# EuCAP 2011 Short Course:
# Electronically Scanned Reflectarrays


Instructors:
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**Abstract**

The short course will provide participants with an overview of electronically scanned reflectarray design and applications. Theoretical and practical design aspects, ranging from the constituent parts, such as reconfigurable and reflective unit cells, to the electronically scanned reflectarray system will be covered. The short course is intended for graduate students and practicing antenna designers.


## Contents

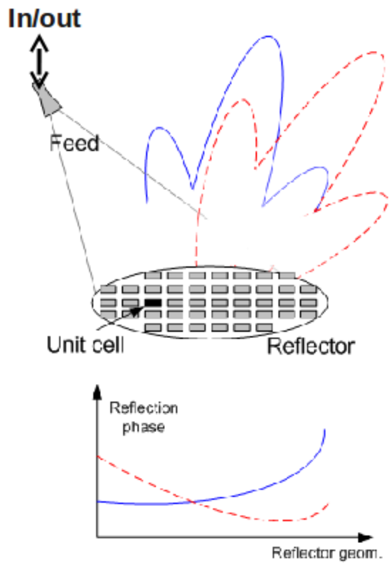


Figure 1: Tile-assembled electronically scanned reflectarray showing constituent parts.



# 1 Introduction

*Estimated duration: 20-25 min., Instructor: Dr. Van Caekenberghe*
The electronically scanned reflectarray system, as shown in Fig. 1, will be introduced, along with its constituent parts (array elements, feeds, orthomode transducers, phase shifters, receivers, transmitters). Antenna array elements, feeds (soft and hard horns, monopulse horns), and feed methods (offset, Cassegrain and Gregorian subreflector based), as well as RF circuits (phase shifters, orthomode transducers) and viable RF technologies (ferroelectrics, ferrites, RF MEMS, semiconductors (p-i-n diodes, FETs), vacuum electronics devices (magnetron, klystron)) will be discussed.

# 2 Theory

## 2.1 Reflectarray system

*Estimated duration: 30-35 min., Instructor: Prof. Encinar*
An overview of the different computational electromagnetic methods used for the analysis of reflectarrays will be presented and the case for the spectral-domain method-of-moments (SD-MoM), which is a full-wave integral equations method, will be made. The SD-MoM method will be used to analyze reflectarrays under the assumption of local periodicity. The technique is applied to the analysis of various types of unit cells (aperture-coupled microstrip antennas and dual-

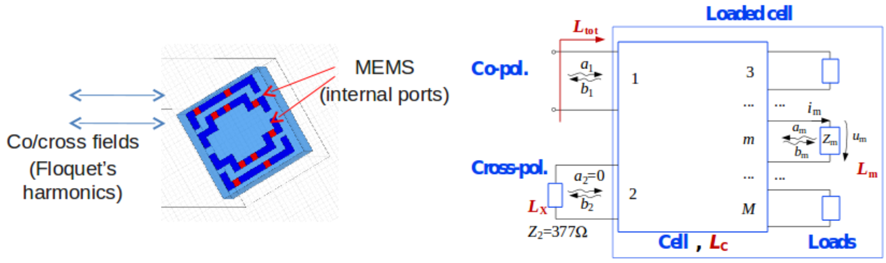


Figure 2: Multiport modeling of RF MEMS reconfigurable unit cell.

stacked aperture coupled microstrip antennas) and then to the analysis and design of reflectarrays. Finally, the analysis of reflectarrays in dual-reflector configuration will be discussed.

## 2.2 Reconfigurable unit cell modeling

### 2.2.1 Full-wave simulation and measurements

*Estimated duration: 20-25 min., Instructor: Dr. Perruisseau-Carrier*
First, the different possibilities to simulate and measure a reflectarray unit cell under the assumption of local periodicity will be discussed. Secondly, different methods to represent embedded control components such as p-i-n diode or RF MEMS switches in the unit cell setup will be compared in terms of computational efficiency, as shown in Fig. 2.

