Dual-Polarized Filtering Antenna for mm-Wave 5G Base Station Antenna Array

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***Abstract*—This paper presents a dual-polarized filtering antenna designed for a 5G mm-Wave base station phased array. The out-of-band radiation of a stacked patch antenna is suppressed by embedding filtering structures along with radiating patches and feed network. Four radiation nulls can be tuned by introducing a combination of open-loop and hairpin resonators at appropriate locations, and a bandpass filtering response can be achieved. The antenna design principles and simulated performance are discussed. The antenna operates in n257 and n258 mm-Wave bands, demonstrating -10 dB impedance bandwidth at 24.25-29.5 GHz. The realized gain remains stable between 5 and 6 dBi at all the operating frequencies. The isolation between the ports and cross-polar discrimination remain better than 20 dB in all the covered frequency range.**

***Index Terms*—5G NR, filtenna, open-loop resonator, stacked patch antenna.**

I. INTRODUCTION

The growing demand for high data rate applications is accelerating the deployment of 5G networks across the globe. Millimeter-wave (mm-Wave) communication offers wide bandwidth for high data rate and low-latency applications, making it a key enabling technology in 5G networks [1]. 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 properties such as its geometry, integration, mutual coupling, and grating lobes during the antenna element design. Antenna in Package (AIP) has been proven to be a commercially viable, compact and reliable technology at mm-Wave frequencies [2]. It also reduces the interconnect losses and the Printed Circuit Board (PCB) area. Microstrip patch antennas are an attractive solution and are widely used in AIP transceivers.

Generally, filters are used in RF transceivers to attenuate out-of-band signals such as wideband noise, signal harmonics and unwanted harmonics. However, the usage of the filter component causes attenuation for the communication signal [3] and increases the size of the radio solution due to component footprint [4]. This problem can be mitigated by implementing a filtering response already at the antenna stage by realizing a filtering antenna. Integrating the filtering response to the antenna reduces the pre-selection filter requirements, enabling a simpler filter to be used in RF frontend or, in the perfect case, eliminate the need for a filter. At sub-6 GHz frequencies, many novel designs are demonstrated for filtering antennas. A dual-polarized filtering antenna is implemented by utilizing the stacking technique and H-shaped feed lines [5]. Similarly, another dual-polarized filtering antenna is presented by placing split ring resonators inside the antenna aperture [6]. However, at mm-Wave frequencies, only a few filtering antenna solutions have been reported. Recently, a dual-polarized, differential antenna with bandpass filtering response at mm-Wave frequencies has been presented by utilizing a combination of stacking, parasitic patches and a cross-slot [7]. The antenna exhibits good electrical performance, but the antenna element size should further be reduced for implementing an array with a wide scanning angle.

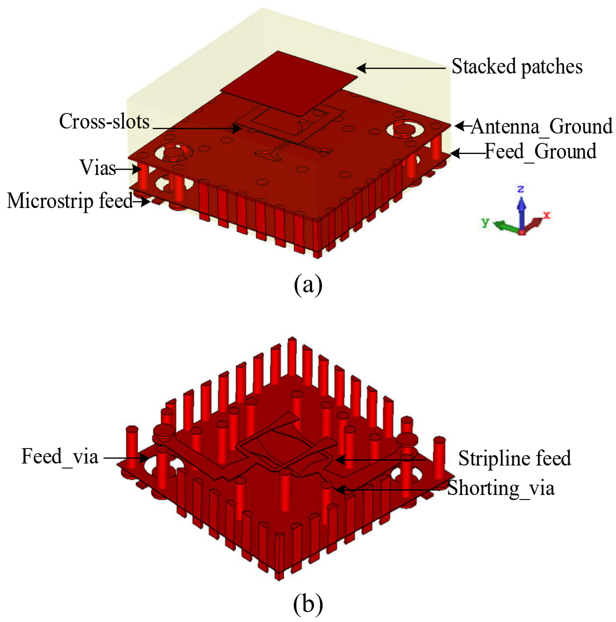


Fig. 1. CST MWS simulation model: (a) Perspective view (b) feed network.

In this paper, a compact dual-polarized antenna covering 26 GHz (n258) and 28 GHz (n257) 5G mm-Wave New Radio (NR) bands [8] with bandpass filtering response is proposed as a unit cell for base station phased arrays. Filtering structures based on Open-Loop Resonators (OLRs) and Hairpin Resonators (HRs) are embedded in the

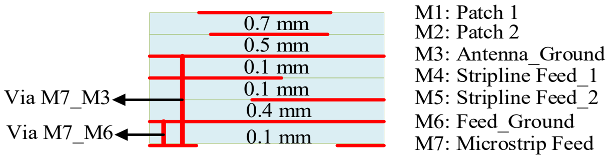


Fig. 2. Stack of the proposed dual-polarized antenna with aperture coupled feed.

aperture coupled stacked patch antenna to achieve the filtering response. Four notches can easily be manipulated by tuning the size of the resonators. There is no added complexity in the PCB stack due to the filtering structures as they are placed over the existing metal layers of the designed antenna.

