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A Novel Multiband Antenna with Parasitic Element for Diverse Wireless Applications

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Abstract*:* This research provides a comprehensive investigation of a Coplanar Waveguide-fed antenna with a secondary parasitic patch for diverse multiband wireless applications. The proposed design consists of four sequential phases that emphasize operational frequency reduction while maintaining a constant overall size. The structure proposed is modelled on a flame retardant (FR4) substrate with an optimised compact dimension of 35 mm × 25 mm. The radiating structure is a simple rectangular patch; a parasitic element is added above it, and changes in ground lead to an improvement in the impedance bandwidth. The proposed configuration resonates for triband; the lower band resonance is tuned by optimizing the slot in the parasitic element; Mutual coupling of the radiating patch and parasitic elements generates the second resonance; and the final resonance is due to a strip in the parasitic patch. This antenna operates at tri-band frequencies (2.45, 3.5, and 5.7 GHz) with fractional bandwidths of 10.5%, 41.7%, and 15.9%, and it can be used for sub-6 GHz 5G, 3.5/5.5 GHz WiMAX, and 2.4/5.2/5.5 GHz WLAN applications, respectively. The antenna has been fabricated, and the prototype's reflection coefficient has been validated with simulated results. The structure also offers positive gain, good impedance, and efficiency above 85% over operating frequencies..

Keywords: *Antenna, CPW, INSAT, WiMAX, WLAN.*

1. Introduction

Due to progress in wireless communication, multiband antennas are gaining popularity due to the increased necessity for multi-functionality and enhanced data rates. Printed antennas are a promising area for achieving multiband functioning in diverse wireless applications [1]. The small size of modern technological products necessitates antenna miniaturization and cheap manufacturing costs [2]. Due to the substrate material being single-sided, it is easily compatible with other microwave devices [3–6]. Coplanar waveguides (CPW) are highly regarded. Multiband antennas are an improvement in contemporary multifunctional wireless communication systems since they resonate at various frequencies, minimizing the need for several antennas element in a communication device. The compact design of multiple resonant antennas is a difficult task that has created opportunities for many researchers to explore a wide range of potential solutions. Stimulating the antenna with multiple feeds, such as microstrip and coaxial probes [7–9], is one of the most frequent multiband approaches. Changing ground and patch geometry, including slots or splits in the ground plane [10] and an extensive ground plane with diverse shapes, such as a circle, rectangle, or square [11], is another method for achieving multiband operation. [12] suggests a slot antenna with a meandering design for multiband band operations. A closely coupled element configuration is too complex for actual engineering applications to be commercially feasible. In [13], a monopole microstrip patch antenna with two stepped slots is used to achieve multiband resonance with a dimension of 30 mm × 34 mm. [14] describes a triband monopole antenna that employs two rectangular split-ring resonators in the ground to resonate for dual bands frequencies. A dielectric resonator-based novel design is presented in [15] for WiMAX and WLAN applications, which is not feasible to implement for all applications.

This research presents a CPW (coplanar waveguide) antenna and its comprehensive analysis on three resonance band frequencies. The proposed structure is based on a cheap and readily accessible FR4 substrate. The four sequential stages of the design process for the proposed antenna, which justify the 80% frequency-based downsizing and multi-band functioning of a single element, are presented. The simulations are performed using the Ansys Electronic Desktop software application. Over the operational frequencies, a good bandwidth of 250 MHz (2.26–2.51 GHz), 1570 MHz (2.98–4.55 GHz), and 910 MHz (5.24–6.15 GHz) is attained.

