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QUAD-BAND RECTANGULAR WIDE-SLOT ANTENNA FOR GPS/WIMAX/ WLAN APPLICATIONS

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Abstract—A compact quad-band rectangular wide-slot antenna is developed for GPS L_1 band, 2.5/3.5/5.5 GHz WiMAX and 2.4/5.2/5.8 GHz WLAN applications. The planar antenna consists of an L-shaped microstrip feed line and three stubs extending from the wide-slot on the ground plane. The performance of the antenna is enhanced by etching meander line on the top of the wide-slot. The proposed antenna has a size of $36 * 42 * 1\,\mathrm{mm}^3$ which is more compact than the previously reported antennas for the same application. The antenna has been simulated, fabricated and measured successfully. The measured results show that the antenna has the impedance bandwidths of 160 MHz (1.54–1.7 GHz), 380 MHz (2.38–2.76 GHz), 570 MHz (3.2–3.77 GHz) and 1130 MHz (5.12–6.25 GHz) for $S_{11} \leq -10\,\mathrm{dB}$. In addition, good radiation characteristics and stable antenna gains over the operating bands are obtained.

1. INTRODUCTION

With the prompt development of modern wireless personal communications in recent years, the demand for wireless devices that have compact dimensions and multi-band operations is enormous. As an important component of these devices, the developed antennas should not only be with multi-band operation but also have simple structure, low profile, and easy integration with the printed circuit board (PCB). The planar monopole antenna because of its attractive features of simple structure, easy fabrication, low cost and reasonably good performance has been widely used for multi-band applications. In [1–4], three pairs

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of dipoles antenna, compact ring monopole with double meander lines, meandered monopole antenna with shorted parasitic strips, and double T-shaped antenna are used for dual/triple band WLAN operations. Double couple C-shaped strips antenna, direct radiation patch with a parasitic C-shaped strip antenna, claw-shaped monopole antenna, and microstrip-fed antenna using defected ground structure are reported for WLAN/WiMAX applications, respectively [5–8]. However, these planar antennas have large size. Slot antennas are also employed to realize multi-band operations due to they have a more compact size than planar monopole antenna [9–12]. Up to now, Quad-band antennas cover GPS/WiMAX/WLAN bands have not been widely reported, which have very important potential applications. In [13], a microstrip circular slot antenna using edge-feeding is proposed to support quad-band applications. However, it has a large size of $53 * 60\,\mathrm{mm}^2$ and doesn't include the 2.5 GHz WiMAX band. A CPW-fed pentagonal monopole antenna with a strip load is presented [14] while it doesn't cover the 2.4 GHz WLAN band and the 2.5 GHz WiMAX band.

In this paper, a low profile rectangular wide-slot antenna for quad-band applications is proposed. The slot antenna is composed of an L-shaped microstrip line and three stubs extending from the wide-slot on the ground plane. In addition, unlike the traditional rectangular wide-slot antenna, the meander line in this design is etched on the top of the rectangular slot to improve the antenna performance. Quad-band characteristics can be obtained by properly selecting the dimensions of the slot, structure, length and position of the four branches. Measured results show that the impedance bandwidths are suitable for three wireless communication systems, such as the global position system, the wireless local area network (WLAN) 2.4/5.2/5.8 GHz, and the worldwide interoperability for microwave access (WiMAX) 2.5/3.5/5.5 GHz. Details of the antenna design and simulated results as well as measured results are presented and discussed.

2. ANTENNA DESIGN AND SIMULATION

The geometry of the proposed quad-band wide-slot antenna is shown in Figure 1. For the design studied here, the microstrip feed line and ground plane are etched on the opposite side of a low-cost FR4 substrate with thickness of 1 mm and relative dielectric constant of 4.4. The L-shaped microstrip feed line which has the width of 1.9 mm is used as the main radiator. Three stubs extending from the wide-slot on the ground plane are introduced to increase the excitation of resonant modes and improve the impedance matching condition. The width of the stubs is fixed at 2.5 mm. The meander line etched on the

