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Electromagnetic Radiation Group (GRE) Annual Research Report 2016/2017

Head of the Group research report

The Electromagnetic Radiation Group (GRE) has a strong team of academics and researchers working on various areas related to antenna engineering and propagation issues. The group has a comprehensive antenna laboratory housed in the iTEAM, with about 1 million euro in infrastructure investment.

During the last year, the GRE has established excellent collaborations with academic and industrial partners, such as the Courant Institute of Mathematical Sciences (New York University), Chalmers University of Technology, University of Oulu, the European Space Agency (ESA) and Thales, among others. Long-lasting links with regional companies have also been established in order to support their technological development. In 2016, GRE completed three important projects, while two new national projects started in 2017 and are currently underway.

GRE research themes and interests cover theory, numerical methods, design and measurement of antennas and propagation. The GRE research lines in antenna engineering cover a very wide range, from UHF to THz bands.

A complete list of research activities can be found at **http://www.iteam.upv.es/group/gre.html**

1.- Project activities

The current research lines of the group include:

- Slot-array antenna design for high-gain applications
- Development of efficient methods for the electromagnetic analysis of complex structures
- 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)
- Diagnosis and antenna measurement
- Propagation and channel modelling

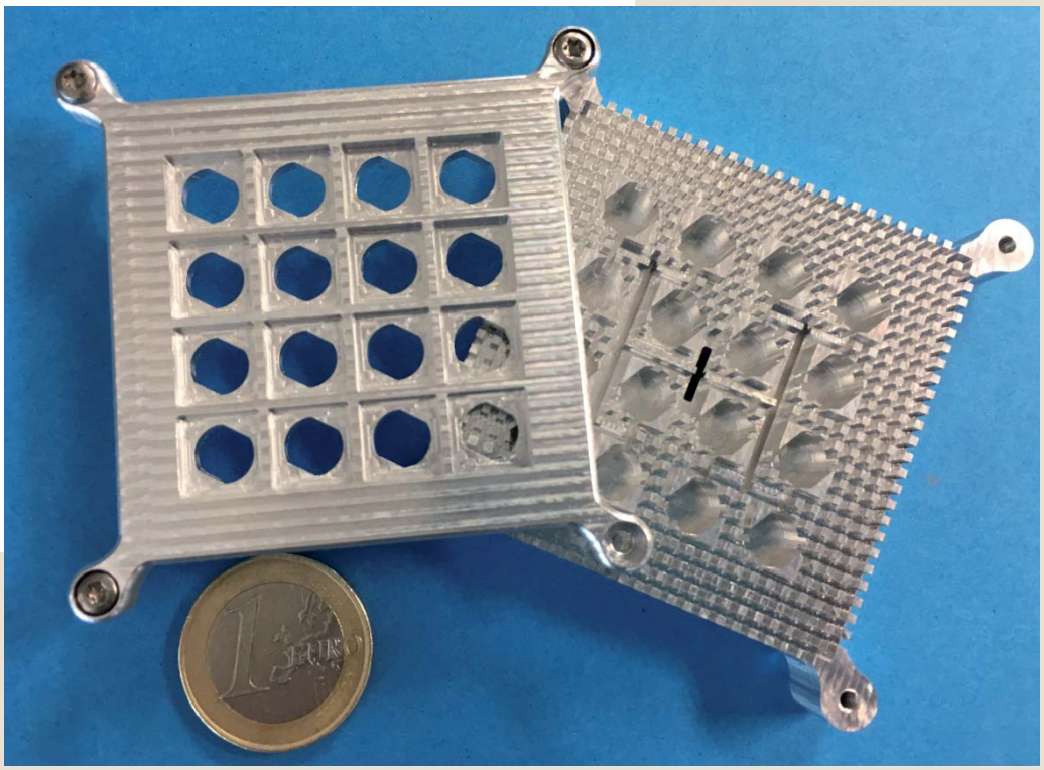
These research lines have been developed within the framework of different research activities. The ongoing projects, as well as the main results obtained and the related publications, are described hereunder.

