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Photonic Integrated Beamformer for Broadband Radio Astronomy

International Workshop
on Phased Array Antenna Systems
for Radio Astronomy
May 3-5, 2010
Design Optimization of Phased Arrays and RF Electronics

Outline

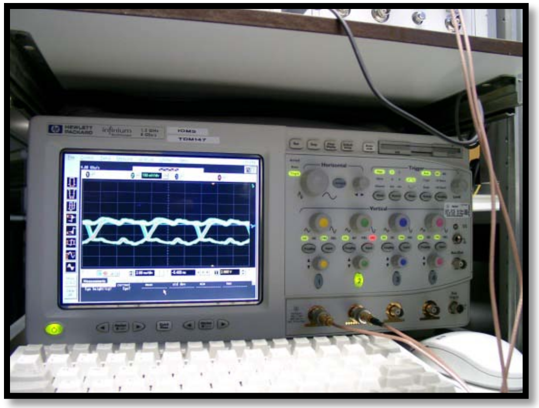
- Introduction
- Photonic integrated beamformers
  - fields of application
  - RF-to-RF characterization
  - demonstration of broadband beamsteering
- Integration
- New architectures
- Conclusions

Telecommunication Engineering Group

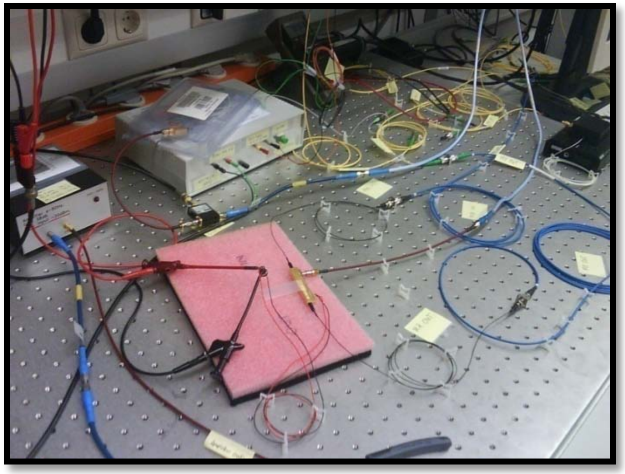
- 6 scientific staff
- 4 postdoctoral researchers
- 12 PhD students
- 6 MSc and BSc students

Three main research areas:

Short range radio



Microwave Photonics



Electromagnetic compatibility

Microwave Photonics Research

- 1 scientific staff
- 1 postdoctoral researcher
- 2 PhD students
- 2 BSc students

What we do:

Microwave photonics techniques

Signal generation	Optical heterodyning for LO generation
Signal distribution	High performance Analog photonic links
Signal processing	Optical beamforming

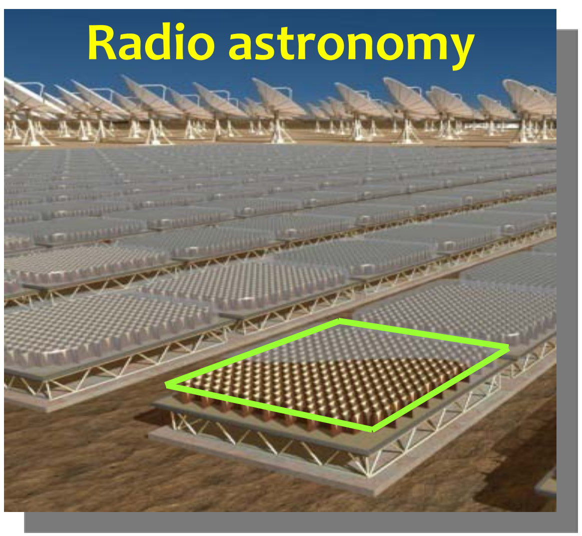
Applications for optical beamforming

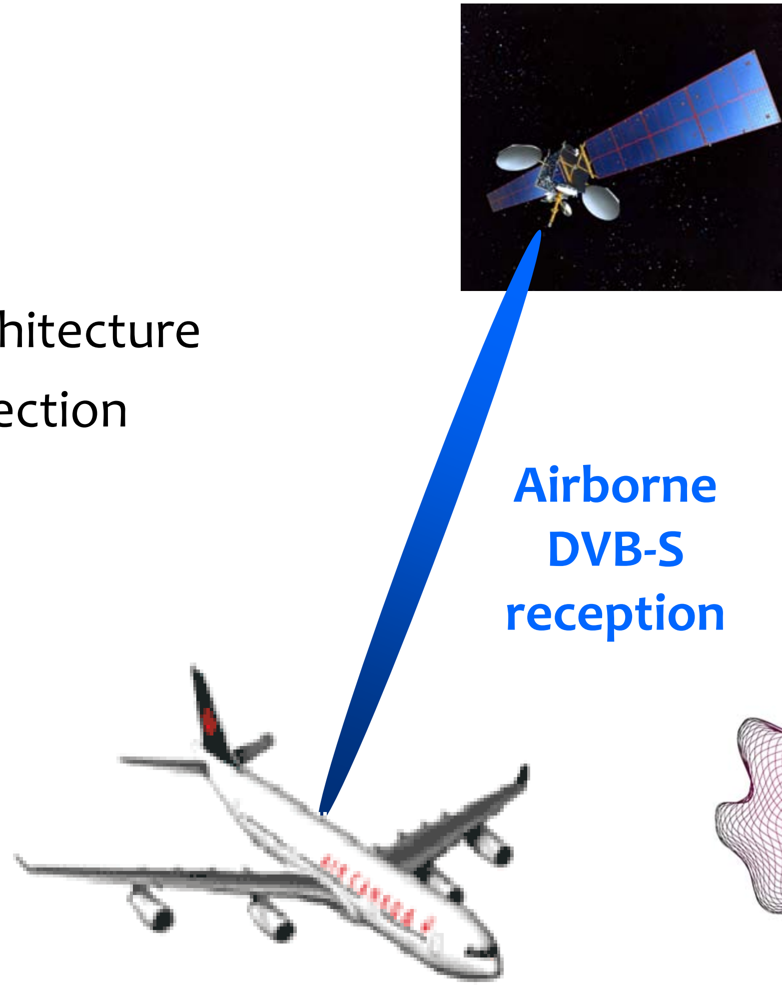
Possible applications:

- DVB-S, radio astronomy, …

Requirements:

- Broadband
- High-resolution, squint-free architecture
- Continuously tunable beam direction





RF-to-RF characterization of a phased array antenna using an integrated OBFN

From

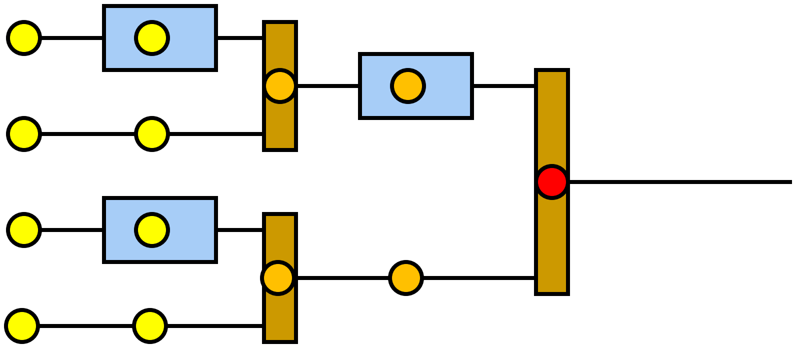
"RF-to-RF Characterization of a Phased Array Receive Antenna Steering System Using a Novel Ring Resonator-Based Integrated Photonic Beamformer", L. Zhuang, M. Burla, C. G. H. Roeloffzen, A. Meijerink, D. A. I. Marpaung, M. R. H. Khan, W. van Etten, A. Leinse, M. Hoekman, R. G. Heideman

Presented at the **2009 International Topical Meeting on MICROWAVE PHOTONICS**, Valencia, Spain, 14-16 Oct. 2009. (Microwave Photonic Techniques for Antennas)

RF-to-RF characterization

- Phased array antenna: principle of operation

Beam forming network: **Delay on**

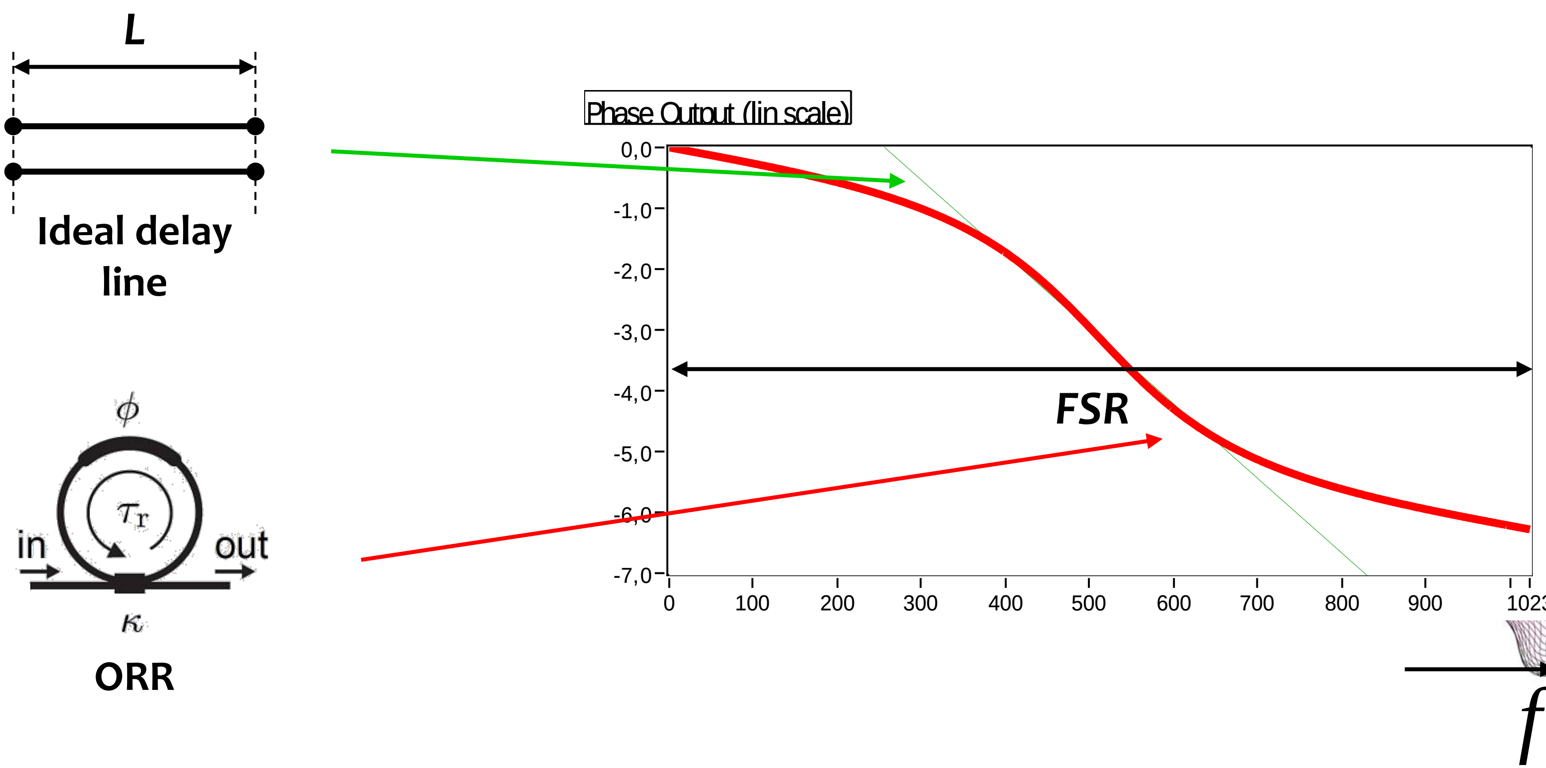


Requirements

- Broadband phased antenna arrays require true time delays
- Not easy to be realized over a broad band
- Photonic technology can help…

RF-to-RF characterization

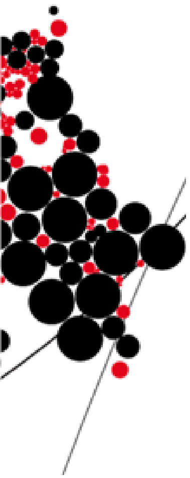
- **Optical delay generation:** implemented using *optical resonators*
- Comparison of an Optical Ring Resonator (ORR) with an ideal delay line:

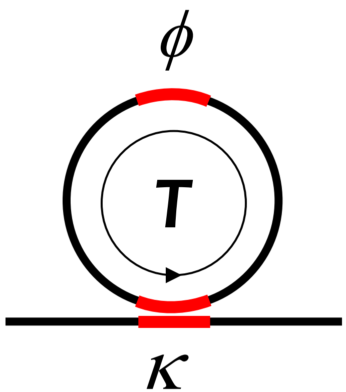


RF-to-RF characterization

- Optical delay generation

Optical ring resonator:

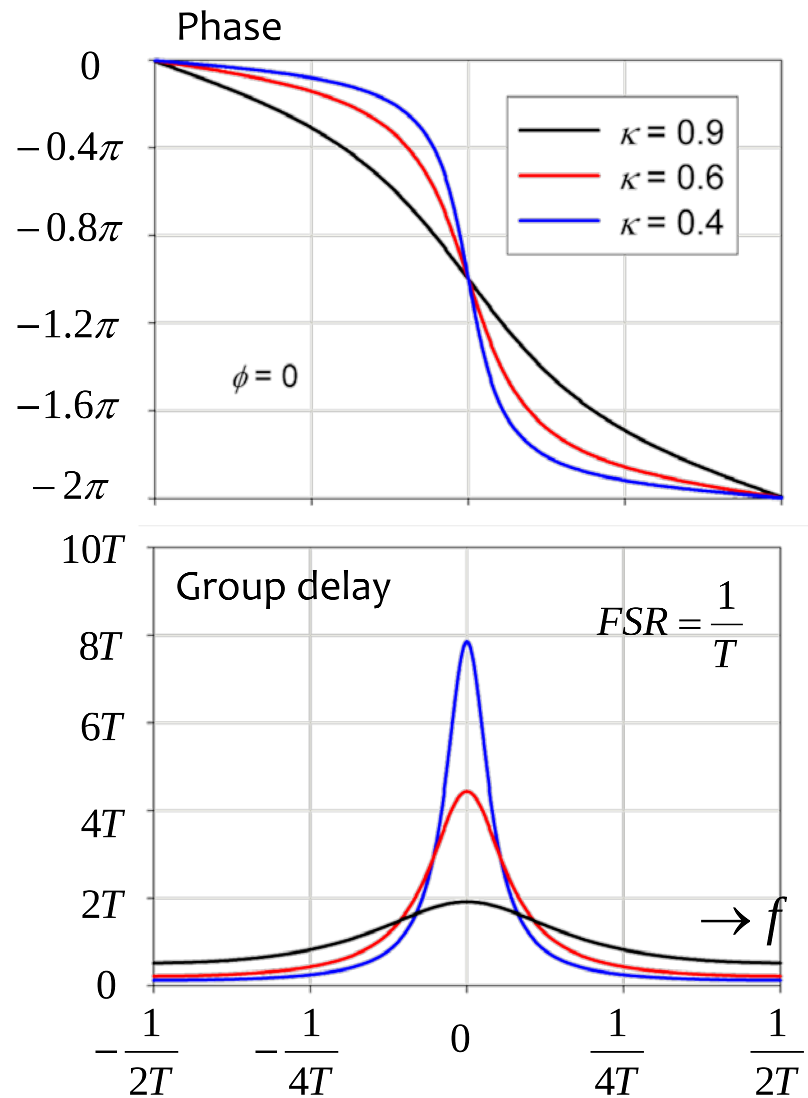


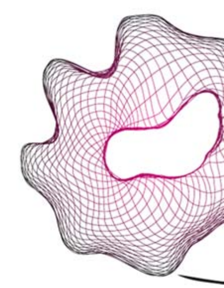


T : Round trip time

κ : Power coupling coefficient

ϕ : Additional phase



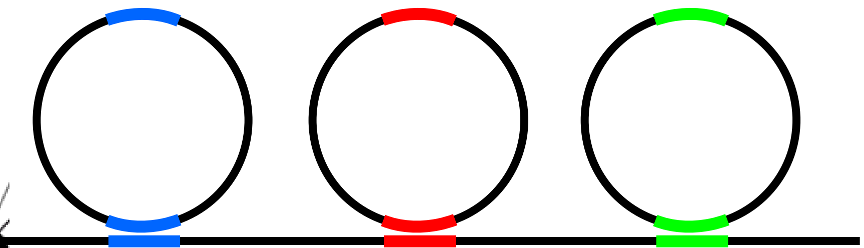


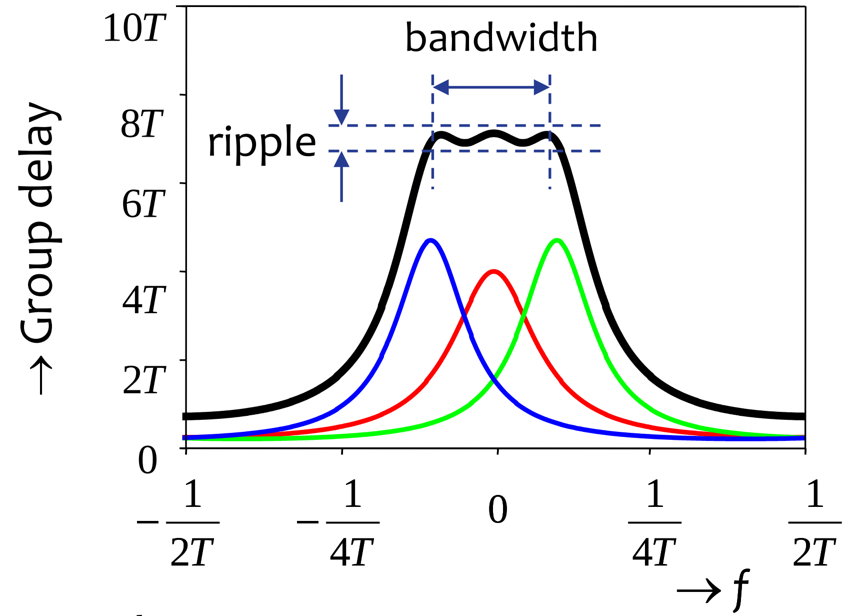
Trade-off: <u>delay vs bandwidth</u>

RF-to-RF characterization

- Optical delay generation

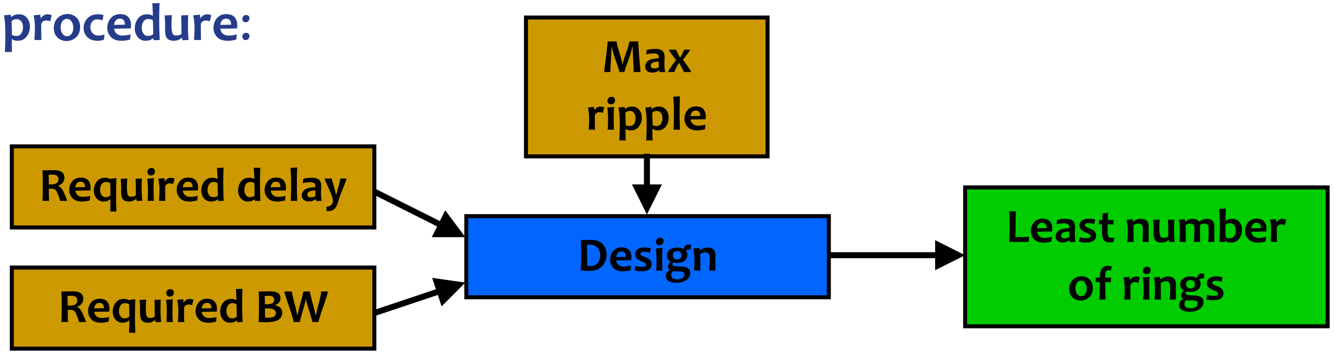
Cascaded ring resonators:





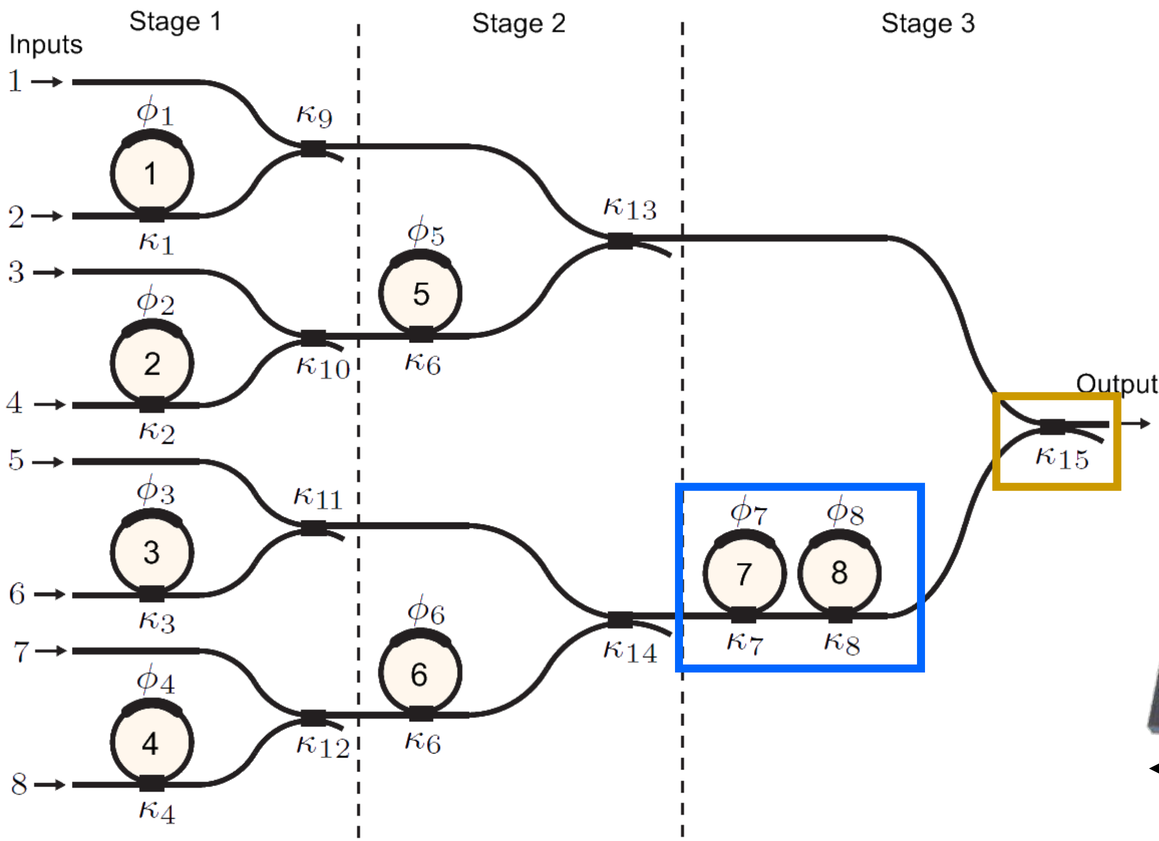
- Enhanced bandwidth
- Trade-off: <u>delay vs. bandwidth vs. delay ripple vs. no. rings</u>

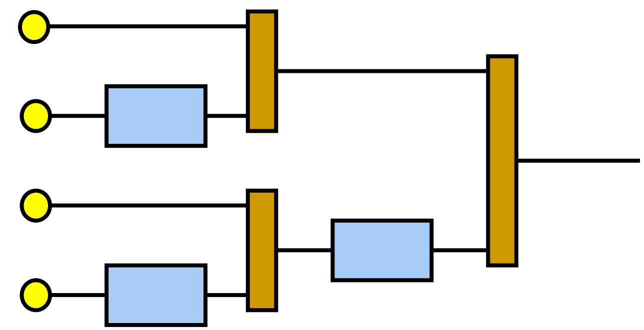
Design procedure:



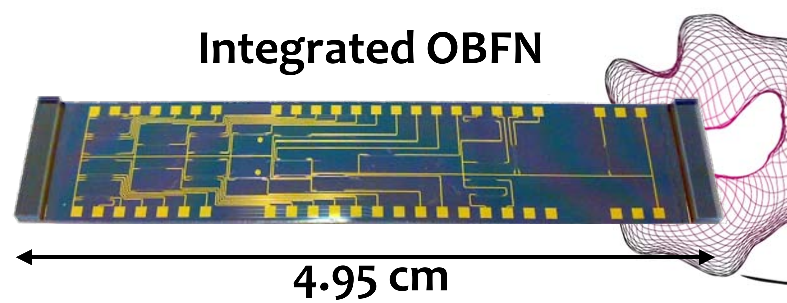
RF-to-RF characterization

- Optical beam forming network (OBFN): binary tree architecture
- Reduction in the number of rings



