The Contribution of Julien Perruisseau-Carrier to Reconfigurable Reflectarray Antennas

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Adaptive MicroNano Wave Systems

In memoriam of Prof.
Julien Perruisseau-Carrier
1979 - 2014

We have missed a brilliant scientist and a wonderful person.

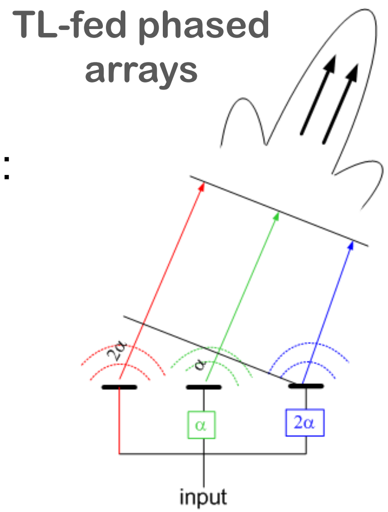
Julien, we miss you.

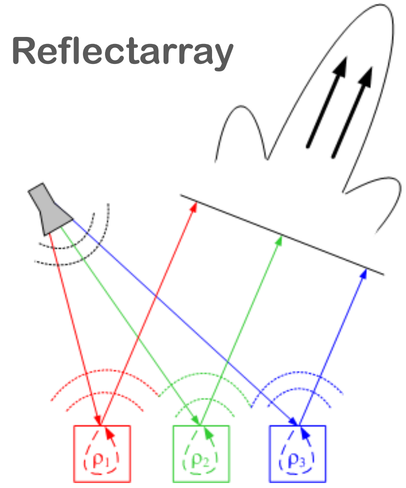
Julien's Contributions

- Julien Perruisseau-Carrier made significant contributions to the field of reconfigurable antennas.
- His research covered interdisciplinary topics: electromagnetics, signal processing, reconfigurable antennas, emerging Micro-nano tecnologies (MEMS, graphene, …), metamaterials, metasurfaces, Terahertz technology, …
- By combining different approaches and technologies, Julien anticipated to future trends in antenna applications by proposing new solutions for "**reconfiguration"** (frequency, polarization, beamwidth and beam pointing).
- It was a pleasure to collaborate with Julien in the following short courses:
  - "Electronically Scanned Reflectarrays", Short course EUCAP 2011, Rome, Italy.
  - "Arrays and Reflect-arrays", Universite Catholique Louvain. European School Of Antennas, Louvain-La-Neuve, Belgium (2012)
  - "Reflectarray Antennas: Design, Reconfigurability and Potential Applications", Short course IEEE AP Symposium, Chicago, USA 2012
- And in some collaborative works:
  - E. Carrasco, M. Barba, J. A. Encinar, J. Perruisseau-Carrier, "Reflectarray element for beam scanning with polarization flexibility," ISAP 2012.
  - E. Carrasco, J.A. Encinar, J. Perruisseau-Carrier, "Evaluation of a reflectarray with independent scanning of two linearly-polarized beams," EUCAP 2012
- In this presentation, we summarize some of Julien's main contributions to reconfigurable reflectarray antennas.

REFLECTARRAY ANTENNAS

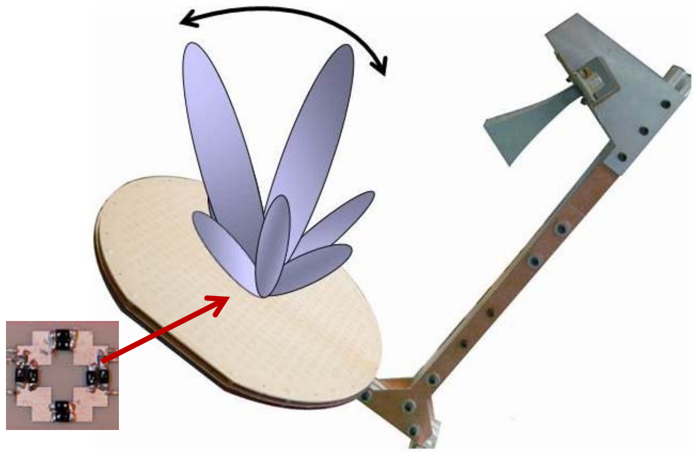
- Known advantages:
  - Vs conventional TL-fed phased arrays:
    - low loss
    - low cost
    - Shared Tx/Rx aperture
  - Vs parabolic reflectors:
    - low cost
    - low weight, conformability
    - possibility of electronic scanning.





ATRACTIVE SOLUTION FOR RECONFIGURATION

- Spatial (beamwidth, scan)
- Frequency
- Polarization
- A combination



[1] J. Perruisseau-Carrier, "Versatile reconfiguration of radiation patterns, frequency and polarization: a discussion on the potential of controllable reflectarrays for software-defined and cognitive radio systems," in IEEE IMWS 2010, RF Front-ends for Software Defined and Cognitive Radio Solutions, Aveiro, Portugal, 2010.

[2] J. Perruisseau-Carrier, "Dual-Polarized and Polarization-Flexible Reflective Cells with Dynamic Phase Control," IEEE Trans. Antennas and Propagation, vol. 55, pp. 1494-1502, May 2010.

Introduction to Beam-Scanning Reflectarrays

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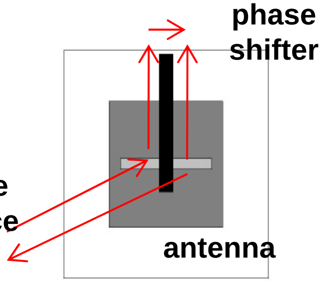
❑ Main technologies for microwave electronic reconfiguration:

	Pros	Cons
Ferrite	• Reliability • Power handling	• Bulky • Magnetic control
Semiconductors	• Reliability • Availbility	• Non-linearities • Losses • Power consumption
MEMS	• **Very low loss • High Freq.** • **'zero' power consumpt.** • **Very linear • Integration**	• Reliability, availability • switching speed • Precision
Liquid Crystals	• **Suitable to very high freq. (upper mm-wave)** • **Cheap**	• Loss at microwaves • switching speed • Sensitivity (temp., inital state,etc)
NEMS (CNT, graphene)	• **Integr. with nanoelectronic** • **Switching speed**	• Very few capabilities demonstrated yet !

Mature → Emerging → Future?

