Optical Beam Forming Networks (OBEFONE)

Final Presentation

ESTEC, November 21st 2008

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Introduction

J.M. del Cura
SENER

Project Team

- Prime Contractor:
  - SENER : Project Management and System Engineering
- Subcontractors:
  - UPV: OBFN Definition, Design and Development for the hybrid architecture and Fiber-based
  - UPC: OBFN Testing (Includes antenna development) for the hybrid architecture
  - TSA: Free-Space architecture
- TRP Project.
  - KOM in Feb 2005
  - Complemented with a CCN

Motivation of the Project

- **The trend in Telecom and EO missions → high performance leading to high complexity**
- **Key requirement → operation at wide bandwidths:**
  - broadband data connections,
  - multi-user operation rates
  - wider communications coverage
  - on-board information processing
  - dynamic allocation of resources
  - high resolutions within a wide observation area in EO missions
- **Increasing need of sophisticated PAA in communication and radar antennae:**
  - Wideband → **TTD**
  - Angular coverage
  - Resolution

↓ **Optical BFN technologies**

OBEFONE

Motivation of the Project

Mission	SEASAT	ERS1	ENVISAT	TerraSAR-X	CosMo-SkyMed	PAMIR
Operational Period	1978	1991-1998	2002-	2007-	2007-	
Frequency-Band	L-band	C-band	C-band	X-band	X-band	X-band
Bandwidth	19 MHz	16 MHz	16 MHz	300 MHz	500 MHz	1800 MHz
Spatial Resolution	25 m	30 m	30 m	1 m	1 m	10 cm
Steering Angle	-	-	10-45º	20-45º El +/- 0.75º Az	+/- 15º El +/- 1º Az	+/- 45º El +/- 45º Az
T/R modules	-	-	320	384	1280	256
Observations	Single Frequency	Single Frequency	Polarimetric capability	Fully polarimetric	Multibeam	

Complex OB system and antennas: large instantaneous bandwidths, wide scanning ranges and multiple simultaneous beams

Motivation of the Project

- **Alternative to beamforming networks implemented in MMICs is needed.**
- **General trends:**
  - Higher frequency developments
  - Antenna bandwidth above 1GHz bandwidth (UWB)
  - Radiation pattern for scanning in the range from ±15º to ±45º
  - Sidelobes below -40dB to -50dB
  - Antenna aperture area and element number

Hybrid Architecture

B. Vidal

UPV

Architecture description

Free Space

+

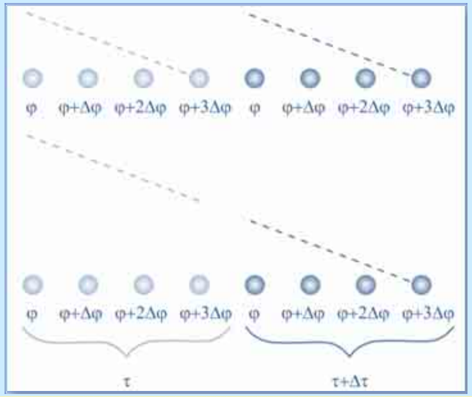
Fiber

Hybrid Architecture

Combination of benefits from:

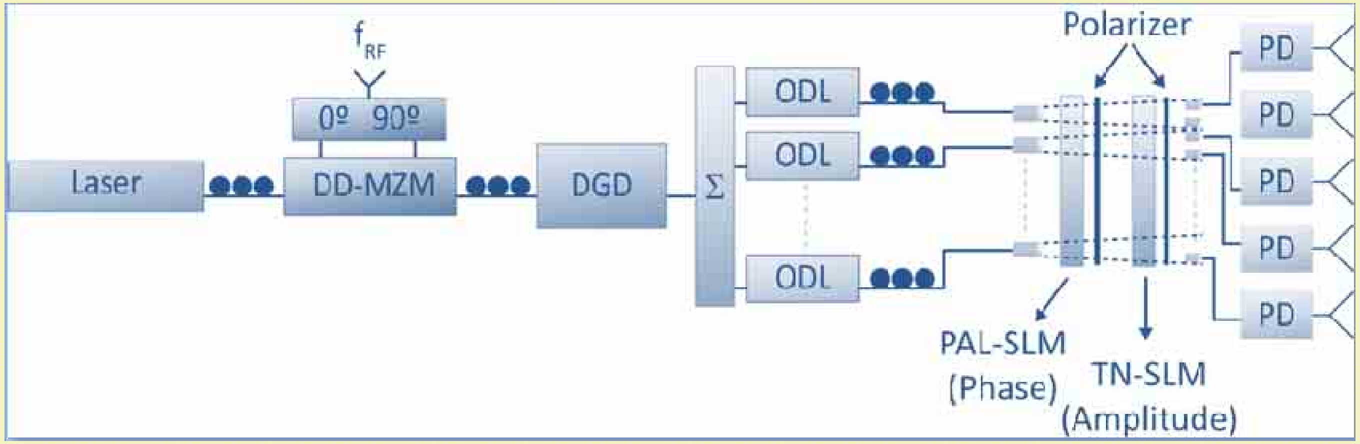
Free-Space optics: Parallelism

Fiber optics: Simple low-loss TTD generation to moderate number of elements → TTD to subarrays



Architecture description

Transmission Mode



Test plan

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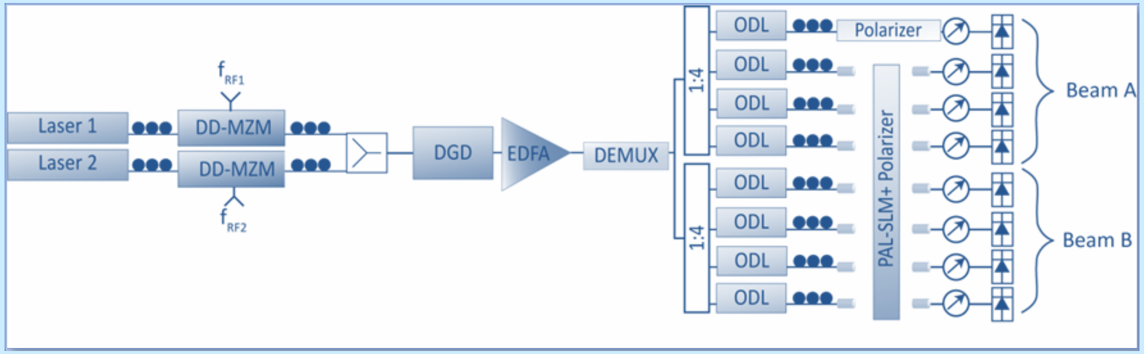
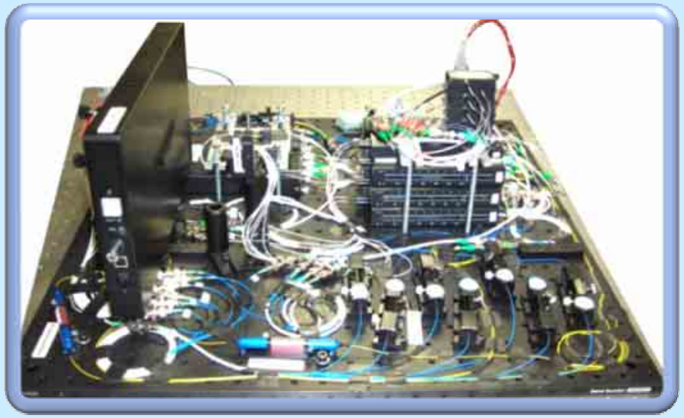
Amplitude and phase measurements	Determination of the radiation pattern for 9 different elevation angles (within a range of ± 20 deg) at 5 frequencies (8GHz ± 0.25GHz, ± 0.5GHz).
Non-uniform distribution	Determination of the radiation pattern moreover for a triangular and a Taylor distribution.
Multibeam	Estimation of the radiation pattern for a uniform amplitude distribution at 8 GHz.

