ROMA TRE
UNIVERSITÀ DEGLI STUDI

iNGEGNERIA
DIPARTIMENTO DI ECCELLENZA

EMLAB³ Laboratory: Scientific activity, Research and Technology Projects

Laboratory of Electromagnetic Fields EMLAB³
«Roma Tre» University
Department of Industrial, Electronic and Mechanical Engineering,
Section of Applied Electronics,
http://emlab.uniroma3.it

EMLAB³: People

PERMANENT STAFF

Director
Giuseppe Schettini
Full Professor

Paolo Baccarelli
Associate Professor

Cristina Ponti
Assistant Professor

EMLAB³: People

STABLE ASSOCIATE RESEARCHERS

Silvio Ceccuzzi
Associate Researcher
ENEA

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Associate Professor
General and Theoretical Electrical Engineering (ATE), Faculty of Engineering, University of Duisburg-Essen, Duisburg, Germany

Ludovica Tognolatti
PhD Student
Roma Tre University

EMLAB^3

Several activities on radiation, guiding, scattering of em waves

- **Computational electromagnetics**
- **Electromagnetic Band-Gap (EBG) Antennas**
- **Leaky waves and Leaky wave antennas**
- **RF and Microwave High-Power Components and Antennas for Plasma Fusion Devices**
- **Scattering and Remote Sensing in complex environments**

❑ Why ad hoc full-wave software?

- **Dedicated codes in Fortran and/or MATLAB for specific investigations not allowed by EM commercial software**

- Modal analysis of open and closed waveguides in periodic structures: Case of complex wavenumbers.

- Near field excited by simple sources in periodic environments: Case of Green's functions of stratified periodic structures.

- Efficient formulation by field expansion in function series better suited to analyze specific geometries, e.g., cylindrical.

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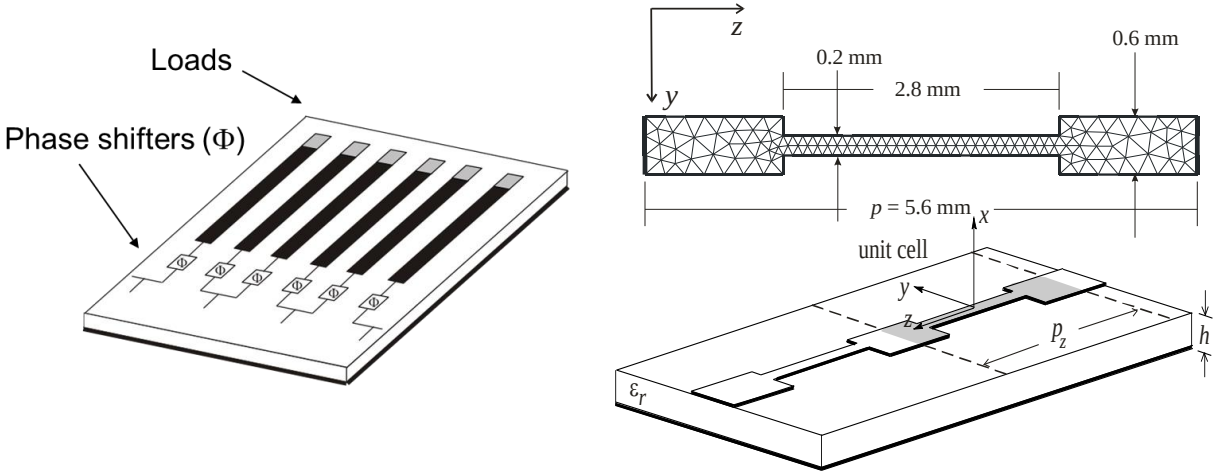
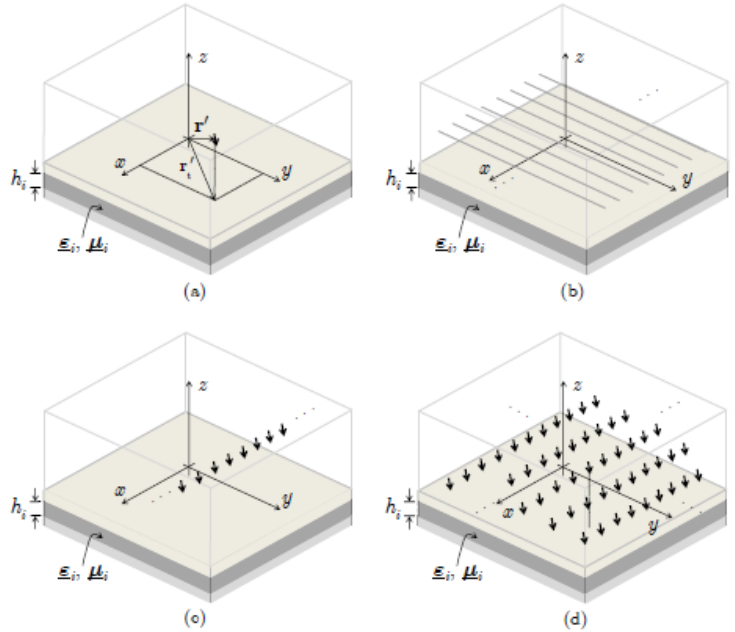
- The Unit-Cell Leaky-Wave Approach



Efficient Method of Moments Analysis of 1-D phased arrays of microstrip Leaky-Wave Antennas (LWAs) and 1-D periodic printed LWAs

