

# ELECTROMAGNETIC RADIATION GROUP (GRE) ANNUAL RESEARCH REPORT 2018/2019

## HEAD OF THE GROUP RESEARCH REPORT

The research areas of the Electromagnetic Radiation Group (GRE) are focused on the analysis and design of antennas at frequency bands ranging from UHF to V band. These frequency bands cover a wide range of applications, e.g. mobile and satellite communications, Wi-Fi, Bluetooth or on-body applications. GRE researchers are also investigating on realistic propagation environments for mobile applications.

GRE participates in many projects with public funding in collaboration with other Spanish universities, such as University Carlos III of Madrid, the Technical University of Barcelona or the Technical University of Cartagena. In addition, GRE collaborates with many foreign universities, such as Chalmers University of Technology, the Courant Institute of Mathematical Sciences or the University of Oulu. From the industrial point of view, GRE works with different technological companies and public entities, such as the European Space Agency (ESA), Thales Alenia Space, Huawei or Airbus. Moreover, GRE supports the local technological development through long-lasting links with regional companies like CELESTICA or MYSHERA.

The evolution of the national research programs in which GRE is involved has led GRE to be in the final year of two national projects, initiated in 2017, and in the second year of a third project granted in 2018. The work in all of them has been carried out in agreement with the proposed schedule, with significantly good results.

In 2019, GRE has released a renewed webpage of the research group: [www.gre.upv.es](http://www.gre.upv.es). This web page aims to offer detailed information about GRE research lines, group members and activities. This web page also informs about the services offered by the group to third-party companies.

## 1.- PROJECT ACTIVITIES

The group activities can be classified into four main research lines:

- Application of the Theory of Characteristic Modes for antenna design in different applications (MIMO, UWB, RFID, mobile communications, UHF, on body antennas).
- Gap waveguide technology for the design of antennas and microwave devices in the mm-wave band
- Development of efficient methods for the electromagnetic analysis of complex structures.
- Propagation and channel modelling.

These research lines are being developed within the framework of different ongoing research projects. Next section describes these projects and the main activities that have been performed during the last year.

### 1.1.- ONGOING PROJECTS

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

Period: 2017-2019

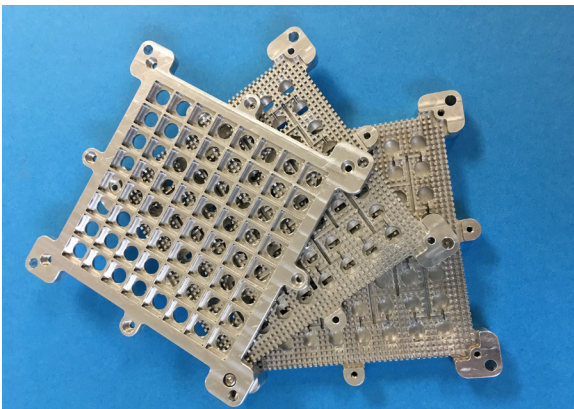
This project was initiated in 2017 within the framework of the Spanish national research program, funded by the Ministry of Economics, Industry and Competitiveness. The scope of this project is focused on the design of ground terminals for the new generation of high-throughput satellites operating in the Ka-band (from 19 to 31 GHz). These satellites have been conceived to provide high-data-rate services in areas not covered by terrestrial networks, such as remote areas, war or natural disasters zones, ships or aircrafts. This increment of the data rate with respect to previous systems is achieved by incrementing the operating frequency band, from the Ku-band to the Ka-band, and implementing a re-use frequency and polarization scheme in a multi-spot beam architecture. The increment of the operating frequency band widens the available bandwidth and, consequently, produces an increment of the data rate. This upscaling, however, does not simply implies an upscaling of the existing terminals in the Ku-band. The re-use scheme of the available resources imposes a set of specifications to the ground terminals that render the design a technological challenge that has not yet found a proper solution.

