# A Differential Dual-band Dual-polarized Antenna for 5G mmWave Communication System

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*Abstract*—**This paper presents a differentially fed, dual-band dual-polarized antenna, suitable for 5G millimeter-wave, base station antenna array. The operating frequency range covers all the millimeter wave frequencies allotted in 5G NR from 24.25 GHz up to 40 GHz. Stacking technique is utilized to achieve wide dual bands and stable radiation pattern. The antenna geometry is simple, adhering to commercial multi-layer PCB fabrication requirements. Antenna design procedure and simulated results are discussed. The operating frequency of the lower band starts from 24.25 GHz up to 29.5 GHz while the higher band covers the 37 GHz to 40 GHz. The realized gain remains stable between 5 to 6 dB at all the operating frequencies. The isolation between the ports and cross-polar discrimination remain better than 30 dB in all the operating frequency range.**

***Keywords— base station antenna array, filtenna, L-probe feed, stacked patch antenna***

## I. INTRODUCTION

The transition from the 4G to 5G networks is gaining momentum due to increasing demand of higher data rate and bandwidth. Millimeter-wave (mm-wave) communication is one of the key enabling technologies in 5G networks, as it offers wide bandwidth [1]. During the last years, there is a significant increase in academic contributions related to 5G mm-wave antennas. At mm-wave frequency bands, antenna design poses several challenges in terms of wide bandwidth, stable gain and symmetric pattern requirements. Dual polarized antennas are generally preferred to reduce the form factor. Antenna in package (AiP) technology is proven economic and reliable at mm-wave frequencies; the design also needs to follow its requirements [2]. At mm-wave frequencies, antenna arrays are preferred to meet the link budget requirements due to high path loss and signal attenuation. It is important to consider the array issues like its geometry, integration, mutual coupling and grating lobes during the antenna element design.

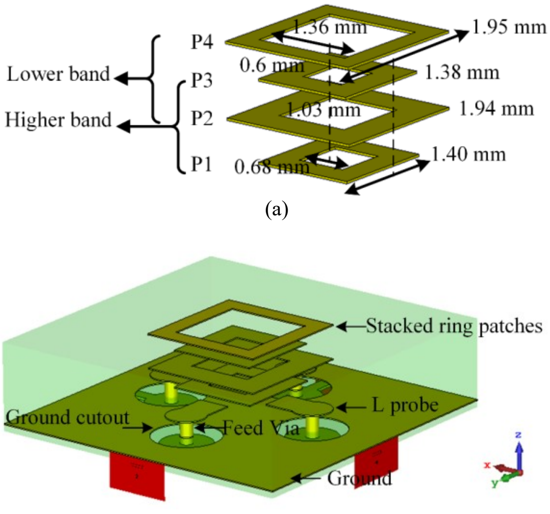
Beam forming RFICs are generally utilized in phased array antennas; balanced I/O stages are preferred in them as they provide better external noise immunity. In this case, a differentially fed antenna has an advantage as it can be directly connected to the RFIC without a balun structure [3]. Microstrip antennas are preferred due to their low profile and ease of integration, although they have limitations like bandwidth, losses and surface waves. Recently, there are few different printed antenna structures being proposed with differential feeding. A bilateral slot line dipole is proposed for mobile terminals covering the 28 GHz band [4]. Another magnetoelectric dipole antenna array is demonstrated to cover the unlicensed, 57-71 GHz frequency band [5].

In this paper, a novel differentially fed, dual-band dual-polarized antenna with L-probe feed, covering all, 26 GHz, 28 GHz and 39 GHz 5G NR mm-wave bands is proposed for base station arrays. The lower band covers 19.5% fractional bandwidth with 26.875 GHz as center frequency while the higher band, centered at 38.5 GHz, offers around 8% of fractional bandwidth. It is an extension of our recently accepted work [6], a single ended, dual-band dual-polarized antenna with aperture coupled feed. The presented antenna is more compact than the single-ended design due to the feeding technique. In section II, antenna geometry, design and operating mechanism along with the feeding technique is discussed. Followed by the simulated results in section III and the paper is concluded in section IV.