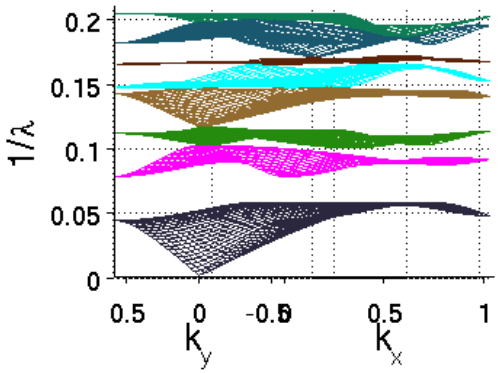
- Accelerated evaluation of Periodic Green's Functions (PGFs)

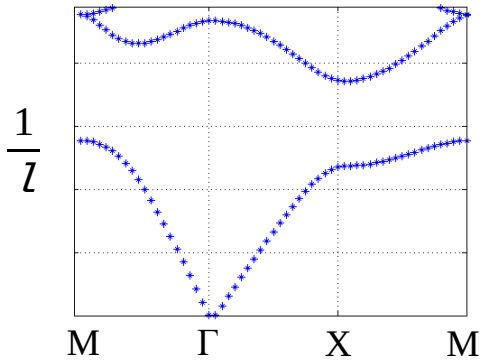
1-D, 2-D, and 3-D PGFs with **complex wavenumbers** both in free-space and layered media: Accelerated procedures based on the Kummer-Poisson, Ewald, and Lattice Sums approaches.



EMLAB³: Computational electromagnetics

- Plane Wave Expansion (PWE) method

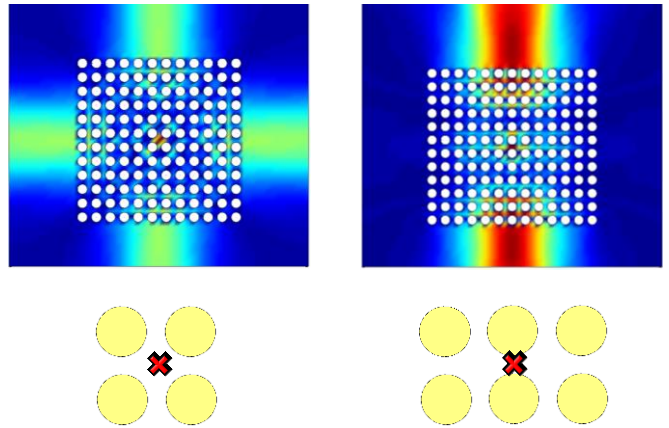




Modal (sourceless) analysis of infinite lattices with whichever unit cell.
Eigenvalues and eigenfunctions of the master equation of 2-D photonic crystals.

- Cylindrical Wave Approach (CWA)

Electromagnetic response of finite-size 2-D arrangement of cylindrical rods to a set of line sources.
Shaping, focusing and/or tilting effects on the radiation pattern of simple sources.



EMLAB³: Projects/Collaborations on Computational electromagnetics

Antenna Centre of Excellence (ACE), Project reference: IST-2004-508009 & IST-2006-026957, 2004-2007.

PRIN 2017 “WPT4WID: Wireless Power Transfer for Wearable and Implantable Devices” (University of Bologna, University of Pavia, Roma Tre University, Sapienza University) kick-off February 2020

PRIN 2006 “Studio e realizzazione di metamateriali per applicazioni all'elettronica ed alle telecomunicazioni” (Roma Tre University , Sapienza University, University of Sannio, University of Naples “Federico II”, University of Salerno), kick-off 2006

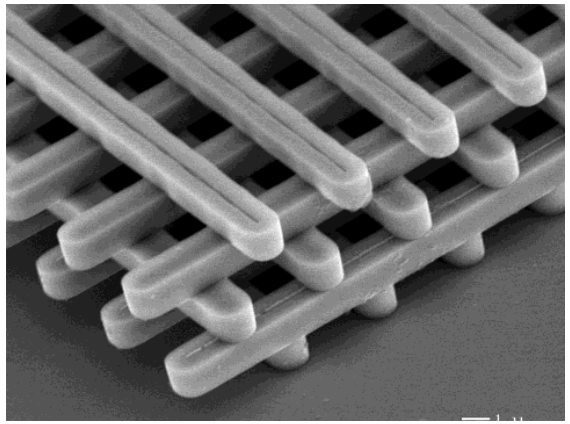
PRIN 2005 “Antenne Integrate Attive per Terminali Mobili ad Alta Efficienza” (University of Roma “Tor Vergata”, Sapienza University, Politecnico di Torino, University of Florence) kick-off 2005