1.1.- Ongoing projects

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

Period: 2017-2019

Next generation of mobile satellite terminals will be able to provide high data rate services in all those areas not covered by terrestrial networks. There exist many situations in which data access is only available through communication satellites: remote areas, war zones, natural disasters, ships, aircrafts, etc. High data rate services are provided by a new generation of satellites operating in Ka band (in the range from 19 to 31 GHz). Current mobile terminals operate in a lower frequency band, Ku, and are not capable of providing the data rates required. However, the availability of new mobile terminals in Ka band is not achieved by a straightforward scaling of existing terminals to the new band. On the contrary, the specifications set to the new Ka-band terminals render the design a technological challenge and indeed an open problem at this time. In this project, new antenna concepts and topologies are being explored targeting at reducing terminal volume and weight so that they may be suitable for on-the-move applications. Furthermore, being a cellular service, the mobile terminal must be capable of switching polarization during handover from one spotbeam to the next. Given all that, the project faces the design of so-called dual antennas sharing the same panel for both polarizations and/or both frequency bands. In addition the project is studying new beam pointing mechanisms. This characteristic contributes largely to the low profile of the terminal. Among the technological solutions, the use of so-called metasurfaces are being considered too. These metamaterials provide interesting guiding properties leading to flat lenses for instance, whose low profile is an appealing feature given the specifications of these terminals. Finally, the project is considering also



Proof of concept of single-layer circularly-polarized aperture array antenna.

manufacturing issues. Direct-metal 3D printing and metallized plastics aer also being investigated with this purpose.

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

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

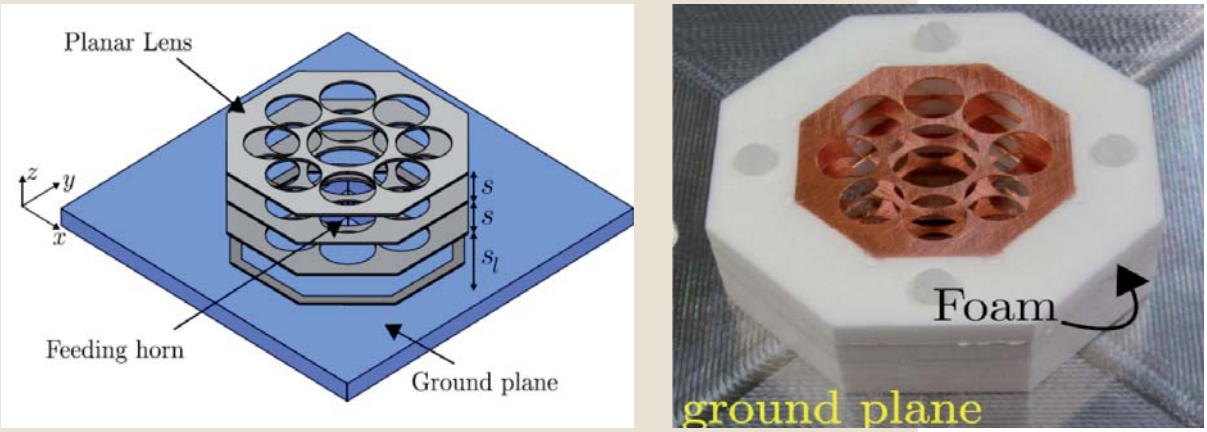
Period: 2017-2019

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 GRE 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

