RadioNet

Photonics in Radio Astronomy

Instituto de Telecomunicações, 2-3 Sep. 2010

Photonic TTD Beamformer based on a tunable PDI

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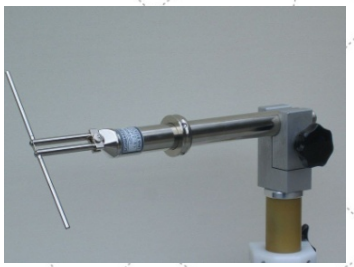
creating and sharing knowledge for telecommunications

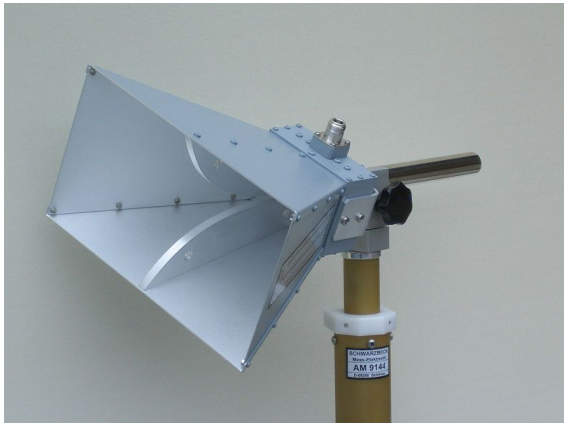
Presentation Outline

- Basic antenna models
- Phased Array Antennas (PAA)
- Beamforming: phase shifters vs. true-time delay (TTD)
- Photonic TTD systems
- Proposed system: Photonic TTD beamformer based on a tunable polarization-domain interferometer
- Conclusions & Future work

Basic antenna models



Dipoles



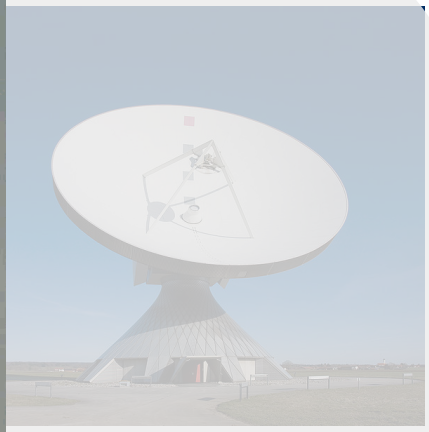
Horn

Parabolic

Basic antennas offer very limited options in designing the radiation diagram.

Antenna arrays

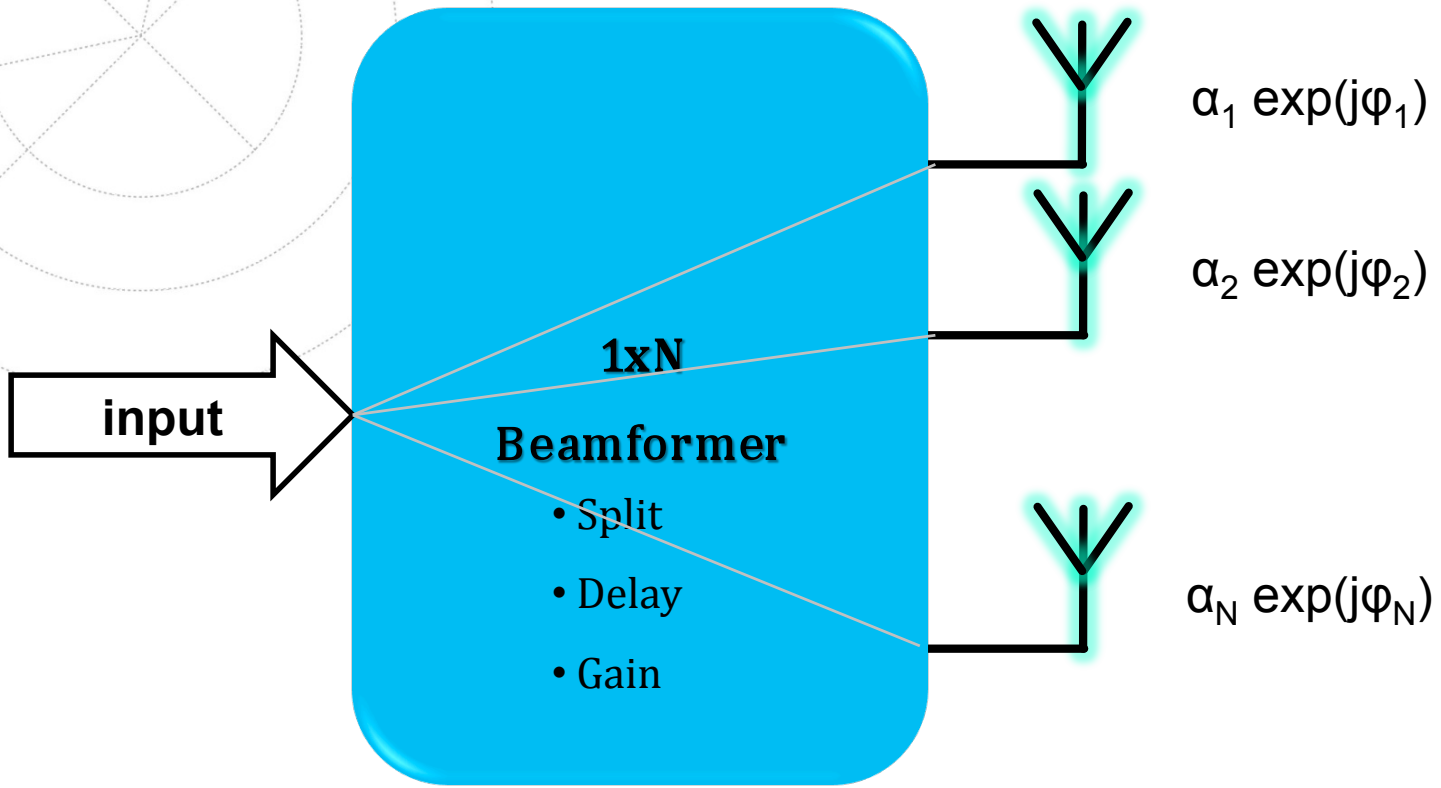
Yagi Antenna (1926)