## II. ANTENNA GEOMETRY AND DESIGN

Antenna stacking is a known technique to enhance the bandwidth of patch antennas. Generally, it is utilized to achieve either wide bandwidth [7] or dual band operation [8]. Here, a novel stacking configuration is utilized to achieve wide and dual band operation with stable radiation pattern. The presented antenna consists of two pairs of coupled ring patches as shown in Fig. 1 (a). A patch antenna can be transformed into ring patch by etching out metal around its center. It is an intermediate configuration between a printed loop and solid patch. Inner length is an additional parameter offered by the ring geometry to control its resonant frequency, impedance and bandwidth. For resonance, the outer length remains between quarter to half-effective wavelength [9].

The substrate material plays a vital role in patch antenna performance in terms of its efficiency and bandwidth. In an AiP, in addition to the antenna performance, other issues also require consideration. For example, the material's compatibility with multilayer process, its mechanical and thermal properties. Generally, a low dielectric constant with low loss is preferred for wider bandwidth and better efficiency of antenna. Keeping in mind other required multilayer board requirements; here Panasonic Megtron 7, is selected for the antenna design, as it can easily be converted in an AiP along with RFIC. It has dielectric constant around 3.35 and dissipation factor of 0.004 at the operating frequencies.



(a)

(b)

Fig. 1. CST MWS simulation model of the proposed antenna. (a) Zoomed view of stacked ring patches. (b) Perspective view of the simulation model with waveguide ports.

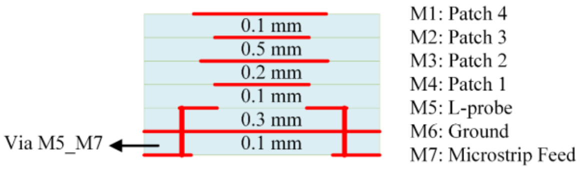


Fig. 2. Stack of the proposed differential, dual band dual polarized antenna with L-probe feeed.

For an antenna array, spacing between the element plays a fundamental role in its far-field performance, particularly gain and grating lobe free scan range. Since the operating frequency bands are wide apart, centered at 26.875 GHz and 38.5 GHz, a compromise is required between the array gain at the lower band and grating lobe free scan range at the higher frequency band. Thus, the unit cell size is kept at 5 mm, λ/2 at 30 GHz.

The proposed antenna design can be initiated by first roughly tuning the lower resonant band. In this case, as shown in Fig. 1(a), the ring patch 2 and patch 4 are coupled to form a wide band. The design follows the guidelines of stacked patch antenna design [10]. It is followed by adding two smaller coupled ring patches, patch 1 and patch 3 for the higher band. The additional ring patches influence the tuning of the lower band, which requires further tuning. It is important to observe here the arrangement of the ring patches; it is done in an alternate manner that is a smaller patch is followed by a larger one. It is also observed that the matching and coupling between the ring resonators is strongly dependent on the spacing between the resonators and the feed. The appropriate gap between the resonators is tuned by iterative simulations. The ring resonators are strongly coupled to the respective adjacent resonator over the frequency spectrum. A salient feature of this configuration is a sharp roll-off and pass band filter like response. In this configuration, wide and dual band operation is achieved with four ring resonators.

In the presented antenna, printed L-probes are utilized for its differential excitation. The differential feed has an added advantage in the form of enhancement in radiation performance. The out of phase current on the two probes, cancel their effect on the radiation pattern. In addition, polarization purity also improves significantly [11]. The proposed antenna is optimized along with the feeding structure. The antenna impedance varies with the feed location and dimensions. In addition, via, pads and ground cutout also influence the matching. The CST MWS simulation model, without connector is shown in Fig. 1b. It is a compact differentially fed, dual-band dual-polarized antenna with a total thickness of 1.3 mm along with 0.1 mm of feed substrate. The antenna stack along with the feed structure is shown in Fig. 2.