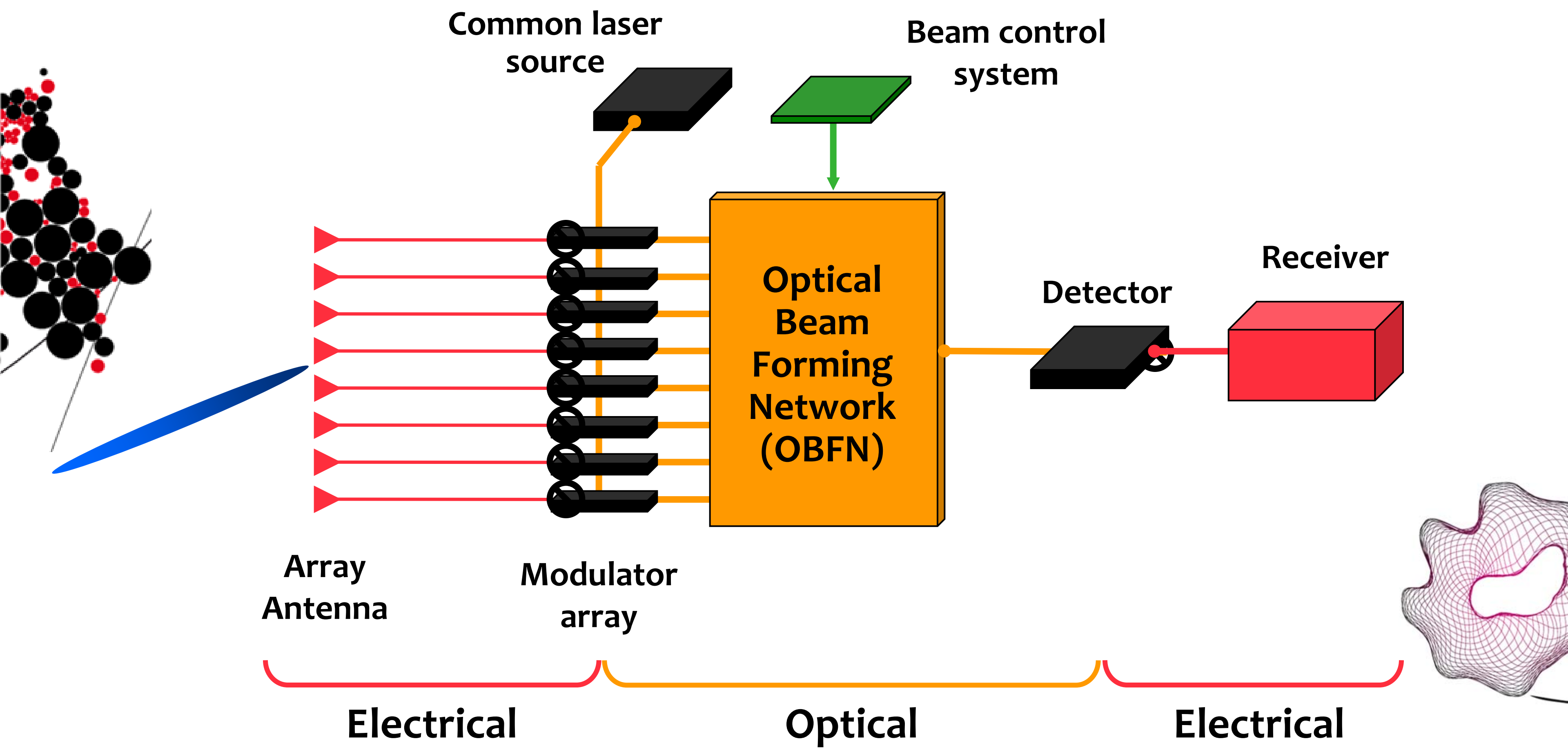


Integrated OBFN



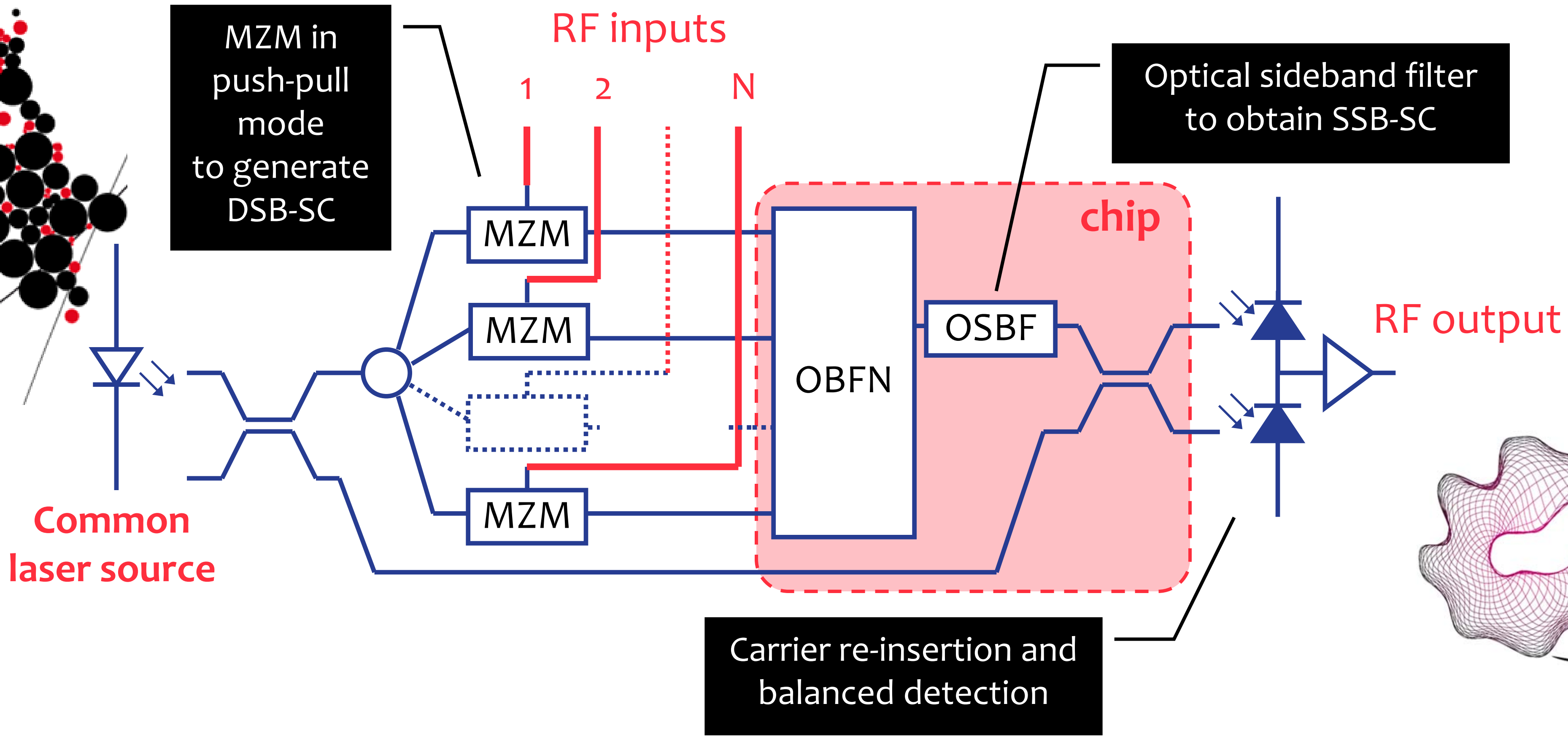
RF-to-RF characterization

- E/O and O/E conversion



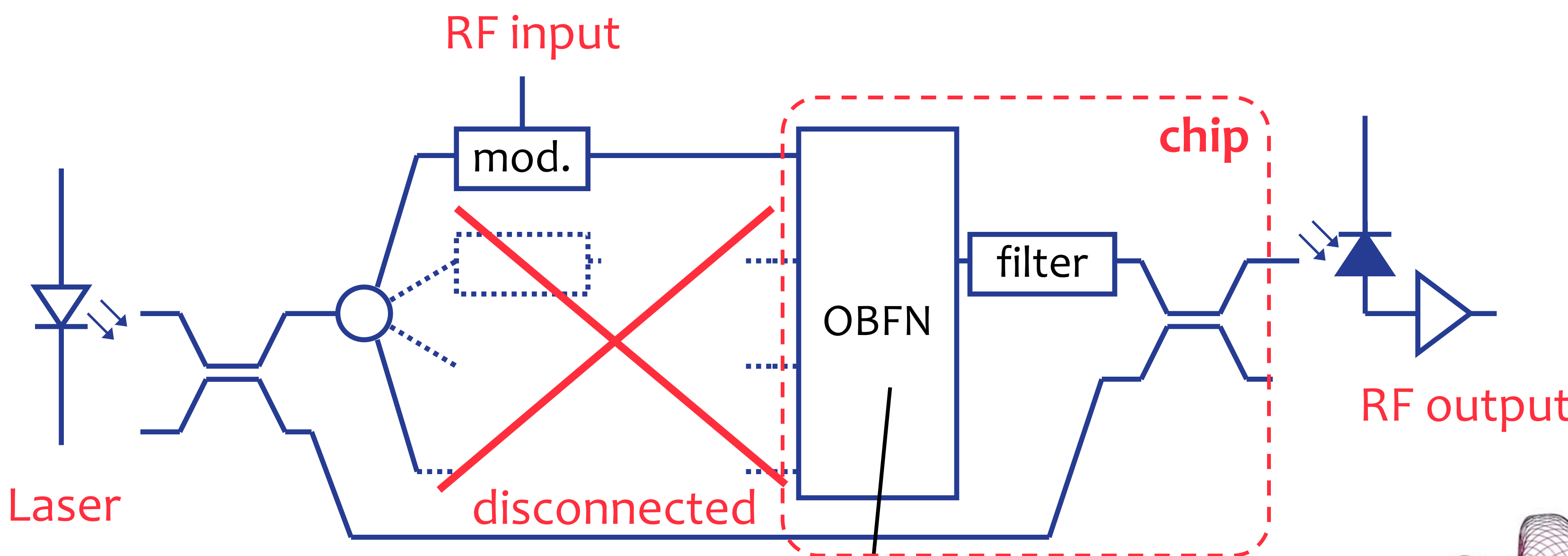
RF-to-RF characterization

- Hybrid measurement setup
- Optical SSB–SC modulation with balanced detection



RF-to-RF characterization

Phase response (broadband delay generation)

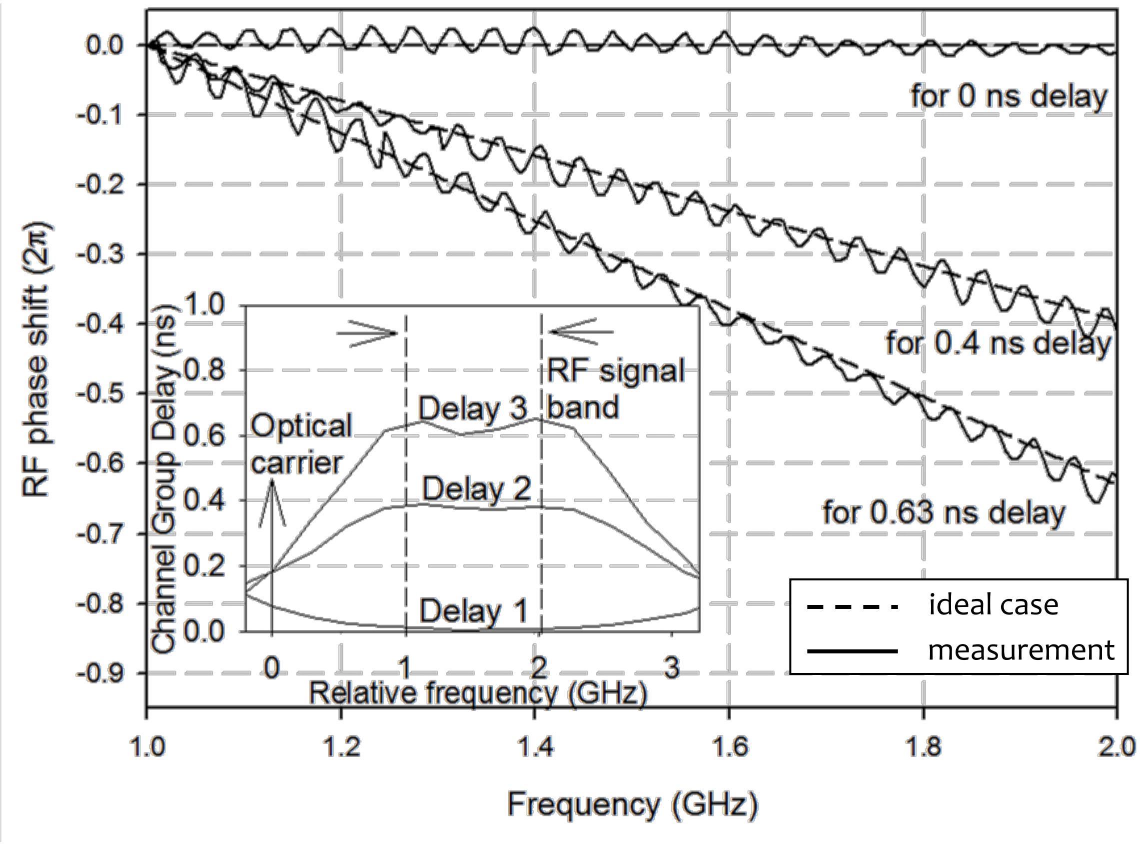


3 different settings
of the delay line
(0 ns, 0.40 ns, 0.63 ns)