Experimental results

Demonstrator architecture

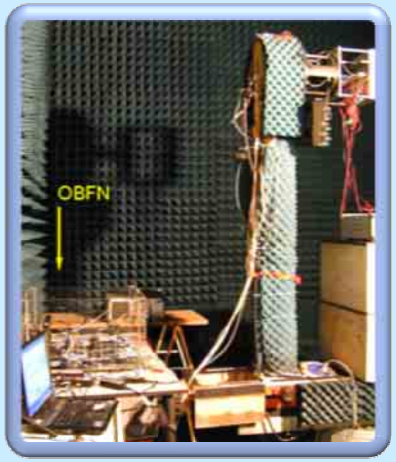


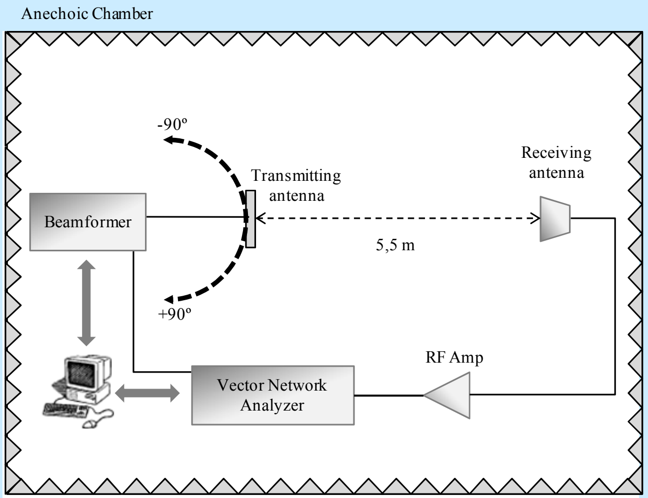


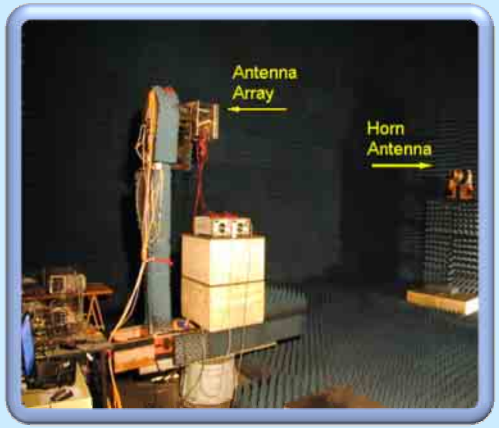
OBEFONE

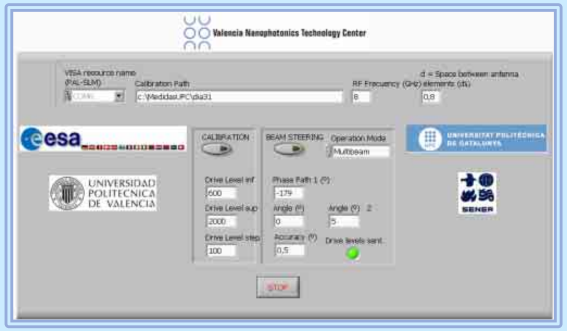
Experimental results

Experimental Setup









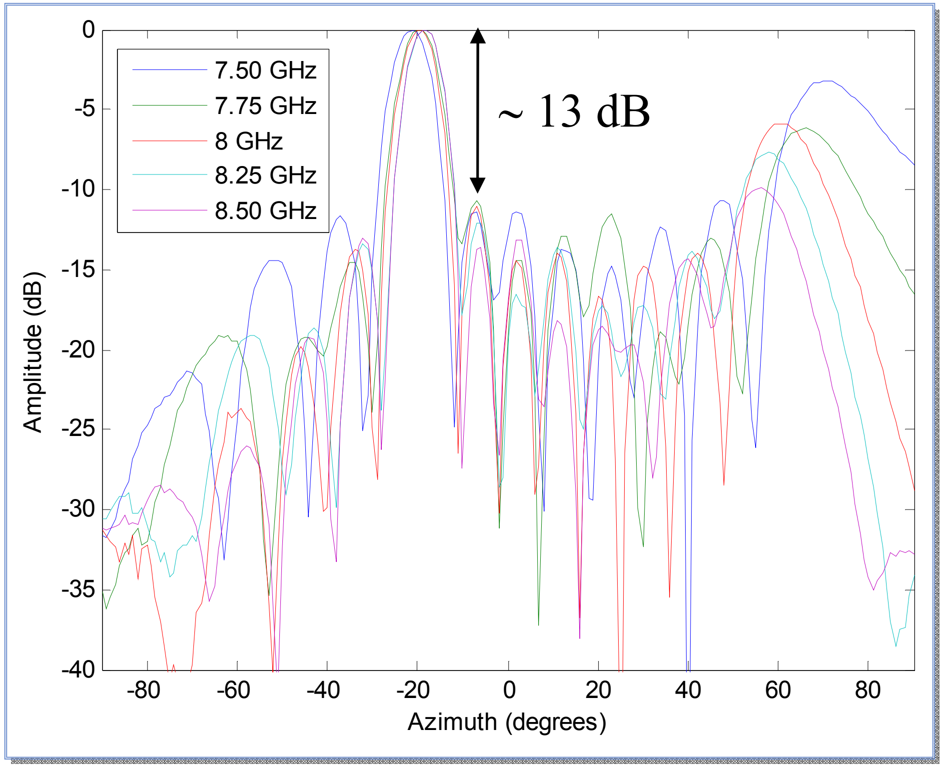
Experimental results

Beam Steering

SQUINT

Frequency (GHz)	Δθ (º)
7.5	1.4
8.5	-1.2

Radiation pattern of the optically controlled phased array antenna (8 elements) steered at -20º

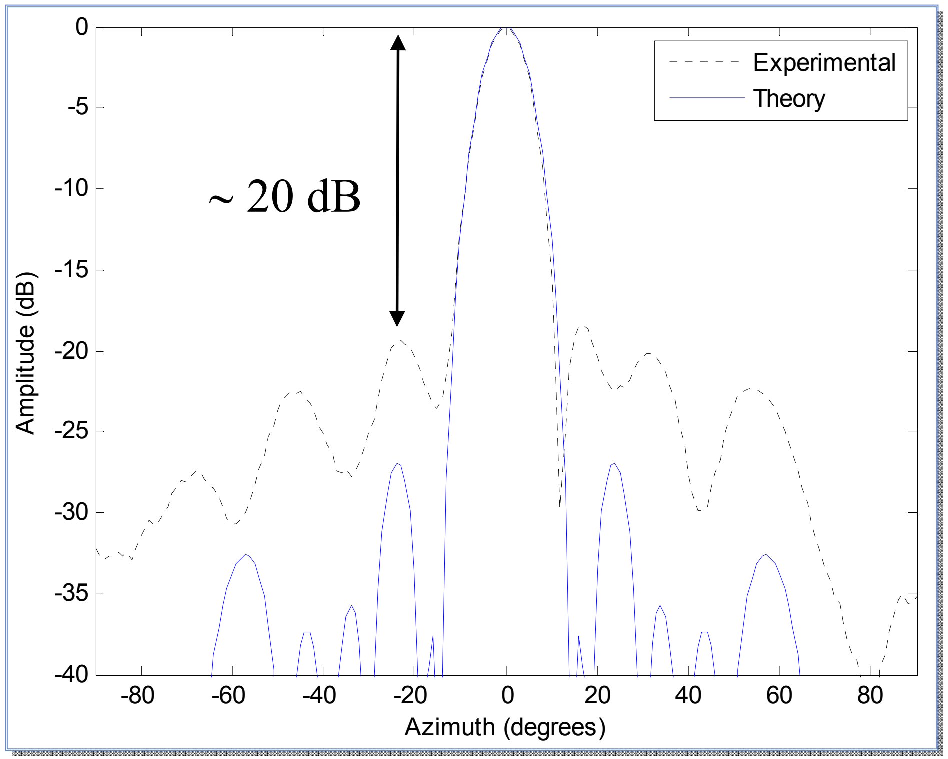


Experimental results

Apodization

	Power (dB)
Channel 1	-12
Channel 2	-6.02
Channel 3	-2.5
Channel 4	0
Channel 5	0
Channel 6	-2.5
Channel 7	-6.02
Channel 8	-12

