

Dual band printed patch antenna on ceramic–polytetrafluoroethylene composite material substrate for GPS and WLAN applications

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Abstract In this paper, a design concept of modified rectangular shape slotted patch antenna with microstrip feed is proposed for GPS and WLAN applications. The proposed simple planar design of the planar antenna is composed of partially extended radiating surface which is loaded with L-shape slot and two wide square slots. The optimized design of the antenna has overall dimension of $40 \times 40 \text{ mm}^2$ and is fabricated on 1.905 mm thick high dielectric substrate ($\epsilon_r = 10.2$) of high frequency copper laminated ceramic composite substrate. The antenna design, simulation and parametric analysis have been performed on finite element method based full-wave 3D electromagnetic field simulation software. The experimental results show that the fabricated antenna has achieved impedance bandwidths ($S_{11} \leq -10 \text{ dB}$) of around 780 MHz (1.13–1.91 GHz) at resonant frequency of 1.48 GHz and 1220 MHz (4.83–6.05 GHz) at resonant frequency of 5.61 GHz respectively. The gain of the fabricated antenna gives maximum value of 3.42 and 4.37 dBi for lower and upper frequency band of operations respectively. The proposed antenna shows almost consistent radiation patterns with adequate radiation efficiency over the frequency bands which make the antenna appropriate for providing services in both L1/L2 GPS and 5.2/5.8 GHz WLAN bands.

Keywords Microstrip antenna · Dual band · GPS · WLAN · Modified rectangular patch · Ceramic–PTFE

1 Introduction

Today's fast-paced world with high speed data transfer in wireless communication systems, the industry standard always demanded adequate bandwidth and interoperability with multiband functionality. Beside the challenging factors, the antenna as a core component of wireless devices should also possess low profile, simple structure, cost effective, easy fabrication characteristics. To deal with the expeditious development in wireless communication technology, the researchers from industry and academia have always spent their efforts in developing dual-/multi-band antenna of light weight, small size, easy integration capability for portable communication devices [1,2]. Through various techniques and designs, the researchers are also trying to confirm that their antenna can follow the bandwidth requirement, gain functionality and standard radiation patterns over the operating frequencies. Out of the different conventional antenna types, the microstrip patch antennas are widely investigated in the last few decades due to their planar structure, small form factor, simple geometrical design and offer less tedious integration facility with other components of wireless equipment [3]. Using the high-speed data communication network, the antennas for global positioning system (GPS) and wireless local area network (WLAN) vastly integrate with the recently evolved smart portable devices like mobile, tablet, laptop etc. The civilian GPS operates at a frequency of 1575.42 MHz (L1) and 1227.60 MHz (L2) [4]; and the WLAN operates at 2.4 GHz (2.4–2.484 GHz), 5.2 (5.15–5.35 GHz), and 5.8 GHz (5.725–5.825 GHz) [5]. Hence designing the antenna operates at more than one fre-

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quency is an essentially required feature as it can simplify the antenna system and takes up less space by replacing two or more separate antennas for individual applications. However, the typical patch antennas have deficiencies in terms of narrow bandwidth, low gain and increased level of cross polarization which need to mitigate through ingenious designs and techniques. From the research point of view, it is certainly a challenging task to maintain wide bandwidth, acceptable antenna gain and compact size at the working frequency band and in some cases it is required to negotiate with performance criteria.

By performing extensive review, it has been found that a number of techniques are available for obtaining dual-/multi-band functionality with satisfactory bandwidth and gain. Various types of dual/multi-band antennas are reported: single slotted patch and ground slot antenna [6], cavity backed annular slot antenna [7], bow-tie shape patch antenna [8], microstrip antenna on low temperature co-fired ceramic multilayer substrate [9], W-slot loaded patch antenna [10], multiple orthogonally slotted patch antenna [11], two nested patch single-feed dual frequency antenna [12], pair of L-shape slot with defected ground plane multiband antenna [13], wide rectangular slotted with E- and T-shape stub loaded quad-band antenna [14] and so forth. Although the recently published literatures have shown a small number of antennas performing both GPS and WLAN functionalities, most of them have limitations in terms of volumetric size, design complexity, marginal gain/bandwidth etc.

