

Design and study of a microstrip slot antenna operating at 2.8/3.1/3.6/4.7/5.4 GHz

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Abstract. A novel design of a multi band microstrip antenna is presented in this work. The double modified U slots planar patch antenna is designed, simulated and fabricated to operate at 2.8 GHz (between 2.794 to 2.846 GHz), at 3.1 GHz (between 3.145 to 3.196 GHz), at 3.6 GHz (between 3.56 to 3.3.644 GHz), at 4.7 GHz (between 4.684 to 4.772 GHz) and at 5.4 GHz (between 5.423 to 5.526 GHz) for WiMAX/WLAN applications. One of the main challenges was keeping a low profile and low cost substrate (1.2mm and FR4 respectively) with penta-band frequency response without scarifying these characteristics. Each resonant frequency is accomplished by modifying each U slot and patch radiator itself. Simulations had been conducted using HFSS software and measured parameters such as reflection coefficient (S11 parameter) was performed with a vector network analyzer. Measured results confirm simulated results that the antenna could work within mentioned frequencies. Parametric study was conducted in order to study the effect of slots variation over the design.

1 Introduction

As a result of development of wireless and satellite communication systems, came out the miniaturization of electronic components and therefore the appearance of microstrip technology and its antennas [1]–[4]. These miniaturization in telecommunications has become more evident during the last 35 years impulsed by low profile devices such as smartphones [5], radio frequency identification systems (RFID) [6], wearable devices [7], and so on; reason why studying, designing and fabricating microstrip antennas (MSA) still receive attention by researchers around the world. Part of this attention recalls to overcome MSA disadvantages such as low gain, narrow bandwidth and so on; and improve its advantages such as low profile, low cost, capable to work at multi-frequency bands, among other characteristics; enabling these structures to be applied on current wireless communication system.

Multiband microstrip antennas are required because current and future devices must be able to communicate each other through different standards, which mean different frequencies band [8], also the antennas used at base stations use array microstrip antenna to deploy telecommunications networks, satellite communication antennas, along with other applications. In order to achieve multi-frequency response several techniques have been applied such as electromagnetic band gap structure (EBG) [9], ring resonator, defected ground structure antenna (DGS) [10], multilayer antenna, reconfigurable antennas [11], slots antennas [12], etc. Among these variety of designs, slot antennas offer several advantages such as keeping a low profile structure, single designs (which makes available for

mass fabrication), bandwidth improvements, multi-frequency response along other antenna improvements. But within slots antenna technique there are options designs to achieve researcher's goal. Some of these options are design the patch radiator with alphabet letter shape such as, L shape [13], S shape [6], F shape [14] and U shape [15]–[17] among others. In this paper, a modified double U slot planar microstrip antenna is designed, simulated and fabricated to operate at 2.8/3.1/3.6/4.7/5.4 GHz for wireless communication such as WiMAX/WLAN applications.

