A Dual-Band Dual-Polarised Stacked Patch Antenna for 28 GHz and 39 GHz 5G Millimetre-Wave Communication

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***Abstract*—Rapid developments in wireless communications demand an antenna that can operate at dual frequency bands in a compact size. In this work, a dual-band dual-polarised antenna is proposed for future 5G wireless communications that can operate at 28 GHz and 39 GHz 5G frequency bands. The proposed antenna is a stacked capacitive coupled patch antenna with bend parasitic elements having a dual-polarisation capability. The design principles and the antenna performance are discussed in detail. The antenna covers 25.75-30.25 GHz and 36.5-41.5 GHz and has a broad bandwidth in both the frequency bands. The proposed antenna element has a peak gain of 7.14 dBi in the lower band and 6.44 dBi in the higher band. The antenna element has a compact size of 3.8 mm × 3.8 mm × 1 mm making it suitable for implementation of antenna arrays in mobile devices.**

Index Terms*—*5G, dual-polarisation, mm-Wave, patch antenna, phased array, smartphone.

I. INTRODUCTION

Recently, some researchers have developed phased antenna arrays for 5G communication at millimetre-wave frequency bands [1-4]. For 5G systems, 28 and 39 GHz frequency bands are strong candidates and its suitability for high data rate and low latency systems are being investigated. Researchers are exploring different antenna designs with a small footprint and wide bandwidth for dual-band operation. On the other hand, dual-polarisation is also preferred, as the antennas have the benefit of allowing two signals, with different orientations, to be transmitted or received on the same antenna and to counteract polarisation mismatch.

Several new and existing dual-polarised designs have been proposed in the previous studies [4-5]. However, the existing dual-polarised antenna designs with dual-band capabilities do not meet the 5G requirement. For example, the design in [6] had a complex feeding mechanism and had a narrow bandwidth of 2.5% at the lower band (LB) and 1.7% at the higher band (HB), thus it is not sufficient for 5G applications, which typically require at least a 10% bandwidth at both frequency bands. In addition, the complex feed structure will distort the radiation pattern at mm-wave frequencies. In [7], a single layer coaxial fed structure was proposed which used reactance loading using stubs and slits to obtain dual-band functionality. The design also suffered from a narrow bandwidth of less than 1% at the LB and HB. In [8], antenna design used capacitive feeding and CPW feeding to obtain dual resonance. This design also suffered from a narrow bandwidth (1% at LB and 2% at the HB). However, the design offered excellent isolation of 25 dB between the two dual polarised ports. In [9-10], the antenna designs used slot coupled feeding and tuning stubs to achieve dual resonance. This design had a wide bandwidth of 11.6% at the LB and 10% at the HB, but used a complex feeding mechanism and used air as the dielectric, which is not practical. In [11], several stacked wideband antenna designs with multiple feeds had been investigated to obtain dual-band operation. However, these designs were complex and used thick substrates, which were not practical for mobile devices. In [17], a tri-band patch antenna was proposed with high gain. However, the radiation pattern had a narrow beam-width and did not provide a stable radiation pattern in the operating frequency range.

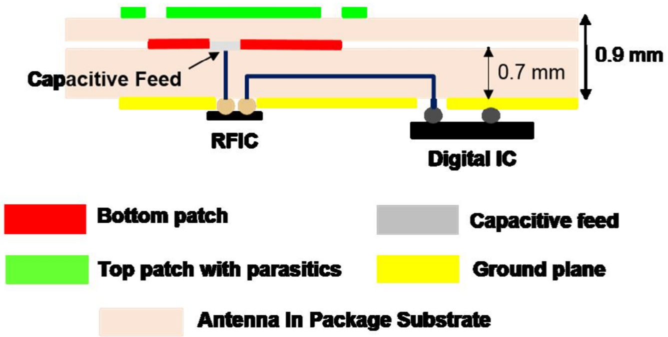
This work discusses the design strategies that have been used to overcome these limitations and to design a compact dual-band dual-polarised stacked capacitive fed patch antenna. The evolution of the design and the performance of the antenna element is explained in Section II. The performance of the antenna element is compared with the state-of-the-art antenna designs in Section III. The conclusions of this work are outlined in section IV.

