Evaluation of a transmit-array base station for mm-wave communications in the Fresnel region

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***Abstract*—A dual-polarized transmit-array is evaluated as an indoor base station antenna for mm-wave communications at 28 GHz. The antenna is designed to produce a constant field distribution in a specific area generating different spots wherein the devices are placed. The antenna is fed in a multi-feed configuration, radiating a different coverage area each feed. The design technique is based on a phase-only synthesis (POS) and a proper distribution of the feeds. The transmit-array is simulated and finally manufactured. The prototype is based on dielectric-only elements which provide a low-cost solution. The results show a high agreement with simulations. Moreover, the presented results validate the design technique as well as transmit-array antennas for this purpose.**

I. Introduction

The next generation of mobile communications 5G, Beyond 5G (B5G) and 6G intend to deploy communications in the millimeter-wave (mm-wave) spectrum (28, 39 and 100 GHz) to provide high-speed wireless access in cellular networks. However, the propagation in mm-wave communications implies higher losses and a higher sensitivity to blockage by physical barriers [1]. Both issues can lead to areas with poor coverage, so-called as “blind” or “dead” zones. These areas can be reduced by increasing the number of base stations (BS) but at the cost of increasing the cost in equipment. An alternate solution is to deploy low-cost BS which coverage is generated only within the area of interest. This means designing antennas whose radiation pattern covers the area wherein the devices will be placed. This approach is quite interesting for indoor scenarios since the “blind” areas are smaller than outdoor. Besides, the antenna must provide a compact structure to be easily integrated into the scenario. In this line, spatially fed array (SFA) antennas are a potential candidate to act as indoor BS.

In this work, a transmit-array antenna is proposed as a low-cost compact antenna to be used as an indoor BS. The transmit-array generates broad spots in the Fresnel region and the distribution of several feed allow a multi-sectoral coverage at 28 GHz. So far, published works related with BS antennas for indoor scenarios are based on far-field assumptions. However, solutions based on aperture antennas may lead to find the receivers within the Fresnel region. A solution based on an antenna aperture is expected to be large in terms of wavelengths. Thus, the receivers may be within the radiated near-field. The transmit-array is designed for a center configuration to radiate a spot in boresight direction and its performance is enhanced by a phase-only synthesis. Then, the transmit-array is fed in a multi-feed configuration to finally evaluate this feeding configuration for shaped-beams within the radiated near-field.

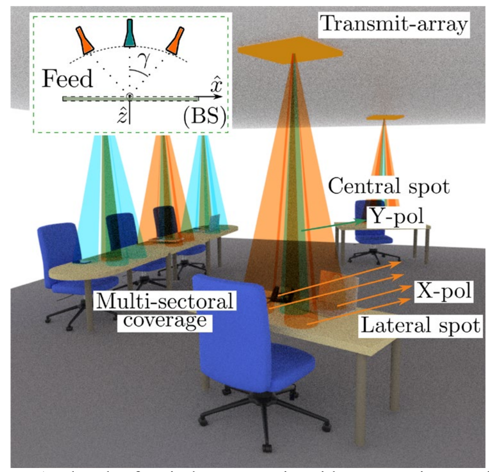

Figure 1. Sketch of an indoor scenario with a transmit-array installed on the wall as a FR2 5G base station (BS).

II. Scenario and antenna optics

A 5G scenario including an indoor transmit-array-based BS is shown in Fig. 1. The transmit-array is comprised of 576 elements distributed on a regular grid of periodicity 5×5 mm^2. The focal distance for the central feed is $f = 100$ mm, thus a relative compact structure is reached with an $f/D = 0.58$. The feeds are horn antennas of 15 dBi gain which work in orthogonal polarization following the spot-polarization scheme of Fig. 1. The feeds are placed over an arc-path described by a circumference equation in the main planes of the transmit-array [2]. The separation between adjacent horn antennas is $\gamma = 15°$. The multi-sectoral coverage is defined in a parallel plane to the antenna aperture at a distance of 1.8 m from the center of the transmit-array. According to the antenna optics, the coverage is within the near-field region $(2D^2/\lambda)$. Each feed generates a different spot resulting on a multi-sectoral coverage within the near-field. Each spot covers a circular area of radius 400 mm wherein the maximum ripple in the amplitude of the electric field is 3 dB.

III. Antenna design and validation

The elements of the transmit-array introduce a phase-shift to radiate the beam in a certain direction and shape the beam. In this case, only the central feed is considered in the design. To generate the beam in boresight $(\theta_0 = 0°, \varphi_0 = 0°)$, which

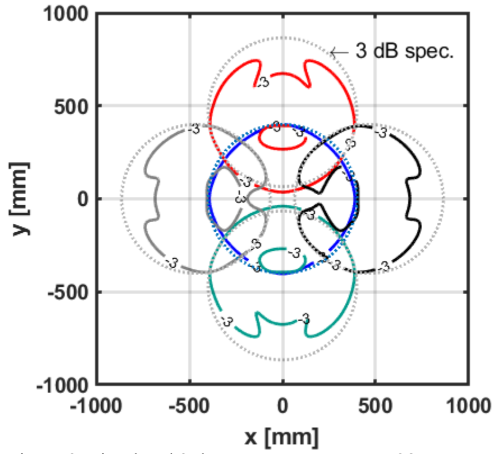

Figure 2. Simulated 3 dB contour coverage at 28 GHz. Central spot (blue line) works in Y-polarization while the other spots in X-polarization.

