Wideband mmWave Antenna for 5G Smartphone

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***Abstract*—This paper presents a compact, wideband antenna suitable for integration into 5G smartphones. Unlike conventional stacked or slot-based 5G antennas, the proposed design introduces an Edge-Loaded Parasitic patch surrounded by Yagi–Uda-inspired directors, enabling enhanced bandwidth and stable gain while maintaining a miniature footprint. The integration of a bottom-fed driven patch with a via-wall structure ensures improved impedance matching and reduced cross-polarisation. Surface current analysis confirms efficient excitation of TM modes with balanced radiation from both patches. In a 1×4 array configuration, the antenna achieves approximately 70% efficiency, supports beam steering up to ± 45°, and maintains a minimum realised gain of 8 dBi.**

***Index Terms*—antennas, electromagnetics, propagation, measurements.**

I. Introduction

In applications where size, cost, and performance are constraints, such as mobile phones, satellites, etc., microstrip antennas become an attractive option. Although many configurations exist for patch antennas in the literature, rectangular and circular patches are the basic and most widely used microstrip antennas. Easy integration and compact size make it a good candidate for portable devices. However, the disadvantage of a microstrip antenna is its narrow bandwidth (BW) [1]. Choice of feeding can mitigate these problems to an extent, but each of the feeding types has its own constraints and hence reduces the antenna performance. There are many research papers that study the performance of the stacked patch from a design point of view [2], [3], [4], [5], [6]. The parasitic coupling method (i.e., without any physical contact) between the driven patch and the parasitic patch was found to provide better bandwidth and impedance matching compared to other feeding methods [7].

Ref. [8] proposed a dual-polarised stacked microstrip antenna for 5G and Wi-Fi, achieving enhanced isolation and a low profile. Similarly, Jang *et al.* [9] developed a stacked dual-patch antenna using a 3D-printed quasi-air substrate to realise wideband characteristics while keeping the structure compact. High-isolation dual-polarised patch antennas remain an active area of research. Santos *et al.* [10] designed a patch antenna-in-package structure with high isolation and dual polarisation targeting 5G applications. Hao *et al.* [11] used substrate-integrated suspended line (SISL) techniques to realise stacked antennas with dual-band operation and multimode radiation suitable for handheld use.

For smartphones, compactness and platform integration are essential. Chang *et al.* [12] presented an orthogonally polarised antenna pair with high isolation and balanced performance optimised for smartphone MIMO. Lu *et al.* [13] reported an extremely low-profile micro-patch antenna that effectively supports dual-band operation for mobile terminals. Furthermore, Cheng and Du [14] proposed a low-profile wideband MIMO antenna with a stacked structure suited for 5G smartphones, while Gao *et al.* [15] introduced a high isolation multimode broadband patch antenna in a low profile design suitable for mobile integration.

A well-known design in this domain is the stacked dual-polarised antenna array proposed by Qualcomm [16], which integrates parasitic patches and orthogonal feed structures to achieve a balanced trade-off between gain, isolation, and bandwidth. While this design serves as an industry benchmark, it exhibits certain limitations— particularly with regard to port-to-port isolation and cross-polarisation levels in constrained or device-embedded environments. Literature designs, including the Qualcomm antenna, were reproduced on a smartphone. Although acceptable in free space, their performance degraded after integration, showing reduced isolation and radiation symmetry.

To overcome these limitations, an enhanced stacked patch antenna is proposed, featuring optimised parasitic geometry, refined via walls, and an edge-loaded parasitic patch. The design achieves improved isolation, wider bandwidth, and stable radiation in both free space and smartphone integration. An antenna design must demonstrate reliable performance within the intended device environment, rather than only in free space conditions. Consequently, the proposed antenna has been optimised through placement studies on a 5G smartphone to ensure that its performance remains consistent after device integration. Owing to the symmetry of the ±45° polarised fields with respect to the metal frame, both polarisations experience comparable electromagnetic perturbations, resulting in nearly identical radiation characteristics after distortion. Consequently, the antenna operates with ±45° linear polarisation.