Printed inverted 'F' antenna (PIFA) with ground bridges is offered for L1 GPS band and 2.4 GHz WLAN applications [15]. But the antenna has got large dimension ($130 \times 80 \text{ mm}^2$), inadequate bandwidth to accommodate the room for GPS L1/L2 bands, the complex ground bridge which is not easy to design and fabricate. Additionally, a sufficient gap has to be maintained from the ground plane to obtain the best performance from PIFA. A G-shape printed monopole antenna is proposed for dual band operation in L1 GPS and 2.4 GHz WLAN band [16]. As of the literature, the antenna is fabricated on $50 \times 50 \text{ mm}^2$ FR4 substrate which is large enough and offer negative gain with inappropriate bandwidth which may limit many applications to function properly. Some researchers came with the idea of single-feed stacked patch for achieving dual band operations for L1 GPS and 2.4 GHz WLAN applications [12, 17]. Although, these antennas offer reasonable bandwidth and gain, most of the cases they are less practical to fabricate, increases the manufacturing cost, the gap between the layers may substantially affect the antenna performances. Recently published work by Liu [8] has fabricated a prototype on the basis of two pairs of printed bow-tie patches which can serve for GPS and 5.2/5.8 WLAN bands. Still the antenna suffers from insufficient bandwidth and unsatisfactory gain property. Rezaeieh [11] has presented a circular shaped multiple

orthogonally slotted antenna for GPS and WLAN applications. Though the proposed antenna offers wider band with adequate gain, but the due to the presence of four pairs of orthogonal slots on the radiating patch and reduced ground plane, the radiation patterns are deteriorate. A radiating area of $56 \times 44 \text{ mm}^2$ is proposed by Cao et. al. [14] to serve GPS/WiMAX/WLAN systems and fabricated on substrate of $\epsilon_r = 3.5$. In the design, a rectangular slot, a T-shaped feed patch, an inverted T-shaped stub, and two E-shaped stubs are utilized to generate four frequency bands. However, mutually inclusiveness of the different design parameters associated with single frequency leads to design complexity of the antenna. The researchers are well concerned about the challenges associated with the widespread impedance bandwidth, good antenna gain, and consistent radiation patterns while maintaining the other antenna parameters like low cost, compact size, easy manufacturing and integration to the system, planar geometrical structure, simple design and so forth. Not to mention, plenty of research opportunities are wide open and possibilities are there to improve the antenna performances by applying numerous ways/techniques.

In this paper, a microstrip line feed simple design patch antenna of $40 (W) \times 35 (L) \text{ mm}^2$ radiating area with GPS and WLAN band functionality is proposed. The slotted rectangular patch antenna is modified by extending its radiating area through the addition of I-beam at the top. The "L" slot, two wide square slots and I-beam as an extension of radiating patch are properly positioned and optimized to achieve a double resonance mode of operation which can cover L1/L2 GPS and 5.2/5.8 GHz WLAN frequency bands. The key parameters of the antenna are judiciously regulated so that good impedance matching can be attained which in turn provides dual resonances, sufficient bandwidths, acceptable gain and convenient profile. Throughout the design processes, the finite element method (FEM) based commercially available electromagnetic field solver HFSS is employed for performing numerical analysis and optimization. With the optimized parametric dimensions, an antenna prototype has been fabricated on high frequency copper laminates composite material substrate ($\epsilon_r = 10.2$) and tested to validate the design criteria. The measured results show that the achieved impedance bandwidths are 780 MHz (1.13–1.91 GHz) and 1220 MHz (4.83–6.05 GHz) with resonant modes of 1.48 and 5.61 GHz respectively. The details of the antenna geometry, parametric investigations, results from simulation and experimental data are critically analyzed and discussed in the following sections.

2 Antenna configuration

The geometrical structure and detail configurations of the proposed dual band antenna are illustrated in Fig. 1. The

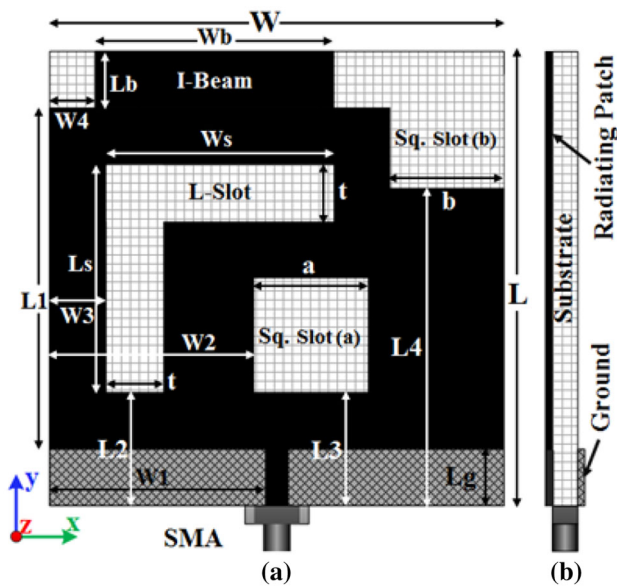


Fig. 1 Geometrical configuration of the proposed antenna **a** top view and **b** side view

