A 3D Printed Lens Antenna for 5G Applications

Christian Ballesteros, Marcos Maestre, Maria C. Santos, Jordi Romeu, Luis Jofre
Signal Theory and Communications Department
Universitat Politecnica de Catalunya (UPC), Barcelona, Spain.
christian.ballesteros@tsc.upc.edu, marcos.maestre@upc.edu, santos@tsc.upc.edu, romeu@tsc.upc.edu, jofre@tsc.upc.edu

***Abstract*—A switchable multi-antenna architecture for lens-assisted beamsteering in the Ka-band region allocated for 5G communications (24-30 GHz) is proposed. The radiating elements are bow-tie antennas mounted with a 3D printed high-permittivity dielectric lens ($\varepsilon_r = 10$). A 5-element array is simulated showing switchable 30° beam steering over a 120° sector with 19 dB maximum gain. Single antenna measurements of a scaled prototype with a Polylactic Acid (PLA) lens ($\varepsilon_r = 2.7$) show gains around 11 dB, in agreement with projected performances.**

I. Introduction

Steerable antenna arrays are playing an important role with regard to the future generation of wireless networks (5G) as they will allow for the optimization of resources by allocating the available bandwidth to dedicated spatial channels serving the active users inside a picocell area. In [1], it is shown that a good alternative for millimeter-wave (mmWave) bands is the use of lens-based switched beam architectures. By selecting one element of the array, and according to its position relative to the lens focus, the beam is properly steered towards a particular direction in the space.

The emergence of 3D printers has simplified the manufacturing process for such kind of dielectric lenses and prototyping is now easier and faster than ever. An example is found in [2], where an Acrylonitrile Butadiene Styrene (ABS) 3D-printed lens is proposed as beam focusing solution at 60 GHz, but without steering capabilities. For the current band of operation (24–30 GHz), other solutions may be found as in [3–5] but they usually imply complex architectures, low gain (below 20 dB) or scanning is not continuous. In this paper, a inexpensive and simple solution is proposed to overcome most of those issues.

II. Switched Array and Dielectric Lens Design

The design proposed in this work is a switched multi-antenna architecture and a dielectric lens to enhance the system gain, required to overcome the high losses in the mmWave region, and focus towards a particular user angular position. The steering capability is obtained by switching among the array elements.

A. Slot bow-tie Antenna

A slot bow-tie antenna is chosen to be the radiating element in the switched array. The bow-tie geometry allows Ultra-wide Band (UWB) performance and the slot typology provides large impedance values and also compatibility with Coplanar Waveguide (CPW) feeding lines, which is interesting in the case of integrating the antenna with a photodiode to work at the end of a Radio over Fiber (RoF) fronthaul network.

