Compact and Small Planar Monopole Rectangular Patch Antenna with Symmetrical Maze-Shaped Slots for BLUETOOTH/WLAN/IMT Applications

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***Abstract*- Microstrip patch antennas are useful in antenna wireless applications because they are simple, lightweight and cheap to fabricate, and compatible with printed-circuit technology. A small and compact triple-band microstrip-fed antenna with defected ground plane for Bluetooth (2.4 GHz), International Mobile Telecommunications (IMT-4.5 GHz) and Wireless Local Area Network (WLAN-2.4/5.2 GHz) is designed.The proposed antenna consists of a rectangular radiating metallic patch with symmetrical maze shaped slots and defected ground plane. The proposed antenna is small (15×15×1.6 mm^3) when compared to general multibandpatch antennas. The antenna proposed is designed and simulated using computer simulation technology (CST). The simulation and measurement results show that the designed antenna is capable of operating over the 2.4–2.5 GHz, 4.4–5.0 GHz, and 5.1–5.39 GHz frequency bands. Radiation pattern and acceptable antenna gain are achieved over the triple operating frequency bands.**

***Index Terms*—Monopole antennas, multiband antennas, wireless area network (WLAN), triple band antennas, CST, VSWR and S_{11}.**

I. INTRODUCTION

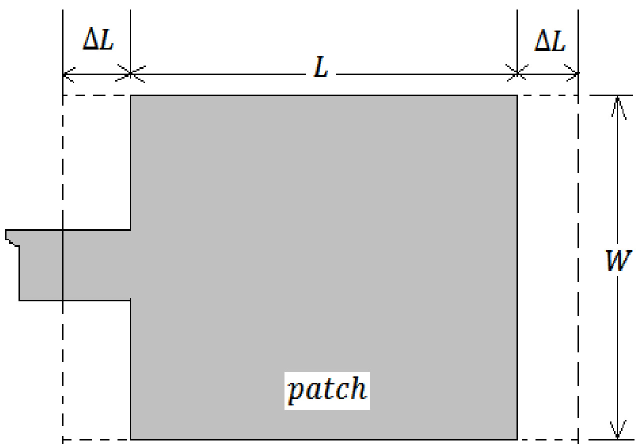
Microstrip antennas are widely used in many applications but suffer from narrow bandwidth which can limit their uses in some modern wireless applications, therefore, there is an increasing demand for low-profile, low cost,easy to fabricate, and multiband/wideband antennas which can be easily integrated within communication systems [1]. A variety of studies have come up with different methods to achieve multiband/wideband operation for printed antennas.Some of the methods employed are changing the physical size of the antenna, by coupling multiple radiating elements distances (which sometime increases the antenna size) [2], by using tuning devices such as varactor diodes [14] or by adding additional parts such as multi layers (which again makes the antenna larger and of a higher profile) [3]. However, these techniques make antenna more complicated, large in sizes and difficult to fit into small and slim devices. A simple technique to achieve the multiband characteristic in a microstrip antenna is embedding a slot of different shapes such as U-slot, E-slot, H-slot or L-slot in the rectangular patch[6]-[7]. In microstrip antennas, embedded slots can also be used to enhance the impedance bandwidth of a multiband antenna[4].

Microstrip patch antennas are being used in a variety of applications like aircrafts (communication and navigation altimeters), in mobile radio (pagers and hand telephones, man pack systems), in biomedical applications (such as microwave cancer therapy) and radar systems [1]. However, two drawbacks of the microstrip antennas are its low gain and narrow bandwidth. To overcome these limitations, many techniques have been proposed and investigated, for example antennas are fabricated on somewhat low–dielectric constant ($\varepsilon_r \leq 10$) [1], microstrip patch antennas on thick substrates, folded shorting wall [5], slotted patch antennas and gap coupled patches [8]-[9]-[13]. This ensures good radiation efficiency and larger impedance bandwidth of the antenna.

