Wideband and Wide Beam-Scanning Dual-Polarized Phased Array Antenna-in-Package Design for 5G Applications

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Abstract—In this work, a 5 × 5 stacked patch rectangular phased array, along with its feeding network, is designed and fabricated in a multilayered low-temperature co-firing ceramic (LTCC) substrate. The single element of the phased array is a dual linear polarized stacked patch microstrip antenna which has improved impedance as well as 3-dB gain bandwidth due to the stacked patch approach. Based on the field distributions, the single element’s orientation is optimized to reduce the mutual couplings between the adjacent elements for a wide beam scanning range over a wide frequency band. The features of multilayered implementation, low dielectric loss, and excellent packaging properties ensure a compact and high-efficiency phased array design and qualify this design as an antenna-in-packaging (AiP) design.

Keywords—phased array; LTCC; beam scanning; AiP

I. INTRODUCTION

With the rapid development of wireless mobile communication technologies, the demand for higher data rate communications has promoted the research for phased array design in the mmWave 5G bands and beyond. The mmWave 5G has been allocated as several different frequency bands, including n257 to n261 bands. Present phased array designs can only cover one to two frequency bands at mmWave 5G which increases the deployment cost and overall system size as the antennas for different 5G bands need to be designed and installed separately. Therefore, it is very advantageous to integrate the beamforming circuits and antenna arrays that operate over a wide frequency range in terms of impedance matching, dual-polarization, gain, and beam-scanning range. However, it is very challenging to realize a wideband mmWave 5G phased array because the mutual coupling and grating lobe effects become the dominant issues for the low and high-frequency bands respectively. This degrades the overall wideband radiation performance, especially its beam-scanning range. Moreover, the typical single element and the phase shifter narrowband characteristics also restrict the overall phased array wideband performance. To overcome the challenges mentioned above, several solutions have been proposed in the literature, such as antenna element with multiple modes [1] and metasurface structure [2] for bandwidth enhancement, switchable antenna for wide scanning range [3].

In this work, a 5 × 5 stacked patch rectangular phased array, along with its feeding network, is designed and fabricated in the multilayered LTCC substrate which presents the good features of multilayered implementation, low dielectric loss, and excellent packaging properties [4][5]. The proposed design achieves a wide beam scanning range of +/- 50 degrees and a maximum gain of 18 dBi over the whole frequency range of 24 to 30 GHz, covering three 5G bands (n257, n258, and n261). It is a good candidate for wideband mmWave 5G applications.

II. DESIGN OF THE SINGLE ELEMENT

Fig. 1 shows the proposed single element design in the multilayered LTCC substrate. A stacked patch is placed on top of the probe-fed driven patch antenna. In this structure, the low-frequency resonance happens in between the driven patch and the GND 1, while the high-frequency resonance mainly occurs in between the stacked patch and the driven patch. By optimizing the sizes of the stacked and driven patches, the two resonance frequencies can merge into one large frequency band, therefore, achieving the bandwidth enhancement. As shown in Fig. 1, this is a multilayered structure with three ground layers. The GND 1 layer is not only the antenna’s ground but also confines the horizontal transition region together with the GND 2 layer. The GND 3 layer is used as the circuit ground to isolate the RF signal from circuit routing. In between the GND 1 and GND 3, the RF signal is transited to the driven patch via ground coplanar waveguide (GCPW), coax-like vertical transition, stripline, and vertical probe as shown in Fig. 1.

Fig. 1. The geometry of the single antenna element
Fig. 2. Simulation results of the single antenna element

Fig. 2 shows the simulated results of the single element. It can be seen that the proposed antenna design presents a wide impedance bandwidth of 7.4GHz from 22.7GHz to 30.1GHz. Besides, it maintains a very low crosstalk level (≤-15dB) between the horizontal and vertical polarization channels as indicated by the $S_{21}$. In addition to the impedance bandwidth, the 3-dB gain bandwidth covers a wide frequency range from 20.1GHz to 30.2GHz. The proposed antenna also shows pure linear polarizations in a wide beam range for both horizontal and vertical polarizations over the whole frequency band.

III. DESIGN OF PHASED ARRAY ANTENNA

The proposed antenna element is then used to build up the 5 × 5 rectangular phased array antenna as shown in Fig.3. In a wideband phased array antenna, the mutual coupling and grating lobe effects become the dominant issues for the low and high-frequency bands respectively. A tradeoff between the mutual coupling and grating lobe issue is made for the element spacing to achieve a wide beam scanning range over a wide frequency band. The array element spacing is optimized to be 5.5 mm (0.55λ₀ at 30GHz and 0.44λ₀ at 24GHz). Based on the field distributions, the single element is oriented 45 degrees to reduce the mutual couplings between the adjacent elements so that the beam scanning range is improved.

The array simulation is conducted in HFSS with the component array domain decomposition method (CADDMM). Fig. 4 (a) and (b) present the phased array’s beam scanning performance of vertical polarization in its E-plane and H-plane respectively, as well as the single element radiation patterns. It can be seen that the proposed 5G phased array achieves a wide beam scanning range of +/- 50 degrees and a maximum gain of 18 dBi over the whole frequency range of 24 to 30 GHz, covering three 5G bands (n257, n258, and n261).

IV. CONCLUSION

In this paper, a dual polarized stacked patch antenna and its 5 × 5 phased array are proposed. The design achieves a wideband and a wide beam scanning performance for mmWave 5G applications. The design concepts of the proposed antenna and its array can be a good candidate for the deployment of the ongoing mmWave 5G network and future 6G network.

REFERENCES