finite element method adopted 3D full-wave commercial program HFSS (high frequency structure simulator) [18] is applied in the design, analysis and numerical simulations for finding the optimal dimensions correspond to the desired antenna properties. The high frequency laminates substrate material having high dielectric constant is considered for the antenna designing process which gives a compact profile for microwave and electronic circuitry applications. The final design of the antenna with its optimal dimensions is constructed on commercial ceramic–polytetrafluoroethylene composite material substrate with permittivity of 10.2, loss tangent 0.0023 and substrate thickness is 1.905 mm. The high frequency copper laminates ceramic composites offer low loss and less moisture effect on electric loss [19]. The rectangular radiating patch is engineered to give it an innovative geometric structure which is formed by loading different rectangular capacitive slots and adding an inductive metallic radiator. The feeding to the antenna's radiating element is performed through 5.0 mm long 2.1 mm wide microstrip line which is properly designed to comply with the $50\ \Omega$ characteristic impedance. The microstrip feed line is soldered to the SMA connector and positioned at the center in x-axis for providing uniform excitation to the radiating patch. Various parametric studies are executed with the help of 3D EM simulation software to verify different parametric dimensions correspond to the expected antenna properties and final optimized dimensions are listed in Table 1. While performing the parametric analysis, the items like substrate material, overall size of the antenna and position of feed are not regarded as a changeable parameter since it has been proved that they certainly have a substantial effect on the antenna performances.

Table 1 Optimal parameter values of the proposed antenna

Parameter	Value, mm	Parameter	Value, mm
L	40	W	40
$L1$	30	$W1$	19.95
$L2$	10	$W2$	18
$L3$	10	$W3$	5
$L4$	28	$W4$	4
Ls	20	Ws	20
Lb	5	Wb	22
a	10	b	10
Lg	5	t	5

To clearly understand the effect of key items on the antenna performances, only one parameter is varied while the others remain constant in the whole process.

3 Parametric investigations

Through the application of proper optimization procedures in electromagnetic simulation software, the ultimate parametric dimensions of the antenna are established. Figure 2 illustrates the step by step processes to design the proposed antenna for dual band operation. The antenna performances in terms of reflection coefficients S_{11} are depicted in Fig. 3 which are associated with different geometric structure of the antenna as noted in legend. The figure clearly shows that the proposed antenna offers two distinct bands of bandwidths 1.01 GHz (1.01–2.02 GHz) and 1.3 GHz (5.01–6.31 GHz) with resonant mode of 1.58 and 5.51 GHz respectively. It can be affirmed that the proposed antenna has achieved the desired resonant frequency due to the insertion of different slots and extending the radiating patch. In the case of elementary structure without any slots (Ant.1), the frequency response is seen to provide a principle excitation mode near about 2.0 GHz and around 5.5 GHz the curve about to touch the -10dB line. Cutting “ L ” slot of thickness “ t ” (Ant.2) would change the streamline of surface currents which help to shift the first resonant mode towards the lower frequency and also creates the second resonant mode of operation. Embedding the wide square slot “ a ” at specified position (Ant.3) shifts the resonant mode towards lower frequency and provides wider bandwidth. Partially lengthening the top portion of the radiating patch through I beam (Ant.4) and applying reduced ground plane assists to achieve further increment to the bandwidth through good impedance matching. The final geometrical structure of the proposed antenna has been constructed by adding another square shape wide slot on top right corner of side length “ b ” (Ant. 5). By setting the proper value for the length of square wide slot, better impedance match-

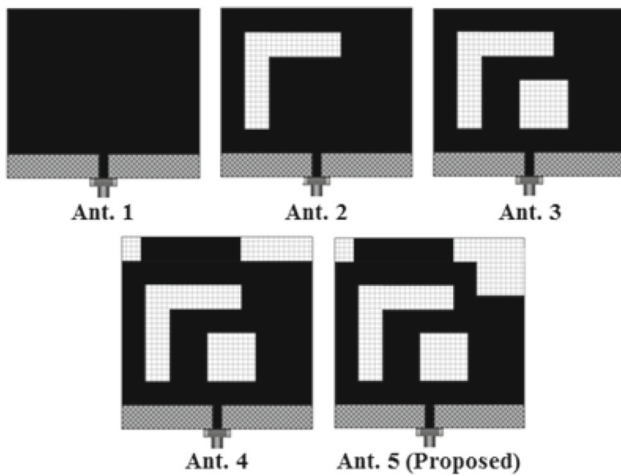


Fig. 2 Step by step processes in designing the proposed antenna

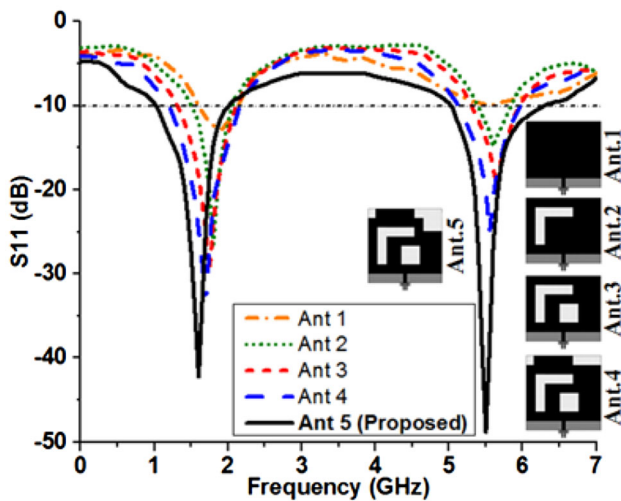


Fig. 3 Simulated reflection coefficient (S11) versus frequency for different antenna structure