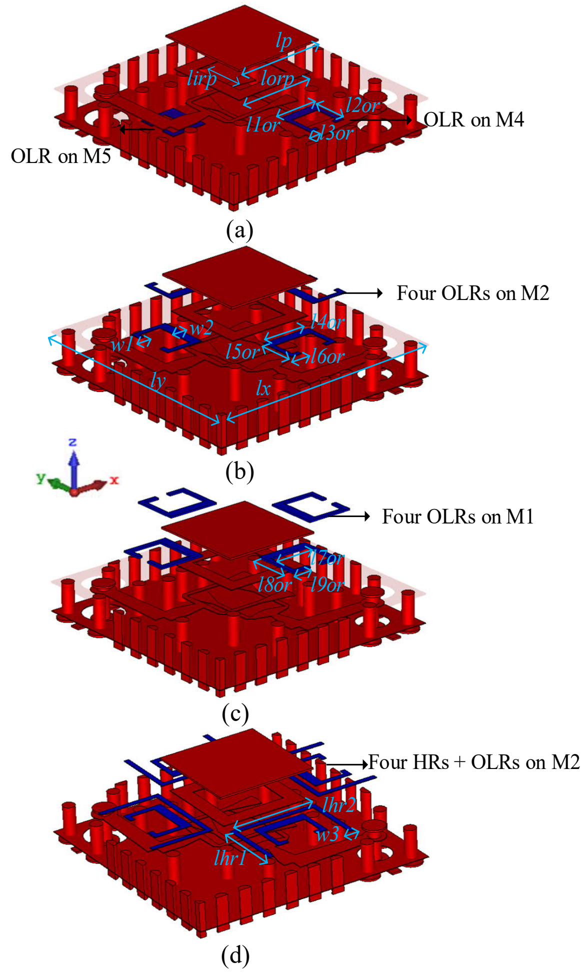
The rest of the paper is organized as follows. Antenna design and its operating mechanism are discussed in Section II. The simulated results are discussed in Section III followed by the conclusion and future work in Section IV.

II. Antenna Design

A. *Antenna element design*

First, a wideband, dual-polarized stacked patch antenna is designed over the desired operating band at 24.25-29.5 GHz. Microstrip patch antennas suffer from low bandwidth, and the patch stacking technique is widely used to mitigate this drawback. It also offers an added benefit of a radiation null at the upper operating frequency along with improved bandwidth and gain performance [5]. A combination of printed ring and patch antenna is utilized to obtain wideband operation as shown in Fig. 1. Geometrically, a ring antenna is an intermediate configuration between a printed loop and a patch. The ring geometry offers an additional parameter, inner length, to control the resonant frequency, impedance and bandwidth of the patch. The ratio of the inner to the outer length of the patch influences its resonant frequency [9]. To enhance the efficiency and bandwidth of microstrip antennas, low dielectric constant and low loss materials are generally preferred. However, for the AIP application, the multilayer PCB fabrication requirements also need to be considered. For the proposed antenna design, Panasonic Megtron 7 [10] is selected; it has a dielectric constant of around 3.35 and a dissipation factor of 0.004 at the operating frequencies. From the uniform planar array perspective, the antenna element dimensions are kept at 5 mm to avoid the grating lobes.

The antenna is designed to have an aperture feed, which keeps the feed network isolated from the radiating structure. Initially, a ring patch antenna resonating around 28 GHz is designed and stacked with a solid patch resonating around 26 GHz. Generally, in the stacked configuration, the lower patch is initially designed to be over-coupled, and the high impedance is compensated by the top-loading patch. The critical parameter in the stacked configuration is the spacing between the resonating elements and the feed, as the coupling strongly depends on it [11]. Considering the AIP, a stripline feed network is adopted, although it needs more



Dimensions (mm)

lx	5.0	*lir*	1.2	*l4or*	1.1	*l8or*	0.9	*w1*	0.1
ly	5.0	*l1or*	*0.6*	*l5or*	1.0	*l9or*	0.4	*w2*	0.2
lp	2.1	*l2or*	*0.5*	*l6or*	0.2	*lhr1*	1.3	*w3*	0.1
lor	1.7	*l3or*	*0.2*	*l7or*	1.1	*lhr2*	1.9		

