ELECTROMAGNETIC RADIATION GROUP

HEAD OF THE GROUP RESEARCH REPORT

The Electromagnetic Radiation Group (GRE) focuses its research activities on various areas related to the analysis and design of antennas, as well as to the analysis of different propagation environments. The operating frequency bands under study range from UHF to the V band, thereby covering a wide range of applications, from mobile terminals to satellite antennas.

The GRE collaborates extensively with many academic and industrial partners, such as Chalmers University of Technology, the Courant Institute of Mathematical Sciences, the University of Oulu, the European Space Agency (ESA), Thales Alenia Space, or Huawei. The support to the local technological development becomes apparent in long-lasting links with regional companies. In 2017, GRE continued the work initiated within the framework of two national projects in 2016, and started a new national project 2017 related to propagation issues. All three projects are currently underway.

GRE research interests cover theory, numerical methods, design and measurement of antennas and propagation. A complete list of research activities can be found at http://www.iteam.upv.es/group/gre.html

1. - PROJECT ACTIVITIES

The group is involved in the following research lines:

- Slot-array antenna design for high-gain applications.
- Waveguide structures for millimeter and sub-millimeter wave bands.
- On-body antennas.
- Application of the Theory of Characteristic Modes for antenna design in different applications (MIMO, UWB, RFID, mobile communications, UHF, etc).
- Development of efficient methods for the electromagnetic analysis of complex structures.
- Diagnosis and antenna measurement.
- Propagation and channel modelling.

The ongoing projects within which the aforementioned research lines are being developed, as well as the main results obtained and the related publications, are described hereunder.

1.1. - ONGOING PROJECTS

SATCOM-KA: New Antennas for Satellite Mobile Communications in Ka-band (TEC2016-79700-C2-1-R).

Period: 2017-2019

Mobile satellite terminals are aimed at providing high data rate services in areas not covered by terrestrial networks, such as remote areas, war zones, natural disasters, ships or aircrafts. These terminals make use of the multi-spot beam coverage given by a new generation of satellites operating in Ka band (from 19 to 31 GHz). The increment of the operating frequency, from the Ku band (in systems implemented so far) to the Ka band, widens the available bandwidth and, consequently, increments the data rate. However, the new mobile terminals in Ka band cannot be simply designed by just upscaling the existing terminals (in the Ku band) to the new band. The specifications set to the new Ka-band terminals render the design a technological challenge that has not yet found a proper solution.

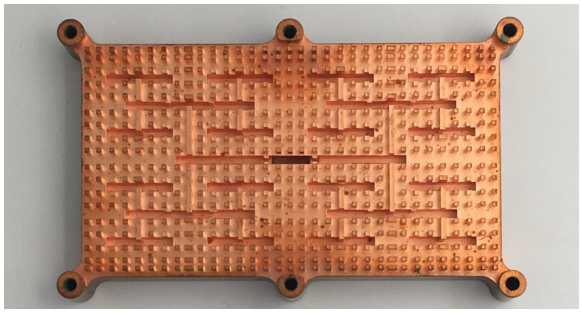
Within the framework of the SATCOM-KA project, new antenna concepts and topologies are being explored for Ka-band mobile satellite terminals, paying special attention to the reduction of the terminal volume and weight, a fundamental characteristic for on-the-move applications. In this context, during the second year of the project, the fabrication of the proposed solutions with metallized plastics, capable of reducing considerably the weight of the antenna, has been investigated. The comparison of the results obtained with this technology, and with the traditional direct-metal 3D printing, has shown the suitability of the new manufacturing technique for the implementation of Ka-band mobile satellite terminals for on-the-move systems.

Additionally, the project addresses the design of dual antennas sharing the same panel for both polarizations and/or both frequency bands, capable of switching polarization during handover from one spot-beam to another. Several solutions have been proposed in this

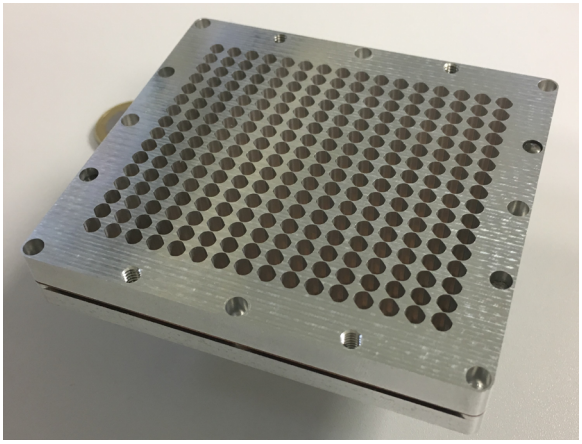
area during the second year of the project, reaching the manufacturing stage a circularly-polarized antenna in the V-band.