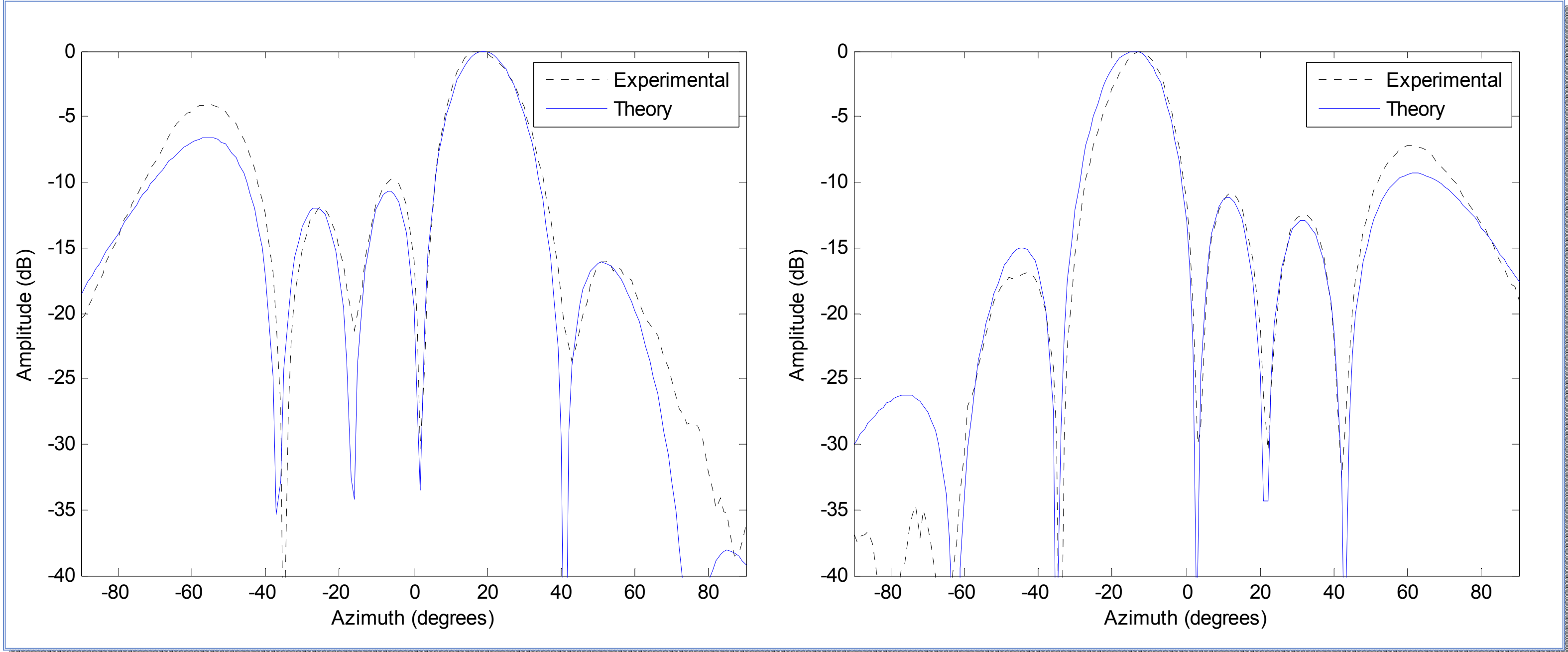
Radiation pattern of the beamformer at 8 GHz , 0º beamsteering angle and triangular weighting



Experimental results

Multibeam Capability

Radiation pattern for the multibeam operation (-13º, 18º)



Conclusion

All-optical implementation of a beamforming network for phased array antennas based on a Nematic Spatial Light Modulator in parallel configuration (PAL-SLM) with phase, amplitude and time delay control.

Advantages:

- Control of a large number of antenna elements using a single PAL-SLM.

Disadvantages:

- The scalability of the demonstrator is limited by the need of collimated beams and diffraction issues.
- Commercial PAL-SLM provide only slow beam switching speed (70ms), limiting the range of potential applications to low speed beamforming systems.

Fiber-based Architecture

B. Vidal

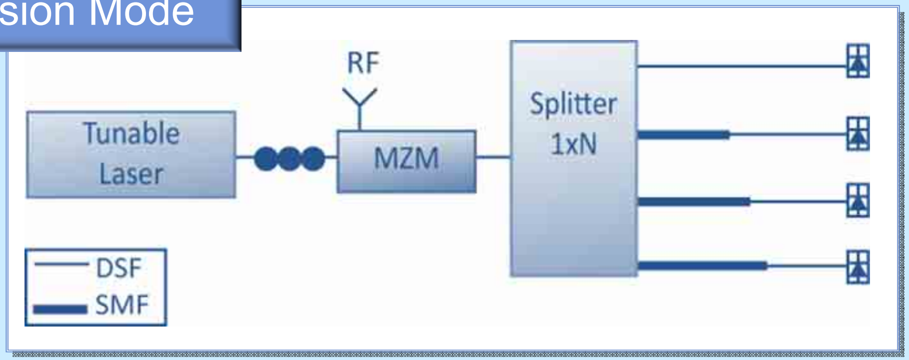
UPV

Architecture description

- ✓ Scalability
- ✓ High beam steering switching speed (< 10 μs)
- ✓ Multibeam capability (limited to two beams)
- ✓ Compactness

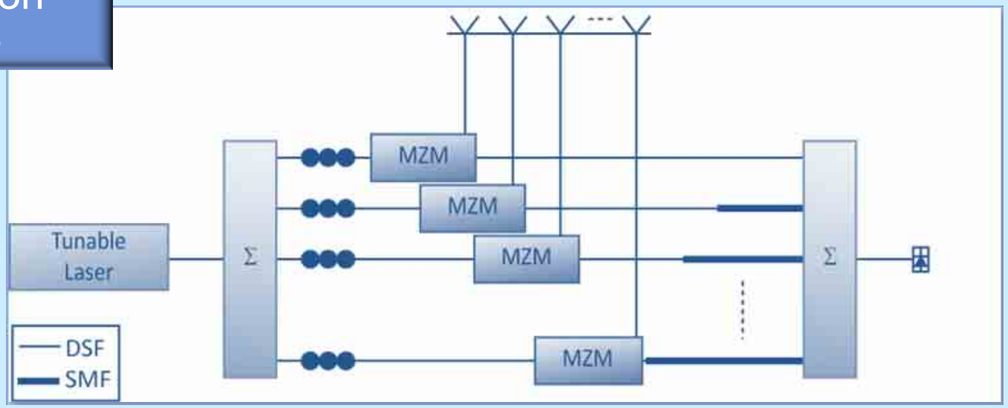
Architecture based on a dispersive prism

