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Antenna with Hexa-Band Capabilities for Multiple Wireless Applications

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Abstract—In this paper, a novel multiband microstrip patch antenna with small frequency ratio is designed and analysed. One can design a multiband antenna at any desired frequencies through these proposed methods. The proposed antenna shows six operating frequencies with very small frequency ratio between two consecutive resonant frequencies 1.1248, 1.1123, 1.0792, 1.1469 and 1.3254 and can be used for various wireless applications, i.e., 2.5 GHz for UMTS and Wi-Fi, 2.812 GHz for CCTV with wireless video links, 3.128 GHz and 3.376 GHz for WiMAX, 3.872 GHz for C-band applications and 5.132 GHz for Lower WLAN. Design procedure and formation of all six bands are presented and discussed. Analysis is done by Ansoft HFSS v. 15 which is based on Finite Element Method (FEM), and simulated results are verified with experimental results of fabricated prototypes which are found in close agreement.

1. INTRODUCTION

Researchers working on the compactness of the system are looking for such an antenna which can be used for more than one application. Multiband antennas have emerged as a primary choice in this regard [1, 2]. Minimum frequency ratio is desirable for multiband antennas, and several works have been reported with small frequency ratio [3, 4]. Several antenna structures have been reported with different feeding networks and small frequency ratio for multiband applications [5, 6]. Multiband antennas for Wireless Local Area Network (WLAN), Universal Mobile Telecommunications System (UMTS) and Worldwide Interoperability for Microwave Access (WiMAX) are in demand nowadays for commercial communication applications [7]. Spectrum 2.5 GHz (2.40 $\sim$ 2.5 GHz) and 5.132 GHz (5.05 $\sim$ 5.35 GHz) can be used for Wi-Fi and WLAN applications according to IEEE 802.11 Standards, respectively [8, 9]. For these specific applications, circularly polarized dual-band antenna [10] and one directional multiband antenna [11] have also been proposed with higher gain. However, it would be better if multiband antenna also covers a few more frequency bands including UMTS-2100 (1920 $\sim$ 2170 MHz), Wi-Fi (2.4 $\sim$ 2.5 GHz), UMTS-2600 (2500 $\sim$ 2690 MHz), C-Band (3.7 $\sim$ 4.2 GHz), Mobile-WiMAX (2.3/2.5/3.3/3.5/5.8 GHz in Asia), and Lower WLAN (5.05 $\sim$ 5.35 GHz).

In this paper, hexa-band antenna is proposed with very small frequency ratio. Design procedure is presented for achieving single to six bands step by step. Characteristics of proposed hexa-band antenna are analysed, and mechanism is explained. This paper is organized in five sections. Introduction and problem statement are defined in the first section. Second section describes the reference antenna which is used for comparison purpose and referred as *Ant_1*. Then a dipole is introduced with reference antenna for dual-band operation and referred as *Ant_2*, which is discussed in Section 3. In the fourth section,

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Inter Digital Capacitor Loaded Loop Resonator (IDCLLR) is introduced to achieve fourth operating band, and antenna is referred as *Ant_3*. Processes of achieving fifth and sixth bands are described in the fifth section, and antenna is referred as *Ant_4*. Analysis is done by Ansoft HFSS v.15 which is based on Finite Element Method (FEM).

2. DESIGN AND ANALYSIS OF REFERENCE ANTENNA ANT_1

Conventional Rectangular Patch Antenna with inset feed is used as a reference antenna for the study and referred as *Ant_1*. The schematic of reference antenna is shown in Figure 1. *Ant_1* is designed and fabricated at 5 GHz on an FR-4 Epoxy substrate of dimensions $35 \times 35 \times 1.5748\,\text{mm} \times \text{mm} \times \text{mm}$. The dielectric constant and loss tangent of substrate are 4.4 and 0.02. Width W, length L, and length of inset feed y_0 of microstrip patch are calculated from [12]. The rectangular patch is fed by microstrip line of length L_{ml} and width W_{ml} [12]. Detailed dimensions of *Ant_1* are given in Table 1.

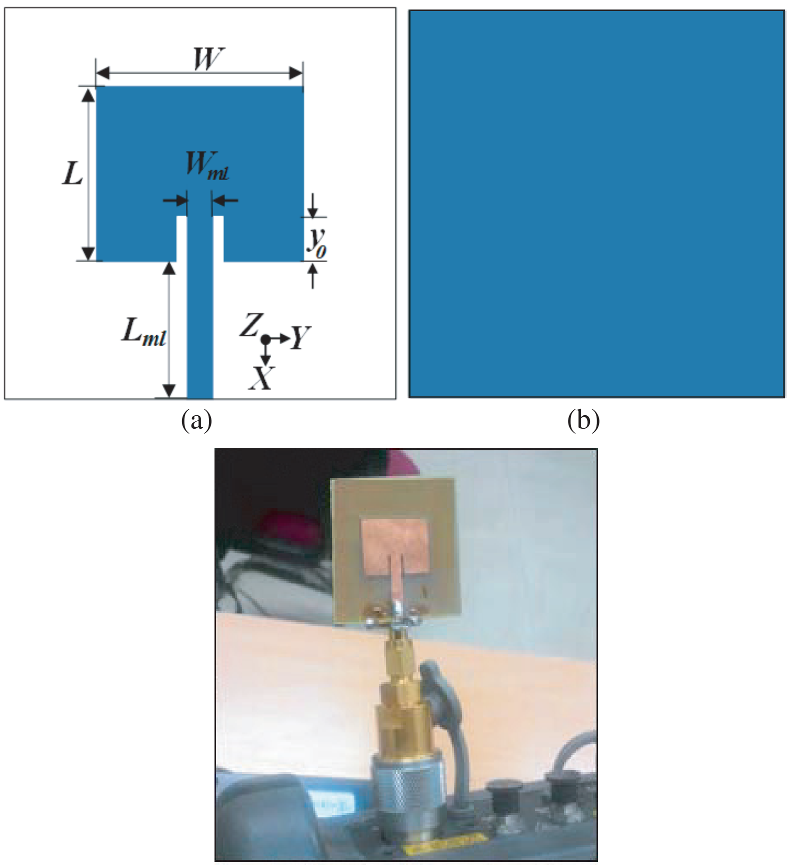


Figure 1. Schematic of reference antenna *Ant_1*. (a) Front side, (b) back side (regular ground plane), and (c) fabricated prototype.

