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Nanophotonic technology in space for beamforming applications

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Presentation Outline

- Motivation
- Application Scenario
- The Butler Matrix
- Heterodine Generation
- Optical Beamforming Network based on OBM
- Measurement Set-up
- Conclusions



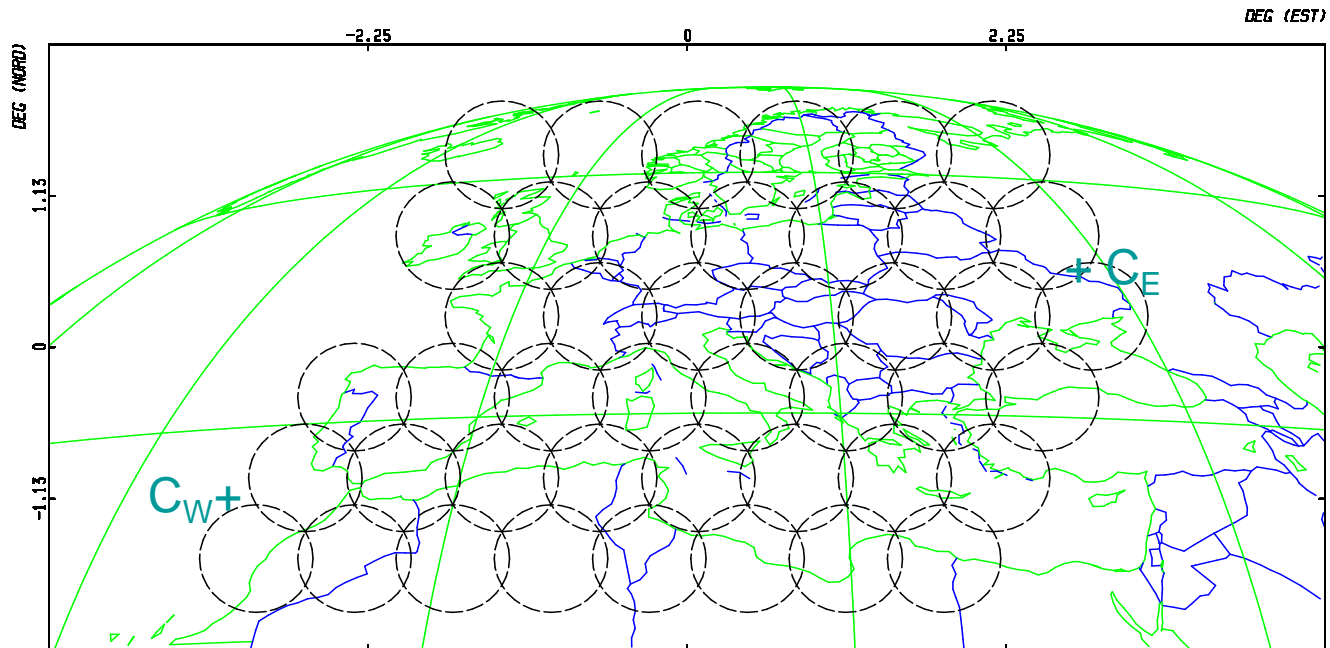
Motivation

- Why to use Nanophotonic Technology in space?
 - EMI Free
 - Size reduction
 - High integration of several functionalities in a single chip
 - Weight reduction
 - Less size = less weight
 - Remote feeding using optical fiber
 - Volume reduction
 - Low consumption
 - Huge electrical bandwidth (typically > 40 GHz).
 - Potential low cost
- Where to use Nanophotonic Technology in space?
 - Where the size/consumption constraints are very hard
 - Where the system complexity is high
 - Where EMI free is required
 - Where scalability is an issue.