Collateral issues are also being considered within the framework of the SATCOM-KA project. On the one hand, new beam pointing mechanisms are being studied to facilitate the tracking of the satellite in ground terminals. On the other hand, the use of Frequency Selective Surfaces to maximize the aperture efficiency of the dual-polarized antennas proposed, and to convert linearly-polarized fields into circularly-polarized fields are also being explored.

This project has been funded by the *Ministerio de Economia Industria y Competitividad (MINECO).*



Corporate feeding network of a slot-array antenna fabricated with metallized plastics



Proof of concept of single-layer circularly-polarized aperture array antenna in the V-band.

MANCOM: Design of High-Gain Multibeam Antennas for Next Generation Communications Systems (TEC2016-78028-C3-3-P).

Period: 2017-2019

The future explosion of wireless data transmissions in 5G systems will lead every user to demand connectivity to everything everywhere. Consequently, innovative smart and efficient technologies must be developed, starting from the antenna system. In this project, new efficient radiating elements are being developed for applications in the microwave (below 6 GHz) and mm-wave band.

The project focuses on various areas:

1. On-body sensing applications: Numerical methods for the computational modelling of the human body up to 6 GHz will be developed for applications related with on-body sensing systems. Multimode antennas will be also developed for these applications, which will be specifically conceived to radiate inside the human body.

2. Reconfigurable mm-wave antenna design for mobile devices: A phased-array antenna with a reconfigurable beam-forming network is going to be implemented for 5G mobile devices in the mm-wave band. Reconfigurable beams will be generated with the aid of LTCC (Low Temperature Co-fired Ceramics) technology, since the required facilities are already available at the GRE-GAM antenna laboratory at iTEAM.

3. Reconfigurable multibeam mm-wave 5G indoor base station design: Metallic planar lenses based on non-periodic Frequency Selective Surfaces (FSS) are being designed for a base station in the 20-30 GHz band. An efficient formulation of an integral equation approach for the analysis of metamaterial lenses in the mm-wave band is being developed. A prototype will be fabricated and characterized at UPV and channel measurement will be performed.

This project has been funded by the *Ministerio de Economia Industria y Competitividad (MINECO).*

Prototype of a metamaterial lens antenna designed at 10 GHz.

ICAR5G: RAdio CHannel research for the deployment of 5G systems in a digital society multi-connected. (TEC2017-86779-C2-2-R).

Period: 2018-2020

There is a widespread agreement among the scientific community, industry and mobile operators that future traffic demands, much higher than the current ones, will require the deployment of new systems with faster as well as more efficient and reliable connections. In the early 2012, ITU-R kicked off the program to develop IMT-2020 systems, thus initiating the definition and research activities of the fifth generation (5G) systems. These new systems will represent a significant improvement over 4G systems, increasing the speed of LTE-Advanced by 1000. 5G represents the possibility of

implementing new business models, making the most of new applications and services by allowing the devices to connect anytime and anywhere. Among the different applications or services expected of 5G technology is to make the concept of Internet of Things (IoT) become a reality. The concepts of smart home, smart office, smart city, among others, along with health-related applications, vehicular communications, high-quality 4K-8K UHD video transmissions, virtual and augmented reality, just to name a few of them, are expected to emerge in the 5G era.

Of all the requirements set out in 5G, those that are most closely related to the capacity increase are the ones drawing the most attention. In this regard, the distribution of ultra-dense networks of base stations to improve the capacity per unit area, the use of new frequency bands, such as millimeter-wave (mmWave), and the combination of beamforming techniques and advanced MIMO systems arise as a requirement in order to increase the capacity. In this scenario, the knowledge of the radio channel holds the key to define the standard, select new frequency bands, and optimize the deployment of the network infrastructure.