Table 1. Design specification of reference antenna *Ant_1*.

Parameter	Value [mm]	Parameter	Value [mm]
W	18.2574	W_{ml}	3.011
L	13.7725	L_{ml}	10.46065
y_0	4.6		

The width of rectangular patch W of *Ant_1* is calculated as,

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

where f_r, ε_r and c are the resonant frequency, relative permittivity, and speed of light in free space, respectively.

The Length of rectangular patch (L) of *Ant_1* is taken as,

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} - 2\Delta L \tag{2}$$

where effective permittivity ε_{eff} is given by

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1 + \frac{12h}{W}}} \tag{2a}$$

and

$$\Delta L = 0.412h\frac{(\varepsilon_{eff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \tag{2b}$$

where h is the thickness of substrate.

3. DESIGN AND ANALYSIS OF DUAL BAND ANTENNA ANT_2

A dipole is embedded with reference antenna *Ant_1* for achieving dual-band characteristics. Half dipole of length $L_n/2$ and width W_n is embedded on signal plane, and the other half dipole is in the ground plane. The schematic of the proposed structure is shown in Figure 2.

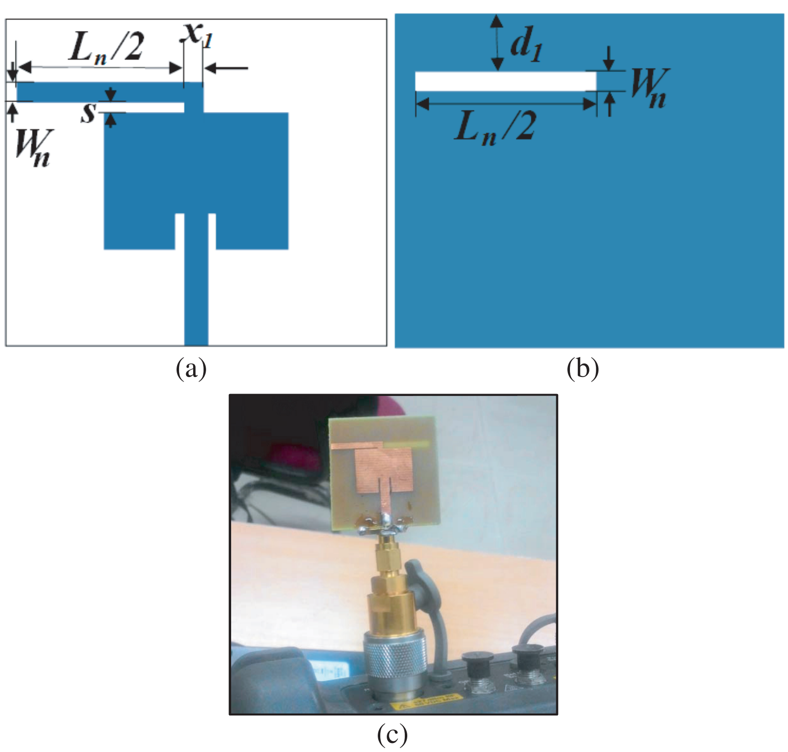


Figure 2. Schematic of proposed dual band *Ant_2*. (a) Top view, (b) bottom view (from back side), and (c) fabricated prototype.

Length L_n of the dipole is calculated as:

$$\frac{L_n}{2}=\frac{c}{4f_r} \tag{3}$$

where c and f_r are the speed of light in free space and resonating frequency of dipole, respectively. Resonant frequency f_r of dipole is taken as 2.5 GHz in this study for achieving dual-band operation. One can choose f_r for desired frequency [12–14].

Width W_n of the dipole is related to its impedance and calculated by Eq. (4). Impedance of the dipole is matched to the input impedance of the edge of the rectangular microstrip patch.

$$W_n = \frac{\pi L_n}{\exp\left(\frac{R_{in}\left(x=0\right)}{120}+2.25\right)} \tag{4}$$

where R_{in} $(x = 0)$ is the input impedance at the edge of rectangular microstrip patch (in x-direction at zero distance) and defined as [12]:

$$R_{in}\left(x=0\right) = \frac{50}{\cos^2\left(\frac{\pi y_0}{L}\right)} \tag{5}$$

where L is the length of the rectangular patch, and y_0 is the length of the inset feed corresponding to $50\,\Omega$ impedance.

This dipole is separated from the edge of the rectangular patch with a distance of s and attached to the patch with a small strip of length x_1 as shown in Figure 2(a). Detailed dimensions of *Ant_2* are presented in Table 2.

Table 2. Design specification of antenna *Ant_2*.

Parameter	Value [mm]	Parameter	Value [mm]
W_n	1.7697	s	0.5
L_n	30	x_1	1.7
d_1	8.1909		

Return loss characteristics with frequency of proposed antenna *Ant_1* and *Ant_2* are shown in Figure 3. This antenna provides two operating bands 2.5 and 5 GHz. First and second bands at 2.5 and 5 GHz are achieved due to dipole and rectangular patch, respectively. Dipole is resonating at 2.5 GHz, which is clearly observed from the current distribution of *Ant_2* shown in Figure 4. The electrical characteristics of fabricated antennas are measured by Agilent$^{\mathrm{TM}}$ Network Analyzer PNA-L series N9914A and are found in good agreement with simulated results.

4. DESIGN AND ANALYSIS OF FOUR BAND ANTENNA ANT_3

Further, Inter Digital Capacitor Loaded Loop Resonator (IDCLLR) is embedded with *Ant_2* for achieving four band operations. IDCLLR is a metallic split ring with inter-digital loading in the gap, which is displayed in Figure 5(a). IDCLLR can be considered as a small resonator and acts as a parallel RLC circuit. According to [15], the unloaded quality factor (Q-value) of a parallel resonator circuit is directly proportional to the equivalent capacitance, and it has a higher quality factor than conventional rectangular SRR which is shown in Figure 5(b).