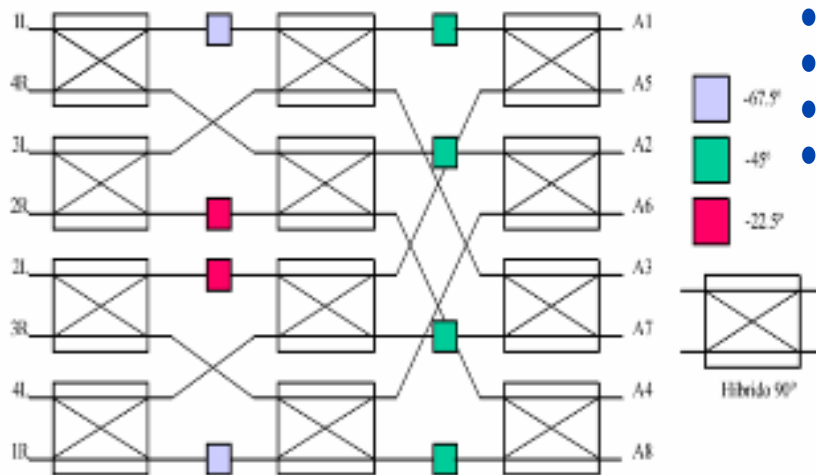
Application Scenario

- Forward link : Satellite towards Users
- Mission description : Coverage of a wide area by multiple fixed narrow beams
- **Direct Radiating Array (DRA) scheme** (hundred of antenna elements)

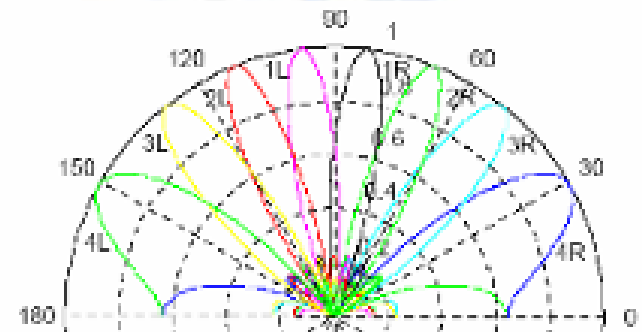


The Butler Matrix

Butler Matrix: Principle of Operation



- Passive Element: no signal distortion
- Performs a FFT: typically with 2^N ports
- Orthogonal Multibeam Capability
- For beam-hopping applications: fixed beams.

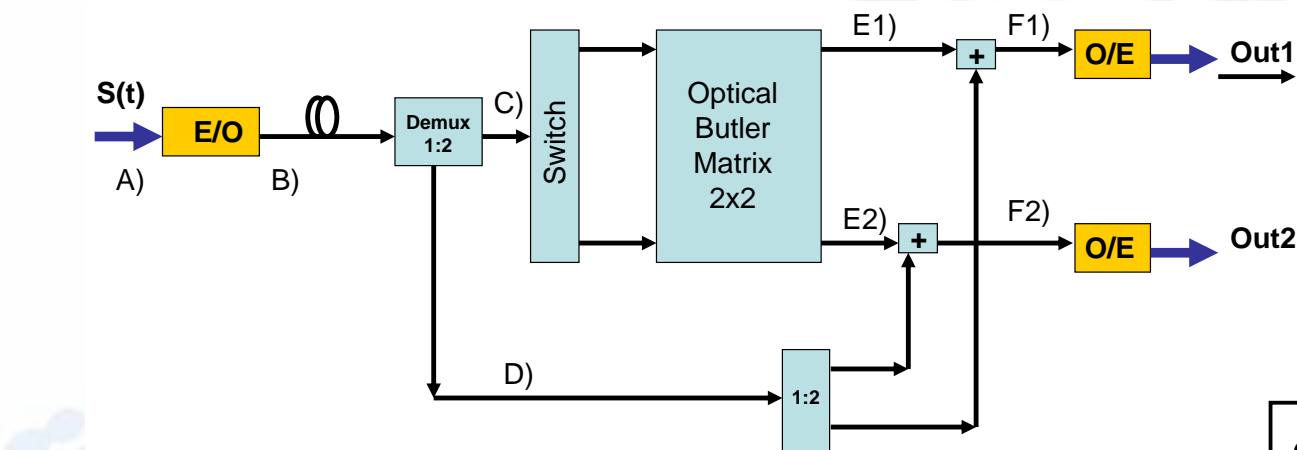


Butler Matrix: Photonic Implementation

- Radio-over-fiber architecture
- Requires photonic heterodyne generation: COHERENT CONDITION
- The structure should be integrated in a integrated device: The Butler Matrix is the core, but it requires additional structures

