

## Novel patch antenna for multiband cellular, WiMAX, and WLAN applications

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**Abstract:** In this paper, a novel multiband patch antenna has been designed, simulated, and measured for GSM, DCS, IMT, WiMAX, and WLAN (IEEE 802.11 a/b/g/n) applications. The proposed antenna consists of a square patch and square-loop elements (connected through  $50\Omega$  microstrip line) excited by a coaxial feed. With the help of square loop elements, the antenna is able to provide multiband response. The proposed antenna occupies an overall size of  $80 \times 80 \times 1.6 \text{ mm}^3$ . The 10 dB bandwidth criterion offers good impedance bandwidth for desired bands. Moreover, gain of the proposed antenna is acceptable with good radiation properties. The proposed antenna is fabricated on FR-4 substrate and it is noted that the simulated and measured results are in good agreement.

**Key words:** Multiband patch antenna, square patch, square loop elements

### 1. Introduction

Rapid progress in cellular and wireless communication systems has increased the demand for mobile stations offering multiple features. Coverage of cellular mobile frequencies and addition of Wi-Fi/WLAN bands has become a basic requirement for any smart phone [1]. Therefore, mobile stations/terminals require antennas to function at multiple frequency bands to accommodate all these required services. With this requirement, the flexibility of portable devices requires them to be small, low cost, and light weight [2]. A patch antenna is one of the major components of any communication device that can provide the required specifications [3]. It is used due to its fabrication simplicity and ease of installation in any smart communication device that can provide required specifications of a modern wireless communication system [3].

In previous years, many researchers presented different patch antenna designs for multiple frequency operation. A proximity coupled feed technique was employed in [4,5] for dual-band frequency operation. David fractal and Durer Pentagon fractal patch antenna designs were used to minimize antenna dimensions. However, the presented feed technique was quite difficult to design and fabricate for real-world antennas. Another proximity coupled patch antenna was presented for tri-band Bluetooth, WLAN, and WiMAX applications [6]. The presented antenna offered very good frequency response for desired bands. Moreover, bandwidth of the proposed frequency bands was increased by using a defected ground structure (DGS). In [7], a compact and novel tri-band antenna design was presented for cellular and WLAN communications. A coaxial feed technique with DGS was used to make such a compact design. In addition, the proposed antenna offered circular polarization in the bands of interest. AbuTarbosh et al. [8] presented a multiband patch antenna for WiMAX and WLAN

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systems. The presented geometry consists of double U-slots etched from main patch elements named small patch and large patch. The patch elements were connected by using two small bridge elements. The double U-slots and bridge elements played an important role in the performance of the presented design. A sectoral Sierpinski Gasket fractal monopole antenna was presented in [9] for GPS, cellular, Bluetooth, and WLAN bands. The presented antenna design was able to provide dual-wideband response for desired bands.

A stacked patch antenna design loaded with a complimentary split ring resonator (CSRR) was presented for multiband characteristics [10]. The CSRR design was based on an iterative scheme and each iteration produced a resonant frequency that tends to a multiple frequency response. Moreover, the authors used CSRR structure as a complementary patch element. In [11], another CSRR based antenna design was presented for multiband wireless applications. In this design, CSRR was designed on the ground plane, which acted as a negative permittivity material in the antenna design, and enhanced impedance bandwidth and gain. The antenna design consisted of three microstrip arms connected to a microstrip feed line, which leads to multiband characteristics. In [12,13], aperture-coupled fed antenna configurations were presented for multiband and dual-band operations. In [12], the authors designed a fractal shape slot on the ground to achieve seven resonant frequencies. In [13], the authors used Minkowski-island fractal shape as a complementary patch that provided dual-band response. A dual-slot patch antenna was investigated in [14] for multiband characteristics. The authors employed two different slot structures to get multiband response. The problem with the antenna was that it provided some attenuation for other frequency bands.

Some researchers proposed different designs of patch antennas to achieve multiband response by employing slots on the rectangular patch such as E-shaped [15], H-shaped [16,17], and C-shaped [18]. The selection of the slots is dependent upon specific resonant frequencies. However, the designs were only related to dual-band and tri-band characteristics. In this paper, we proposed a patch antenna that is capable of operating at six different frequency bands. In the proposed design, a square patch and square-loop elements are introduced to achieve multiband characteristics. The proposed design is simple and smaller compared to the previously presented designs.

Following the introduction, Section 2 describes the proposed patch antenna design and Section 3 presents simulation and measured results. We conclude the paper in Section 4.