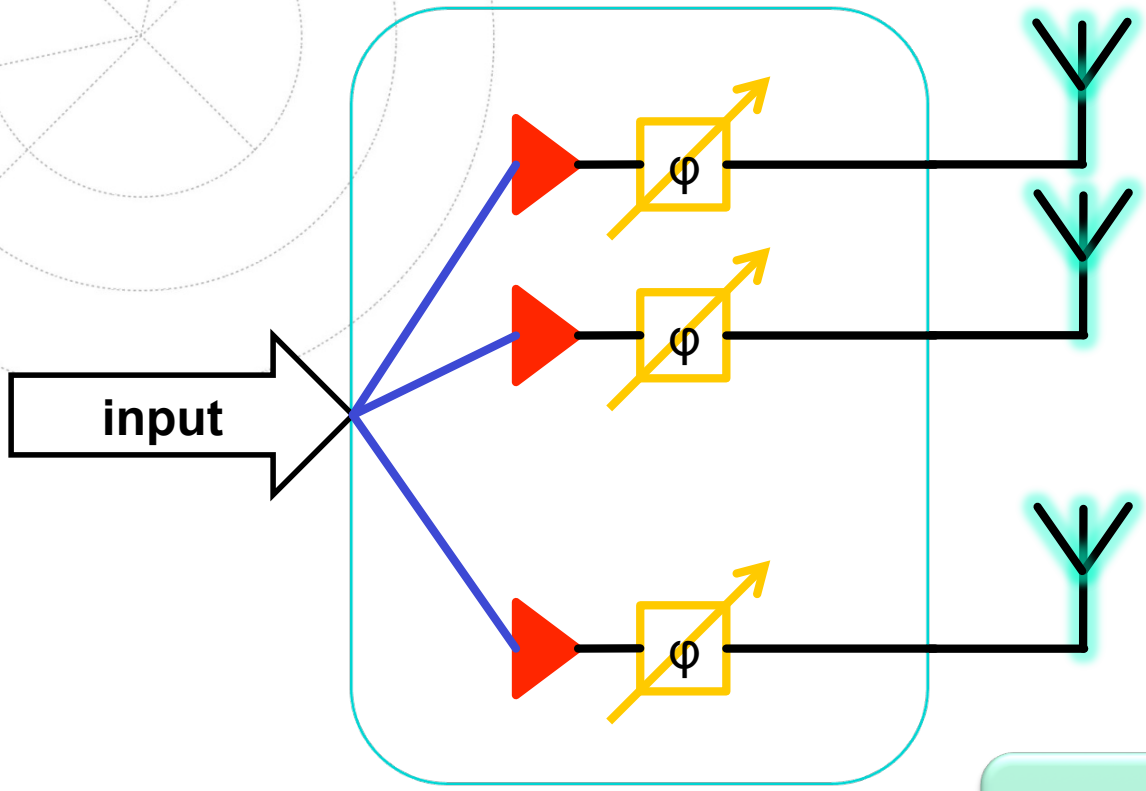
Parabolic

Basic ante… …signing the

Phased array antenna – Transmitter scheme

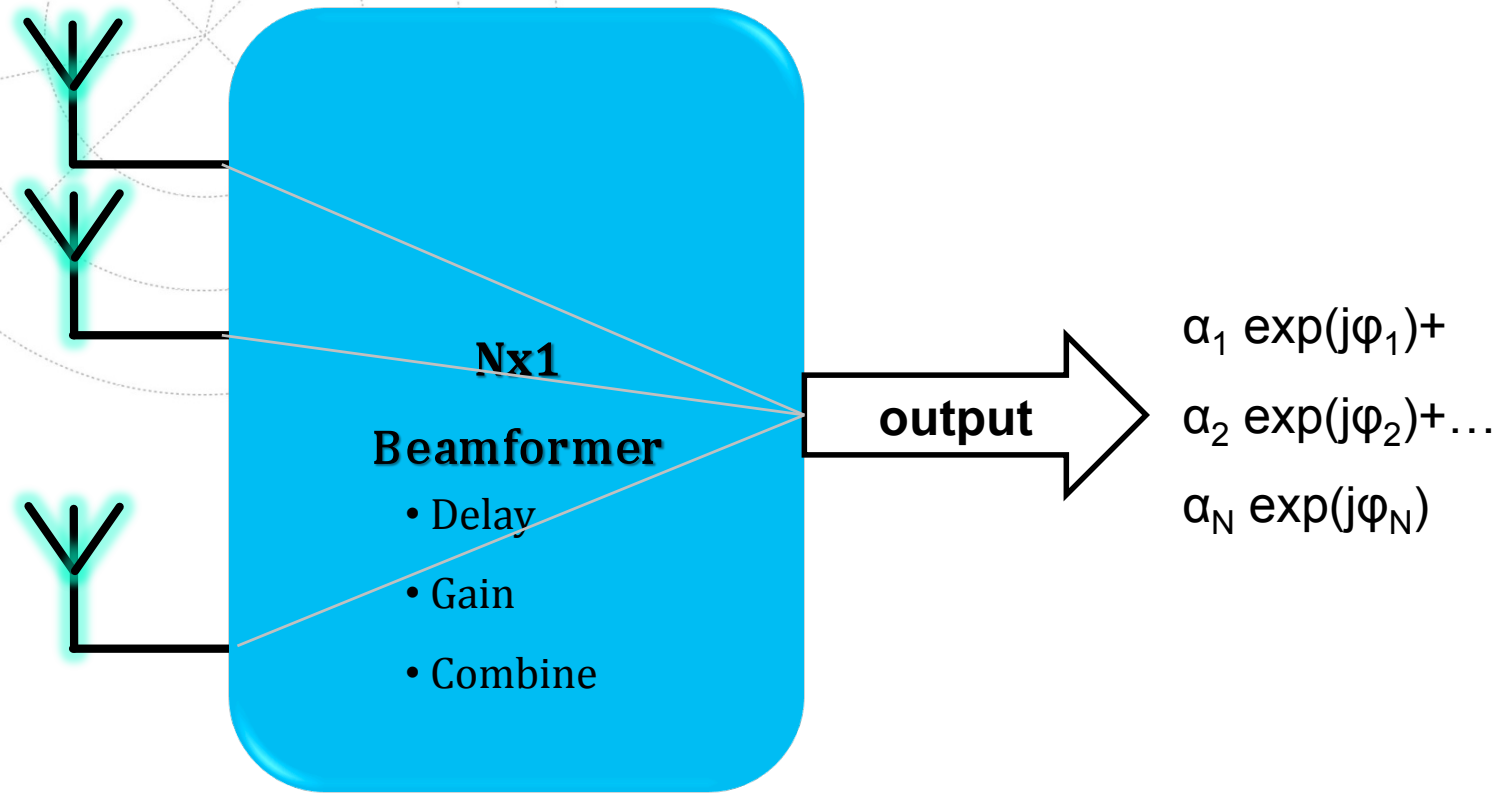


Phased array antenna – Transmitter scheme



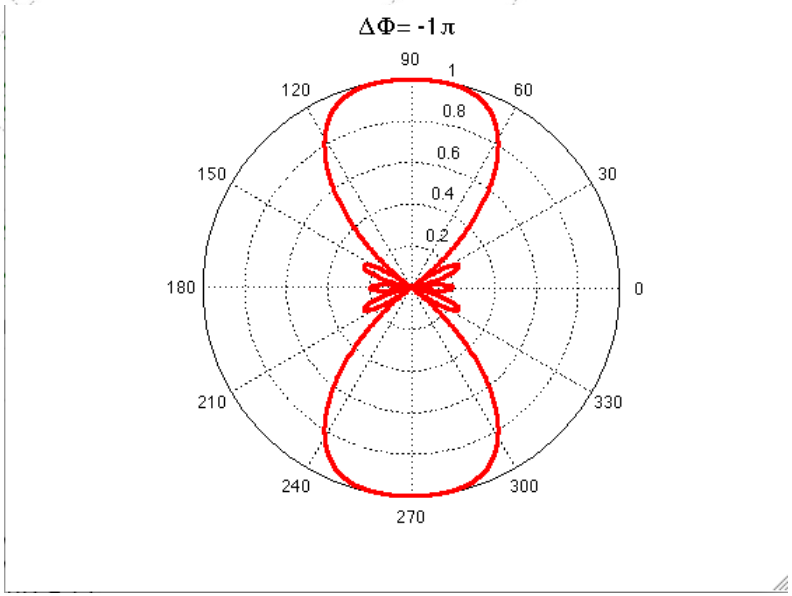
Flexibility in design

Phased array antenna – Receiver scheme

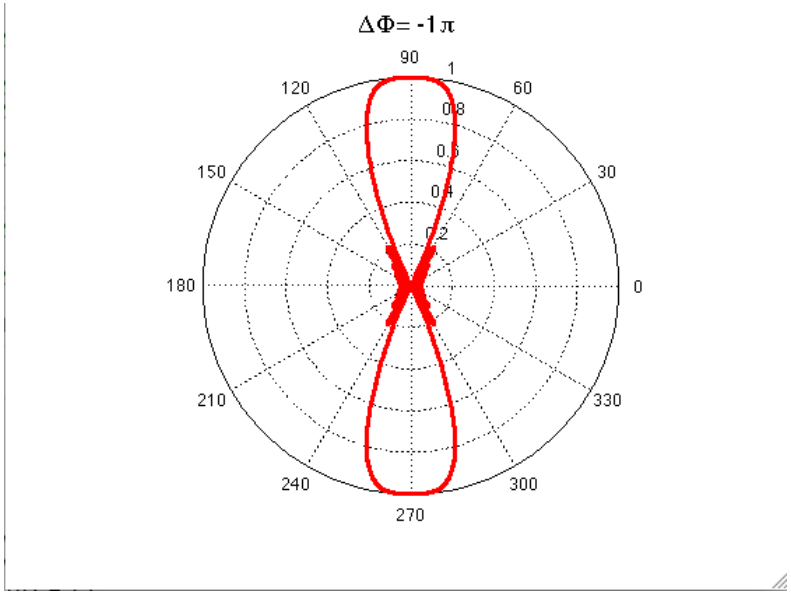


Phased array antenna design – impact of N

N = 5; α_i =1

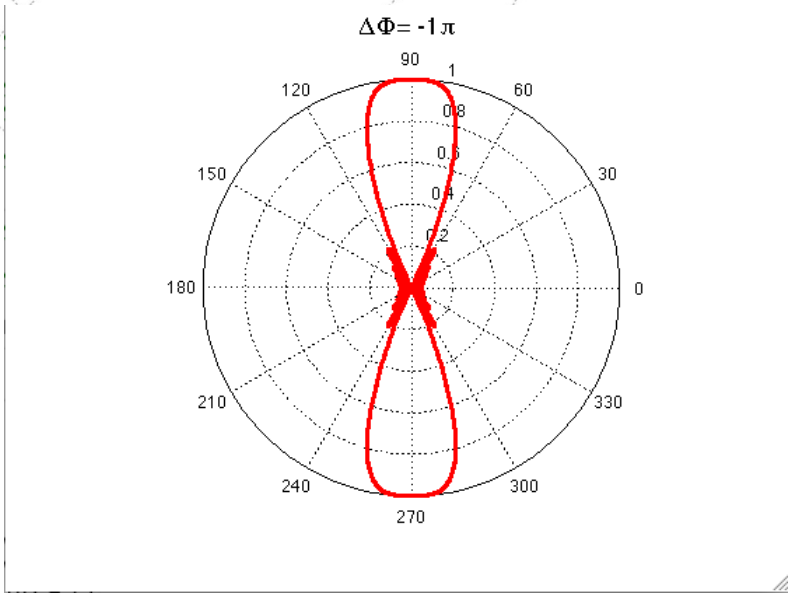


N = 20 ; α_i =1



Phased array antenna design – impact of α

N = 20 ; α_i =1



N = 20 ; α_i =Blackman

Beamforming – Phase shift or TTD?

