

A Millimetre-Wave Two-Dimensional 64-Element Array for Large-Scale 5G Antenna Subsystems

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Abstract—This paper presents the comprehensive design and evaluation of a novel large-scale millimetre-wave (mm-wave) two-dimensional (2-D) 64-element antenna array, for operation in the 28-GHz frequency band. The primary objective of this work is to study the feasibility of designing a high-performance array based on liquid-crystal polymer (LCP) substrate for the deployment in the fifth generation (5G) wireless communication networks and infrastructures. The planar 5G array has presented an impedance bandwidth of 400-GHz, with a peak gain of 23.2 dBi at 27.7-GHz. Moreover, the operation of the mm-wave antenna array has been analysed and validated through a set of high-resolution full-wave electromagnetic (EM) simulations, conducted based on the time-domain finite integration technique (FIT). The proposed 28-GHz 2-D antenna array is a high-performance subsystem in order to be potentially employed in the next-generation 5G communications.

Index Terms—5G, antenna array, two-dimensional, wireless.

I. INTRODUCTION

The mm-wave spectrum is considered as a backbone of 5G infrastructures, based on much smaller cell deployment, in order to effectively enhance the radio frequency (RF) system capacity and spatial reuse to facilitate the drastic advancement in wireless applications and services [1]. It is highly desired to exploit the distinctive features that the mm-wave frequency bands offer, to efficiently ensure the high data rate and performance of the next-generation systems, based on the appropriate employment of the analytical system-level design, channel modelling, and RF link budget techniques [2]. This would further result in the efficient antenna design at the RF front-end, capable of high-performance and high-gain operation based on the intended RF spectrum, in order to effectively provide the optimal quality of service (QoS) and to improve the overall effective transmission bandwidth that enhances the data throughput and network capacity. Moreover, as one of the primary enabling technologies for the realisation of 5G wireless networks, the mm-wave antenna arrays comprising a large number of elements, which are also aggregated with the channel estimation and precoding techniques, would confirm the desired outputs; hence, resulting in the appropriate integration of the high-performance antenna systems at the access point (AP) level, in order to sustain a highly-efficient spectrum utilisation.

Furthermore, the next-generation wireless communications would also focus on the applications of the flexible electronics, to ensure the key requirements for the practical RF deployment, including the mobility, robustness, reliability, and flexibility to offer effective conformity with the shape of the bearing surface. In this regard, the efficient development of a mm-wave antenna

array is the fundamental stage for the systematic realisation of the 5G subsystems at the physical (PHY) layer. This is of crucial importance to overcome the imperfect ambient conditions in the mm-wave channels. Therefore, a complete investigation on the design and evaluation of high-performance RF solutions for the system implementation is of vital significance to characterise the performances of the 5G networks. Hence, this work addresses the development of this essential front-end as an integrated part of the 5G framework. To the best of the authors' knowledge, this work is the first attempt to design the large-scale LCP-based 28-GHz 2-D 64-element array with the corporate feeding network.

II. ANTENNA DESIGN AND ANALYSIS

The large-scale microstrip 28-GHz 2-D 64-element array has been thoroughly developed based on the Rogers ULTRALAM 3850HT recyclable, flexible, and also multi-environmental LCP laminate, with the dielectric constant of $\epsilon_r = 2.9$, loss tangent of $\tan\delta = 0.0025$, substrate thickness of $h = 0.18$ mm, and top- and bottom-cladding of $t = 17.5$ μm , as reported in [3–5]. The high-performance computing (HPC)-based full-wave EM simulations have been conducted using the robust transient solver (i.e., the CST STUDIO SUITE software). The planar mm-wave antenna array has been formed by placing the rectangular patch elements along a line in both the axes. There are eight antenna elements on the X -axis, as well as eight elements on the Y -axis. The single patches of the array have been appropriately fed by the quarter-wave transformer lines connected to the antenna patches [6–8].

Moreover, the quarter-wave transformers feeding the array elements match the input impedance to an impedance which is realisable using the microstrip lines. The design of the mm-wave array has been carried out based on the seminal work presented in [9]. The RF design combines the design of the individual array elements with the design of the feeding network. The developed single-layer microstrip 2-D 64-element antenna array has been fed by a corporate feeding network with the feed lines printed on the same side of the LCP substrate as the antenna array elements. Furthermore, the patches of the mm-wave antenna have been fed from a single feeding point. The quarter-wave transformers have been also added before each junction for the efficient impedance matching by precisely adjusting the width and length of the input matching section of the feeding network. This would also result in the reduction of the mismatch due to the reflections from the discontinuities. It should be noted that the total field of the array is determined by the vector addition of the EM fields radiated by the individual antenna elements based on the assumption that the current in each element is the same as that of the isolated one.