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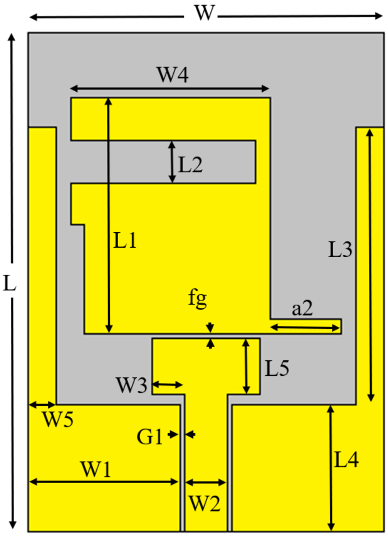


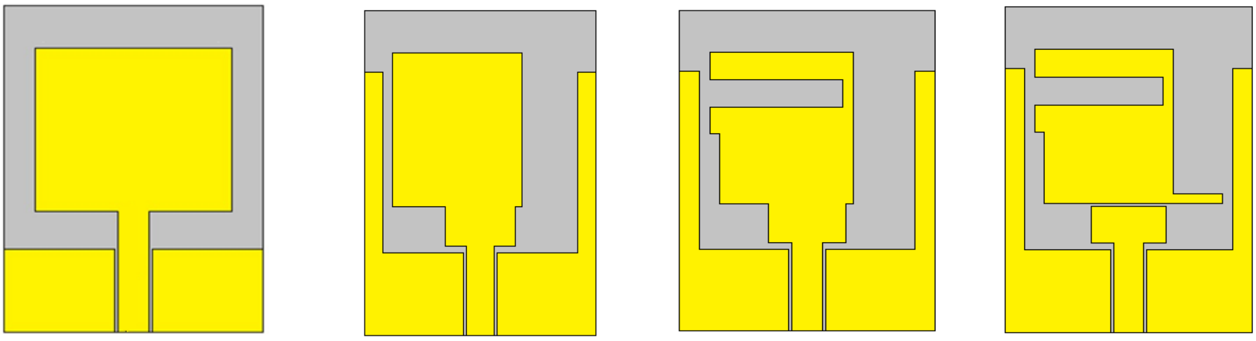
Fig. 1. Antenna Geometry

2. Antenna Design

Figure 1 illustrates the proposed antenna's construction geometry. This is printed on a 1,6 mm thick FR4 substrate. The antenna has a feed width of 3 mm and is designed for 50 Ω input impedance. To create the capacitive coupling effect, a rectangular parasitic patch with slots and strips is introduced above the conductor. Due to this design procedure, we have observed multiband resonance. The proposed model has a smaller size of 35 mm × 25 mm and covers the lower band (2.26-2.51 GHz), the middle band (2.98-4.55 GHz), and the higher band (5.24-6.15 GHz). The proposed structure's parameter and dimensions is tabulated in Table 1.

Table 1. Antenna parameter and dimensions.

Parameter	**Dimensions (mm)**	**Parameter**	**Dimensions (mm)**	**Parameter**	**Dimensions (mm)**
L	35	L3	21.9	W1	10.7
W	25	L4	8.9	W2	3
L1	17.6	L5	4	W3	2.3
L2	3	a2	5	W4	13
W5	2	fg	0.3	G1	0.2



Antenna1 Antenna2 Antenna3 Antenna4

Fig.2 Antenna's design evolution.

The proposed antenna's design progression begins with a four-sided radiating patch (Antenna1) that operates at 5.7 GHz. Throughout the entire evolution process, antenna length and width remain unchanged, while changes are introduced in the ground and radiating patch. In step two (Antenna2), we can notice changes in the ground structure and radiating patch. Because of the changes, the structure resonates for dual bands, but the lower band has less resonance. In step three, a slot is created in the radiating patch, enables multi frequency band resonance with a lower impedance bandwidth. In the third step, a slot in the radiating patch is introduced, which enables multiband resonance with a lesser bandwidth. In the final step, a secondary parasitic patch with a slot and strip improves the impedance band for all three resonance bands, which operates over WLAN, Sub 6 GHz 5G and WiMAX applications. So based on the optimization in the evolution process, antenna4 has good impedance matching.