In practice:

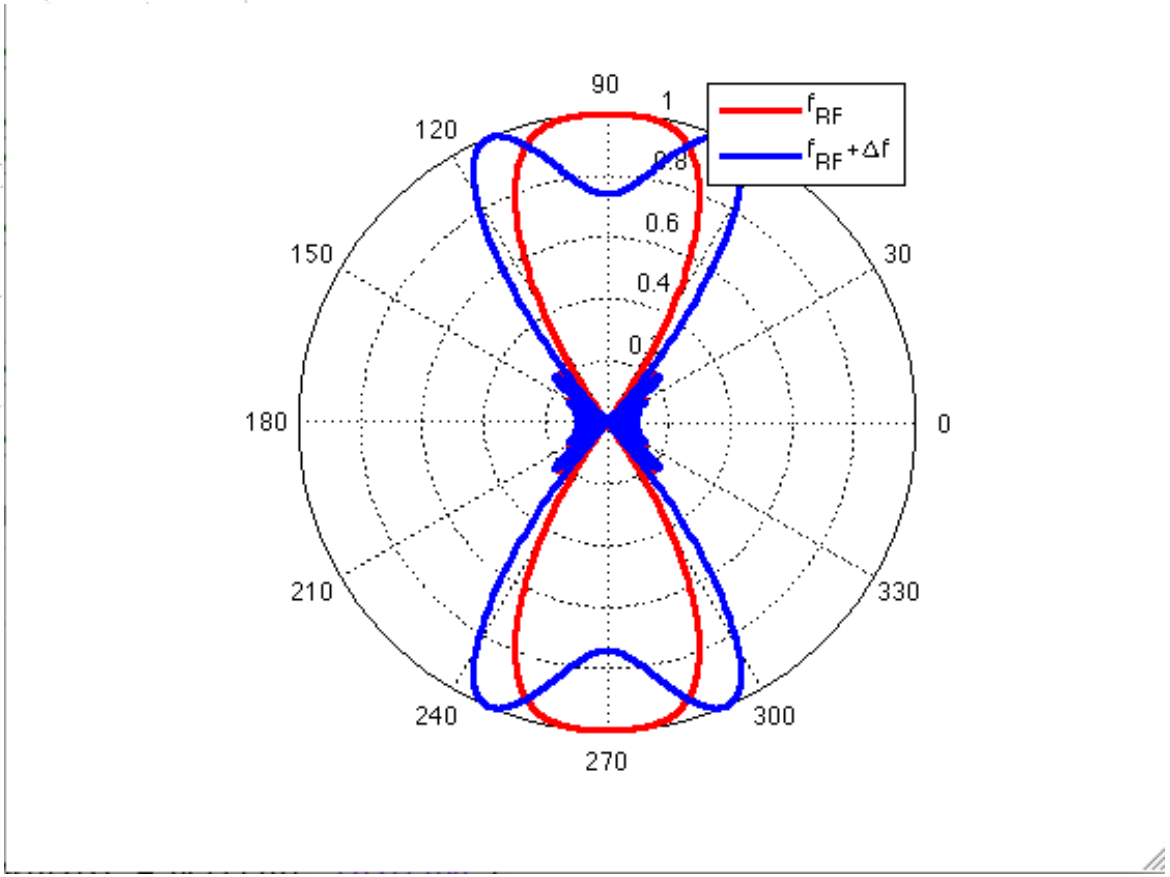
- $\alpha_i = \alpha_i(f)$ (e.g. low pass filtering) → **beam distortion**
- $\varphi_i = \varphi_i(f)$ (e.g. dispersion) → **beam squinting**

$$\mathrm{AF}(\Theta) = \frac{1}{N} \sum_{a=0}^{N-1} \alpha_i e^{j\left[a 2\pi \frac{f}{c} d \cos(\Theta) + \phi_i\right]}$$

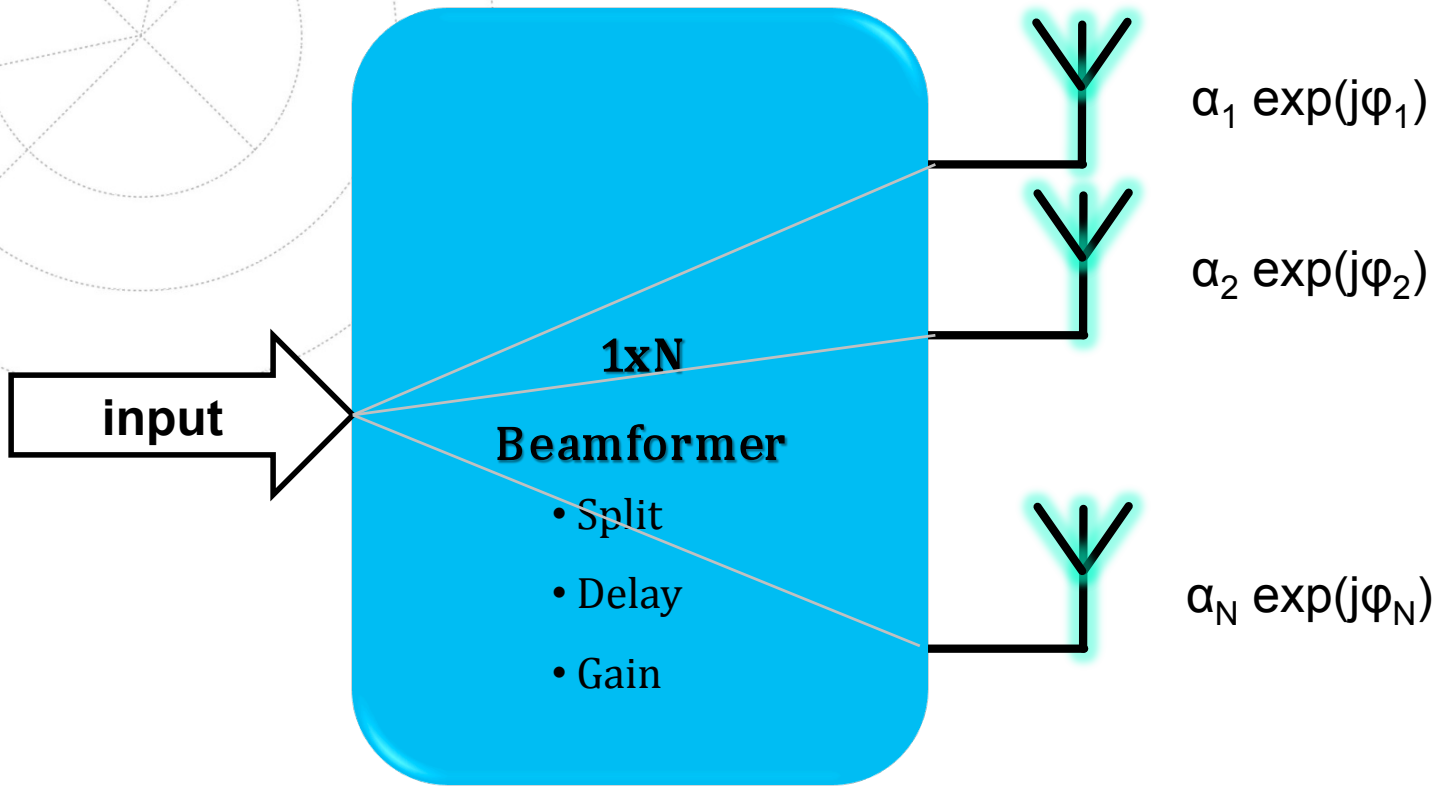
PS VS. TTD:

- $\varphi_i = \varphi_i$ → **phase shifting**
- $\varphi_i = \varphi_i f$ → **true-time delay:** enables broadband operation