The SATCOM-KA project has explored new antenna concepts and topologies 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. With this in mind, during the first two years of the project, solutions based on metallized plastics, capable of reducing considerably the weight of the antenna, were

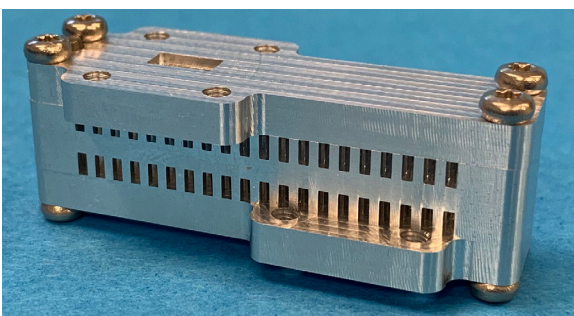
investigated. The comparison of this technology with the traditional direct-metal 3D printing proved the suitability of the new manufacturing technique for the fabrication of Ka-band ground terminals for on-the-move systems.

However, main research efforts have been focused on sharing the same antenna panel for both polarizations and/or both frequency bands, capable of switching the polarization or the operating frequency band during handover from one spot-beam to another. In particular, two solutions in gap waveguide technology have been proposed. Measured results of manufactured prototypes have shown excellent results in terms of return loss and radiation pattern. The attached image shows a picture of a dual-polarized antenna with two layers, each of them in charge of one polarization. A similar structure for the dual-band solution has also been presented. Alternative single-layer dual-band configurations have been explored. Attached picture shows a double-sided groove-gap waveguide used in this alternative configuration. The performance of a diplexer in gap waveguide technology to split, or combine, the K and Ka bands signals into a single waveguide in the dual-band solution has been also studied during the last year of the project.

Additionally, other topologies and devices are being studied. A frequency selective surface working as a microwave planar lens antenna capable of eliminating the grating lobes of the dual-polarized antenna has been designed and fabricated with excellent measured results. Also, new beam pointing mechanisms are being studied to facilitate the tracking of the satellite in ground terminals.



*Dual-polarized slot-array antenna in gap-waveguide technology*



*Double-sided groove-gap waveguide.*

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

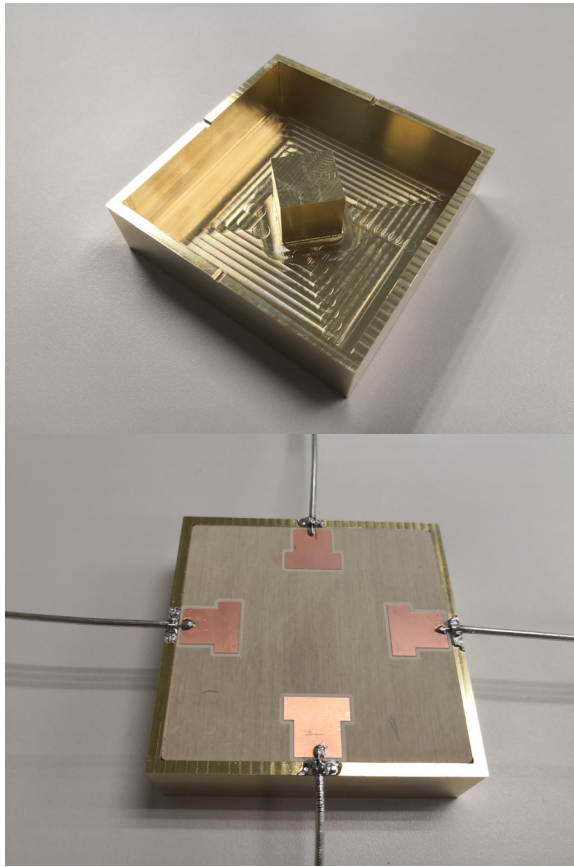
Period: 2017-2019

This project, funded by the Spanish Ministry of Economics, Industry and Competitiveness (MINECO), was granted in 2017. The main goal of this activity was the design of new types of antennas for the upcoming 5G generation of mobile communications. One of the key features of this new generation will be the possibility of attending the future demands of massive connectivity of users. These demands are being reported in numerous studies, consequence of the future explosion of wireless data transmissions, when users will demand connectivity to everything everywhere. Current forecasts indicate that, in a decade, the number of connected devices could reach hundreds of billions, driven by many novel applications beyond personal communications. To deal with this traffic, the development of new technologies, not yet implemented, is required. One of the key aspects of these technologies will be the antenna systems under study in this project.

