Antennas and Propagation Lab. Annual Research Report 2019

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Head of the Group research report

The Antennas and Propagation Laboratory (APL) 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 APL 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, APL 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.

APL 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

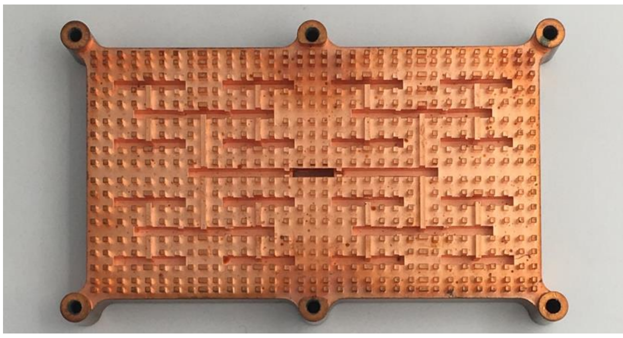
Mobile satellite terminals are aimed at providing high data rate services in areas not covered by terrestrial networks, such as remote areas, war zones, natural disasters, ships or aircrafts. These terminals make use of the multi-spot beam coverage given by a new generation of satellites operating in 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.

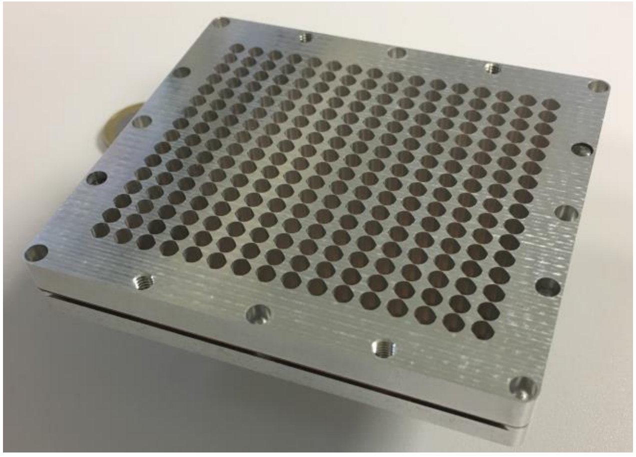
Additionally, the project addresses the design of dual antennas sharing the same panel for both polarizations and/or both frequency bands, capable of switching polarization during handover from one spot-beam to another. Several solutions have been proposed in this area during the second year of the project,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

Massive connectivity is one of the key features that will be demanded by users in future 5G wireless communications systems. Numerous reports are showing quantitative evidence of the future explosion of wireless data transmissions, as every user will demand connectivity to everything everywhere. According to current forecasts, the number of devices in a decade could reach the tens or even hundreds of billions, driven by many novel applications beyond personal communications. Therefore, 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:

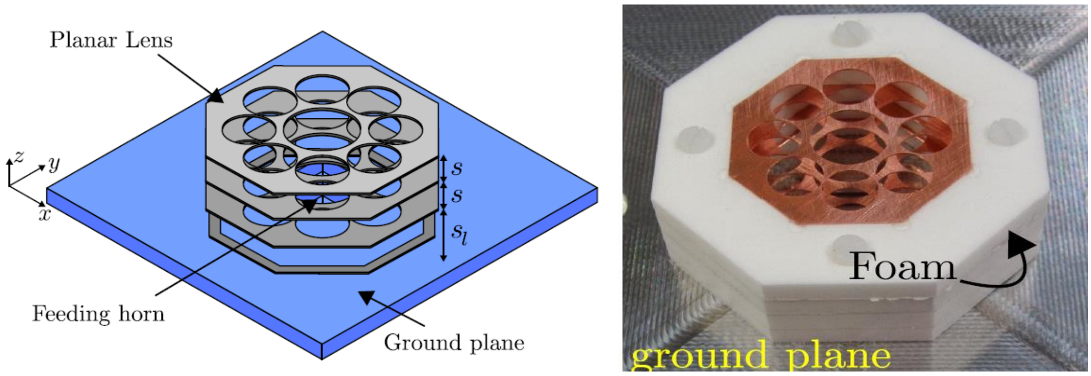
1. On-body sensing applications: An integral equation approach for a computational modelling of the human body is going to be developed in the band from 1 to 6 GHz, for applications related with on-body sensing systems. Analysis and design of multimode antennas for on-body sensing applications using characteristic modes is also going to be performed. These multimode antennas 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 are going to be generated with the aid of LTCC (Low Temperature Co-fired Ceramics) technology, since the required facilities are already available at the APL 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 20-90 GHz band. An efficient formulation of an integral equation approach for the analysis of metamaterial lenses in

the mm-wave band are being developed. A prototype will be fabricated and characterized at UPV and channel measurement will be performed.

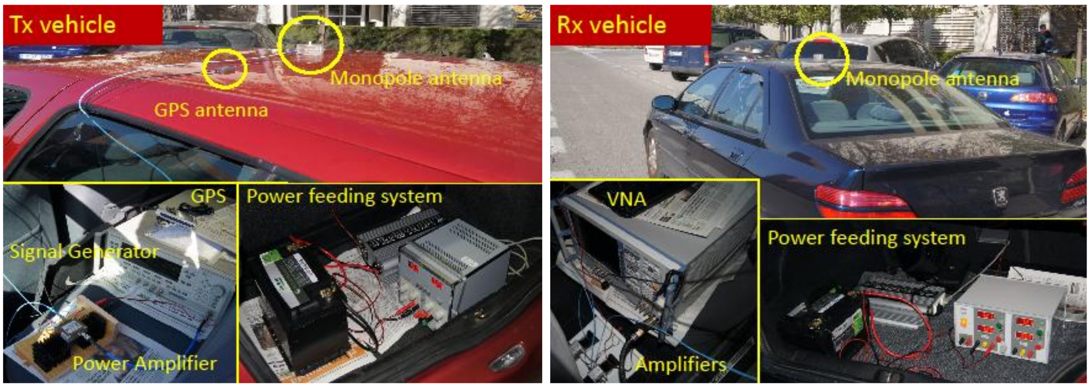
This project has been funded by the Ministerio de Economia Industria y Competitividad (MINECO).