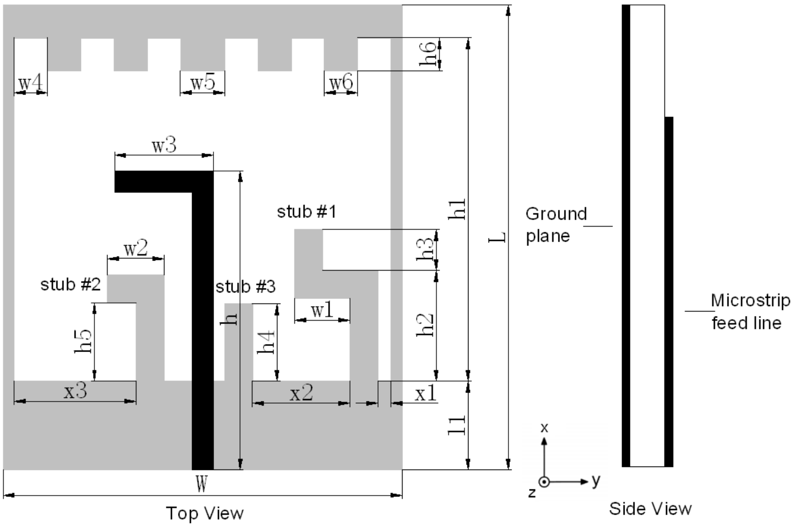


Figure 1. Geometry of the proposed quad-band wide-slot antenna.

Table 1. Optimized parameters of the proposed antenna (see Figure 1).

Parameter	W	L	w_1	w_2	w_3	w_4	w_5	w_6	l_1	h
Value (mm)	36	42	5	5.1	8.9	3	4	3	8	27
Parameter	h_1	h_2	h_3	h_4	h_5	h_6	x_1	x_2	x_3	
Value (mm)	31	10	3.7	7	7.1	3	1.2	8.8	11	

top of ground plane prolongs the current route and thus reduces the overall size of the antenna at the same required lower frequency [15]. The dimensions of the proposed antenna are optimized and shown in Table 1.

The design and optimization process are carried out by electromagnetic simulation software Ansoft HFSS V12. The simulated return loss of the proposed antenna with optimized parameters as listed in Table 1 is shown in Figure 2. Quad modes resonating at 1.56, 2.55, 3.62, and 5.42 GHz with bandwidths for return loss less than −10 dB which are about 70 MHz (1.52–1.59 GHz), 300 MHz (2.4–2.71 GHz), 550 MHz (3.18–3.73 GHz), and 1210 MHz (5.06–6.27 GHz) are obtained according to the result. In order to present the design process clearly, the return loss of the designed Antenna #1 (with only L-shaped microstrip feed line), Antenna #2 (the proposed antenna

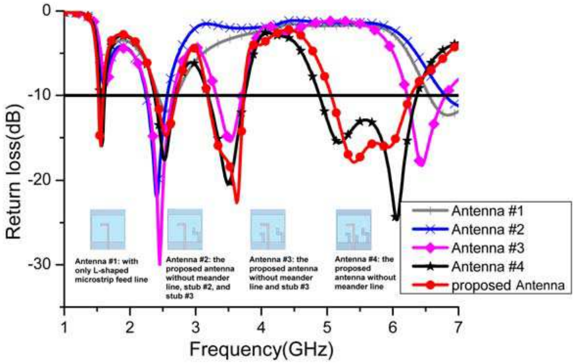


Figure 2. Simulated return loss against frequency under various configurations of the antenna.

without meander line, stub #2, and stub #3), Antenna #3 (the proposed antenna without meander line and stub #2), and Antenna #4 (the proposed antenna without meander line) is also analyzed and shown in Figure 2. When the wide-slot antenna is just fed by the L-shaped microstrip line, three fundamental resonant modes are formed at 1.58, 2.55, and 6.85 GHz. When stub #1 is added, the 2.55 GHz resonant mode is enhanced while the other two modes almost do not change. Then stub #2 is added, a new 3.52 GHz resonant mode is produced and the 6.85 GHz resonant mode shifts to 6.43 GHz. After stub #3 is added, a huge improvement is appeared at the 1.58 GHz resonant mode and the 6.43 GHz resonant mode shifts to 6.06 GHz, where wide-impedance matching condition is achieved. Finally, the meander line is etched on the top of the wide-slot to improve the antenna performance. It can be seen that when the meander line is etched, the return loss of the stop band at 2.97 GHz increases 1.77 dB from −6.15 dB to −4.38 dB and the return loss of the pass band at 5.59 GHz decreases 3.5 dB from −12.8 dB to −16.3 dB.