The range of applications and possibilities of the next generation of mobile communications is huge. This project has been focused on three specific areas in the microwave (below 6 GHz) and mm-wave bands:

1. On-body sensing applications: A computational modelling of the human body has been developed in the band 1 to 6 GHz using an integral equation approach. Also, within the framework of this project, several multimode antennas for on-body sensing applications have been analyzed and designed. These antennas have been specially conceived to radiate towards the human body and account for the attenuation produced by human tissues in the propagation of RF waves.
2. Reconfigurable mm-wave antenna design for mobile devices: the next 5G technology will demand for antennas with a reconfigurable radiation pattern capable of pointing the pattern towards the users dynamically. In this second area of the project, phased-array antennas with a reconfigurable beam-forming network have been studied in the mm-wave band. These antennas have been designed considering the LTCC (Low Temperature Co-fired Ceramics) fabrication technology. At GRE premises, there is available an antenna laboratory that implements this fabrication process, especially appropriate for the fabrication of mm-wave devices.
3. Reconfigurable multibeam mm-wave 5G indoor base station design: Two types of antennas have been considered for this area. Firstly, metallic planar lens antennas based on non-periodic frequency selective surfaces have been designed for the frequency range of 20-30 GHz. A prototype has been fabricated and tested at GRE premises.

Secondly, a cavity-backed antenna fed at four different points has been proposed for 5G femto-cells. The prototype of this antenna has shown measured results with an excellent performance for indoor environments.



*Four-port cavity-backed antenna for indoor 5G femto-cells.*

**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.

With the aim of studying the radio channel for the new 5G scenario, in 2018 started the project ICAR5G, funded by the Spanish Ministerio de Economía, Industria y Competitividad (MINECO). The objectives of this 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.

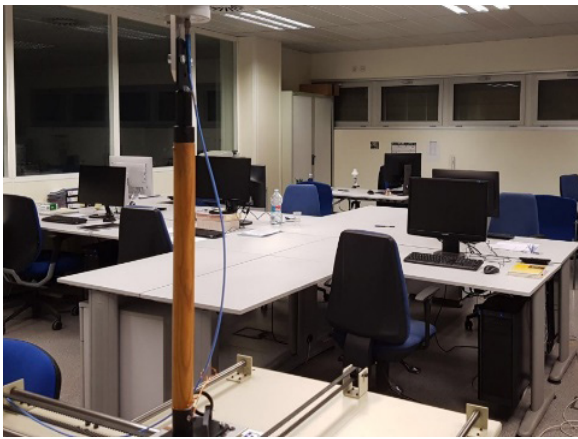
Extensive channel measurements in underground and indoor office environments have been collected using a channel sounder implemented in the frequency domain. From the channel measurements, realistic channel models have been analyzed and developed in the potential frequency bands to deploy the future 5G systems, with special attention to mmWave, e.g., 26, 28, 38 and 60 GHz. The performance of advanced MIMO techniques, that can be introduced into 5G systems, are being investigated in these particular environments from the channel models.







(b)



(a)

Extensive channel measurements have been collected in (a) underground and (b) indoor office environments in order to evaluate the propagation characteristics and develop new channel models in the potential 5G mmWave frequency bands

## 2. RESEARCH RESULTS

### 2.1. FEATURED PUBLICATIONS

**1. An Augmented Regularized Combined Source Integral Equation for Nonconforming Meshes**, F. Vico, L. Greengard, M. Ferrando-Bataller and E. Antonino-Daviu, *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 4, pp. 2513-2521, April 2019.

DOI: 10.1109/TAP.2019.2891399

**Abstract:** We present a new version of the regularized combined source integral equation (CSIE-AR) for the solution of electromagnetic scattering problems in the presence of perfectly conducting bodies. The integral equation is of the second kind and has no spurious resonances. It is well conditioned at all frequencies for simply connected geometries. Reconstruction of the magnetic field, however, is subject to catastrophic cancellation due to the need for computing a scalar potential from magnetic currents. Here, we show that by solving an auxiliary (scalar) integral equation, we can avoid this form of low-frequency breakdown. The auxiliary scalar equation is used to solve a Neumann-type boundary value

problem using data corresponding to the normal component of the magnetic field. This scalar equation is also of the second kind, nonresonant, and well conditioned at all frequencies. A principal advantage of our approach, by contrast with the hypersingular electric field integral equation, the combined field integral equation, or CSIE formulations, is that the standard loop-star and related basis function constructions are not needed, and preconditioners are not required. This permits an easy coupling to fast algorithms such as the fast multipole method. Furthermore, the formalism is compatible with nonconformal mesh discretization and works well with singular (sharp) boundaries.