Two Approaches for Reconfigurable Unit Cells

fixed-resonator + reconf. phase shifter



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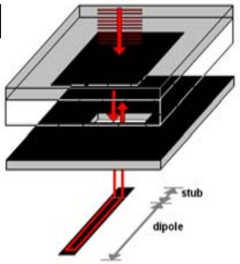

free space
antenna
phase shifter

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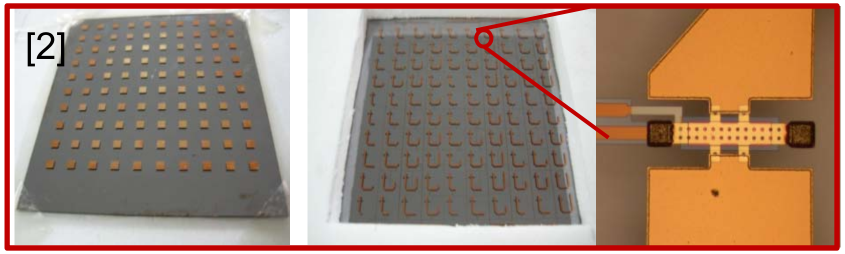
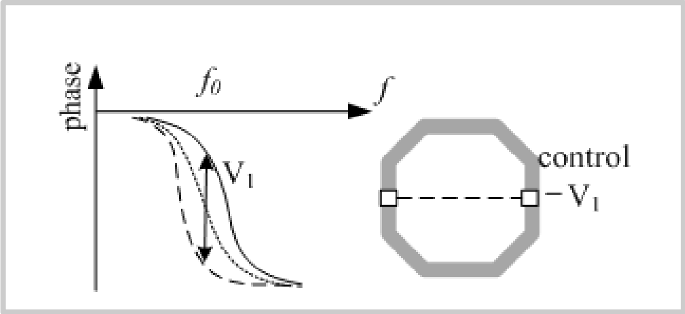


[1] E. Carrasco et al. "Dual-polarization reflectarray elements for Ku-band Tx/Rx portable terminal antenna", Eucap 2010, Barcelona.

[2] Ö. Bayraktar , Ö. Çivi, and T. Akın "Beam Switching Reflectarray with MEMS Controls," Eucap 2010, Barcelona.

reconfigurable resonator



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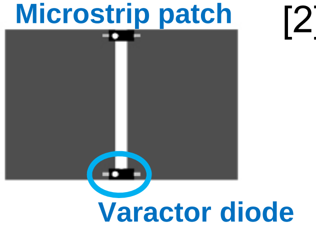

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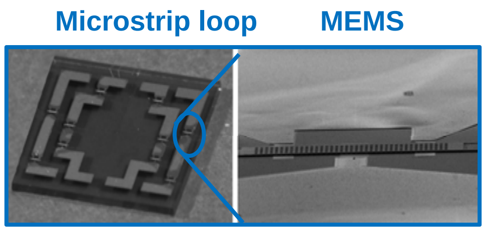
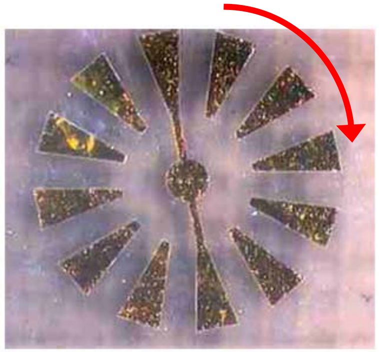


[1] Hum et al., "Modeling and Design of Electronically Tunable Reflectarrays," IEEE T-AP, vol. 55, 2007.

[2] Perruisseau-C.et al., "Monolithic MEMS-based reflectarray cell digitally reconfigurable over a 360° phase range" IEEE AWPL, 2008.

Dual-band Circularly-polarized RF MEMS Beam-Switching Reflectarray

- "Sequential rotation" approach was proposed for circular polarization passive and reconfigurable reflectarrays using rotated dipoles or circular rings or slots with switches.
- Julien proposed a dual-frequency CP reflectarray using interleaved rings of different sizes, which integrate six RF-MEMS
- An antenna capable of independent beam-switching in both K and Ka bands was demonstrated using frozen MEMS.



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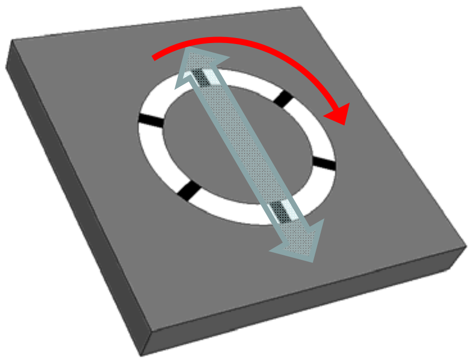

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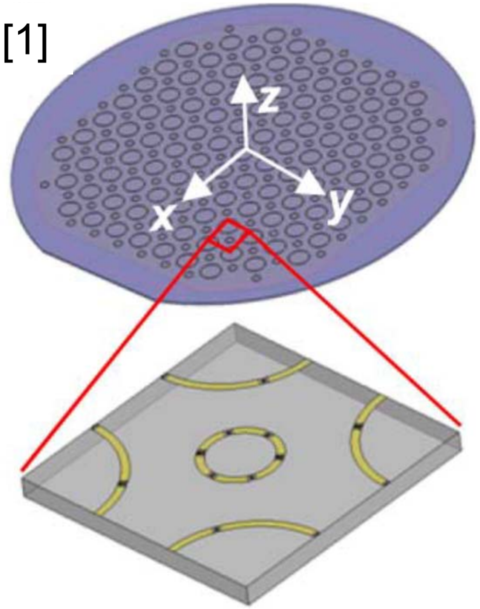
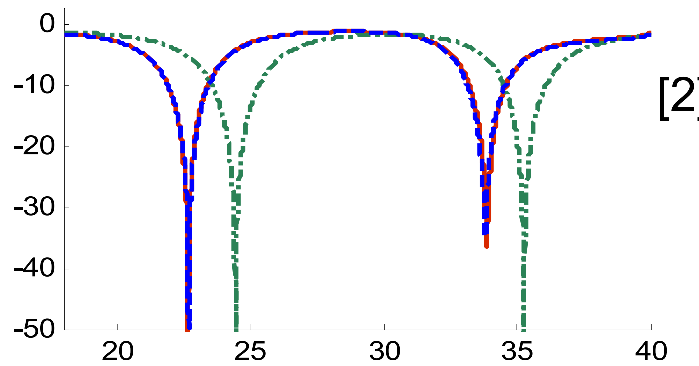


[1] C. Guclu, J. Perruisseau-Carrier, and O. Aydin Civi, "Proof of Concept of a Dual-band Circularly-polarized RF MEMS Beam-Switching Reflectarray" IEEE Trans. Antennas Propag.,

Accurate Modelling of Reconfigurable Unit-Cells

Julien made contributions to the accurate modelling of the cells:

- **A diode or a MEMS should never be considered as an ideal switch in a RA cell design:**
  - **Reactive part is not zero in 'on' and 'off' states**
    → strongly affect the element response
  - **Resistive part contributes to the RA cell thermal losses**
- **→ Modeling and design of a reflectarrays cell must include the actual diode/MEMS model [1-2] !**

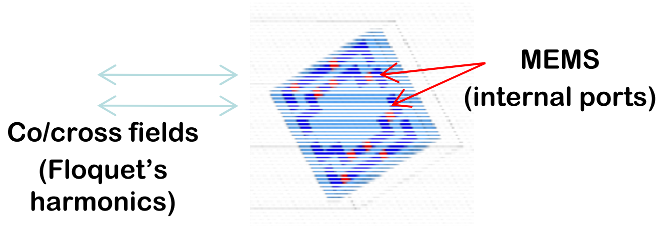


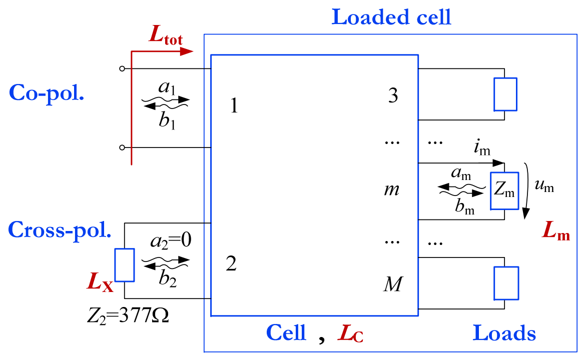
[1] J. Perruisseau-Carrier, et al., "Contributions to the Modeling and Design of Reconfigurable Reflecting Cells Embedding Discrete Control Elements," *IEEE Trans. Microw. Theory Tech.,* vol. 6, 2010.