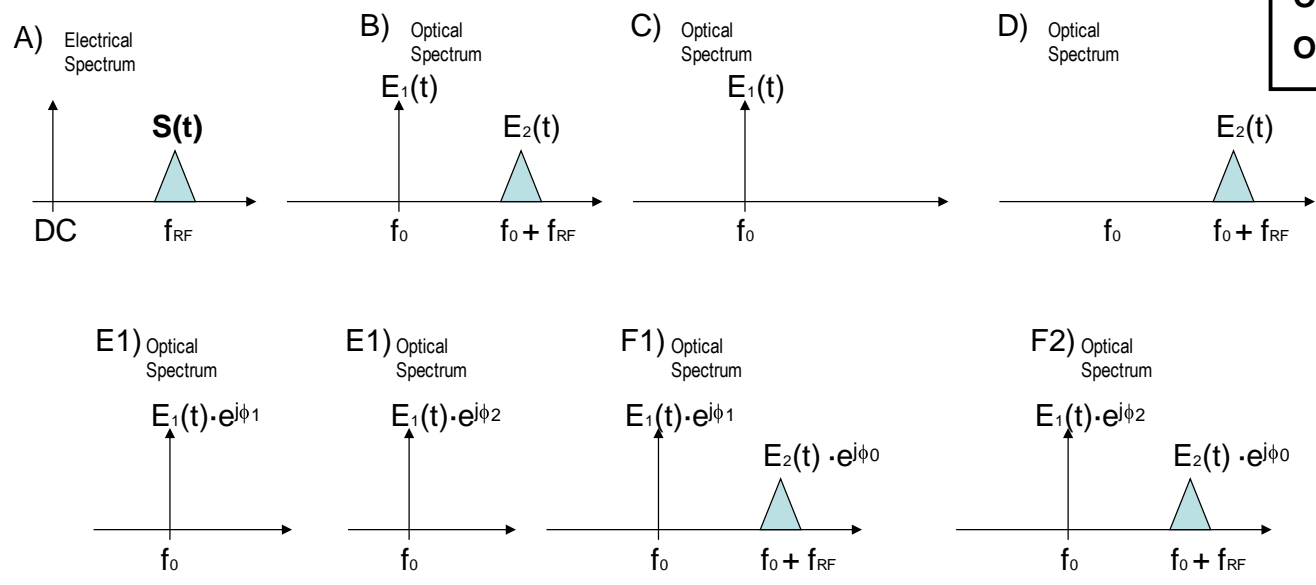
Heterodyne generation

Butler Matrix: Heterodyne Generation

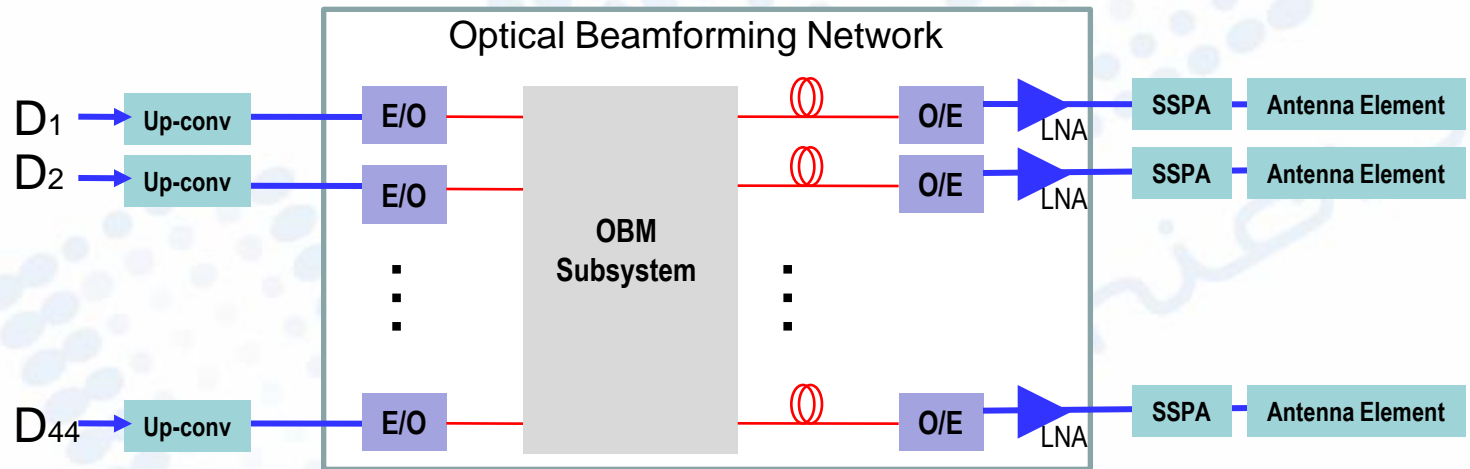


$$\text{Out1} = S(t) \cdot e^{j(\phi_1 - \phi_0)}$$

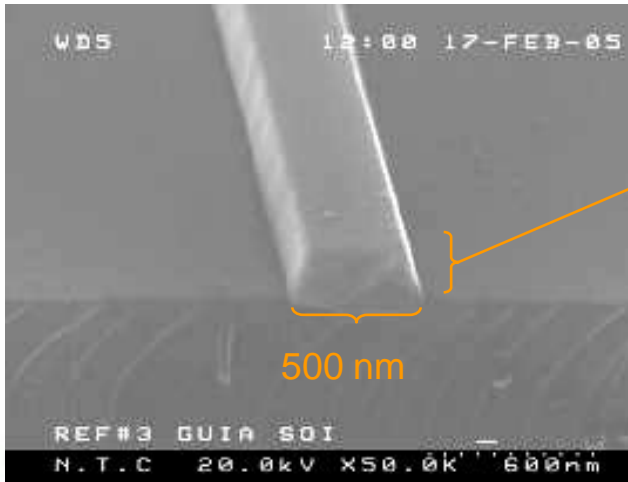
$$\text{Out2} = S(t) \cdot e^{j(\phi_2 - \phi_0)}$$