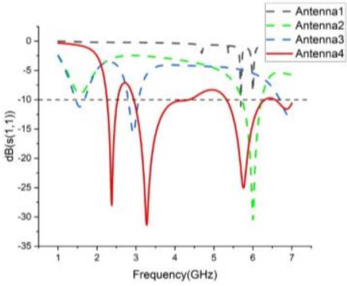
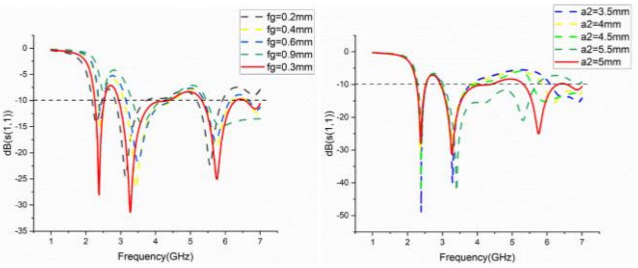


Fig.3. Reflection coefficient comparison of different Antenna

3. Parametric Study

Optimization of different antenna parameters is analysed using ANSYS HFSS simulation software. Two antenna parameters that have an elevated effect on reflection coefficients are fd (gap between the radiating elements) and a2 (length of the strip). With a 1 mm scale, the gap between the radiating elements (fd) is varied between 0.2 mm and 0.9 mm. The changes in fd affect the antenna reflection coefficients at all three resonance frequencies. The middle and last resonance frequency bands shift towards the higher frequency band as the gap increases.



[a] [b]

Fig. 4. S11 Comparison for fg and a2 parameter

Figure 4[a] illustrate the comparison of the S_{11} parameter for diverse values of fd. For the parameter value of 0.3 mm, the antenna resonance frequency exhibits good impedance matching in all three frequency bands. Similarly, the strip length (a2) is altered from 3.5 mm to 5.5 mm with a scaling of 0.5 mm. The parameter a2 effect on the antenna S_{11} characteristics is illustrated in the figure 4[b]. Varying the length of the strip shows there is enhancement in the S_{11} value in the first and second bands, but the third band misses on 5 GHz WiMAX and WLAN applications. For the proposed antenna, the strip length is selected as 5 mm because it covers the necessary application bands.

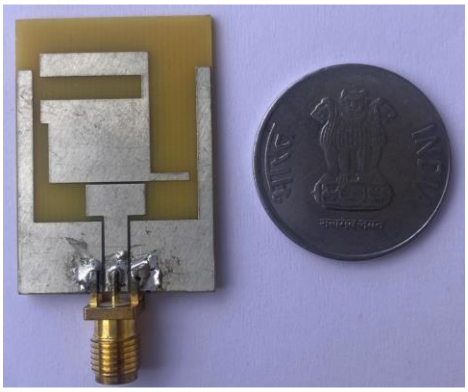


Fig. 5. Fabricated antenna prototype

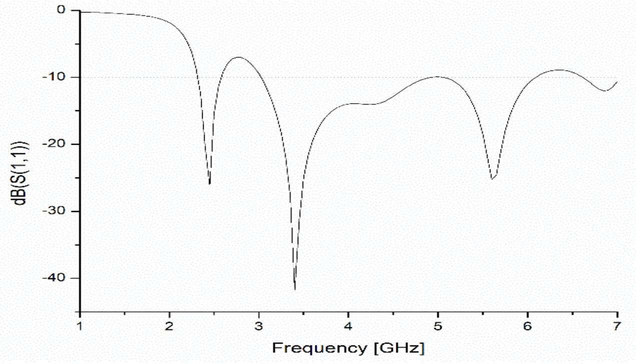


Fig. 6. Reflection Coefficient Measurement

4. Result and Discussion:

The proposed antenna design (Figure 1) is created and its characteristics are assessed. The prototype's return loss (|S11| dB) is obtained using an Agilent VNA (NA9901). The designed antenna-fabricated structure is depicted in Figure 5. Figure 6 illustrates the prototype's measured return loss (|S11| dB). The graph demonstrates that the simulated operating frequencies range from 2.26 to 2.51 GHz, 2.98 to 4.55 GHz, and 5.24 to 6.15 GHz, whereas the measured operating frequencies range from 2.26 to 2.51 GHz and 2.98 to 6.15 GHz. The measured and simulated results agree, that the antenna's bandwidth is adequate for WLAN, WiMAX, sub-6 GHz 5G, and INSAT applications. Peak gain is stated to be positive for operating frequencies of 2.5 GHz, 3.4 GHz, and 5.7 GHz.

