladding
- Si thickness = 200 nm
- SiO_2 layer = 3000 nm
- Waveguide width = 500 nm



- Mode profile highly confined
- Effective refraction index @ 1550 nm = 2,36

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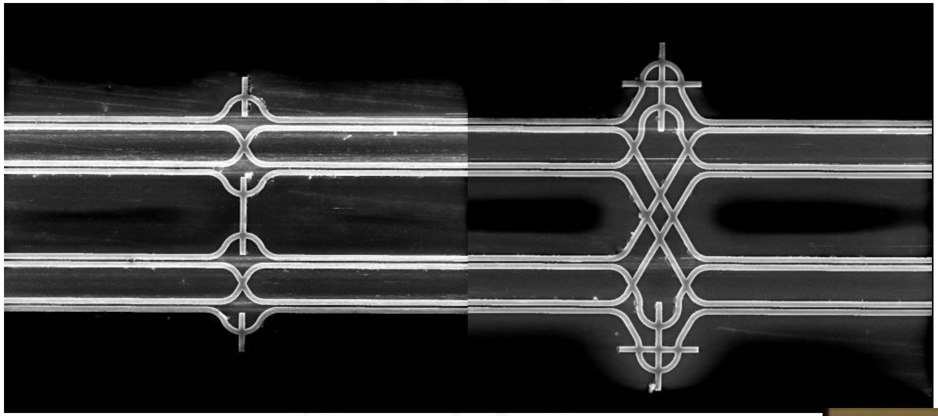
Tests and Results

10 cm

18 GHz 8x8 Butler Matrix

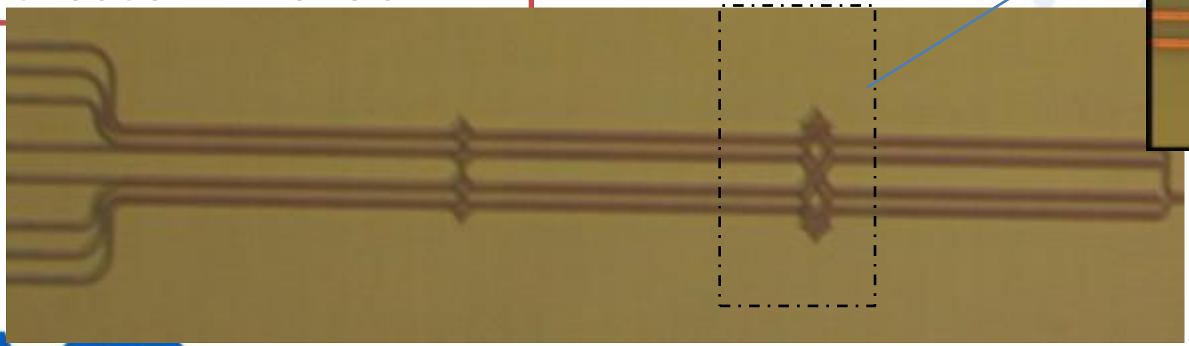
Technical Research and Manufacturing, Inc.