EMLAB³ Selected References on Computational electromagnetics

- ✓ P. Baccarelli, P. Burghignoli, C. Di Nallo, F. Frezza, A. Galli, P. Lampariello, and G. Ruggieri, "Full-wave analysis of printed leaky-wave phased arrays", *Int. J. RF Microw. Computed Aided Eng.*, vol. 12, pp. 272-287, May 2002, DOI: 10.1002/mmce.10024.
- ✓ P. Baccarelli, C. Di Nallo, S. Paulotto, and D. R. Jackson, "A full-wave numerical approach for modal analysis of 1D periodic microstrip structures", *IEEE Trans. Microwave Theory Tech.*, vol. 54, pp. 1350-1362, Apr. 2006, DOI: 10.1109/TMTT.2006.871353, .
- ✓ P. Baccarelli, S. Paulotto, and C. Di Nallo, "Full-wave analysis of bound and leaky modes propagating along 2D periodic printed structures with arbitrary metallisation in the unit cell", *IET Microw. Antennas Propag* (special issue on Metamaterials), vol. 1, n. 1, pp. 217-225, Feb. 2007, DOI: 10.1049/iet-map:20050321.
- ✓ G. Valerio, P. Baccarelli, P. Burghignoli, and A. Galli, "Comparative analysis of acceleration techniques for 2-D and 3-D Green's functions in periodic structures along one and two directions", *IEEE Trans. Antennas Propag.*, vol. 55, pp. 1630-1643, Jun. 2007, DOI: 10.1109/TAP.2007.897340.
- ✓ G. Valerio, P. Baccarelli, S. Paulotto, F. Frezza, and A. Galli, "Regularization of mixed-potential layered-media Green's functions for efficient interpolation procedures in planar periodic structures", *IEEE Trans. Antennas Propag.*, vol. 57, pp. 122-134, Jan. 2009, DOI: 10.1109/TAP.2008.2009695.
- ✓ G. Valerio, S. Paulotto, P. Baccarelli, A. Galli, D. R. Jackson, D. R. Wilton, and W. Johnson, "Efficient computation of 1-D periodic layered mixed potentials for the analysis of leaky-wave antennas with vertical elements," *IEEE Trans. Antennas Propag.*, vol. 63, pp. 2396-2411, Jun. 2015. DOI: 10.1109/TAP.2015.2412959.
- ✓ V. Jandieri, P. Baccarelli, G. Valerio, and G. Schettini, "1-D periodic lattice sums for complex and leaky waves in 2-D structures using higher order Ewald formulation," *IEEE Trans. Antennas Propag.*, vol. 67, no. 4, pp. 2364–2378, Apr. 2019, DOI: 10.1109/TAP.2019.2894280.
- ✓ S. Ceccuzzi, V. Jandieri, P. Baccarelli, C. Ponti, and G. Schettini, "On beam shaping of the field radiated by a line source coupled to finite or infinite photonic crystals," J. Opt. Soc. Am. A, vol. 33, no. 4, pp. 764–770, Apr. 2016.

❑ Why Electromagnetic Band-Gap (EBG) Antennas?

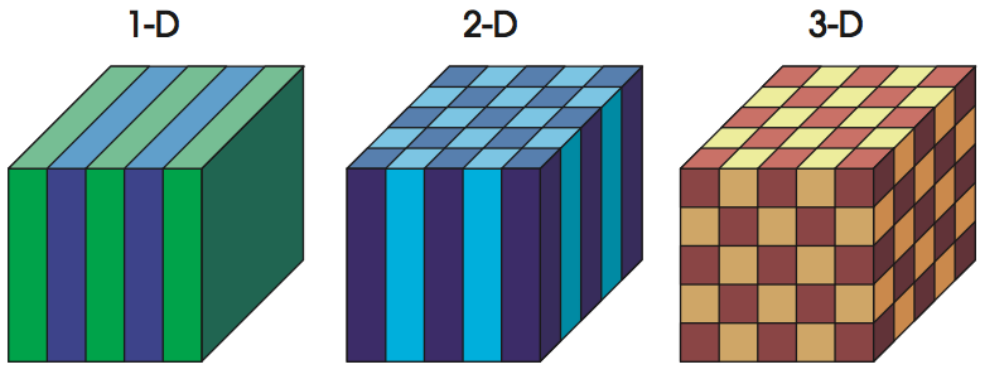
- Low cost (can be produced with additive manufacturing)
- Low loss (dielectric material)
- **Moderate to high gain, good band properties**
- Minimum space (especially in millimeter range)

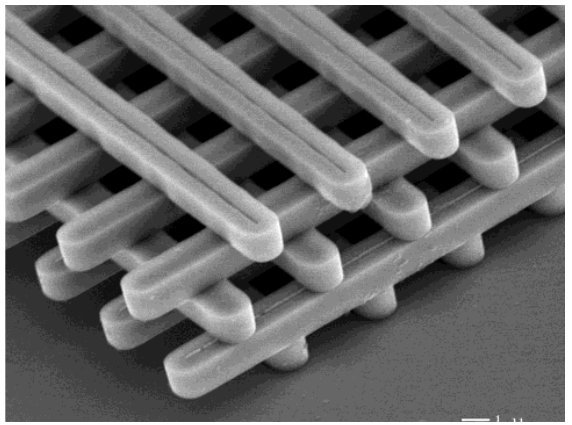


EMLAB³: Dielectric EBG Materials

Artificial **Dielectric** **E**lectromagnetic **B**and-**G**ap (**EBG**) Materials show many advantages with respect to Conventional ones:

- Significant cost-reduction of antennas and microwave components
- Low losses also in the mm-Wave spectrum (envisioned in ***5G*** wireless communication systems to extend bandwidth and channel capacity)
- Compatible with some advanced manufacturing technologies (e.g., 3D-Printing, Low-cost Ceramic Sintering, Additive Manufacturing).