Geometry and prototype of a multilayer planar lens based on FSS designed at 20 GHz.

2.- Research results

The propagation research activities in the APL are oriented to the characterization, modeling and development of wireless channels in both narrowband and wideband cases. Path loss modeling, time- and frequency-selectivity behavior of wireless channels and fading processes are covered in different frequency bands and wireless systems based on the combination of extensive channel measurements and ray tracing techniques. Path loss propagation models for both vehicular-to-vehicular (V2V) and vehicular-to-infrastructure (V2I) have been developed from channel measurements at 700 MHz and 5.9 GHz carried out in typical expected vehicular communications scenarios, i.e., urban, suburban, rural and highway, for different road traffic densities, vehicular speeds and traffic conditions. Moreover, channel measurements for typical scenarios such as indoor, outdoor and outdoor to indoor environments applied to the future 5G wireless systems are being collected in order to build appropriate channel models.



Measurement setup on-board the transmitter and receiver vehicles involved in vehicular channel measurements.

Furthermore, it has been developed software for the simulation of homogeneous and inhomogeneous dielectric materials using the Lippmann-Schwinger integral equation method. The method has been tested in complicated geometries. It has been shown to be very robust, accurate and fast. It has been also proposed a novel method for computing the scattering of perfect electric conductors based on decoupled potentials. The method is stable for multiply connected geometries.

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** Santillán-Haro, D., Antonino-Daviu, E., Sánchez-Escuderos, D., & Ferrando-Bataller, M. 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.

2.1.- 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.** Sánchez-Escuderos, Daniel; Boria Esbert, Vicente Enrique; Baquero Escudero, Mariano, Guglielmi, Marco, Ref.: P201830106, Publication date: 7/2/2018

2.2 Awards

1. 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.

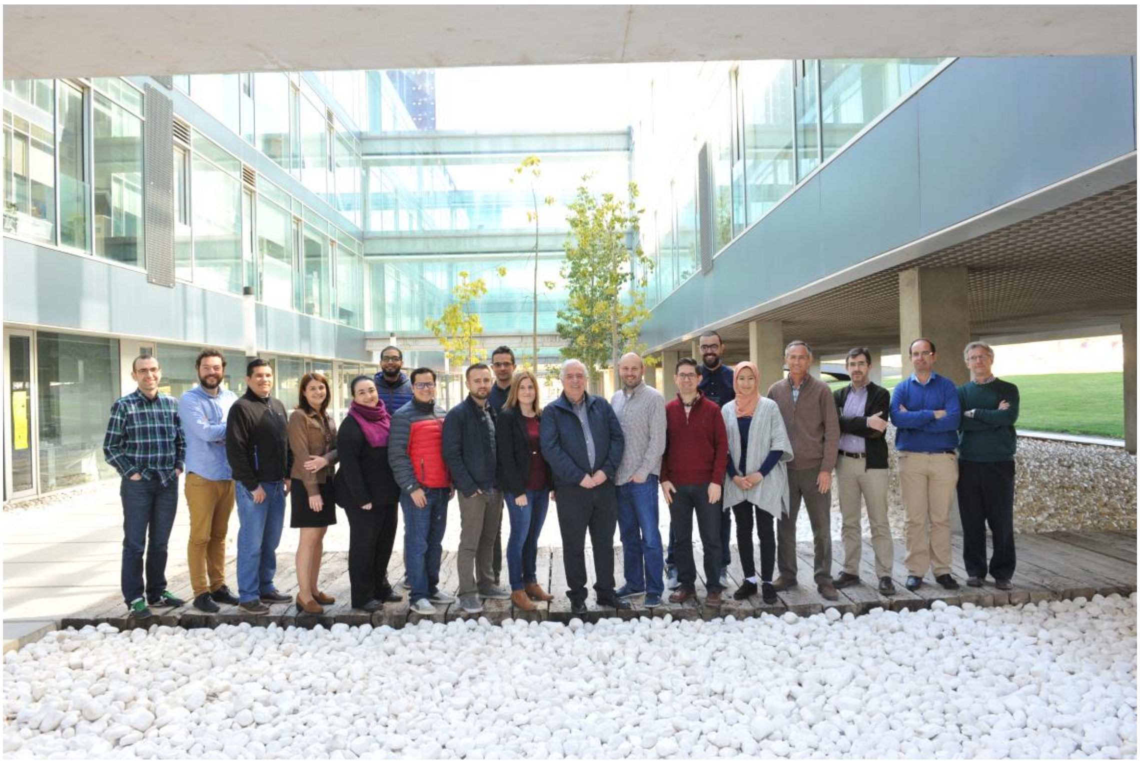
3.- Facilities

The APL 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 APL’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 APL’s laboratory for the fabrication of microwave circuits and antennas on planar substrates.

The APL 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 APL 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 APL, 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.



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