2 Antenna design

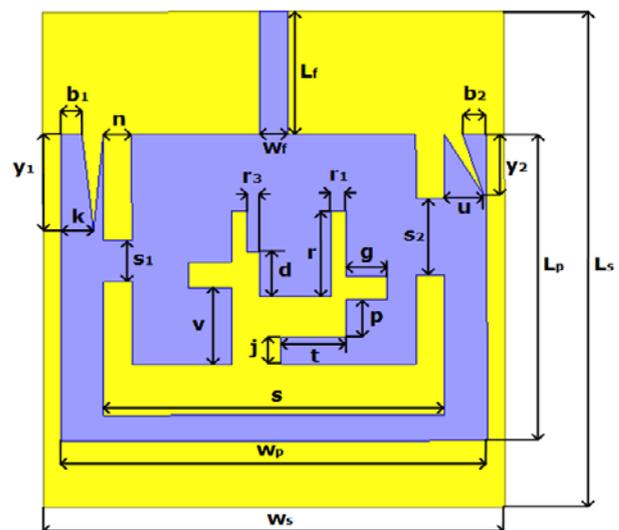


Fig. 1 Antenna Design Parameters

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The geometry of the proposed antenna is shown in Fig. 1. The antenna is designed and simulated on a FR4 substrate with relative permittivity $\epsilon_r = 4.4$; the substrate is easy to get in domestic market and also less expensive than other used antenna substrates for high-frequency applications, with a thickness $h = 1.2\text{mm}$, and a loss tangent $\delta = 0.02$ using HFSSv17.2 which is based on Finite Element Method (FEM), the rest of parameters are summarized in Table 1 and Table 2.

Table 1 Parameters Design

Parameter	Value (mm)	Parameter	Value (mm)
Ls	38.8	n	2
Ws	32.5	k	2.3
h	1.2	s1	3.2
Lp	24	s	24
Wp	30	s2	6
Wf	2	b2	1.7
Lf	9.6	y2	4.8
b1	1.5	u	2.8
y1	5.5	r2	0.9

Table 2 Parameters Design

Parameter	Value (mm)
d	3.5
v	6
j	2.1
t	4.6
p	3
g	2.9
r3	6.7
r2	1.1

Based on [15]–[20], the U slot technique offers the opportunity to get multi-frequency operation in the same way as the slots allow to add one or more resonance frequency or shift them to desired ones keeping a low profile antenna, however most of those designs are fed by coaxial connector and either patch radiator or slots are no modified in deed. Moreover, other designs [21]–[23] shows U slots patch antenna feeding by stripline getting compact design and multi-frequency response. For this reason the mentioned technique is used to get multiband operation in current research.

3 Simulation results

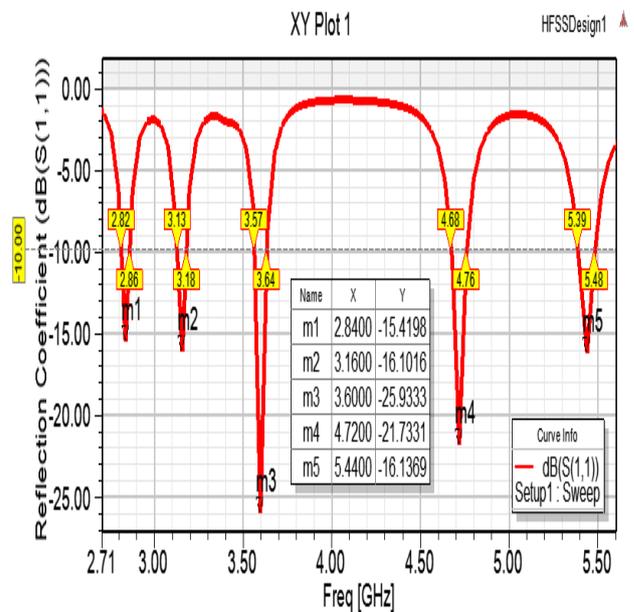


Fig. 2 Reflection Coefficient (S11 Parameter)

Based on reflection coefficient results (S11 parameter curve) of Fig. 2, it is emphasized that at the 1st frequency band of 2.8 GHz the resulting impedance bandwidth is going from 2.817 to 2.863 GHz, getting the lower reflection coefficient of -15.4198dB at 2.84 GHz, at 2nd frequency band of 3.1 GHz the impedance bandwidth is going from 3.131 to 3.184 GHz with the lower reflection coefficient of -16.1016dB at 3.16 GHz, at the 3rd frequency band of 3.6 GHz the impedance bandwidth is going from 3.565 to 3.636 GHz with the lower reflection coefficient of -25.9333dB at 3.6 GHz, at the 4th frequency band of 4.7 GHz the impedance bandwidth is going from 4.677 to 4.76 GHz with the lower reflection coefficient of -21.7331dB at 4.72 GHz, and at the 5th frequency band of 5.4 GHz the impedance bandwidth is going from 5.389 to 5.483 GHz with the lower reflection coefficient of -16.1369dB at 5.44 GHz to operate for WiMAX and WLAN applications.