IDCLLR has a strong magnetic response when applying a time varying magnetic field along the axis of the ring and confines the signal propagation in a specific band. According to [16], the resonant frequency of IDCLLR is $f_0 = (L_0C_0)^{-1/2}/2\pi$, and the width of the band gap is proportional to $(L_0/C_0)^{1/2}$, where C_0 and L_0 stand for the equivalent capacitance and inductance of IDCLLR.

Two identical IDCLLRs are embedded along the microstrip line as shown in Figure 6(a) for achieving third and fourth bands and referred as *Ant_3*. Detailed design specifications of *Ant_3* are given

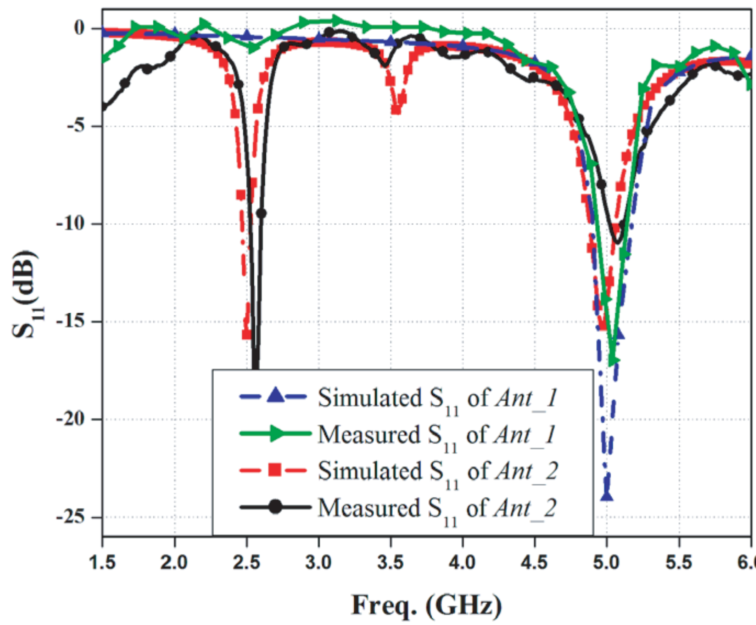


Figure 3. Measured and simulated S_{11} characteristics with frequency of *Ant_1* and *Ant_2*.

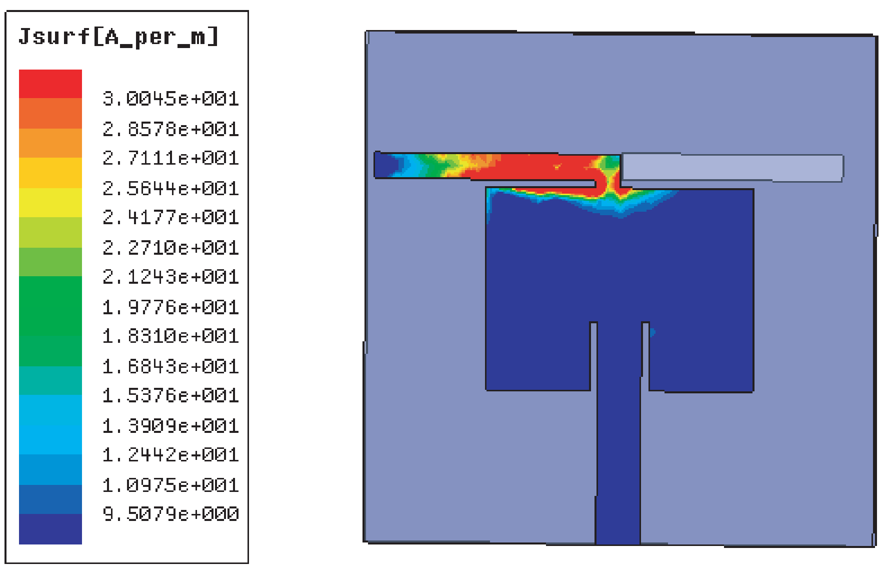


Figure 4. Current distribution of proposed *Ant_2* at 2.5 GHz.

in Table 3. The fabricated prototype of *Ant_3* is shown in Figure 6(b). Simulated and measured return loss characteristics of *Ant_3* are shown in Figure 6(c). Current distributions are shown in Figures 7(a) and 7(b). Four operating bands 2.3–2.48 GHz, 3.3–3.38 GHz, 3.41–3.481 GHz, and 4.89–5.21 GHz are achieved with very small frequency ratios.

5. DESIGN AND ANALYSIS OF SIX BAND ANTENNA ANT_4

Further, a Complementary SRR (CSRR) is embedded at the edge of the rectangular patch, and length of the ground slot is increased to $L_n + x_1$ as shown in Figure 8. A conducting strip of length x_1 is used to attach the half dipole with another antenna structure on the signal plane whereas a complementary

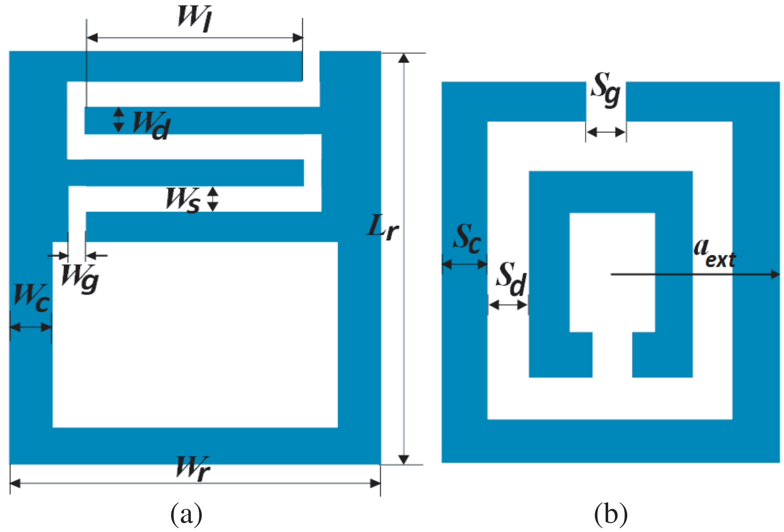


Figure 5. Schematic of (a) IDCLLR, (b) SRR.

Table 3. Design specification of antenna *Ant_3*.