To further examine the above excitation mechanism of the proposed antenna, the effects of the designed parameters on the antenna performance are presented in Figure 3. Firstly, the effect of L-shaped microstrip feed line on matching condition of the proposed antenna is studied. Figure 3(a) depicts simulated return loss of the antenna when h changes from 26 mm to 28 mm. It is seen that all bands are affected when the length of the feed line changes. Figure 3(b) shows how the length of stub #1 affects the antenna performance. It is concluded that the resonant frequency and bandwidth of the

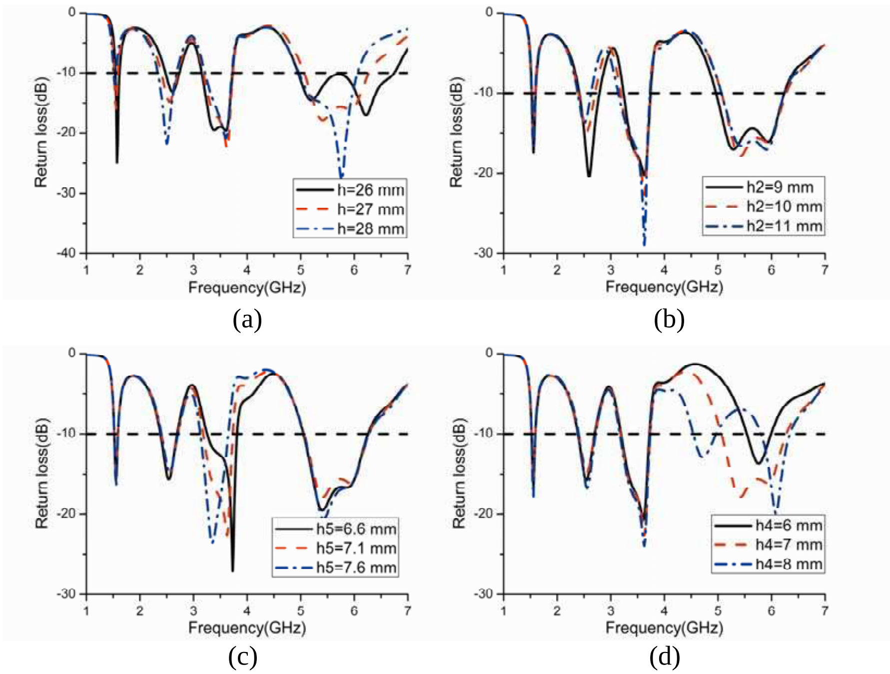
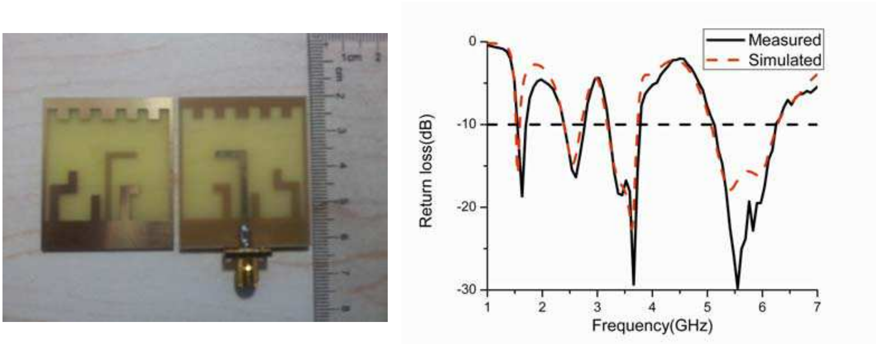


Figure 3. Simulated return loss against frequency for the proposed antenna with various h, h_2, h_5 and h_4.

second resonant mode decreases as h_2 increases from 9 mm to 11 mm while the other three resonant modes are nearly not affected. The simulated return loss when the length of stub #2 changes is presented in Figure 3(c). With the increase of h5 from 6.6 mm to 7.6 mm, the first, second and fourth resonant modes do not be significantly changed but the third resonant mode moves to lower frequency band. Figure 3(d) illustrates how the antenna performance is influenced by the length of stub #3. Obviously, varying the length of stub #3 seriously affect the impedance matching of the fourth resonant mode, whereas less change is seen for the other three resonant modes.