ing can be achieved which may lead to attain the desired frequency band with adequate operating bandwidth to cover the GPS and WLAN applications. By examining the surface current distributions at both of the frequency bands (Fig. 13), one can clearly understand the effects of the inclusion of different slots and inductive element on the radiating patch.

The investigations are extended further to determine the optimum dimension associated with the outmost performance in terms of the reflection coefficient (S11) achieved from the proposed antenna structure. For this purpose, the inclusion of the key items are checked and optimized one by one through a number of numerical simulations. Figure 4 shows the curves for the reflection coefficients (S11) by varying the thickness of “L” slot from 3.0 to 6.0 mm. The figure suggests that, for the value of $t = 5.0$ mm would create good impedance matching which assist in achieving the desired resonant mode of operation with decent wideband

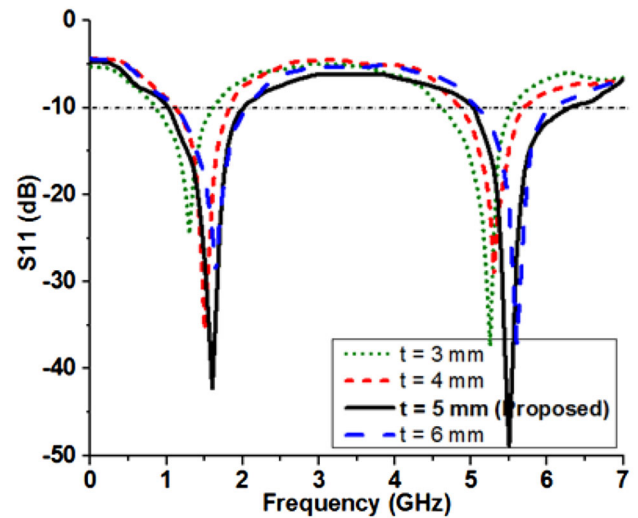


Fig. 4 Simulated reflection coefficients for different value of t (thickness of “L” slot)

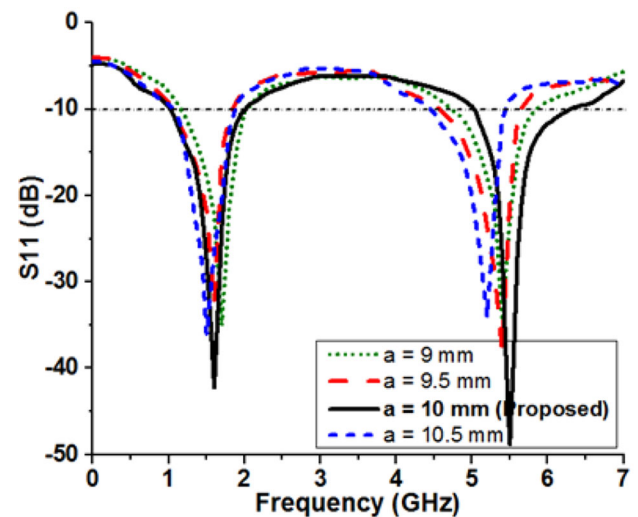


Fig. 5 Simulated reflection coefficient (S11) for the proposed antenna with different values of side length of square slot “ a ”

functionality. The other instances offer narrower bandwidth with resonance shift which are not acceptable for intended applications. Regulating the side length value of the square slot “ a ” have substantial effects on the reflection coefficients (S11) which are plotted against frequency as shown in Fig. 5. Out of the varying side length (from 8.0 to 10.5 mm), it can be seen that $a = 10.0$ mm produces a better impedance matching which in turn offers the expected resonant mode of operation and wanted bandwidth.