**2. Designing Slot Antennas in Finite Platforms Using Characteristic Modes** N. Mohamed Mohamed-Hicho, E. Antonino-Daviu, M. Cabedo-Fabrés and M. Ferrando-Bataller, *IEEE Access*, vol. 6, pp. 41346-41355, 2018.

DOI: 10.1109/ACCESS.2018.2847726

**Abstract:** In this paper, the application of the Theory of Characteristic Modes for the design of narrow-in-width open slot antennas embedded in finite platforms is investigated. Purely magnetic and electric characteristic modes (CM) of a slot etched in both an infinite and a finite ground plane are analyzed, with the aim to provide a physical understanding of the slot behavior and its interaction with the metallic ground plane. Instead of traditional CM analysis, an alternative approach is proposed, which consists in dividing the design procedure into the separate and complementary analysis of purely magnetic and electric CM. Based on this analysis, some guidelines for the design of open slot antennas are provided, and a simple and compact narrow-in-width wideband open slot antenna is designed. Simulations and measurements are presented for the optimized slot antenna, showing an impedance bandwidth of 47.48% with a very stable radiation pattern.

**3. Dual-polarized planar lens antenna designed with a quad-ridged frequency selective surface**, H H. C. Moy-Li, D. Sánchez-Escuderos, E. Antonino-Daviu, M. Ferrando-Bataller, *Microwave and Optical Technology Letters*. 2019; 61: 479- 484.

DOI: 10.1002/MOP.31583

**Abstract:** This letter presents a microwave planar lens illuminated by a radially corrugated horn antenna. The lens is formed by a set of 5×5 multilevel unit cells working as a frequency selective surface. Each layer of the unit cells is formed by a square metallic ring with two sets of orthogonal stubs. The length of each set of stubs controls the transmission phase shift for each polarization, so that the lens can be configured independently for two orthogonal polarizations. The lens presented in this letter makes use of this operation to compensate the phase profile of the radiation pattern generated by the feeder. A

prototype, with the lens located at  $0.59 \lambda$  from the feeder, has been fabricated. Measured results show a maximum gain above 14.44 dBi within the operating frequency band (12.55-13.10 GHz), and a crosspolar level below -32 dB within the HPBW.

**4. The Folded Normal Distribution: A New Model for the Small-Scale Fading in Line-of-Sight (LOS) Condition** J. Reig, V. M. Rodrigo Peñarrocha, L. Rubio, M. T. Martínez-Inglés and J. M. Molina-García-Pardo, *IEEE Access*, vol. 7, pp. 77328-77339, 2019.

DOI: 10.1109/ACCESS.2019.2921340

**Abstract:** In this paper, a novel form of the folded normal (FN) distribution has been proposed to model the small-scale fading in wireless communications. From a multiple-input multiple-output (MIMO) measurement campaign conducted in a lab environment with the line-of-sight (LOS) conditions at both the 60 and the 94 GHz bands, the authors obtain the parameters of the Rician, FN, and  $k$ - $\mu$  distributions. These parameters have been calculated by using the least square (LS) approximation and with techniques of statistical inference. The FN distribution provides the best fitting to the experimental results using the Kolmogorov-Smirnov (K-S) test for the inferred estimators with values of the fulfillment of 100% and 69.82% at the 60 and 94 GHz bands, respectively, for a significance level of 1%.

**5. Empirical characterization of the indoor multi-user MIMO channel in the 3.5 GHz band.** R. P. Torres, J. R. Pérez, J. Basterrechea, M. Domingo, L. Valle, J. González, L. Rubio, V. M. Rodrigo-Peñarrocha and J. Reig, *IET Microwaves, Antennas & Propagation*, in press, 2019.