3. RESULTS AND DISCUSSION

Based on the dimensions given in Table 1, the proposed quad-band rectangular wide-slot is fabricated and measured. The photograph of the fabricated antenna is shown in Figure 4(a). The measured result is performed by using a vector network analyzer (VNA) Agilent



(a) (b)

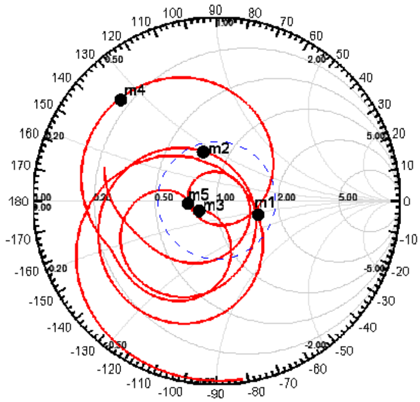
Figure 4. (a) Photograph of the proposed quad-band rectangular wide-slot antenna. (b) Measured and simulated return loss of the proposed antenna.

Table 2. Measured and simulated impedance bandwidths of the proposed quad-band rectangular wide-slot antenna.

	f_1 (GHz)	f_2 (GHz)	f_3 (GHz)	f_4 (GHz)
	BW (GHz)	BW (GHz)	BW (GHz)	BW (GHz)
Measured	1.63	2.6	3.6	5.55
	1.54–1.70	2.38–2.76	3.2–3.77	5.12–6.25
Simulated	1.56	2.55	3.62	5.42
	1.52–1.59	2.4–2.71	3.18–3.73	5.06–6.27

E8363B. Figure 4(b) plots the measured and simulated return loss against the frequency of the proposed antenna, where good agreements between them have been observed. Obviously, four resonant modes at frequencies of 1.63, 2.6, 3.6 and 5.5 GHz are excited, with good impedance matching. The measured impedance bandwidths for $S_{11} \leq -10$ dB are about 160 MHz (1.54–1.70 GHz), 380 MHz (2.38–2.76 GHz), 570 MHz (3.2–3.77 GHz), and 1130 MHz (5.12–6.25 GHz), which can be used for the applications of 1.57–1.58 GHz GPS L_1 band, 2.4–2.484 GHz, 5.15–5.35 GHz, and 5.725–5.825 GHz WLAN bands, and 2.5–2.69 GHz, 3.4–3.69 GHz, and 5.25–5.85 GHz WiMAX bands. In order to be convenient for comparison, measured and simulated data is also listed in Table 2. The smith chart of the simulated input impedance of the proposed antenna is shown in Figure 5. It is observed that the resonant modes are within the VSWR = 2 circle.

To explain the excited resonant modes of the proposed antenna



Name	Freq
m1	1.575 GHz
m2	2.45 GHz
m3	3.5 GHz
m4	4.5 GHz
m5	5.7 GHz

Figure 5. Smith plot of antenna impedance.