Some other key design parameters for the proposed geometrical structure of the antenna are also considered for parametric investigations to understand their effects. To increase the aperture area and thereby strengthening the overall radiation, the topmost portion of the radiating patch is

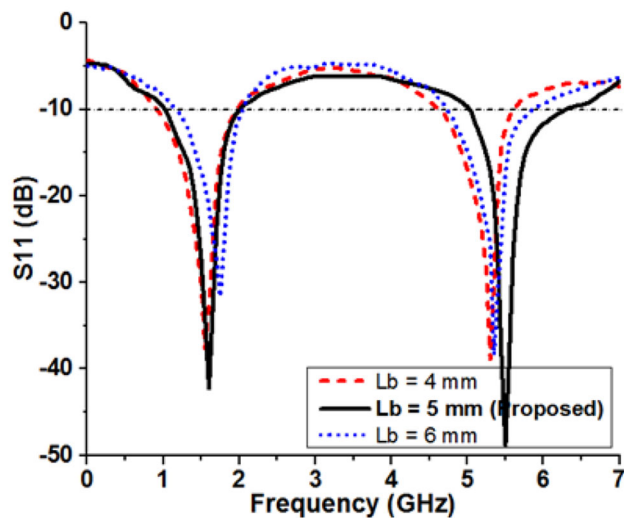


Fig. 6 Simulated reflection coefficient (S11) for the proposed antenna for different length of I -beam added at the top of radiating patch

extended by I -beam of around $\lambda/10$ wide (with respect to lower resonant mode) and $\lambda/40$ long inductive element. The length of the I -beam is generously adjusted so that it can give the widest bandwidth and intended resonant frequency as required for the applications. The effect of the tuning of I -beam length on the reflection coefficient (S11) for the proposed antenna is presented in Fig. 6. The inclusion of open square slot “ b ” at the top right corner of the radiating patch is also studied and the effects can be observed in Fig. 7. It can be clearly seen that the side length of 10.0 mm of the square open slot gives optimum antenna performances in terms of lowest reflection coefficient and widest bandwidth at expected resonant mode of operations.

In recent times, the researchers have carried out extensive research on the utilization of reduced/defected ground plane which has serious effect on antenna bandwidth and radiation efficiency [20–22]. The elementary theory of electromagnetic radiation relies on the concept that an equal magnitude and opposite phase surface current is induced on the finite and complete ground plane which may be responsible to generate coupling mismatch and give rise to cross polarization effect. Whereas, using the reduced or defected ground plane by avoiding the radiating patch area may help to minimize the cross polarization effect. Figure 8 presents the effects of ground plane size with different lengths, the curve for reflection coefficients are plotted against operating frequency bands. A optimize ground plane of 5.0 mm long and 40.0 mm wide is proposed for the dual band antenna since it gives much broader frequency bands at the intended resonant mode of operations.

A study has also been performed by using four different dielectric material substrates and presented through Fig. 9. The analysis would help to investigate the effects

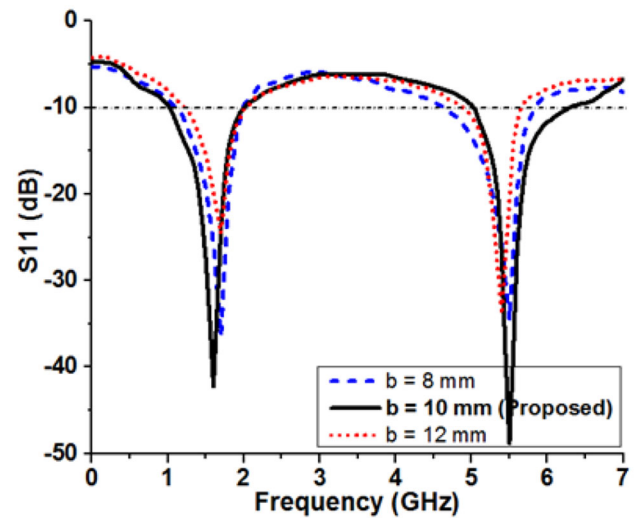


Fig. 7 Effect of change of side length of square slot “ a ” on the reflection coefficient (S11) of the proposed dual band antenna

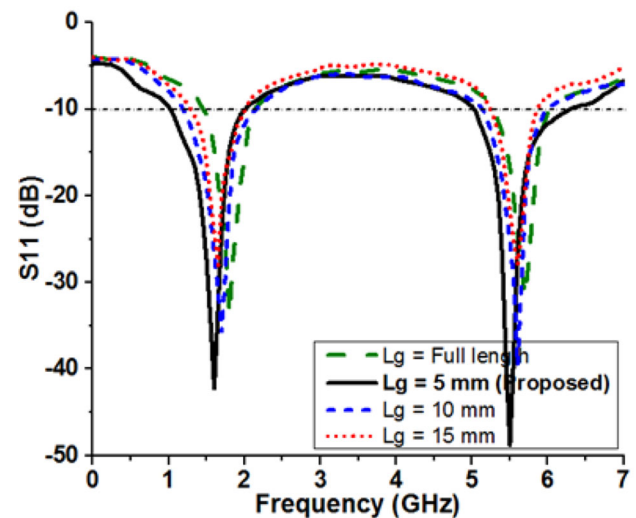


Fig. 8 Different lengths of ground plane and their effect on the reflection coefficient (S11) of the proposed antenna