RF-to-RF characterization

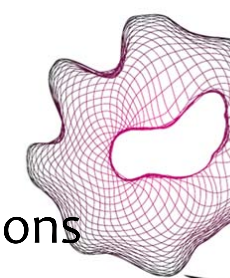
Phase response (broadband delay generation)

- Results [1]



RF phase shift vs frequency

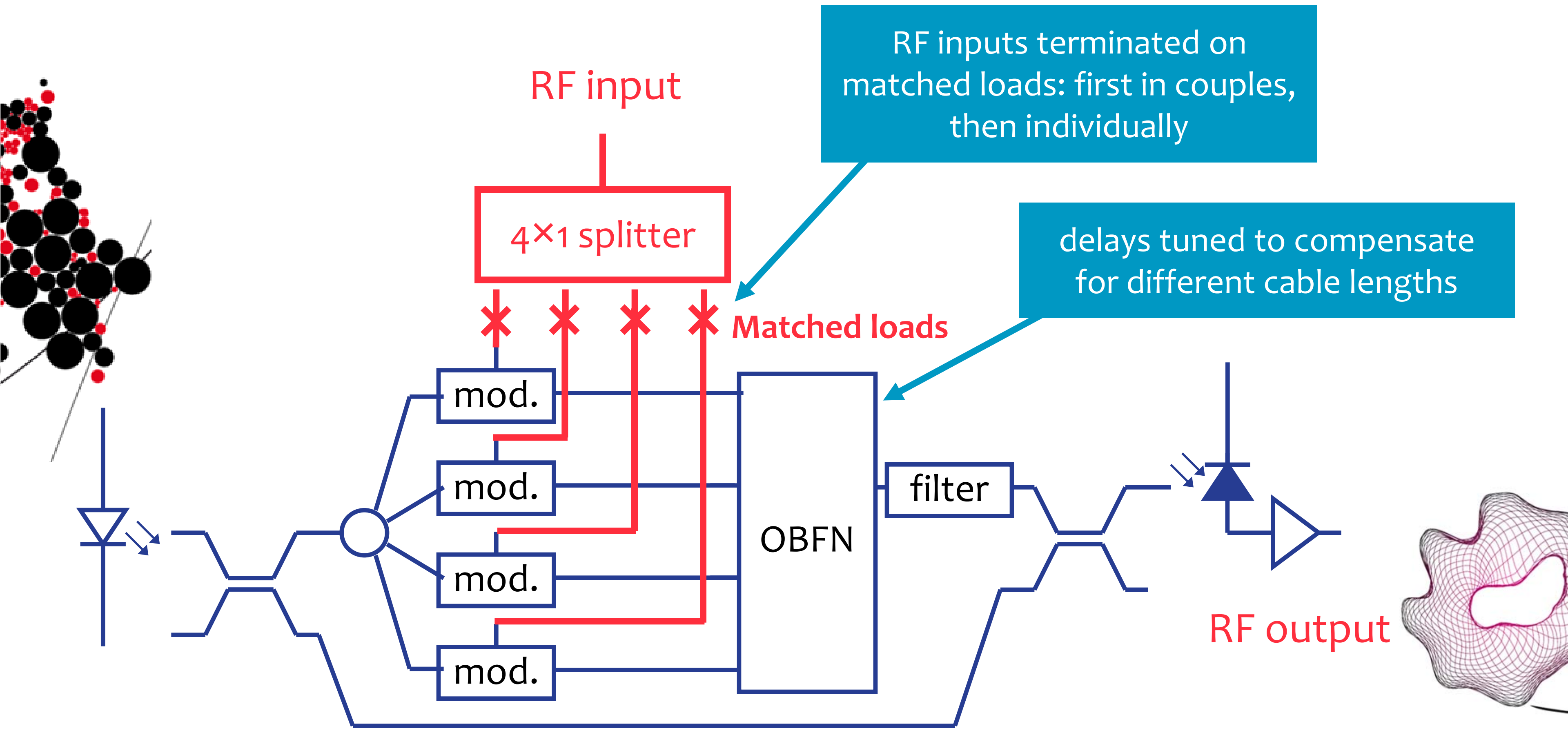
- 3 delay settings: 0 ns, 0.4 ns, 0.63 ns
- **Linear phase characteristic** with frequency
- TTD operation demonstrated
- Ripple due to the Fabry-Perot reflections in the fiber connectors



[1] *"RF-to-RF Characterization of a Phased Array Receive Antenna Steering System Using a Novel Ring Resonator-Based Integrated Photonic Beamformer"*, L. Zhuang, M. Burla, C. G. H. Roeloffzen, A. Meijerink, D. A. I. Marpaung, M. R. H. Khan, W. van Etten, A. Leinse, M. Hoekman, R. G. Heideman, MWP 2009, Valencia, Spain, 14-16 Oct. 2009.

RF-to-RF characterization

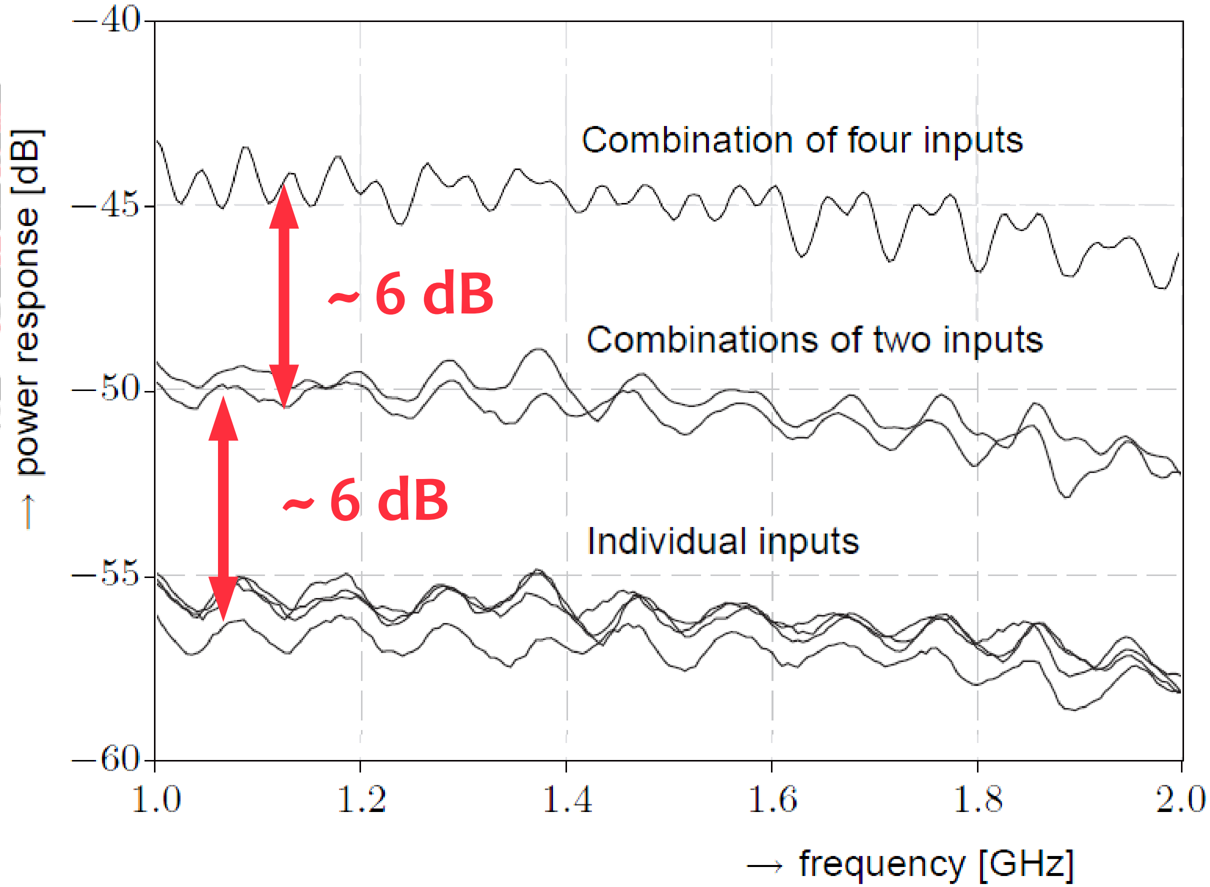
Power response (coherent combining)



RF-to-RF characterization

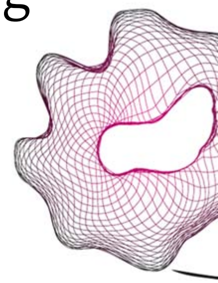
Power response (coherent combining)

- Results



RF power output vs frequency

- 6 dB increase of the RF power level each time the number of combined signals is doubled
- Coherent combining demonstrated

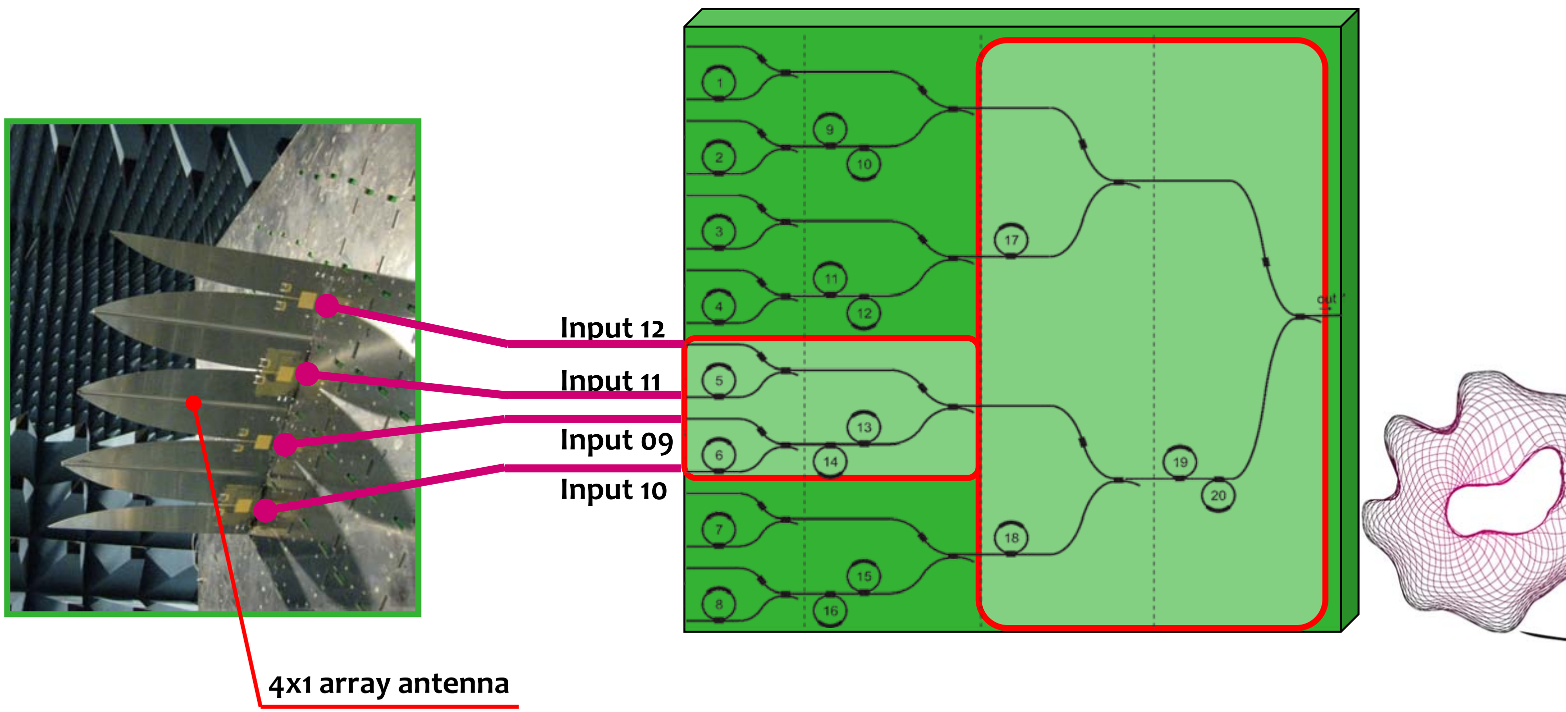


OBFN measurement: “SKY” demonstrator

Within SKADS (Square Kilometer Array Design Study)

