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Design and Analysis of a Dual Band Printed Antenna for V2X, HiperLAN2 and Other Wireless Applications

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Abstract

A compact and novel microstrip patch antenna showing dual band characteristics is presented in this paper. Proposed antenna resonating over two different frequencies 4.56 GHz and 5.66 GHz ranging from 4.15 GHz to 5.05 GHz and 5.40 GHz to 6.24 GHz respectively. Antenna is simulated and fabricated on FR-4 substrate having dielectric constant of 4.4 and thickness 1.6 mm, selected because of its low cost. Antenna dimensions L_{Sub} and W_{Sub} are 21 mm and 15 mm respectively. Antenna consists of a complex patch geometry and a partial ground plane incorporating an equilateral triangular slot with 2 mm side. This triangular slot in the ground plane significantly improves impedance matching and enhances bandwidth. Lower band (4.15 GHz to 5.05 GHz) is useful for C-band, generally used for satellite communications and industrial applications. Second frequency band (5.40 GHz to 6.24 GHz) involves the Wi-Fi 6E, Fixed Wireless Access and Dedicated Short Range Communication (DSRC) which are used primarily for vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) communications and V2X, HiperLAN2 (5.47–5.72 GHz) communication spectrum. Antenna exhibits stable radiation patterns and suitable gain across both bands. The proposed antenna is compact and can be integrated into modern communication devices. High Frequency Structure Simulator (HFSS) software is used to create, optimize, and simulate the proposed antenna.

Keywords: Dual Band Antenna, V2X, Wi-Fi 6E, FR-4, Multiband Antenna, HiperLAN2.

1. Introduction

Multiband antennas are popular because of their multi functionality with improved data rate. Multi-band antennas with high bandwidth play important role in WLAN, Wi-Fi 6E and other wireless communication services. Currently due to the development of communication technologies such as 5G, research focuses on different antenna technologies for different applications. vehicle to everything (V2X) is a technology which is crucial for autonomous driving and standardized by DSRC and C-ITS in US and Europe respectively [1]. Antennas developed for V2X are mounted on the car case. Improved bandwidth can be achieved with defective ground structures and metamaterials [2]. For the purpose to minimize or avoiding accidents and to enhance the driving safety V2X (vehicle to everything) communication technology are being developed that can accurately determine the location and exchange the information about the pedestrian, auto-mobile, infrastructure, network and any obstacles. Classification of vehicle to everything (V2X) communication technology is vehicle to vehicle (V2V), vehicle to infrastructure (V2I), vehicle to pedestrians (V2P) and vehicle to networks (V2N) [3]. The National Highway Traffic Safety Administration (NHTSA) reported in 2024 that more than 40990 people died in road accidents in the year 2023. This figure represents the highest number of fatalities since 2005 and marks a 10.5% increase in traffic deaths compared to 2020 [4]. V2X can play major role to minimizing a traffic death rate [6,7]. Frequency range from 617MHz to 6GHz covers V2X, Sub 6GHz and 5G in [5]. Currently, many dual band antennas have been reported in [8-12] for different operating frequency bands and applications, all these antennas are microstrip patch antennas. The reason for working in different frequencies or applications is that their design, size, structure is different from each other. For making microstrip patch antenna different slots, stubs or slit of different sizes and shapes are used. Compact planar monopole microstrip antenna is suitable for WLAN application [8] and Dual Band SIR Coupled Dipole Antenna is used for ISM band application [9] which both antennas cover the 2.4/5.2/5.8/GHz operating band. A compact dual rectangular split ring monopole antenna is designed for 5G, sub 6GHz and WLAN application, in this antenna one common arm connects the two split rings together, these split rings easily controlled

