A Report on New Antennas for Satellite Communications on-the-move in Ka-band

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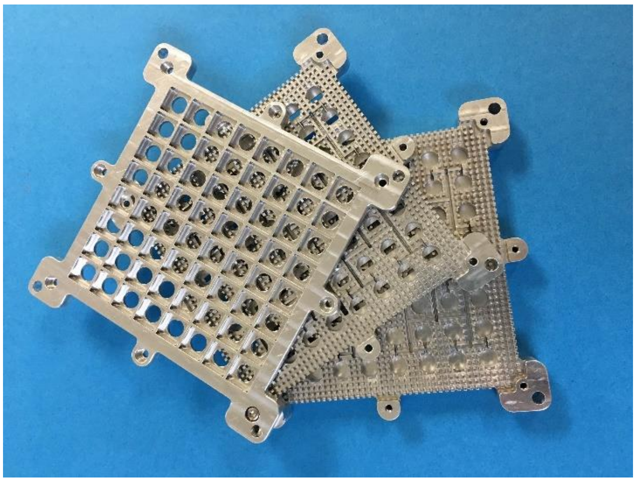
This project was initiated in 2017 within the framework of the Spanish national research program, funded by the ministry of economics, industry and competitiveness. The scope of this project is focused on the design of ground terminals for the new generation of high-throughput satellites operating in 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 impose 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. Attached image show 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 are being explored. Attached picture show a double-sided groove-gap waveguide used in this alternative configuration.

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.

2.1. Featured publications

1. **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 × 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.

2. **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 × 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.

3. **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 × 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).

4. **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 8×8 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).

5. **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 4x4 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.

6. **Compact Combline 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.