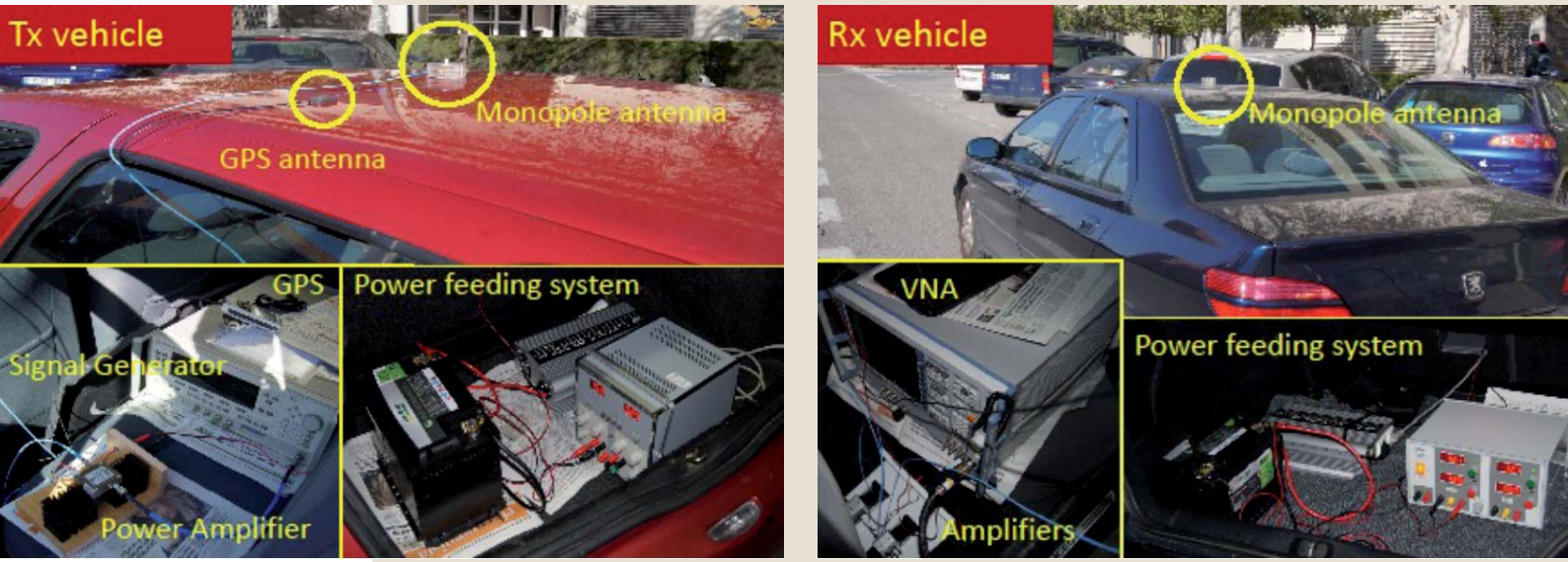
The propagation research activities in the GRE are oriented to the characterization, modeling and development of wireless channels in both narrowband and wideband cases. Path loss modeling, time- and frequency-selectivity behavior of wireless channels and fading processes are covered in different frequency 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.

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.

During 2016, three projects have come to an end:

Millimeter waves in LTCC technology for 2020 antenna systems (MIL20)

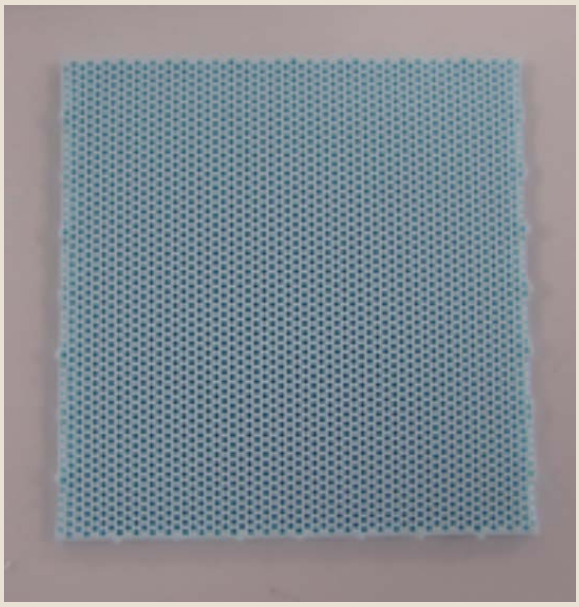
This national project, funded by Ministerio de Industria, Economia y Competitividad and lasting for three years, started at 2013 with the aim of



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

applying LTCC (Low Temperature Co-fired Ceramics) technology for the design of mm-wave antennas for next generation communications systems.

Different objectives were set and achieved during the project: Development of new integral equation methods for analyzing complex 3D dielectric-metallic objects using DPIE (Decoupled Potential Integral Equation) formulation; development of an electromagnetic simulation program for the computation of Characteristic Modes in magnetic structures, periodic structures and metal-dielectric bodies; design of a high-gain antenna at 20 and 60 GHz using a multilayer periodic superstrate through characteristic modes analysis; evaluation of the antenna directionality characteristics impact on the space, time and frequency channel behavior; design, fabrication and measurement of a switched beam antenna in V band (40-75 GHz) based on SSGW (Suspended Strip Gap Waveguide) technology; explore the advantages of gap waveguides in LTCC technology as an alternative to conventional SIW technology for applications in mm-wave band; and design, fabrication and measurement of a fixed beam high-gain antenna in D band (110-170GHz), consisting in a LTCC feeding network, a slot array and a LTCC lens.