The objectives proposed in the ICAR5G project are to generate knowledge and new radio channel models based on extensive measurement campaigns, complementing the actions already being developed in other projects, to evaluate the different technologies to be implemented in the radio interface and to optimize the deployment of base stations. In addition, this knowledge is intended to assist decision-making in the process of reorganization and assignment of frequencies in future 5G systems by the standardization and radio spectrum management bodies.

This project has been funded by the *Ministerio de Economia Industria y Competitividad (MINECO).*

A measurement campaign has been developed in a typical underground environment in order to evaluate the propagation characteristics of some of the proposed 5G bands

2. RESEARCH RESULTS

2.1. FEATURED PUBLICATIONS

1. Low-Cost Ka-band Switchable RHCP/LHCP Antenna Array for Mobile SATCOM Terminal, J. I. Herranz-Herruzo, A. Valero-Nogueira, M. Ferrando-Rocher, B. Bernardo, A. Vila and R. Lenormand, IEEE Transactions on Antennas and Propagation, vol. 66, no. 5, pp. 2661-2666, May 2018.

*DOI:*10.1109/TAP.2018.2806421

Abstract: Achieving a functional antenna for mobile satellite communications terminals in Ka-band is probably one of the most challenging tasks in current antenna engineering, particularly bearing in mind they need to be low profile and "affordable." This quest is involving many companies in the field. Our contribution represents one of such efforts. The antenna is based on a slotted waveguide array technology to maximize efficiency and it features a number of novel solutions, going from its robust polarization switching mechanism, to the use of a thin wideband polarizer and the utilization of groove gap waveguides. This communication reports the measured data of a fully functional prototype to validate its novel contributions.

2. Low-Profile Radially Corrugated Horn Antenna, H. C. Moy-Li, D. Sánchez-Escuderos, E. Antonino-Daviu and M. Ferrando-Bataller, IEEE Antennas and Wireless Propagation Letters, vol. 16, pp. 3180-3183, 2017.

DOI: 10.1109/LAWP.2017.2767182

Abstract: This letter proposes a low-profile horn antenna with radial corrugations. The depth and width of the corrugations are suitably chosen to excite the mode HE11 in the corrugated section. This mode spreads uniformly across the whole aperture, thereby maximizing the radiating area and the aperture efficiency. The good polarization purity of mode HE11 provides a good cross-polar level and a low side-lobe level. The structure is fed by a circular waveguide with two matching elements on the feeding plane that minimize the return loss level. A prototype has been fabricated and measured to operate in the Ku band. The prototype, with a height of just 6.9 mm, provides a maximum gain above 12.2 dBi and an aperture efficiency better than 72 % within the operating frequency band.

3. On Multimode Equivalent Network Representation of Finite Arrays of Open-Ended Waveguides, D. Sánchez-Escuderos, M. Baquero-Escudero, P. Soto, V. E. Boria and M. Guglielmi, IEEE Transactions on Antennas and Propagation, vol. 65, no. 8, pp. 4334-4339, Aug. 2017.

DOI: 10.1109/TAP.2017.2710267

Abstract: This paper describes a multimode equivalent network (MEN) representation of a finite array of open-ended lossless waveguides on an infinite ground plane. The derivation is

based on an integral equation formulated at the interface between the waveguides and the free-space region. The MEN is formulated using the concept of accessible and localized modes, and includes ports for the free-space plane waves. The MEN derived can be easily combined with the MENs of other microwave components, thus allowing for the accurate analysis and design of more complex systems composed of waveguide elements and radiating apertures. Both simulated and experimental results are presented showing very good agreement, thereby fully validating the proposed equivalent network representation.

4. Analysis and Design of a Metamaterial Lens Antenna Using the Theory of Characteristic Modes D. Santillán-Haro, E. Antonino-Daviu, D. Sánchez-Escuderos, and M. Ferrando-Bataller, International Journal of Antennas and Propagation, 2018.

DOI: 10.1155/2018/6329531

Abstract: A new single-layer metamaterial lens antenna aimed to operate at 10 GHz is proposed in this paper. The lens antenna consists of twelve capacitively coupled unit cells distributed along a ring and illuminated by an open-ended circular waveguide with a metallic resonant ring. The theory of characteristic modes is used to analyze the metamaterial lens, in order to provide an insight into the radiation characteristics of the antenna. The proposed antenna has been optimized, obtaining a large bandwidth and a maximum directivity of 12.88 dBi at 10 GHz.