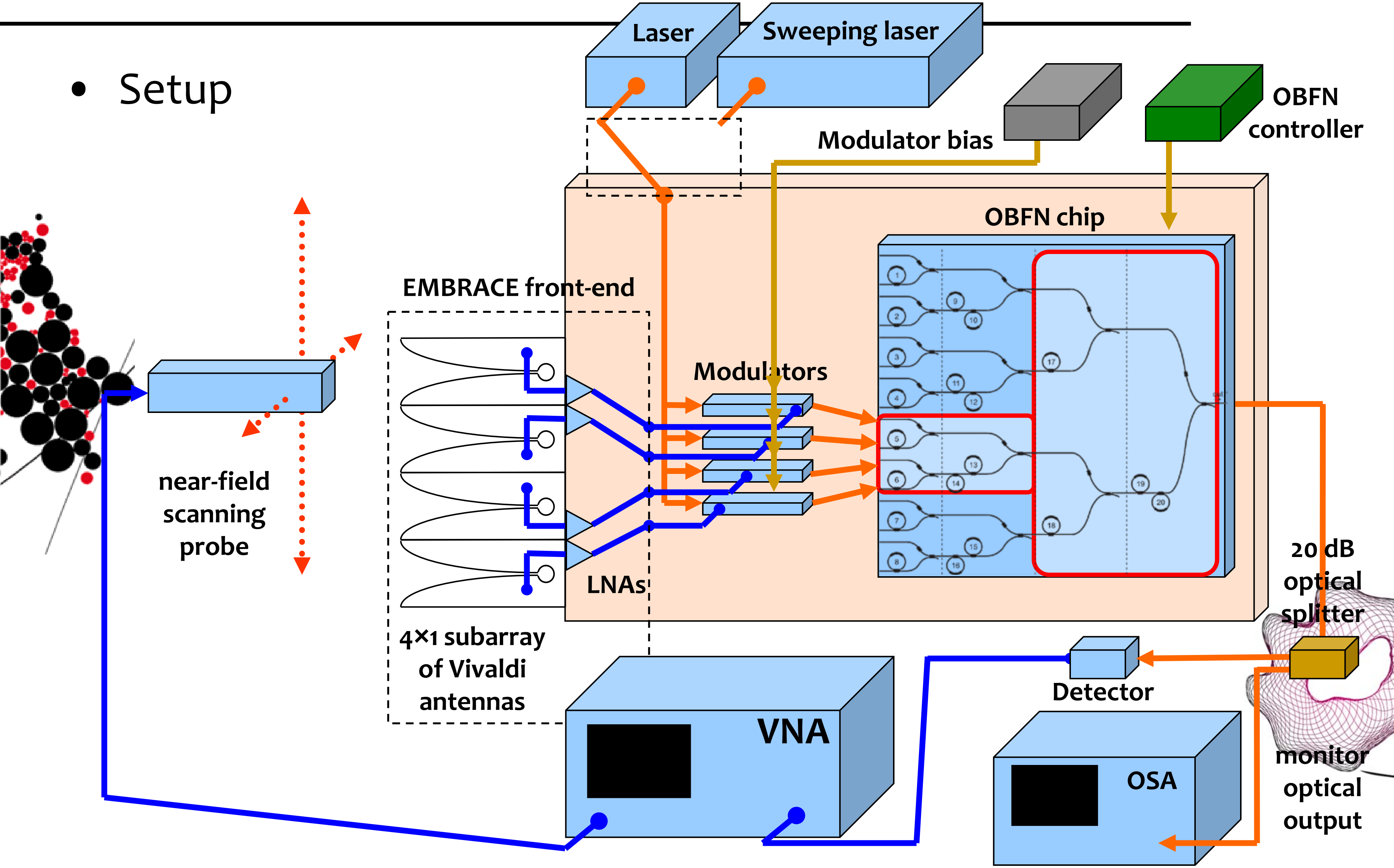
SKY demonstrator: an RF Photonic test bench

- Work carried on in ASTRON: modification of the EMBRACE phased array by using a **photonic beamformer**
- Operating band: **500-1500 MHz**
- Use of a **subarray** of the original EMBRACE tile



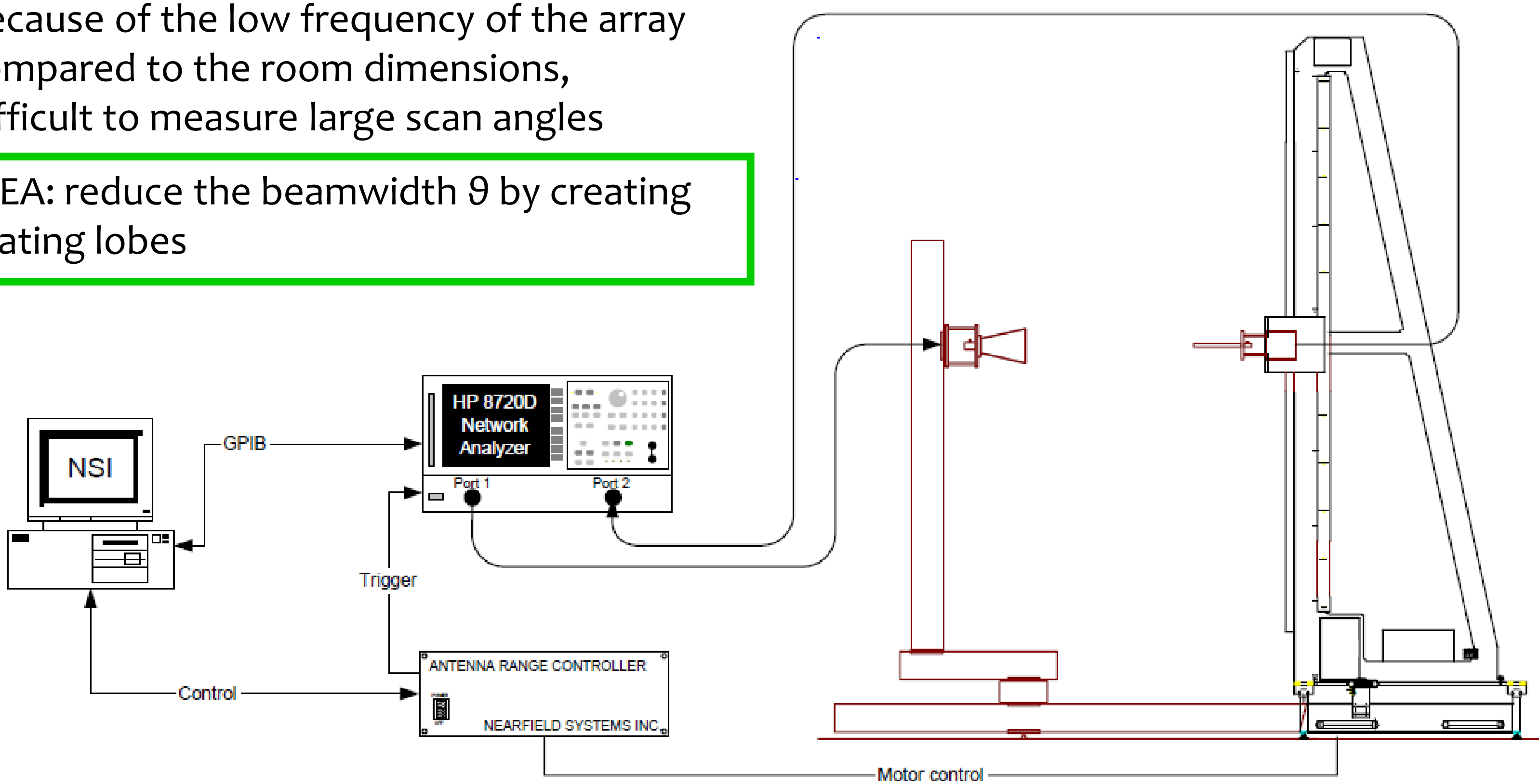
SKY demonstrator

- Setup



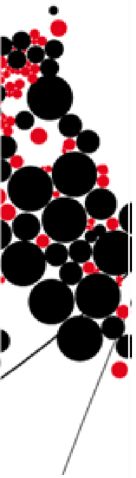
Preliminary demonstrator

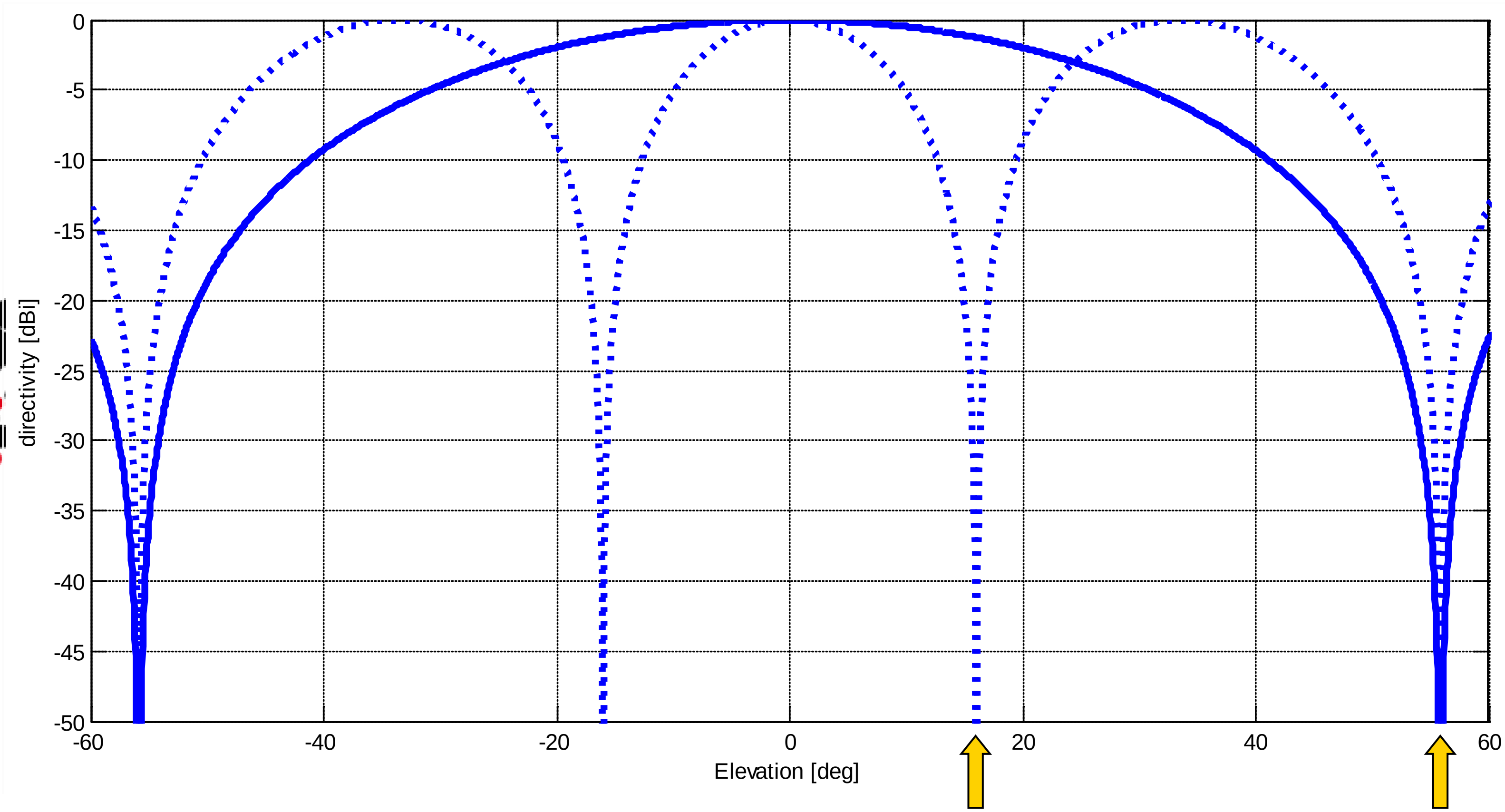
- Near-field antenna measurement
  - Far-field are calculated using FFT on the basis of a near-field measurement
  - Started by measuring an array of 2 AEs
  - Because of the low frequency of the array compared to the room dimensions, difficult to measure large scan angles
  - IDEA: reduce the beamwidth ϑ by creating grating lobes