The main contribution of this work lies in the introduction of a compact, edge-loaded stacked patch antenna that maintains stable performance after smartphone integration—an aspect often overlooked in prior 5G antenna designs [17], [18]. Unlike conventional stacked or slot-based approaches, the proposed antenna incorporates a novel edge-loaded parasitic patch and Yagi–Uda-inspired directors, achieving improved bandwidth, higher efficiency, and enhanced radiation stability within a reduced footprint. The paper is organised as follows. Section II describes the antenna structure, Section III presents the operating principles and simulation results, and Section IV concludes the work.

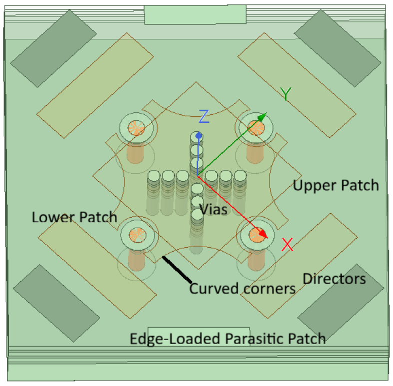


Fig. 1. Antenna Structure

II. Antenna Structure

Fig. 1 shows the configuration of the proposed antenna that employs a simple structure comprising a driven patch on the bottom layer that is capacitively fed by four differential coaxial probes (i.e. 0°/180°), and a parasitic patch on the top layer surrounded by directors. The parasitic patch is edge-loaded (as explained in the following section) and is positioned along the substrate boundary on the top layer. The differential feeding technique helps to improve cross-polarisation [19]. Fig. 1 shows the antenna stack-up that consists of seven layers, including four substrate layers separated by prepreg films. The overall dimensions of the antenna are 4.5 mm × 4.5 mm × 0.906 mm. The square lower patch measures 2.2 mm with truncated corners to enhance bandwidth, while the square upper patch has a side length of 1.79 mm and is enclosed by directors. The upper patch dimension is deliberately kept below 2 mm, since prior analysis showed that for endfire operation in a 5G smartphone, the patch facing the slot in the frame must be smaller than the nominal 2 mm slot size to have better performance. Etching a slot in the frame effectively enlarges the array aperture, resulting in an enhancement of the realised gain.

Fig. 2 presents the exploded view of the proposed antenna. Insights from previous investigations, including antenna placement studies and the effect of the frame slot on the antenna, were incorporated into the current design. The initial version comprised only two stacked patches with two feeds, which resulted in an asymmetric current distribution and a tilt of the radiation pattern away from the broadside at higher frequencies. To mitigate this, a via wall was introduced to suppress surface currents and reduce cross-polarisation, consistent with the approach in [20]. Although the inclusion of a middle patch with optimised dimensions can enhance bandwidth, as demonstrated in [21], this element was omitted from the final prototype due to fabrication constraints.

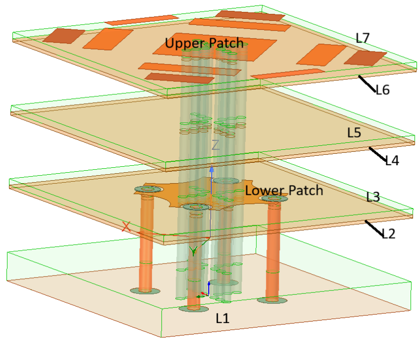


Fig. 2. Antenna Structure-Exploded view

III. Operating Principle & Results

A parasitic patch can act as a director, reflector, or resonator depending on its size, position, and separation from the driven element [22], [23], [24]. When a parasitic patch is attached to the edge of the dielectric substrate alongside a central driven patch, antenna bandwidth, gain, and radiation characteristics can be improved, although there are challenges in impedance matching. This forms the basis of the novel concept of edge loading of parasitic patches.