In order to further study the penta-band operation properties of the proposed antenna, surface current distributions (A/m) of the whole antenna at frequencies of 6 (solution frequency), 2.8, 3.1, 3.6, 4.7 and 5.4 GHz are given in Fig. 4–9.

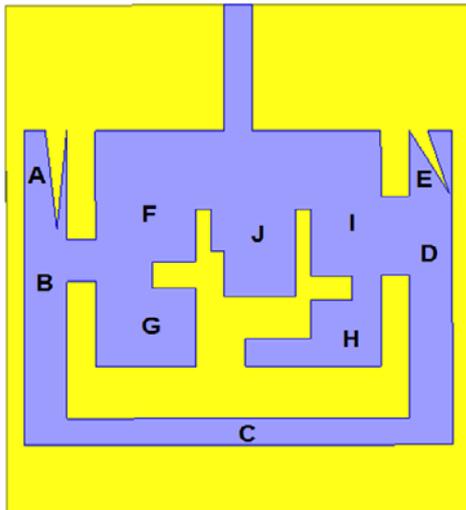


Fig. 3 Antenna Regions

shown in Fig. 3 for better understanding on current density paths.

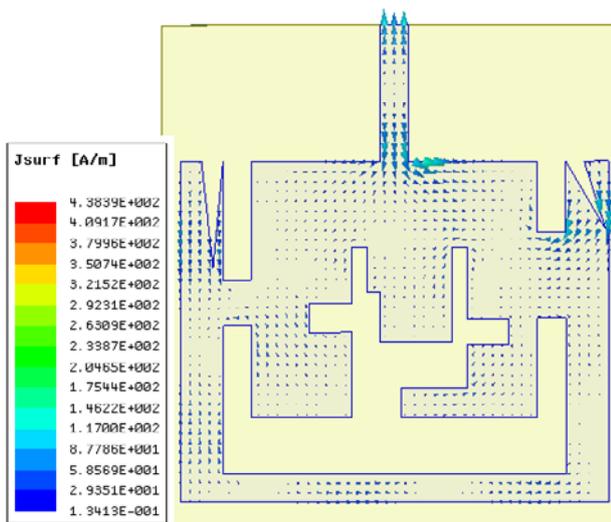


Fig. 4 Vector of Surface Current Density at 6 GHz

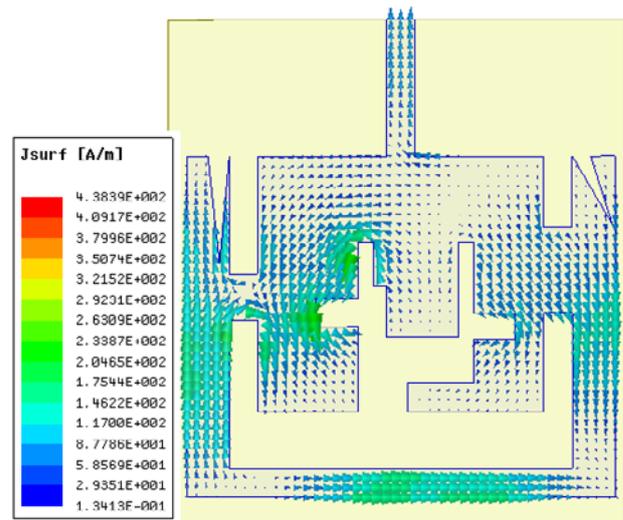


Fig. 6 Vector of Surface Current Density at 3.16 GHz

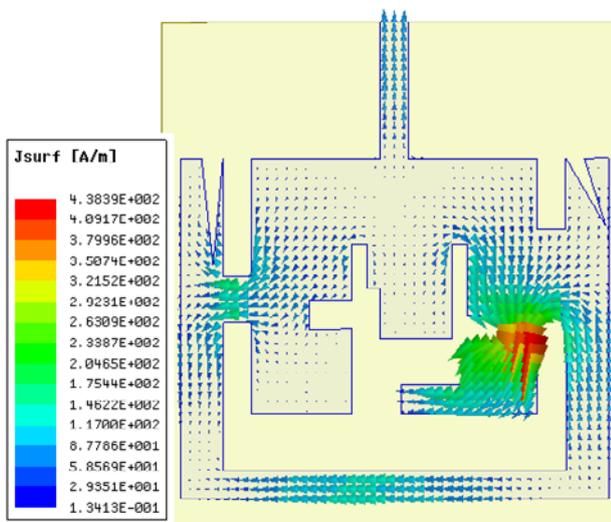


Fig. 5 Vector of Surface Current Density at 2.84 GHz

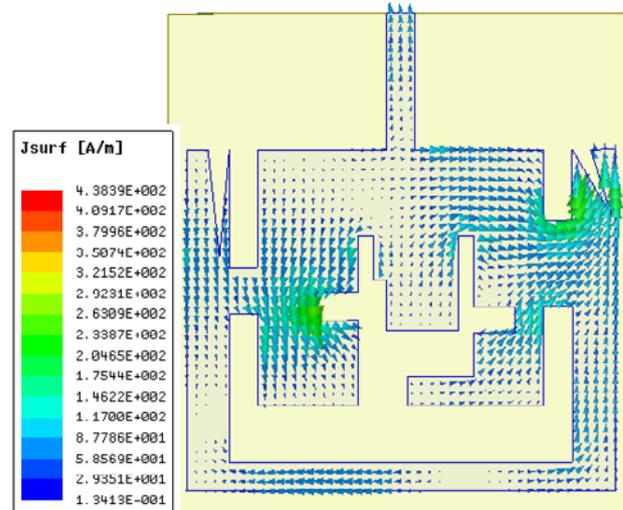


Fig. 7 Vector of Surface Current Density at 3.6 GHz