EMLAB³: Projects/Collaborations on EBG Materials/Antennas

COST (european COoperation in the field of Scientific and Technica research), Action MP0702 “Towards Functional Sub-Wavelength Photonic Structures” 2012

PRIN 2017 “Quick, reliable, cost effective methodology for DIagnostics of Conformal Antennas (DI-CA)” (University of Genoa, University of Campania, Roma Tre University) kick-off February 2020

PRIN 2017 “WPT4WID: Wireless Power Transfer for Wearable and Implantable Devices” (University of Bologna, University of Pavia, Roma Tre University, Sapienza University) kick-off February 2020

PRIN: Progetto di Ricerca di Interesse Nazionale

- ✓ F. Frezza, L. Pajewski, E. Piuzzi, C. Ponti, and G. Schettini, "Radiation- enhancement properties of an X-band woodpile EBG and its application to a planar antenna," Int. J. Antennas Propag., vol. 2014, no. 5, 2014.
- ✓ S. Ceccuzzi, L. Pajewski, C. Ponti, and G. Schettini, "Directive EBG antennas: a comparison between two different radiating mechanisms," IEEE Trans. Antennas Propag., vol. 62, no. 10, pp. 5420–5424, Oct. 2014.
- ✓ C. Ponti, S. Ceccuzzi, G. Schettini, P. Baccarelli, «Tapered EBG superstrates for low-permittivity resonator antennas,» Proceedings of the 2016 IEEE Int. Symp. on Antennas and Propagation, pp. 345-346.
- ✓ S. Ceccuzzi, V. Jandieri, P. Baccarelli, C. Ponti, and G. Schettini, "On beam shaping of the field radiated by a line source coupled to finite or infinite photonic crystals," J. Opt. Soc. Am. A, vol. 33, no. 4, pp. 764–770, Apr. 2016.
- ✓ S. Ceccuzzi, C. Ponti, and G. Schettini, "Directive EBG antennas based on lattice modes," IEEE Trans. Antennas Propag., vol. 65, no. 4, pp. 1691–1699, Apr. 2017
- ✓ V. Jandieri, P. Baccarelli, G. Valerio, and G. Schettini, "1-D periodic lattice sums for complex and leaky waves in 2-D structures using higher order Ewald formulation," IEEE Trans. Antennas Propag., vol. 67, no. 4, pp. 2364–2378, Apr. 2019.
- ✓ S. Ceccuzzi, P. Baccarelli, C. Ponti, and G. Schettini, "Effect of source position on directive radiation in EBG structures with epsilon-near-zero behavior," IEEE Antennas Wireless Propag. Lett., vol. 18, no. 6, pp. 1253–1257, Jun. 2019.

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❑ Why Leaky Waves and Leaky-Wave Antennas (LWAs)?

- **A leaky wave can be used to make an LWA**
- LWAs are simple and easy to make, and can provide a directive beam at microwave and mm-wave frequencies.
- The beam is steerable by changing frequency or with electronic biasing
- **A leaky wave can appear on a printed-circuit transmission line**
- They can cause loss of power, crosstalk, spurious performance
- It is good to be able to predict when they will occur

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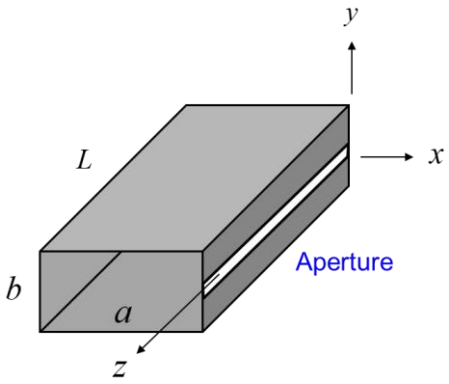
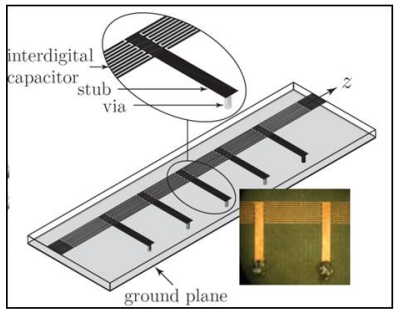
Advantages of LWAs:

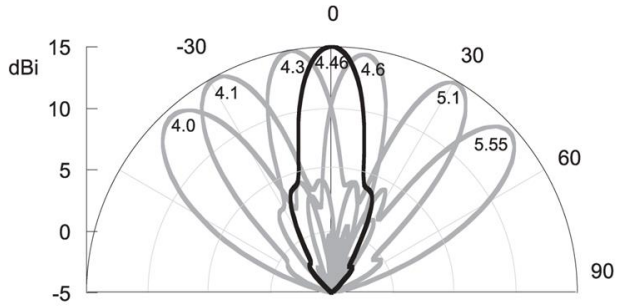
- They provide a simple means of obtaining narrow beams (highly-directive patterns).
- They allow for beams pointing at almost arbitrary angles
- They are usually simple and low cost.
- They often have relatively low material loss (compared to using an antenna array with a more complicated feed network)
- They are attractive at high microwave and millimeter-wave frequencies
- The beam naturally scans with frequency (an easy way to obtain beam scanning).
- They can be made to scan electronically by incorporating tunable elements into the design (varactor diodes, ferrites, graphene, etc.)

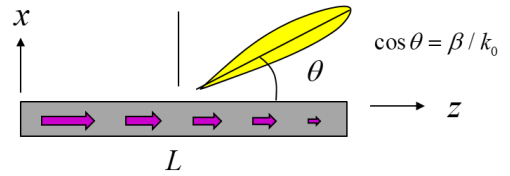
A rectangular waveguide realization



A microstrip realization







EMLAB³: Projects/Collaborations on LWAs

Antenna Centre of Excellence (ACE), Project reference: IST-2004-50800[illegible]
& IST-2006-026957, 2004-2007.