[2] C. Guclu et al. "Proof of Concept of a Dual-band Circularly-polarized RF MEMS Beam-Switching Reflectarray" IEEE Trans. Antennas Propag., 2012

Efficient Simulation of Cells Embedding Control Elements

- **The MEMS are replaced by circuit models in full-wave simul. either:**
  - **A) by a 'passive' impedance:**
    - **Faster simulation than with detailed MEMS geometry**
    - **One simulation per state still required**
  - **B) by ports loaded by the desired impedances in post-processing**
    - **Only one full-wave simulation needed for all cell states !**
    - **The MEMS can be represented by a general impedance function (no need to extract a circuit model)**





System description:

$$\begin{bmatrix} b_1 \\ \mathbf{b}_{2M} \end{bmatrix} = \begin{bmatrix} S_{A\alpha} & \mathbf{S}_{B\alpha} \\ \mathbf{S}_{C\alpha} & \mathbf{S}_{D\alpha} \end{bmatrix} \begin{bmatrix} a_1 \\ \mathbf{a}_{2M} \end{bmatrix}$$

$$\mathbf{a}_{2M} = \mathbf{\Gamma}_\alpha \mathbf{b_{2M}} = \mathrm{diag}\left(\mathbf{0}, \rho_3, \rho_4, \ldots, \rho_{\mathrm{M}}\right) \mathbf{b_{2M}}$$

General solution:

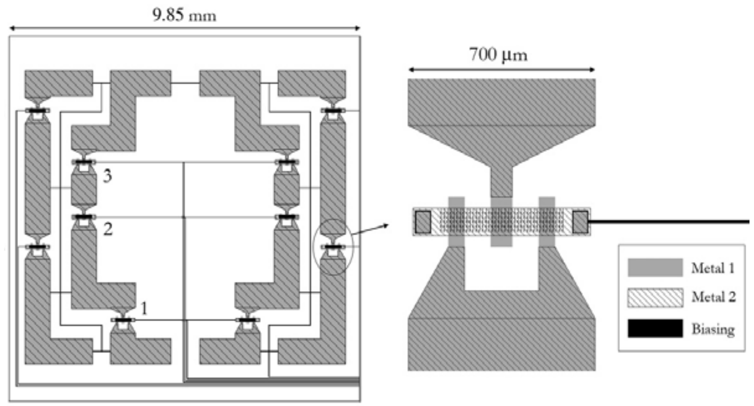
$$\mathbf{a}_{2M} = \mathbf{\Gamma}_\alpha \left(\mathbf{I} - \mathbf{S_{D}}_\alpha \mathbf{\Gamma}_\alpha\right)^{-1} \mathbf{S_{C}}_\alpha \mathbf{a_1}$$

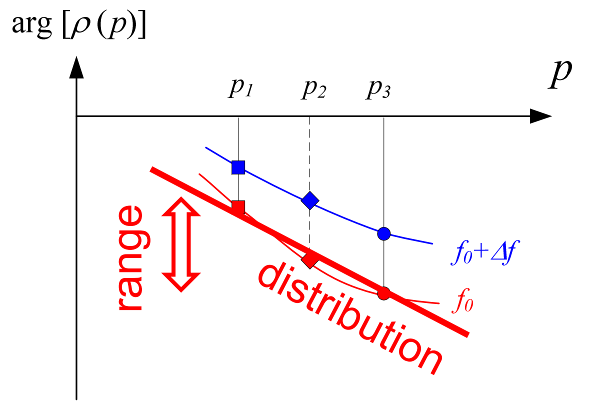
$$\mathbf{b}_{2M} = \mathbf{S}_{C\alpha} a_1 + \mathbf{S}_{D\alpha} \mathbf{a}_{2M}$$

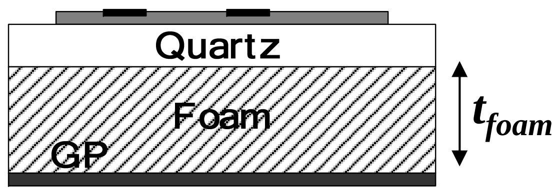
MEMS-based Linear-polarized Cell

- **Digital MEMS control**
  - **Robustness**
  - **Phase range**
- **5-bit control**
  - **Corresp. to 4-bit effective resolution → space telecom requirement**
- **MEMS positions**
  - **Optimized for a good (uniform) phase states distributions**

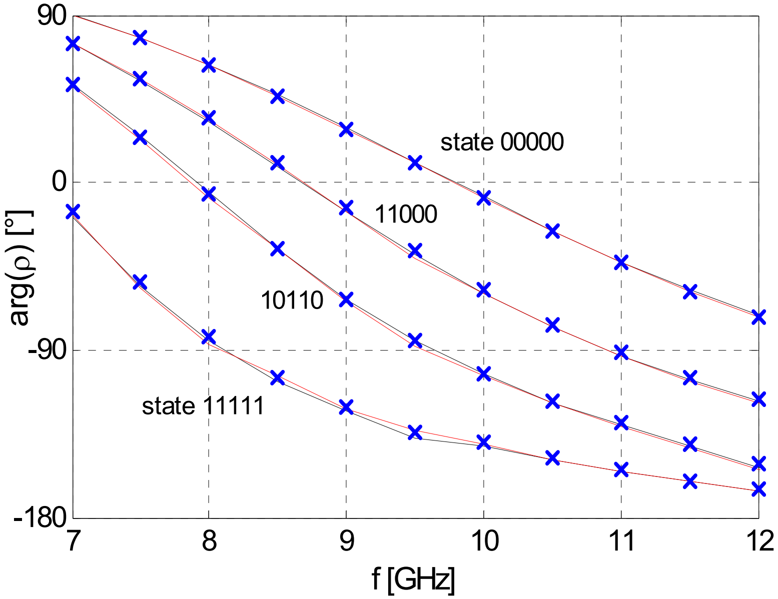
    → reduced phase quantization errors
- **Substrate thickness**
  - **Tradeoff BW-loss vs range (see next)**

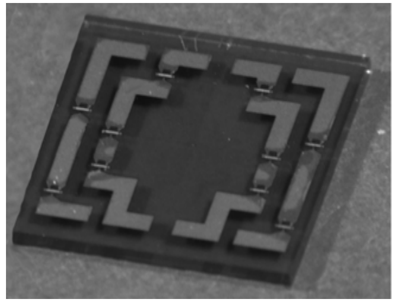






❑ Validation and comparison of the methods:





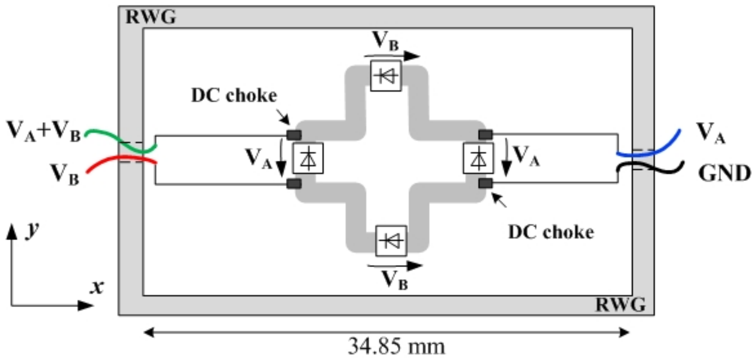
MEMS modeling	C.T. for 32 states
— 1) Detailed geometry	5 days
— 2A) RLC boundaries	4 hours
× 2B) Internal ports	9 minutes

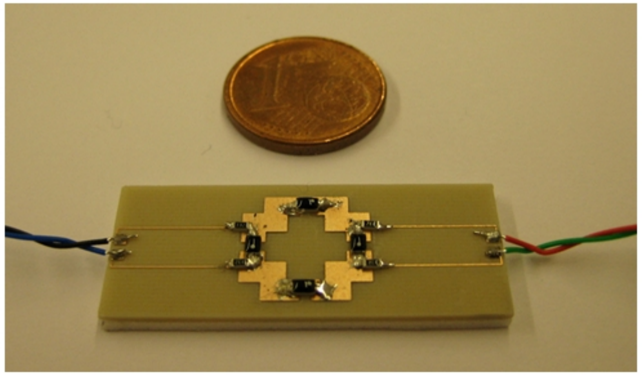
- Requires appropriate treatment of the parasitics in the extraction-insertion of the circuit model
- Good correlation between the different methods
- Drastic computational time reduction

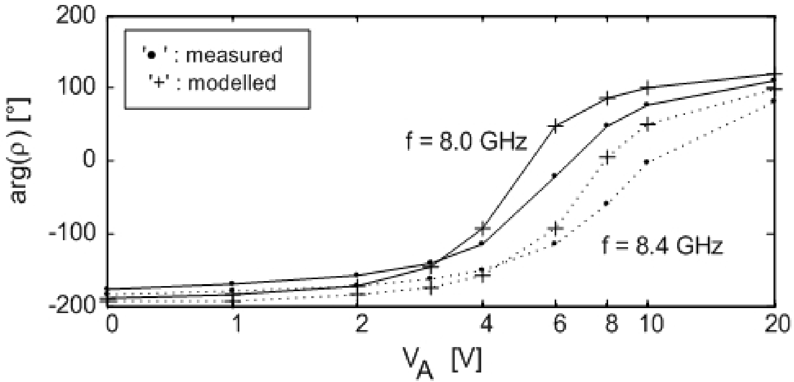
[1] J. Perruisseau-Carrier, et al., "Contributions to the Modeling and Design of Reconfigurable Reflecting Cells Embedding Discrete Control Elements," *IEEE Trans. Microw. Theory Tech.,* vol. 6, 2010.

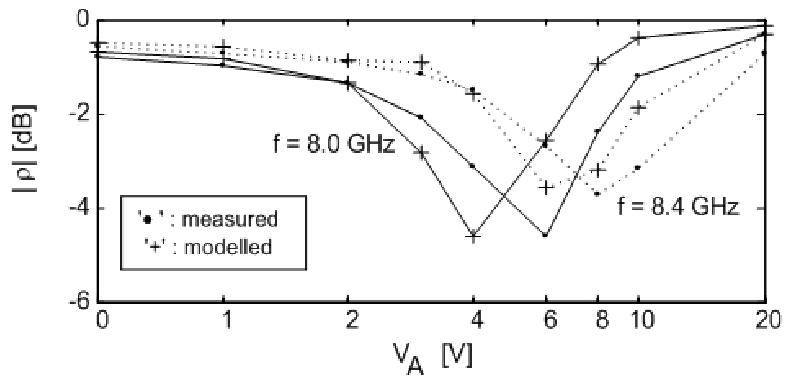
Diode-based Dual-polarized Cell

- **Two simplifications were used for simple measurements:**
  - **Cell full symmetry → full dual-pol. measurements not necessary**
  - **Only one cell placed in the RWG: large incident angles**
    → only for validation sim.-meas. agreement !



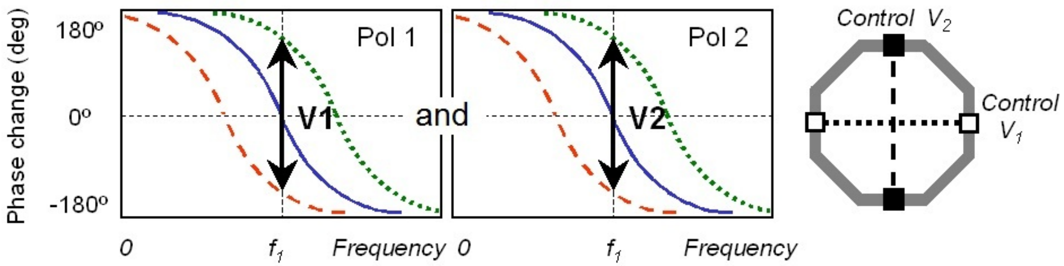


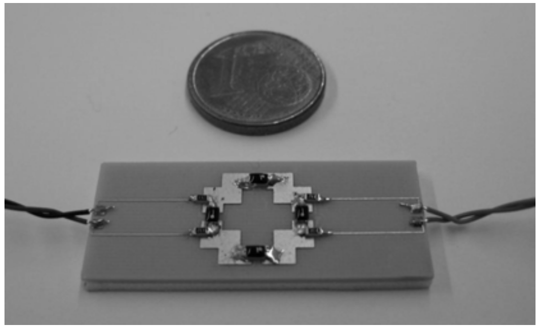




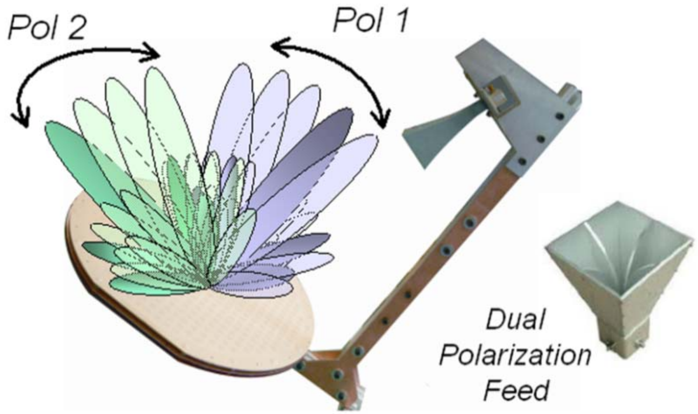
Dual Polarization Independent Beam Scanning Reflectarray

- Based on a dual-LP cell with independent control similar to that presented earlier:



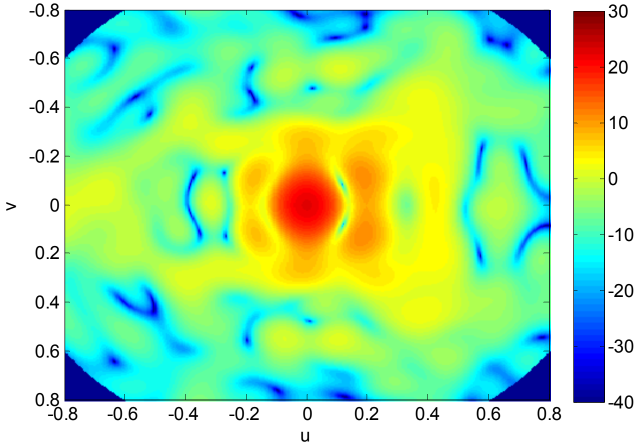


- Next we show computed array performance results scanning one beam with one of the voltages

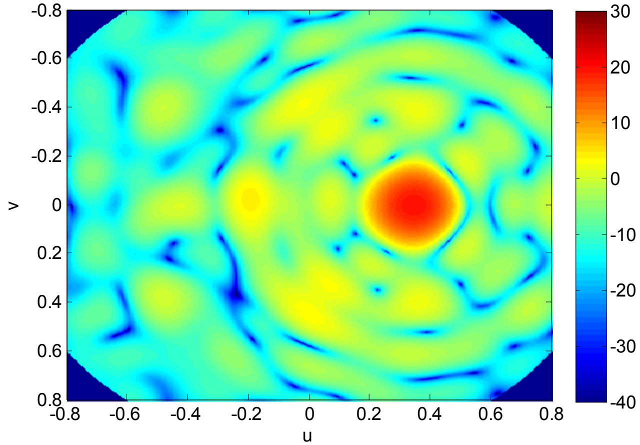


❑ Co-polarization patterns for four repr. pointing angles

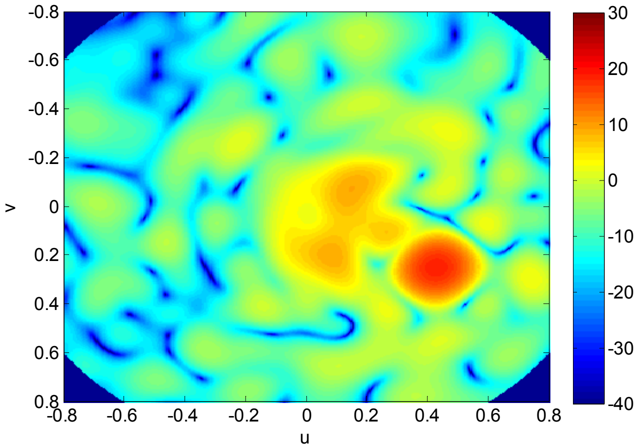
Beam 1. θ=0º, φ=0º



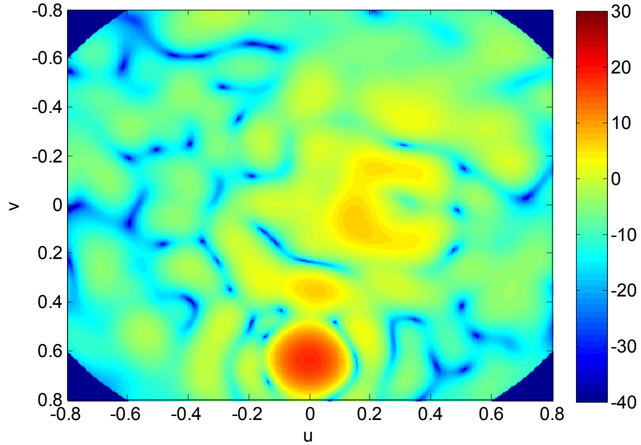
Beam 2. θ=20º, φ=0º



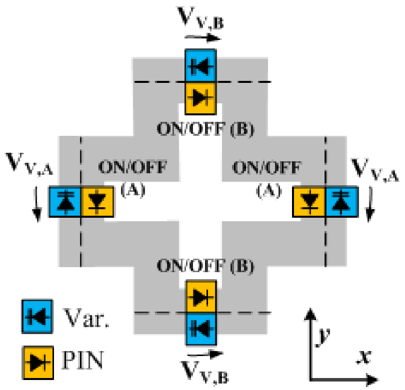
Beam 3. θ=30º, φ=30º

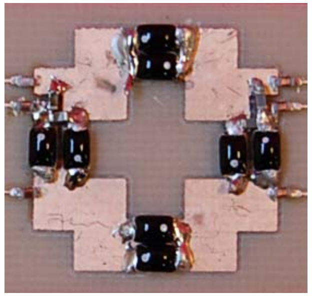


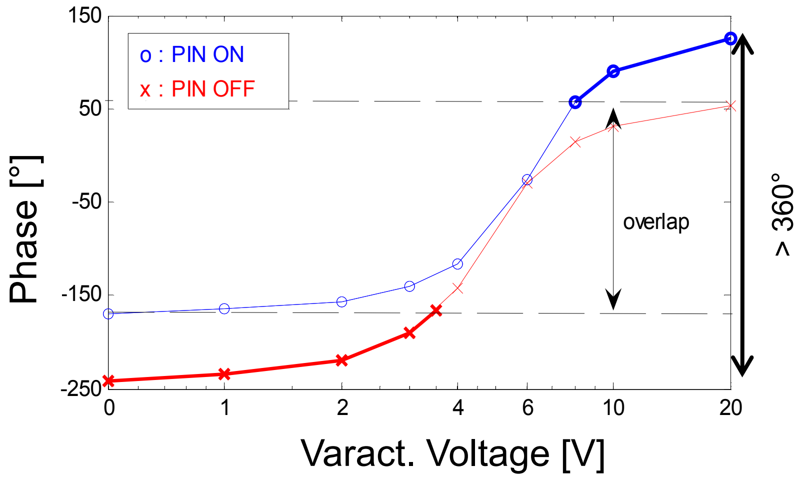
Beam 4. θ=40º, φ=90º

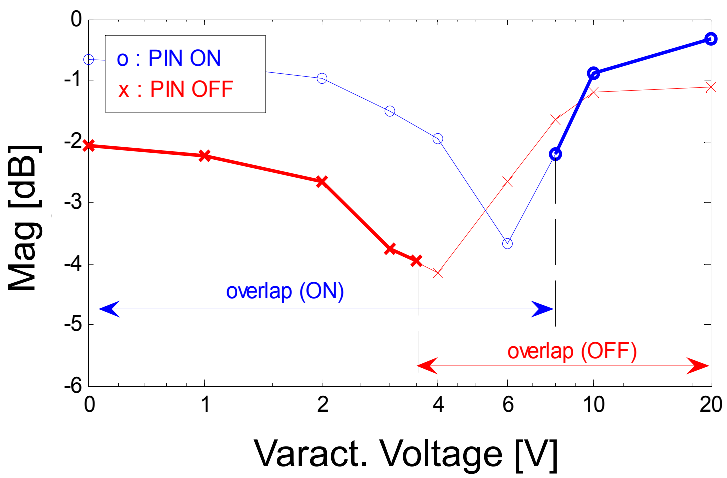


- Variant of the previously presented dual-polarized with a pin diode in parallel with each varactor