It can be clearly seen from these figures that the current distributions are different in all frequencies. The antenna has been divided in several regions (A-J) as is

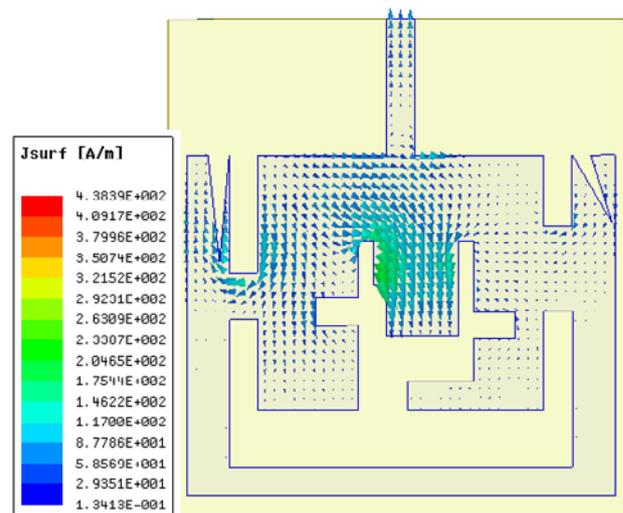


Fig. 8 Vector of Surface Current Density at 4.72 GHz

In Fig. 4 for instance, the current has a very low flow and magnitude, which means that the patch radiator is not excited at this frequency as is it was expected. But, when the antenna operates at 2.8 GHz it was noticed that the current flows from I and D to H region where is mainly concentrated having the strongest magnitude, also is possible to observe a moderate current density flowing from F to B region and from right to left of C region as is shown in Fig. 5. This clearly indicates the importance of the slots defined by g , p , s_2 and t parameters on the proposed antenna resonance response.