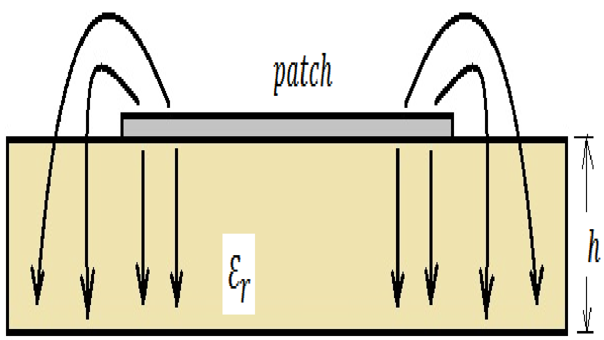
This designed presents, a small microstrip-fed antenna with defected ground plane and is designed for triple-band operation.It satisfies the following operational bands: 2.4-GHz WLAN(2.4–2.484 GHz specified by IEEE 802.11b/g standards), 2.4-GHz BLUETOOTH (2.4–2.5 GHz), 4.5 GHz IMT (4.4-4.9 GHz),and 5-GHz WLAN (5.15–5.35GHz specified by IEEE 802.11a standards). Triple-band operation of the proposed and designed antenna is achieved by cutting symmetrical maze shaped slots inside the compact rectangular patch. The proposed antenna has a low profile of 15×15×1.6 mm^3. Simulated results of triple band antennas are presented along with the measured results of the triple band antenna. The simulation is carried out via CST software.

II. ANTENNA DESIGN AND CONFIGURATION

In this letter, all the designing parameters as shown in fig. 1 are calculated using standard patch relationship and then antenna is designed. The microstrip patch antenna in figure (1(a) and (b)) looks longer than its physical dimensionsbecause of the effect of fringing. The effective length therefore is differing from the physicallength by Δl.



(a)



(b)

Fig. 1(a) Physical and Effective Length of a Microstrip Patch and (b) Electric Field Lines [10]

A very popular approximation to calculate the effective length of the patch is given by [10]

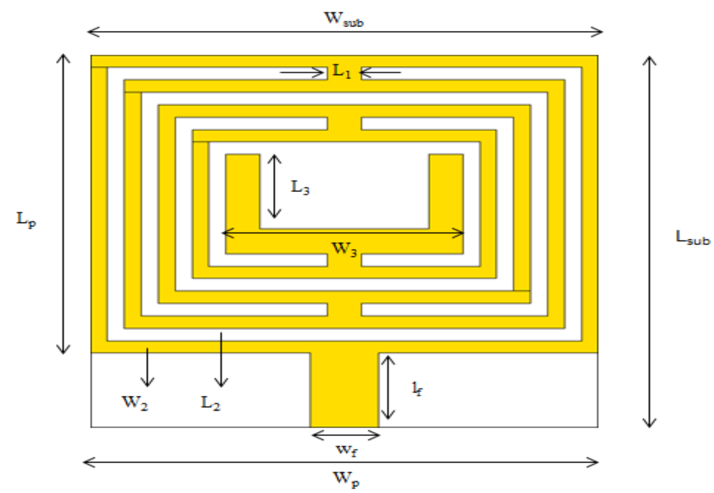
$$L = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} - 2\Delta l \qquad 2.1$$

$$W = \frac{c}{2f_r\sqrt{\frac{\varepsilon_r+1}{2}}} \qquad 2.2$$

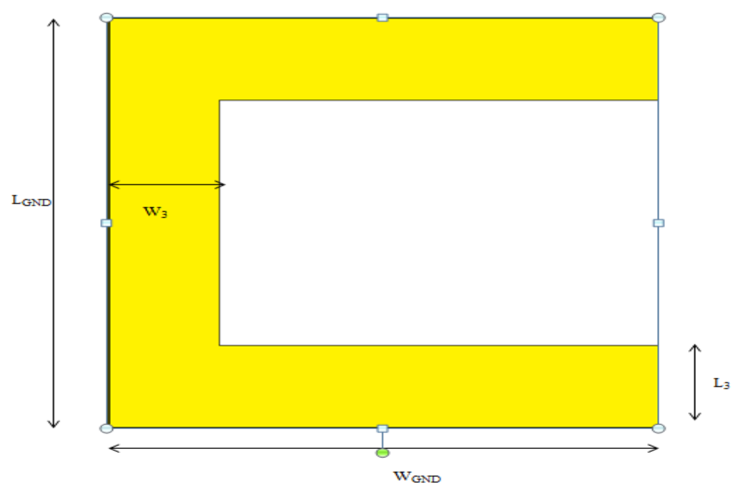
$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+\frac{12h}{w}\right) \qquad 2.3$$

$$\Delta l = \frac{0.412h\,[(\varepsilon_{eff}+0.3)(\frac{w}{h}+0.234)}{(\varepsilon_{eff}-0.258)(\frac{w}{h}+0.8)} \qquad 2.4$$

Where c is velocity of light, and f_r is resonating frequency; ε_r is dielectric permittivity; ε_{eff} is effective dielectric constant.