of the different substrate materials on impedance bandwidth. The chosen substrate materials are Ceramic–PTFE ($\epsilon_r = 10.2$, $\tan\delta = 0.0023$), Ceramic Thermoset Polymer Composite ($\epsilon_r = 6.3$, $\tan\delta = 0.0023$), Epoxy Resin Fiber-Glass ($\epsilon_r = 4.6$, $\tan\delta = 0.02$) and Glass-PTFE ($\epsilon_r = 2.2$, $\tan\delta = 0.0009$). It can be clearly observed from the figure that ceramic–PTFE composite material substrate provides wider bandwidth and lower return loss value for the proposed antenna geometry. Due to the higher relative permittivity (dielectric constant $\epsilon_r = 10.2$), low dielectric loss (0.0023) and tight dielectric constant, ceramic–PTFE composite material offers better performance compared to the other three substrate materials.

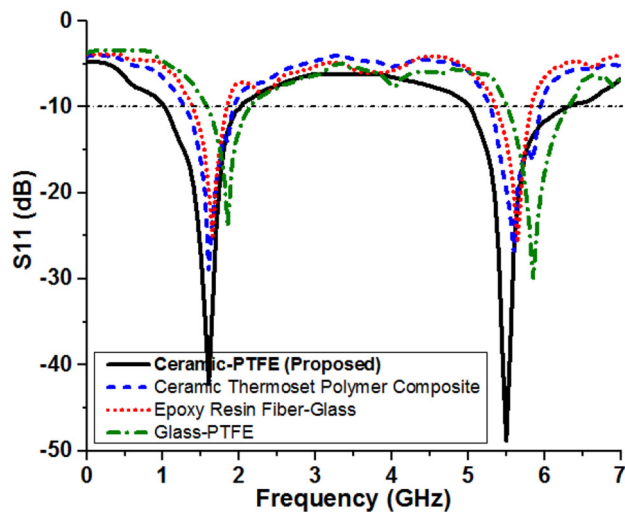


Fig. 9 Reflection coefficient (S_{11}) versus frequency for four different substrate materials

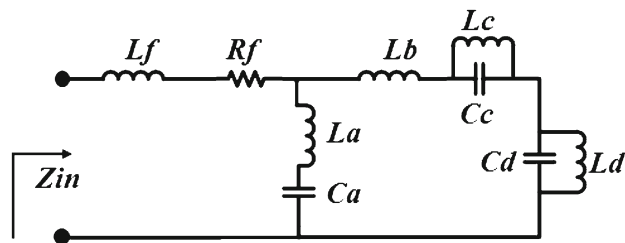


Fig. 10 Conceptual equivalent circuit model of the proposed antenna

A conceptual Equivalent Circuit Model for the proposed antenna has been considered to serve as an additional design perspective. As depicted in Fig. 10, the proposed circuit model is formed by superimposing the circuit model for the loading elements (slot and patch element). However, further analysis has to be carried out using any reliable Simulation Program with Integrated Circuit Emphasis package to validate the equivalent circuit model and find the parametric values of RLC components.

4 Results analyses

The final design of the proposed antenna with the optimal dimensions listed in Table 1 is fabricated on ceramic-polytetrafluoroethylene high frequency laminates composite material substrate which has a dielectric constant of 10.2. Figure 11 illustrates the photographic view of the fabricated antenna. The physical module of the proposed antenna is measured in a standard anechoic chamber with the help of Agilent E8362C vector network analyzer (VNA). The gain of the antenna is measured by following the three antenna method where two identical horn antennas are used as a reference [23, 24] and the radiation patterns are measured inside