3.3GHz–3.6GHz and 5.15GHz–5.5GHz frequency band [10]. Simple dual-frequency printed rectangular patch antenna with the dimension 70 mm×60 mm×2.87 mm its operating frequencies of 2.45 GHz and 3.48 GHz it is suitable for wireless applications for example Wi-MAX and Blue-tooth 2.0 [11]. A dual band shark fin integrated vehicle antenna design for 5G and Wi-Max Applications introduces a corporate fed patch antenna array, and a quasi-Yagi antenna work for dual band applications at 5.5 GHz and 26 GHz frequency [12]. The goal of U-slot square patch antenna is broadside radiation; this unique dual band antenna covers industrial scientific medical (ISM) bands at the frequency 2.4/5.8 GHz. This antenna designed for the upper bandwidth is expanded and two resonant modes are maintained. It can be obtained by the two antennas put together and fed with a single coaxial probe. It is suitable for wireless communication [13]. In [14] microstrip patch antenna was designed for V2X (vehicle to everything) applications, patch antenna in [15] cover the multiband and [16] and [17] cover the triple band and dual band antenna respectively. We explore to determine vehicle to everything (V2X) connectivity may be used to enhance the autonomous auto's perceptual capabilities, achieves robust performance even under harsh, noisy environments conditions, reduce traffic difficulties.

Dual band antenna which is a circular monopole antenna is designed in [18]. Antenna shows dual band response with operating frequencies 3.3–4.0 GHz and 5.6–6.0 GHz. Size of the antenna substrate is 22 mm×12 mm. Also, antenna is integrated with frequency selective surface (FSS) to enhance the gain and efficiency. An-other antenna showing dual band response in the band 4.98-5.56 GHz and 5.74-6.62 GHz is presented in [19]. Two rectangular radiators with different sizes are connected, which generates two different operating frequencies. Antenna can be used for 5G applications.

In this paper, an F-shaped antenna with inverted L-shaped stub connected for dual band operation is proposed which is compact in size and exhibits sufficient gain. The prototype of the proposed antenna is fabricated, and the simulation results are compared with some of the existing antennas.

2. Antenna Structure

Figure 1 shows the geometry of the proposed antenna. Fr-4 epoxy material which is available commercially is used as the substrate with dielectric constant of 4.4 and loss tangent of 0.002. Fr-4 substrate material is sufficient for low to mid-band frequencies. The patch of the antenna is a multi-segmented F-shaped structure with lengths labelled as L_1 to L_6 and widths W_1 to W_5 which are responsible for a wide frequency range and specific impedance matching. The position of the L-shaped structure on the left side of the patch is optimized for desired results. Antenna is fed by microstrip feed line having width W_f and length L_f and position and dimensions are optimized as these are critical for impedance matching and ensure the efficiently transfer of signal from source to the antenna. Simulation of the antenna was carried out using high frequency structure simulator (HFSS) by ANSYS. Figure 2 shows the front view and back view of fabricated antenna with the measuring scale.

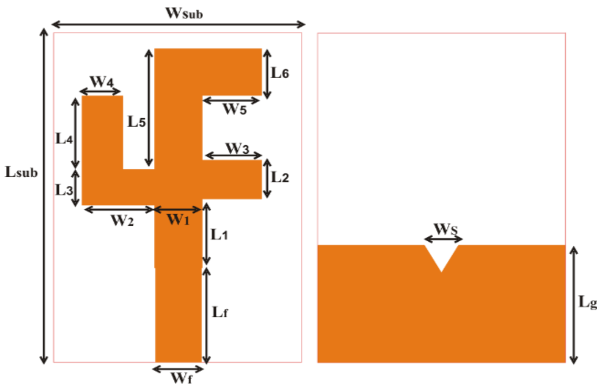
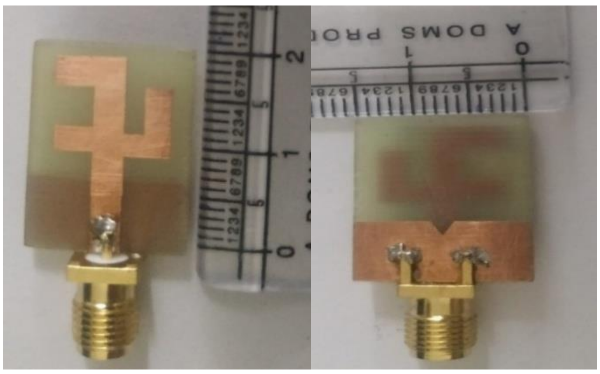


Fig. 1- Front view and back view of antenna



(a) (b)

Fig.2-. Fabricated Prototype (a) Front View (b) Back View

Ground plane shown on the right side of image is a partial ground in which an equilateral triangular slot with side of 2mm is etched to enhance the bandwidth and impedance matching. Dimensional parameters of the antenna are summarized in table 1. As antenna size used in electronic devices is decreasing continuously so maintaining impedance matching is challenging. Also, fabrication of compact antenna is challenging because a small variation in dimensions can change the antenna characteristics. Design methodology used to design the final antenna is given in flow chart as shown in figure 3. There are different phases of design process which are followed.