(a) Front View



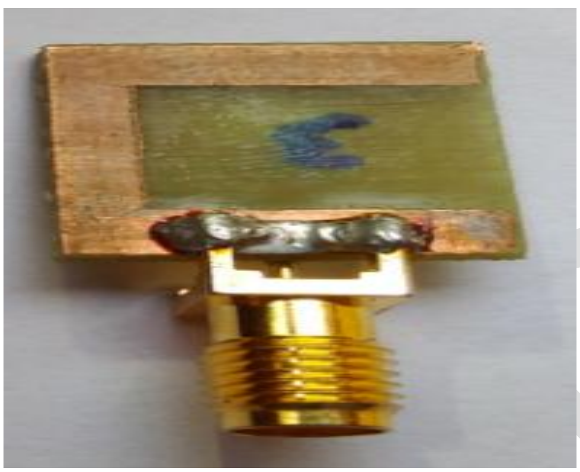
(b) Back View

Fig. 2. Configuration of the Proposed Antenna.

To design a small, compact and low profile antenna that provides the desired performance that includes omnidirectional radiation patterns at WLAN/BLUETOOTH/IMT frequency bands [11], the following design technique has been used. The dimensions of the patch antenna were significantly reduced, and symmetrical maze-shaped slots were cut out within the rectangular patch. The proposed monopole patch antenna is fed by a microstrip line partially backed by a defected ground plane [12] to provide the connection of the antenna to an external circuit.

Based on this design technique, the optimizeddimensions of thecompact monopole antenna including the size of thesubstrate and the ground plane are obtained using a parametric study. Extensive simulation has been performed usingthe CST software to get the values of reflection coefficient S_{11},surface current distributions, radiation pattern and gain.

(a)



(b)

Fig. 3. Prototyped Antenna (a) Front View and (b) Back View

Theschematic configuration of the proposed monopole antenna fed by a microstrip line for triple-band operation is shown in Fig. 2, which is printed on an FR4 substrate of thickness t_{sub}=1.6 mm,a loss tangent of 0.024and permittivity of ε_r=4.4. In this letter,the design of the proposed antenna is based on a microstrip-fed monopole antenna that is low-profile, simple and easy to fabricate, therefore we start by choosing the dimensions of the proposed antenna. These dimensions, including the substrate, are $W_{sub} \times L_{sub}$ = 7.5×7.5 mm^2.The antenna consists of a rectangular radiating patch with symmetrical maze shaped slots, a feedline, and a defected ground plane. Regarding defective ground structures (DGS), due to the slot in the ground plane, an additional current path is obtained [15]. Moreover, this defective ground structures (DGS) changes the capacitance and inductance of the input impedance, which in turn leads to a change in the antenna gain and bandwidth [16]-[17].A 12×7.5 mm^2rectangular patch is connected to a $w_f \times l_f$ = 2×3 mm^2microstrip feedline to achieve an impedance of 50 Ω.The optimal parameters of the designed antenna are shown in table 1, which is used to fabricate the antenna shown in Fig. 3.

TABLE 1
Dimensions of the Proposed Antenna (mm)

L_{GND}	W_{GND}	L_{sub}	W_{sub}	t_{sub}
7.5	7.5	7.5	7.5	1.6
l_f	w_f	L_p	W_p	L_1
3	2	12	7.5	1.0
W_1	L_2	W_2	L_3	W_3
1.0	0.5	0.5	3	7

The simulation results display threeresonant bands at frequencies of 2.4, 4.5, and 5.2 GHz is shown in Fig. 4, withbandwidths specified for S_{11}< -10dB, of about 100 MHz (2.4–2.5 GHz), 500 MHz (4.4–4.9 GHz), and 200 MHz (5.1–5.3 GHz), respectively.The experimental results display five resonant bands at frequencies of 2.4, 3.9, 4.3, 5.1 and 5.6 GHz is shown in Fig. 5, withbandwidths specified for S_{11}< -10dB.