## 2. Proposed antenna design

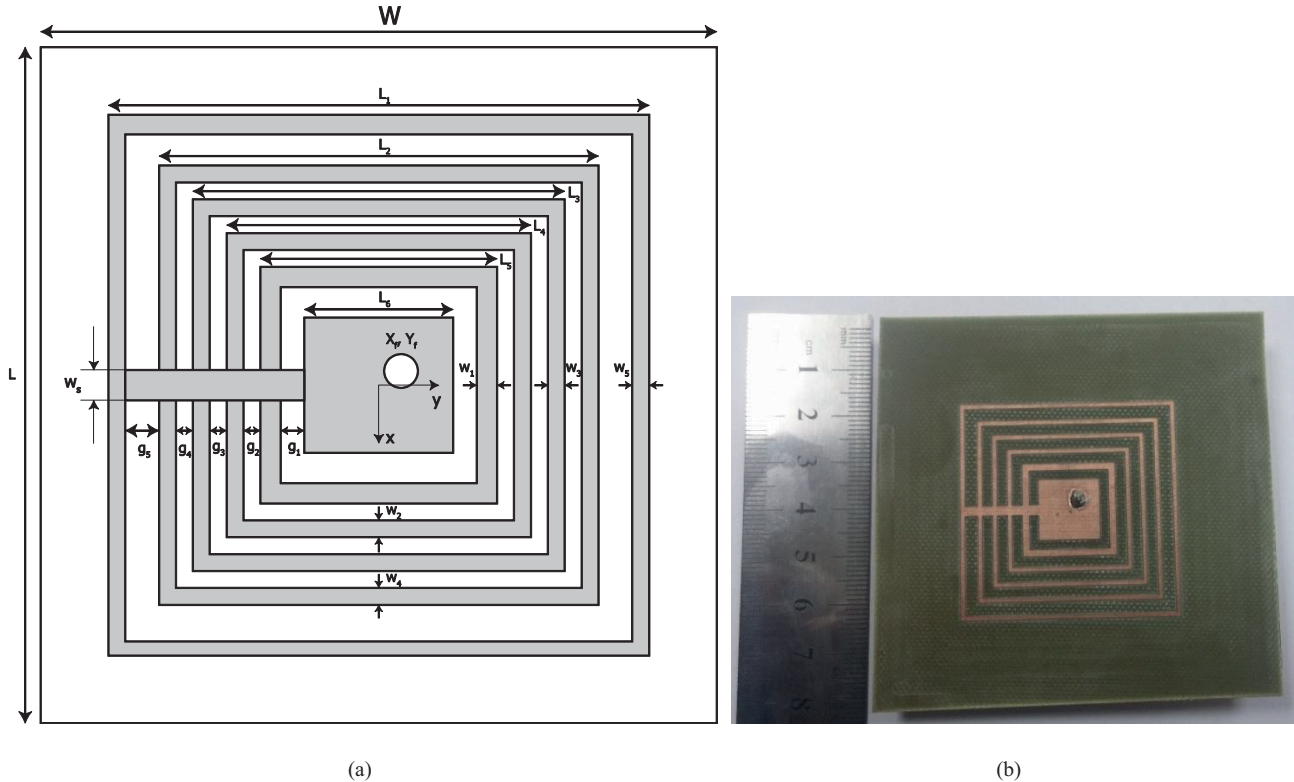
The design of the proposed antenna is shown in Figure 1a and the prototype of the fabricated antenna is shown in Figure 1b. The simulation of the proposed antenna is carried out in Ansys HFSS and the antenna is fabricated on a low cost FR-4 substrate having thickness of 1.6 mm, relative permittivity of 4.4, and loss tangent of 0.002. From Figure 1a, it can be seen that the proposed antenna design consists of a square patch and five square-loop elements. The square patch is excited by using a coaxial feed and the rest of the square-loop elements are excited by connecting them with a square patch through a  $50\Omega$  microstrip line denoted as  $w_s$ . The width of the microstrip line is calculated by using

$$Z_o = \frac{120\pi}{\sqrt{\epsilon_{reff}} \left[ \frac{w_s}{h} + 1.393 + \frac{2}{3} \ln \left( \frac{w_o}{h} + 1.444 \right) \right]}, \quad (1)$$

where

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2}, \quad (2)$$

where  $Z_o$  is the characteristics impedance, which is  $50\Omega$ ,  $w_s$  is the width of microstrip line,  $h$  is the thickness of the substrate,  $\epsilon_{reff}$  is the effective dielectric constant of the substrate, and  $\epsilon_r$  is the relative permittivity of the substrate.