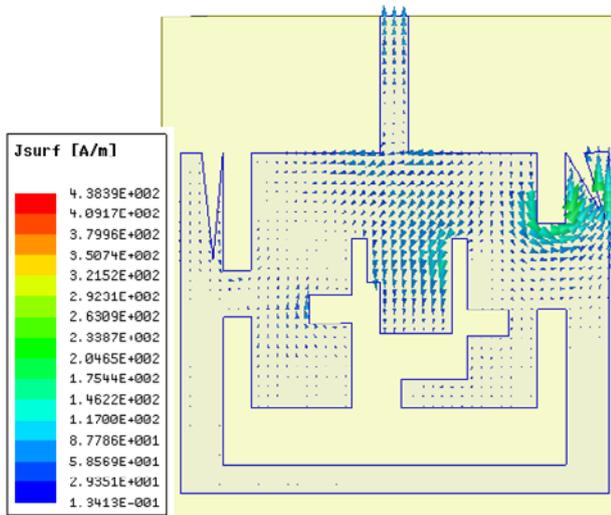


Fig. 9 Vector of Surface Current Density at 5.44 GHz

Fig. 6 shows that the current has uniform distribution at B, C, D, F and G regions. The current paths flows from upper to lower side of B region, from left to right side of C region, from lower to upper side of D region and from F to G region, acting these areas as the resonator for the antenna at 3.6 GHz. At 3.6 GHz the current is flowing from I, H and D regions to E region, also from F to G region, making possible to observed the highest current magnitude at E and G regions and weak magnitude at A, B and C regions, making E and G regions antenna resonate at mentioned band as is shown Fig. 7 which makes the antenna resonate at this frequency.

Fig. 8 shows that the surface current is going from F to J region with highest magnitude and concentration at J region which mean this area is excited and resonate at 4.7 GHz. The J and E regions acts as resonator at 5.4 GHz as the flow path of surface current is going from I to E region and from upper side to lower side of J region, concentrating the highest density and magnitude at mentioned frequency as is shown in Fig. 9.

Controlling the reactance inductive and reactance capacitive contributions of each slot it is possible to do by modifying width, length and position of these structures, which mean that currents path is also modified. Therefore, resonance frequencies can be controlled towards higher and or lower ones.

Introducing slots on the antenna patch modified the current path and so can be used to generate and multiple resonance frequencies band, for WiMAX and WLAN applications.

The gain radiation pattern at solution frequency is shows in Fig. 10. Maximum gain occur at $\phi = 190$ and $\phi = 360$ degrees.

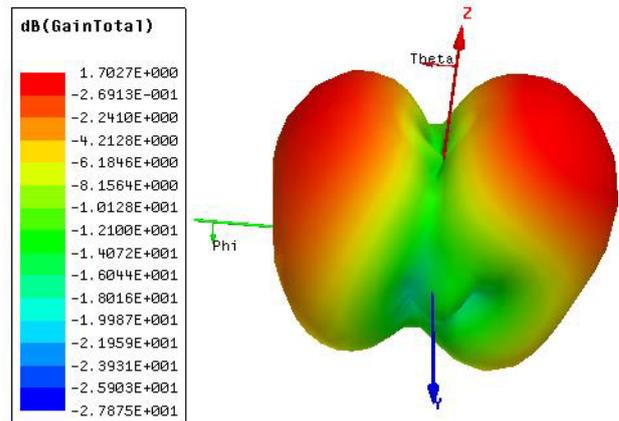


Fig. 10 Gain-Radiation Pattern

4 Parametric Study

Parametric study of planar patch microstrip antenna is conducted by varying the width, length and position of slots antenna to understand how it does affects these variations over the resonance frequencies, impedance bandwidth and reflection coefficient values