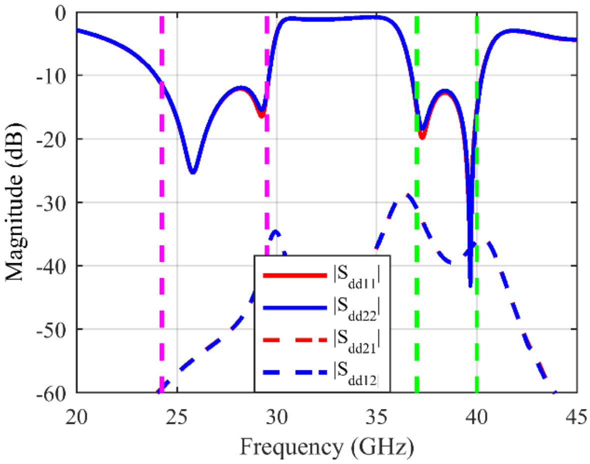


Fig. 3. Simulated differential S-parameters of the proposed antenna.

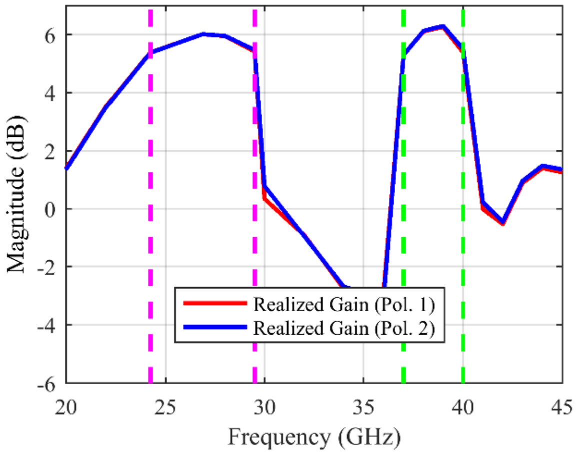


Fig. 4. Simulated realized gain of the proposed antenna

## RESULTS AND DISCUSSION

The S-parameters of the differential ports are calculated by the following equations [12]. Here port 1, 2 and port 3, 4 are grouped together.

$$S_{dd11} = 1/2 \times (S_{11} - S_{21} - S_{12} + S_{22}) \quad (1)$$

$$S_{dd12} = 1/2 \times (S_{13} - S_{14} - S_{23} + S_{24}) \quad (2)$$

$$S_{dd21} = 1/2 \times (S_{31} - S_{41} - S_{32} + S_{42}) \quad (3)$$

$$S_{dd22} = 1/2 \times (S_{33} - S_{34} - S_{43} + S_{44}) \quad (4)$$

The simulated differential S-parameters of the proposed antenna element are presented in Fig. 3. The plots for the two groups of differential ports are same as the structure is symmetric. Impedance matching is below -10 dB at both the lower and higher bands. The important filtering and sharp roll-off feature can be observed in the plot as discussed earlier. The isolation between the ports is better than 40 dB and 30 dB in both the lower and higher bands respectively. The gain of the proposed antenna is stable between 5 to 6 dB across both the