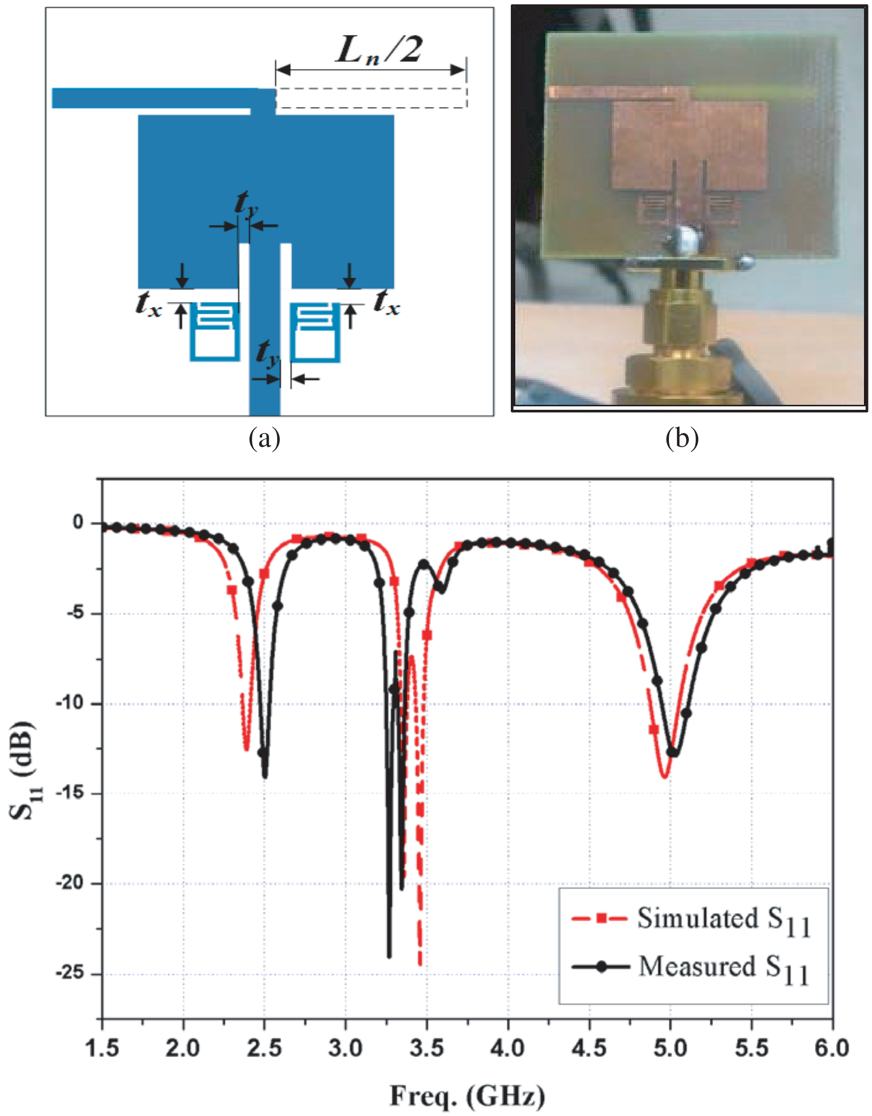
Parameter	Value [mm]	Parameter	Value [mm]
W_r	4	W_l	5
L_r	5	W_d	0.3
W_s	0.2	W_c	0.6
W_g	0.1	t_x	1.11225
t_y	0.4945		

slot of length x_1 is used to attach the grounded half-dipole slot. Length x_1 is founded by parametric analysis in order to obtain the desired operating band. One right outer arm of CSRR is taken out from the edge of the rectangular patch which provides the effects of slits [17–19]. This antenna provides six operating frequency bands and is referred as *Ant_4*. The fabricated prototype of *Ant_4* is shown in Figure 8(c). The locations S_{x1} and S_{y1} of CSRR from the patch sides are taken as 4.38775 mm and 2.7945 mm, respectively. Detailed design specifications of *Ant_4* is depicted in Table 4.

Table 4. Design specification of antenna *Ant_4*.

Parameter	Value [mm]	Parameter	Value [mm]
S_{x1}	4.38775	d_1	8.1909
S_{y1}	2.7945	$(L_n + x_1)$	31.7

Simulated and measured return loss characteristics of *Ant_4* are shown in Figure 8(d). Current distributions are shown in Figures 9(a) and 9(b). *Ant_4* provides six operating bands at 2.5, 2.812, 3.128, 3.376, 3.872, and 5.132 GHz with very small frequency ratios and may be used for various applications such as 2.5 GHz for UMTS2600 (2.5 $\sim$ 2.690 GHz) and WiFi (2.4 $\sim$ 2.5 GHz), 2.812 GHz for video link using CCTV camera, 3.128 GHz & 3.376 GHz for WiMAX (2.3/2.5/3.3/3.8/5.8 GHz in Asia), 3.872 GHz for C-band (3.7 $\sim$ 4.2 GHz) and WiMAX (2.3/2.5/3.3/3.8/5.8 GHz in Asia) and 5.132 GHz for Lower WLAN (5.05 $\sim$ 5.35 GHz). Proposed Antenna *Ant_4* provides six operating bands with frequency ratio between two consecutive resonant frequencies of the values of 1.1248, 1.1123, 1.0792, 1.1469 and

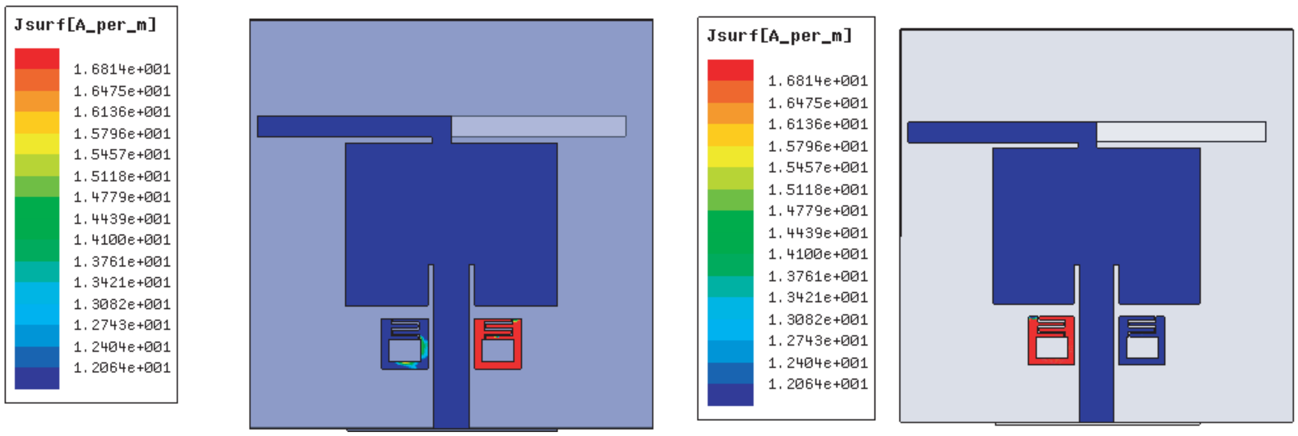


(c)