Preliminary demonstrator

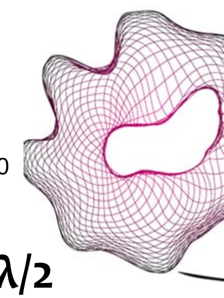
- Simulated patterns



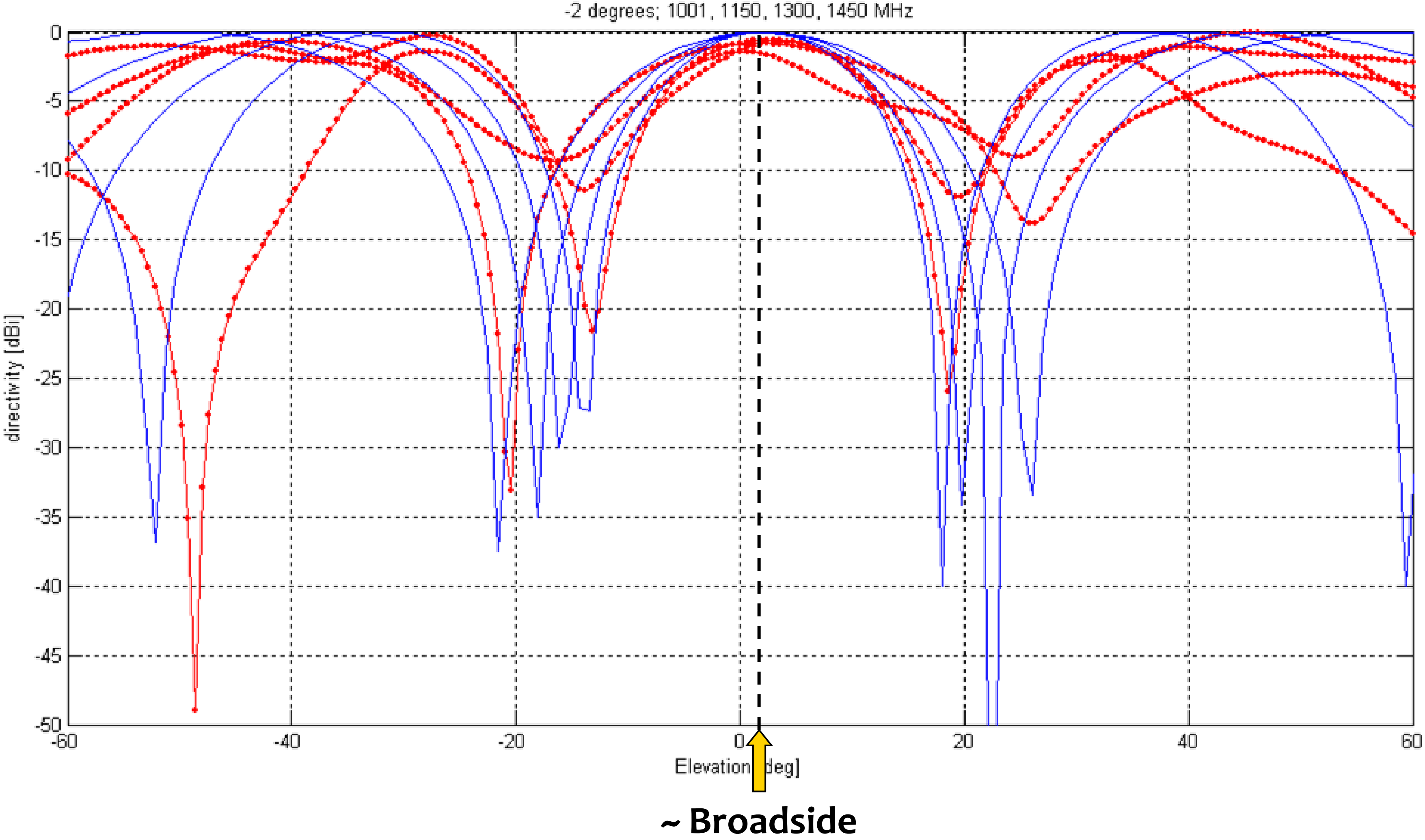


2×1, d = 3λ/2
15.9 deg

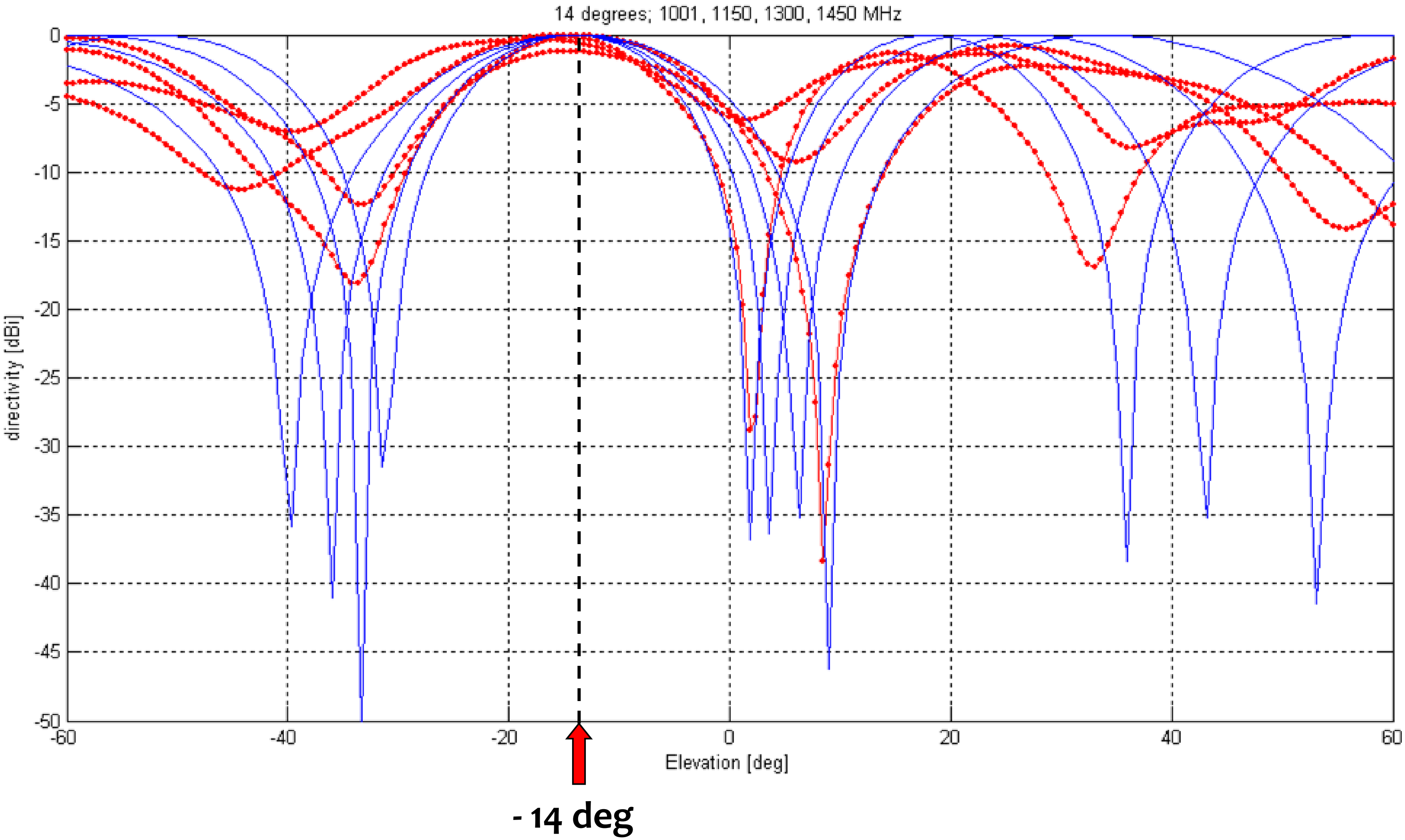
2×1, d = λ/2
55.6 deg



Preliminary demonstrator

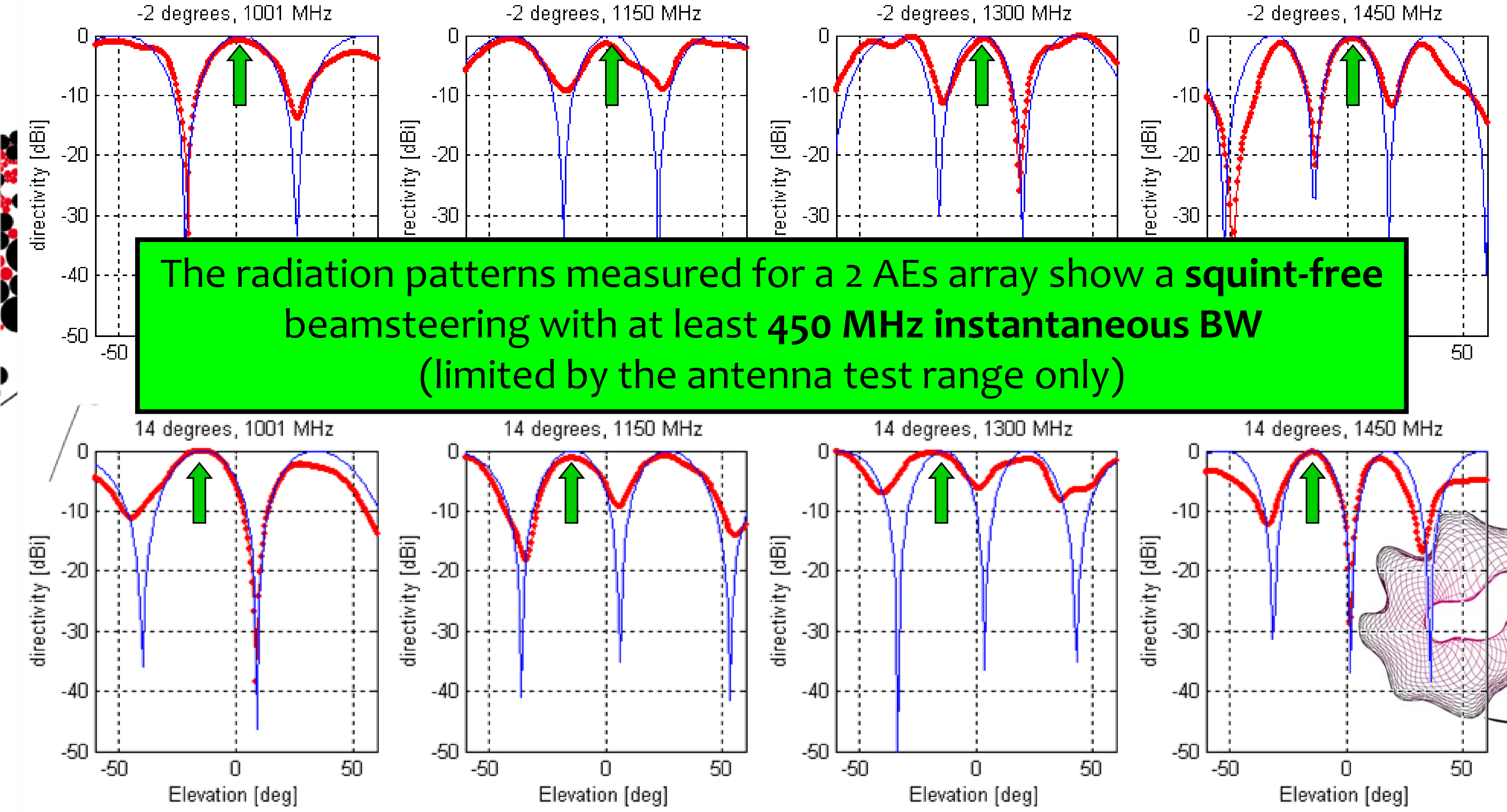


Preliminary demonstrator



Preliminary demonstrator

- Antenna patterns: simulated vs measured



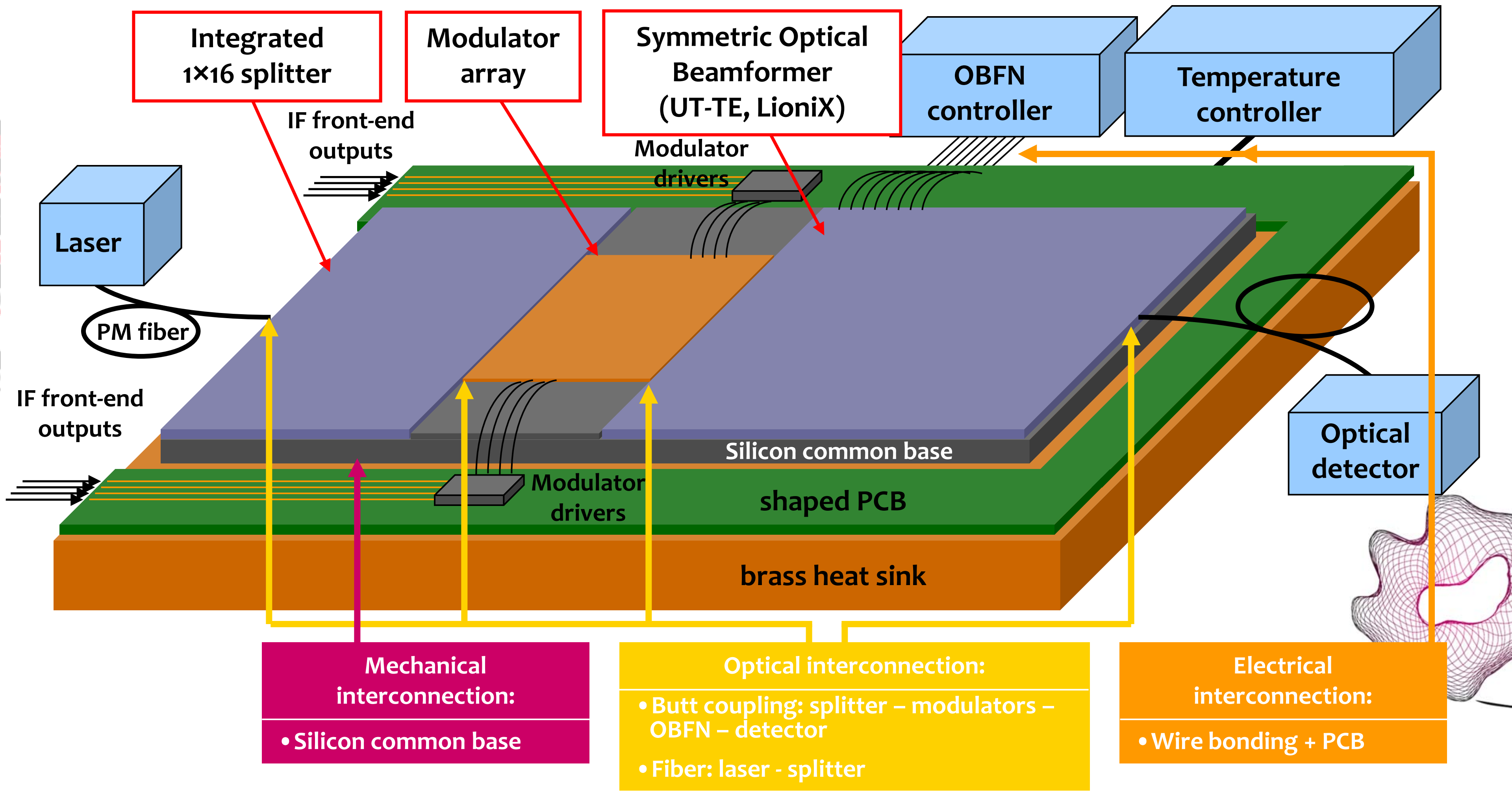
The radiation patterns measured for a 2 AEs array show a **squint-free** beamsteering with at least **450 MHz instantaneous BW** (limited by the antenna test range only)

Towards optical integration

- Current work: *extension* to more antenna elements