III. RESULTS AND DISCUSSION

A. Antenna Configuration and Realised Gain

Fig. 1 presents the developed structure of the mm-wave 2-D array comprising of 64 antenna elements on the LCP substrate with dimensions of $60.46 \times 67.98 \text{ mm}^2$. The patch antennas are assembled within a corporate feeding network, where each patch is optimised to the dimensions of $4.0 \times 2.9 \text{ mm}^2$. Moreover, a boresight radiating beam has also been achieved from the well-matched array with the numerically computed peak realised gain of 23.2 dBi at the resonant mm-wave frequency of 27.7-GHz.

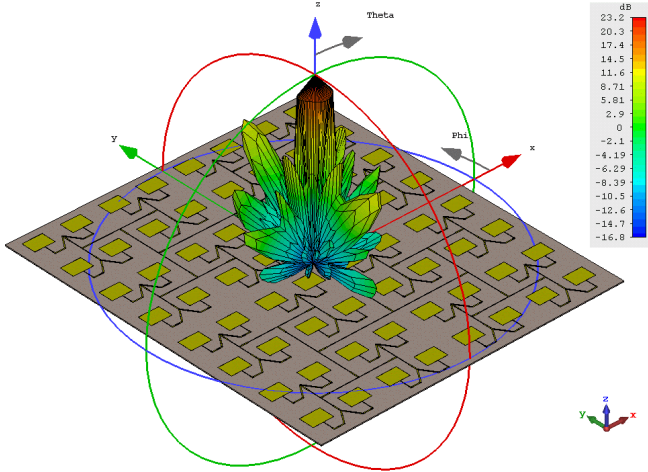


Fig. 1. Configuration and EM far-field realised gain of the large-scale LCP-based mm-wave 2-D 64-element antenna array for 5G wireless subsystems.

B. Impedance Bandwidth

Fig. 2 shows the simulated and measured bandwidths of the proposed mm-wave LCP-based array, in terms of the reflection coefficient (i.e., S_{11}) plot. The measurements of the planar array depict an impedance bandwidth of 400-MHz in the frequency range of 27.57–27.97 GHz, while the conformal assembly shows a bandwidth of 27.55–27.98 GHz, with -10 dB as a reference. Fig. 2 also presents the fabricated prototype of the designed 2-D mm-wave array realised by the LPKF laser structuring method. The designed antenna array is well-suited to effectively support the next-generation 5G wireless communication subsystems.

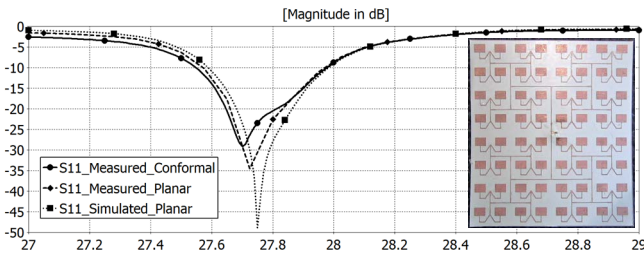


Fig. 2. Simulated and measured reflection coefficient (i.e., S_{11}) plots of the large-scale LCP-based mm-wave 64-element antenna array for 5G systems.

C. Radiation Pattern

Fig. 3 depicts the high directivity and high gain of the LCP-based 2-D 64-element antenna array and refers to a narrow 3-dB beamwidth of approximately 8.3° . The normalised EM radiation

patterns evaluated at 27.7-GHz present the estimated sidelobe level (SLL) is below -10 dB for both of the plane cuts at $\phi = 0^\circ$ and $\phi = 90^\circ$, which is -13 dB and -11.5 dB , respectively.

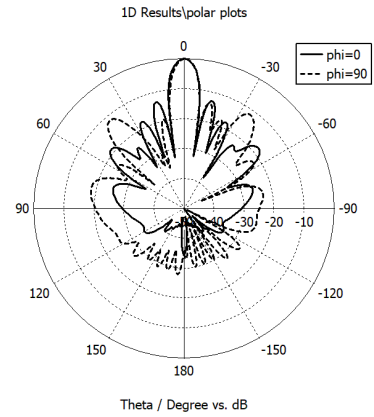


Fig. 3. Simulated EM radiation pattern plots of the large-scale 2-D mm-wave 64-element antenna array for 5G wireless communication subsystems.

IV. CONCLUSION

This contribution has undertaken the comprehensive design and RF performance evaluation of a large-scale 64-element two-dimensional array for operation in the 28-GHz frequency band. The presented mm-wave antenna exhibits outstanding outputs in terms of the impedance bandwidth, realised gain, and directivity. The impedance bandwidth of 400-GHz has been achieved with the peak realised gain of 23.2 dBi and 3-dB beamwidth of 8.3° at 27.7-GHz. The mm-wave 2-D array can be potentially used as a cost-effective, low-profile, and lightweight subsystem in the flexible and conformal 5G cellular networks and infrastructures.

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