Transmission Mode

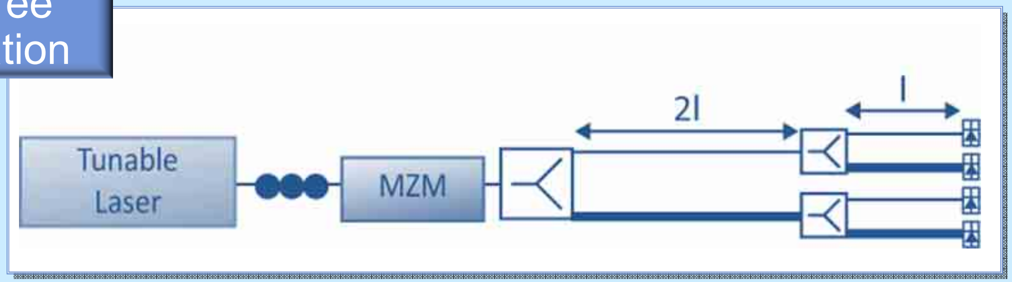


Architecture description

Reception Mode



Binary-tree configuration

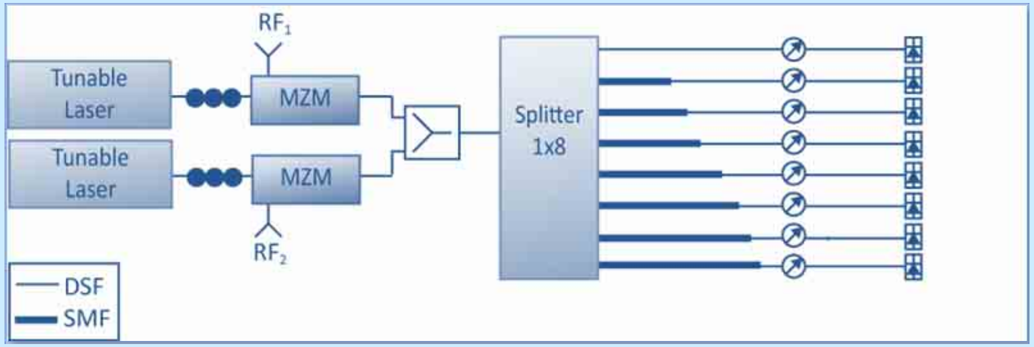


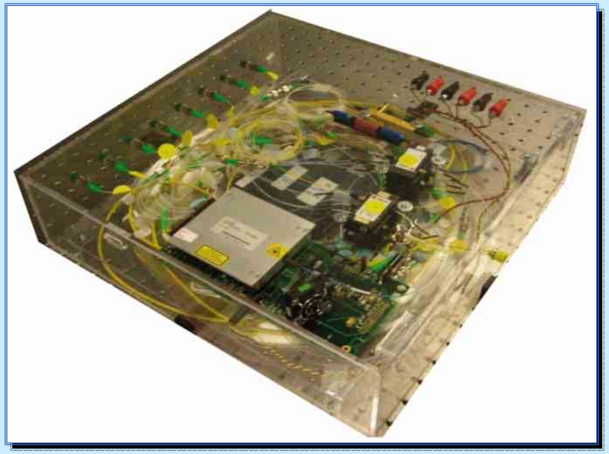
Test plan

Amplitude and phase measurements	• Estimation of the radiation pattern (0º, 10º and 20º) at 8 GHz, 7.5GHz, 8.5GHz and 4GHz .
Non-uniform distribution	• Phase and amplitude measurements will be carried out for different amplitude distributions (uniform, triangular, Taylor).
Stability measurements	• The evolution of the estimation of the radiation pattern will be measured over 1 hour.
Multibeam	• Estimation of the radiation pattern for a uniform amplitude distribution at 8 GHz.
Beam steering speed	• The beam steering speed will be derived from wavelength tuning measurements. • Characterization of the beamformer propagation delay.

Experimental results

Experimental Setup





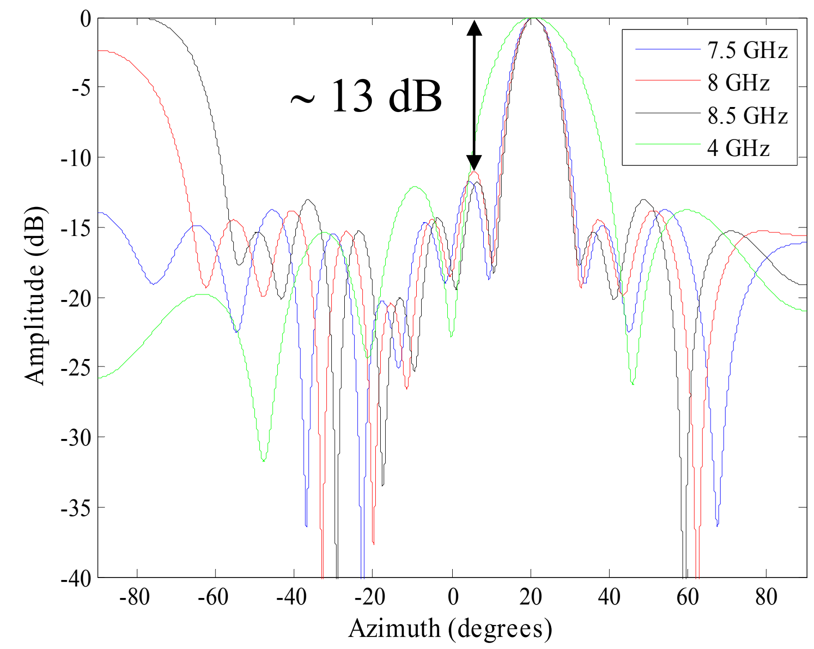
Experimental results

Beam Steering

- λ = 1552.90 nm
- Uniform amplitude distribution
- 8 antenna elements spaced 0.7λ
- θ = 20.8º

NO BEAM SQUINT

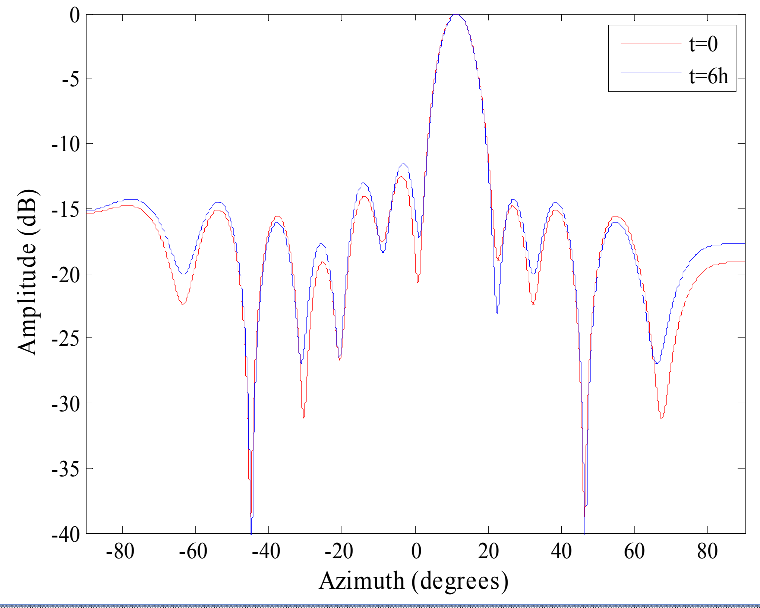
Radiation pattern estimation of an 8 element antenna calculated from the amplitude and phase measurements (channel 32).



Experimental results

Stability

Radiation pattern estimation of an 8 element antenna calculated from the amplitude and phase measurements (channel 41).