Optical Beamforming Network based on OBM

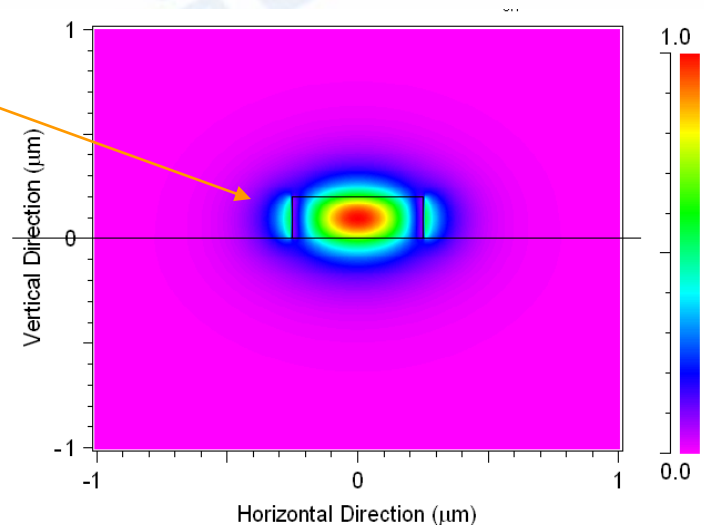


Optical Butler Matrix in SOI Technology



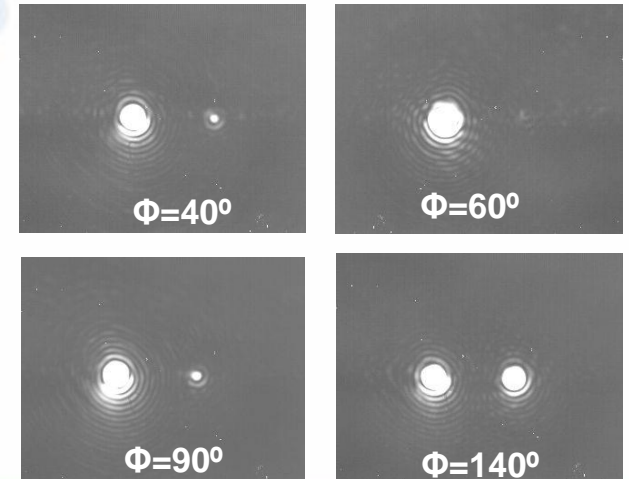
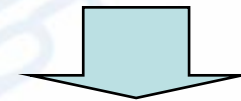
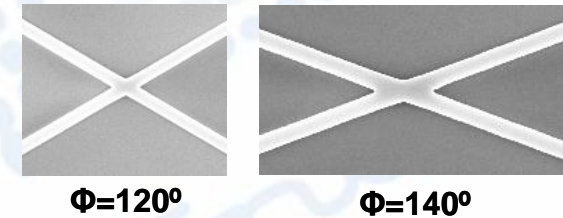
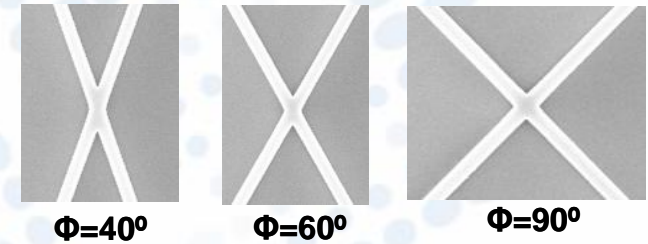
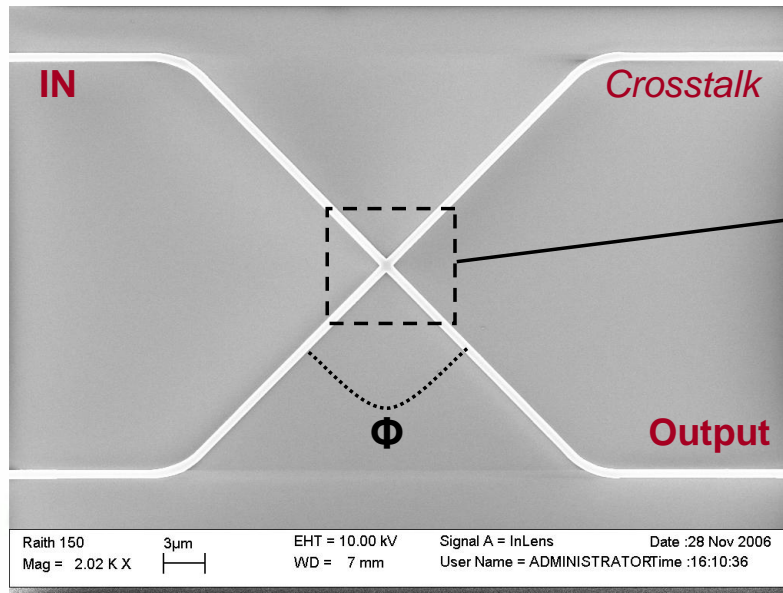
- Thin silicon (Si) layer on top of an Oxide (SiO₂) cladding
- Si thickness = 200 nm