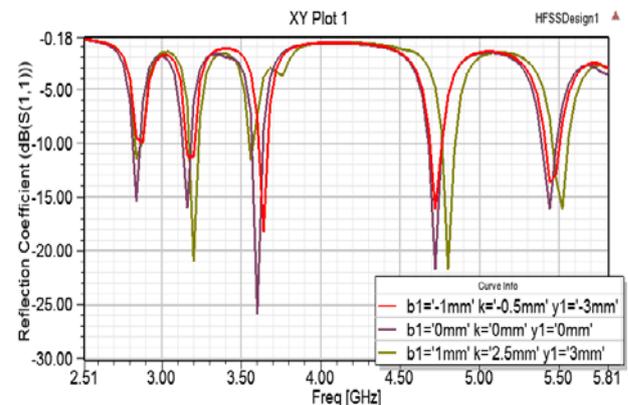


Fig. 11 Parameters b_1 , k and y_1 .

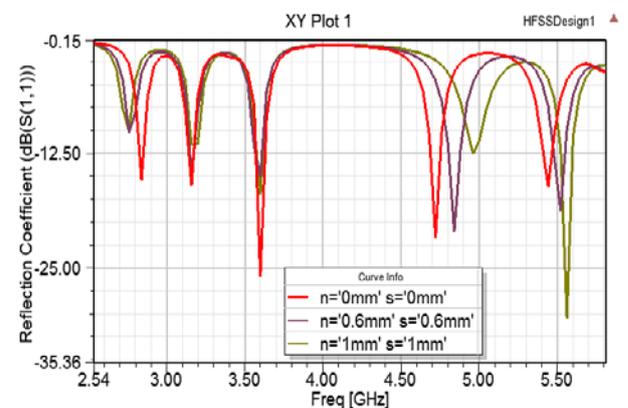


Fig. 12 Parameters n and s .

As it can be seen from Fig. 11 it is possible to study the effects of the slot variations defined by parameters b_1 , k and y_1 .