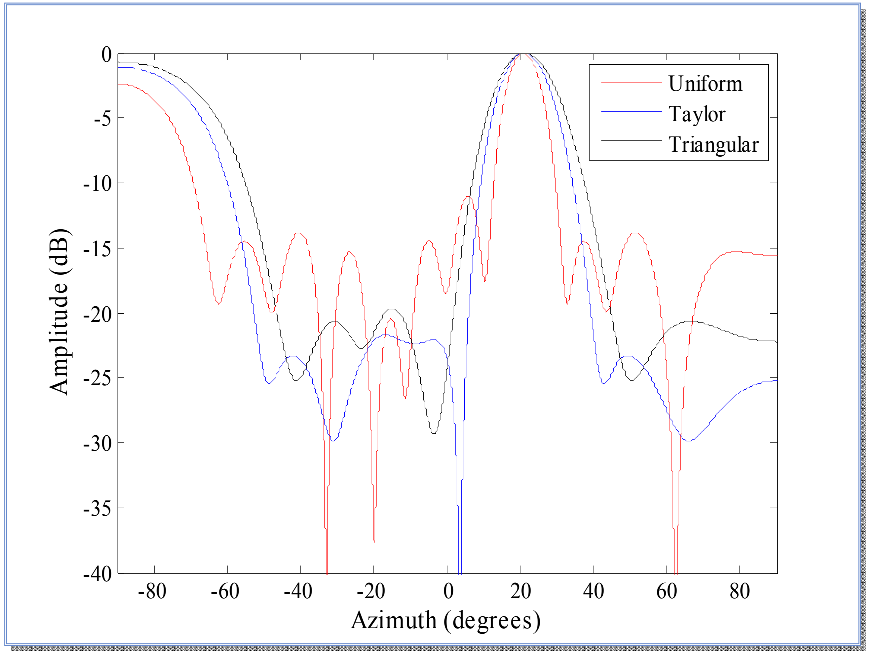


Experimental results

Apodization

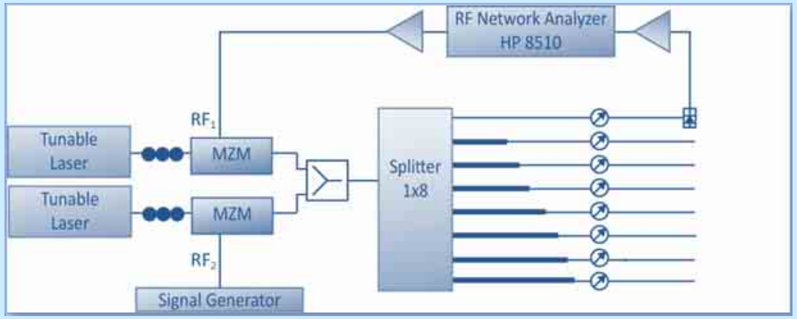
Branch	Taylor (dB)	Triangular (dB)
0	-8.92	-12
1	-3.99	-6.02
2	-1.25	-2.5
3	0	0
4	0	0
5	-1.25	-2.5
6	-3.99	-6.02
7	-8.92	-12

Radiation pattern estimation of an 8 element antenna calculated from the amplitude and phase measurements (channel 32).

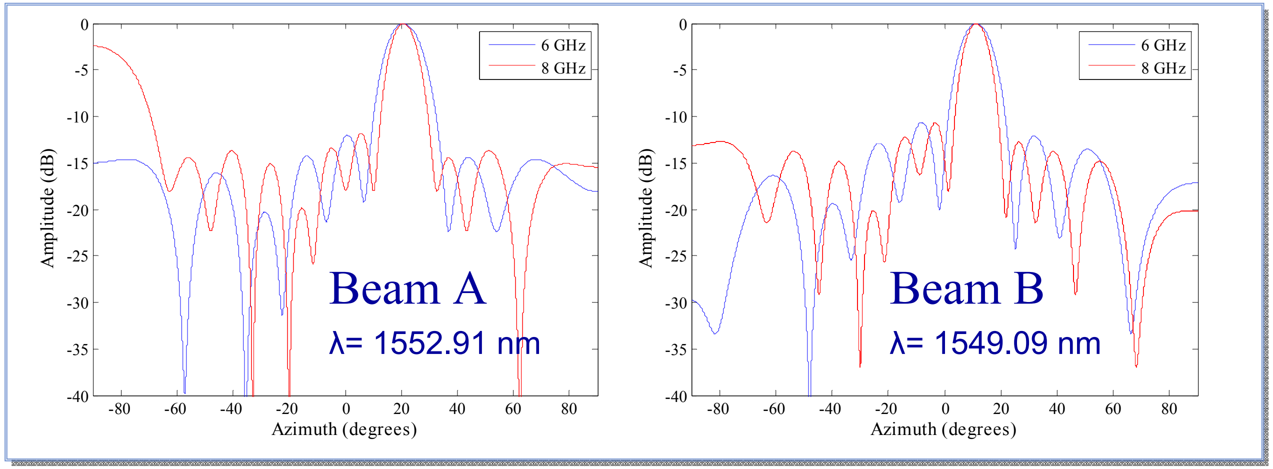


Experimental results

Multibeam capability



Radiation pattern estimation of an 8 element antenna calculated from the amplitude and phase measurements (steering at 20º and 10º).



Experimental results

Laser Characterization

AltoNet 1200 by Intune

Channels	84 (1527.94nm -1531.32nm)
Spacing	50 GHz (± 2.5 GHz)
Power	3 dBm
Time in each state	400 ns

Conclusion

All-optical implementation of a beamforming network for phased array antennas based on a dispersive prism.

Advantages:

- Wide instantaneous bandwidth (up to 100 GHz)
- Scalability (e.g. TTD unit weight around 10 g/channel)
- Continuous and flexible time delay
- Insertion loss: Optical fiber (0.2dB/km) + splitting loss + splicing points
- Fast tuning (400ns)
- Integration in the antenna remote feeding scheme
- Straightforward multibeam capability (each beam → laser + MZM, 329 g/channel)

Conclusion

Future Scenarios
(Telecom & Earth Observation)

↓

Increasing bandwidth

↓ ↓

TTD | Larger antennas

↓ ↓

Optical Beamforming

Conclusion

- *Large narrowband antennas with phase control*

RF TECHNOLOGY
INTEGRATED OPTICS FOR FUTURE REQS

- *Large antenna arrays with moderate bandwidth*
  - ✓ Spot-SAR
  - ✓ Beam-hopping telecom missions
- *Antenna arrays with tens of elements and broad bandwidth*
  - ✓ Broadband multiservice antenna arrays
- *Deployable direct radiating arrays*
  - ✓ Remote feeding

OPTICAL BF BASED ON A
DISPERSIVE PRISM

Free-Space Architecture

S. Formont

Thales Systemes Aeroportes

Free-Space Architecture

Activities in the CCN OBEFONE project :

1) Assessment of the TTD already developed
- wide instantaneous bandwidth covering the X band

2) Demonstration of Spatial Light Modulator
- switching speed below 100us.

