Dual-Polarized Patch Antenna-in-Package with High Isolation for Ka-Band 5G Communications

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Abstract—In this paper we describe the design of a dual polarized packaged patch antenna for 5G communications with improved isolation and bandwidth for Ka-band. The results were validated using FEM and Momentum co-simulations in ADS. The novelty of the approach is the use of parasitic elements in the same layer to circumvent bandwidth limitations, thereby reducing the layer count in contrast to previous designs, combined with a differential feeding technique for improved isolation and radiation pattern stability, albeit at the expense of an increased complexity in the matching process. A peak gain of 5 dBi, isolation above 40 dB and a radiation efficiency of 60% were obtained.

Index Terms—Antenna-in-Package, Patch Antenna, Polarization Diversity, 5G

I. INTRODUCTION

The European 5G communication band in the frequency range from 24.25 to 27.5 GHz is settled as the most adequate solution for limited coverage and high throughput scenarios [1]. Its usage drives the need for new antenna technologies capable of beamforming, polarization diversity and large bandwidths.

Patch antennas are a possible solution for the challenge of 5G Ka-band antennas, given their size which facilitates package integration, simplicity and ability to support two polarizations in two degenerate modes. Nonetheless, their bandwidth is usually very limited and bandwidth improvement techniques are generally required in broadband communication systems [2].

The most common solution found in the state-of-the-art to overcome bandwidth limitations is the usage of a stacked patch topology. However, such technique can lead to higher order modes which will degrade radiation pattern stability throughout the band of operation [3]. Furthermore these higher order modes also compromise isolation in dually-polarized antennas. In some cases, a different patch topology had to be used to improve isolation between polarizations.

In this work we propose the usage of a patch antenna with parasitic elements in the same layer to improve its bandwidth, reducing the layer count from typical stacked patches as reported in [4]. Based on [5], we utilized a differential feeding technique. By doing this, each mode is excited with two feeds with opposing phases, which cancel out higher order modes, reduce feed radiation and reinforce the fundamental degenerate modes $TM_{010}$ and $TM_{100}$ of the patch antenna. Ultimately, this improves isolation between polarizations and radiation pattern stability.

II. ANTENNA DESIGN

In this work a land-side die antenna-in-package was considered as shown in the stackup of Fig. 1. The core material is Rogers RO4350B and the prepreg is Rogers RO4450T. These substrates offer a good compromise between cost, moderate permittivity values ($\varepsilon_r \approx 3.5$) and low losses ($\tan \delta \approx 0.004$). The metal layers are all composed of 17.5 µm thick copper.

The patch and its parasitics are designed in M$_1$ metal layer, as shown in Fig. 2. The vertically polarized stream (port 1) is fed from M$_3$ and the horizontal (port 2) from M$_5$ metal layer. In each feeding network a half-wavelength 50Ω transmission line was connected between the two corresponding balanced ports to obtain the needed 180° phase shift. Another 50Ω line was connected to one of the balanced ports in each
polarization, to evaluate the single-ended reflection coefficient. As seen in Fig. 3, a low reflection coefficient, at the centre frequency of 26 GHz, was obtained at both ports, after Momentum simulation in ADS (Advanced Design System), by setting \( ps = 2.75 \text{ mm}, \ fo = 0.8 \text{ mm}, \ pl = 1.7 \text{ mm}, \ pw = 1.2 \text{ mm}, \ pg = 0.1 \text{ mm} \). However a limited bandwidth of approximately 2.5 GHz was verified, which falls short from the needed 3.25 GHz.

Because of the bandwidth limitation a matching network had to be designed. Since the transition from the antenna feeding networks to the PCB would present some parasitics, the matching network was designed after such transition was characterized. The full system will be presented in section IV.

III. PCB TO PACKAGE TRANSITION

The transition between the hosting PCB and the antenna-in-package was designed as a simple connection between a microstrip on the host PCB and a stripline on M5 layer of the package. To connect to the feeding network on M3 an internal transition between M3 and M5 was also designed. After FEM simulation return losses higher than 14 dB and insertion losses lower than 0.25 dB were obtained which validate the transition.

IV. FINAL DESIGN EVALUATION

To compensate the PCB to package transition parasitics and the reduced bandwidth verified in section II, the procedure was to detune the patch antenna by setting the dimensions \( ps = 2.83 \text{ mm}, \ fo = 0.8 \text{ mm}, \ pl = 1.7 \text{ mm}, \ pw = 0.7 \text{ mm}, \ pg = 0.1 \text{ mm} \), so that optimum gain was achieved. A matching network was then introduced to obtain 50Ω input impedance.

The matching network circuit is shown in Fig. 4 and its values are given in Table I for both the V-Pol and H-Pol inputs of the antenna. Despite the rotational symmetry of the antenna, the matching networks are different because of an added transition between M3 and M5 metal layers, which results in a non-symmetric S-parameter matrix. This transition serves as a connection between M3 layer and the package to PCB transition. The values of both matching networks were obtained by resorting to a PSO (Particle Swarm Optimization) algorithm. The upper bound for the impedance of each transmission line was obtained by calculating the characteristic impedance of a stripline with the minimum trace width of 100 µm, for easier fabrication. This impedance was calculated using ADS and the value obtained was \( Z_{\text{max}} = 53.8 \Omega \).

The final layout is presented in Fig. 5, where the values of Table I were mapped to striplines. In this layout, the transition between metal layers M3 and M5 is also shown, as well as the package to PCB transition. A 3D representation of the model is shown in Fig. 6.
PCB, are shown in Fig. 7, where it can be seen that not only the reflection coefficient magnitude is below −10 dB in both ports, but also the isolation is greater than 40 dB over the bandwidth of 24.25 GHz to 27.5 GHz. The E-Plane and H-Plane radiation patterns at the centre frequency of 26 GHz are shown in Fig. 9. It can be seen that the radiation pattern suffers practically no change from the beginning to the end of the 5G Ka-band. Such is due to the differential feed topology which reinforces the fundamental TM_{00} and TM_{01} degenerate modes and cancels higher order modes. A radiation efficiency of approximately 60% and a peak gain of 5 dBi was observed in both V-pol and H-pol ports.

![Graph](image)

Fig. 7. Simulated results for the magnitude of V-Pol (port 1) and H-Pol (port 2) S-parameters.

![Graph](image)

Fig. 8. Simulated V-pol (a) and H-pol (b) radiation patterns at 24.25 GHz.

![Graph](image)

Fig. 9. Simulated V-pol (a) and H-pol (b) radiation patterns at 26 GHz.

![Graph](image)

Fig. 10. Simulated V-pol (a) and H-pol (b) radiation patterns at 27.5 GHz.

V. CONCLUSIONS

In this work a new topology of patch antenna-in-package was shown. The simulation results showed a very high isolation and a good match in both ports. Nonetheless, despite reducing the number of layers for the antenna, extra complexity is added in the matching process. Furthermore, it was shown that with our design that a frequency stable radiation pattern, from 24.25 GHz to 27.5 GHz, can be obtained.

In the future we are aiming at manufacturing and measuring the performance of the antenna and exploit techniques to reduce the matching network complexity.

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