DOI: 10.1049/iet-map.2018.6215

**Abstract:** This study presents an analysis of the capabilities of using multi-user multiple input multiple output (MU-MIMO) in indoor environments at the 3-4 GHz band through an empirical characterisation of the MU-MIMO channel, obtaining a statistical description of the degree to which this specific multi-user channel verifies the condition of 'favourable propagation'. Different metrics have been considered to measure the degree of orthogonality between the channels, such as the orthogonality coefficient or the condition number. In addition, in order to obtain a direct measure of the goodness of the channel in terms of the achievable spectral efficiency, the capacity of the channel has been calculated for different numbers of users and base station antennas and compared with theoretical i.i.d. Rayleigh channels.

**6. Full-Metal K-Ka Dual-Band Shared-Aperture Array Antenna Fed by Combined Ridge-Groove Gap Waveguide** M. Ferrando-Rocher, J. I. Herranz-Herruzo, A. Valero-Nogueira and B. Bernardo-Clemente, *IEEE Antennas and Wireless Propagation Letters*, vol. 18, no. 7, pp. 1463-1467, July 2019.

DOI: 10.1109/LAWP.2019.2919928

**Abstract:** This letter presents an  $8 \times 8$  dual-band shared-aperture array antenna operating in K-(19.5-21.5 GHz) and Ka-band (29-31 GHz) using gap waveguide technology. Radiating elements consist of circular apertures located on the top plate of the antenna and excited by two stacked cavities with different diameters for dual-frequency operation. A waffle grid is used on top to increase the effective area of apertures and reduce grating lobes. Each stacked cavity is fed by its appropriate corporate-feeding network: The upper feeding layer operates at 20 GHz band, and the lower one at 30 GHz band. As a result, the antenna presents two ports, one for each band, which radiate a directive far-field pattern with linear polarization, orthogonal to each other. Experimental results show impedance and radiation pattern bandwidths larger than 1.5 GHz in both bands.

**7. Performance Assessment of Gap-Waveguide Array Antennas: CNC Milling Versus Three-Dimensional Printing** M. Ferrando-Rocher, J. I. Herranz-Herruzo, A. Valero-Nogueira and B. Bernardo-Clemente, *IEEE Antennas and Wireless Propagation Letters*, vol. 17, no. 11, pp. 2056-2060, Nov. 2018.

DOI: 10.1109/LAWP.2018.2833740

**Abstract:** This letter focuses on comparing manufacturing features of three-dimensional (3-D) printing techniques versus conventional computer numerical control (CNC) milling in the context of gap waveguide technology. To this end, a single-layer array antenna has been designed as a demonstrator. The antenna under test, intended for Ka-band, is composed of  $8 \times 8$  radiators fed by a gap-waveguide (GW) corporate network. Two identical prototypes have been manufactured, but each applying a different fabrication technique, i.e., 3-D printing and CNC milling. The experimental results of both antennas are presented, under the same conditions and measurement facilities. The conclusions drawn in this letter provide a valuable assessment of 3-D-printing viability for GW arrays against the conventional milling technique.

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.

**8. 60 GHz Single-Layer Slot-Array Antenna Fed by Groove Gap Waveguide** M. Ferrando-

Rocher, A. Valero-Nogueira, J. I. Herranz-Herruzo and J. Teniente, *IEEE Antennas and Wireless Propagation Letters*, vol. 18, no. 5, pp. 846-850, May 2019.

DOI: 10.1109/LAWP.2019.2903475

**Abstract:** A V-band single-layer low-loss slot-array antenna is presented in this letter. Radiating slots are backed by coaxial cavities, which are fed through a groove gap waveguide E-plane corporate feed network. Cavity resonances are created by shortening nails with respect to the surrounding ones. This fact enables a compact single-layer architecture since coaxial cavities and feeding network can share the same bed of nails. A  $16 \times 16$  array is designed, constructed, and measured to demonstrate the viability of this concept for high-gain single-layer slot-array antennas. In addition, this solution can be extended to circular polarization by seamlessly adding a polarizer above the slots without changing the feeding network piece. Measurements show a relative bandwidth of 10% with input reflection coefficient better than -10 dB and a mean antenna efficiency above 70% within the operating frequency band (57-66 GHz).