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EMLAB³ Selected References on LWAs

- ✓ P. Baccarelli, P. Burghignoli, F. Frezza, A. Galli, and P. Lampariello, "Novel modal properties and relevant scanning behaviors of phased arrays of microstrip leaky-wave antennas", *IEEE Trans. Antennas Propag.*, vol. 51, pp. 3228-3238, Dec. 2003, DOI: 10.1109/TAP.2003.820962.
- ✓ S. Paulotto, P. Baccarelli, F. Frezza e D. R. Jackson, "Full-wave modal dispersion analysis and broadside optimization for a class of microstrip CRLH leaky-wave antennas", *IEEE Trans. Microwave Theory Tech.*, vol. 56, pp. 2826-2837, Dec. 2008, DOI: 10.1109/TMTT.2008.2007333.
- ✓ J. T. Williams, P. Baccarelli, S. Paulotto, and D. R. Jackson, "1-D combline leaky-wave antenna with the open-stopband suppressed: design considerations and comparisons with measurements", *IEEE Trans. Antennas Propag.*, vol. 61, pp. 4484-4492, Sept. 2013, DOI: 10.1109/TAP.2013.2271234.
- ✓ S. Paulotto, P. Baccarelli, and D. R. Jackson, "A self-matched wide scanning u-stub microstrip periodic leaky-wave antenna", *J. Electromagn. Waves Appl.*, vol. 28, pp. 151–164, Jan. 2014., DOI: 10.1080/09205071.2013.858609.
- ✓ S. K. Podilchak, P. Baccarelli, P. Burghignoli, A. Freundorfer, and Y. M. M. Antar, "Analysis and design of annular microstrip-based planar periodic leaky-wave antennas", *IEEE Trans. Antennas Propag.*, vol. 62, pp. 2978-2991, Jun. 2014. DOI: 10.1109/TAP.2014.2314735.
- ✓ A. Galli, P. Baccarelli, and P. Burghignoli, "Leaky-wave antennas," in *Wiley Encyclopedia of Electrical and Electronics Engineering*, J. Webster, Ed. New York, NY, USA: Wiley, 2016, DOI: 10.1002/047134608X.W1222.pub2.
- ✓ W. Fuscaldo, P. Burghignoli, P. Baccarelli, and A. Galli, "Graphene Fabry-Perot cavity leaky-wave antennas: plasmonic vs. non-plasmonic solutions," *IEEE Trans. Antennas Propag.*, vol. 65, pp. 1651 - 1660, Apr. 2017,DOI: 10.1109/TAP.2017.2670520.
- ✓ D. Comite, P. Burghignoli, P. Baccarelli and A. Galli, "2-D Beam Scanning With Cylindrical-Leaky-Wave-Enhanced Phased Arrays," *IEEE Trans. Antennas Propag.*, vol. 67, pp. 3797-3808, Jun. 2019, DOI: 10.1109/TAP.2019.2902678.
- ✓ P. Baccarelli, P. Burghignoli, D. Comite, W. Fuscaldo, and A. Galli, "Open-Stopband Suppression via Double Asymmetric Discontinuities in 1-D Periodic 2-D Leaky-Wave Structures," *IEEE Antennas Wireless Propag. Lett.*, vol. 18, pp. 2066-2070, Oct. 2019, DOI: 10.1109/LAWP.2019.2937473.

EMLAB³ RF and Microwave High-Power Components

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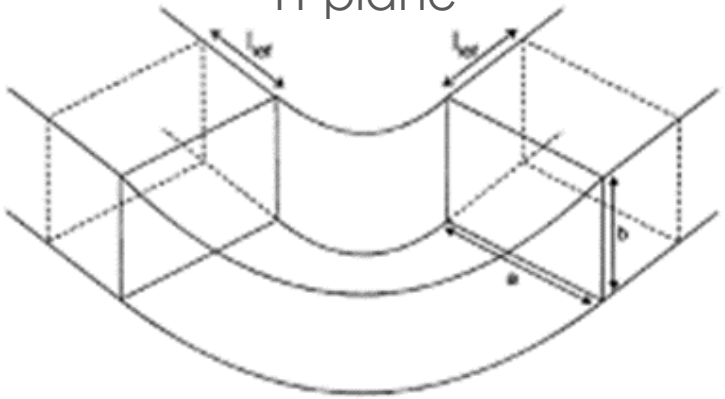
❑ Why RF and Microwave High-Power Components?

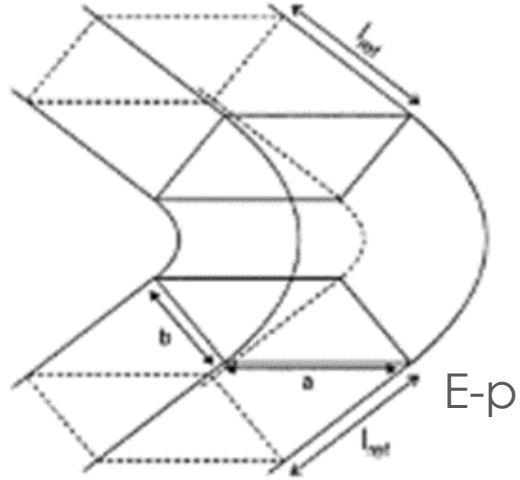
- **High power in electromagnetic waves is needed in nuclear fusion, particle accelerators, power beaming, radars, …**
- In nuclear fusion high-power waves allow plasma heating and current drive as well as plasma control and stabilisation
- Experimental activity for future Production of Clean Energy in existing fusion machines (JET, FTU, International Tokamaks).
- Design activity for next-generation fusion machines (DTT, ITER, DEMO):
  - RF and Microwave plants
  - Antennas