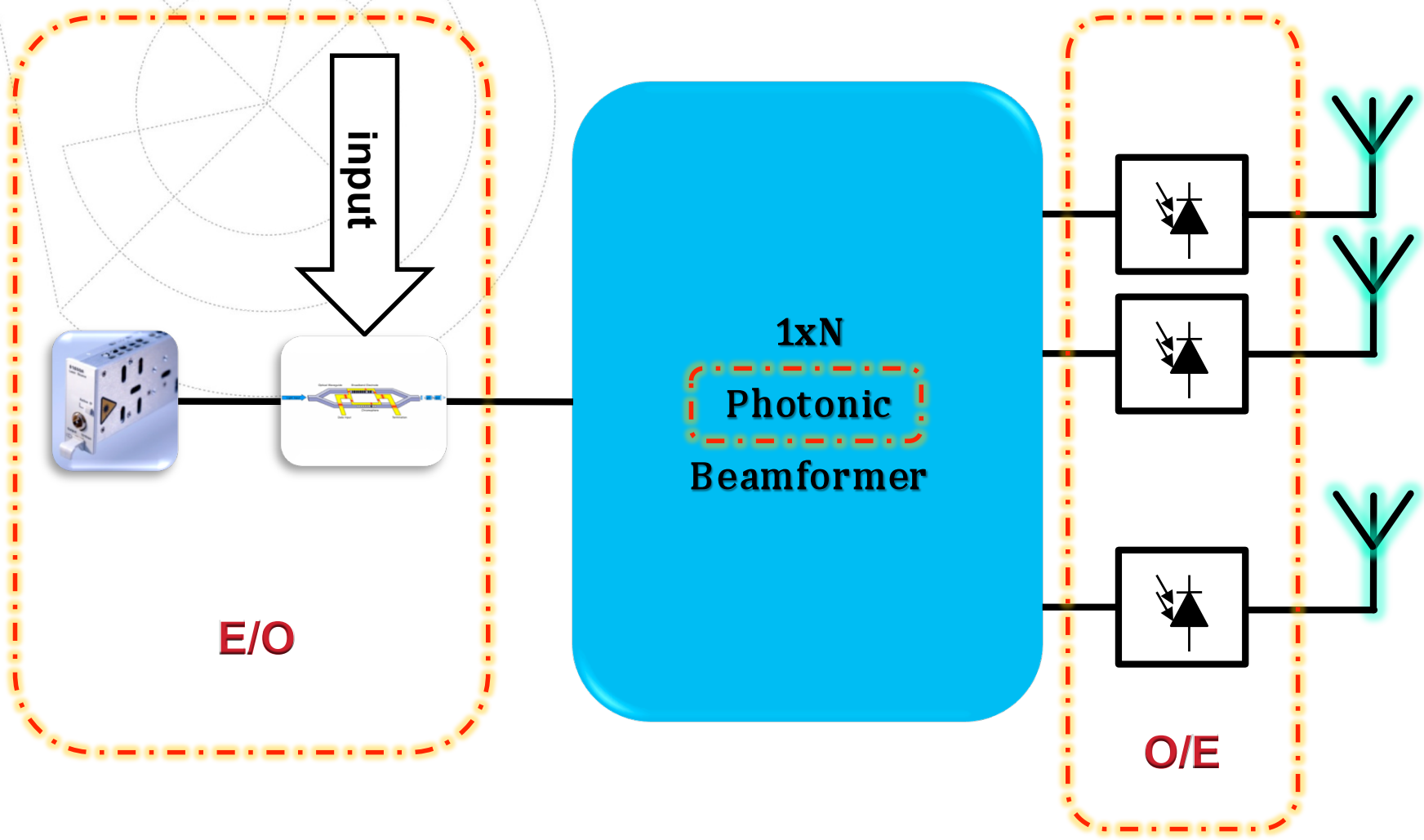
Phase shift – beamsquinting



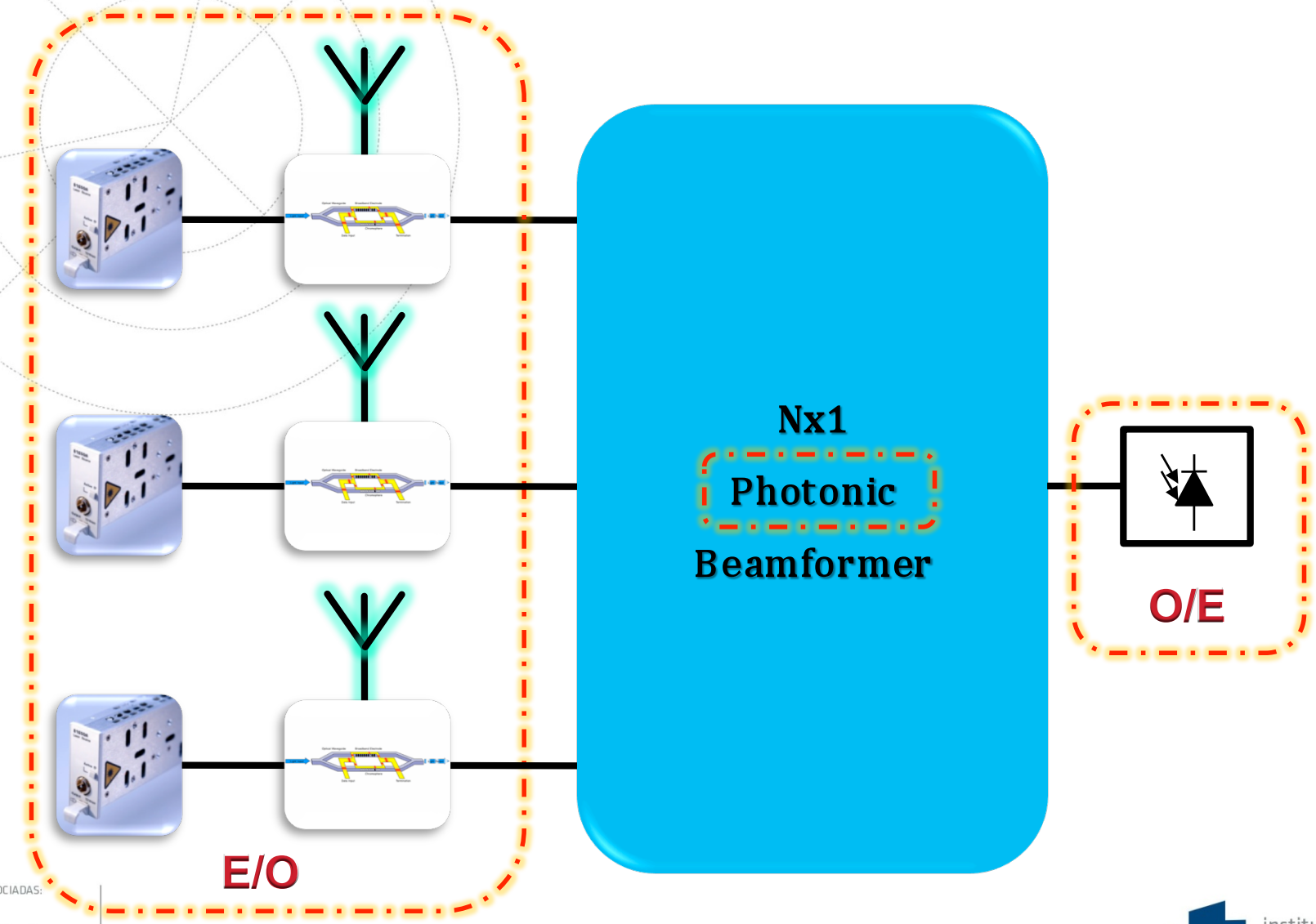
Photonic TTD beamformer



Photonic TTD beamformer – Transmitter scheme



Photonic TTD beamformer – Receiver scheme



Photonic TTD beamformer SOTA – **spatial mux**

US005428218A

United States Patent [19]

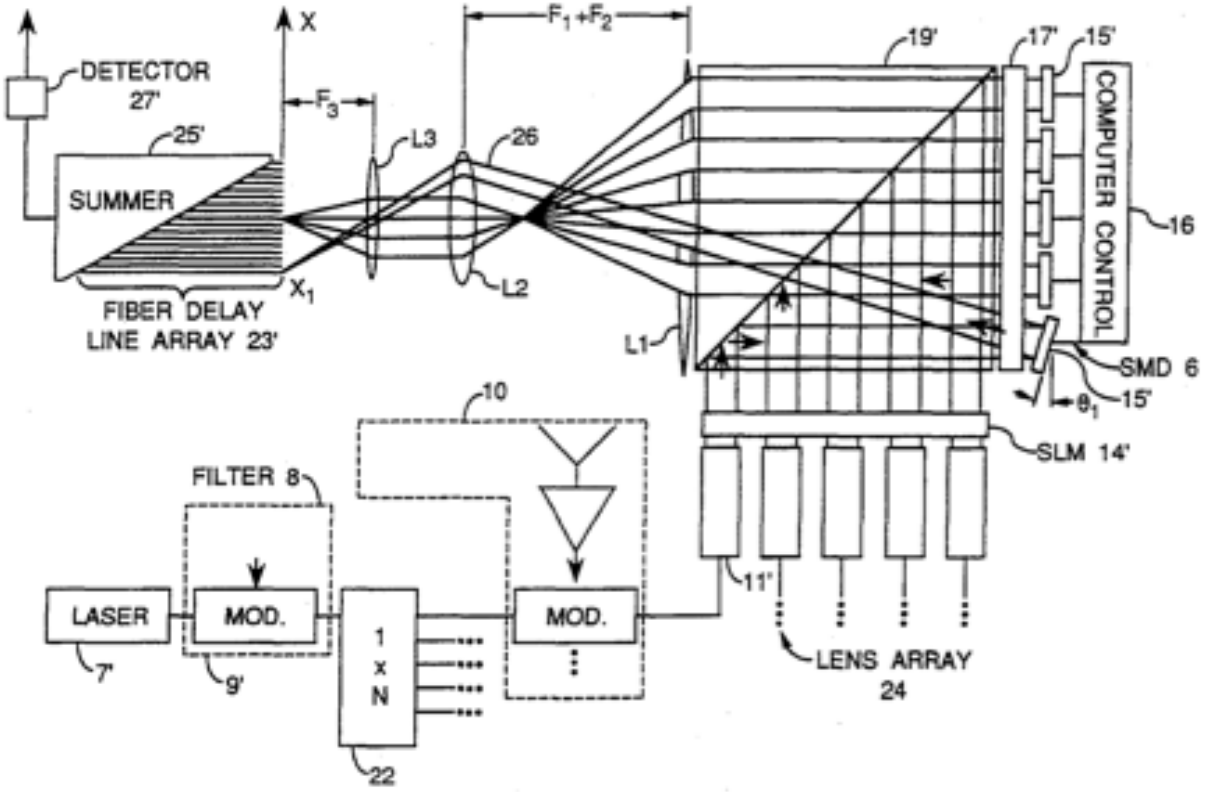
Toughlian et al.

[11] **Patent Number: 5,428,218**

[45] **Date of Patent: Jun. 27, 1995**

[54] **VARIABLE TIME-DELAY SYSTEM FOR BROADBAND PHASED ARRAY AND OTHER TRANSVERSAL FILTERING APPLICATIONS**

4,696,061	9/1987	Labrum	455/609
4,976,518	12/1990	Burns	350/96.16
4,996,412	2/1991	Anafi et al.	250/201.9
5,117,239	5/1992	Riza	342/375
5,220,163	6/1993	Toughlian et al.	250/201.9



Photonic TTD beamformer SOTA – **light dispersion**

US005461687A

United States Patent [19]

Brock

[11] **Patent Number: 5,461,687**

[45] **Date of Patent: Oct. 24, 1995**

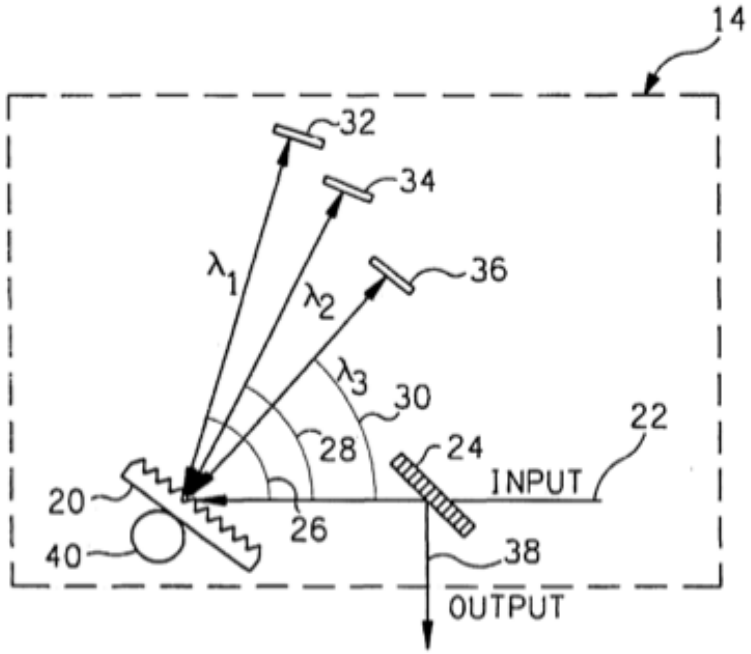
[54] **WAVELENGTH CONTROLLED OPTICAL TRUE TIME DELAY GENERATOR**

[75] Inventor: **John C. Brock**, Redondo Beach, Calif.