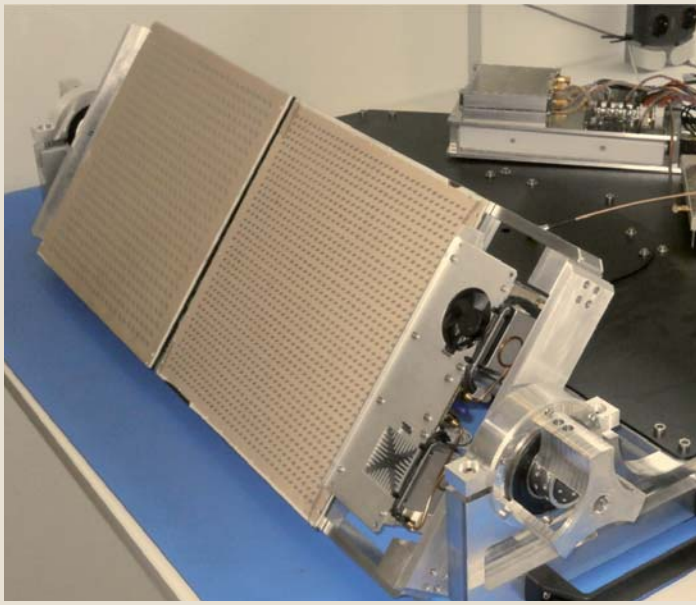


Planar lens fabricated on LTCC.

Low Cost and Compact Mobile Terminal (LOCOMO)

In 2013, European Space Agency (ESA) granted project LOCOMO (Low cost and compact Ka-band mobile SATCOM terminal) to develop a Ka-band SOTM low profile antenna terminal that could be conveniently integrated onto terrestrial vehicles. This terminal will be able to provide broadband services anywhere and anytime, even in motion. The project target was to achieve a SOTM terminal for Ka band at a reasonable cost. The target applications were national security, emergency systems and Dual-Use systems, where military frequency bands will be made available for civilian missions as well. The challenge of LOCOMO terminal has been to reach a commitment of low profile and low cost while satellite regulation and high performance services are achieved. The regulation introduces a serious limitation out of the geostationary orbit, making extraordinarily complex the development of low profile antennas.

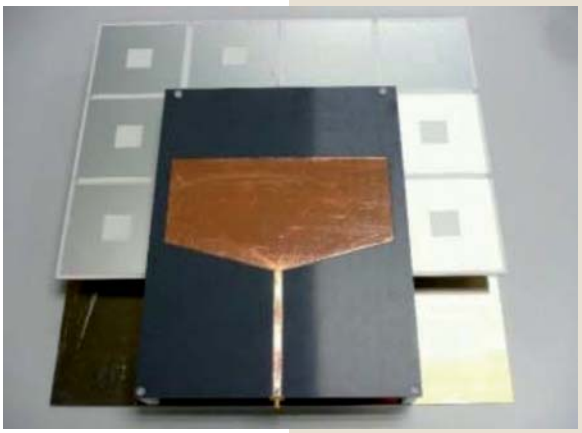
During mid 2017 the project will be officially closed with a successful outcome for GRE, since the antenna designed complies satisfactorily with the objectives of the project. The picture below shows the antenna.



Ka-band antenna for SOTM applications.

Use of High Impedance Surfaces for the Design of Low-Profile Antennas for Wideband Applications (GV/2015/065)

This project, funded by the regional administration Generalitat Valenciana and with a duration of two years, aimed to design a low-profile wideband planar antenna for Digital Television (DTV) reception in the UHF band (from 470 MHz a 790 MHz), in order to provide a more compact solution to traditional Yagi-Uda antennas. The basic idea for achieving low-profile was to use a metamaterial High Impedance Surface (HIS) as a reflector for a wideband planar monopole antenna. As the HIS surface acts as a magnetic conductor, a very low-profile antenna was achieved, with a height of less than 0.1λ (53.6 mm) and a total weight of 0.352 kg. In order to reduce cost, the antenna was designed using low-cost materials. Studies of the conformability of the antenna were also performed, providing solutions for the integration of the antenna with curved surfaces. The antenna developed in the project is shown in the picture below:



Low-profile antenna for DTV applications in the UHF band.