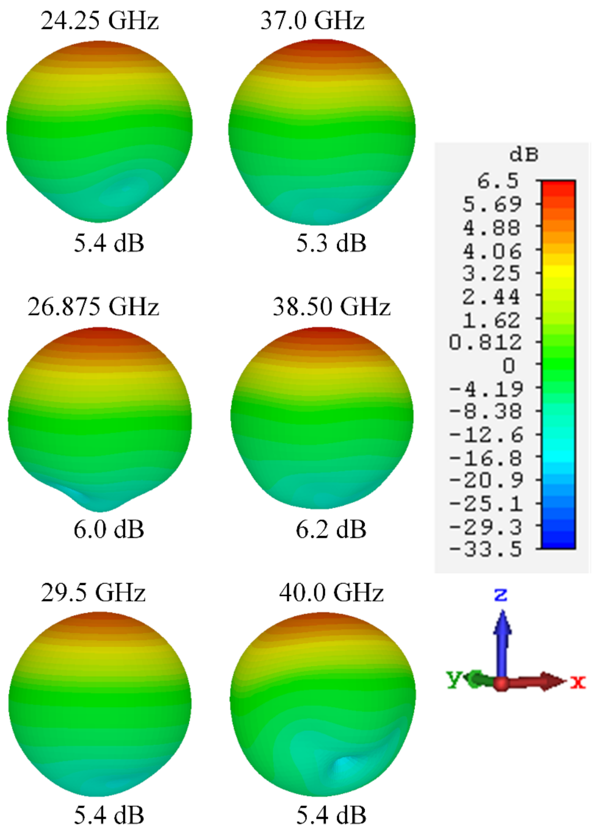


Fig. 5. Simulated 3D radiation pattern of the proposed antenna at different frequencies in lower and higher frequency band.

frequency bands. The realized gain is plotted against frequency in Fig. 4. A sharp decrease in gain is observed between the two operating bands. Fig. 5. shows the 3D radiation pattern at different frequencies of the studied bands. 2D plots of the radiation pattern at center frequencies of the operating bands, 26.875 GHz and 38.5 GHz, are presented in Fig. 6. The radiation pattern seems to be almost symmetric in both, the E- and H-planes. Cross-polar discrimination (XPD) is another important far field parameter, plotted in Fig. 7. It is better than 30 dB in both the operating bands.

## III. CONCLUSION

This paper presented a multilayer, differentially fed, dual-band dual polarized antenna for mm-Wave base station arrays, covering 5G NR bands from 24.25 GHz to 40 GHz. A novel antenna configuration is introduced by stacking antenna elements in an alternating resonance order. The antenna is compact, fed by printed L-probe. The demonstrated antenna shows wide dual bands, good isolation and XPD, with stable radiation pattern at all the operating frequencies. From the fabrication point of view, it is a simple geometry meeting the requirements of common commercial fabrication capabilities with minimum via requirements. However, the additional metal layers may increase the fabrication cost.

## ACKNOWLEDGMENT

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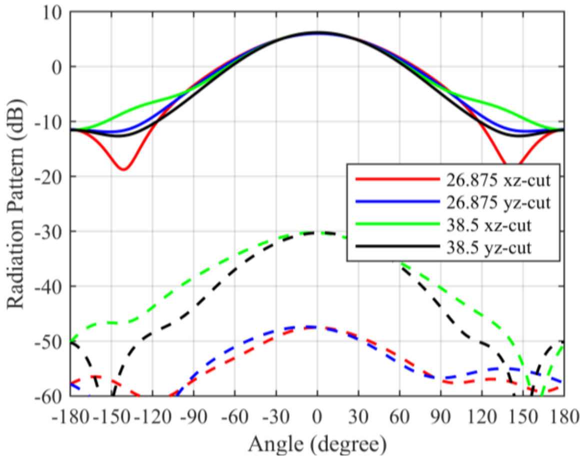

Fig. 6. Simulated co-polarized (solid) and cross-polarized (dot) cuts at center frequencies of the bands.

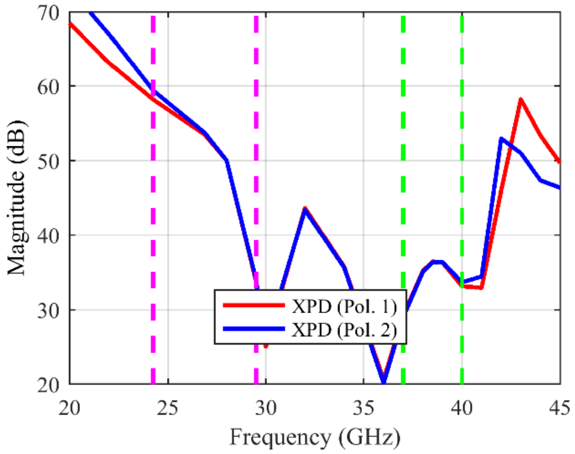

Fig. 7. Simulated Cross-polar discrimination, XPD plot of the proposed antenna.

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