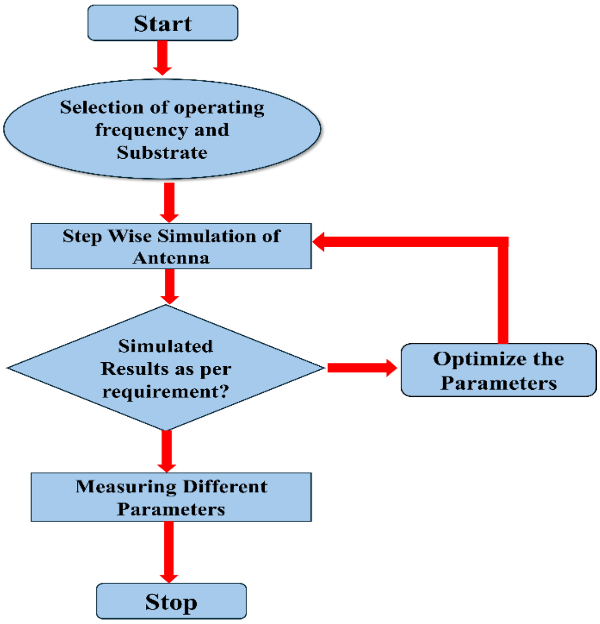


Fig. 3- Flow Chart of the design Methodology

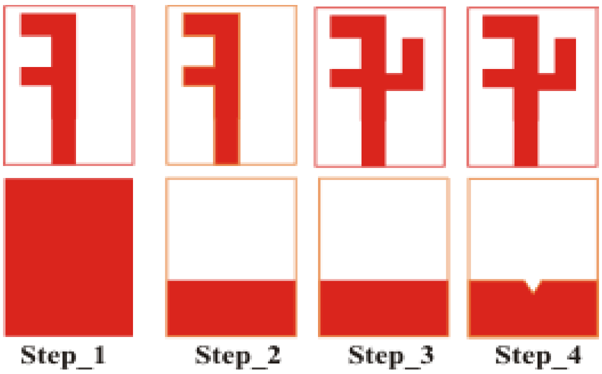


Fig. 4- Evolution of the Proposed Antenna

Four step evolution process is adopted to obtain the dual band antenna and step wise evolution of the antenna is depicted in figure 4. Initially an antenna with full ground and F-shaped patch is tried. In the next step, the ground is reduced to 7.5 mm. It produces a wideband response in the lower band as shown in figure 5. In the third of evolution, an inverted L-shaped structure is added in left side of the patch which results in a dual band response, but the second band is not as per requirement. To get the desired band and further improve the return loss parameters an equilateral triangular shaped slot is etched in the ground plane which improves the impedance matching characteristics of the antenna and shifts the operating frequency to desired one. Also, inclusion of triangular slot increases the bandwidth which can be observed from step wise results which are given in figure 5. Figure 6. illustrated the simulated surface current distribution of proposed antenna for both the operating frequencies. It can be observed that at 4.56 GHz the surface current is dominating in the lower portion of the feed and upper portion of the F-shaped structure. At 5.66 GHz, the middle and upper sections show the maximum current densities, which are critical for efficient radiation. The distribution indicates that these regions are responsible for radiation. In the outer section of the antenna, lower current densities are observed, which influences the antenna's impedance and overall radiation pattern.