[73] Assignee: **TRW Inc.**, Redondo Beach, Calif.

5,066,133	11/1991	Brienza	385/37 X
5,117,239	5/1992	Riza	342/375
5,210,807	4/1993	Ames	385/24
5,231,405	7/1993	Riza	342/375
5,305,009	4/1994	Goutzoulis et al.	342/157

Primary Examiner—Brian Healy

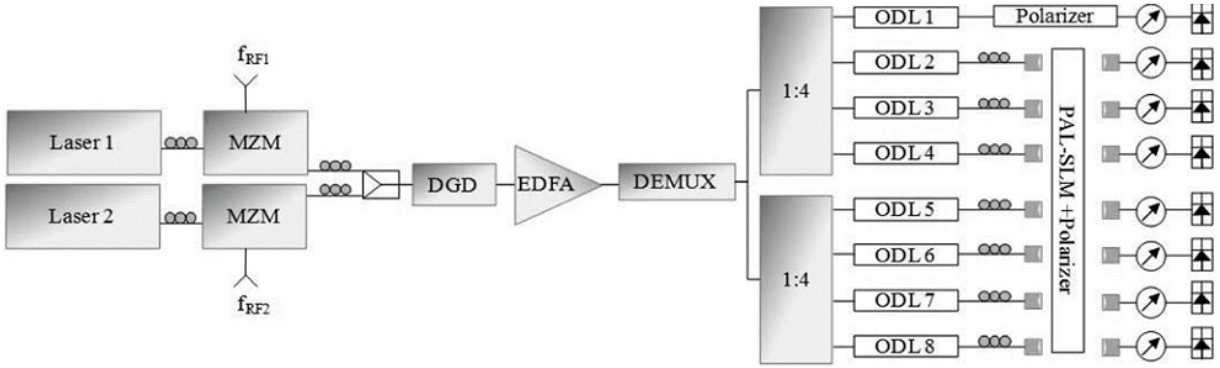


Photonic TTD beamformer SOTA – **hybrid setup**

1594 IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 56, NO. 6, JUNE 2008

Optically Beamformed Wideband Array Performance

Lluís Jofre, *Senior Member, IEEE*, Chrysavgi Stoltidou, Sebastián Blanch, Teresa Mengual, Borja Vidal, Javier Martí, *Member, IEEE*, Iain McKenzie, and J. M. del Cura



Photonic TTD beamformer SOTA – **hybrid setup**

JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 28, NO. 1, JANUARY 1, 2010 3

Novel Ring Resonator-Based Integrated Photonic Beamformer for Broadband Phased Array Receive Antennas—Part I: Design and Performance Analysis

Arjan Meijerink, *Member, IEEE*, Chris G. H. Roeloffzen, *Member, IEEE*, Roland Meijerink, *Student Member, IEEE*, Leimeng Zhuang, *Student Member, IEEE*, David A. I. Marpaung, *Student Member, IEEE*, Mark J. Bentum, *Senior Member, IEEE*, Maurizio Burla, *Student Member, IEEE*, Jaco Verpoorte, Pieter Jorna, Adriaan Hulzinga, and Wim van Etten, *Senior Member, IEEE*

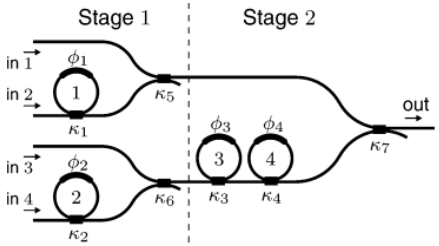


Fig. 3. Binary tree-based 4 × 1 optical beamforming network (OBFN) consisting of four ORRs and three combiners.

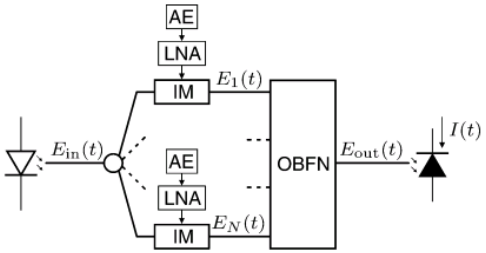
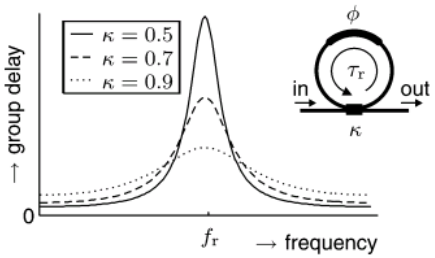
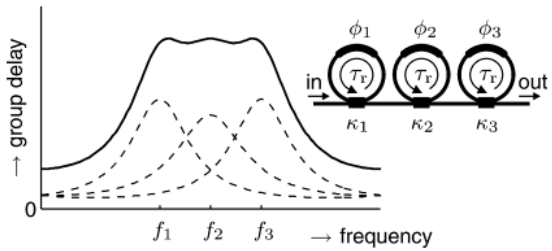
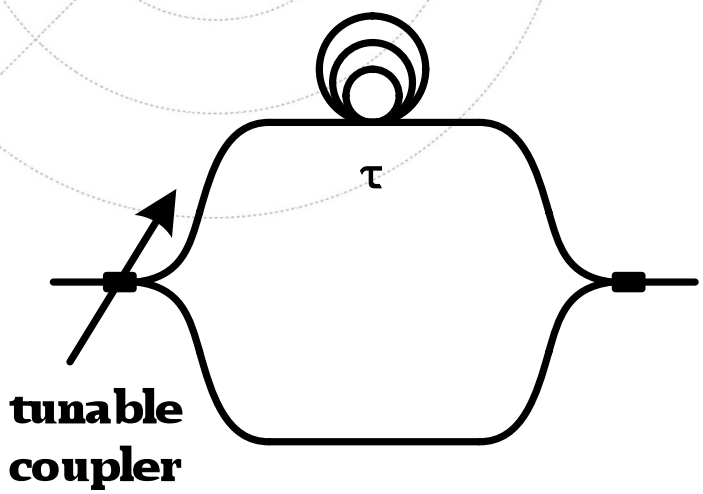


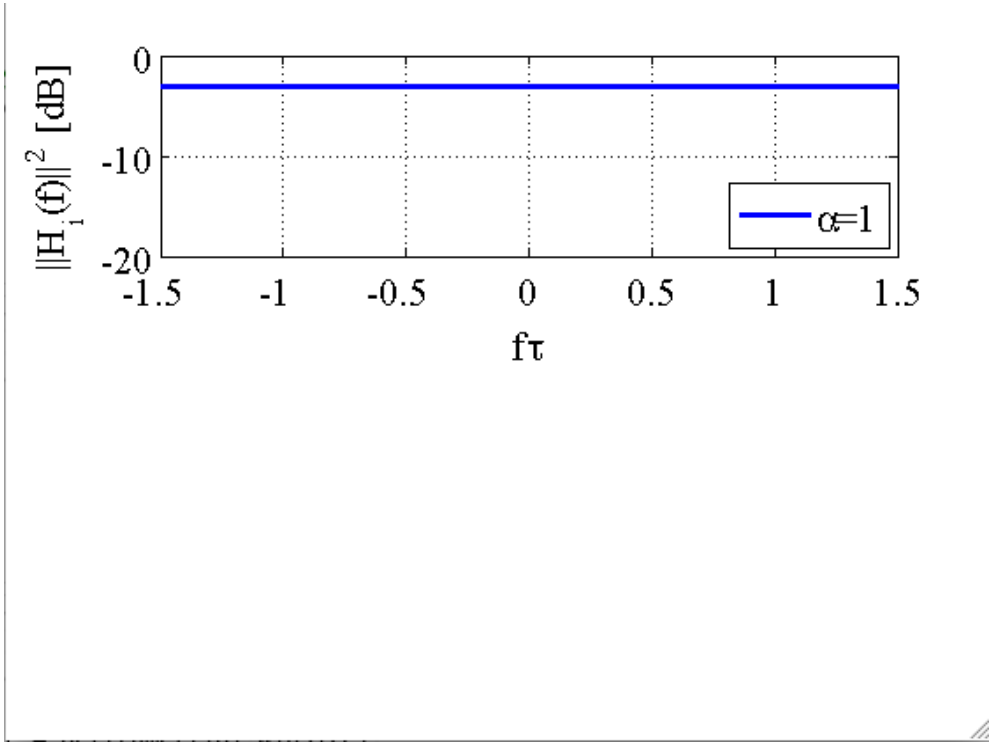
Fig. 4. Beamformer scheme with N inputs, using optical intensity modulation (IM) and direct optical detection. (AE = antenna element, LNA = low-noise amplifier, OBFN = optical beamforming network).