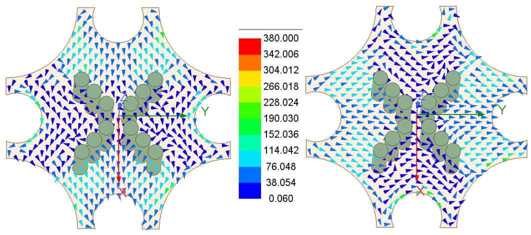


Fig. 3. Surface Current(Unit-A/m) at 29.29GHz

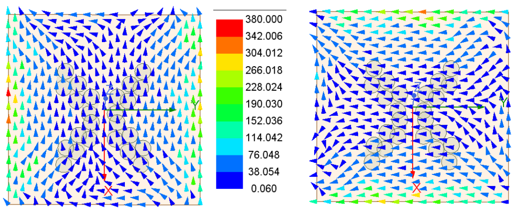


Fig. 4. Surface Current(Unit-A/m) at 40.55GHz

Fig. 3 and 4 show the surface current analysis on the lower and upper frequency bands. The surface current distributions exhibit standing-wave patterns with maxima concentrated along the patch edges and no dominant circulating currents, indicating that the antenna operates in transverse magnetic (TM) modes. The presence of a continuous ground plane enforces a nonzero electric field component normal to the patch surface, while suppressing longitudinal magnetic fields, which is characteristic of TMmn resonant modes in microstrip antennas. At the first resonance (29.3 GHz), both upper and lower patches are active, while at the second resonance, the lower, upper, and directors all contribute. Without vias, only the lower patch resonates in the first mode, and only the upper patch resonates in the second mode. By introducing vias, the two resonances are brought closer together, enabling both patches to resonate simultaneously. For the lower band (<30GHz), the resonant frequency decreases with increasing upper patch dimension, whereas in the higher band (37–43 GHz), the resonant frequency increases with larger upper patch size. Incorporating Yagi–Uda antenna principles into the patch design introduces directors that enhance the antenna gain, in agreement with prior studies [25], [26], [27], [28]. Fig. 5 compares the bandwidth of a single element and the array. Isolation levels exceeding 12 dB are observed across all bands of interest. Prior studies have shown that when the antenna is mounted on a smartphone in an end-fire configuration with its broadside aligned to the slot in the frame, the resonance shifts by approximately ±2 GHz depending on slot length. This frequency shift and bandwidth narrowing are attributed to the strong electromagnetic coupling between the antenna aperture and the nearby slotted frame, which modifies boundary conditions, increases stored reactive energy, and detunes the input impedance. Similar effects of bandwidth reduction and resonance shift due to frame–slot coupling in end-fire arrays have been reported in the literature [17], [18]. Free-space optimisation compensates for bandwidth shift, yielding 24.5–40 GHz coverage after integration via slot length control.

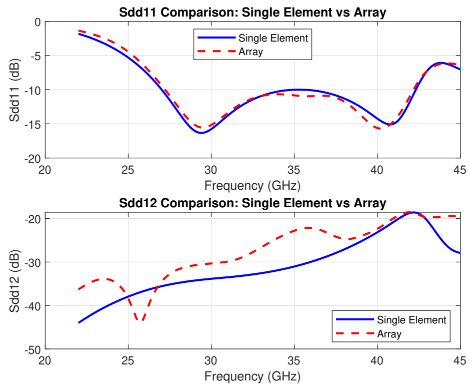
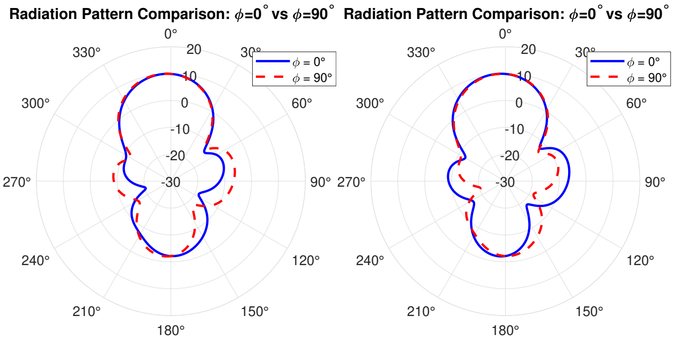