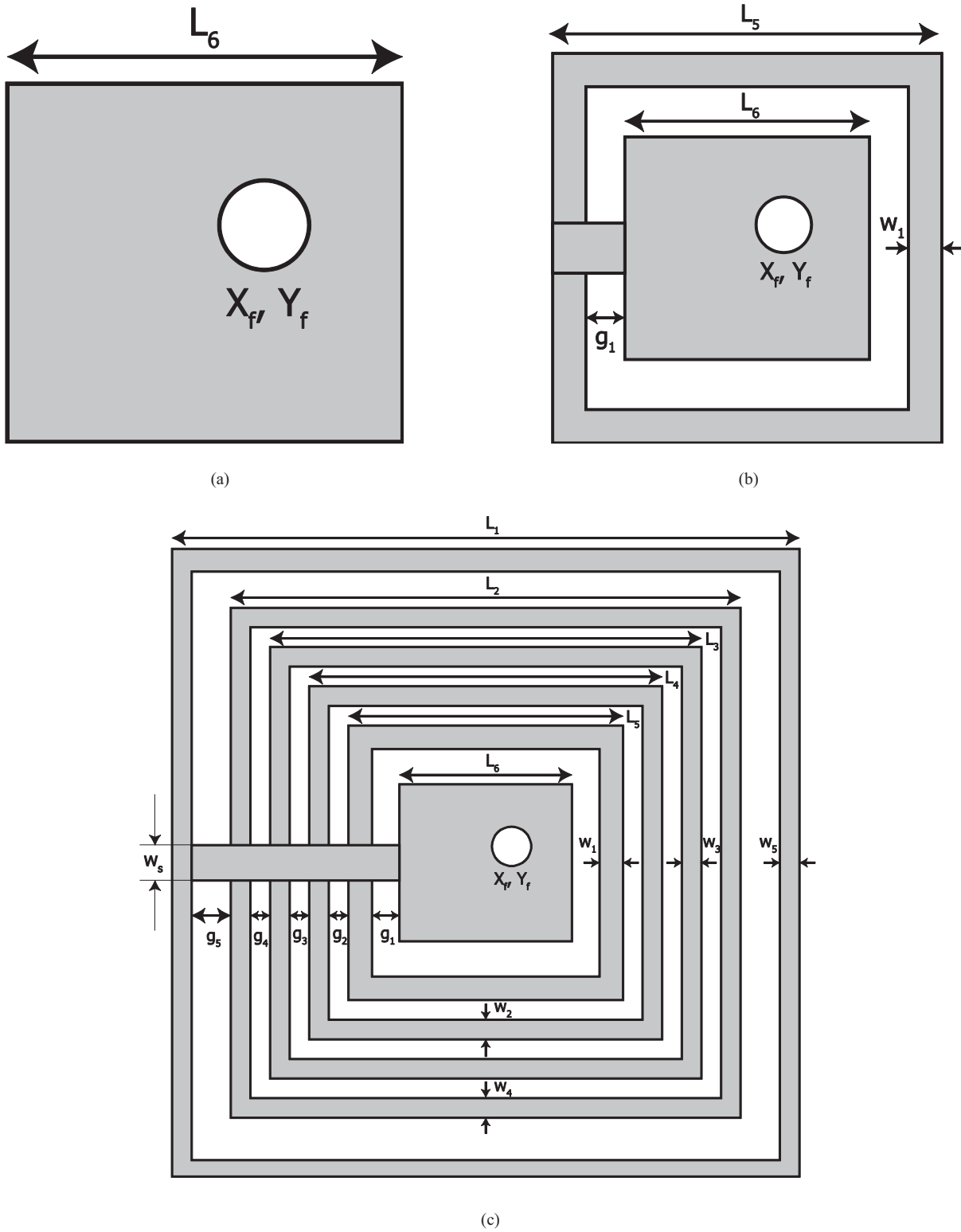


**Figure 1.** a) Design of the proposed multiband patch antenna; b) Prototype of the fabricated multiband patch antenna.

The square patch element provides resonance at 5.25 GHz, whereas square-loop elements are able to resonate at GSM (800 MHz), DCS (1800 MHz), IMT (2100 MHz), WLAN (2.45 GHz), and WiMAX (3.5 GHz), respectively. The lengths of the square patch and square-loop elements are calculated according to the design formulas given in [3]. At first, the length of the square patch, as shown in Figure 2a, is calculated for resonant frequency 5.25 GHz and the numerical value is  $L = 14.48$  mm. It is required to justify the length of the patch in terms of wavelength, which means that the length of a patch is equal to half of the wavelength, i.e.  $L = \lambda/2$ . For this purpose, the length of the patch is justified by using the following equation:

$$\lambda = \frac{c}{f_r \sqrt{\epsilon_r}}, \quad (3)$$

where  $\lambda$  is the wavelength in terms of permittivity,  $c$  is the speed of light ( $3 \times 10^8$  m/s), and  $f_r$  is the resonant frequency. By using Eq. (3), the patch length for  $f_r = 5.25$  GHz is calculated, which is  $\lambda/2 = 13.6$  mm. The lengths with respect to wavelength for the rest of the square-loop elements are calculated accordingly. The position of the coaxial feed ( $X_f$  and  $Y_f$ ) and other parameters like  $w$ 's and  $g$ 's are optimized during the simulation to get better results. The design parameters along with their respective values are provided in the Table.