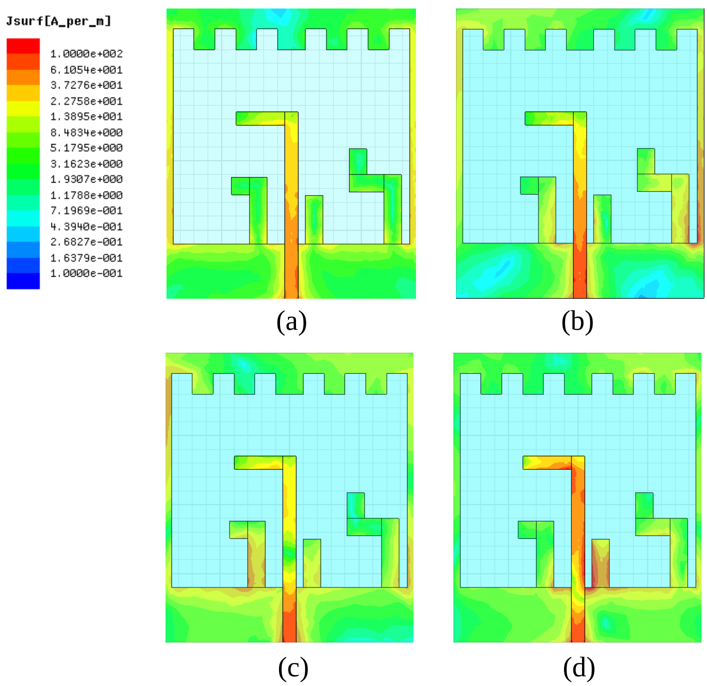
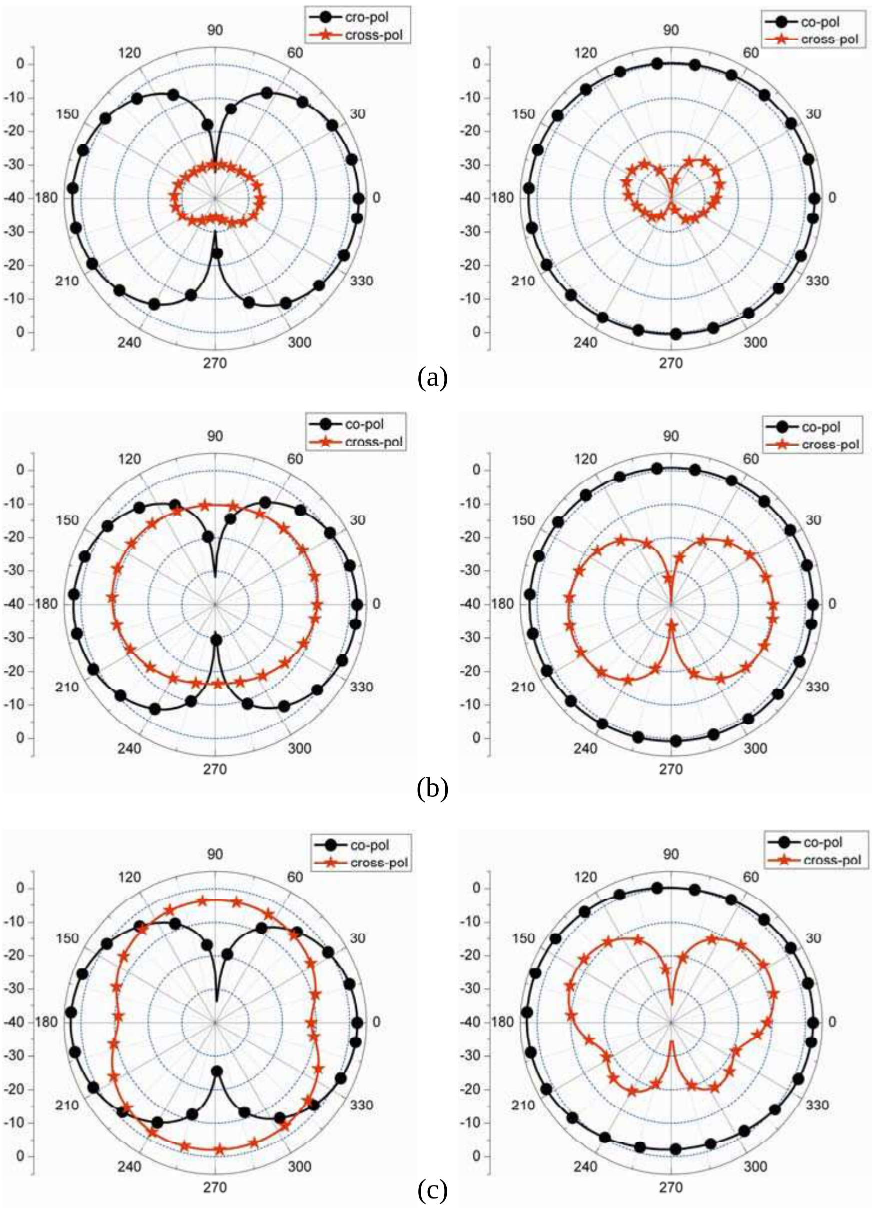
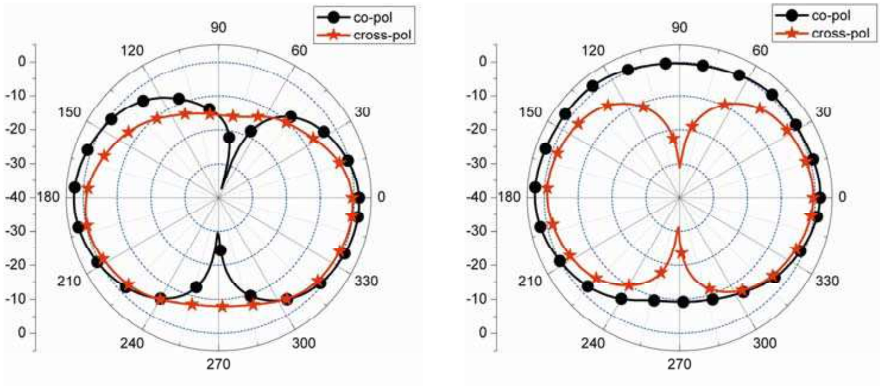