9. **8x8 Ka-Band Dual-Polarized Array Antenna Based on Gap Waveguide Technology** M. Ferrando-Rocher, J. I. Herranz-Herruzo, A. Valero-Nogueira, B. Bernardo-Clemente, A. U. Zaman and J. Yang, *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 7, pp. 4579-4588, July 2019.

DOI: 10.1109/TAP.2019.2908109

**Abstract:** This paper describes an 8x8 fully metallic high-efficiency dual-polarized array antenna working at the Ka-band, based on the gap waveguide (GW) concept. The radiating element is a circular aperture backed by two stacked cylindrical cavities, which are orthogonally fed to achieve a dual-polarized performance. Both feeding layers consist of a GW corporate network to reach all the cavities backing each radiating element. Cavities are naturally integrated within the bed of nails hosting grooves and ridges for the guiding electromagnetic (EM) field, leading to a low-profile dual-polarized array in the Ka-band. The experimental results present good agreement with simulations.

The measured radiation patterns agree well with the simulation and the antenna provides an average gain over 27 dBi within its operating bandwidth (29.5-31 GHz).

10. **Single-Layer Circularly-Polarized Ka -Band Antenna Using Gap Waveguide Technology** M. Ferrando-Rocher, J. I. Herranz-Herruzo, A. Valero-Nogueira and A. Vila-Jiménez, *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 8, pp. 3837-3845, Aug. 2018.

DOI: 10.1109/TAP.2018.2835639

**Abstract:** A single-layer circularly polarized array antenna is proposed in the context of the so-

called gap waveguide (GW) technology. This ultracompact antenna combines the corporate-feeding network and the radiating apertures over one single layer, standing out among other solutions proposed so far in this technology. Apertures are backed by chamfered cylindrical cavities and are fed through a corporate feeding network, which combines both groove and ridge GWs. Cavities are naturally integrated within the bed of nails hosting grooves and ridges, leading to a very low-profile  $4 \times 4$  array. Experimental results are presented to confirm the good radiation performance obtained by simulations. The proposed array architecture may be seamlessly enlarged to any size thanks to the scalability of the gap-based corporate feeding network, making this solution very attractive for medium to high-gain applications.

11. **Compact Combine Filter Embedded in a Bed of Nails**, M. Baquero-Escudero, A. Valero-Nogueira, M. Ferrando-Rocher, B. Bernardo-Clemente and V. E. Boria-Esbert, *IEEE Transactions on Microwave Theory and Techniques*, vol. 67, no. 4, pp. 1461-1471, April 2019.

DOI: 10.1109/TMTT.2019.2895576

**Abstract:** In this paper, we propose a compact topology for high-frequency bandpass filters using coaxial cavities embedded in a bed of nails, including a complete design procedure combining equivalent circuit models and full-wave simulators. The resonance generated around a shortened cylindrical nail of the bed hosting structure is used as the basic element of the proposed filter, which is fed through groove gap waveguides. For design purposes, an equivalent circuit model of the considered resonance is first obtained, and then the coupling levels between resonators are recovered with the distance between adjacent shortened nails. In order to validate the proposed structure and its design procedure, a filter prototype with a bandpass response (centered at 30 GHz and with relative bandwidth of 1.7%) has been designed, manufactured, and measured. Good experimental results, in terms of insertion losses (with a minimum value of 1.6 dB) and return losses (greater than 16.6 dB in the whole passband), have been achieved.

## 2.3. AWARDS

1. Prof. Eva Antonino-Daviu has been awarded by the IEEE Antennas and Propagation Society with the 2019 Lot Shafai Mid-Career Distinguished Achievement for her contribution to the systematic design of antenna systems for practical applications using characteristic modes and promoting access of women to engineering.
2. Miguel Ferrando-Rocher has been awarded by the Spanish Association of Telecommunications Engineers (COIT) with the 2019 Airbus Defense and Space award to the best PhD dissertation in satellite communications.