EMLAB³ RF and Microwave High-Power Components

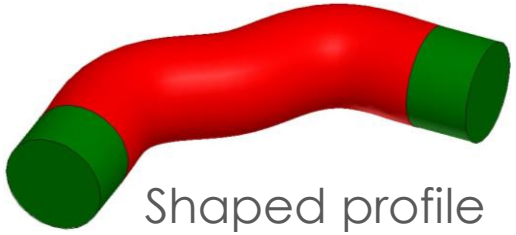
- Design of oversized waveguide components:

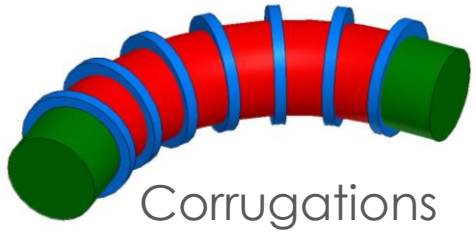
  - Bends for rectangular waveguides:

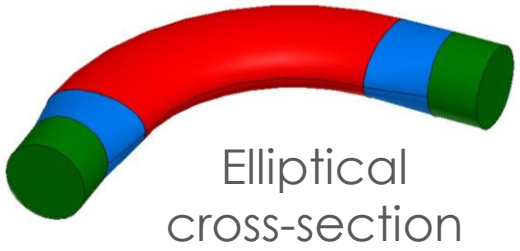




  - Bends for circular waveguides:



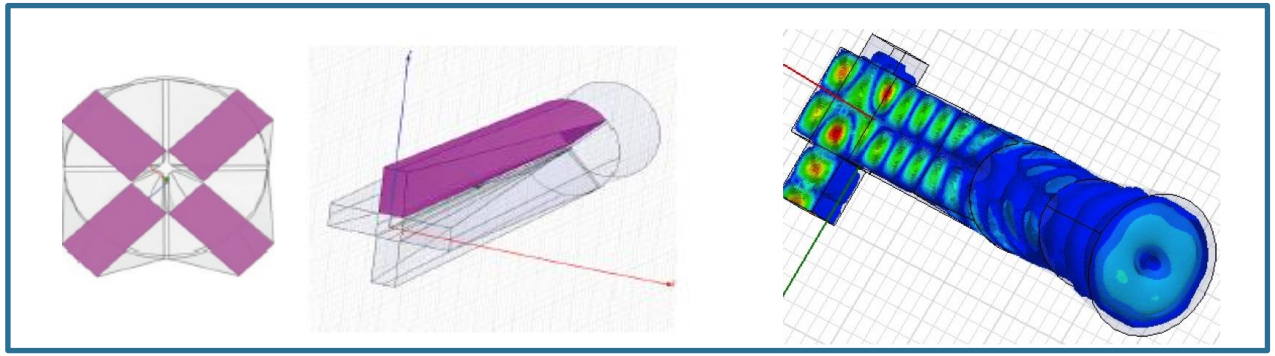




EMLAB³ RF and Microwave High-Power Components

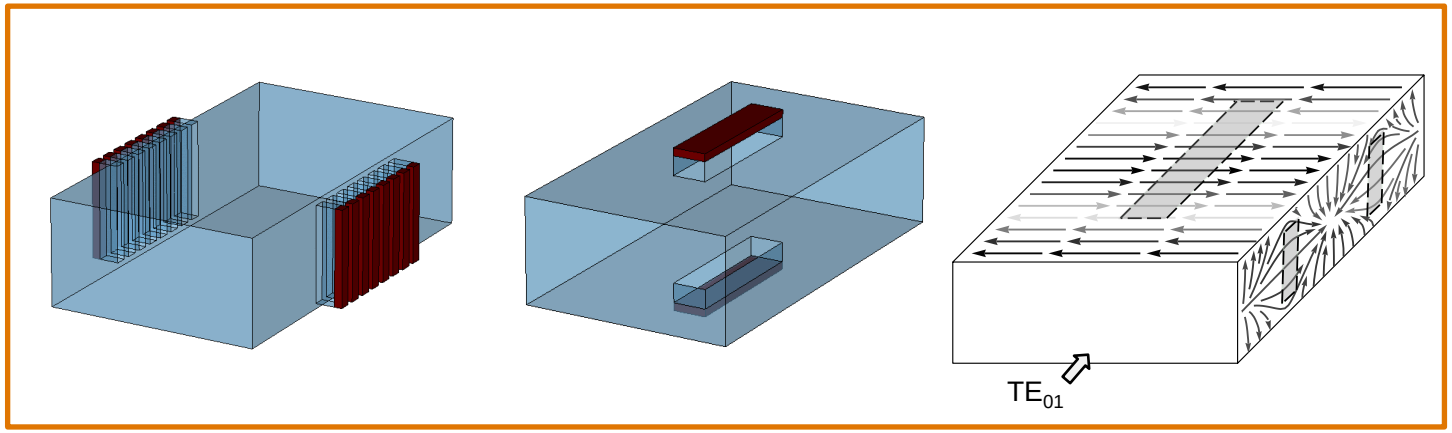
- Mode converters

  (e.g., from rectangular to circular oversized waveguide)