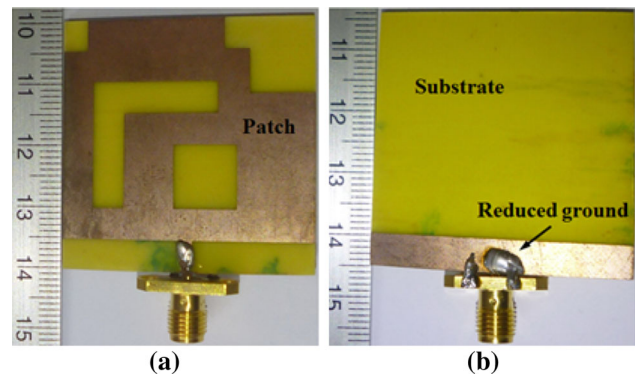


Fig. 11 Photograph of the proposed antenna **a** front view **b** back view

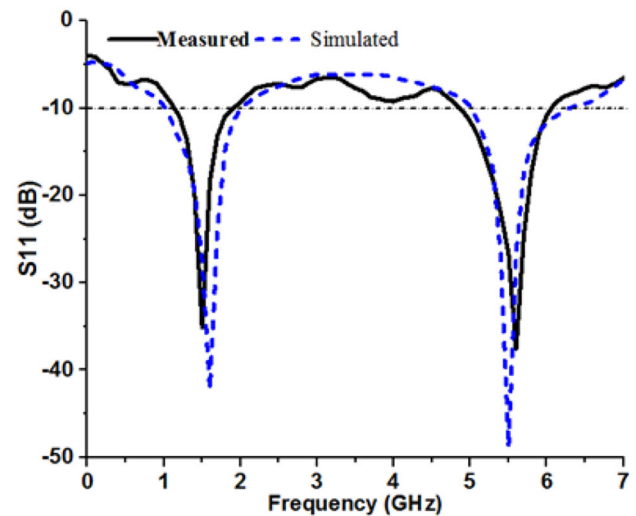


Fig. 12 Measured and simulated reflection coefficient (S_{11}) of the proposed dual band antenna

the standard anechoic chamber where specially designed software is used for controlling the entire system.

The simulated and measured reflection coefficients (S_{11}) of the proposed antenna are given in Fig. 12. From the figure it can be clearly observed that the curves for measured and simulated data indicate reasonable agreements. Undoubtedly, the measured -10 dB impedance bandwidth of the lower resonant band of 780 MHz (1.13–1.91 GHz) is wide enough to cover both of the GPS L1/L2 bands and for higher resonant mode of 1.22 GHz (4.83–6.05 GHz) bandwidth can successfully cover the WLAN 802.11a standard operates in 5.2/5.8 GHz frequency bands. The measured data also show the minimum reflection coefficient of -35.4 and -37.9 dB at the resonant frequency 1.48 and 5.61 GHz respectively. The slight differentiation (less than 5%) between the measured and simulated data may be partly attributed from the fabrication tolerance, cable loss and imperfection in measurement.

The simulated surface current distribution of the proposed antenna at 1.5 and 5.5 GHz accomplished by HFSS are shown

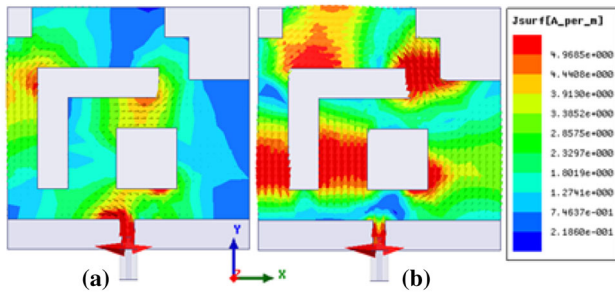


Fig. 13 Simulated surface current distribution of the antenna **a** 1.5 GHz and **b** 5.5 GHz

in Fig. 13. The figures show that the current distributions for both of the frequencies are different from each other. For the lower frequency band at 1.5 GHz, the surface currents are appeared to concentrate on the area near the connection between the feed line and patch, top left edge of the “L” slot and in between the top portion of the square slot “a” and “L” slot. This certainly verifies that the lower resonant frequency is excited with the influence of “L” slot and wide square slot “a”. On the other hand, increased intensity of surface currents at higher frequency band of 5.5 GHz is seen in different areas other than the lower resonant mode. For higher frequency, the surface currents are seen to be concentrated on the bottom edge areas or “L” slot, the zone between the I-beam and “L” slot and the space between the open square slot “b” and “L” slot. The current distribution phenomenon in this case signifies the inclusion of inductive element I-beam and wide open square slot “b” to achieve the second resonant frequency and desired bandwidth.

The measured far-field radiation patterns normalized in E- and H-plane for the proposed antenna at 1.5 and 5.5 GHz are shown in Fig. 14. For both of the frequency bands, the radiation patterns are seen nearly symmetric and with very good broadside radiation. The cross polarization effects are less than -30 dB and for higher resonant frequency the radiation deteriorates slightly. This may be due to the asymmetrical radiation from patch for asymmetrical loading of different slots on its surface and reduced ground plane. The variation of measured gain and radiation efficiency of the proposed antenna is plotted against frequency which is illustrated in Fig. 15. The antenna has achieved maximum gains of 3.42 and 4.37 dBi, and maximum radiation efficiency of 82.4 and 84.3% for lower frequency and upper frequency band respectively. The Smith chart of the proposed antenna is presented in Fig. 16, which can be used to validate the input impedance and voltage standing wave ratio (VSWR). From the figure it can be identified that two resonant frequencies are resided inside VSWR 2:1 circle and the input impedances are complied with the standard 50Ω characteristic impedance. In the attached table, the Rx values are associated with the input