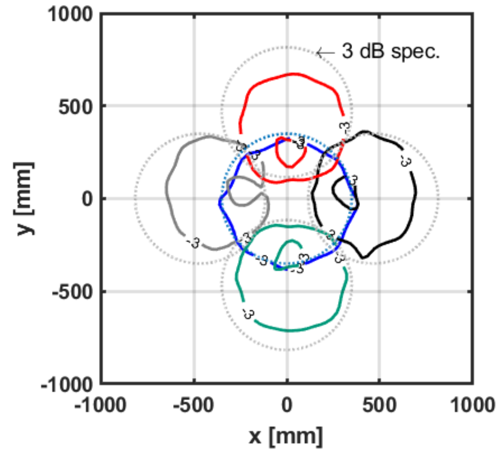

Figure 3. Measured 3 dB contour coverage at 28 GHz. Central spot (blue line) works in Y-polarization while the other spots in X-polarization.

corresponds to the central spot, the required phase-shift distribution on the transmit-array is obtained as:

$$\phi_{el}(x_m, y_n) = k_0[d_i - (x_m \cos\varphi_0 + y_n \sin\varphi_0)\sin\theta_0] \quad (1)$$

where d_i is the distance between the feed and the (m,n)th element and k_0 is the vacuum wave-number. This phase distribution generates a pencil beam in far-field. However, the near-field at 1.8 m does not meet the criteria of 3 dB within 400 mm. To enlarge the central spot performance a phase-only synthesis is carried out. The POS synthesizes the phase $\phi_{el}(x_m, y_n)$ introduced by the elements according to certain specifications. The generalized Intersection Approach for near-field [3] is used imposing constraints in the power density according to the spot definition. After this process a new phase distribution $\phi_{el}(x_m, y_n)$ is reached, and it radiates the spot area from 5.72° to nearly 27° for a 3 dB contour (see Figure 2). The near-field within the spot presents a quite flat distribution with less than 1.5 dB ripple. Now, the transmit-array is fed with the 5 horn antennas to evaluate the multi-zone coverage. Although the POS does not consider the adjacent feeds in the synthesis process, the spot produced by the 4-lateral horn antennas are also improved due to antenna optics definition and the feed distribution (see Figure 2) [2].

Then, the elements of the transmit-array are designed to introduce the phase-shift obtained in the POS in both polarizations. As the POS, the design is carried out considering the angles of incidence for the central feed. Dielectric-only elements are proposed to provide a low-cost and easy-manufactured solution. These elements are based on a dielectric material with an embedded air-gap [4]. In the design process, the dimensions of the air-gap are adjusted to control the infill of the cell, thus the phase-shift. The output of the design is an air-gap distribution whose elements minimize the difference between their phase-shift and the obtained in the POS. This layout is manufactured in a standard 3D printed using Fused Deposition Modeling (FDM) and is evaluated in a planar acquisition range at the University of Oviedo.

The measured 3 dB contour at 28 GHz is presented in Fig. 3, resulting in a high agreement with simulations. For the central beam, the generated spot is roughly 21°(for a 3 dB contour) with a maximum ripple of 1.5 dB. The lateral spots behave as the previous simulations predicts, obtaining a width of almost 12° for a 3 dB decay. The total length of the multi-sectoral coverage in its main planes ($x = y = 0$) is 44.6°, which corresponds to 86% of the simulated coverage.

IV. Conclusions

A transmit-array antenna is analyzed to generate a multi-sectoral coverage for mm-wave communications within the Fresnel region of the antenna. The transmit-array is designed using a POS together with a proper distribution of the feeds. The design is validated through a prototype. Measurements highly agree with simulations and a multi-sectoral coverage of 44.6° is obtained. These results present transmit-array antennas as suitable alternatives for base stations in indoor communications.

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References

[1] M. Shafi, *et al.*, “Microwave vs. Millimeter-Wave Propagation Channels : Key Differences and Impact on 5G Cellular Systems,” *IEEE Commun. Mag.*, vol. 56, no. 12, pp. 14-20, December 2018.

[2] M. Arrebola, J. A. Encinar, and M. Barba, “Multifed Printed Reflectarray With Three Simultaneous Shaped Beams for LMDS Central Station Antenna,” in *IEEE Trans. Antennas and Propag.*, vol. 56, no. 6, pp. 1518-1527, Jun. 2008.

[3] Á. F. Vaquero, M. Arrebola, M. R. Pino, R. Florencio, and J. A. Encinar, “Demonstration of a Reflectarray with Near-field Amplitude and Phase Constraints as Compact Antenna Test Range Probe for 5G New Radio Devices,” in *IEEE Trans. Antennas and Propag.*, vol. 69, no. 5, pp. 2715-2726, May. 2021.

[4] Á. F. Vaquero, M. R. Pino, M. Arrebola, S. A. Matos, J. R. Costa, and C. A. Fernandes, “Bessel Beam Generation Using Dielectric Planar Lenses at Millimeter Frequencies,” in *IEEE Access.*, vol. 8, pp. 216185-216196, Nov. 2020.