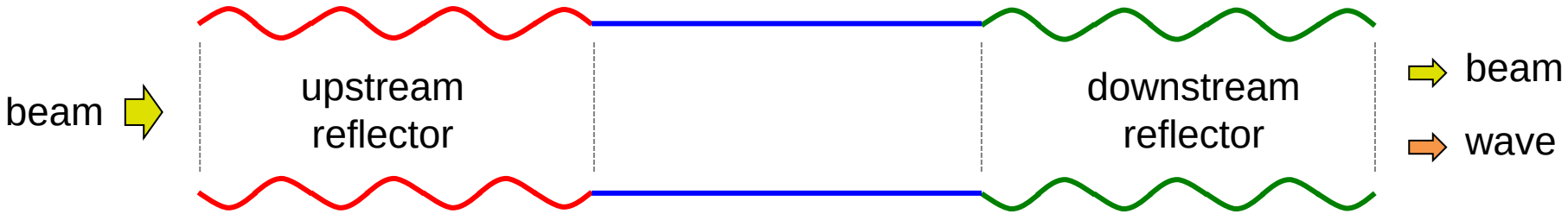
- Mode filters

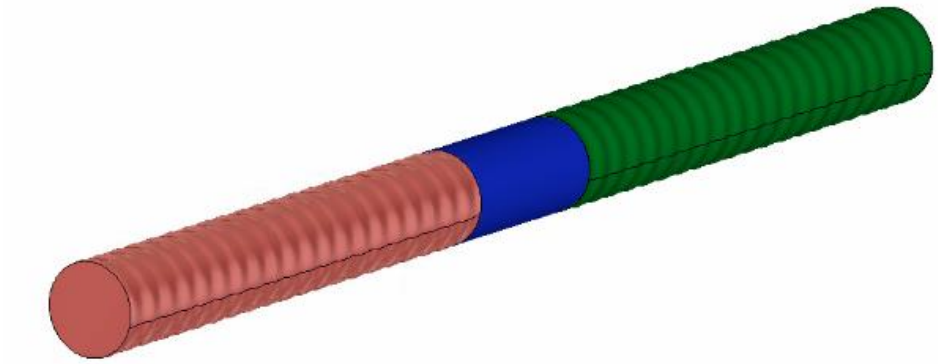
  (lossy corrugations are used to damp dangerous spurious modes)



EMLAB³ RF and Microwave High-Power Components

- Cavity design for innovative mm-wave sources:





- Resonator with distributed Bragg reflectors for Cyclotron Auto-Resonance Maser

EMLAB³: Projects on Microwave HP Components

Research Contract UE-funded, with Euratom-Enea Association: ITER (International Thermonuclear Experimental Reactor) Task "Heating and Current Drive" HCD-08-03-01: "Conceptual Design of the LHCD System for ITER", UE, Working Group 2: "The Launcher", Working Group 3: "Transmission Line"

COST Action IC1301 on Wireless Power Transmission on Sustainable Electronics (WiPE) (http://www.cost-ic1301.org/?page=partners/33)

EUROFUSION Consortium from 2015

EMLAB³ References on Microwave HP Components

- ✓ Ceccuzzi, S., Ponti, C., Ravera, G.L., Schettini, G., "Mode Filters for Oversized Rectangular Waveguides: A Modal Approach", IEEE Transactions on Microwave Theory and Techniques 63(8),7154520, pp. 2468-2481 (2015)

- ✓ Ceccuzzi, S., Ponti, C., Ravera, G.L., Schettini, G., "Physical mechanisms and design principles in mode filters for oversized rectangular waveguides," IEEE Transactions on Microwave Theory and Techniques 65(8),7891599, pp. 2726-2733 (2017)

- ✓ Cardinali, Castaldo, Cesario, et al., "Radio-frequency current drive for thermonuclear fusion reactors," Scientific Reports 8(1),10318 (2018)

- ✓ Ravera, G.L., Ceccuzzi, et al., " Optimization of TE11/TE04 mode converters for the cold test of a 250 GHz CARM source, " Fusion Engineering and Design 146, pp. 745-748 (2019)