Figure 6. Proposed antenna *Ant_3*. (a) Schematic, (b) fabricated prototype and (c) simulated and measured return loss characteristics with frequency.

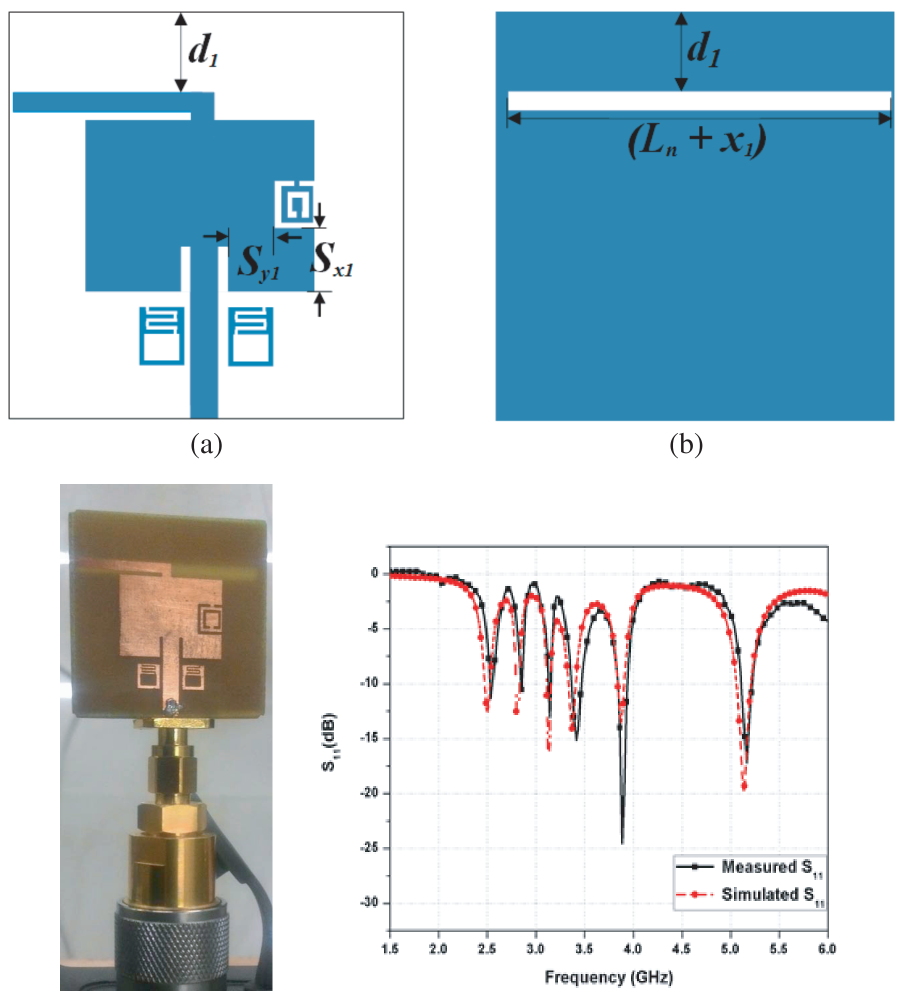
Table 5. Summary of results of presented antennas *Ant_2*, *Ant_3* and *Ant_4*.

Multiband Antenna	*Ant_2*	*Ant_3*	*Ant_4*
Number of radiating bands	2	4	6
Minimum Frequency ratio	2.001	1.002	1.07
Applications	UMTS2600, WiFi, Lower WLAN	WiFi, WiMAX, C-band, Lower WLAN.	UMTS2600, WiFi, CCTV camera, WiMAX, C-band, Lower WLAN.



(a) (b)

Figure 7. Current distributions of proposed antenna *Ant_3* at (a) 3.35 GHz, (b) 3.45 GHz.



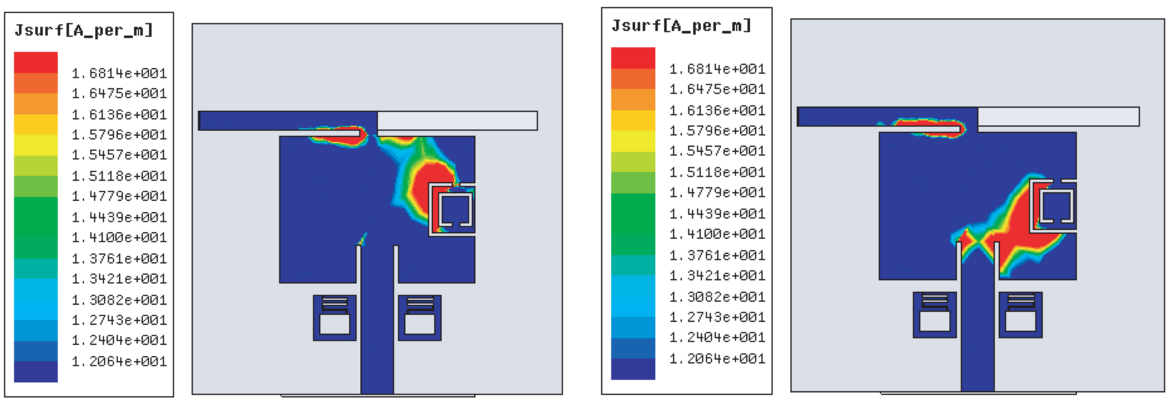
(a) (b)

(c) (d)

Figure 8. Proposed antenna *Ant_4* for six operating band operation. (a) Top View of schematic, (b) bottom view of schematic, (c) fabricated prototype and (d) measured and simulated return loss characteristics with frequency.