- SiO₂ layer = 3000 nm
- Waveguide width = 500 nm
- Single-mode for TE polarization

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



Centro de Tecnología Nanofotónica de Valencia

Optical Butler Matrix in SOI Technology

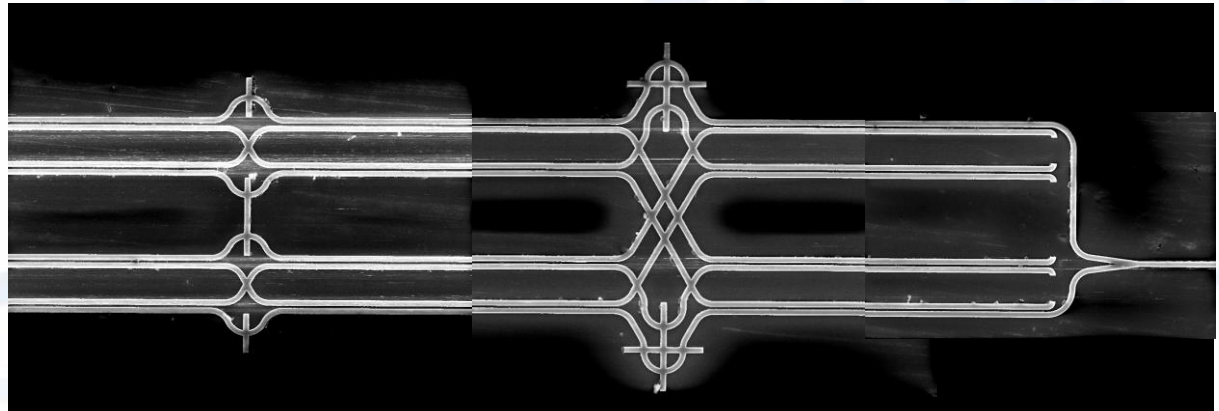


- Ultra-compact wave waveguide crosses
- Reduce the system size: compactness
- Optimum angles of 60° and 120°
- Low crosstalk