Assessment of the free space TTD unit

Objective : Performance evaluation of 2~3 channels

Status :

- Adjustment of channels (amplitude and delay matching)
- Demonstrator assessment :
  - For all the possible delays measurement of :
    - Phase mismatch
    - Amplitude mismatch
    - Delay
- Operating frequency : 0.01~20GHz.
- Assessment of the temperature behaviour of the demonstrator

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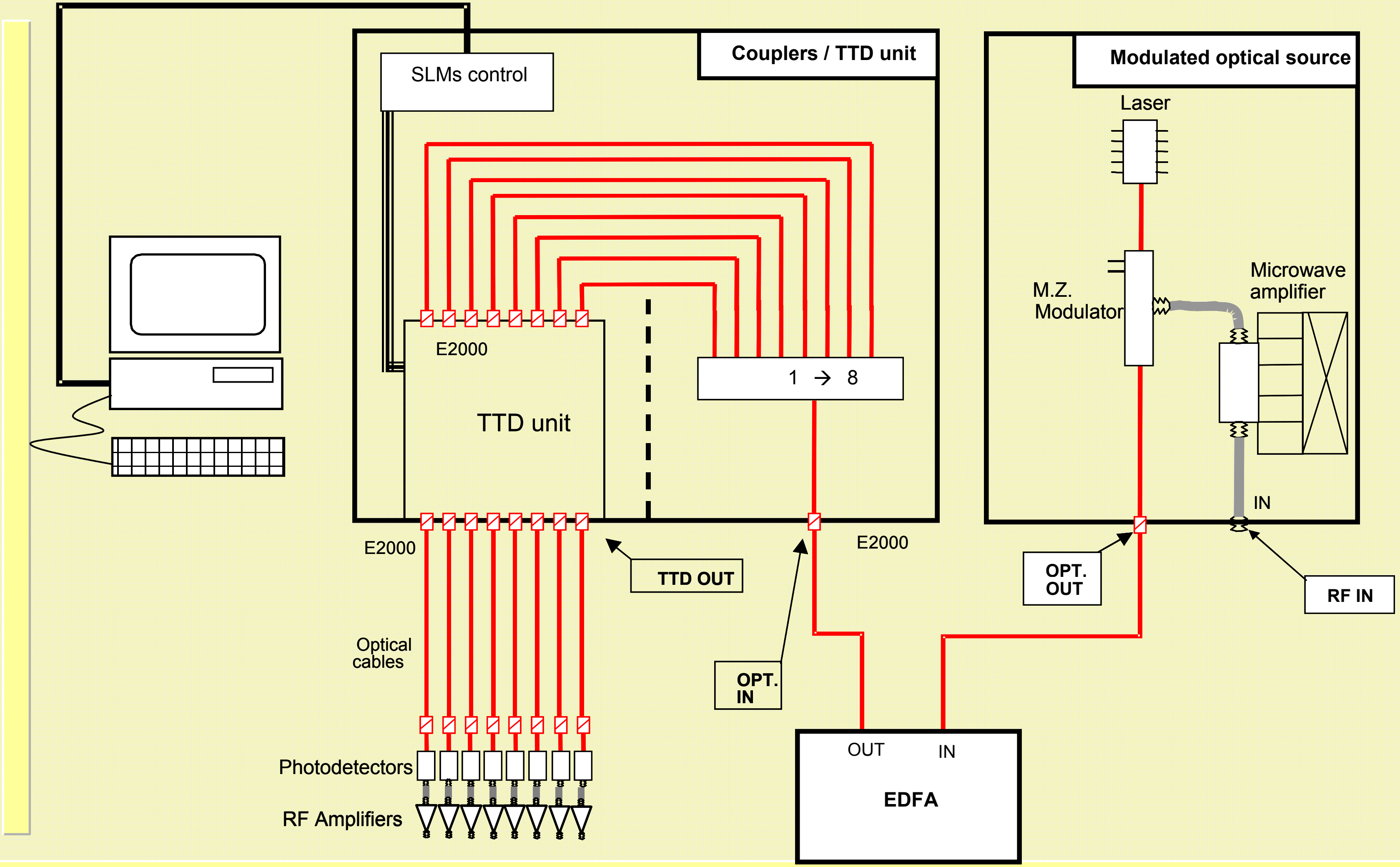
Demonstrator synopsis



TTD demonstrator

Size : ½ A4 paper sheet

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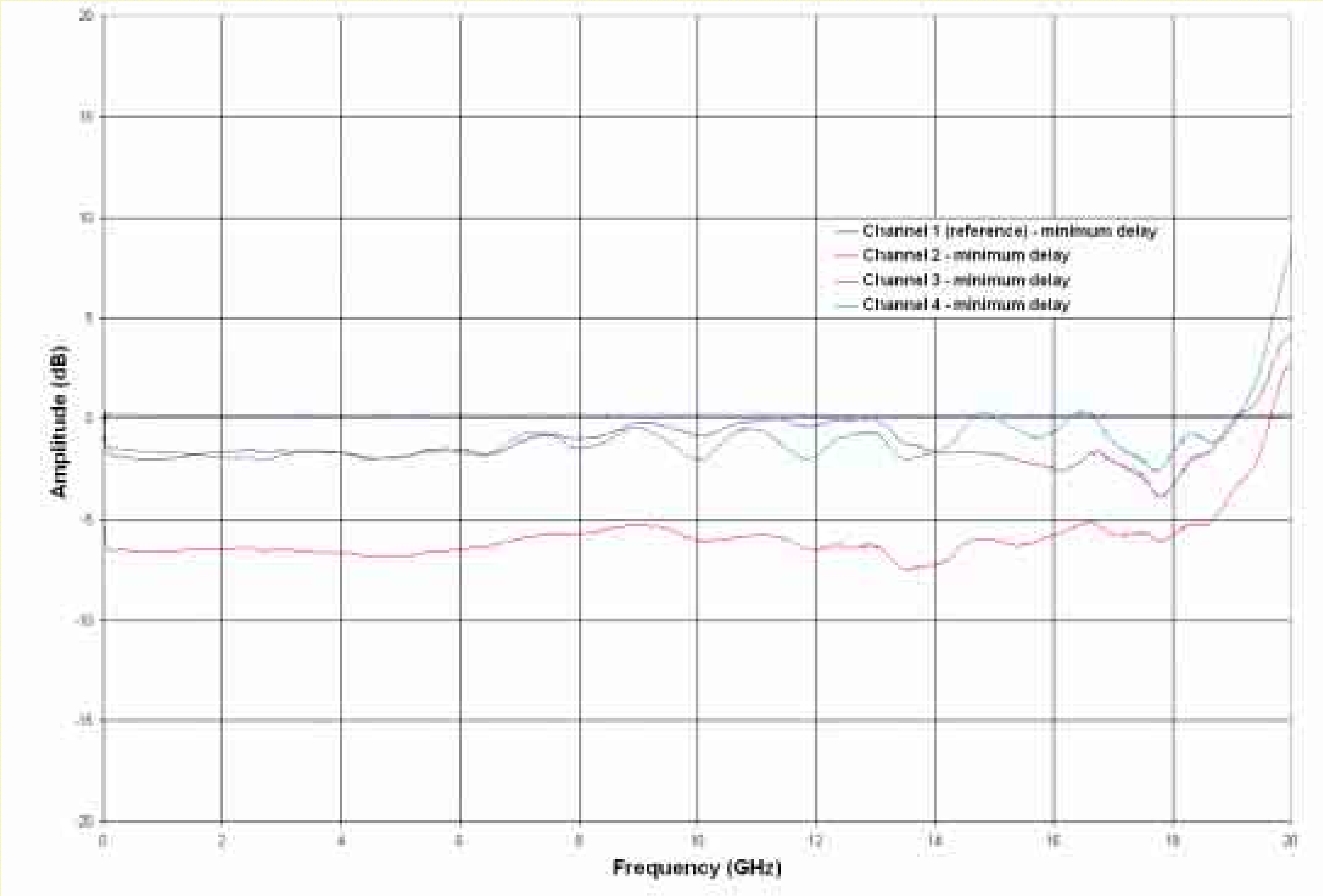
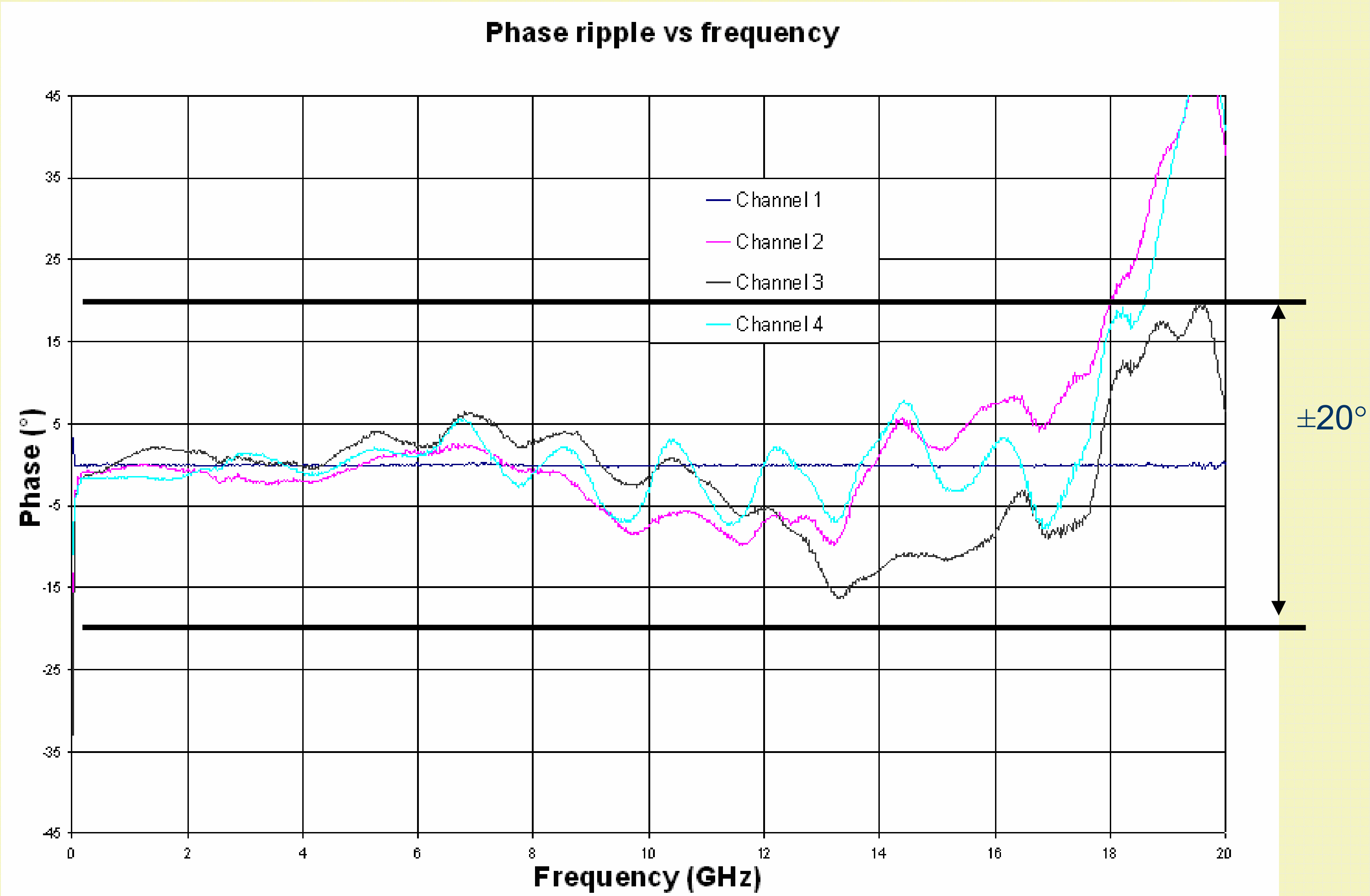
Frequency response ch 1 to 4 (1 is reference)