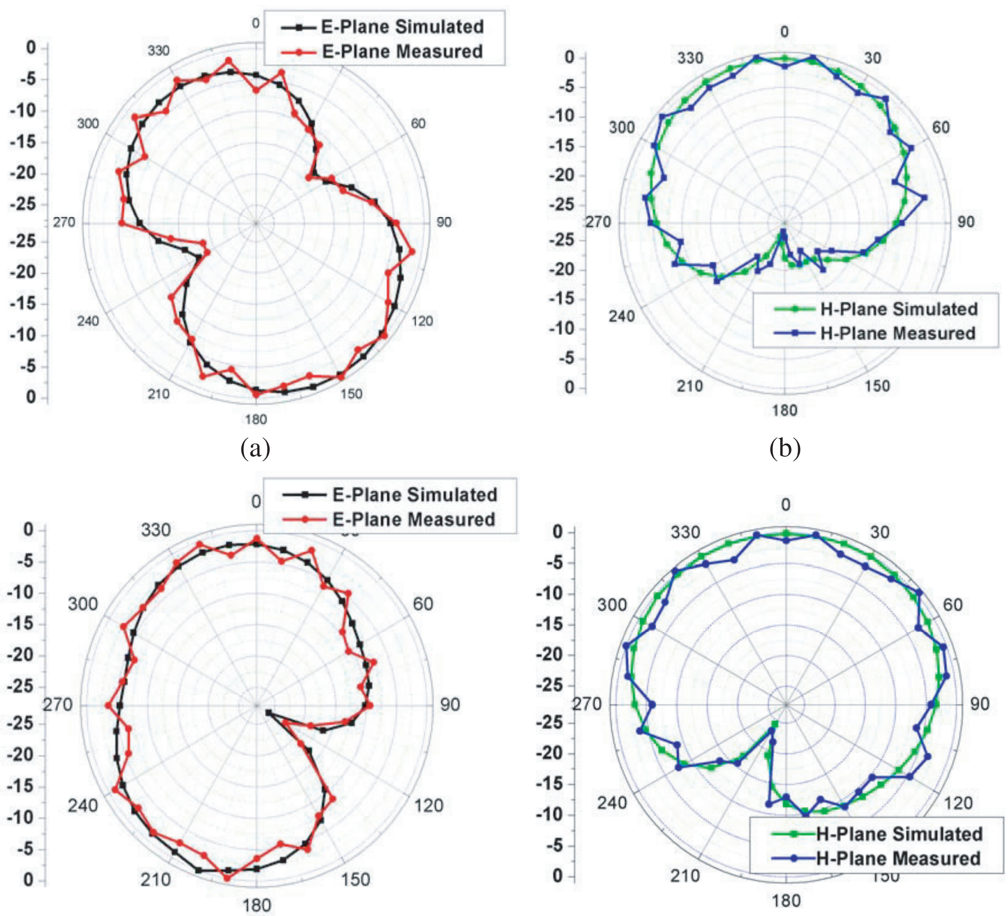
Table 6. Frequency ratio comparison of the proposed *Ant_4* with recent works.

Multiband/dual band Antenna	Proposed antenna *Ant_4*	[3]	[4]	[5]	[6]	[20]	[22]
Number of resonating bands	6	2	2	2	2	2	6
Minimum Frequency ratio	1.070	1.28	1.21	1.05	1.03	1.103	1.073



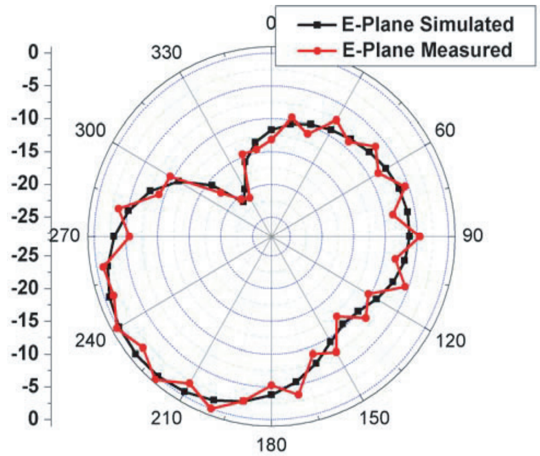
(a) (b)

Figure 9. Current distributions of proposed antenna *Ant_4* at (a) 3.376 GHz, (b) 3.872 GHz.



(a) (b)

(c) (d)


E-Plane Simulated
E-Plane Measured
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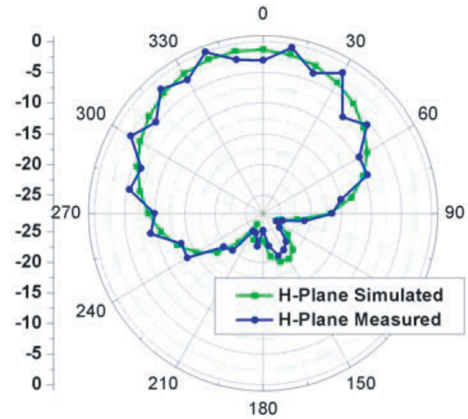
300
330

(e)