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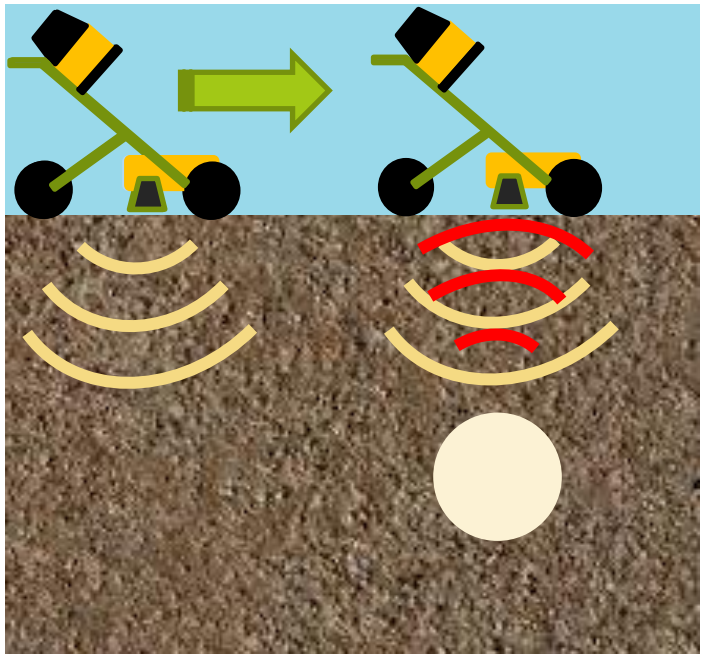
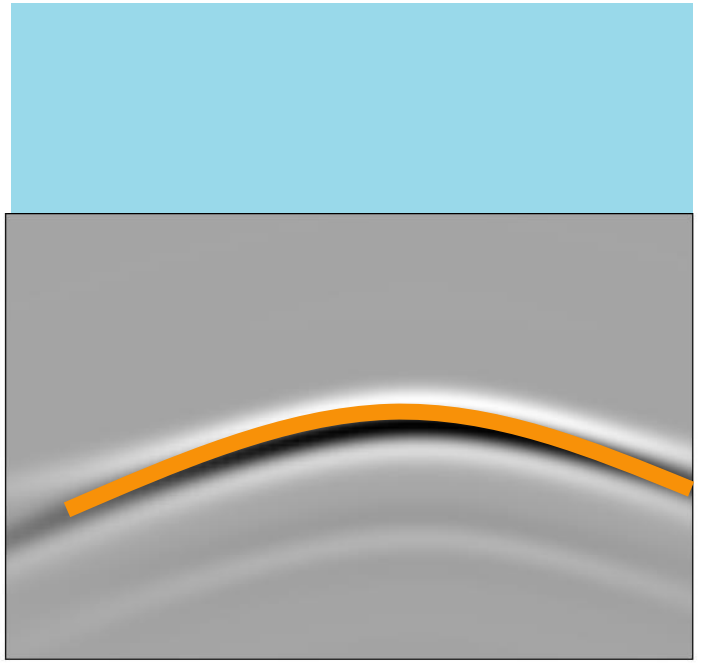
❑ Why Radars for detection in complex environments?

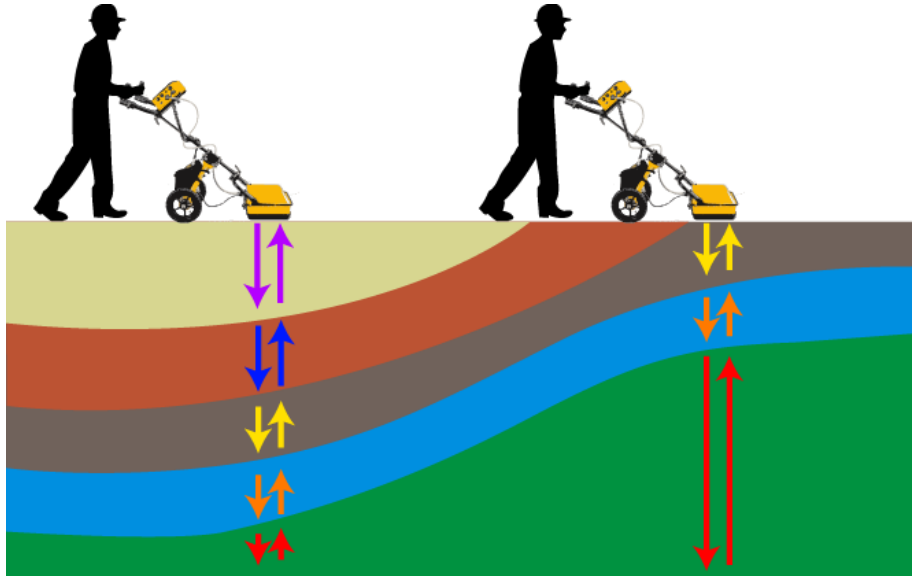
- **Several uses (civil, military, safety, security)**
- Rescue of people in accidents (earthquakes, avalanches, etc..)
- Check of building structures, of buried services
- Check of pavement quality of the streets
- Search of archaeological ruins, sites
- Search of mines, search of hidden menaces

Remote sensing with the Ground Penetrating Radar

- Cultural Heritage and Archeology
- Geology
- Mapping of buried services
- Maintenance of roads and buildings
- Security







Regional Research Project (Lazio)

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COST TU1208 «Civil Eng. Applications of Ground Penetrating Radars», 2017

PRIN 2015 «U-VIEW Ultra-wideband Virtual Imaging Extra Wall for high-penetration high quality imagery of enclosed structures» (University of Genoa, University of Cosenza, Sapienza University), end February 2020

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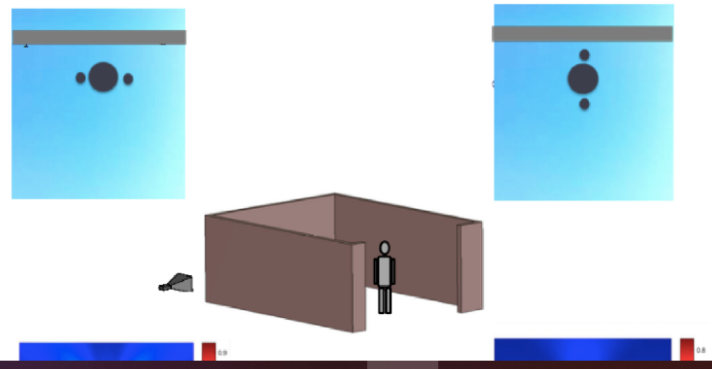
IEEE OJAP Special Section on "Direct and Inverse Electromagnetic Scattering Methods"

Submission deadline: 31 October 2020

Aims & Scope: The study of the electromagnetic scattering is of particular relevance in the frame of several applied disciplines ranging from radar detection to everyday life critical situations, to geophysical or archaeological research, civil engineering, biological imaging, and so on. The deepening of the methods of analysis, both for direct methods,



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