II. ANTENNA ELEMENT DESIGN AND PERFORMANCE

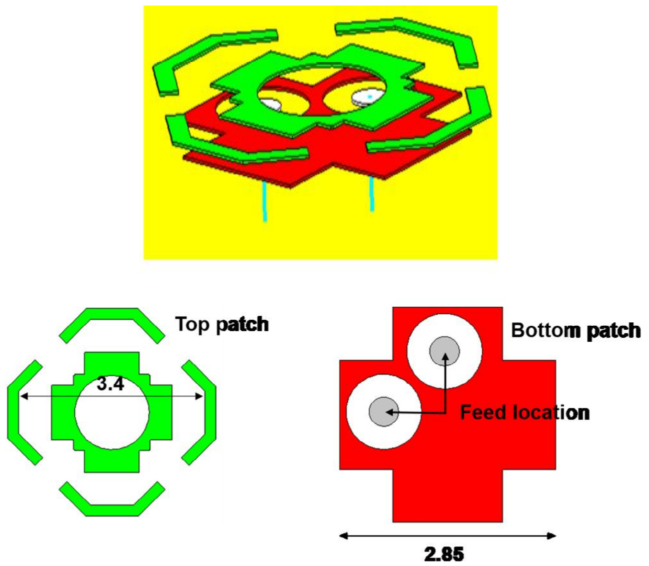
A. Antenna Element Design

For future 5G systems, dual-band antennas of broad bandwidth with bandwidth percentage of at least 10% is required for each band. The prospective 5G frequency bands are 26.5-29.5 GHz and 37-40.5 GHz [12-13].

A new architecture for millimetre-wave 5G antenna based on Antenna-in-Package (AiP) technology is introduced in Fig. 1 (a) which has been developed from the feeding techniques in [14]. The dual-band operation is implemented using the stacked patch antenna configuration with the bottom patch designed for LB operation at 28 GHz and top patch designed for HB operation at 39 GHz. Two feeds are used for dual-polarisation capability. The capacitive feed integrated with the bottom patch layer improves the bandwidth. Four parasitic elements are added in the same layer as the top patch to improve the bandwidth and isolation in the HB. Rogers RT5880 (ε_r= 2.2) of size 10 mm × 10 mm × 0.9 mm is used as the substrate for the AiP module. The ground plane is the same size as the substrate. The feed lines from the RFIC to the capacitive feed section is modelled as a discrete port in CST Microwave Studio simulation. The RFIC uses an RF phase shifter to provide progressive phase shifts to each antenna element to implement array scanning [15]. Each of the RFIC is powered using DC lines from a digital IC [16].



(a)



(b)

Fig. 1. (a) Proposed Antenna-in-Package architecture (b) Proposed design with overall dimensions of the top and bottom patch in mm (Rogers RT5880 substrate is hidden).

The proposed antenna is a dual-polarised stacked capacitive fed patch antenna with bend parasitic elements as shown in Fig. 1 (b) and has an overall size of 3.8 mm × 3.8 mm × 0.9 mm. The bottom patch has an edge length of 0.27λ at 28 GHz and the top patch has an edge length of 0.28λ at 39 GHz. The parasitic elements have a length of 0.32λ at 40.5 GHz. The feed locations are such that the TM_{10} and TM_{01} orthogonal patch modes are effectively excited.

It has been demonstrated in previous work, that wide band can be achieved using capacitive feeding which helps to utilise thicker substrates to achieve wider bandwidth [4-5]. Hence, a dual-polarised capacitive fed patch antenna with two feeds is used as the starting point for this design. The dual-band resonance is obtained in the next step by stacking two different patches each designed for the respective frequency band as shown in Fig. 2. This gives the capability to tune both the frequency bands independently.