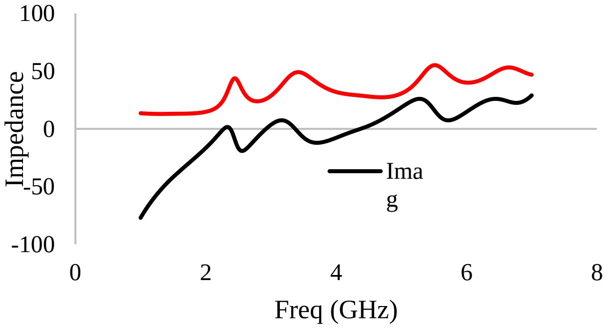


Fig. 7. Antenna Impedance

Figure 7 shows the variance in imaginary and real impedance numbers at the three operating frequencies. At 2.45 GHz, the observed 50 Ohm impedance of the antenna is 48.19 Ohm, at 3.5 GHz, it is 47.71 Ohm, and at 5.7 GHz, it is 48.06 Ohm. At all three resonant frequencies, it is observed that zero is the imaginary value. Figure 8 depicts the proposed antenna's radiation efficiency across its complete operational bandwidth. The observed efficiency is 86.21% at 2.45 GHz, the lower operating band. For the 3.5 GHz middle band, the efficiency is 91%, and for the higher operating band, 5.7 GHz, it is 85.49%.

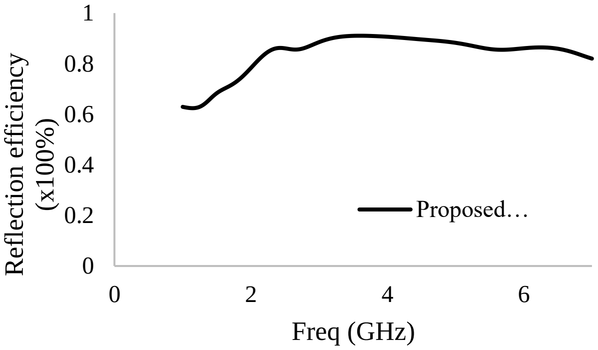


Fig. 8. Proposed antenna Efficiency

Figure 9 depicts the extraction of the antenna's current distribution over operational frequencies. From the concentration it is clear from the existing current distribution that the antenna resonance in the lower band is due to the creation of a slot in the parasitic element. Similarly, for middle-band resonance, mutual inductance between the radiating element and parasitic patch is observed. For the higher band resonance, the parasitic patch's strip has a higher current concentration. Due to these three techniques, the triband resonance of the antenna is achieved.

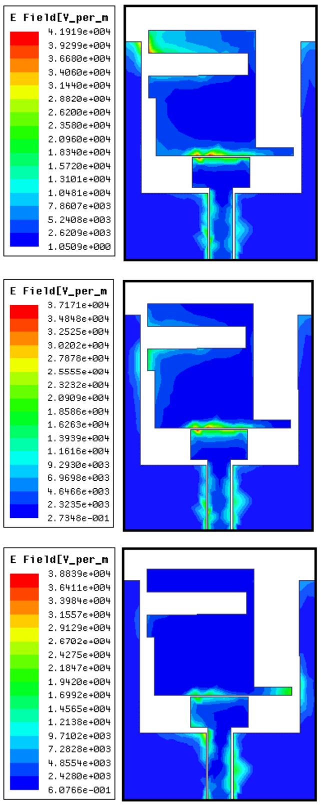


Fig. 9. Current distribution at 2.5 GHz, 3.4 GHz and 5.7 GHz.