**Figure 2.** Design of three antennas: a) Antenna 1; b) Antenna 2; c) Antenna 3 (proposed antenna).

**Table.** Design parameters of the proposed multiband patch antenna.

Parameters	Values (mm)	Parameters	Values (mm)
$L$	80	$g_2$	2
$W$	80	$g_3$	2
$L_1$	44	$g_4$	2
$L_2$	37	$g_5$	2.5
$L_3$	31	$w_1$	3
$L_4$	25	$w_2$	2
$L_5$	19	$w_3$	2
$L_6$	12.5	$w_4$	2
$g_1$	1.75	$w_5$	2
$X_f$	-1.5	$Y_f$	2
$w_s$	2	–	–

### 3. Results and discussion

To provide a better understanding of performance of the proposed antenna, three antenna designs are presented in Figure 2. A simple square patch in Figure 2a, named Antenna 1, having length and width of  $12.5 \times 12.5 \text{ mm}^2$  is simulated by using a coaxial feed and the respective return loss result is shown in Figure 3. It is observed from the result that the square patch is able to provide resonance at 5.25 GHz frequency band. After that, a square-loop element is connected with a square patch through a  $50\Omega$  microstrip line as shown in Figure 2b, named Antenna 2, to verify the topology of the proposed design. The result of Antenna 2 is also shown in Figure 3 and it is noted from the result that Antenna 2 gives dual-band response for 3.4 GHz and 5.3 GHz frequency bands. In Antenna 3, shown in Figure 2c, four more square-loop elements are inserted with the design of Antenna 2 to get a multiband response. The simulated return loss result of Antenna 3 is shown in Figure 3. From the result, it is clear that the antenna provides multiple frequency response and the noted resonant frequencies are 790 MHz, 1.79 GHz, 2.14 GHz, 2.45 GHz, 3.4 GHz, and 5.3 GHz. According to 10-dB bandwidth criteria, the impedance bandwidths for the desired bands are 42 MHz, 25 MHz, 25 MHz, 32 MHz, 29 MHz, and 123 MHz, respectively.

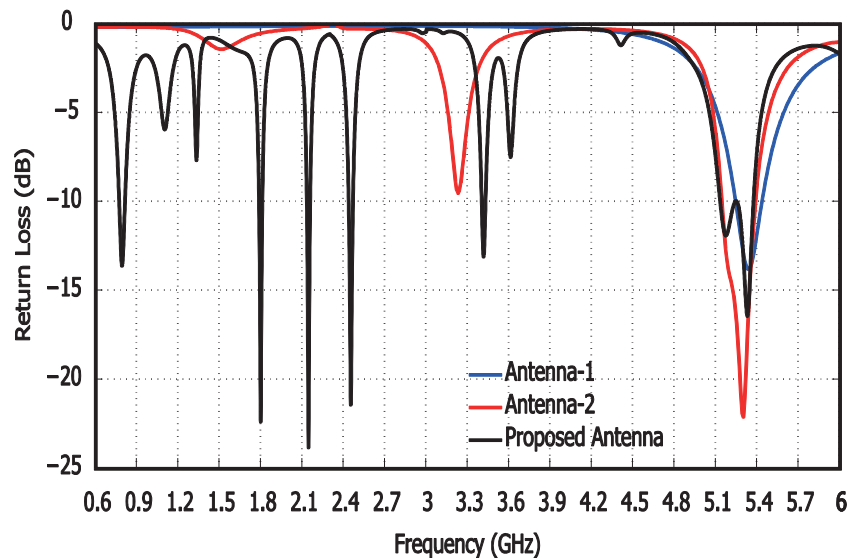
**Figure 3.** Simulated return loss for antennas 1, 2, and 3.

Figure 4 shows the simulated and measured return loss results for the proposed multiband patch antenna. The measurement of the antenna is done by using Agilent Technologies Network Analyzer N5242A in the frequency range of 0.5–7 GHz. The measured results show that the antenna operates for multiple frequencies and good agreement is seen between simulated and measured results. Some of the discrepancies between simulated and measured results are due to manual soldering of the connector, and the actual permittivity and loss tangent of the substrate might not be the same. The simulated gain of antenna is depicted in Figure 5. The noted gains on the desired bands are 0.58 dBi, 0.88 dBi, 1.5 dBi, 1.83 dBi, 2.3 dBi, and 3.95 dBi, respectively. It has been seen that for lower frequency bands (GSM and DCS) the gain is low while rest of the bands provide good gain. The gain of the antenna is also simulated in CST Microwave Studio to validate the far-field performance. It is evident from Figure 5 that the antenna gain simulated using Ansys HFSS is in

