Antennas and Propagation Lab (APL)

HEAD OF THE GROUP RESEARCH REPORT

The Antennas and Propagation Lab (APL) (formerly named Electromagnetic Radiation Group, GRE) is a research group 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 APL cover a wide range of applications, e.g. mobile and satellite communications, Wi-Fi, Bluetooth, UWB, IoT or on-body applications.

APL 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, APL works with different technological companies and public entities, such as the European SpaceAgency (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, 2018-2021.

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.

RECOMM: REconfigurable antennas for mm-wave broadband COMMunications

Funding entity and duration: Proyecto PID2019-107688RB-C22 de la Agencia Estatal de Investigación (MCIN/ AEI/10.13039/501100011033), 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 beam pointing, 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.

(a)

(b)

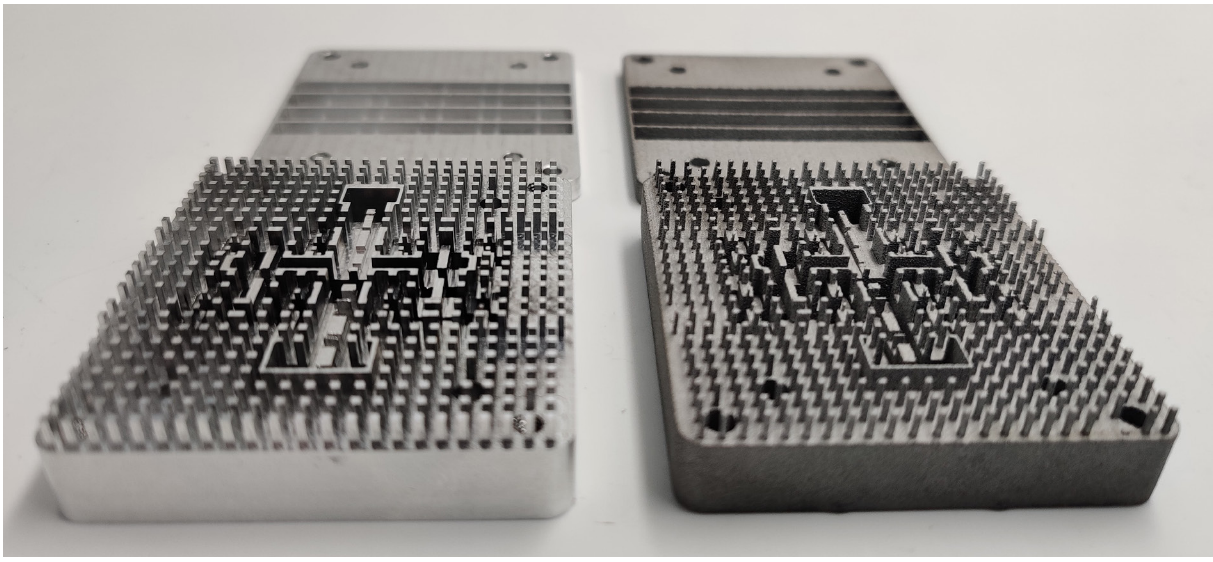
Extensive channel measurements have been collected in (a) underground and (b) indoor office environments in order to evaluate the propagation characteristics and develop new channel models in the potential 5G mmWave frequency bands.

Project MUMSYS: MUltimode and Multibeam reconfigurable x-wave antennas for communication and sensing SYStems.

Funding entity and duration: Proyecto PID2019-107885GB-C32 de la Agencia Estatal de Investigación del Ministerio de Ciencia e Innovación, 2020-2022.

Summary of the Project: The main goal 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 focus 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 antennas will be integrated into devices such as bracelets, key chains, clothing or other small devices, with low ECC coefficient for the new 5G and ISM bands. The new antennas will exhibit reconfigurable capability and will

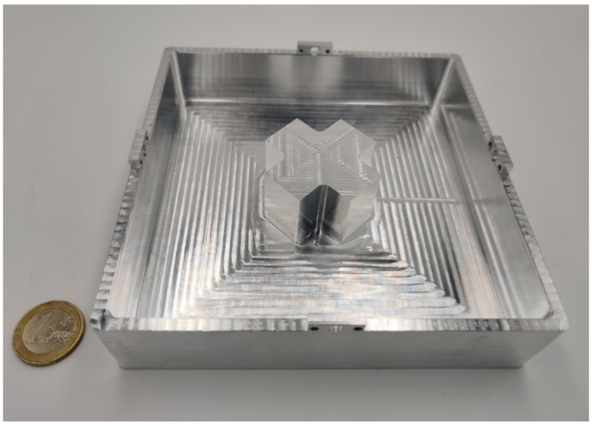


Layer of the manufactured prototype of a dual-band single-layer slot array antenna fed by K/Ka-band dual-mode resonators in Gap Waveguide Technology.

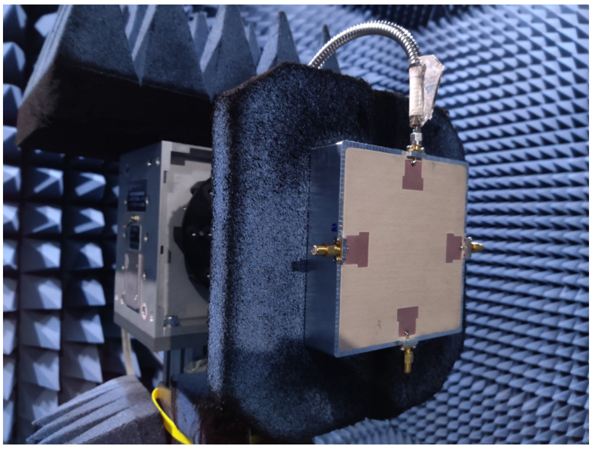
be developed for Internet of Things (IoT), communications and human body sensing applications. New fabrication methods such as conductive inks, metal deposition on plastic 3D prototypes, or metal embroidery on fabrics will be explored as a low-cost alternative to classical microstrip technology. Low Temperature CoFired Ceramic (LTCC) technology will be also used for multi-sensor wireless systems and IoT applications, where compact reconfigurable antennas of very small size that can be easily integrated into printed circuit boards are required. Equipment obtained through the Valencia International Campus of Excellence will be used for manufacturing LTCC circuits.