Table 1-Dimensional Parameters of the Proposed Antenna

Parameter	Value (mm)	Parameter	Value (mm)
L_{Sub}	21	W_1	2.9
W_{Sub}	15	W_2	4.4
W_f	2.8	$W_3= W_5$	3.6
L_f	6	W_S	2
L_1	4.4	L_g	7.5
$L_2= W_4$	2.5	L_5	7.7
L_3	2.3	L_6	3
L_4	4.7		

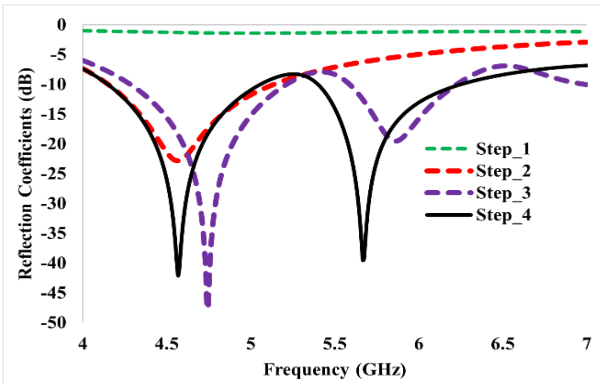


Fig.5- Return loss evaluated step wise

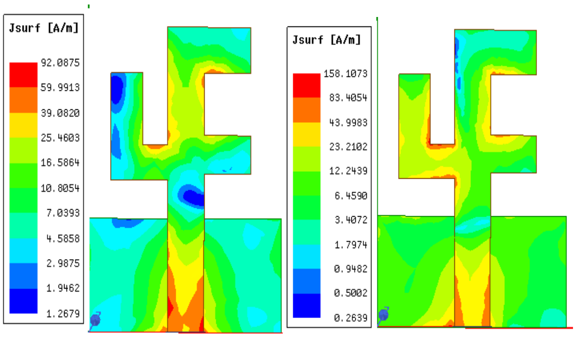


Fig.6- Surface Current Distribution at (a) 4.56 and (b) 5.66 GHz

3. Results and Discussion

The simulation of the antenna was performed using high frequency structure simulator V.18. The performance of the antenna is analysed in terms of different antenna characteristics such as reflection coefficients, gain, 2D radiation pattern and surface current distribution. The return loss curve of the antenna shows first resonance at 4.56 GHz and second resonance at 5.66 GHz, with return loss values of -42.09 dB and -39.52 dB, respectively with adequate bandwidth.

Table 2- Validation of the proposed antenna

Ref.	Size (mm × mm)	Operating Band (GHz)	Max. Gain (dBi)	η
[11]	70×60	3.26–3.39	3.2	NA
[15]	150×70	2.73–3.12 and 4.32–4.68	4	75-80
[21]	20×15	5.74–6.62	1.8 and 3.8	85-90
[22]	62×62	6.2	1.8 and 2.45	90
[23]	70×70	1.41-1.93 1.48-1.93	1.8 and 2.45	90
[24]	160×100	0.916-0.942 and 0.903-0.929	7.1and 9.2	83.3-94.3
[25]	14×12	26.65-29.2 and 36.95-39.05	1.27 and 1.83	76-78
[26]	52.3×58.69	2.45 and 5.8	2.74 and 1.98	NA
Proposed Work	15×21	4.15–5.05 and 5.40-6.24	2.4 and 2.8	93-95

Where η- is the efficiency

The prototype of the proposed antenna is fabricated and measured using Keysight N9916A 14 GHz VNA to validate the simulated results. Simulated and measured S11 parameters as a function of frequency are presented in Figure 7. There is a slight difference between simulated and measured results which are due to fabrication process and soldering. Figure 8 illustrates the gain variation of the antenna across both the operating bands. The gain was achieved with the antenna exceeding 2.4 dBi at 4.56 GHz and 2.8 dBi at 5.66 GHz. The gain plot at 4.56 is omnidirectional because at 4.56 GHz antenna is operating in fundamental modes. This omnidirectional behaviour of antenna is useful where wide coverage is required. Similarly, at 5.66 the antenna operates in higher order modes which results in a unidirectional radiation pattern and this type of antenna is useful where we require coverage in a particular direction. Further this gain can be enhanced by using other dielectric materials such as rogers 5880 and other gain enhancement techniques in the future.