### 2.2.2 Linear and non-linear equivalent circuit modeling

*Estimated duration: 20-25 min., Instructor: Prof. Hum*
Physical intuition into the operation of a reconfigurable reflectarray unit cell can be obtained by modeling the unit cell with an equivalent circuit, based on a transmission line (parallel-plate waveguide or rectangular waveguide) model. In addition large-signal models of active components, such as p-i-n diodes and MMIC amplifiers, can be inserted to simulate the large-signal (non-linear) behavior of the unit cells. Characteristics of active unit cells, such as harmonic generation and inter-modulation distortion, will be discussed.

# 3 Design

## 3.1 Resonant reflectarrays

*Estimated duration: 20-25 min., Instructor: Dr. Perruisseau-Carrier*
One of the two main approaches to implement reconfigurable reflectarray unit cells is to embed discrete control components, such as RF MEMS or p-i-n diodes directly in a - generally planar - resonating structure. In this way, the resonant frequency of the unit cell can be dynamically tuned, and in turn, the reflection phase at the desired reflectarray operation frequency can be controlled. This section will discuss the principle and design of such cells. Semiconductor diode

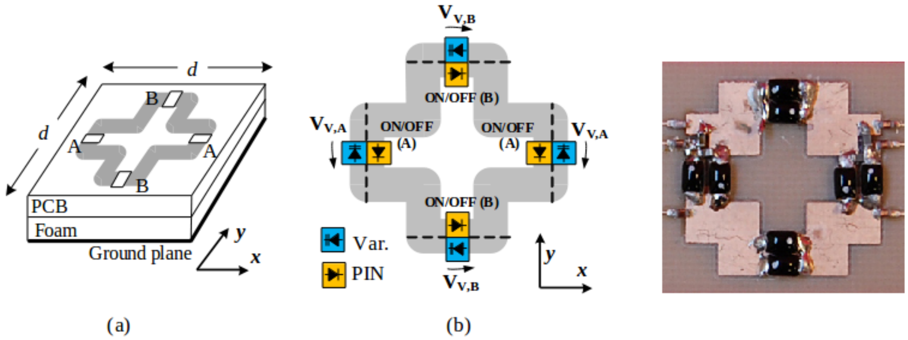


Figure 3: Resonant reflectarray unit cell with embedded silicon diodes

(shown in Fig. 3) and RF MEMS switch based demonstrators will be discussed, and their advantages and disadvantages will be exposed.

### 3.2 Wideband reflectarrays

*Estimated duration: 20-25 min., Instructor: Prof. Encinar*
The operation bandwidth of large reflectarrays is reduced if the phase shift is invariant with frequency and limited to 360°. A unit cell based on a cascade of an aperture-coupled microstrip antenna and a true-time-delay phase shifter is capable of introducing phase shifts in excess of 360°, while avoiding beam squinting. Some results will be presented to show the improvement in bandwidth when introducing the true-time-delay phase shifters in reflectarrays. Theoretical and experimental results will be shown for the reconfigurable unit cell and electronically scanned reflectarrays in X-band.

### 3.3 A related approach: the lens array

*Estimated duration: 30 min., Instructor: Prof. Hum*
Building on both the idea of the resonant unit cell and the brick-assembled reflectarray, reconfigurable apertures that exhibit both reflective and transmissive behavior can be developed. The transmissive version, commonly known as the array lens, will be presented in detail. Design approaches and implementations based on use of coupled resonators, as well as low-profile guided-wave phase shifters, will be presented.

## 4 Applications

Passive electronically scanned reflectarrays find application in:

### 4.1 Real-beam radar

*Estimated duration: 15-20 min., Instructor: Dr. Van Caekenberghe*
This section will discuss the use of the electronically scanned reflectarrays in real-beam radar. A short introduction to real-beam radar will be given prior

to comparing the electronically scanned reflectarray with other antennas using other analog (IF, optical, RF) or digital beamforming techniques.

### 4.2 Space applications

*Estimated duration: 15-20 min., Instructor: Prof Encinar*
Synthetic aperture radar (SAR) applications of (electronically scanned) reflectarrays, such as earth observation, will be discussed. A short introduction to SAR and SAR modes will be given prior to comparing the advantages of using (electronically scanned) reflectarrays in space-borne SAR, and highlighting applications. In addition, direct broadcast satellite technology will be discussed.