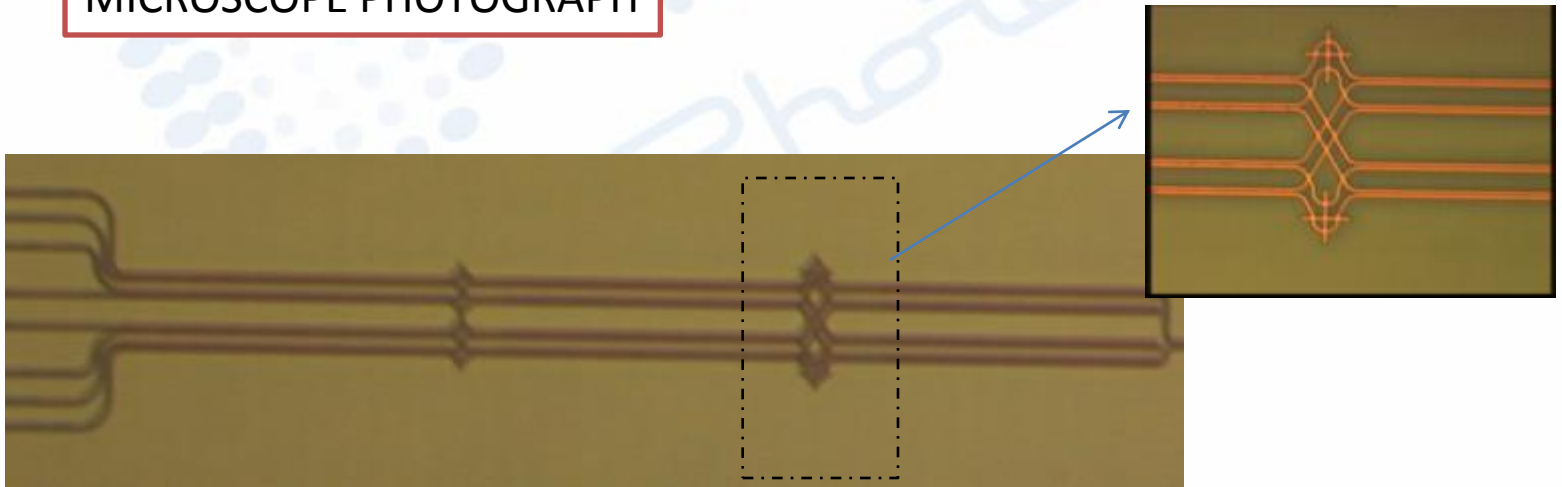


Optical Butler Matrix in SOI Technology

SEM PHOTOGRAPH



MICROSCOPE PHOTOGRAPH



Optical Butler Matrix in SOI Technology

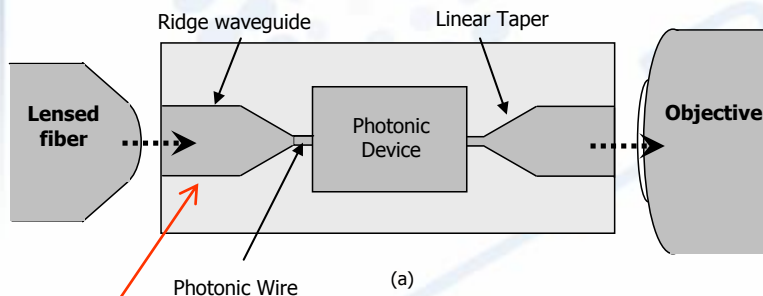
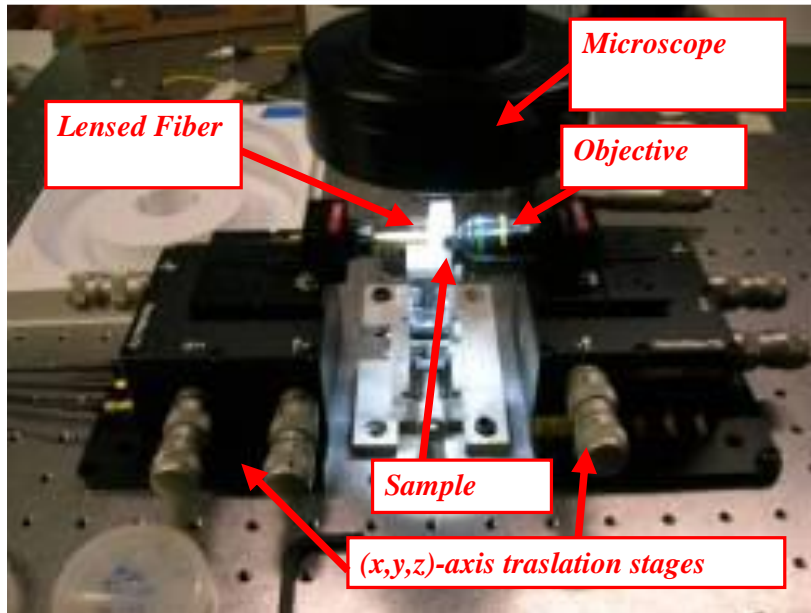
PERFORMANCE