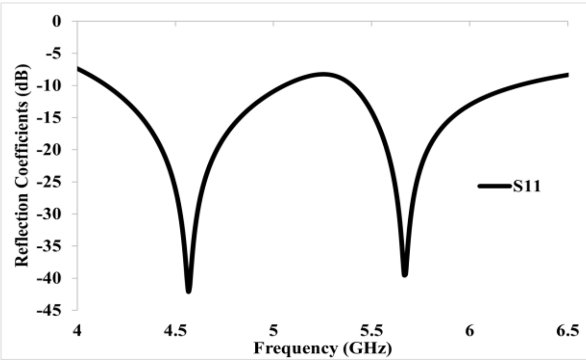


Fig.7- Return loss curve (S11 parameter) as a function of frequency

Simulated radiation efficiency over both operating bands 4.15-5.05 GHz and 5.40-6.24 GHz exceeds 93% and 95% respectively. Gain and efficiency plot for both the operating bands is shown in figure 8.

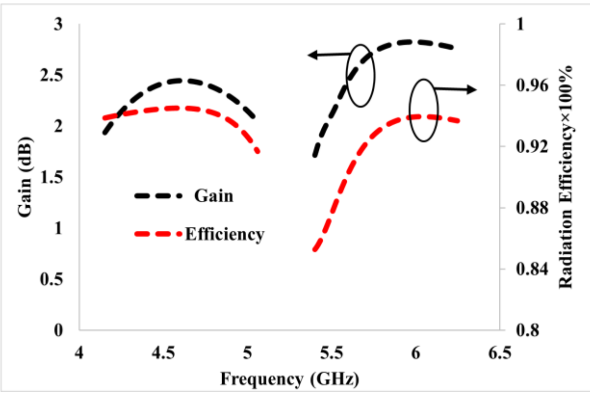


Fig.8- Gain and Efficiency Plot in respective operating Bands

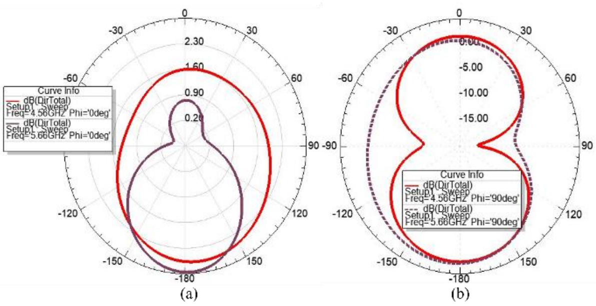


Fig.9- Radiation pattern in (a) XZ plane (b) YZ Plane

Figure 9 shows the Radiation plot at 4.56 is omnidirectional because at 4.56 GHz antenna is operating in fundamental modes. This omnidirectional behaviour of antenna is useful where wide coverage is required. Similarly, at 5.66 the antenna operates in higher order modes which results in a unidirectional radiation pattern and this type of antenna is useful where we require coverage in a particular direction.

In table 2, the proposed antenna is compared with some of the existing antennas which proves that the proposed antenna is compact and better in the terms of performance.

4. Results Conclusion and Future Directions

A compact and multi segmented microstrip patch antenna showing dual band response is proposed in this paper. The simulation results reveal that the antenna effectively operates over two frequencies 4.56 GHz and 5.66 GHz, make it useful for V2X, Wi-Fi 6E, HiperLAN2 (5.47–5.72 GHz) and other wireless applications. Equilateral triangular slot in the ground plane plays an important role in enhancing the bandwidth and improving its impedance matching. Lower band falls within C-band which is useful for satellite communication especially for fixed satellite services as well as ground-based stations. The compactness and above explained performance characteristics of the antenna indicates that the antenna is well designed and suitable for the above-mentioned applications. The above characteristics also enable the integration of the antenna into communication devices where space requirement is the main concern. Additionally, the gain provided by the antenna is sufficient.

Antenna showing dual band response but there are several challenges also that need to be addressed and there are other modifications that can be addressed. The proposed antenna can be implemented as reconfigurable antenna by loading switching devices such as PIN diode or varactor diode between different segments of the antenna. This enables the antenna that switches between different frequency bands. This antenna can be enabled to operate over wideband frequency by adjusting the position of the L-shaped structure. Also, the gain, efficiency and other performance parameters can be improved by integrating the antenna with frequency selective surface (FSS) in future.

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