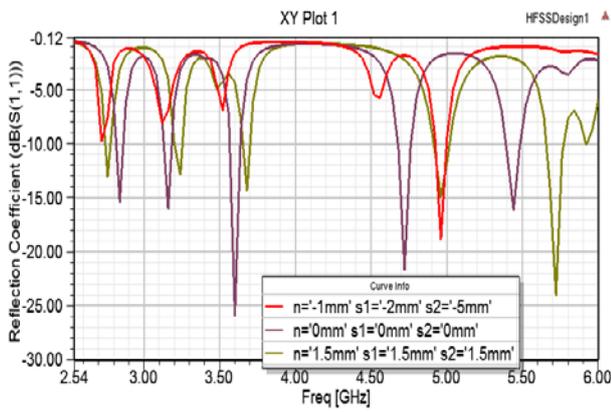


Fig. 13 Parameters n , $s1$ and $s2$

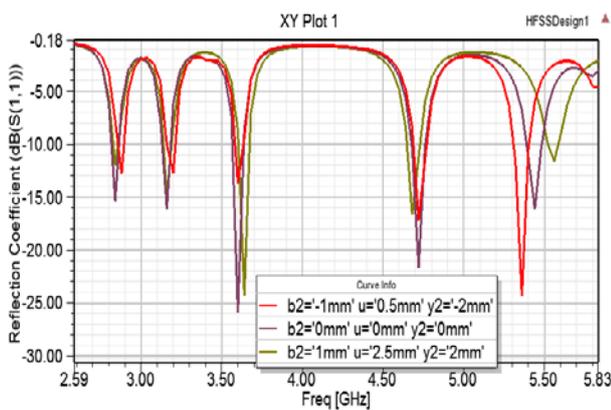


Fig. 14 Parameters $b2$, u and $y2$

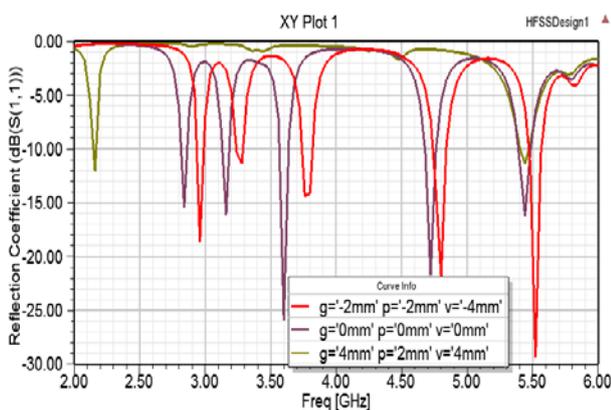


Fig. 15 Parameters g , p and v

When mentioned parameters decrease, the reflection coefficient values for all frequencies increase compare with same parameters without modifications, and the 1st frequency is suppressed; but when the parameters increase their dimensions is possible to observe that the 4th and 5th resonant frequencies are moved toward higher ones and 1st and 3rd frequencies have higher reflection coefficient values. It is also possible to observe that at 2nd, 4th and 5th frequency the reflection coefficient values are lower or equal than without modifications.

As either parameters increase or decrease, the impedance bandwidth shown in most cases a decrement. When parameters n and s increase their dimensions from 0 to 0.6 and then to 1 mm, the 4th and 5th frequency changes toward higher ones, also is possible to evidence that the 1st, 2nd, 3rd and 4th frequencies increase their

reflection coefficient values suppressing the 1st frequency band as is shown in Fig. 12.

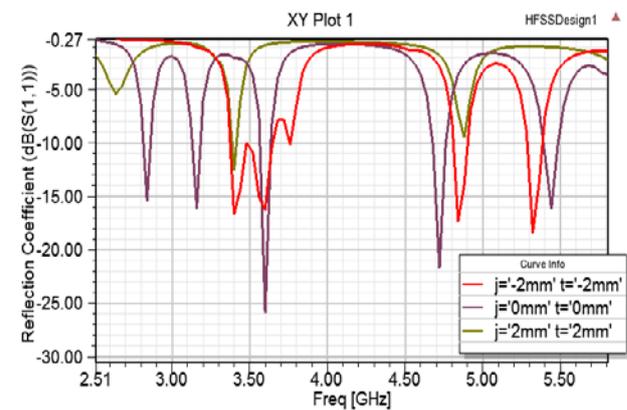


Fig. 16 Parameters j and t

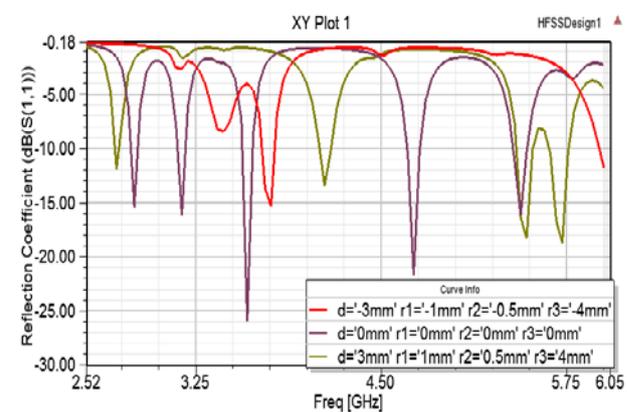


Fig. 17 Parameters d , $r1$, $r2$ and $r3$.

Fig. 13 shows the results of variation parameters of n , $s1$ and $s2$. When the slot parameters decrease, it shows the suppression of frequencies 1st to 4th (return loss greater than -10B) and the 5th frequency is shifted to 4.9 GHz, but when slots dimension increase the resonating frequency is shift to higher frequency band (from 2nd to 5th frequency band) but the 1st frequency changes to lower resonance frequency).

The effects of slot parameters defined by $b2$, u and $y2$ are simulated as is shown in Fig. 14. Decreasing slots dimension defined by the mentioned parameters are reflected by the increment of reflection coefficient values for 1st to 4th frequency band and decrement and shifting to lower resonating of 5th frequency band, but the increment of slot dimension mean an increment of reflection coefficient for all frequencies.