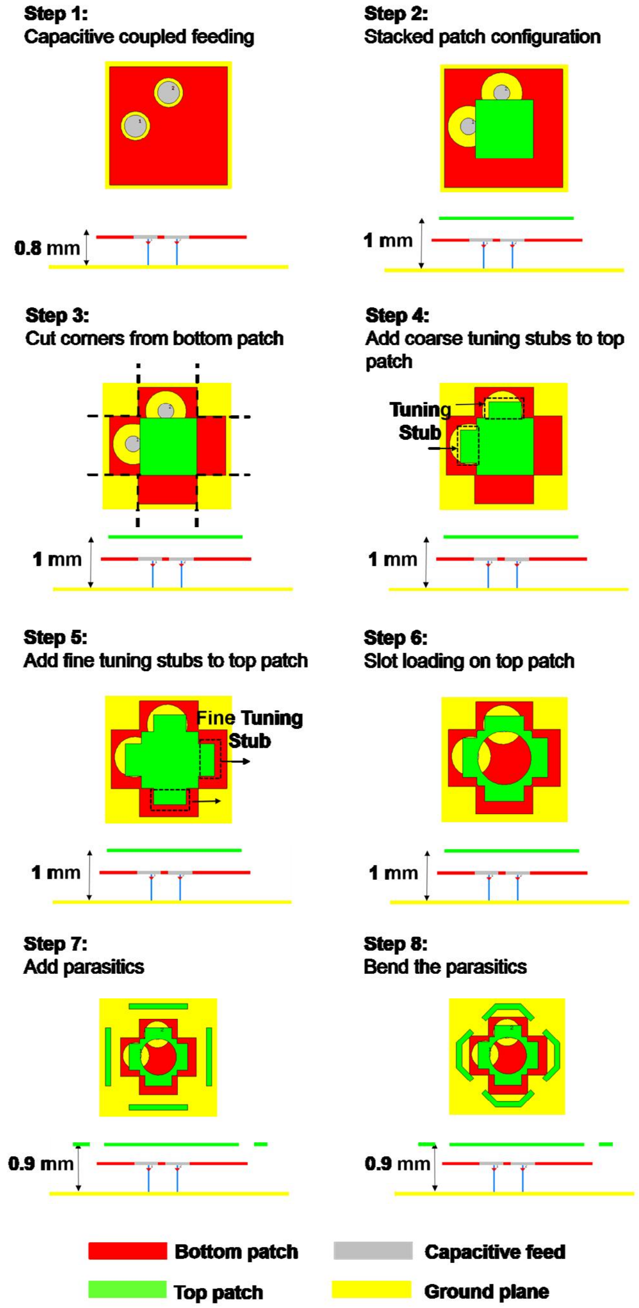


Fig 2. The evolution of the proposed design.

After stacking the capacitive fed patch antenna, reactance loading is implemented by removing the corner sections from the bottom patch to tune the LB independently. This also facilitates in the reduction of the bottom patch size due to the increase in the length of the current path. In the next step, tuning stubs are added to the top patch at the edges adjacent to the feed to tune the HB independently by adjusting impedance without having to change the actual feed position. Another pair of tuning stubs is added to the top patch edges opposite to the feeding position to fine tune HB independently and reduce the cross-polar levels, which were introduced due to the addition of the pair of tuning stubs adjacent to the feeding location. Reactance loading and stub loading enables independent control of both LB and HB. In the next stage, reactance loading by cutting a circular slot in the middle of the top patch is done to tune HB independently and providing an additional degree of freedom for impedance matching. By combining reactance loading and stub loading, the bandwidth of both LB and the HB can be optimised to get a broadband dual-polarised design.

However, the isolation between the orthogonal polarization ports in the HB still needs improvement. This isolation can be improved by adding parasitic elements along the edges of the patch as an additional layer. The parasitic elements, which are adjacent to the feeds, trap energy from the feed, thereby, reducing the amount of energy leaked into the orthogonally polarised feed. In addition, a new resonance is created in the HB at 40 GHz due to the parasitic elements, which helps to widen the bandwidth in the HB. In the final stage, the parasitics are bent to reduce the overall area of the antenna element to 3.8 mm × 3.8 mm. Bending the parasitic elements also improves the isolation between adjacent antenna elements when used in an array configuration due to the reduction in magnetic coupling.

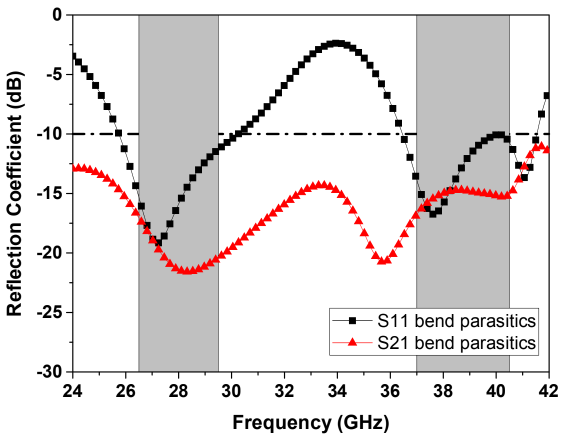


Fig. 3. Simulated S-parameters of the antenna element.