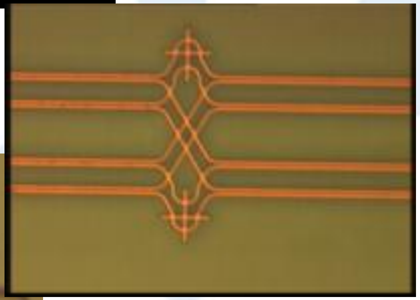
SEM PHOTOGRAPH



L= 0.5 mm

MICROSCOPE PHOTOGRAPH





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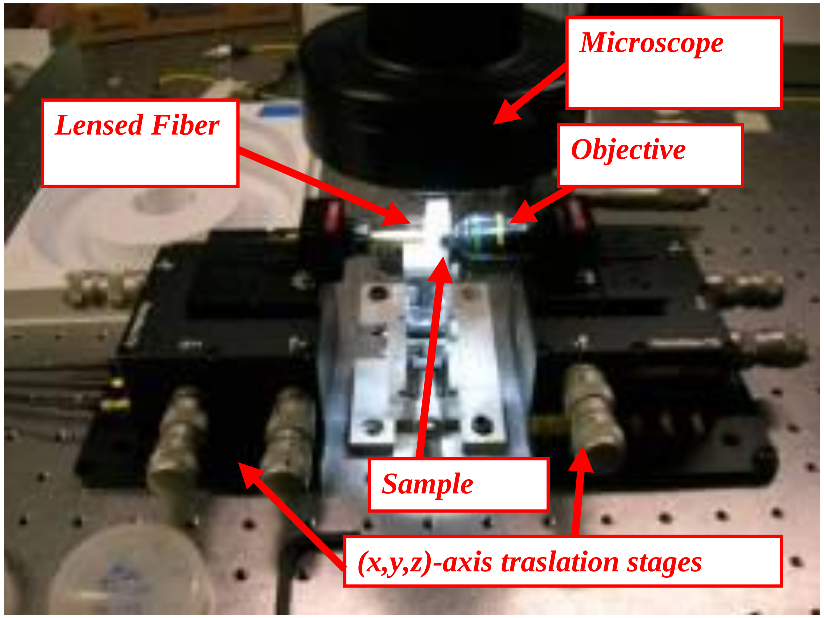
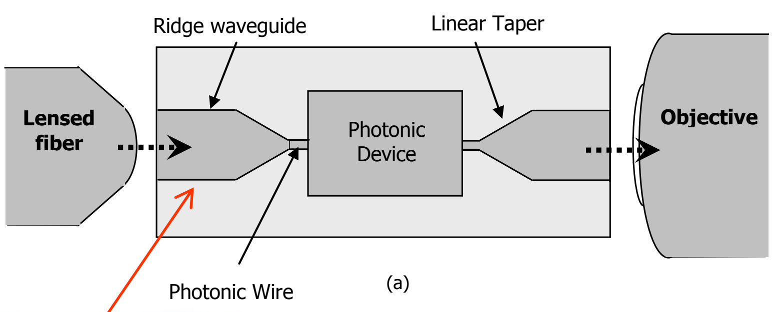
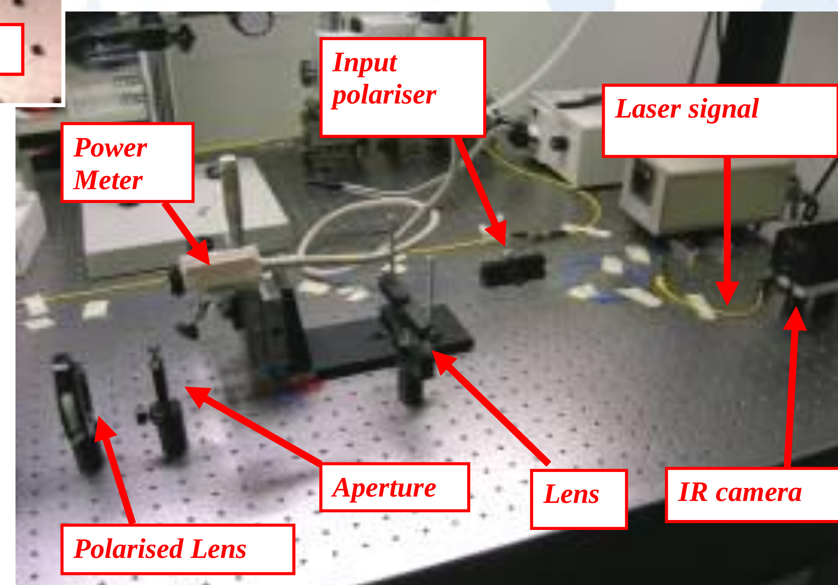
TESTS AND RESULTS

MEASUREMENTS AT CHIP LEVEL





Reference Waveguide (3μm wide)



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TESTS AND RESULTS

Parameter	Specification	Obtained
Standard deviation of phase errors	$\sigma_\phi < 10/\sqrt{2}$	$\sigma_\phi < 5 - 10^{o}$
Standard deviation of amplitude errors	$\sigma_a < 0.5$ dB	$\sigma_a < 2$ dB

Due to the in-chip test method

- Phase performance in line with the specifications
- Amplitude performance worse than specifications
  - Mainly due to the coupling method (introduce extra attenuations)
  - Amplitude equalization is expected in future devices.
    - Chip post-proccesing

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TECHNOLOGY COMPARISON

- Targeted for **high complexity beamforming networks for array antennas (DRA)**

Example: 44 beams. 256 antenna elements

BFN option	Estimated mass	Estimated volume	DC consump.	EMI FREE	Upgradeability in Nº of antenna elements
'Pure-RF' with Butler Matrixes	100%	100%	100%	NO	Low/medium
'opto-μwave'	70%	<1%	200%	YES	High
Comments	**Cable vs. Fiber mass shaving has not been considered**	Greater for large antennas	Including added amplifiers to compensate converion losses	Infinite isolation	Easy for large number of antenna elements (in the Opto-uwave)