H-Plane Simulated
H-Plane Measured
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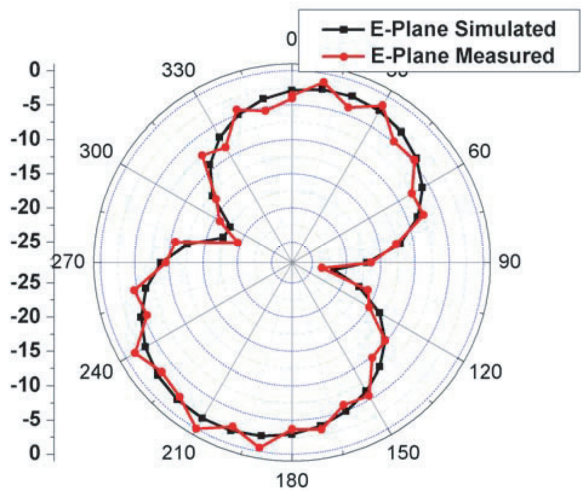
(f)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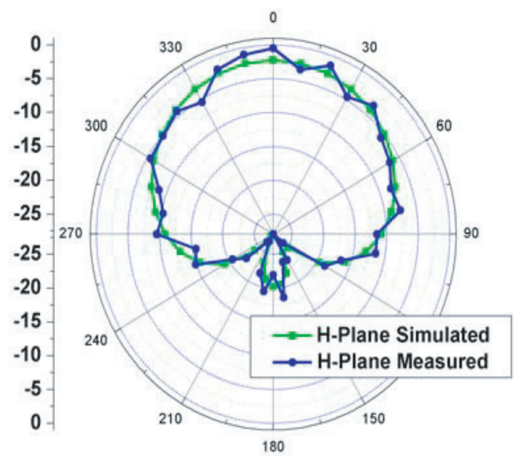
(g)


H-Plane Simulated
H-Plane Measured
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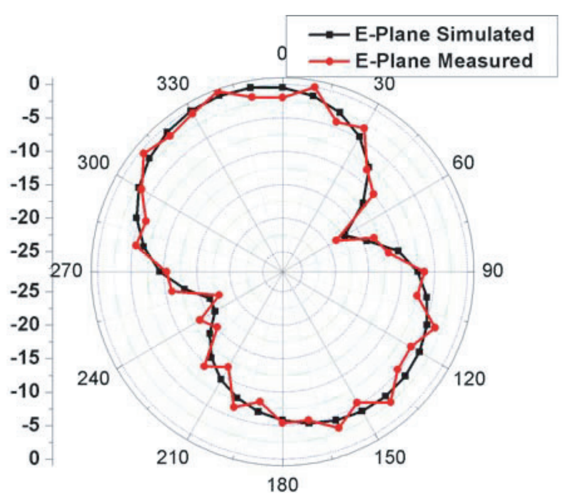
(h)


E-Plane Simulated
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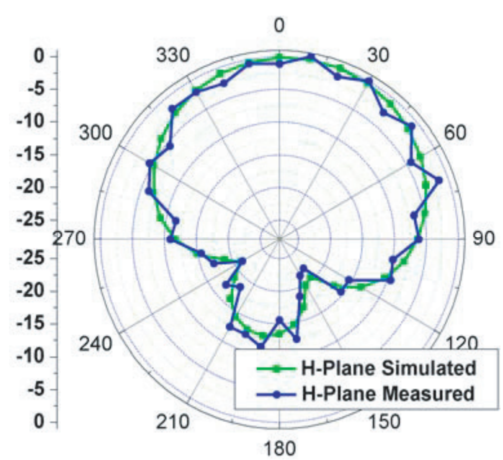
(i)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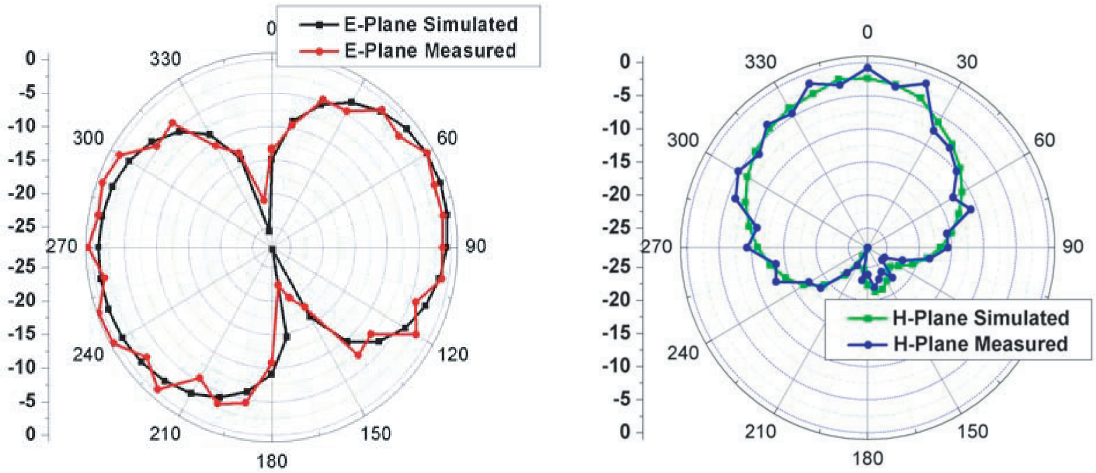
(j)



(k) (l)

Figure 10. Normalized measured and simulated radiation pattern of proposed antenna *Ant_4*. (a) *E*-Plane at 2.5 GHz, (b) *H*-Plane at 2.5 GHz, (c) *E*-Plane at 2.812 GHz, (d) *H*-Plane at 2.812 GHz, (e) *E*-Plane at 3.128 GHz, (f) *H*-Plane at 3.128 GHz, (g) *E*-Plane at 3.376 GHz, (h) *H*-Plane at 3.376 GHz, (i) *E*-Plane at 3.872 GHz, (j) *H*-Plane at 3.872 GHz, (k) *E*-Plane at 5.132 GHz, and (l) *H*-Plane at 5.132 GHz.

1.3254, respectively. Summary of results of the presented antennas is given in Table 5. A comparison of frequency ratio of proposed antenna *Ant_4* with recently reported works is given in Table 6. Table 7 presents the comparison of performance of proposed antenna *Ant_4* with literature [3–6, 9, 11, 20–22]. Proposed structure offers six bands, which is the main advantage of the proposed structure over the available literature, and secondly, frequency ratio between two consecutive bands is minimum.

Radiation patterns of proposed antenna *Ant_4* are demonstrated in Figure 10 at all six resonant frequencies. Measured gain of *Ant_4* is shown in Figure 11, and it is observed that the proposed antenna shows good radiation characteristics with 2.52, 4.21, 3.78, 4.2, 3.52, and 5.08 dBi gain at the six resonant frequencies, respectively.