III. Results and Discussion

An antenna prototype with the dimensions given is fabricatedand tested, and its numerical and experimental results for $S_{11}$and radiation patterns are presented and discussed. It can be seen that the simulated impedance bandwidthfor S_{11}< -10dB is 2.4–2.5, 4.4–5.0, and 5.1–5.39 GHz frequency bands.The simulation results display threeresonant bands at frequencies of 2.4, 4.5, and 5.2GHz. Good agreement between the simulated results and measured data is observed. The small indifference betweenthe measured data and simulated results is due to the effect of the fabrication toleranceandSMA connector.Fig. 4 shows the simulated S-parametersof the proposed antenna and Fig. 5 shows the measured S-parameters of the proposed antenna.

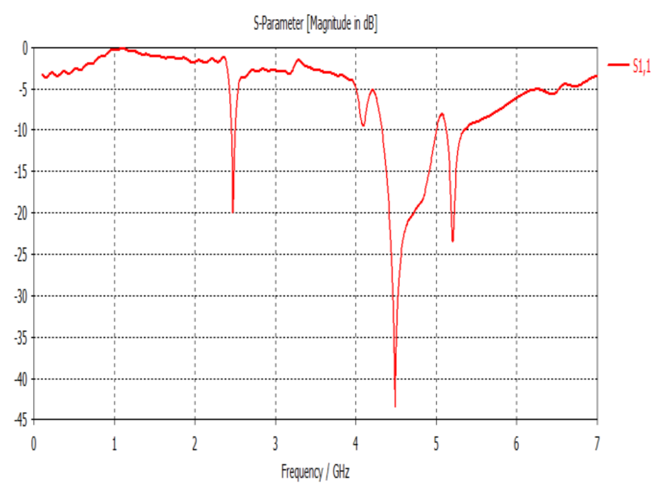


Fig. 4. Simulated S-Parameter Result of the Multi Band Monopole Antenna.

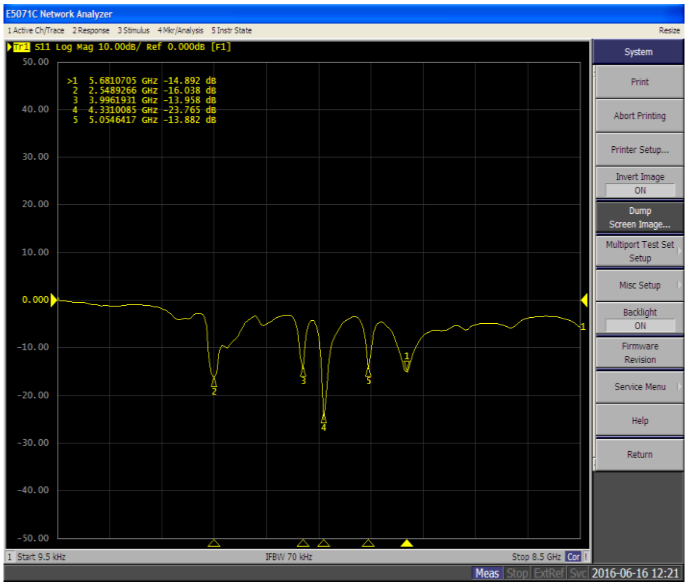


Fig. 5. Measured S-Parameter Result of the Multi Band Monopole Antenna.

To understand the phenomenon behind resonance, the simulated current distributions of the antenna at the three resonant frequencies of 2.47, 4.48, and 5.20 GHz is shown in Fig. 6.From this simulation [cf. Fig. 6(a)], it is observed that for the lowest frequency band, a large surface current density is found along the gap in between the symmetrical maze-shaped slots.For the second and the third frequency bands, the current distributions are concentrated around the corner of symmetrical maze-shaped slots [cf. Figs. 6(b) and 6(c)].