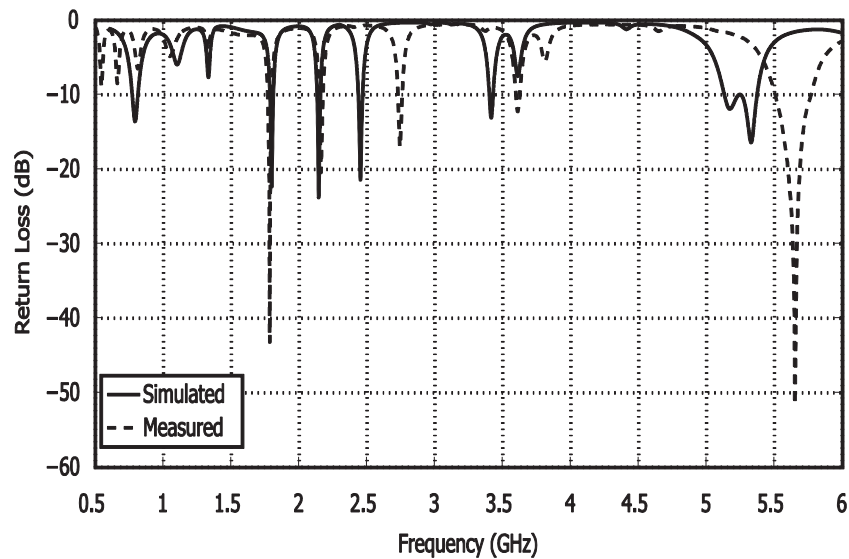


Figure 4. Simulated and measured return loss results for the proposed multiband patch antenna.

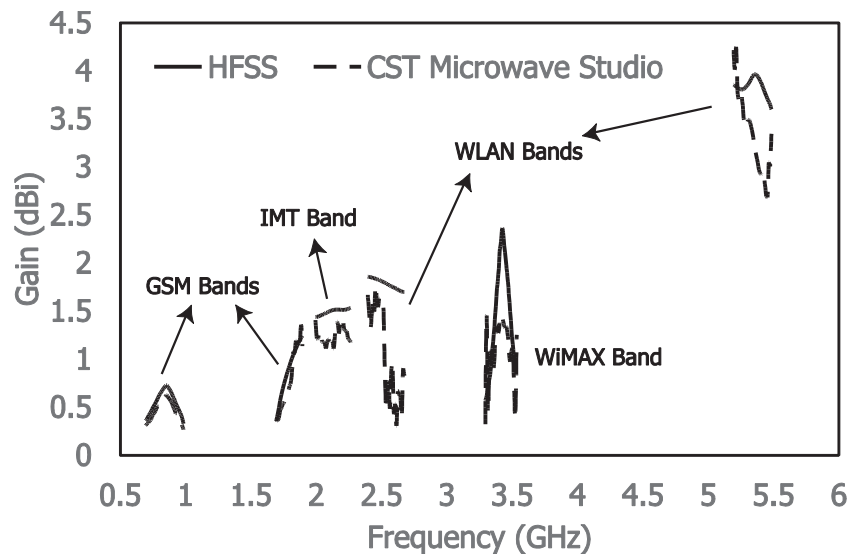
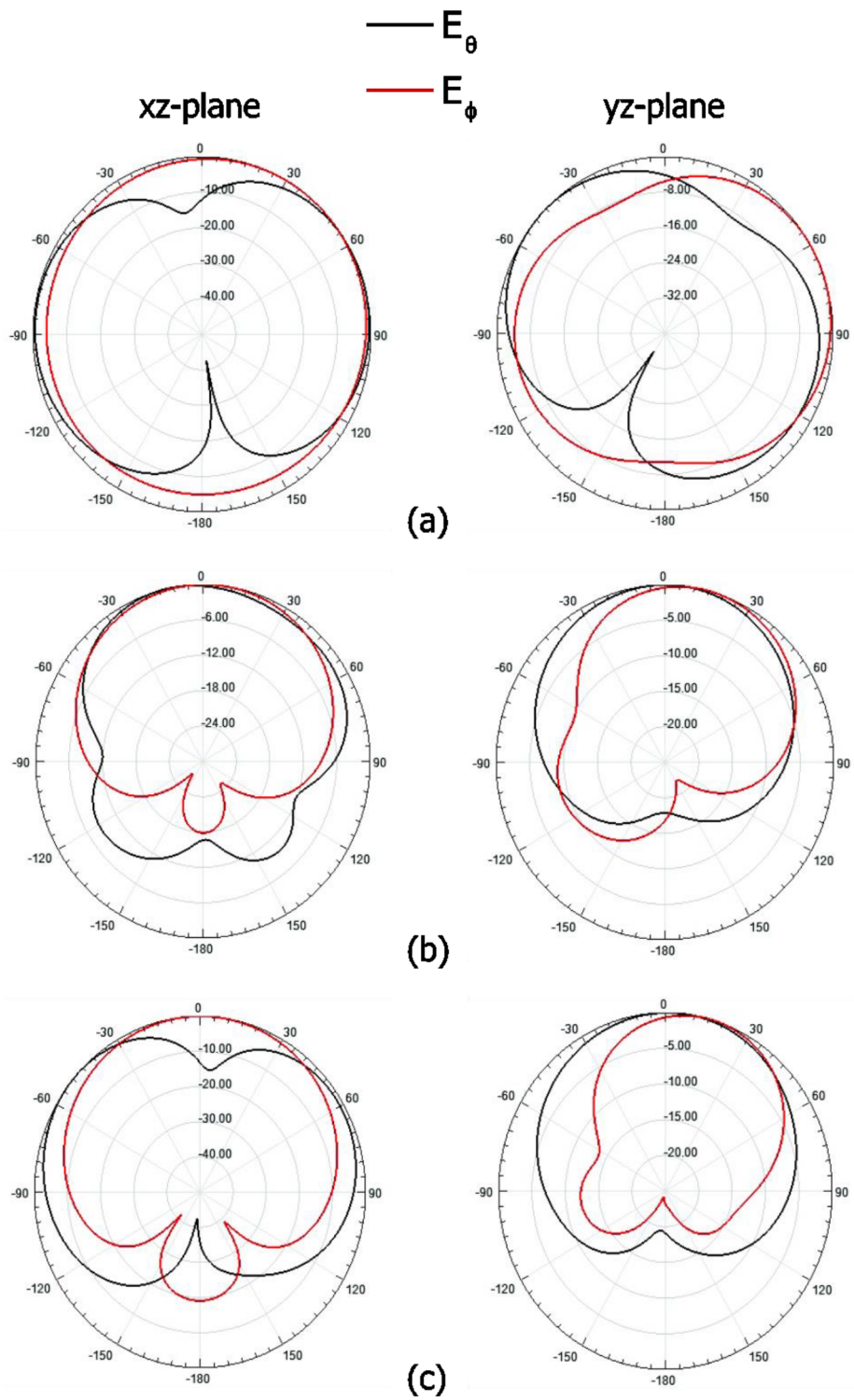