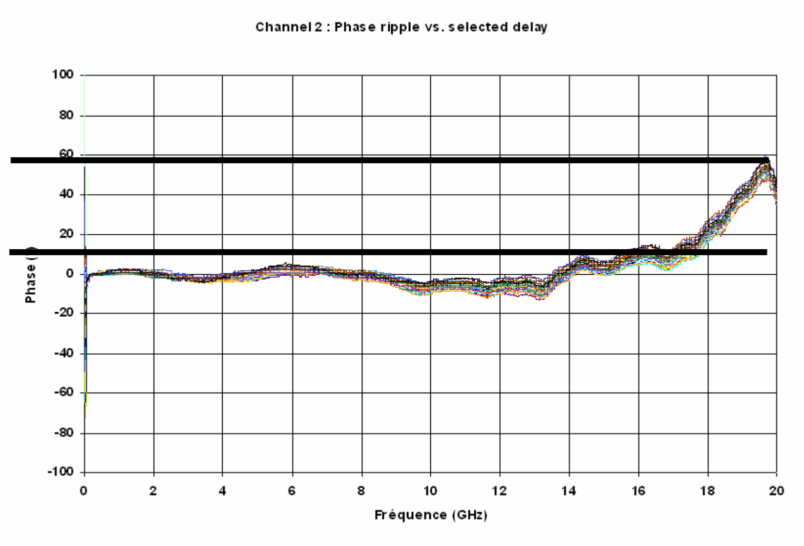


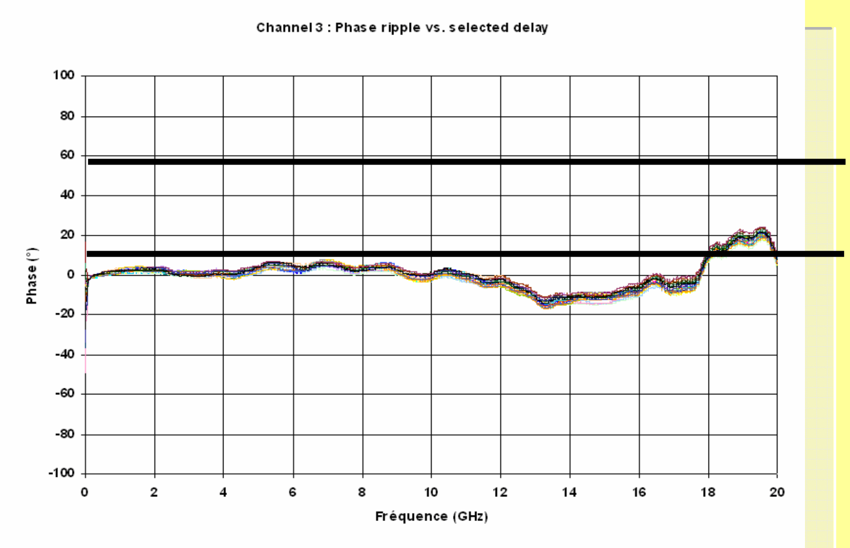
±2dB

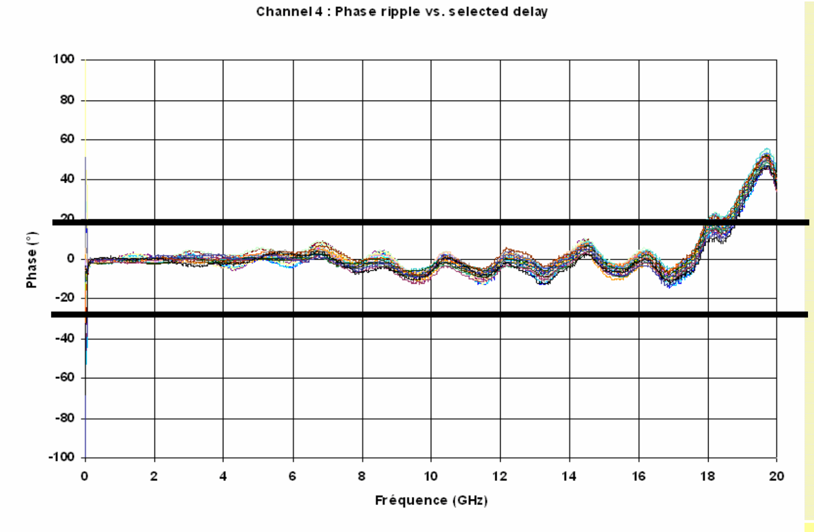
Phase ripple for the different channels (no delay)



Phase ripple for the different channels







Reference ch. 1.

