ELECTROMAGNETIC RADIATION GROUP

HEAD OF THE GROUP RESEARCH REPORT

The research areas of the Electromagnetic Radiation Group (GRE, www.gre.upv.es) are focused on the analysis and design of antennas at frequency bands ranging from UHF to V band, and on propagation measurements and channel modeling for vehicular and 5G systems, with special emphasis on potential mmWave frequency bands. Antenna analysis and design carried out at GRE cover a wide range of applications, e.g. mobile and satellite communications, Wi-Fi, Bluetooth, UWB, IoT or on-body applications.

GRE participates in many projects with public funding in collaboration with other Spanish universities, and collaborates with other foreign universities (in Sweden, USA and Finland) as well. 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, and also supports the local technological development through long-lasting links with regional companies like Celestica, MYSHERA or AITEX.

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 and 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 measurements and channel modelling at mm-wave frequencies.

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

1.1.- ONGOING PROJECTS

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

Funding entity and duration: Ministerio de Economia, Industria y Competitividad, 2018-2020.

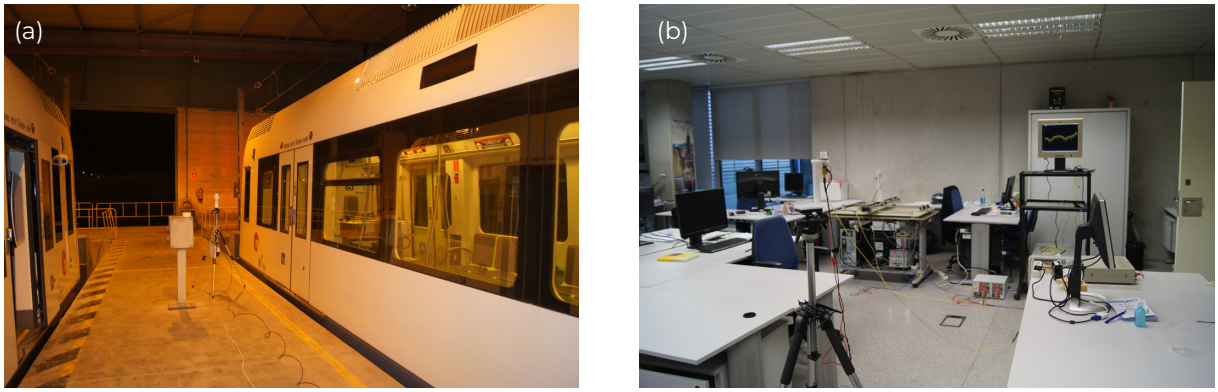
Summary of the project: The future traffic demands will require the deployment of new communication systems with faster as well as more efficient and reliable connections. The new 5G systems will represent a significant improvement over 4G systems, increasing the speed of LTE-Advanced by 1000. To increase channel capacity, the distribution of ultra-dense networks of base stations, 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 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 properties for the new 5G scenarios, the project ICAR5G started in 2018. The objectives of this project are to generate new radio channel models based on extensive measurement campaigns, complementing the actions being already 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.

Up to now, extensive channel measurements in underground and indoor office environments have been collected using a novel channel sounder implemented in the frequency domain and based on the use of radio over fiber (RoF) links with omnidirectional antennas. 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. These models have been compared with ray-tracing techniques to develop diffuse scattering models. The performance of multiuser MIMO techniques, that can be introduced into 5G systems, have also been investigated in these particular environments from the channel models.

MUltimode and Multibeam reconfigurable x-wave antennas for communication and sensing SYStems (MUMSYS)

Funding entity and duration: Ministerio de Ciencia e Innovación, 2020-2022.



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.

Summary of the project: In order to comply with communication, radar and sensing needs, there is a growing demand for highly flexible and effective antenna systems able to operate in different modes, frequency bands (from microwave to millimeter waves and eventually the low part of the THz spectrum) and environments (indoor-outdoor, cellular to vehicular).