### 4.3 Wireless communication and passive identification

*Estimated duration: 15-20 min., Instructor: Dr. Van Caekenberghe*
This section will discuss the advantages and disadvantages of multiple input / multiple output (MIMO) arrays on the one hand, and electronically scanned arrays, and electronically scanned reflectarrays in particular, on the other hand, in case of line-of-sight (LOS) and non line-of-sight (NLOS) wireless communication. In addition phase conjugation and time reversal techniques will be discussed for application in passive identification (Identification friend or foe (IFF), radio frequency identification (RFID)).

## Instructor's biographies

### Julien Perruisseau-Carrier

Julien Perruisseau-Carrier was born in Lausanne, Switzerland, in 1979. He received the M.Sc. and Ph.D. degrees from the Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland, in 2003 and 2007, respectively. In 2003, he was a Visiting Researcher with the Communication Group, University of Birmingham, U.K. From 2004 to 2007, he was with the Laboratory of Electromagnetics and Acoustics (LEMA), Ecole Polytechnique Fédérale de Lausanne (EPFL), where he completed the doctoral degree while working on various European Union (EU) funded projects. Since December 2007, he has been a Research Associate with the Centre Tecnològic de Telecomunicacions de Catalunya (CTTC), Barcelona, Spain. His research interest mainly concerns reconfigurable microwave devices. In particular, he has been involved in the development of dynamically reconfigurable reflectarrays, antennas, and metamaterials. Dr. Perruisseau-Carrier was the recipient of the Young Scientist Award of the URSI-EMTS 2007 Conference and of the IEEE AP-S Raj Mittra Travel Grant 2010.

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## José A. Encinar

José A. Encinar was born in Madrid, Spain. He received the Electrical Engineer and Ph.D. degrees, both from Universidad Politécnica de Madrid (UPM), in 1979 and 1985, respectively. Since January 1980 has been with the Applied Electromagnetism and Microwaves Group at UPM, as a Teaching and Research Assistant from 1980 to 1982, as an Assistant Professor from 1983 to 1986, and as Associate Professor from 1986 to 1991. From February to October of 1987 he stayed at Polytechnic University, Brooklyn, NY, as a Post-doctoral Fellow of the NATO Science Program. Since 1991 he is a Professor of the Electromagnetism and Circuit Theory Department at UPM. In 1996 he was with the Laboratory of Electromagnetics and Acoustics at Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland, and in 2006 with the Institute of Electronics, Communication and Information Technology (ECIT), Queens University Belfast, U.K., as a Visiting Professor. His research interests include numerical techniques for the analysis of multi-layer periodic structures, design of frequency selective surfaces, printed arrays and reflectarrays. Prof. Encinar has published more than one hundred and fifty journal and conference papers, and he is holder of four patents on array and reflectarray antennas. He was a co-recipient of the 2005 H. A. Wheeler Applications Prize Paper Award and the 2007 S. A. Schelkunoff Transactions Prize Paper Award, given by IEEE Antennas and Propagation Society. He has been a member of the Technical Programme committee of several International Conferences (European Conference on Antennas and Propagation, ESA Antenna Workshops, Loughborough Antennas & Propagation Conference). He is an IEEE Fellow member.

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## Koen Van Caekenberghe

Koen Van Caekenberghe received the Ph.D. degree in electrical engineering from the University of Michigan, Ann Arbor, in 2007. His doctoral research involved RF MEMS technology for radar sensors.

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## Sean Victor Hum

Sean Victor Hum was born in Calgary, Alberta, Canada. He received his B.Sc., M.Sc. and Ph.D. degrees from the University of Calgary in 1999, 2001, and 2006 respectively. In 2006 he joined the Edward S. Rogers Sr. Department of Electrical and Computer Engineering where he currently serves as an assistant professor. Prof. Hum received the Governor General's Gold Medal for his master's degree work on radio-on-fiber systems in 2001. In 2004 he received an IEEE Antennas and Propagation Society Student Paper award for his work on electronically tunable reflectarrays. In 2006, he received an ASTech Leaders of Tomorrow award for his work in this area. He is also the recipient of three teaching awards. Prof. Hum served on the steering committee and technical program committee for the 2010 IEEE AP-S International Symposium on Antennas and Propagation. In August 2010, he was appointed as an Associate Editor for the IEEE Transactions on Antennas and Propagation. His present research interests lie in the area of reconfigurable RF antennas and systems, antenna arrays, and ultra-wideband communications.

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