Fig. 3. Case study to observe the influence of different filtering resonators on the antenna performance. (a) Case A: Feed striplines loaded with OLRs. (b) Case B: The lower ring patch is surrounded by four OLRs. (c) Case C: The top solid patch is surrounded by four OLRs. (d) The lower ring patch is surrounded by four HRs along with OLRs.

substrate volume than a microstrip structure. The stripline structure also excites the parallel plate modes [12] at the operating frequencies. These modes can efficiently be suppressed by placing shorting vias around the slot aperture. To shield the signal, a coaxial-like structure is emulated by placing grounded vias around the feed via [13]. Fig. 2 shows the stack of the designed antenna with seven metal layers. Layers M1-M3 form the radiating structure and its ground while the remaining metal layers are used for the feed network. The layer M7 is only required for standalone antenna testing, and it can therefore be excluded in AIP implementation. To simplify the fabrication process, all the vias are connecting M3 to M6, with a via diameter of 0.2 mm. An additional 0.1-mm via is connecting M6 to M7,

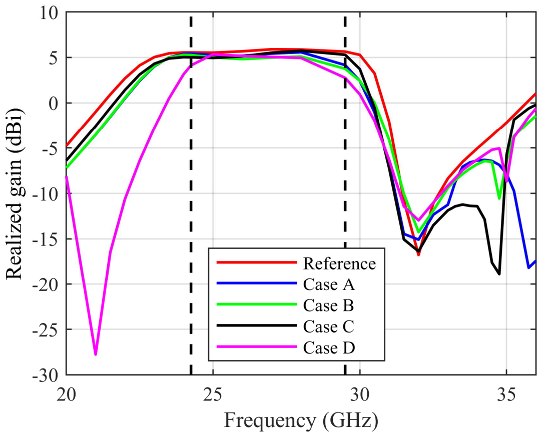


Fig. 4. The effect of different resonators placement on the radiation performance of the designed antenna.

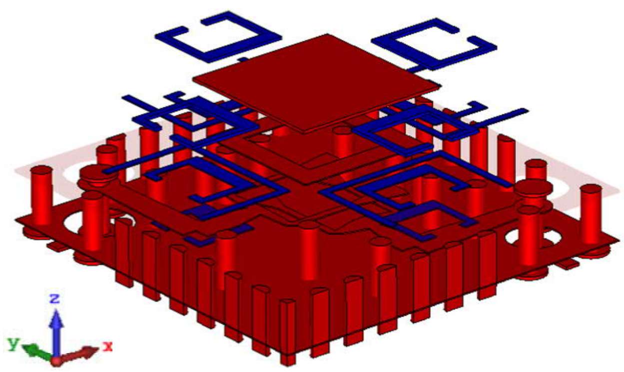


Fig. 5. Simulation model of the proposed filtering antenna.

and it is used for the ground connection. CST Microwave Studio is utilized for all the simulations.

B. Antenna element embedded with filtering structures

OLRs and HRs are widely used in planar microwave filter applications [14]. Here, they are embedded in the designed antenna (Sec. II-A) to achieve wideband suppression or multiple notches in the out-of-band radiation. A case study is presented in the following to observe the effect of each set of resonators on the radiation performance of the proposed antenna.

Fig. 4 compares the gain plots of the antenna embedded with resonators and the reference antenna (Sec. II-A). For the sake of clarity, results are shown only for one polarization as the other one has very similar behavior. The first notch around the higher stopband, 32 GHz, is common for all the cases. This radiation null with a sharp roll-off is due to the stacked patch configuration. In Case A, Fig. 3a, the feeding striplines are loaded with the OLRs on metal layers M4 and M5. A second notch around 36 GHz can be observed in Fig. 4 due to the filtering resonator. Similarly, in Cases B and C the OLRs are placed around the patches, on layers M2 and M1. This results in a second notch in their respective gain plots. For Case D, a second larger HR is placed along

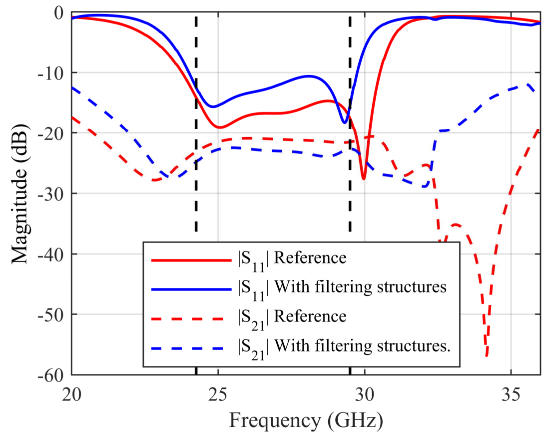


Fig. 6. Simulated S-parameters of the Reference and the proposed design.