Figure 5. Simulated gain for the proposed multiband patch antenna.



**Figure 6.** Simulated co-polarization and cross polarization radiation pattern in the  $xz$  and  $yz$ -plane for the proposed multiband patch antenna: a) 790 MHz; b) 1.79 GHz; c) 2.14 GHz; d) 2.45 GHz; e) 3.4 GHz; and f) 5.3 GHz.

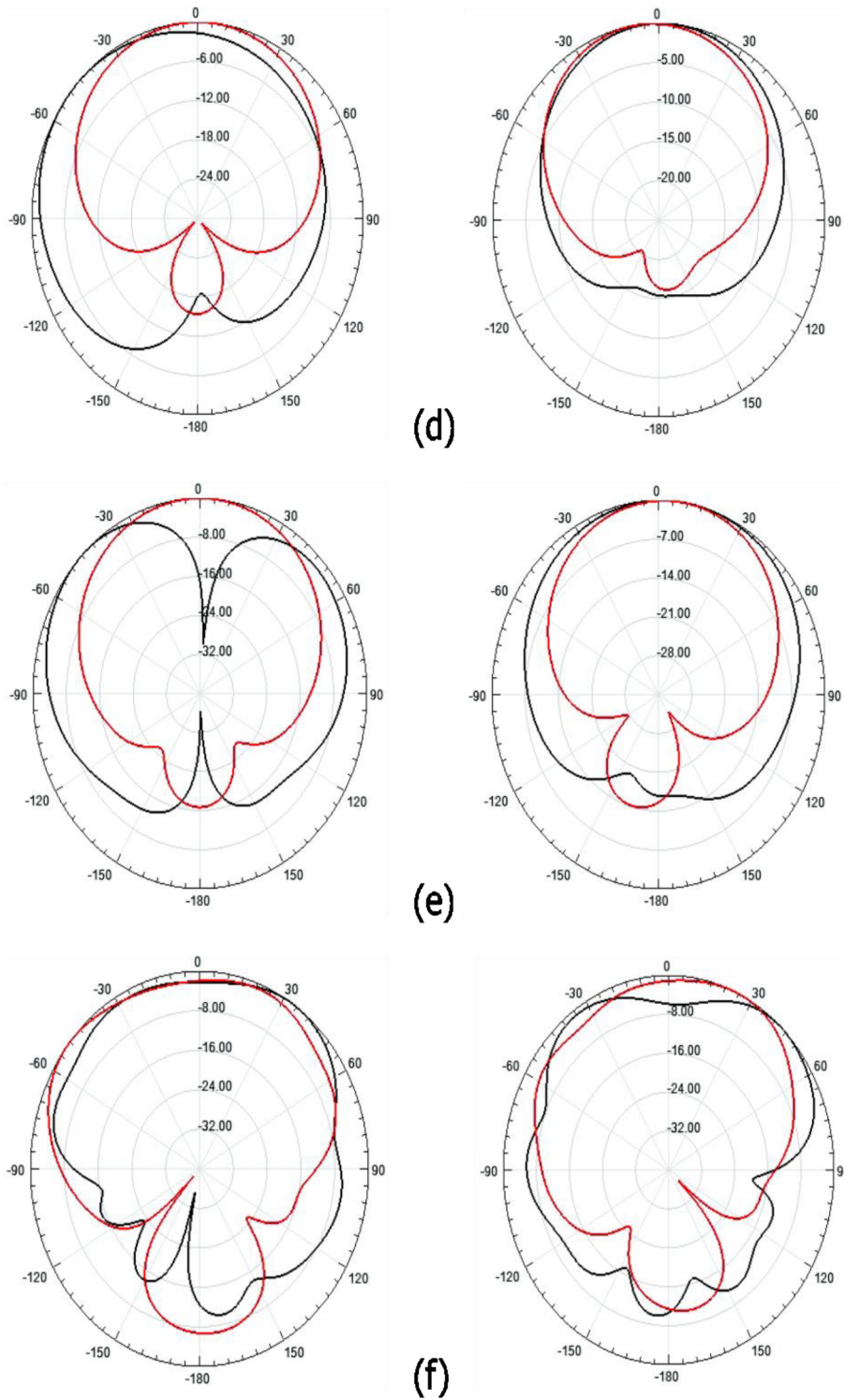
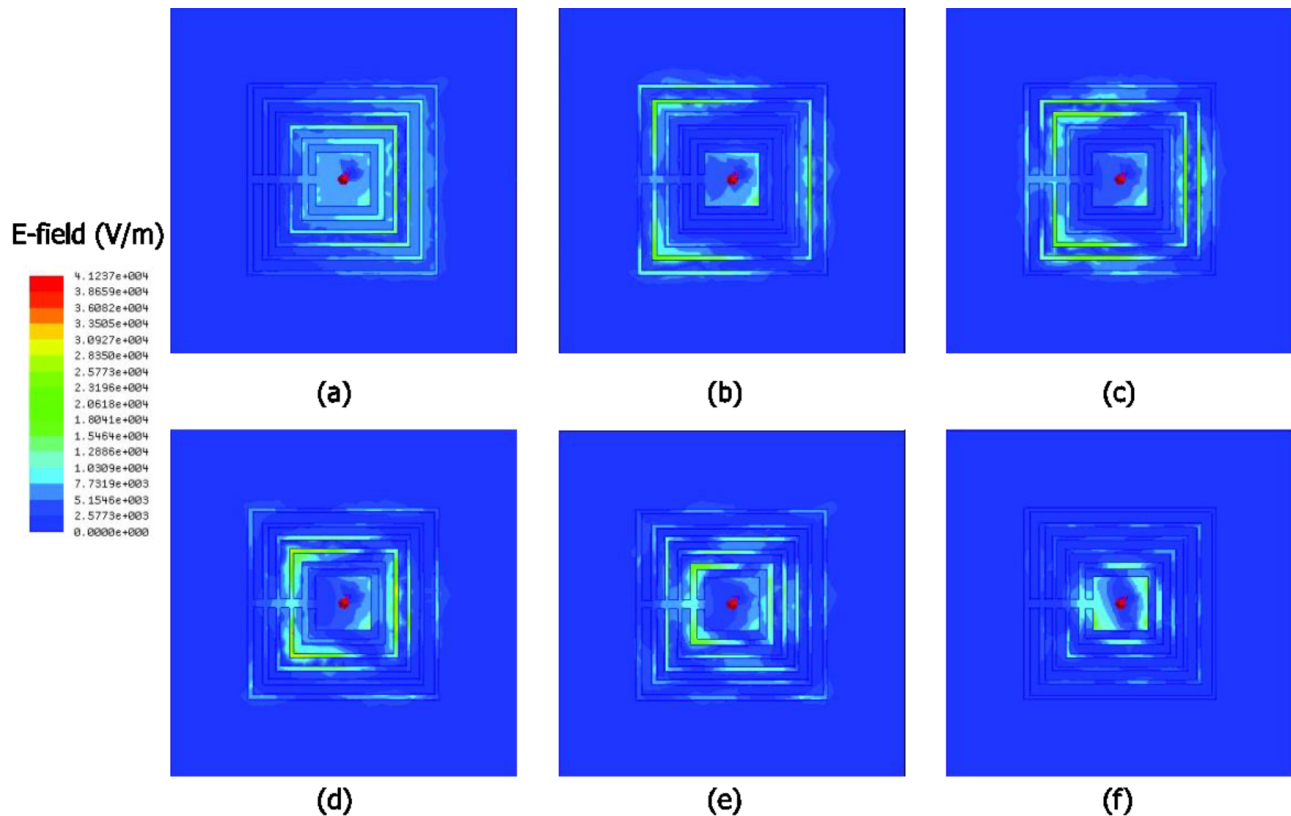


Figure 6. Continued.



good agreement with the gain result of CST MWS. The far-field simulated radiation patterns of the proposed antenna in the  $xz$ -plane ( $\phi = 0^\circ$ ) and  $yz$ -plane ( $\phi = 90^\circ$ ) for the desired resonant frequencies are depicted in Figure 6. The red solid line represents co-polarization and the black solid line represents cross-polarization radiation patterns. They indicate that the antenna has an omnidirectional radiation pattern at 790 MHz, while for the rest of the frequency bands, the radiation patterns are almost broadside for both the planes. The cross-polarization level is relatively high due to the increase in the horizontal component of surface current. In Figure 7, the simulated E-field magnitude is plotted for different resonant frequencies. It is demonstrated from the plot that each resonant frequency is generated from its respective loop element. It is also observed from Figure 7a that the combined effect of four loop elements is providing a lower frequency band.