2.1.- Featured publications

- Circularly Polarized Slotted Waveguide Array with Improved Axial Ratio Performance, Miguel Ferrando-Rocher, Jose I. Herranz-Herruzo, Alejandro Valero-Nogueira, and Vicent Miquel Rodrigo, IEEE Trans. on Antennas and Propagation, pp.4144-4148, Sept. 2016.

DOI: 10.1109/TAP.2016.2586492

This communication demonstrates experimentally the improvement in axial ratio performance when a slot is combined with a set of three parasitic dipoles instead of one. The analysis is performed in the context of slotted-waveguide arrays and SATCOM applications in Ka band, where a bandwidth specification as wide as 7.5% can be demanded.

- Microwave Planar Lens Antenna Designed with a Three-Layer Frequency Selective Surface, D. Sanchez-Escuderos, H. Ching Moy-Li, E. Antonino-Daviu, M. Cabedo-Fabres, M. Ferrando, IEEE Antennas and Wireless Propagation Letters, vol. 16, pp. 904-907, 2017.

DOI: 10.1109/LAWP.2016.2614342

In this paper, a low-profile planar lens is presented in order to increase the gain of a feeding aperture. The lens antenna consists of a multilevel Frequency-Selective Surface (FSS) formed by a nonuniform distribution of circular holes on a metallic sheet. The antenna has been fabricated and measured at iTEAM facilities, showing very good results.

- Design Guidelines for the Excitation of Characteristic Modes in Slotted Planar Structures, E. Antonino-Daviu, M. Cabedo-Fabres, M. Sonkki, N. Mohamed Mohamed-Hicho, M. Ferrando-Bataller, IEEE Trans. on Antennas and Propagation., vol. 64, no. 12, pp. 5020-5029, Dec. 2016.

DOI: 10.1109/TAP.2016.2618478

This paper provides some design guidelines for the excitation of broadband slotted planar antennas, addressing key issues such as coupling, symmetries and multiple feeding. The Theory of Characteristic Modes is used to identify the collection of current modes that exists on these structures, dealing to a valuable understanding of the radiating mechanisms and allowing a more controlled design process. Based on the information yielded by this modal analysis, a capacitive-coupled dual-feed circular aperture antenna is designed, fabricated and measured.

- Propagation characteristics of groove gap waveguide below and above cutoff. A. Berenguer, V. Fusco, D. E. Zelenchuk, D. Sánchez-Escuderos, M. Baquero-Escudero, V. E. Boria-Esbert. IEEE Transactions on Microwave Theory and Techniques, 64(1), 27-36, 2016.

DOI: 10.1109/TMTT.2015.2504501

This work presents a discussion of both below and above cutoff propagation characteristics of groove gap waveguides (GGW), recently proposed as a potential alternative to conventional waveguides in the millimeter-wave band. Furthermore, this paper introduces a simple model that explains the observed GGW behavior and establishes well its propagation characteristics. Two thru-reflect-line calibration kits were showing good agreement with the proposed analysis model results.

- Low-loss circularly polarized periodic leaky-wave antenna. D. Sánchez-Escuderos, M. Ferrando-Bataller, J. I. Herranz, V. M. Rodrigo-Peñarrocha. IEEE Antennas and Wireless Propagation Letters, 15, 614-617, 2016.

DOI: 10.1109/LAWP.2015.2463672

This letter presents a periodic leaky-wave array antenna with circular polarization at millimeter-wave frequencies. The antenna was designed on the low-loss planar Goubau transmission line to maximize the radiation efficiency of the antenna. The unit cell of the array was formed by four dipoles located on both faces of the Goubau line' substrate. A prototype was fabricated and measured giving excellent results in terms of impedance bandwidth, axial ratio bandwidth, radiation efficiency and gain.

- Wideband Double Monopole for Mobile, WLAN, and C2C Services in Vehicular Applications. D. V. Navarro-Méndez, L. F. Carrera-Suárez, D. Sánchez-Escuderos, M. Cabedo-Fabrés, M. Baquero-Escudero, M. Gallo, D. Zamberlan. IEEE Antennas and Wireless Propagation Letters, 16, 16-19, 2017

DOI: 10.1109/LAWP.2016.2552398

This letter presents a three-dimensional antenna solution for automotive applications. The proposed solution is formed by two independent antennas, perpendicularly placed inside a plastic cover with a shark-fin shape. The first antenna is a double-shorted monopole that provides service in the LTE700, GSM850, and GSM900 bands, whereas the second antenna is a drop-shaped monopole that operates in the DCS1800, PCS1900, WCDMA2100, WLAN2400, LTE2600, WiMAX2350, and Wi-Fi at 2.4-GHz bands, and in the Wi-Fi at 5 GHz and C2C bands.