2. Planar metallic lenses for reconfigurable multibeam 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 UPCT. In addition, new reconfigurable antennas based on multiple coupled resonators will be proposed and analyzed using the Theory of Characteristic Modes.

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 UPC designed planar transmission lines. The array will consist of multiple antennas, a time-multiplexed feeding network and electronics based on the new standards.



(a)



(b)

(a) Prototype of a four-port wide-band cavity-backed antenna for a sub-6 GHz 5G indoor base station measured in the anechoic chamber; (b) View of the isolating X-Shaped block in the square cavity.

2. Research results

2.1.- Featured publications

1. **True-Time-Delay Mechanical Phase Shifter in Gap Waveguide Technology for Slotted Waveguide Arrays in Ka band**, D. Sánchez-Escuderos, J.I. Herranz-Herruzo, M. Ferrando-Rocher, A. Valero-Nogueira, *IEEE Transactions on Antennas and Propagation*, vol. 69, no. 5, pp. 2727-2740, May 2021, **DOI:** 10.1109/TAP.2020.3030993.

   A novel all-metal mechanical phase shifter in gap waveguide technology is proposed to provide 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. **Dual-Band Single-Layer Slot Array Antenna Fed by K/Ka-Band Dual-Mode Resonators in Gap Waveguide Technology,** M. Ferrando-Rocher, J.I. Herranz-Herruzo, A. Valero-Nogueira, M. Baquero-Escudero, *IEEE Antennas and Wireless Propagation Letters*, vol. 20, no. 3, pp. 416-420, March 2021, **DOI:** 10.1109/LAWP.2021.3054408.

   A 4 × 4 single-layer dual-band array antenna operating in the K- and Ka-band using gap waveguide (GW) technology is proposed. The antenna presents two ports, one for each band, and radiates a directive far field pattern with linear polarization. A diplexer is integrated as part of the network to separate both working bands.

3. **Selective Laser Sintering Manufacturing as a Low Cost Alternative for Flat-Panel Antennas in Millimeter-Wave Bands,** M. Ferrando-Rocher, J. I. Herranz-Herruzo, A. Valero-Nogueira and B. Bernardo-Clemente, *IEEE Access*, vol. 9, pp. 45721-45729, 2021, **DOI:** 10.1109/ACCESS.2021.3067637.

   In this paper, the capabilities of Selective Laser Sintering metal 3D-Printing technology to achieve a lightweight and cost-effective flat panel antenna in the millimeter wave band are studied. Measured performance of an SLS antenna prototype is benchmarked with the performance of the previously measured CNC antenna. Experimental results reveal the strengths and weaknesses of this particular low-cost additive manufacturing technique with respect to traditional subtractive manufacturing techniques.

4. **Four-Port Wide-Band Cavity-Backed Antenna With Isolating X-Shaped Block for Sub-6 GHz 5G Indoor Base Stations,** J. Molins-Benlliure, E. Antonino-Daviu, M. Cabedo-Fabrés and M. Ferrando-Bataller, *IEEE Access*, vol. 9, pp. 80535-80545, May 2021, **DOI:** 10.1109/ACCESS.2021.3084852.

   A four-port wideband cavity-backed antenna is presented for indoor base stations applications. The antenna is composed of a square open cavity with an X-shaped isolating block and 4 feeding monopoles symmetrically and orthogonally arranged in the aperture of the cavity. A novel methodology based on Characteristic Modes Analysis (CMA) is used for identifying the modes, which are contributing to the coupling. As a result of this analysis, an X-shaped isolating block placed at the center of the cavity is proposed for increasing the isolation between ports. A wide-band four-port antenna with unidirectional radiation patterns is obtained with a measured impedance bandwidth (S11<-10 dB) ranging from 1.55 to 6 GHz (118%), covering most of the sub-6 GHz 5G bands. The proposed antenna provides four independent radiation patterns, with 16 dB of measured minimum isolation between ports and an efficiency higher than 84%. Multiple-input multiple-output (MIMO) compatibility is confirmed with a 4x4 MIMO simulated system with an envelope correlation coefficient (ECC)<0.5 in different propagation conditions. The antenna is easy to fabricate and presents a compact size of 129.5 x 129.5 x 28.2 mm^3 (0.68λ x 0.68λ x 0.15λ, at a frequency $f=f_{min}=1.55$ GHz). Moreover, the antenna has the advantage of avoiding complex feeding structures with baluns or directional couplers.

5. **Radiation Pattern Reconfigurable Antenna for IoT Devices,** Z. Mahlaoui , E. Antonino-Daviu and M. Ferrando-Bataller, *International Journal of Antennas and Propagation*, vol. 2021. **DOI:** 10.1155/2021/5534063.

   This paper proposes a versatile radiation pattern reconfigurable antenna based on the characteristic mode theory. The analysis starts from two parallel metallic plates with the same and different dimensions. By means of two PIN diodes, the size of one of the parallel metallic plates can be modified and consequently the behavior of the radiation pattern can be switched between bidirectional and unidirectional radiation patterns. Moreover, a SPDT switch is used to adjust the frequency and match the input impedance. The reconfigurable antenna prototype has been assembled and tested, and a good agreement between simulated and measured results is obtained at 2.5GHz band, which fits the IoT applications.