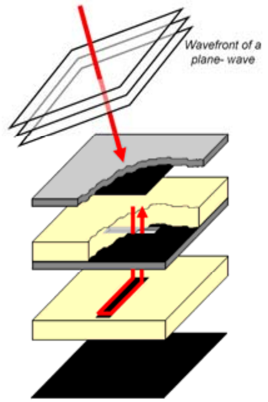




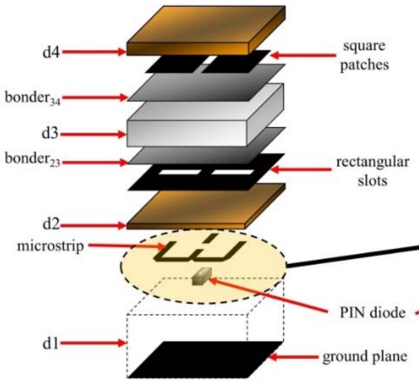


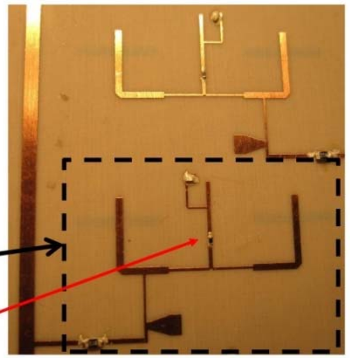
[1] J. Perruisseau-Carrier, "Dual-Polarized and Polarization-Flexible Reflective Cells with Dynamic Phase Control," *IEEE Trans. Antennas Propag.*, vol. 58, pp. 1494-1502, 2010.

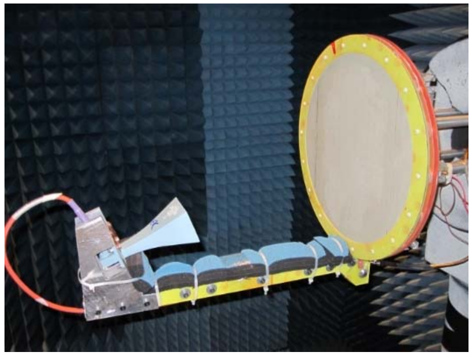
Aperture-Coupled Reflectarray Cell

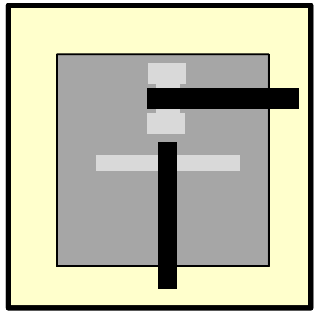


- ✓ Differential spatial phase delay compensation by the introduction of TRUE-TIME DELAY.
- ✓ Bandwidth improvement in large reflectarrays.
- ✓ Phase delay proportional to twice the length of the microstrip line (-2βL).
- ✓ Low losses can be achieved.
- ✓ Low cross-polarization levels.
- ✓The control elements are isolated from the impinging energy because the presence of the ground plane.
- ✓ Gathering for cost and complexity reduction.
- ✓Compatibility with electronic control devices (PIN diodes, varactors, MEMS).
- ✓ Can be extended to dual-polarization.









Previous experience with aperture-coupled reflectarrays (E. Carrasco, M. Barba, J. A. Encinar, UPM)

+

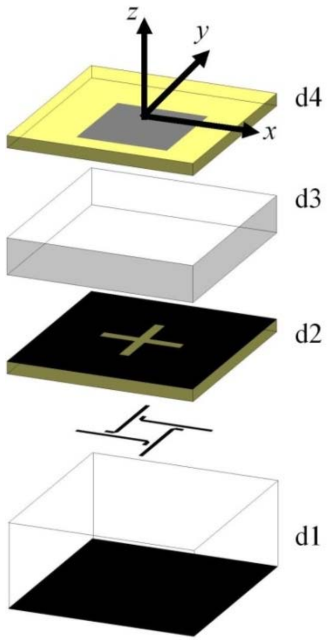
Previous experience with devices for phase reconfiguration (J. Perruisseau-Carrier, EPFL)

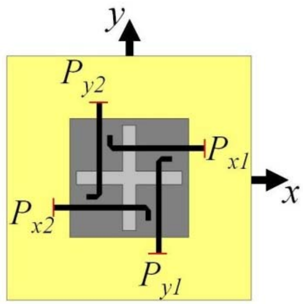
=

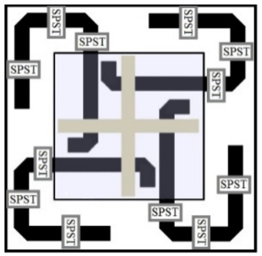
Phase & Polarization Reconfiguration in RA using PIN diodes & Aperture-Coupled Topology

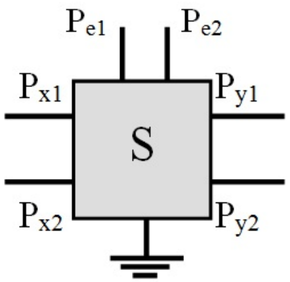
Spatial and Polarization Reconfiguration

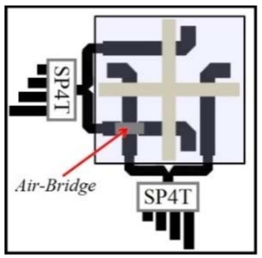
- The **cross slot** allows to keep the **symmetries** and therefore to obtain **exactly the same behaviour in both orthogonal polarizations**, a very linear phase response and low cross-polarization.