When slot dimension defined by g , p and v decreases the antenna exhibit a shift to higher frequencies for the five bands, however when variations include the increment of slot dimensions the antenna resonate at two bands at 2.2 GHz and 5.4 GHz band as the other three frequencies are suppressed at all as is shown in the Fig. 15.

As Fig. 16 shows, there is a shift toward to higher resonance frequencies when parameters g , p and v decrease their values and the antenna become a dual band antenna when mentioned parameters decrease their values suppressing the other three frequencies band.

A suppression of four frequencies is shown in Fig. 17 when the parameters d , r_1 , r_2 and r_3 present a decrement of their dimensions making the antenna resonate at only one frequency band (3.7 GHz) suppressing the other four; but when parameters increase their values, the antenna resonate at four frequencies. It can be also observed a remarkable difference between parameters variations results, indicating a highly sensitivity of mentioned parameters to these variations.

5 Fabrication and Measurement

The antenna was made using the LPKF ProtoMat S103 circuit board plotter for producing PCB/antenna prototypes. Once the antenna was fabricated (top and bottom view of fabricated antenna are shown in Fig. 18, the reflection coefficient parameter was measured (S11).

As shown in Fig. 19 there is a good agreement between simulated and measured results. Some discrepancies can be seen between the simulated and measured results, which may occur because the effect of the SMA connector, the fabrication imperfections and the measurement calibration while using the VNA.

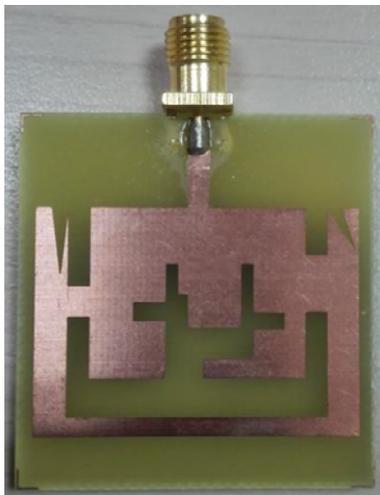


Fig. 18 Top View Fabricated Microstrip Antenna

The antenna resonates at 2.8 GHz (between 2.794 to 2.846 GHz), at 3.1 GHz (between 3.145 to 3.196 GHz), at 3.6 GHz (between 3.56 to 3.3.644 GHz), at 4.7 GHz (between 4.684 to 4.772 GHz) and at 5.4 GHz (between 5.423 to 5.526 GHz) for WiMAX/WLAN applications.

In this design, if the slots are absent, the antenna will only have one major current path on each of the patch elements. However, in the presence of the current slots, the current path on each of the patch elements is disturbed and perturbed, hence creating the penta-band operation.



Fig. 19 Simulated vs Measured Results

3 Conclusions

In the current work, a penta-band antenna with two modified U slots is designed, simulated and fabricated without modifying the ground plane, keeping a low profile (1.2mm) and using a low cost substrate (FR4). The antenna parameters were simulated using HFSS software and measurements were developed with a Vector Network Analyzer for impedance matching. Simulated and measured results show that the antenna resonates at 2.8 GHz (between 2.794 to 2.846 GHz), at 3.1 GHz (between 3.145 to 3.196 GHz), at 3.6 GHz (between 3.56 to 3.3.644 GHz), at 4.7 GHz (between 4.684 to 4.772 GHz) and at 5.4 GHz (between 5.423 to 5.526 GHz) for WiMAX/WLAN applications.

Slots played a key role as they control the resonance frequencies. Adjusting accordingly width length and position modified current distribution concentrated at slots and then modifying the resonance frequencies, facilitating the antenna to resonate at other three frequencies.

Therefore, the designed antenna can work within WiMAX and WLAN compliance applications. Current antenna may work as a reference for future works related to optimization and improvement of slotted planar patch antennae looking to miniaturize current dimensions, improve gain or modifying other desired characteristics aiming to improve it.

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