- Felipe Vico, Leslie Greengard, Miguel Ferrando, Fast convolution with free-space Green's functions, Journal of Computational Physics, Volume 323, 15 October 2016, pp. 191-203.

DOI: 10.1016/j.jcp.2016.07.028

In this paper we show a novel quadrature method to compute convolutions with free space Green's functions. The method has spectral accuracy and can be computed in FFT time.

- Susana Loredo, Adrián del Castillo, Herman Fernández, Vicent M. Rodrigo-Peñarrocha, and Lorenzo Rubio, "Small-scale fading analysis of the vehicular-to-vehicular channel inside tunnels," Wireless Communications and Mobile Computing, vol. 2017, pp.1-6, 2017.

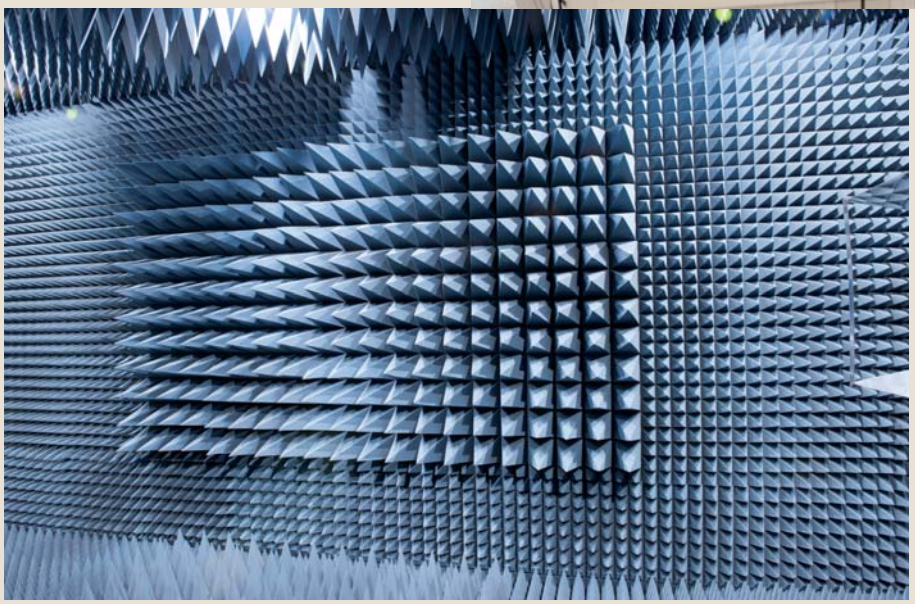
DOI: 10.1155/2017/1987437

This paper presents a small-scale fading analysis of the vehicular-to-vehicular (V2V) propagation channel at 5.9 GHz when both the transmitter (Tx) and receiver (Rx) vehicles are inside a tunnel and are driving in the same direction. This analysis is based on channel measurements carried out at different tunnels under real road traffic conditions. Since there are so far few published results for these confined environments, the results obtained can be useful for the deployment of V2V communication systems inside tunnels.

3.- Facilities

The GRE has a laboratory with all the facilities needed to build and measure the researcher's designs. In order to make the prototypes, a CNC milling machine with 5 microns of accuracy and 3 axes (x, y, z) is used. Some prototypes can be seen in ongoing projects figures. Our main successful

CNC milling.



Anechoic chamber.

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Laboratory of High Frequency Circuits.

prototypes include pillars of 0.25 mm by side and 2 mm high, or designs working perfectly at 60 GHz. For performing microwave circuits and antennas on planar substrates two options are available: a micro milling machine or chemical etching.

The GRE antenna laboratory has the ability to prototyping, characterization, measurement (up to 50GHz) and analysis of antennas and microwave devices. Thanks to the capabilities of the laboratory, any deviation from the antennas and microwave devices designed are corrected in order to ensure the specifications demanded, thereby obtaining a totally reliable antenna or microwave device.

For characterization, measurement and analysis, the laboratory has 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 measurement of different parameters of antennas and microwave devices in frequency (up to 67 GHz) and time domain. We also have a signal (spectrum) analyzer up to 26 GHz.

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.