*Prof. Eva Antonino-Daviu receiving the 2019 Lot Shafai Mid-Career Distinguished Achievement award.*

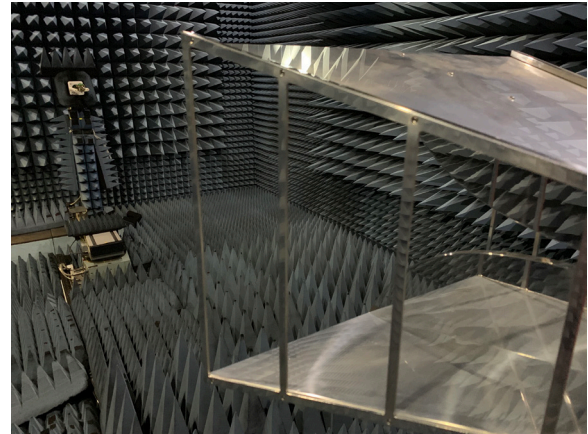
### 3.- FACILITIES

The laboratory of the GRE is hosted in the iTEAM premises. With an about 1 million euro in infrastructure investment, the facilities are intended to fabricate and measure antennas and microwave devices with high precision (some of them are shown in the ongoing projects figures). The main fabrication equipment is a 3-axes CNC milling machine with an accuracy of 5 microns. The highest frequency microwave device fabricated with this equipment has been a filter operating in the 60 GHz, with posts of 0.25 mm width and 2 mm high. The good measured results of this prototype validated the equipment for the fabrication of V-band antennas and devices. Alternatively, a micro milling machine and a chemical etching line are also available in the laboratory for the fabrication of planar microwave circuits and antennas.

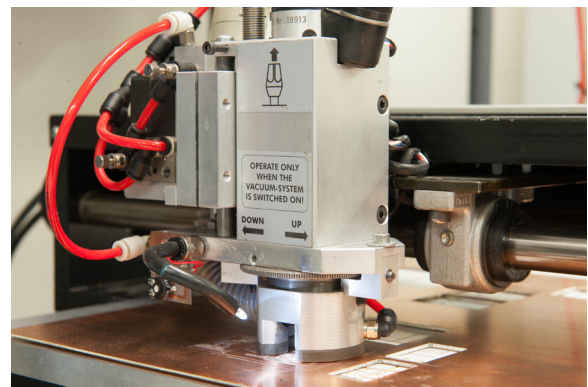
The testing equipment of the GRE is able to characterize the fabricated antennas and microwave devices up to 67 GHz. These measurements are done by means of two Vector Network Analyzers that allow measurements of different parameters in frequency and time domain. Also, the GRE laboratory includes an anechoic chamber with roll over azimuth spherical system for measurement of antenna radiation patterns up to 40GHz. 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 deviations between simulated and manufactured designs.

The GRE manages, together with the GAM (Microwave Applications Group), the laboratory of High Frequency Circuits (LCAF) in LTCC Technology. This laboratory is focused on the fabrication of high frequency components on multi-layer modules in Low Temperature Co-fired Ceramics (LTCC) technology. LTCC enables the miniaturization of RF components, the packaging of millimeter-wave devices, and the fabrication of Multi-Chip-Module (MCM) and

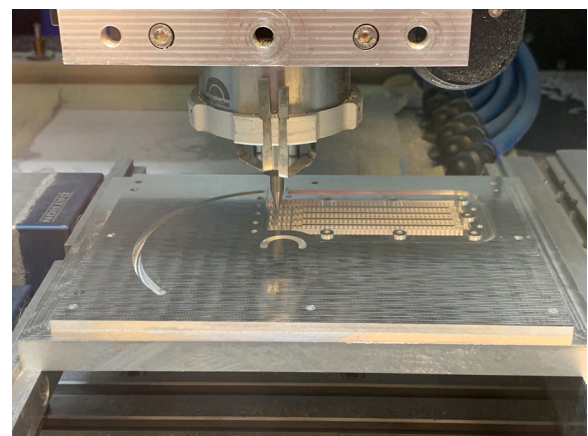
System-in-Package (SiP) designs. Furthermore, this technology is also of great interest in other applications, not strictly related to information and communication technologies, such as ceramic packaging, highly integrated electronics, microfluidics or sensors.



*Standard gain horn ready for measurements in the anechoic chamber.*



*Planar circuits milling machine.*



*CNC milling machine.*