The objective of this project is to conceive and develop a new generation of reconfigurable antennas operating into the microwave and millimeter frequency (x-Wave) domains of the electromagnetic spectrum, to face the challenges and requirements of incoming applications. Specifically, the project will be focused on various areas:

1. Multibeam and mutimode antennas for the sub-6 GHz band: Different models of antennas will be designed using the Theory of Characteristic Modes. The new antennas will exhibit reconfigurable capability and will be developed for Internet of Things (IoT), communications and human body sensing applications. New fabrication methods such as conductive inks, metal deposition on plastic 3D prototypes, or metal embroidery on fabrics will be explored as a low-cost alternative to classical microstrip technology. Low Temperature CoFired Ceramic (LTCC) technology, available at UPV facilities, will be also used for multi-sensor wireless systems and IoT applications.

2. Planar metallic lenses for reconfigurable multi-beam mm-wave indoor low-cost 5G base station: A planar lens with low cost single metallic layer will be designed. The reconfigurable beam characteristic of the base station will be obtained by switching the feeding in different positions. A prototype will be fabricated and characterized at UPV and channel measurement will be performed at Universidad Politécnica de Cartagena.

3. New beam-forming networks, antenna switching and control for multi-beam applications: Complete systems will be developed to determine the angle of arrival of the waves to the base station. The antenna, that will be designed at UPV, will be an array of apertures, slots or notches with a specific beamforming network, designed using Universitat Politècnica de Catalunya designed planar transmission lines. The array will consist of multiple antennas, a time-multiplexed feeding network and electronics based on the new standards.

REconfigurable antennas for mm-wave broadband COMMunications (RECOMM)

Funding entity and duration: Ministerio de Ciencia e Innovación, 2020-2022.

Summary of the project: In the coming years, the implementation of broadband communications systems in the millimeter band with global coverage will acquire special relevance. It aims at a convergence of the fixed and mobile services to offer a universal quality of service similar to that of the already mature fiber optic networks. The imminent deployment of 5G networks promises to provide broadband service in sufficiently populated areas, the rest being covered by next-generation communications satellites. The latter allow uninterrupted connection in means of transport (trains, ships, planes) and serve as backup in areas affected by natural disasters or conflict and / or remote zones.

The development of antennas for satellite communications in Ka band, valid for trains or airplanes, represents a great technological challenge that has not yet been effectively solved by the industry. Very low profile antennas must meet very demanding specifications in terms of gain, secondary lobes, high purity circular polarization, and dual band operation. To these requirements must be added a high degree of reconfigurability, since they must be able to switch polarization in addition to pointing the beam dynamically towards the satellite to compensate for the movement. Also, the

deployment of the emerging 5G demands reconfigurable multibeam antennas capable of serving several users simultaneously.

This project addresses the development of new antenna concepts in the millimeter band capable of meeting the demanding needs of these communication systems. Special attention is paid to highly efficient antennas, dual in polarization and / or frequency and capable of reconfiguring their radiation pattern. The control of the aiming of the beam, maintaining the flat character of the antenna, is one of the main objectives of the project. The implementation of a low-cost alternative mechanism to electronic phase shifters opens the door to the development of competitive low-profile terminals. Innovative solutions capable of generating several simultaneous directing beams are also implemented, valid for multi-user and/or multi-path MIMO communications.

2.- RESEARCH RESULTS

Two National projects have ended in 2019:

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

Funded by Ministerio de Economia, Industria y Competitividad during period 2017-2019, new antenna concepts and topologies for Ka-band terminals (in the range from 19 to 31 GHz) for satellite communications were explored in this project, targeting at reducing terminal volume and weight so that they may be suitable for on-the-move applications. The proposal was focused on the antenna panel, probably the most complex part of the whole terminal: the mobile terminal comprises TX and an RX antennas operating at well-separated bands (30 GHz and 20 GHz, respectively).