Parameter	Specification	Obtained
Standard deviation of phase errors	$\sigma_{\phi} < 5^{\circ}$	$\sigma_{\phi} < 5.04^{\circ}$
Standard deviation of amplitude errors	$\sigma_{\phi} < 0.5 \text{ dB}$	$\sigma_{\phi} < 2 \text{ dB}$

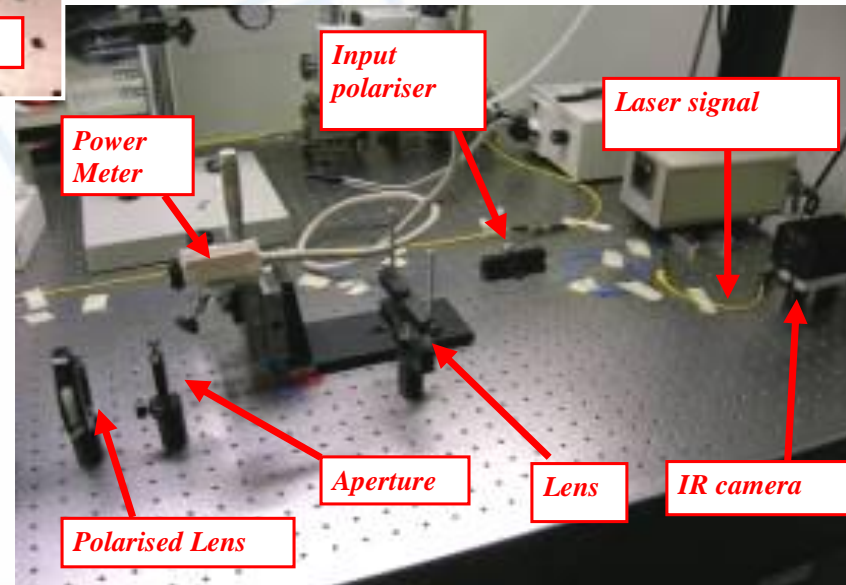
- Phase performance in line with the specifications
- Amplitude performance a bit worse than specifications
 - Mainly due to the coupling method (introduce extra attenuations)
 - Amplitude equalization is expected in future devices.



Measurement Set-up



Reference Waveguide ($3\mu\text{m}$ wide)



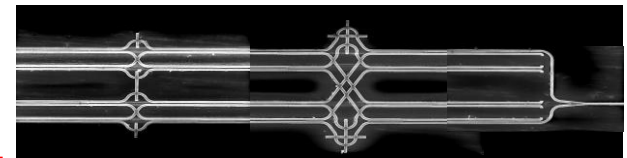
Conclusions

- Successful fabrication of an SOI integrated 8x8 Optical Butler Matrix
- The performance obtained is comparable with the required for the traditional electrical solution
- When integrated in a Ratio-over-Fiber system, it enables the remote feeding of antenna elements by optical fibre: weigh reduction
- EMI free technology
- Low weigh, size
- CMOS-Compatible technology: mass manufacturing



10 cm

18 GHz 8x8 Butler Matrix
Technical Research and Manufacturing, Inc.



0.003 cm

>40 GHz 8x8 Optical Butler Matrix