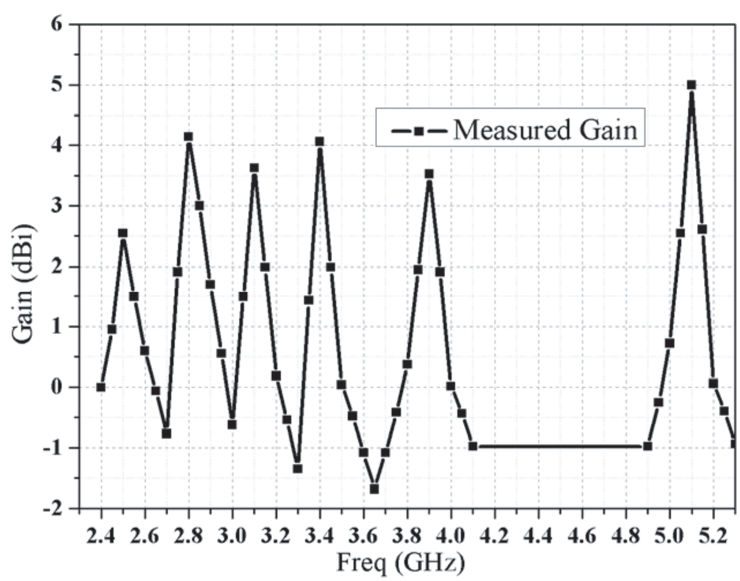


Figure 11. Measured gain with frequency of proposed antenna *Ant_4*.

Table 7. Performance comparison of proposed *Ant_4* with latest literature.

Multiband Antenna	Number of radiating bands	Bandwidth					
		I	II	III	IV	V	VI
[3]	2	16%	12.5%	-	-	-	-
[4]	2	5.88%	6.08%	-	-	-	-
[5]	2	2.79%	2.67%	-	-	-	-
[6]	2	3.12%	4.18%	-	-	-	-
[9]	3	4.7%	3.7%	2.4%	-	-	-
[11]	4	1.2%	2%	1.9%	0.9%	-	-
[20]	2	2.99%	2.72%	-	-	-	-
[21]	4	0.7%	2.1%	2.2%	1.4%	-	-
[22]	6	0.3%	0.10%	0.08%	0.02%	0.21%	0.11%
Proposed Antenna *Ant_4*	6	1.6%	1.3%	1.25%	5.84%	4.33%	4.83%
Multiband Antenna	Number of radiating bands	Gain (dBi)					
		I	II	III	IV	V	VI
[3]	2	6.12	5.1	-	-	-	-
[4]	2	1.35	3.5	-	-	-	-
[5]	2	1.95	2.8	-	-	-	-
[6]	2	5.23	4.65	-	-	-	-
[9]	3	1.7	1.4	2.5	-	-	-
[11]	4	4.1	6.2	8	6.2	-	-
[20]	2	4.5	4.5	-	-	-	-
[21]	4	4.8	4	6	8	-	-
[22]	6	1.7	1.83	3.17	3.2	3.23	5.82
Proposed Antenna *Ant_4*	6	2.52	4.21	3.78	4.2	3.52	5.08

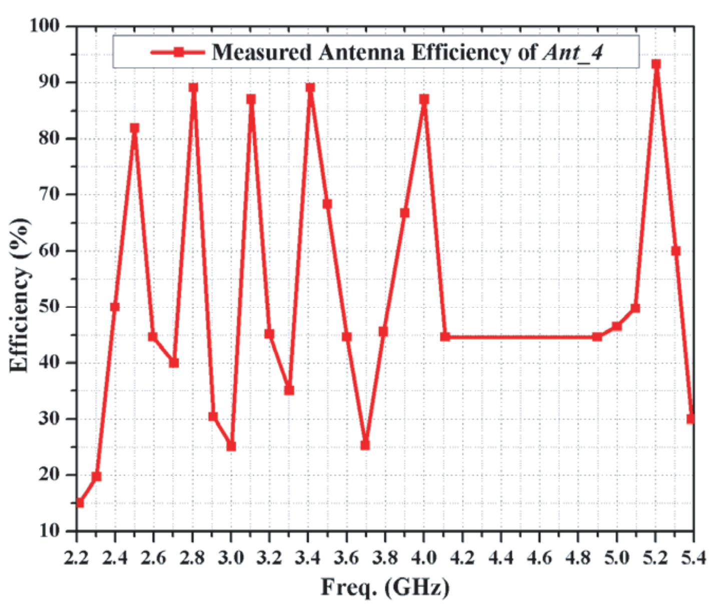


Figure 12. Measured antenna radiation efficiency with frequency of *Ant_4*.

Figure 12 shows the radiation efficiency of proposed antenna *Ant_4*. Radiation efficiency of the proposed antenna at non-resonating frequencies is quite low which means that the antenna does not radiate at non-resonating bands. Thus, at all non-resonance-frequency-bands, there will be no interference and mutual coupling as the antenna is not radiating at those bands.

Radiation characteristics of the designed antennas are measured in an anechoic chamber using Agilent Spectrum Analyser. Normalized values of E-plane and H-plane characteristics are calculated in the study whereas three antenna methods (using Friss-Transmission formula) are used to measure the gain of antennas. Measured results of fabricated prototypes are found in good agreement with simulated ones.

6. CONCLUSION

A microstrip patch antenna for six operating bands with small frequency ratios and narrow RF channel frequencies is designed and analysed. Step by step procedure for achieving each band is presented. Proposed antenna *Ant_4* resonates at 2.5, 2.812, 3.128, 3.376, 3.872, and 5.132 GHz with very small frequency ratio between two consecutive resonant frequencies 1.1248, 1.1123, 1.0792, 1.1469 and 1.3254. It may be used for various applications such as 2.5 GHz for UMTS2600 (2.5 $\sim$ 2.690 GHz) and WiFi (2.4 $\sim$ 2.5 GHz), 2.812 GHz for video link using CCTV camera, 3.128 GHz & 3.376 GHz for WiMAX (2.3/2.5/3.3/3.8/5.8 GHz in Asia), 3.872 GHz for C-band (3.7 $\sim$ 4.2 GHz) & WiMAX (2.3/2.5/3.3/3.8/5.8 GHz in Asia) and 5.132 GHz for Lower WLAN (5.05 $\sim$ 5.35 GHz). The proposed structure is fabricated by standard photolithography process, and measured results are in good agreement with simulated ones.

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