Further Developments

- Improvement of the phase/amplitude performance
- Extend higher number of I/O ports
- Implementation of the whole heterodine structure (RF performance)
- Whole system packaged (including the fiber coupling)

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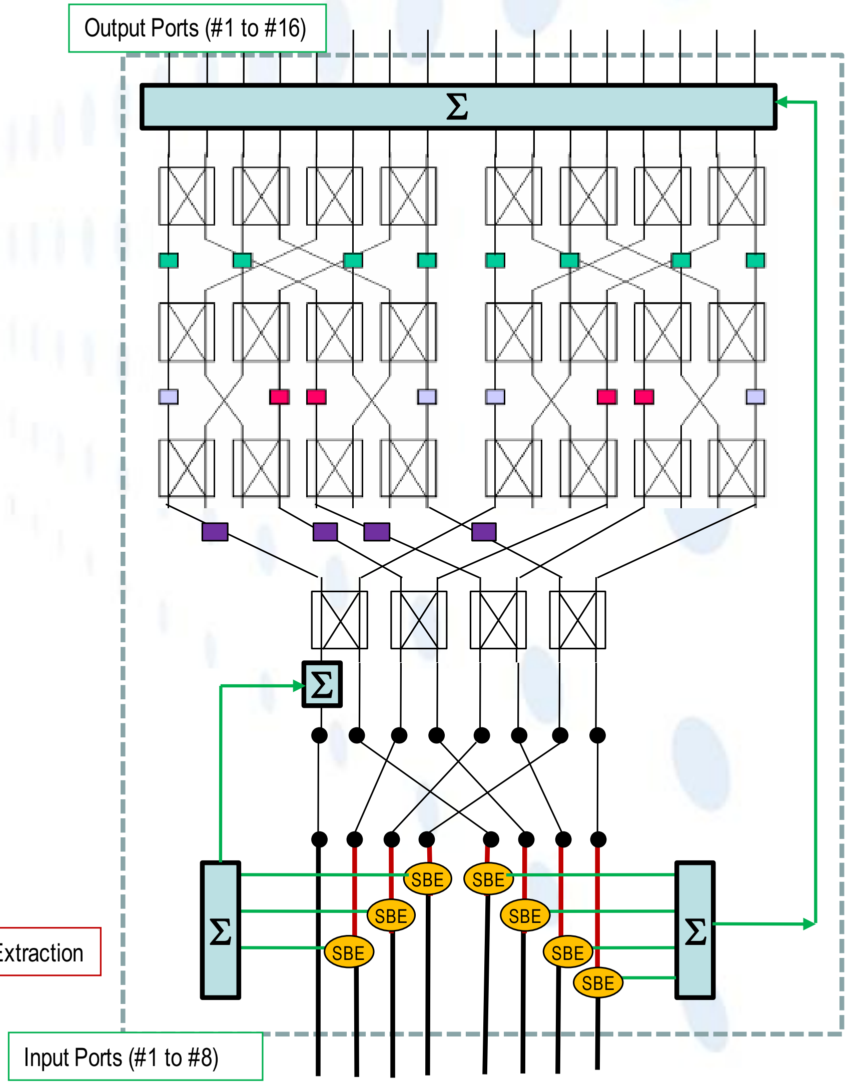
Further Developments

Optimised OPTICAL Butler Matrix (OBM)

- **Basic Unit (BU)** for the OBFN design

- Based on 8x8 Butler Matrices and a **proprietary 2N beam multiplication solution**: simpler than the truncated 16x16 alternative (especially much fewer line crossing's)

- **Heterodine distribution included in the basic unit**:
  - Result in a 8x16 Butler matrix "RF-to-RF"
  - Different Basic Units can be interconnected with optical fiber
  - Do not requires the integration of optical switches inside the block.



SBE: Side-Band Extraction

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CONCLUSIONS

- Successful fabrication of an SOI integrated 8x8 Optical Butler Matrix
- The performance in terms of phase/amplitude obtained is comparable with the traditional electrical solution
- Low mass and size
- Remote feeding by optical fibre: weigh reduction
- EMI free technology
- Promising alternative for the implementation of Beamforming systems.

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THANK YOU FOR YOUR ATTENTION

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