5. On the Contribution to the Field of the Nonphysical Characteristic Modes in Infinite Dielectric Circular Cylinders Under Normal Excitation T. Bernabéu-Jiménez, A. Valero-Nogueira, F. Vico-Bondia and A. A. Kishk, IEEE Transactions on Antennas and Propagation, vol. 66, no. 1, pp. 505-510, Jan. 2018.

DOI: 10.1109/TAP.2017.2768581

Abstract: Here, a detailed analysis of characteristic modes and fields of an infinite dielectric circular cylinder when computed through the Poggio-Miller-Chang-Harrington-Wu-Tsai formulation is carried out. The purpose is to determine their contribution to the total field, inside and outside the dielectric body and under two possible excitations: incident plane wave or electric line source within the cylinder. The study has been done analytically to provide necessary physical insight of the results obtained. New details about the so-called nonphysical modes are provided. It is found that these modes, that can be neglected outside the dielectric body, do have a significant contribution to the inner field when the excitation source is within the dielectric body. It is concluded that the terms physical and nonphysical characteristic modes should be replaced for radiating and nonradiating characteristic modes.

6. A Comparison Between Natural Resonances and Characteristic Mode Resonances of an Infinite Circular Cylinder T. Bernabéu-Jiménez, A. Valero-Nogueira, F. Vico-Bondia and A. A. Kishk, IEEE Transactions on Antennas and Propagation, vol. 65, no. 5, pp. 2759-2763, May 2017.

DOI: 10.1109/TAP.2017.2670368

Abstract: Here, some aspects in the interpretation of the solutions of a PEC infinite circular cylinder with the Theory of Characteristic Modes are presented. First, natural resonances and characteristic mode resonances (CMRs) are introduced and compared. Second, characteristic eigenvalues are used to find those natural resonances considering complex ka values. Furthermore, by linking the standard and the generalized eigenvalue problems, a relation between natural resonances and characteristic mode eigenvalues is shown. Finally, the thesis stating that external CMR does not imply maximum field scattering is also demonstrated.

7. Small-scale distributions in an indoor environment at 94GHz J. Reig, M.T. Martinez-Ingles, J.M. Molina-Garcia-Pardo, L. Rubio Arjona, V. M. Rodrigo Peñarrocha, Radio Science, vol. 52, no. 7, pp. 852-861, 2017.

DOI: 10.1002/2017RS006335

Abstract: In this paper, an extensive multiple-input multiple-output measurement campaign in a lab environment has been conducted at the 94 GHz band. Using a vector network analyzer, updown converters, and omnidirectional antennas displaced in virtual arrays, we have obtained an estimation of the distribution parameters for the most usual distributions employed in the small-scale fading modeling, i.e., Rayleigh, Rice, Nakagami-m and □-μ, by using statistical inference techniques. Moreover, in this scenario the best fit distribution to the experimental data is the Weibull distribution, using the Kolmogorov-Smirnov test. However, the □-μ distribution provides the best fitting to the experimental results in terms of the lower tails of the distributions.

2.2. PATENTS

1. Antena de frecuencia dual. Miguel Ferrando Rocher, Jose Ignacio Herranz Herruzo, Alejandro Valero Nogueira, Ref.: P201731194, Publication date: 10/10/2017

2. Dispositivo de cruce de microondas. Daniel Sánchez-Escuderos; Vicente E. Boria Esbert; Mariano Baquero Escudero, Marco Guglielmi, Ref.: P201830106, Publication date: 7/2/2018

GRE team

2.3. AWARDS

Best Student Paper Award at the National URSI Conference in 2017, "Single-Layer Circularly-Polarized Ka-Band Antenna using Gap Waveguide technology", Miguel Ferrando-Rocher, Jose I. Herranz-Herruzo, Alejandro Valero-Nogueira, Antonio Vila-Jiménez.