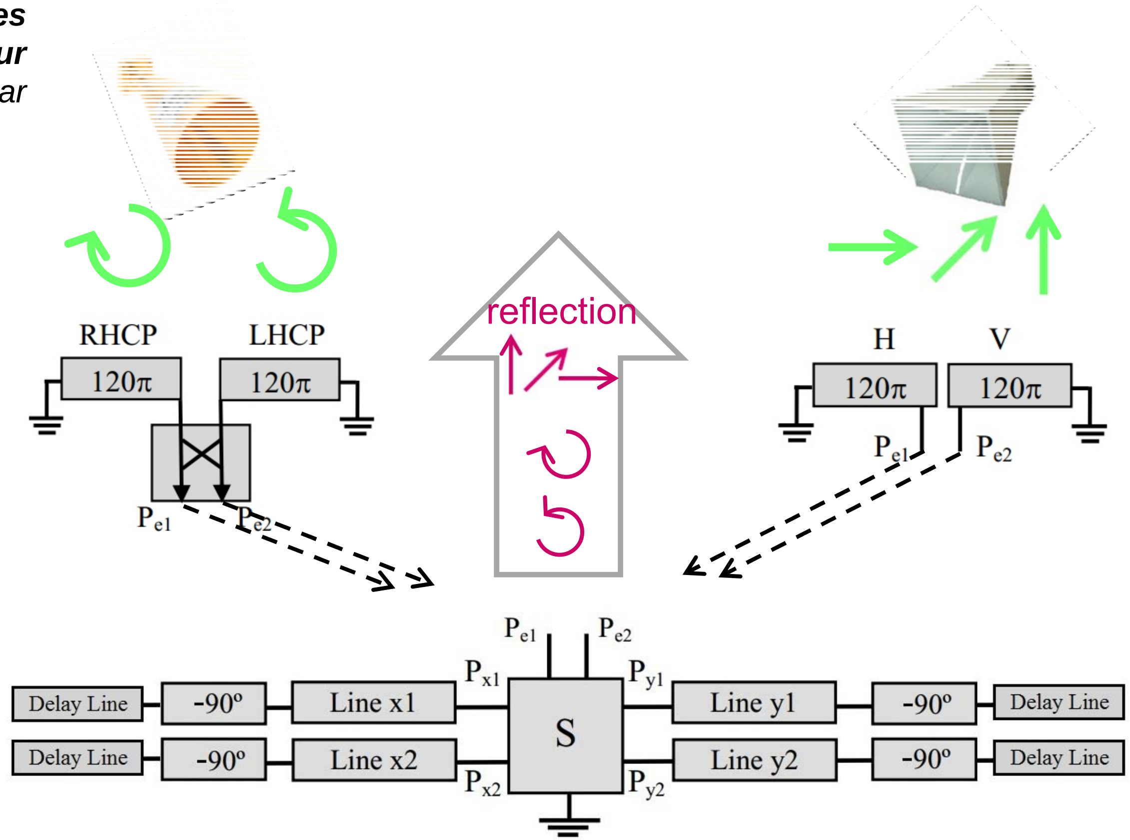






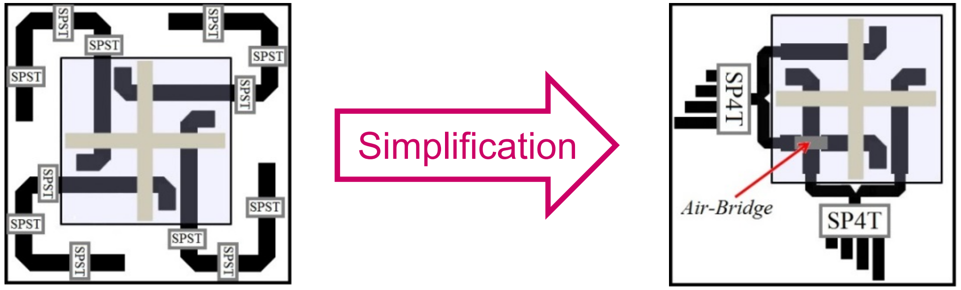






Eduardo Carrasco, Mariano Barba, José A. Encinar, Julien Perruisseau-Carrier, **"Reflectarray Element for Beam Scanning with Polarization Flexibility"**, International Symposium on Antennas and Propagation, Nagoya, Japan, November 2012.

Spatial and Polarization Reconfiguration

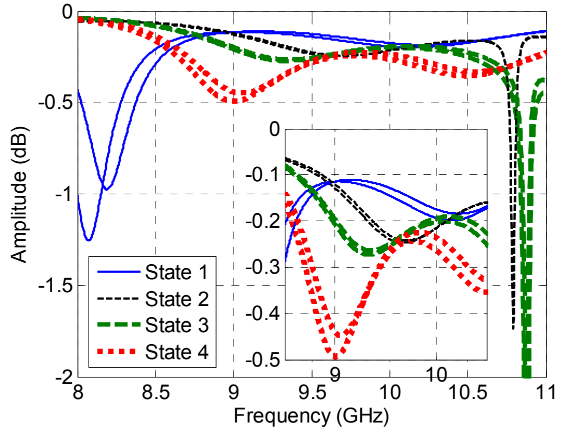


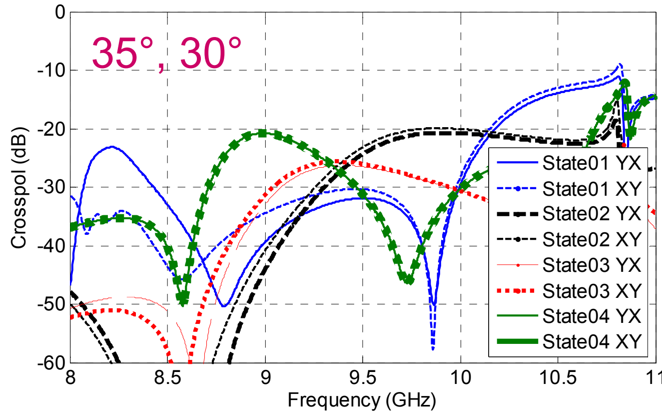
Critical point: air bridge

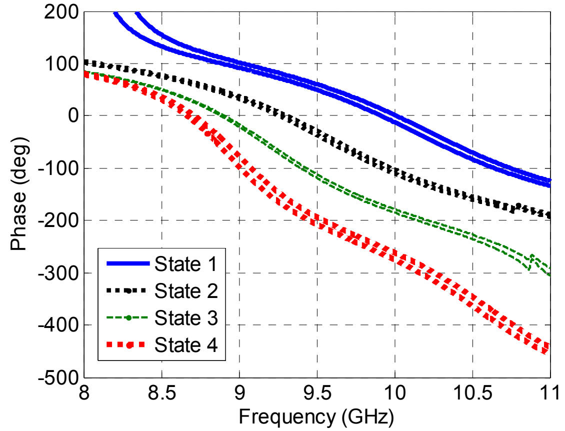
The phase and amplitude response in both polarizations must be similar in order to reduce any impact in the polarization purity.

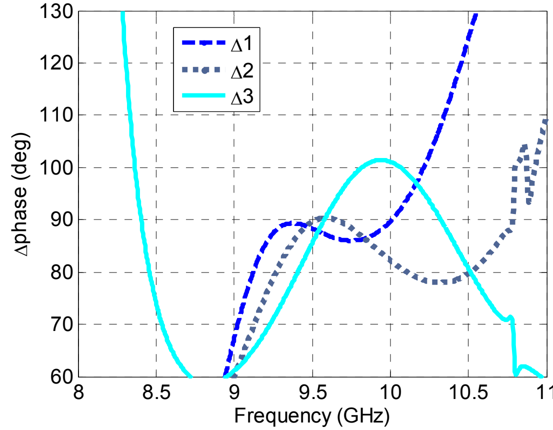
Low loss

X and Y pol amplitudes practically the same!