Summary

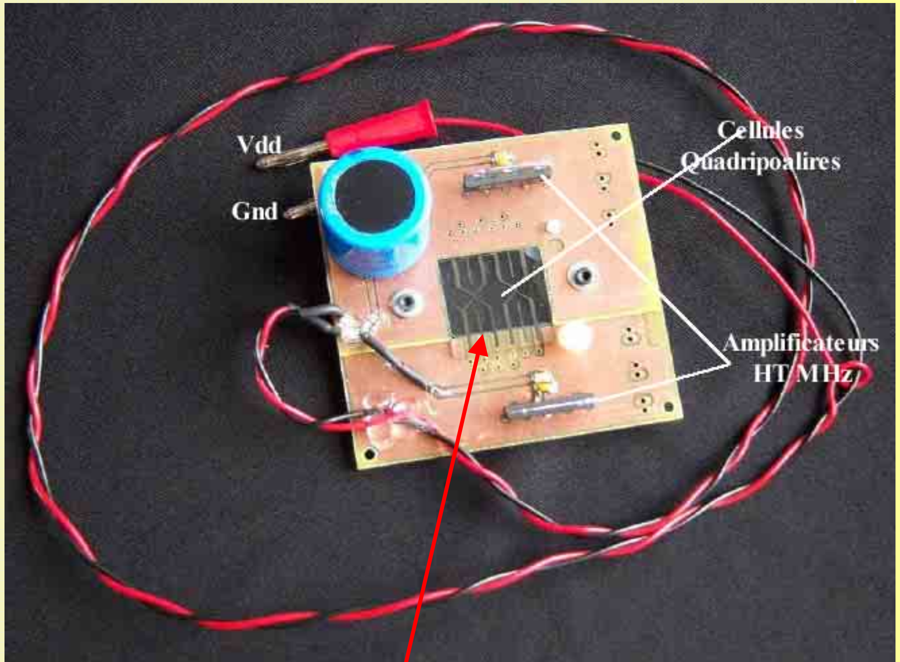
Item	Performances
Electrical bandwidth	0.01-18 GHz
Number of TTD bits	5
$\square_{min}$	**7 ps**
$\square_{max}$	**205.9 ps**
Accuracy of the delay matching	**<±3ps**
Type of SLM's	Nematic
Amplitude ripple over the full bandwidth	**<±2dB°**
Phase ripple over the full bandwidth	**<±20°**

Measured performances of the free-space demonstrator

High-speed SLM

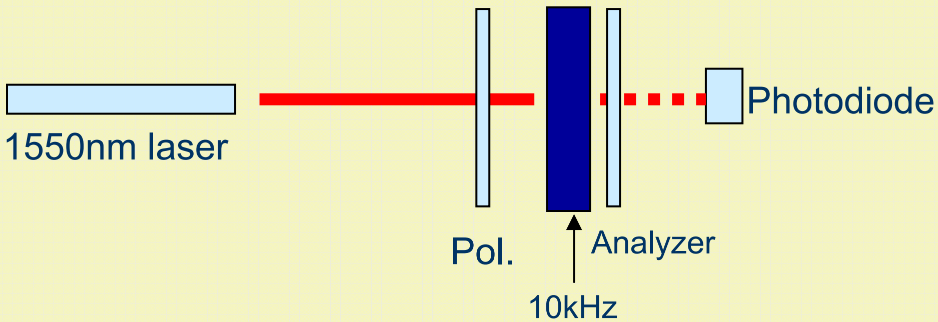
Specifications

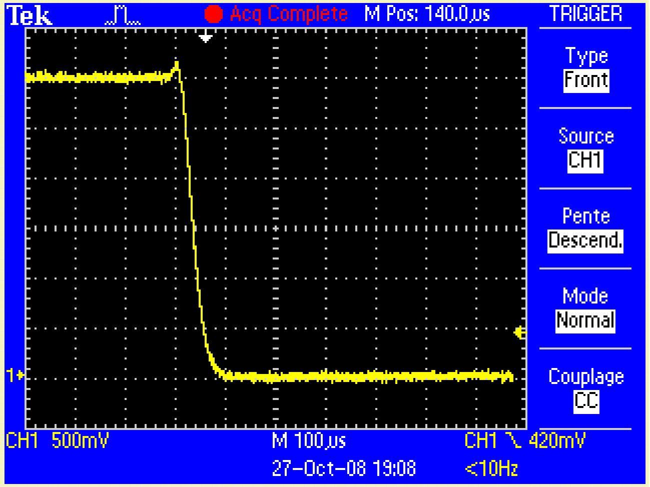
- Response time < 100us
- Operating wavelength 1.55um
- Transmission > 80%
- Pixel size 2 x 2mm
- Liquid crystal type : Nematic
- No refresh time



2 pixels with 2 different electrode configurations

Switching time measurement set-up





- **Switching time : ~80us**
- **Transmission > 80% at 1.55um.**

Conclusion

- Free space TTD demonstrator evaluated.
- Free space approach has the following benefits :
  - Performances are reproducible (given by design);
  - Reduced fibre management,
  - Compactness and light weight

  - Wide instantaneous bandwidth (several octaves),
  - Low latency time for RF signal propagation inside the OBFN architecture ,
  - Reversible architecture (work for both emission and reception),
  - Dynamic re-arrangement possible
  - Scalable architectures

- High-speed SLM
  - First cell assessed
    - Test of 2 different electrode designs
    - Switching time ~80us
    - No refresh time (Nematic liquid crystal)

Conclusions

J.M. del Cura
SENER

Conclusions

- BFN based on optical technologies is a promising solution for the future telecom and EO applications
- Advantages:
  - Reduced mass and volume
  - TTD architecture more efficient in photonic or optic than in RF
  - EMI immunity
  - Improved deployable antenna systems
- Three optical possible architectures:
  - Free-Space optics
  - Integrated phase-control structures
  - TTD fiber approaches.
- The optimum solution can be a single optical technology or a combination of them. In a general scenario, hybrid (optical and electrical) technologies can be the optimum solution.

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Conclusions

Scenario	Applications	Suitable OBF family	Advantages	Drawbacks	State-of-the-art
LARGE NARROWBAND ANTENNAS	- Telecom P/Ls - SAR.	Integrated OBF	Can meet new requirements (e.g multibeam capability) Saving in mass and size Multi-beam capability	MMIC (RF) is a mature technology compliant with current existing requirements. New OBFN approaches are less mature and add a dev. cost, so shall be used when new requirements justify it.	
LARGE ANTENNAS WITH MODERATE BANDWIDTH	- Telecom satellites with large antenna arrays (Spaceway) - Hopping beam telecom architectures - SAR with large antennas (ScanSAR)	- Combination of fiber TTD OBF or free space based TTD architecture with RF phase / amplitude control	Saving of mass and size Fast tuning TTD to subarrays to reduce beam squint "remoting beamforming" simplified deployment Multi-beam capability	Fast switching → higher consumption	- Fast (200 ns) beam switching demonstrated at 8 GHz for 8 elements -TX, RX, nulling, 2D demonstrated between 2-18 GHz with 8 elements - TTD demonstrated at 42 GHz for 4 elements
MEDIUM-SIZE BROADBAND ANTENNAS (TENS-HUNDREDS ELEMENTS)	- GEO & LEO missions with medium size arrays where multiple services in different bands are centralised in the array	- Fiber TTD or free space architecture	Saving of mass and size Fast tuning No beam squint "remoting beamforming" simplifying deployment Multi-beam capability	Fast switching → higher consumption	- Fast (200 ns) beam switching demonstrated at 8 GHz for 8 elements - TX, RX,, nulling, 2D demonstrated between 2-18 GHz with 8 elements - TTD demonstrated at 42 GHz for 4 elements