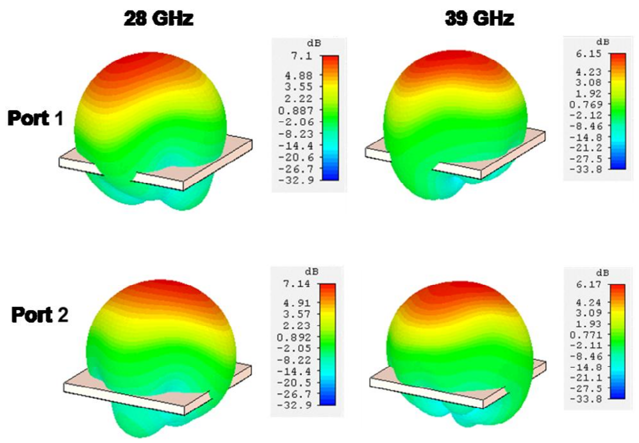


Fig. 4. Radiation pattern of antenna element at 28 GHz and 39 GHz.

B. *Antenna Element Performance*

The simulated reflection coefficient of the antenna element is shown in Fig. 3. The results indicate a 10 dB return loss over 25.75-30.25 GHz and 36.5-41.5 GHz, which covers the required frequency bands.

A worst-case isolation of 17 dB and 15 dB is seen between the two feeds of the dual-polarised patch antenna in the LB and HB respectively. The antenna element has a total efficiency above 90% and 86% in the LB and HB respectively.

The radiation patterns of the two feeds of the proposed antenna element at 28 GHz and 39 GHz are shown in Fig. 4. The antenna element exhibits a stable broadside radiation pattern with realised peak gains around 7.1 dBi and 6.15 dBi for both the feeds at 28 GHz and 39 GHz respectively. The slight tilt of the radiation pattern is due to the asymmetric feed placement with respect to the square patch element. Hence, the radiation pattern is slightly tilted towards the feed position, as strong currents exist along the slot around the feed in the lower band.

III. Comparison With State-Of-The-Art Antenna Designs

In order to evaluate the achievements of the proposed dual-band, dual-polarised antenna element with respect to existing designs, the antenna element is compared with some recently published mm-wave dual-band antenna designs as shown in Table I.

TABLE I
COMPARISON OF PROPOSED ANTENNA WITH TWO RECENT ANTENNA DESIGNS

Design	[12]	[13]	**This work**
Frequency Bands (GHz)	23-29 37-40.5	27.7-28.15 36.7-38.9	**25.7-30.2** **36.5-41.5**
Antenna Size (mm^3)	7.2 × 6.9 × 0.127	20 × 5.5 × 0.254	**3.8 × 3.8 × 0.9**
BW_{LB} (GHz)	6	0.45	**4.5**
BW_{HB} (GHz)	3.5	2.2	**5**
$Gain_{LB}$ (dBi)	4.58	5.2	**7.14**
$Gain_{HB}$ (dBi)	6.15	5.9	**6.44**
Polarisation	Single linear	Single linear	**Dual linear**

The key parameters are bandwidth in the LB as well as the HB, antenna size, antenna element gain in the LB as well as the HB and the capability of supporting dual-polarisation. Although there exist several dual-band dual-polarised antenna designs for various other frequency bands and applications, only the low profile antenna designs are chosen for a fair comparison.

The proposed antenna element provides a peak gain of 7.14 dBi in the LB and 6.44 dBi in the HB, which is higher than any other existing mm-wave low profile dual-band antenna designs. The proposed antenna element is of low profile and has a size of 3.8 mm × 3.8 mm × 1 mm. It provides a wide bandwidth of 4.5 GHz in the LB and 5 GHz in the HB with dual-polarisation capability.

IV. Conclusion

A stacked capacitive fed patch antenna with bent parasitic elements has been proposed and designed for dual-band, dual-polarised operation at 28 GHz and 39 GHz 5G frequency bands. The addition of the parasitic elements improved the bandwidth and isolation performance in the higher band. The proposed antenna element provided a peak gain of 7.14 dBi in the lower band and 6.44 dBi in the higher band, which is higher than any other existing low profile dual-band antenna design. It has a wide bandwidth of 4.5 GHz in the lower band and 5 GHz in the higher band with dual-polarisation capability. The antenna design has a low profile, occupied space of 3.8 mm × 3.8 mm × 1 mm, and is a strong candidate for dual-band dual-polarised mm-wave antenna array implementation in mobile phones.

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