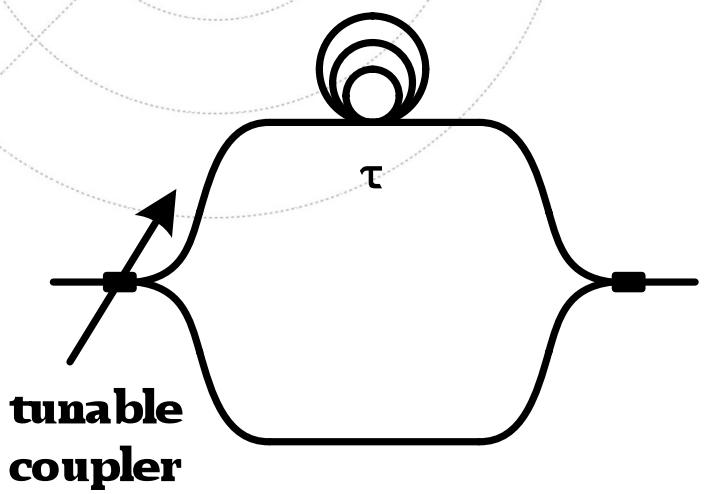
Tunable Mach-Zehnder delay interferometer

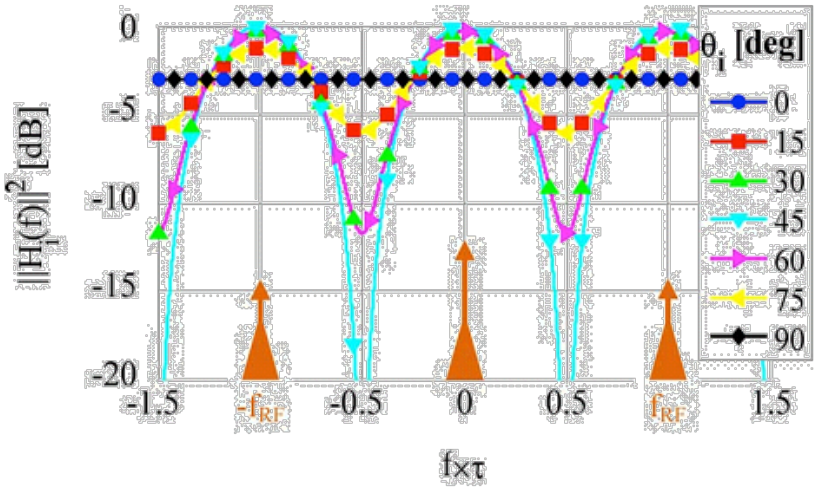


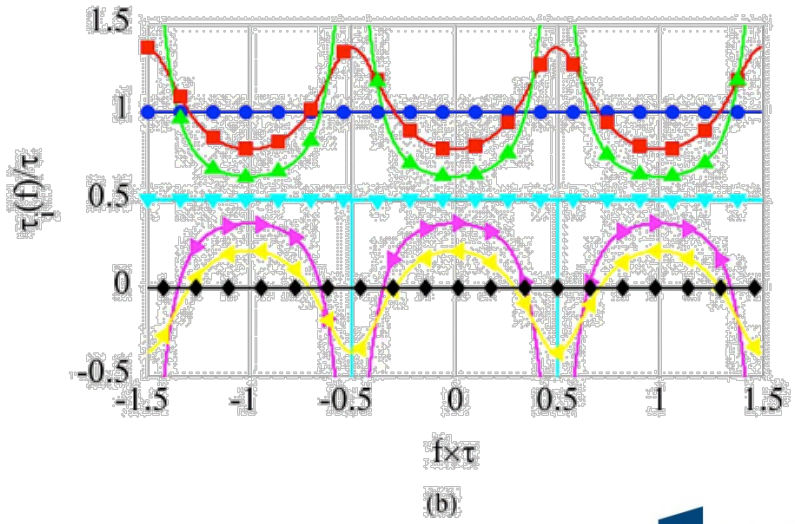


Tunable Mach-Zehnder delay interferometer

$$\tau = \begin{cases} \frac{N-1}{2f_{\mathrm{RF}}}, & \text{when } N \text{ is odd} \\ \frac{N}{2f_{\mathrm{RF}}}, & \text{when } N \text{ is even.} \end{cases}$$