Figure 6. Simulated current distribution of the proposed antenna at (a) 1.575 GHz, (b) 2.45 GHz, (c) 3.5 GHz, and (d) 5.5 GHz.

in more detail, the simulated surface current distribution at 1.575, 2.45, 3.5 and 5.5 GHz carried out by HFSS V12 is shown in Figure 6. When the antenna works at lower frequency band (at the 1.575 GHz), a large surface current density is observed along the L-shaped microstrip feed line and two vertical margins of the slot as shown in Figure 6(a). As was expected, the current distribution becomes more concentrated along the stub #1, stub #2, and stub #3 when the antenna is excited at 2.45, 3.5, and 5.5 GHz, respectively. According to the design process in Figure 2 and the current distribution in Figure 6, we conclude





(d)

Figure 7. Simulated radiation patterns for the proposed antenna at (a) 1.575 GHz, (b) 2.4 GHz, (c) 3.5 GHz, and (d) 5.5 GHz.

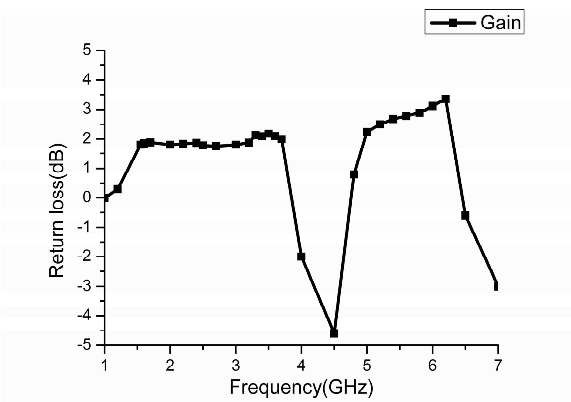


Figure 8. The peak gains for the proposed antenna.

that the wide-slot and the L-shaped microstrip feed line excites three fundamental resonant modes and new current path is introduced when the new stubs are added to the antenna which makes new resonant modes appear. Thus, multi resonant modes with good and wide-impedance matching conditions are obtained.

The simulated far-field radiation patterns in YOZ plane (H-plane) and XOZ plane (E-plane) for frequencies at 1.575, 2.4, 3.5, and 5.5 GHz are normalized and plotted in Figure 7, respectively. It is observed that the proposed antenna features fairly omni-directional radiation patterns in H-plane and monopole-like radiation patterns in the E-plane. Figure 8 shows the measured peak gains against frequency. The ranges of the measured antenna gains across the 1.63, 2.6, 3.6, and 5.55 GHz bands are about 1.8–1.87, 1.75–1.86, 1.87–2.18, and 2.24–3.36 dBi, with an average value of 1.84, 1.81, 2.06, and 2.8 dBi, respectively.

4. CONCLUSION

A compact L-shaped microstrip feed wide-slot antenna for quad-band operations with numerical and experimental results has been presented. The antenna has a simple structure and is easy to be fabricated on FR4 substrate with size of $36 * 42 * 1\,\text{mm}^3$. By adding three kinds of stubs to the fundamental L-shaped microstrip feed wide-slot antenna, the proposed antenna excites four resonant modes covering the 1.54–1.70, 2.38–2.76, 3.2–3.77, and 5.12–6.25 GHz bands. In addition, the antenna shows acceptable radiation characteristics and stable gain across the operating bands, which are attractive for practical application in the GPS/WiMAX/WLAN communications.

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