The proposed antenna 3D radiation pattern is shown in figure 10, which demonstrates its bidirectional and omnidirectional nature in the lower band. The 3D radiation pattern of the proposed structure for the middle and higher bands has disturbances due to the position of the resonator. The literature review comparing the suggested concept to existing designs [11–15] is presented in Table 2.

Table 2 Literature comparison

Ref.	Dimensions (mm)	Frequency (GHz)	Peak Gain (dBi)	Applications
[11]	80 mm × 80 mm	1.56, 2.49, 3.5, 5.24	3.49	IRNSS, 5G, WLAN
[12]	45 mm × 40 mm	2.4, 5.5, 28	1.95, 3.76,7.35	4G, 5G
[13]	30 mm × 34 mm	2.17,3.52,5.25	-1.0,1.0,3.50	UMTS,WiMAX,WLAN
[14]	28 mm × 32 mm	2.45,3.50,5.70	3.95,4.25,1.95	WiMAX,WLAN
[15]	50 mm × 50 mm	2.45,3.42,5.13	3.29,3.37,4.16	WiMAX,WLAN
Prop.	35 mm × 25 mm	2.45,3.5,5.7	0.75,1.53,1.94	WiMAX,WLAN, 5G

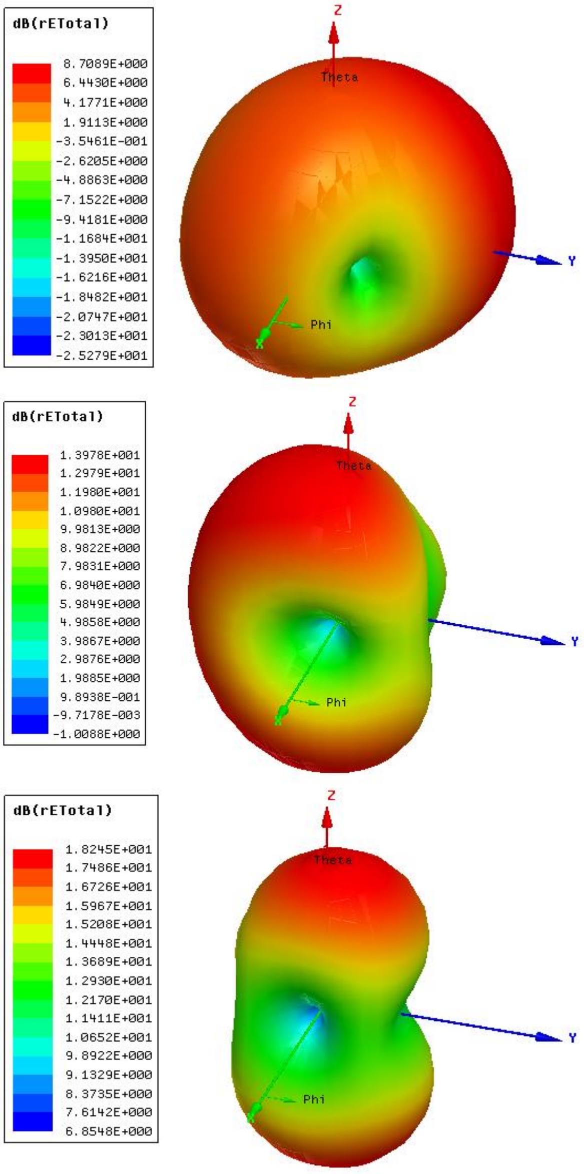


Fig. 10. 3D radiation pattern at 2.5 GHz, 3.4 GHz and 5.7 GHz.

5. Conclusion

A novel and small Coplanar Waveguide fed multiband design with a secondary parasitic patch for diverse wireless applications is presented. By loading slots and strips into a parasitic element, bandwidth enhancement and impedance matching were accomplished. It shows antenna operation at tri-band frequencies (2.45, 3.5, and 5.7 GHz) with fractional bandwidths of 10.5%, 41.7%, and 15.9%; it can be used for WLAN, sub-6 GHz 5G and WiMAX applications, respectively. The proposed antenna characteristics are analysed, and they show good characteristics over operating frequencies.

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