- Difficulties: optical *phase de-synchronization* issues due to the presence of several meters of fiber between the splitting and the combining points generate output power fluctuations
- Need for **integration** to fully exploit the advantages given by the optical beamformer
- Current ongoing national and European projects (MEMPHIS, SANDRA) aim to a fully integrated system

OBFN integration

- *Application*: phased array antenna for airborne **Ku-band TV-SAT** receiver



New OBFN designs

- **New OBFN designs**

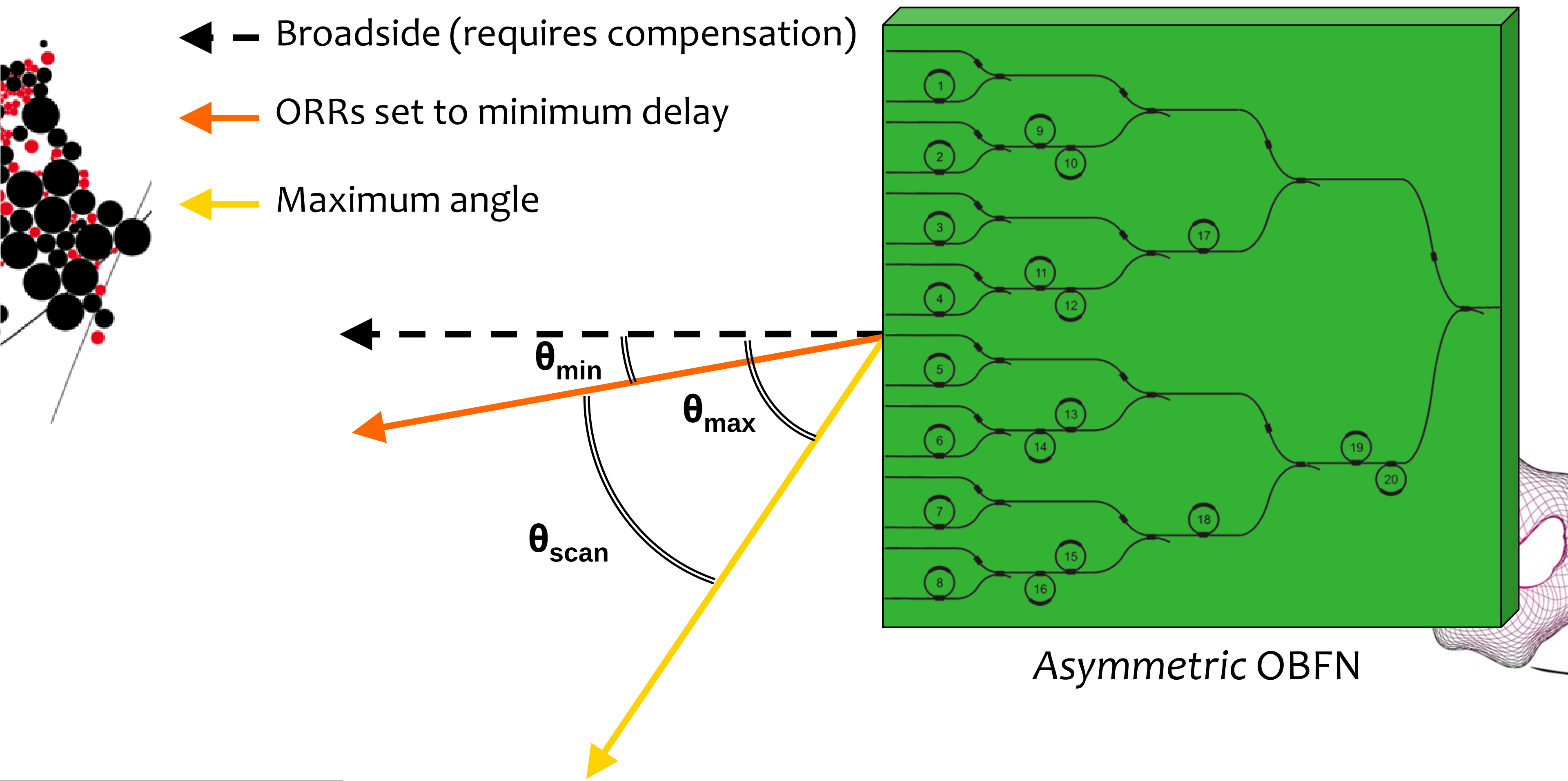
1. ***Symmetric OBFN***
   for built-in symmetric beamsteering

2. ***Multi-wavelength OBFN***
   employing ORR periodicity for ***reduced dimensions***

3. ***Multi-beam OBFN***
   for ***multiple simultaneous beams***
   - studies and simulations addressing several possible architectures