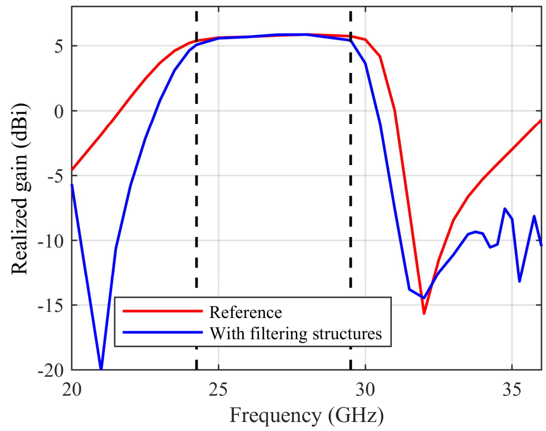


Fig. 7. Simulated realized gain at boresight of the Reference and the proposed design.

with OLRs on M2 as shown in Fig. 3d. The corresponding gain plot in Fig. 4 shows a bandpass response with two additional nulls. The first null, around the lower stopband, is due to the HR, while the second one at higher frequencies is because of the OLR. It is good to observe here that no fabrication complexity is added due to the inclusion of resonators in the reference design. The proposed filtering antenna is obtained by combining all the four different resonator placements discussed here.

III. Results and Discussion

The simulation model with all the filtering structures is shown in Fig. 5. In the following, the simulated performance of the reference antenna (Sec. II-A) is compared with the proposed antenna. The comparison of S-parameters is presented in Fig. 6. Although the proposed antenna meets the -10 dB impedance criteria, matching is slightly deteriorated due to the presence of resonators and would require further optimization. The isolation between the ports is not affected and remains better than 20 dB.

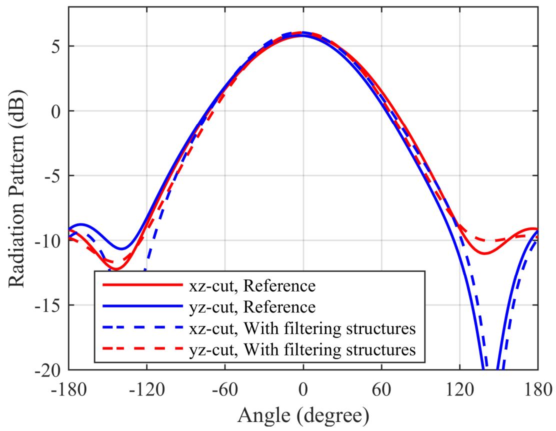


Fig. 8. Simulated *xz*-cut and *yz*-cut at 27 GHz of the Reference and the proposed designs.

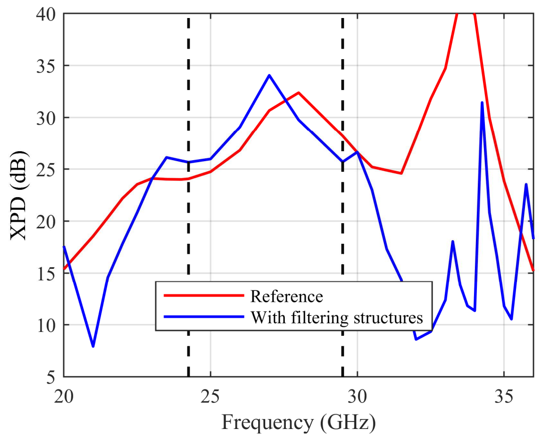


Fig. 9. Simulated XPD of the Reference and the proposed design.

Fig. 7 shows the realized gain plots. A sharper roll-off and a null at lower stopband are obvious in the proposed antenna. Moreover, out-of-band radiation at a higher stopband is better suppressed with the filtering structures. It can be noticed here that the passband gain is not affected by the added resonators, except for a slight deterioration at the passband edges. The radiation patterns around the center frequency are shown in Fig. 8. There is no major influence of the filtering structures over the radiation pattern. Another important far-field parameter is the cross-polar discrimination (XPD), which is plotted in Fig. 9. The two plots are very close in the passband and the XPD of the proposed design is better than 25 dB.

IV. Conclusion

This paper presented a multilayer, dual-polarized filtering antenna. The antenna can be used as a unit cell for mm-Wave base station phased arrays, and it covers the 26 and 28 GHz 5G NR bands. The filtering is achieved without adding extra circuit or fabrication complexity. Moreover, the filtering characteristics did not affect other antenna performance indicators such as bandwidth, isolation, gain, or XPD. From the fabrication point of view, it is a simple geometry that meets the specifications of common commercial fabrication capabilities with minimum via requirements. Next, the designed antenna will be optimized for array implementations, with some additional optimization of the matching and filtering performance to achieve a good operation in an array.

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