Furthermore, being a cellular service, the mobile terminal must be capable of switching polarization during handover from one spotbeam to the next. Therefore, the project has faced the design of so-called dual antennas sharing the same panel for both polarizations and/or both frequency bands, so that overall surface reserved to the antenna is lower. In addition, the project has studied new beam pointing mechanisms so that the antenna may remain static while the main beam moves tracking the satellite.

Mechanical Phase Shifter in GapWaveguide Technology for Slotted WaveguideArrays in Ka band

During the last year, main effort has been devoted to mechanically-scanned-beam antennas, giving rise to a new concept of mechanical phase shifter which has been experimentally verified. This concept has been subject to a patent and a journal paper.

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

Funded by Ministerio de Economia, Industria y Competitividad during period 2017-2019, the main goal of this project was the design of new types of antennas for the 5G generation of mobile communications. This project has 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 from 1 to 6 GHz using an integral equation approach and several multi-mode antennas for on-body sensing applications have been analyzed and designed.

2. Reconfigurable mm-wave antenna design for mobile devices: These antennas have been designed using LTCC (Low Temperature Co-fired Ceramics) fabrication technology available at GRE premises.

3. Reconfigurable multibeam mm-wave 5G indoor base station design: Different metallic planar lens antennas based on non-periodic frequency selective surfaces have been designed for the frequency range of 20-30 GHz, and a prototype has been fabricated and tested at GRE premises. Moreover, 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.

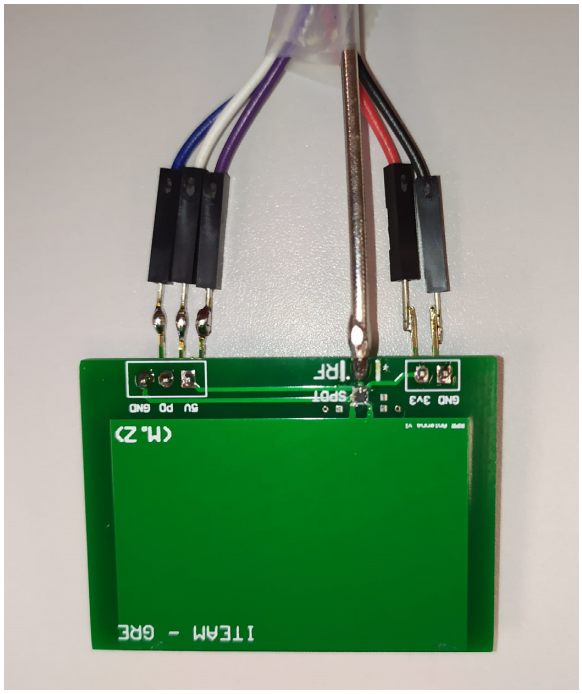
Regarding the propagation and channel modeling research line, statistical channel models based on propagation measurements at mm-wave frequency bands have been developed. These models stablish a path loss dependence on both distance and frequency and their parameters have been derived using regression and optimization techniques.

2.1.- FEATURED PUBLICATIONS

1. True-Time-Delay Mechanical Phase Shifter in GapWaveguide Technology for Slotted Wave-guideArrays in Ka band, D. Sánchez-Escuderos, J.I. Herranz-Herruzo, M. Ferrando-Rocher,

A. Valero-Nogueira, IEEE Trans. on Antennas and Propagation, under review, 2020.

A novel all-metal mechanical phase shifter in gap waveguide technology is proposed to provide



Fabricated radiation-pattern reconfigurable antenna prototype.

beam scanning capabilities to conventional slot array antennas along the elevation plane. To validate experimentally the beam-steering functionality, a 4x8 slot-array antenna has been designed and fabricated, along with the phase-shifting mechanism.