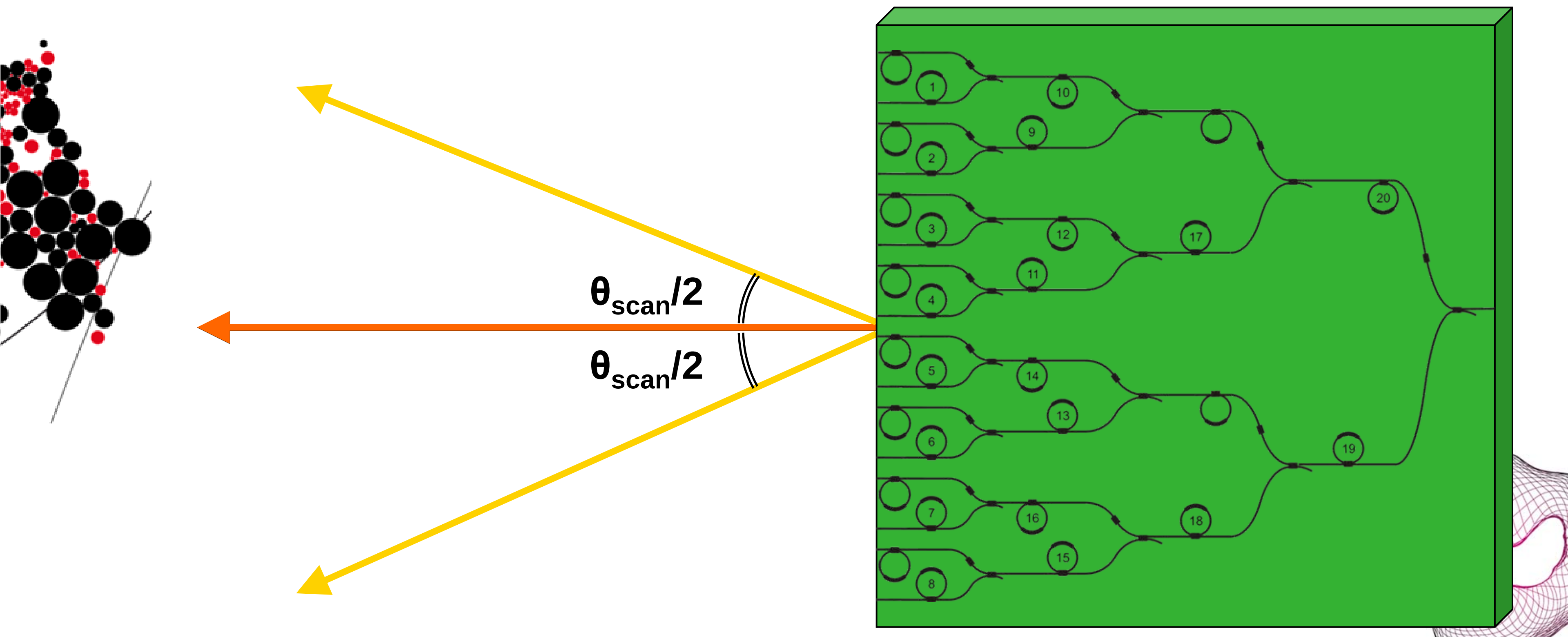
New OBFN designs

1. **Symmetric OBFN** (demonstrator 2)**:** *built-in symmetric beamsteering*



New OBFN designs

1. **Symmetric OBFN** (demonstrator 2)**:** built-in symmetric beamsteering

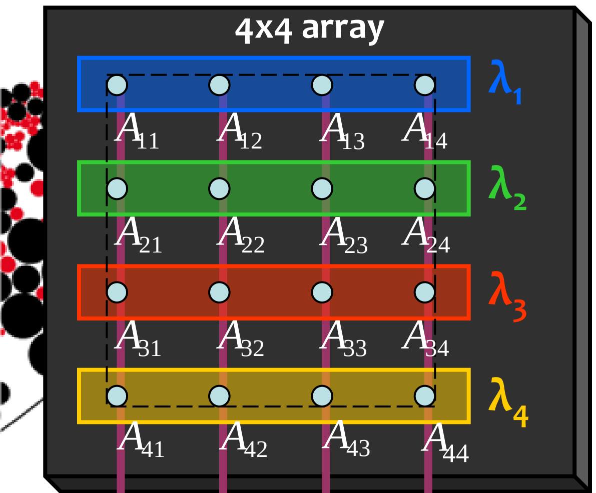


Symmetric OBFN

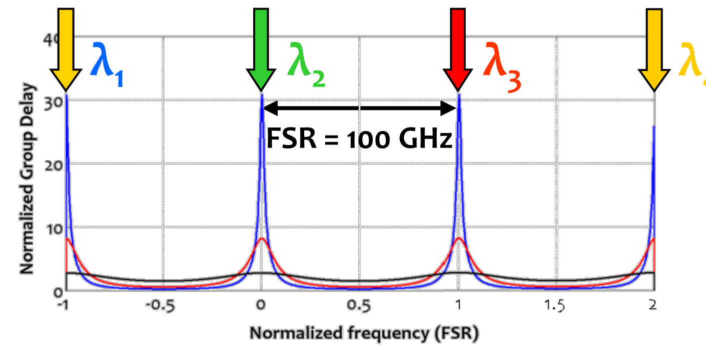
New OBFN designs

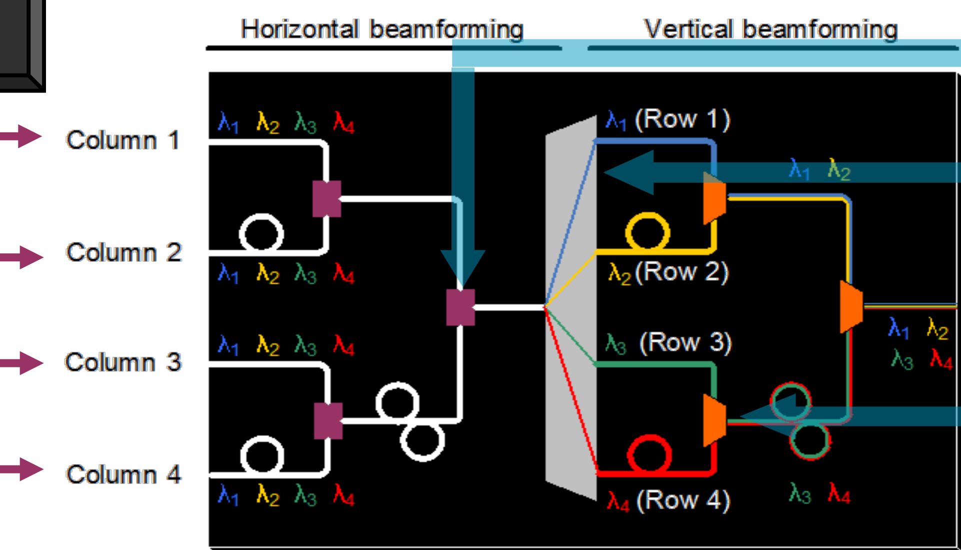
2. Multi-wavelength OBFN: use peculiar advantages of photonic systems

- Exploit the **frequency periodicity** of the ORR to realize a compact MWL system



Reduced dimensions & complexity: 8 rings instead of 20





Wavelength multiplexing (WDM):

4 wavelengths per channel

Combiner
Symmetric MZI

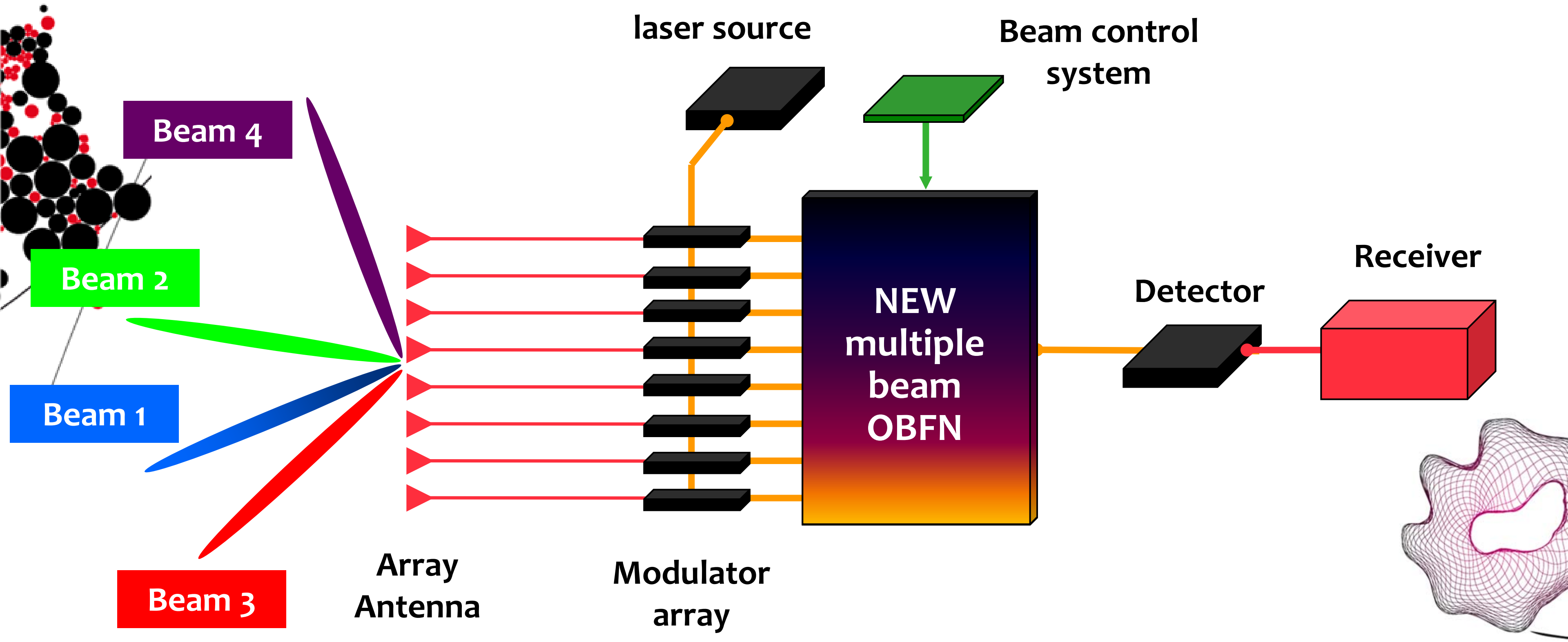
1x4 DE-MUX
Asymmetric MZI
(FSR: 200 GHz 1st stage 400 GHz 2nd stage)

2x1 MUX
Asymmetric MZI

LabView model has been implemented

New OBFN designs

3. **Multi-beam OBFN:**
   multiple simultaneous & independent beams

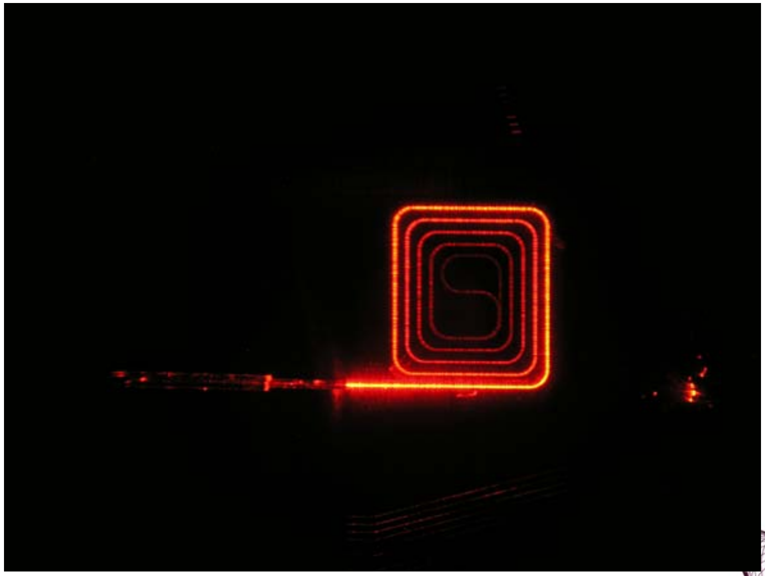


- possible FPA application

Waveguide technology

- Waveguide technology optimized for **low loss** propagation: new geometry defined

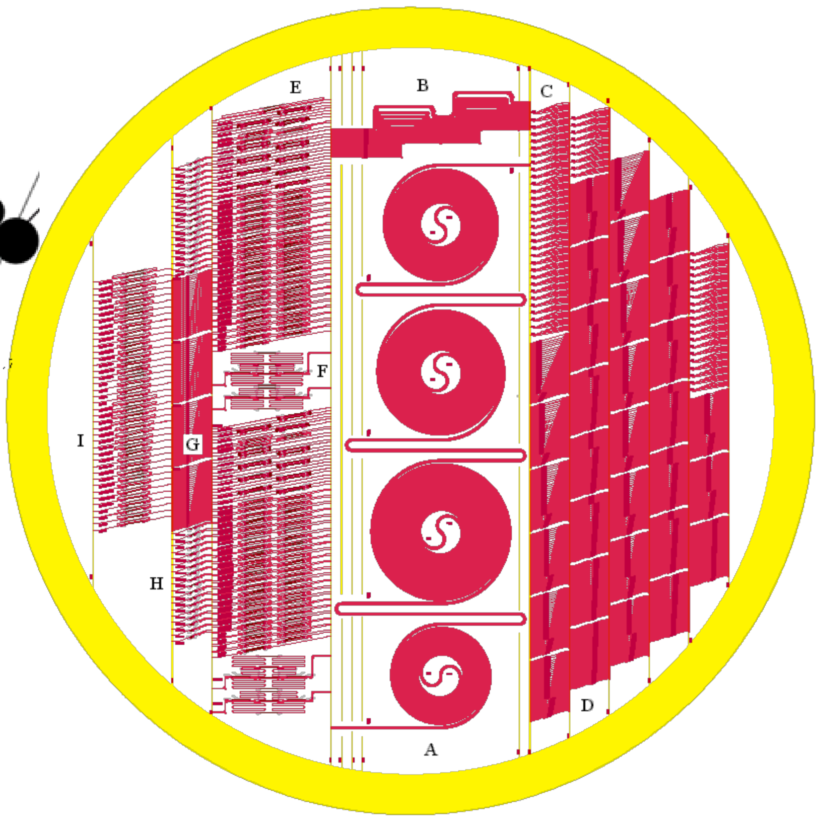
“old” “new”



- First test samples finished. Results look promising (Expected atten. <0.2 dB/cm, bend. radius ≈ 100 um)

Waveguide technology

- Realization of Basic Building Blocks (BBBs) on test mask for characterization (from FP7 SANDRA project)



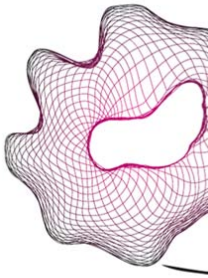
Fabrication and characterization of the BBBs will be the input for the new OBFN geometry

Conclusions

Conclusions

Optical Beamformers based on Optical Ring Resonators

- RF-to-RF measurements demonstrated:
  - ✓ **continuously tunable delay generation** - phase response
  - ✓ **coherent combining capability** - power response
- "SKY" OBFN demonstrator:
  - ✓ Radiation patterns measured for a 2 AEs array show a **squint-free** beamsteering with **at least 450 MHz instantaneous BW**
  - ✓ Currently being extended to more AEs
- Ongoing research for **new OBFN architectures** for:
  - ✓ symmetric scanning, reduced size, multiple beams (FPAs)



- Currently completing a flexible control system for beam shape control

UNIVERSITY OF TWENTE.

Thank you

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