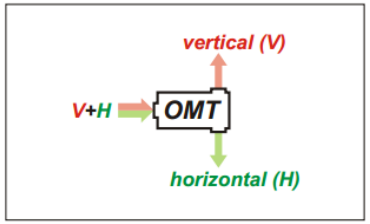


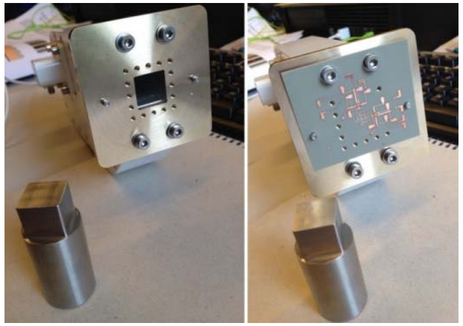


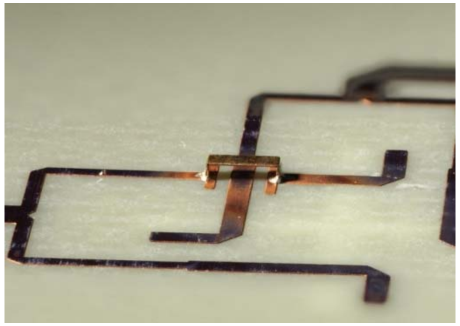


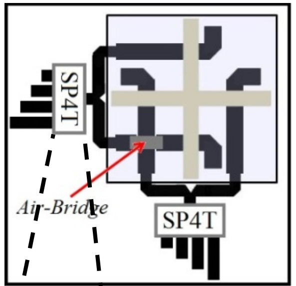


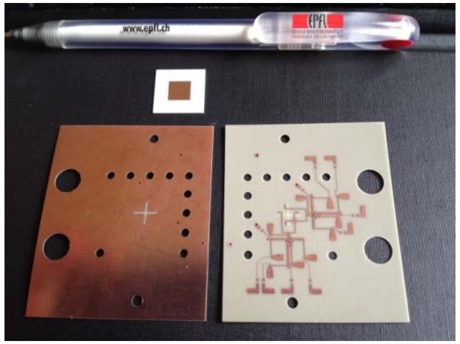
Spatial and Polarization Reconfiguration











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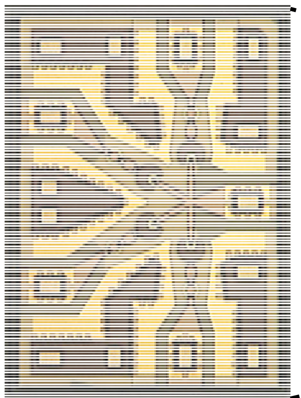
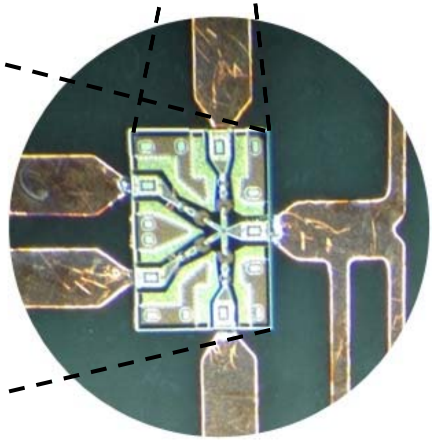
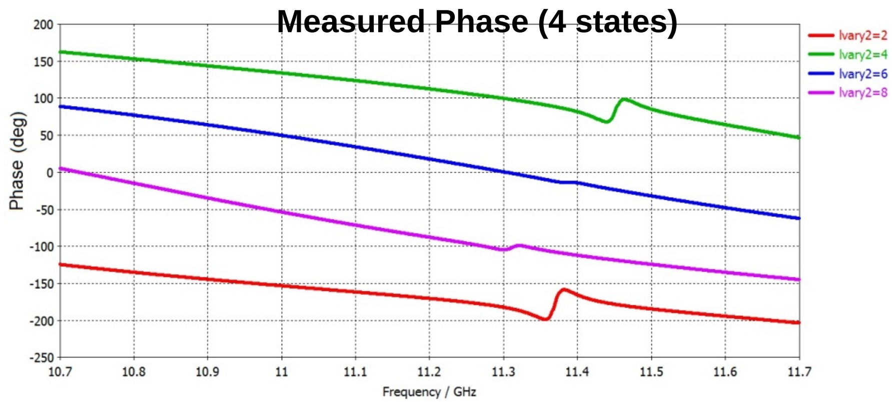
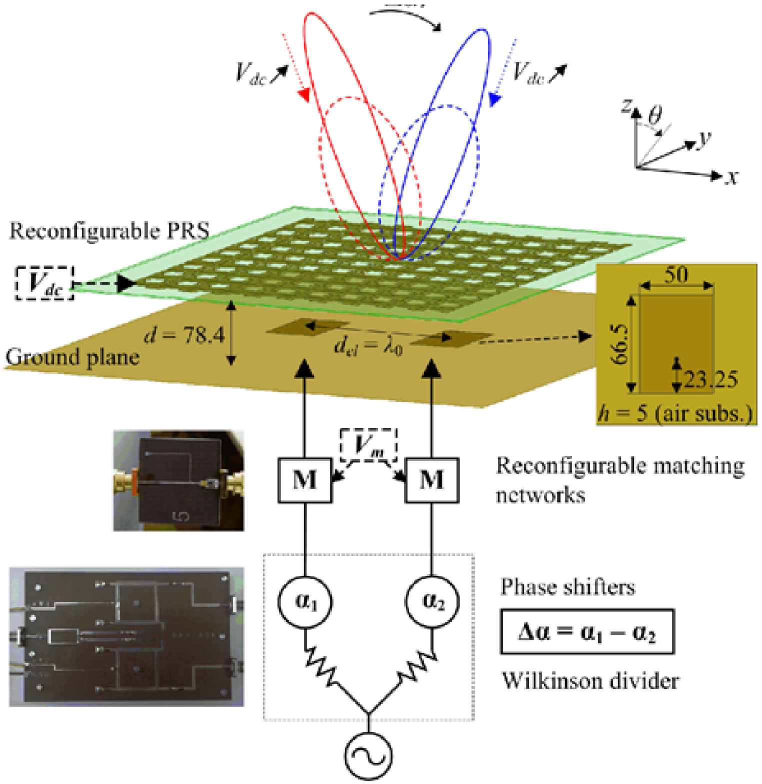






Independent Scanning and Beamwidth Control

- **An antenna with independent scanning and beamwidth control was demonstrated.**
- **The beamwidth is controlled by reconfiguring a partially reflective surface (PRS) with varactor diodes**
- **The beam is steered by using a small phased array as a source of the Fabry-Pérot cavity.**
- **A fully operational prototype was fabricated and measured, showing good agreement between simulated and measured results.**



[1] T. Debogovic, J. Perruisseau-Carrier, "Array-Fed Partially Reflective Surface Antenna With Independent Scanning and Beamwidth Dynamic Control", IEEE Transactions on Antennas and Propagation, vol.62, no.1, pp.446,449, Jan. 2014

Conclusions

- Just a few examples of the many contributions made by Prof. Julien Perruisseau-Carrier to the field of **“reconfigurable reflectarrays”** have been presented.
- We would like to remark that the significance of combining different types of reconfiguration (beam, frequency and polarization) in antennas for future applications, which were pioneered by Julien.
- Many other contributions to this field were not mentioned here because of time limitation.
- Finally, we recognize the significant contributions of Julien to other frontier fields, such as antennas in THz’s and reconfigurable antennas using new materials as graphene, but these topics will be covered in other presentations

In memoriam of Prof.
Julien Perruisseau-Carrier
1979 - 2014

We have missed a brilliant scientist and a wonderful person.

Julien, we miss you.