2. Millimeter wave MISO-OFDM transmissions in an intra-wagon environment, C. Sanchís-Borras, J.-M. Molina-Garcia-Pardo, L. Rubio, J. Pascual-Garcia, V. M. Rodrigo-Peñarrocha, L. Juan-Llácer, and J. Reig, IEEE Transactions on Intelligent Transportation Systems, pp. 1-10, In Press (pre-print version available). DOI: 10.1109/TITS.2020.2983028

Abstract: The maximum achievable throughput is analyzed in the intra-wagon channel when MISO-OFDM techniques are used, by means of real wideband propagation channel measurements at 28 and 37 GHz. Results provide useful insight to better understand the intra-wagon channel properties and deploy the future 5G wireless networks in this particular scenario at mmWave frequencies.

3. Grating Lobes Reduction Using a Multilayer Frequency Selective Surface on a Dual-Polarized Aperture Array Antenna in Ka-Band, D. Sánchez-Escuderos, J.I. Herranz-Herruzo, M. Ferrando-Rocher, A. Valero-Nogueira, IEEE Access, vol. 8, pp. 104977-104984, May 2020. DOI: 10.1109/ACCESS.2020.3000069

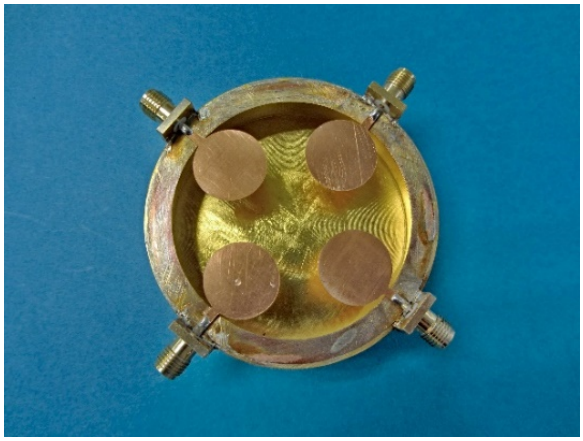
This paper presents a multilayer frequency selective surface (FSS) for a dual-polarized aperture array antenna in Ka-band. The 8 × 8 elements of the array are cylindrical open cavities with a diameter of 0.6λ at 30 GHz, and spaced one wavelength. Due to this separation between elements, grating lobes appear. FSS can be a solution to this problem without modifying the feeder architecture nor the radiating elements.

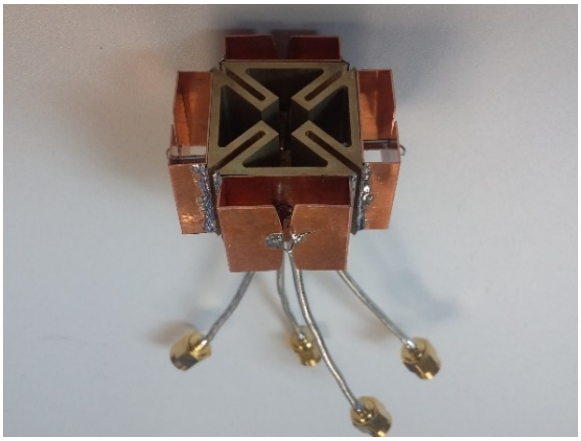
4. Dual Circularly Polarized Aperture Array Antenna in Gap Waveguide for High-Efficiency Ka-Band Satellite Communications, M. Ferrando-Rocher, J.I. Herranz-Herruzo, A. Valero-Nogueira, B. Bernardo Clemente, IEEE Open Journal on Antennas and Propag. vol 1, pp 283-289, 2020. DOI: 10.1109/OJAP.2020.3001087

A fully metallic Ka-band dual circularly polarized antenna array is presented. It consists of 64 circular apertures (8×8) and it is implemented in gap waveguide technology. The antenna includes 4 layers, which are completely metallic, leading to a highly efficient performance. Experimental results confirm good performance in terms of axial ratio, reflection coefficient and efficiency from 29 GHz to 31 GHz.