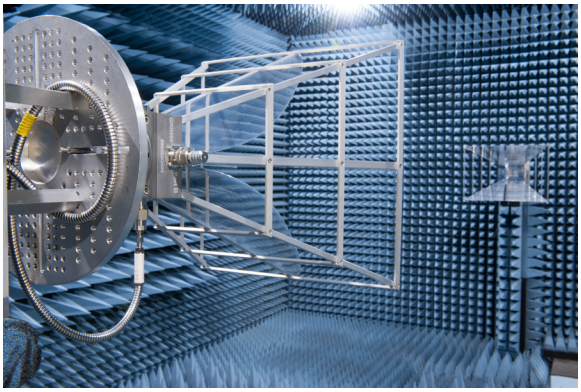
3.- FACILITIES

The GRE has a comprehensive antenna laboratory hosted in the iTEAM premises, with about 1 million euro in infrastructure investment. The facilities are intended to fabricate and measure the antennas and circuits designed by the researchers within the framework of the different ongoing projects. Prototypes (some of them are shown in the ongoing projects figures) are mainly fabricated in a 3-axes CNC milling machine with 5 microns of accuracy. The smallest prototypes developed in the GRE's premises are formed by pillars of 0.25 mm by side and 2 mm high, working perfectly at 60 GHz. Alternatively, a micro milling machine and a chemical etching line are also available in the GRE's laboratory for the fabrication of microwave circuits and antennas on planar substrates.

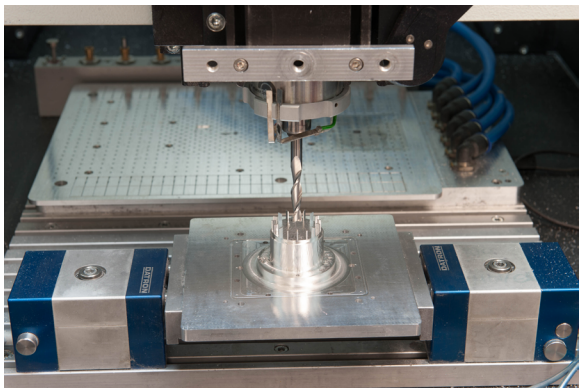
The GRE antenna laboratory is able to characterize and measure (up to 50GHz) antennas and microwave devices. The main equipment includes an anechoic chamber with roll over azimuth spherical system for measurement of antenna radiation patterns (up to 40GHz) and two Vector Network Analyzers that allow measurements of different parameters of antennas and microwave devices in frequency (up to 67 GHz) and time domain. In addition, a signal (spectrum) analyzer up to 26 GHz is available at GRE premises. These capabilities, together with the expertise of the technical staff, form a perfect combination capable of detecting any deviation from the simulated designs in the manufactured prototypes and, proposing solutions for their correction.

The GRE, together with the GAM (Microwave Applications Group), also has the laboratory of High Frequency Circuits (LCAF) in LTCC Technology focused on the fabrication of high frequency components and particularly on multi-layer modules in Low Temperature Co-fired Ceramics (LTCC) technology.

LTCC is a key enabling technology for RF/microwave component miniaturization, millimeter-wave packaging, Multi-Chip-Module (MCM) and System-in-Package (SiP) designs. Furthermore, it is also of great interest in a huge number of applications not strictly related to information and communication technologies as ceramic packaging, highly integrated electronics, microfluidics or sensors.



Standard gain horn ready for measurements in the anechoic chamber



CNC milling

Prototyping

MIGUEL FERRANDO ROCHER RECEIVES THE "YOUNG SCIENTISTS URSI 2017" AWARD

Miguel Ferrando Rocher, researcher at the Institute of Telecommunications and Multimedia Applications (iTEAM) of the Universitat Politècnica de València has achieved the "Young Scientists URSI 2017" award by the International Union of Radio Science (URSI) to the best paper presented during the XXXII national symposium of URSI, held in Cartagena (Spain) in September 2017.

The award was granted for his work on the development of a new antenna concept that contributes to reduce the profile and weight of current antennas and could be applied to offer high-speed Wifi on trains or airplanes. In addition, it could be integrated into rescue teams in order to provide satellite coverage in uninhabited areas or affected by some catastrophe with devastated infrastructure.

The prototype has been manufactured and validated entirely in the laboratories of the iTEAM research institute of the Universitat Politècnica de València. The high gain and large bandwidth stand out as the main advantages of the antenna. "Moreover, its performance in terms of gain is up to what the market demands and therefore is a very attractive candidate to meet the huge market of satellite communications in Ka-band."

The research group is collaborating with companies working in similar applications and interested in such solutions as Thales Alenia Space and the European Space Agency (ESA). "The antenna, provided timely financing, could be on the market within 2 years," says Miguel Ferrando Rocher.