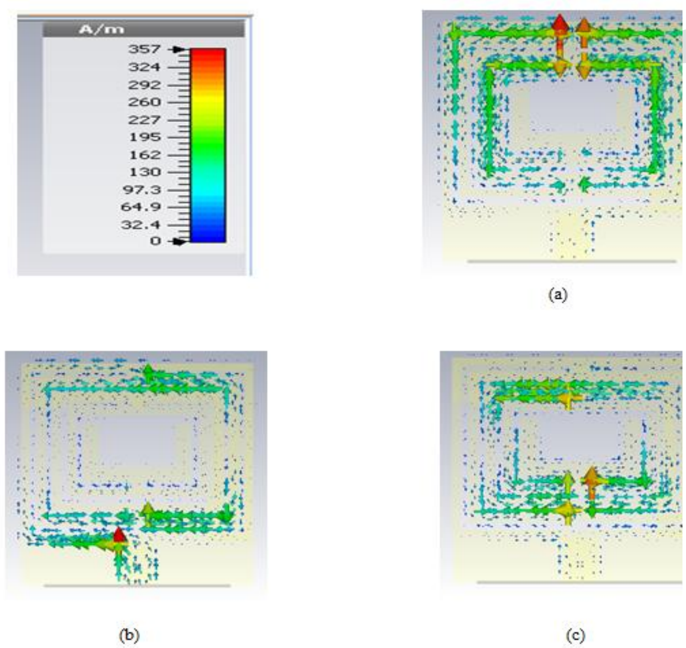


Fig. 6. Surface Current Distribution on the Patch Antenna at Various Resonance Frequencies (a) 2.47, (b) 4.48, and (c) 5.20 GHz.

Fig. 7 shows simulated radiation patternsincluding the co-polarization and cross-polarization in the H-plane (xz-plane) and E-plane (yz -plane).

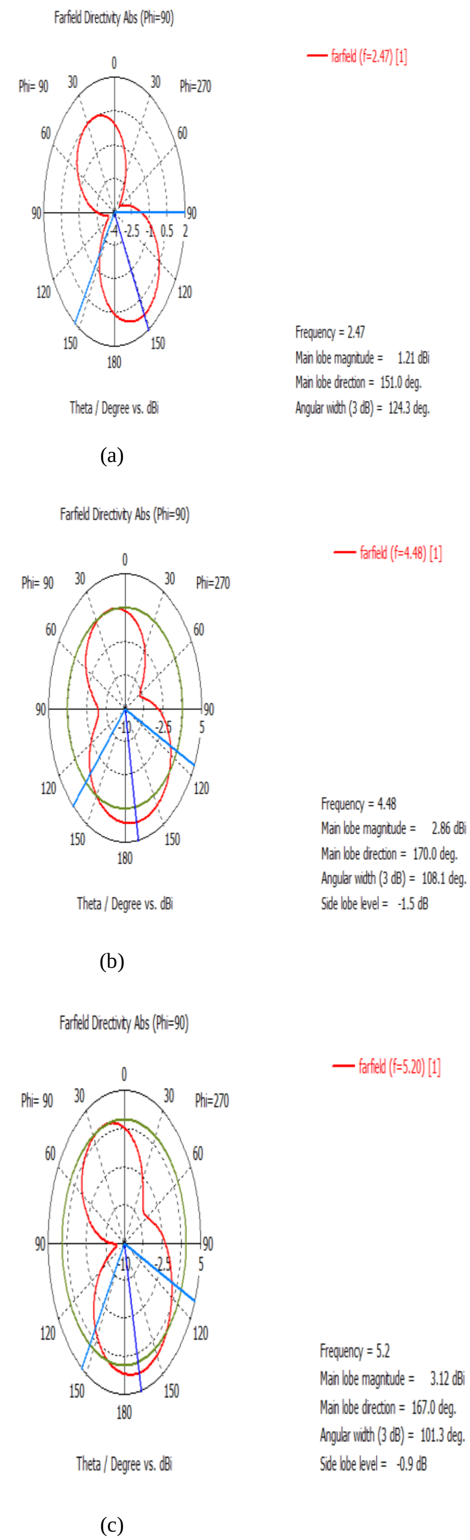


Fig. 7. StimulatedRadiation Patterns of the Multi Band-Monopole Antenna at the Frequencies of (a) 2.47, (b) 4.48, and (c) 5.20 GHz.

IV. CONCLUSION

A novel microstrip-fed monopole rectangular patch antenna design for atriple-band operation is presented. The proposed antenna iscomposed of a pair of symmetrical maze-shaped slotsinside the rectangular patch and defected ground plane [16]-[17] that provides multiple frequency bands. Simulation results and measured data arein good agreement, and they show that the desired gain, and radiation patterns for IMT (4.5 GHz), WLAN (2.4/5.2/5.7 GHz), and Bluetooth (2.4 GHz) applicationscan be achieved. The antenna is of relatively small dimensions ($15\times15\times1.6$ mm^3). The proposed antenna can be anexcellent choice for BLUETOOTH/WLAN/IMTapplications due to itssmall size [11], low cost, simple structure, good multiband characteristics,and omnidirectional radiation pattern over the mentioned bands.Simulated and measured results show that the proposed antenna could be a good candidate for BLUETOOTH/WLAN/IMT applications.

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