Fig. 5. Bandwidth of Antenna

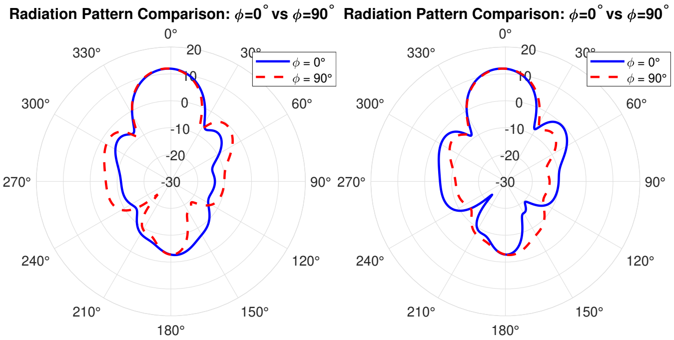
Fig.6 and Fig.7 show the Gain Radiation Patterns in the lower and upper bands of 1×4 array. The obtained radiation patterns exhibit good symmetry and stable main-beam direction across the operating bands, confirming the effectiveness of the proposed structure in suppressing unwanted cross-polarisation and maintaining consistent end-fire radiation characteristics

Fig. 8 illustrates the total efficiency (in linear) of the 1×4 array across the operating band in free-space. The antenna achieves approximately 70% efficiency in both the lower and upper frequency ranges, while maintaining a minimum beam-steering gain of 8 dB within 0° to ± 45°.



(a) 45°Polarisation (b) -45°Polarisation

Fig. 6. Radiation Pattern of 1x4 array at 27.75GHz (in dBi)



(a) 45°Polarisation (b) -45°°Polarisation

Fig. 7. Radiation Pattern of 1x4 array at 39.25GHz (in dBi)

The state-of-the-art comparison for a single element is provided in Table I. The proposed antenna offers wider bandwidth, higher efficiency, and improved integration stability compared to existing 5G smartphone designs. However, its multilayer configuration and via-wall implementation slightly increase fabrication complexity. In future work, we will aim to reduce the complexity of the proposed design while maintaining the wide operation bandwidth of the antenna.

TABLE I
STATE OF ART

Reference	Bandwidth (in GHz)	Gain (in dBi)
[29]	23.5-30.5	5.1
[30]	25-30	6
[31]	24.25-29.5	>4
[32]	27.5-30 , 36–39	>7
[33]	23.88 28.15	>6.3
[34]	24.2-44.1	7.5
[35]	23-30	
This work	26–42 GHz	LB->5.8, HB>6.5

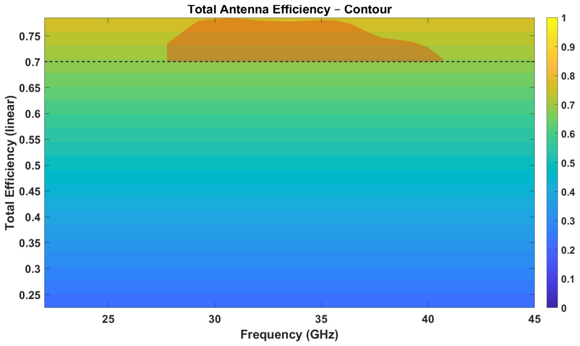


Fig. 8. Total Efficiency of 1x4 array

IV. Conclusion

A compact 5G antenna optimised for smartphone integration has been designed, analysed, and experimentally validated. The antenna achieves wide bandwidth and high efficiency, maintaining stable performance in both free-space and integrated environments. The novelty of this work lies in the introduction of an edge-loaded parasitic patch combined with Yagi–Uda-inspired directors, which enhances bandwidth, improves radiation stability, and minimises performance degradation after device integration. The proposed design therefore provides a practical and integration-resilient solution for next-generation 5G mobile terminals.

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