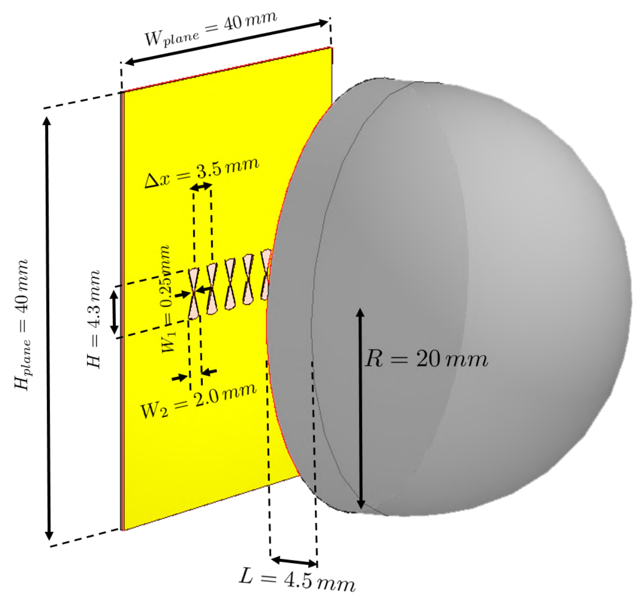


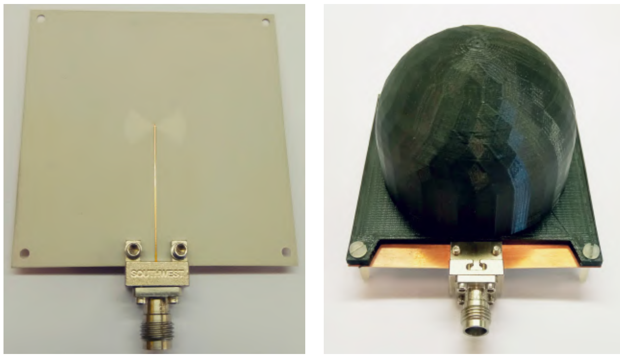
Fig. 1. Complete setup with the bow-tie antenna switched array and the dielectric lens dimensions.

The geometry is optimized to work in the presence of a high permittivity ABS lens in the Ka band region corresponding to 5G communications (24 to 30 GHz). The substrate is a 254 μm thick Rogers RO3003, with dielectric properties $\varepsilon_r = 3$ and $tan\delta = 0.001$, under a copper layer of 17 μm. The plane dimensions are $40\,mm \times 40\,mm$.

B. Dielectric Lens and Beam Steering

Specialized materials for RF applications such as the ABS filaments provided by PREPERM® allow the use of different permittivities to produce beamshaping lenses with a 3D printer. For the numerical simulation, the ABS1000 material is chosen. According to the manufacturer specifications, its dielectric constant is $\varepsilon_r = 10$ and loss tangent $tan\delta = 0.004$ The considered geometry is an extended hemispherical lens of $R = 20\,mm$ radius and $L = 4.5\,mm$ extension, once optimized. The design criteria can be found in [6].

The antenna offset position with respect to the lens focus determines the scanning angle. In case of extended hemispherical lenses, the relationship is given by $tan(\gamma) = \frac{\Delta x}{L}$ [7], where γ is the scanning angle and Δx is the element offset. Fig. 1 shows the dimensions of the entire setup.



(a) Microstrip-to-slot transition at the bottom side of the antenna.

(b) PLA lens mounted on top of the bow-tie slot.

Fig. 2. Experimental set-up of a bow-tie antenna with a dielectric lens.

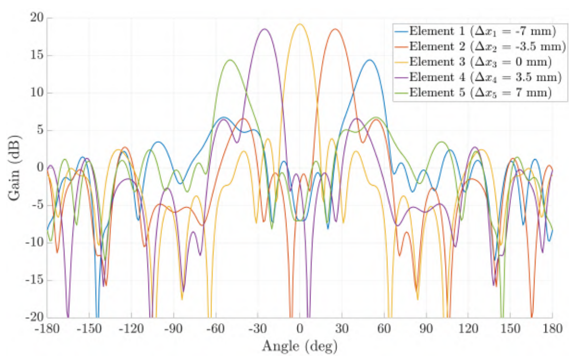


Fig. 3. Realized gain at 30 GHz of the ABS lens array simulated with CST.

III. Simulations and Experimental Verification

The system performance is simulated and validated by experimental measurements. The antenna matching and radiation gain are evaluated for a 3D printed prototype by means of the realized gain of the entire system.

A. Measurement set-up

The testing campaign is carried out with a PLA prototype of the dielectric lens, whose properties are in the order of $\varepsilon_r = 2.7$ and $tan\delta = 0.01$ according to [8] and [9]. In this case, both the lens and the bow-tie antenna are properly optimized to operate in the frequency band of interest for the new conditions. The PLA lens is completely filled of material with a volume fraction greater than 90%. A microstrip-to-slot transition is used to feed the antenna without disturbing the radiation pattern and allow its characterization. Fig. 2 shows the complete set-up. A reference 17 dBi horn antenna is used for the S_{21} measurements.

B. Results

The array is designed to cover a 120° sector by switching the beam among five antennas. Fig. 3 presents the simulated radiation patterns for the corresponding antenna offset with respect to the ABS lens focus.

Simulated and measured results are presented between 20 and 40 GHz for the single element mounted on a PLA lens.