**Figure 7.** Simulated E-field magnitude for the proposed multiband patch antenna: a) 790 MHz; b) 1.79 GHz; c) 2.14 GHz; d) 2.45 GHz; e) 3.4 GHz; and f) 5.3 GHz.

#### 4. Conclusion

A novel coaxial fed multiband patch antenna was presented. The antenna is designed and fabricated on  $80 \times 80 \times 1.6 \text{ mm}^3$  FR-4 substrate. The use of square patch and square-loop elements provide multiple resonances with good impedance bandwidth. The presented antenna offers good radiation characteristics with acceptable values of gain. Moreover, the measured return loss result shows good agreement with the simulated data. The proposed multiband antenna is a good candidate for GSM, DCS, IMT, WiMAX, and Wi-Fi/WLAN communication.

## References

- [1] Zhang T, Li R, Jin G, Wei G, Tentzeris M. A novel multiband planar antenna for GSM / UMTS / LTE / Zigbee / RFID mobile devices. *IEEE T Antenn Propag* 2011; 59: 4209-4214.
- [2] Chen ZN. *Antennas for portable devices*. Chichester, UK: Wiley, 2007.
- [3] Balanis CA. *Antenna Theory: Analysis and Design*. New York, NY, USA: Wiley, 2005.
- [4] Abraham J, Mathew T. David fractal antenna for multiband wireless communication. In: 2014 2nd International Conference on Electronic Design; 19–21 August 2014; Penang, Malaysia: IEEE. pp. 15-19.
- [5] Abraham J, John KKA, Mathew T. Microstrip antenna based on durer pentagon fractal patch for multiband wireless applications. In: 2014 International Conference on Information Communication and Embedded Systems; 27–28 February 2014; Chennai, India: IEEE. pp. 1-5.
- [6] Bakariya PS, Dwari S, Sarkar M, Mandal MK. Proximity coupled microstrip antenna for Bluetooth, WiMAX and WLAN applications. *IEEE Antenn Wirel Pr* 2015; 14: 755-758.
- [7] Jhammb K, Li L, Rambabu K. Novel-integrated patch antenna with multi-band characteristics. *IET Microw Antenna P* 2011; 15: 1393-1398.
- [8] AbuTarboush HF, Nilavalan R, Budimir D, Al-Raweshidy HS. Double U-slots patch antenna for tri-band wireless systems. *Int J RF Microw C E* 2010; 20: 279-285.
- [9] Choukiker YK, Behera SK, Jyoti R. Sectoral Sierpinski Gasket fractal antenna for wireless LAN applications. *Int J RF Microw C E* 2012; 22: 68-74.
- [10] Gangwar D, Das S, Yadava RL. Multiband microstrip patch antenna using CSRR. In: 2013 International Conference on Microwave and Photonics; 13–15 December 2013; Dhanbad, Jharkhand, India: IEEE. pp. 1-4.
- [11] Issa IB, Essaaidi E. Compact multiband square complementary split ring resonator patch for wireless applications. In: 2013 13th Mediterranean Microwave Symposium; 2–5 September 2013; Saida, Lebanon: IEEE. pp. 1-4.
- [12] Ali SA, Rafique U, Ahmad U, Khan MA. Multiband microstrip patch antenna for microwave applications. *IOSR J Elect Comm Eng* 2012; 3: 43-38.
- [13] Hung TF, Liu JC, Wei CY, Chen CC, Bor SS. Dual-band circularly polarized aperture-coupled stack antenna with fractal patch for WLAN and WiMAX applications. *Int J RF Microw C E* 2014; 24: 130-138.
- [14] Kumar K, Gangwar RPS. Design of six band microstrip antenna. *International Journal of Latest Technology in Engineering, Management & Applied Science* 2016; 5: 52-55.
- [15] Izadi OH, Mehrparvar M. A compact microstrip slot antenna with novel E-shaped coupling aperture. In: 2010 5th International Symposium on Telecommunication; 4–6 December 2010; Tehran, Iran: IEEE. pp. 110-114.
- [16] Wong HTK, Chiou T. Broadband dual-polarized aperture-coupled patch antennas with modified H-shaped coupling slots. *IEEE T Antenn Propag* 2002; 50: 188-191.
- [17] Afzal W, Rafique U, Ahmed MM, Khan MA, Mughal F. A tri-band H-shaped microstrip patch antenna for DCS and WLAN application. In: 2010 19th International Conference on Microwaves, Radar and Wireless Communications; 21–23 May 2012; Warsaw, Poland, IEEE. pp. 256-258.
- [18] Chen NZN. Aperture-coupled asymmetrical C-shaped slot microstrip antenna for circular polarization. *IET Microw Antenna P* 2009; 3: 372-378.