5. Millimeter wave channel measurements in an intra-wagon environment, L. Rubio, V. M. Rodrigo-Peñarrocha, J.-M. Molina-Garcia-Pardo. L Juan-Llácer, J. Pascual, and J. Reig, IEEE Transactions on Vehicular Technology, vol. 68, no. 12, pp. 12427-12431, October 2019. DOI: 10.1109/TVT.2019.2947205

Useful measurement results of the propagation channel characteristics in an intra-wagon environment at mm-wave frequencies are presented. The measurements were collected inside an underground convoy from 25 to 40 GHz in the





Fabricated prototypes: (a) UWB antenna with cavity and dual polarization; (b) MIMO multibeam antenna.

frequency domain. These results allow us to have a better knowledge of the path loss and time dispersion characteristics of the propagation channel in this particular environment, characterized by rich-scattering with long delays.

6. Planar Lens Antenna for High Data Rate Applications, D.A. Santillán-Haro, E. Antonino-Daviu, D. Sánchez-Escuderos, M. Ferrando-Bataller, Wireless Communications and Mobile Computing, vol. 2019. DOI: 10.1155/2019/5125287.

A low-profile lens antenna formed by 2 metallic rings with strips short-circuiting both rings is presented. The theory of characteristic modes is used to facilitate the design, optimization, and analysis of the structure. Measured results show a large operating bandwidth (14.7% relative -14 dB impedance bandwidth) with a maximum directivity above 13.70 dBi and a return loss better than 14 dB.

7. Fading evaluation in the mm-Wave band, T. R. Rufino-Marins, A. Antônio dos Anjos, V. M. Rodrigo Peñarrocha, L. Rubio, J. Reig, R. A. Amaral de Souza, and M. D. Yacoub, IEEE Transactions on Communications, vol. 67, no. 12, pp. 8725-8738, September 2019. DOI: 10.1109/TCOMM.2019.2941493

A thorough mm-wave measurement campaign is carried out in an indoor environment to characterize the short-term fading channel behavior. The measurements are conducted in a variety of scenarios, with frequencies ranging from 55 GHz to 65 GHz, in line-of-sight and non-line-of-sight conditions, and combinations of horizontal and vertical polarizations at both transmitter and receiver. A number of fading models are tested and the statistics under analysis are those characterizing the fading amplitude and the frequency selectivity.

8. Design of a Dual-band Frequency Reconfigurable Patch Antenna based on Characteristic Modes, Z. Mahlaoui, E. Antonino-Daviu, A. Latif, M. Ferrando-Bataller, International Journal on Antennas and Propagation, vol. 2019. DOI: 10.1155/2019/4512532.

A WLAN frequency reconfigurable patch antenna based on the characteristic mode analysis is proposed. The antenna presents a reconfigurable lower band (at 2.4 GHz) and a steady band at higher frequencies (from 5.3 GHz to 5.8 GHz). Varactor diodes are used in the antenna in order to tune the lower band, while the second operating frequency keeps stable.

9. Integral equation methods for electrostatics, acoustics and electromagnetics in smoothly varying, anisotropic media, L.M. Imbert-Gerard, F. Vico, L. Greengard and M. Ferrando, SIAM Journal on Numerical Analysis, vol. 57, no. 3, pp. 1020–1035, 2019. DOI: 10.1137/18M1187039.

A collection of well-conditioned integral equation methods for the solution of electrostatic, acoustic, or electromagnetic scattering problems involving anisotropic, inhomogeneous media is presented. In the electromagnetic case, this approach involves a minor modification of a classical formulation. In the electrostatic or acoustic setting, we introduce a new vector partial differential equation, from which the desired solution is easily obtained. It is the vector equation for which we derive a well-conditioned integral equation.

2.2.- PATENTS

The mechanical phase shifter is currently under a patent process: DESFASADOR MECÁNICO, PCT/ES2020/070296.

2.3.- AWARDS

1. Miguel Ferrando-Rocher has been awarded by Universitat Politècnica de València with one Premio Extraordinario de Tesis Doctoral to the best PhD dissertation in ICT in 2020.