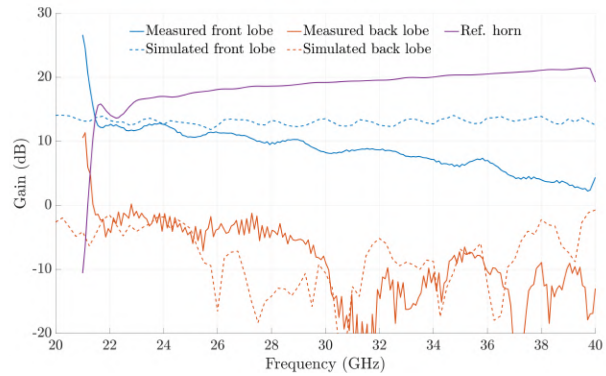


Fig. 4. Measured and simulated front and back gain of the PLA lens.

The S_{21} measurements describe the impact of the dielectric lens absorbing back radiation and focusing towards the desired position. Hence, the inter-element coupling and surface waves are reduced as well, allowing for the simultaneous radiation of multiple elements without pattern distortion. Fig. 4 presents the gain of the PLA lens obtained from the S_{21} measurements between the reference 17 dBi horn and the lensed single bow-tie when radiating from the front (blue) and the back (red).

Acknowledgement

This work was supported by the Spanish "*Comision Interministerial de Ciencia y Tecnologia*" (CICYT) under projects TEC2013-47360-C3-1-P, TEC2016-78028-C3-1-P and MDM2016-O6OO, and Catalan Research Group 2017 SGR 219. The Spanish Ministry of Education contributes via a doctoral grant to the first author (FPU17/05561).

References

[1] M. Imbert *et al.*, "Assessment of LTCC-based dielectric flat lens antennas and switched-beam arrays for future 5G millimeter-wave communication systems," *IEEE Trans. Antennas Propag.*, 2017.

[2] A. Bisognin *et al.*, "3D printed plastic 60 GHz lens: Enabling innovative millimeter wave antenna solution and system," in *2014 IEEE MTT-S Int. Microwave Symp. (IMS2014)*, June 2014, pp. 1–4.

[3] M. A. Hassanien, M. Jenning, and D. Plettemeier, "Beam steering system using rotman lens for 5G applications at 28 GHz," in *Antennas and Propag. & USNC/URSI Nat. Radio Sci. Meeting, 2017 IEEE Int. Symp.* IEEE, 2017, pp. 2091–2092.

[4] S. Romisch *et al.*, "Multi-beam discrete lens arrays with amplitude-controlled steering," in *Microw. Symp. Digest, 2003 IEEE MTT-S Int.*, vol. 3. IEEE, 2003, pp. 1669–1672.

[5] S. I. Orakwue, R. Ngah, and T. A. Rahman, "A two dimensional beam scanning array antenna for 5G wireless communications," in *2016 IEEE Wireless Commun. Netw. Conf.*, April 2016, pp. 1–4.

[6] D. F. Filipovic, S. S. Gearhart, and G. M. Rebeiz, "Double-slot antennas on extended hemispherical and elliptical silicon dielectric lenses," *IEEE Trans. Microw. Theory Tech.*, vol. 41, no. 10, pp. 1738–1749, Oct 1993.

[7] H. Frid, "Closed-Form Relation Between the Scan Angle and Feed Position for Extended Hemispherical Lenses Based on Ray Tracing," *IEEE Antennas Wireless Propag. Lett.*, vol. 15, pp. 1963–1966, 2016.

[8] G. A. Ramírez Arroyave and J. L. Araque Quijano, "Broadband Characterization of 3D Printed Samples with Graded Permittivity," in *2018 Int. Conf. on Electromagnetics in Advanced Applications (ICEAA)*, Sep. 2018, pp. 584–588.

[9] J. M. Felício, C. A. Fernandes, and J. R. Costa, "Complex permittivity and anisotropy measurement of 3D-printed PLA at microwaves and millimeter-waves," in *2016 22nd Int. Conf. on Applied Electromagnetics and Communications (ICECOM)*, Sep. 2016, pp. 1–6.