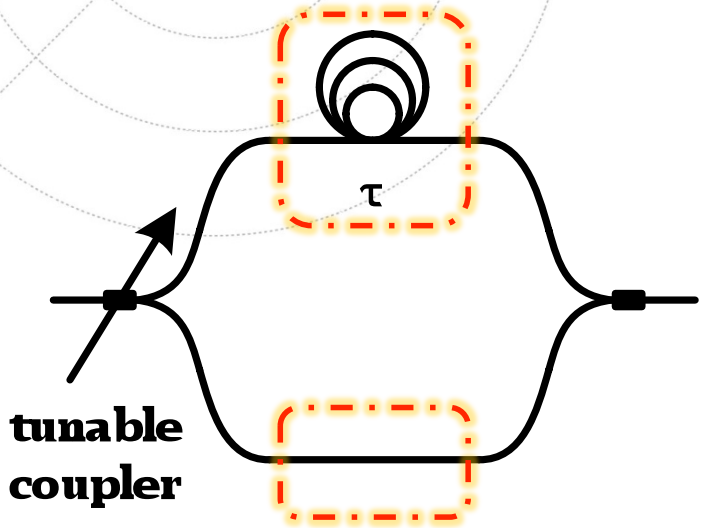


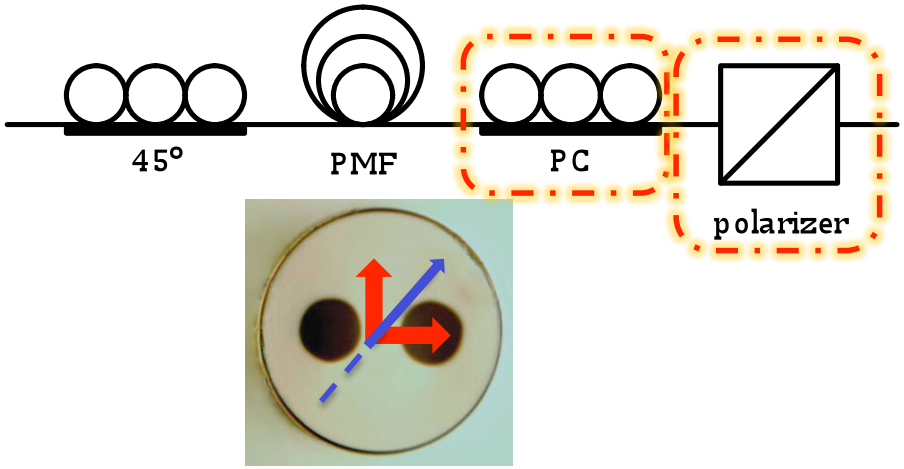




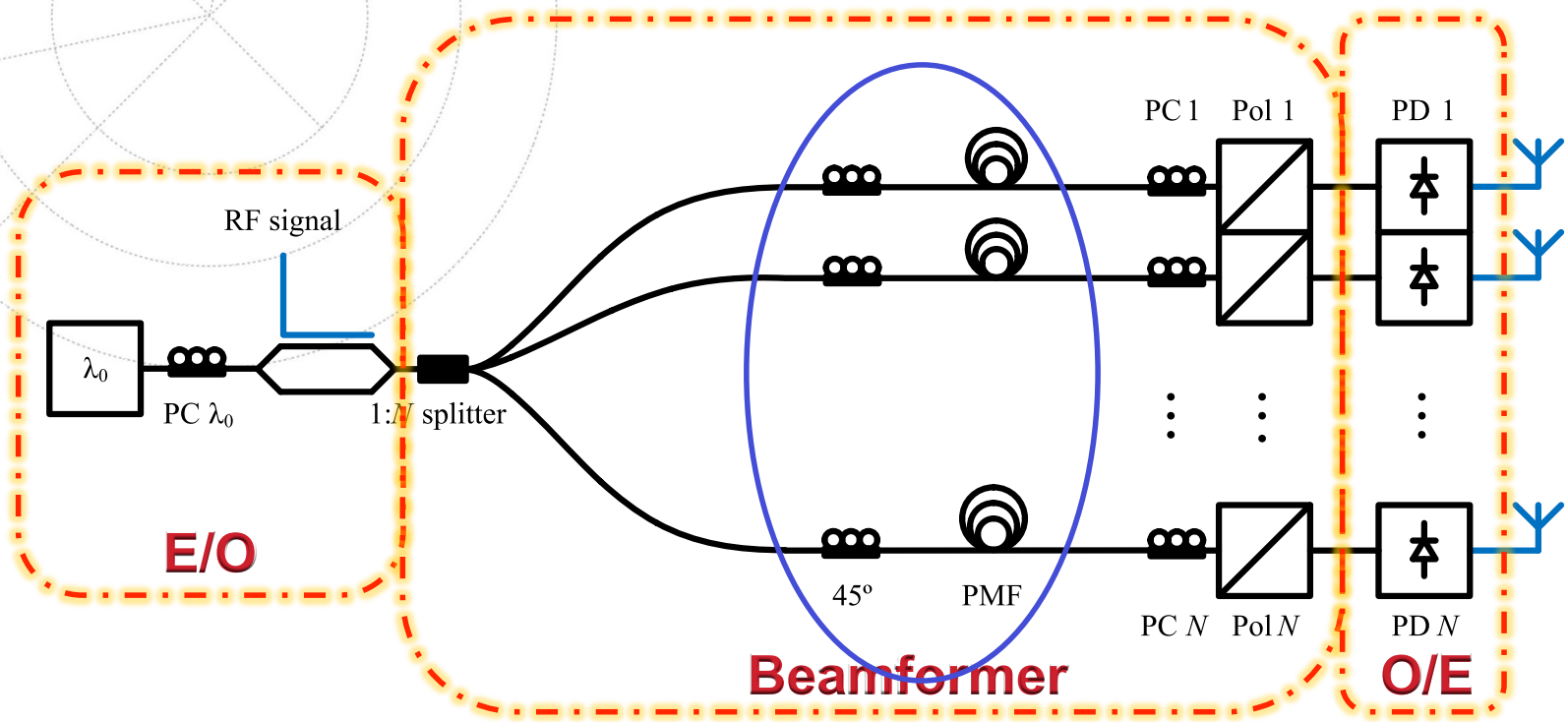
Quasi-ideal tunable delay line

TMZDI implementation – PDI

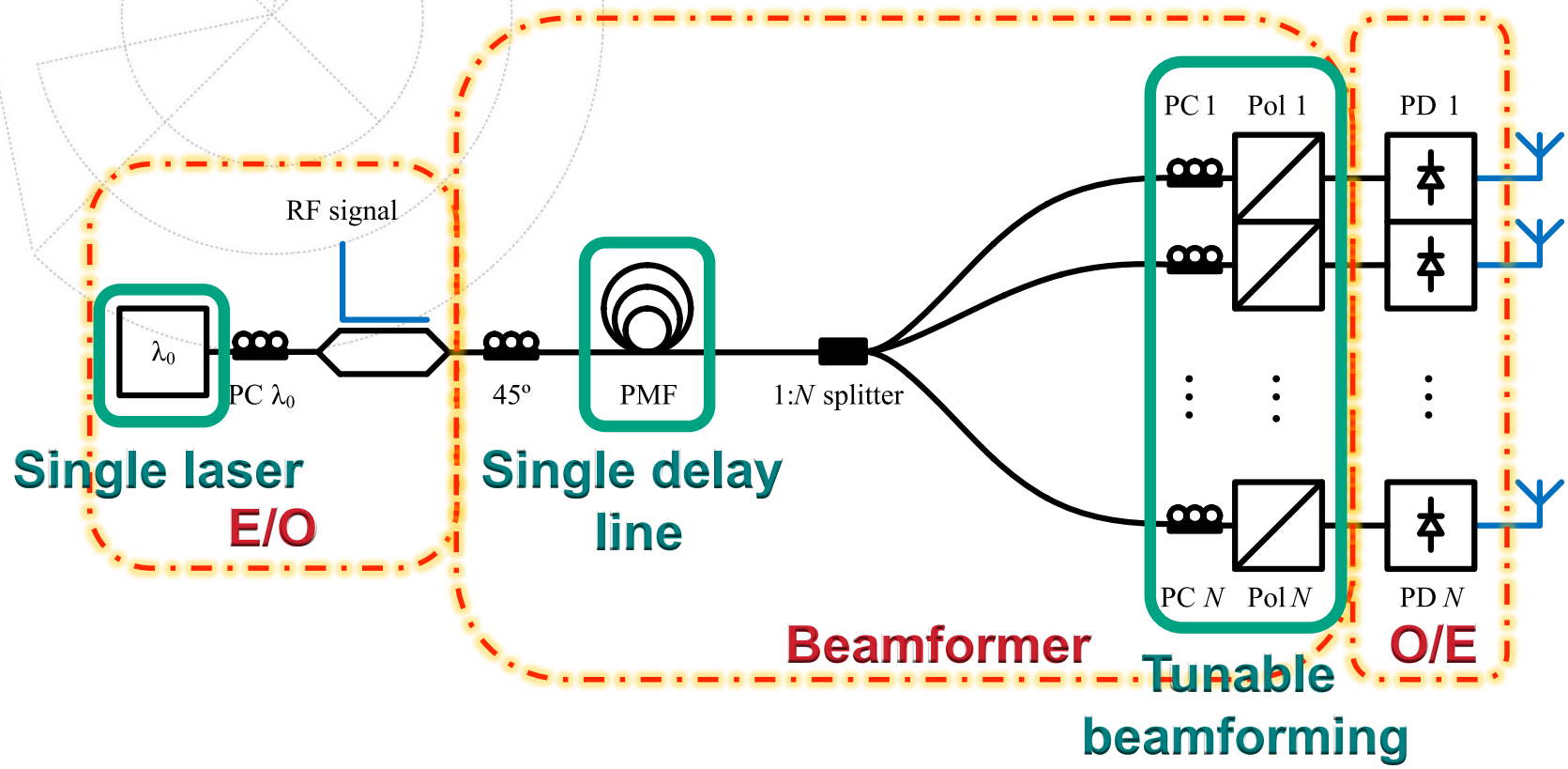




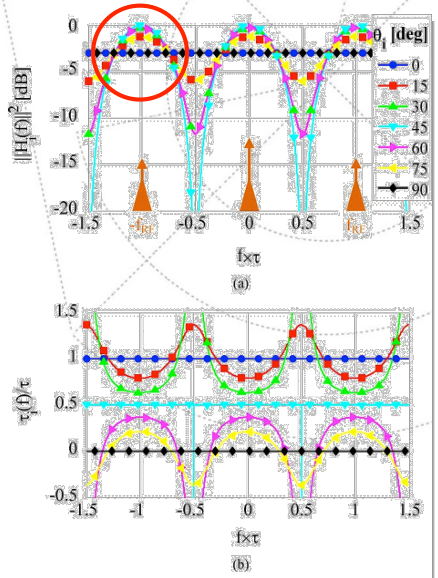
Beamformer based on PDI

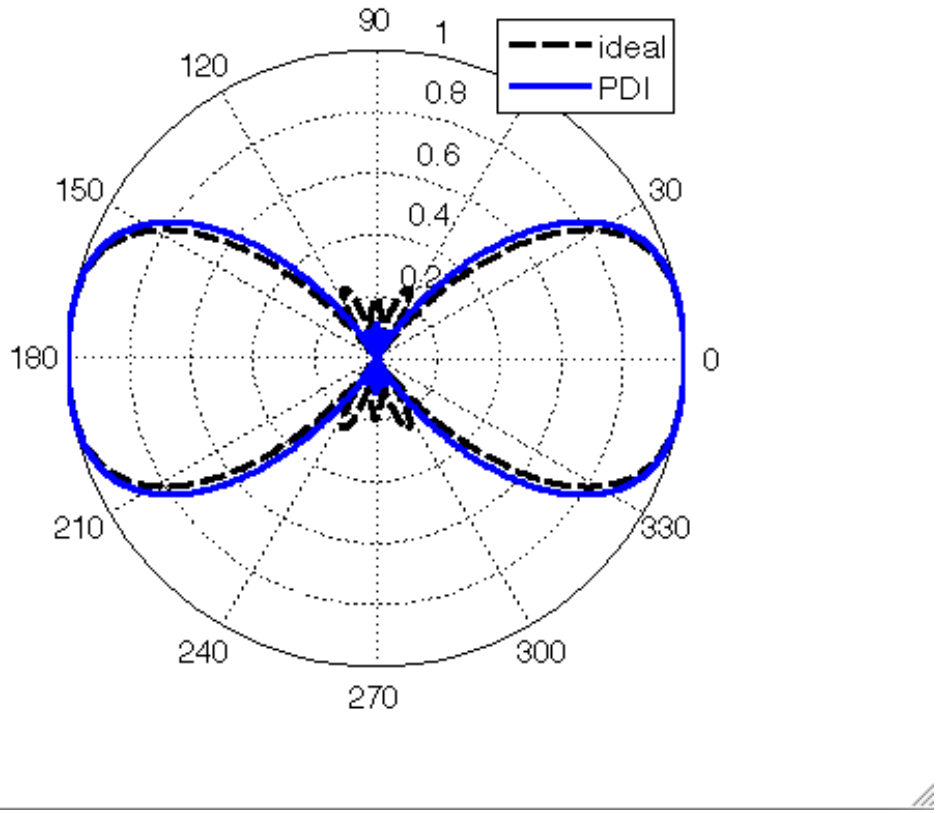


Beamformer based on PDI – optimization

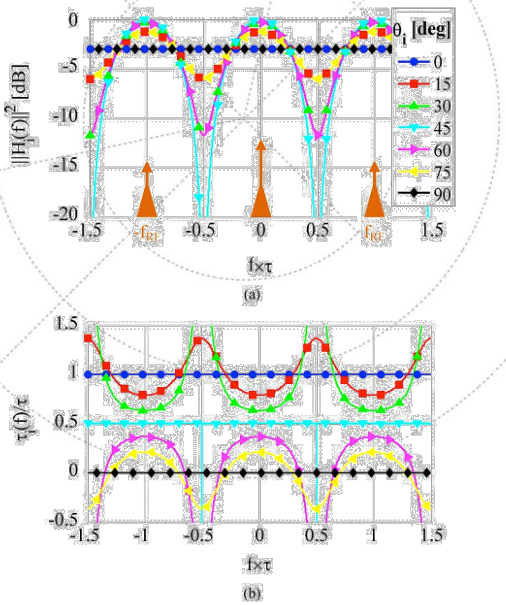


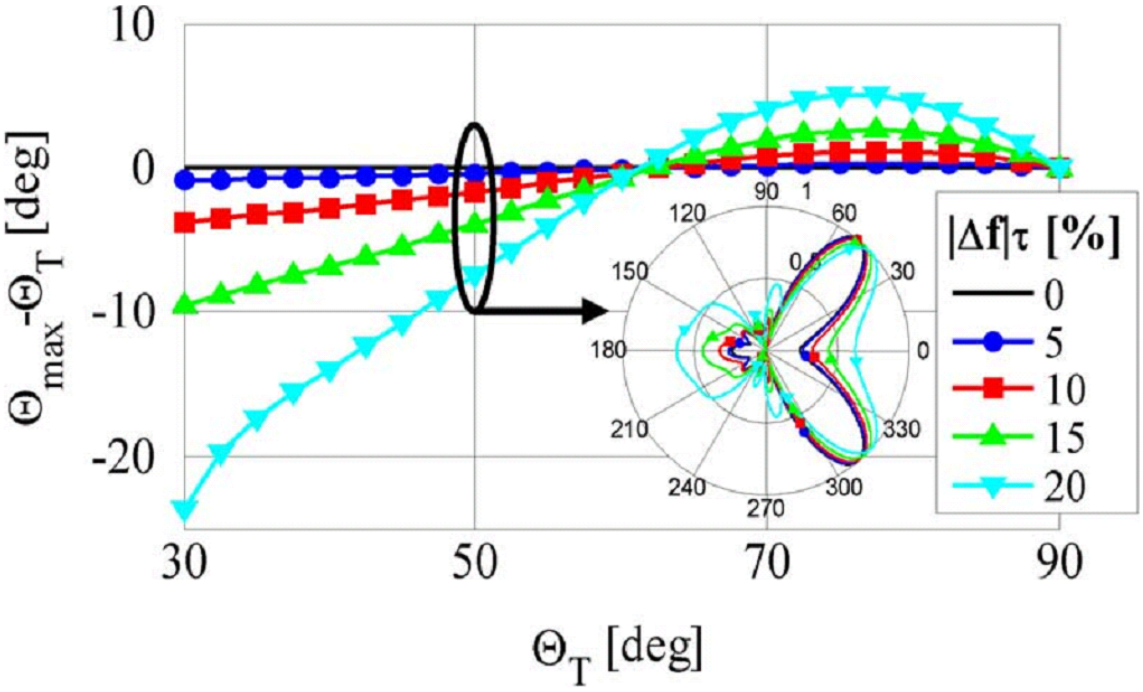
Ideal TTD vs. Proposed scheme



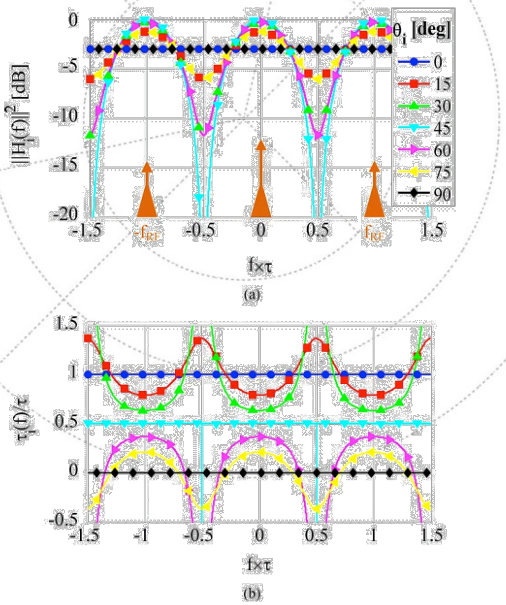


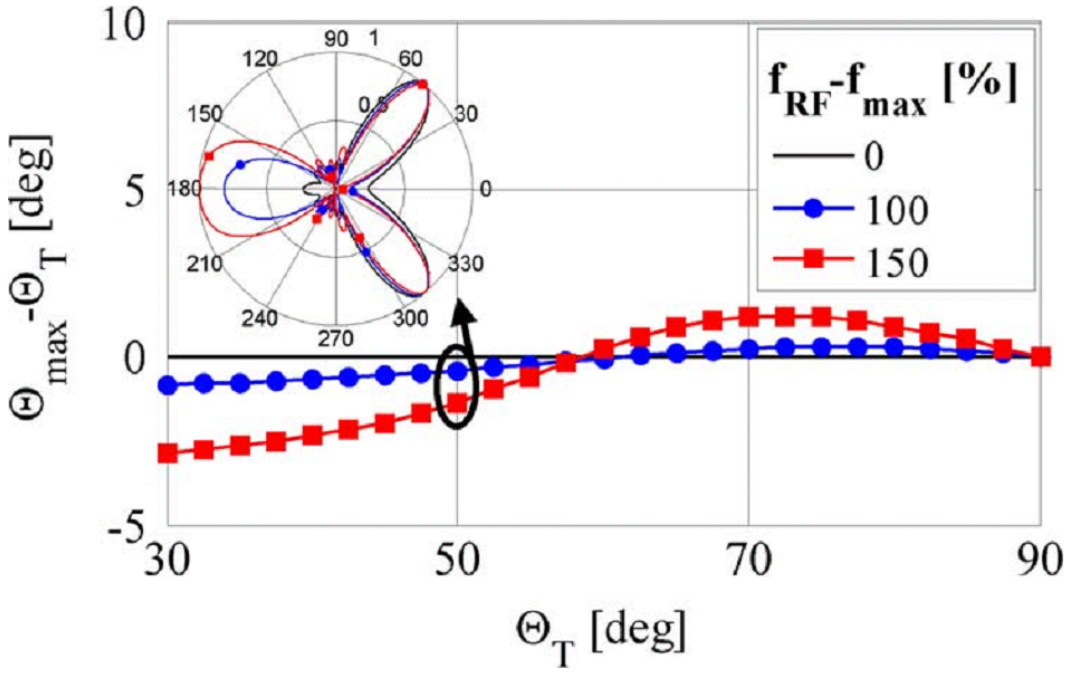
PDI Decentering





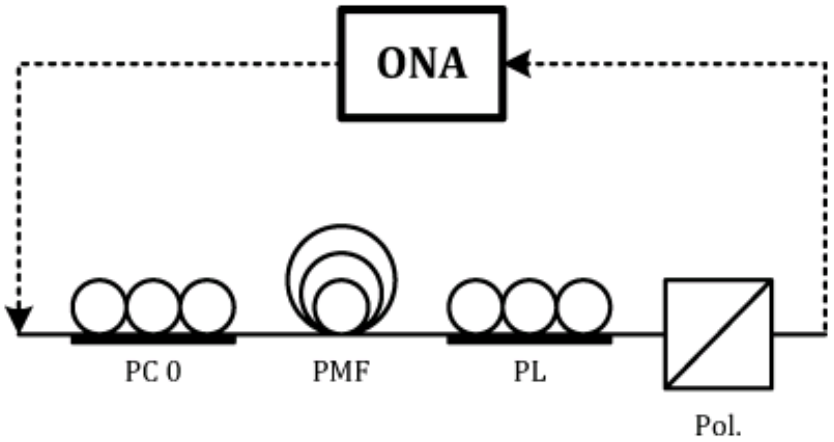
Centered PDI, with f_{RF}-f_{max}≠0

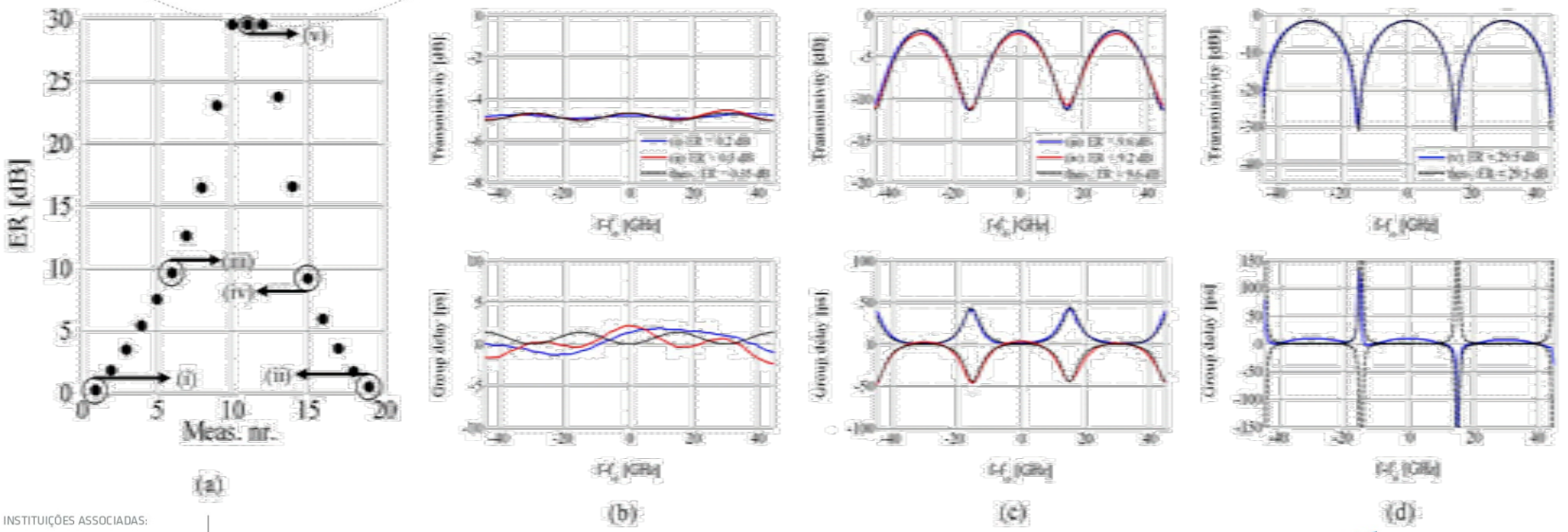




Precise centering between the laser and the PDIs must be ensured to avoid beamsquinting

Experimental assessment





Conclusions

- A novel photonic TTD beamformer was presented.
  - Advantages: one laser, one delay line, simple tunability.
  - Simple devices ease the implementation in integrated optics.
  - Problem: coherent operation → integrated optics.
- Future work
  - Receiver scheme.
  - Incoherent operation.
- More details in:
  - Drummond, M. V.; Monteiro, P. P.; Nogueira, R. N.; , "Photonic True-Time Delay Beamforming Based on Polarization-Domain Interferometers," IEEE/OSA Journal of *Lightwave Technology, vol.28, no.17, pp.2492-2498, 2010*

Acknowledgements

- FCT PhD scholarship SFRH/BD/40250/2007.
- THRONE PTDC/EEA-TEL/66840/2006.
- FP7 RadioNet.

Thank you.