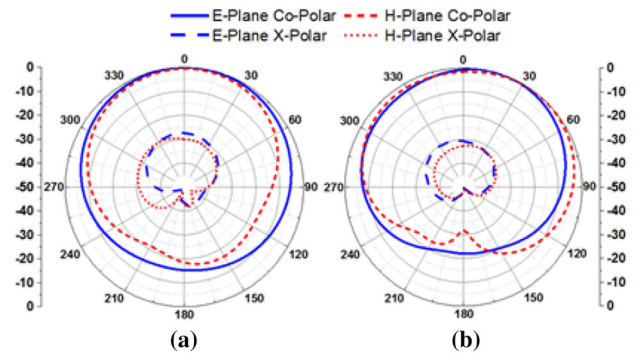


Fig. 14 Radiation patterns of the proposed antenna measured at **a** 1.5 GHz and **b** 5.5 GHz

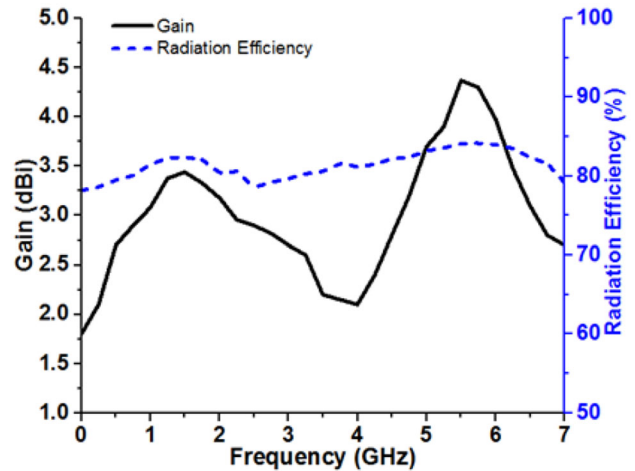


Fig. 15 Measured gain and radiation efficiency of the proposed antenna versus frequency

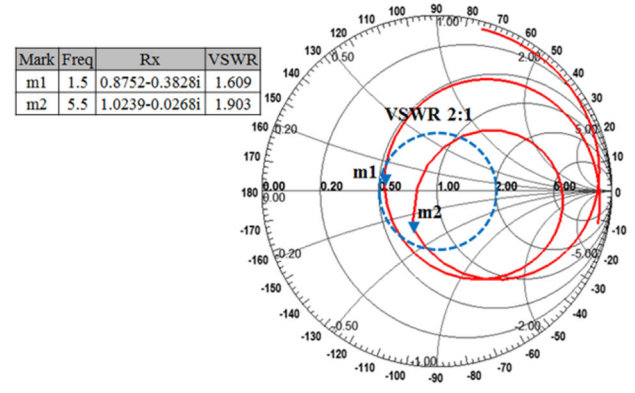


Fig. 16 Smith chart of the proposed antenna

impedance in Smith chart and the marker m1, m2 represent the resonant frequencies.

Table 2 shows the performance comparison between the proposed and some of the relevant reported antennas. Comparing the listed parameters, the proposed antenna offer wider bandwidths with adequate gain in compare to the relevant

Table 2 Performance comparison between the proposed and relevant reported antennas

References	Patch area, mm ²	Frequency band, GHz	Bandwidth, MHz	Ref. coefficient (S11), dB	Max. gain, dBi
[8]	50 × 50	1.54, 5.73	670, 1130	−12, −16	N/A
[11]	30 × 30	1.8, 4.8	1000, 1143	−15, −17	3.1, 3.1
[13]	32 × 22.6	1.6, 3.5, 5.5	420, 590, 1500	−25, −12, −14.5	1.81, 3.52, 4.36
[14]	56 × 44	1.575, 2.45, 3.5, 5.2	90, 145, 700, 760	−22.5, −18, −13.5, −20	3.55, 3.93, 5.02, 4.86
This work	40 × 35	1.5, 5.5	780, 1220	−35.4, −37.9	3.42, 4.37

reported antennas. Based on the overall aperture area, the proposed antenna offers wide bandwidths, low reflection coefficients and higher gains at the GPS and WLAN bands.

5 Conclusion

A dual band modified rectangular slotted patch antenna with microstrip feeding has been proposed in this paper which can cover L1/L2 GPS and 5.2/5.8 GHz WLAN frequency bands. The fabricated antenna has got simple structure with combination of rectangular shaped slots and extension and overall patch volume is $40 (W) \times 35 (L) \times 1.905 (h) \text{ mm}^3$. Through numerous simulations in HFSS, the geometry of the antenna is optimized and regulating certain key parts of the antenna may lead to achieve intended frequency or resonances and adequate bandwidths. The optimized parametric values are used for fabricating the antenna on ceramic–polytetrafluoroethylene composite material substrate with $\epsilon_r = 10.2$ and it has been found that the experimental results agreed well with the simulation results. The proposed antenna shows good radiation properties, acceptable gains over the operating bands and sufficient impedance bandwidths which are suitable to cater the services in GPS and WLAN applications.

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