

A BIDIRECTIONAL MULTIBAND ANTENNA WITH MODIFIED FRACTAL SLOT FED BY CPW

C. Mahatthanajatuphat and P. Akkaraekthalin

Faculty of Engineering
King Mongkut's University of Technology North Bangkok
Bangkok 10800, Thailand

S. Saleekaw

College of Industrial Technology
King Mongkut's University of Technology North Bangkok
Bangkok 10800, Thailand

M. Krairiksh

Faculty of Engineering
King Mongkut's Institute of Technology Ladkrabang
Bangkok, 10520, Thailand

Abstract—This paper presents a multiband slot antenna with modifying fractal geometry fed by coplanar waveguide (CPW) transmission line. The presented antenna has been designed by modifying an inner fractal patch of the antenna to operate at multiple resonant frequencies, which effectively supports the digital communication system (DCS 1.71–1.88 GHz), worldwide interoperability for microwave access (WiMAX 3.30–3.80 GHz), IMT advanced system or forth generation mobile communication system (3.40–4.2 GHz), and wireless local area network (WLAN 5.15–5.35 GHz). Manifestly, it has been found that the radiation patterns of the presented antenna are still similarly to the bidirectional radiation pattern at all operating frequencies. The properties of the antennas, for instance, return losses, radiation patterns and gain are determined via numerical simulation and measurement.

1. INTRODUCTION

Presently, the technologies of wireless communication systems have been rapidly ever growing demands for greater capacities broadband service and transmission speeds to support multimedia, image, speech, and data communication. In order to response the rapidly growing demands, an antenna should be responsible in many frequency bands. Accordingly, the multiband antenna is desired in many systems. In the literature reviews, there are various multiband antennas that have been developed over the years, which can be utilized to achieve the objectives of multiband operation, for instance, the PIFA [1, 2] for using in mobile phone application, the slot spiral antenna [3] for dual band or multiband operation, the triangle-shaped monopole antenna [4], and other [5–23]. Recently, the developing multiband antennas have been improved due to use of the fractal concept. The term of the fractal geometries was first originated by Mandelbrot [24] to describe a family of complex shapes that have self-similarity or self-affinity in their geometrical structure. We have found some advantages of the fractal geometries, which support the attribute of multiband frequency operations.

Recently, the Sierpinski gasket monopole antenna was introduced by Puente [25]. This popular antenna used the self-similarity properties of the fractal shape to translate into its electromagnetic behavior. Then, the classic Sierpinski gasket was developed by generating the Pascal triangle [26]. However, other antennas, which have the characteristic of multiband created by fractal geometries, are following: multiple ring monopole antennas [27], coplanar waveguide (CPW) fed circular fractal slot antenna [28], double square loop antenna [29], etc..

In this paper, the modified fractal slot antenna fed by CPW is presented, which operates in digital communication system (DCS 1.71–1.88 GHz), worldwide interoperability for microwave access (WiMAX 3.3–3.8 GHz), IMT advanced system or forth generation (4G) mobile communication system (3.4–4.2 GHz), and wireless local area network (WLAN 5.15–5.35 GHz). The proposed antenna consists of a matching CPW-fed line, which connected between $50\ \Omega$ CPW line and the modified fractal patch of radiating slot antenna. The modified fractal slot is utilized to create the multiple resonance frequencies. However, the parameters of the proposed antenna will be investigated by simulation using the full wave method of moment (MOM) software package, IE3D. The experiments of the fabricated antenna prototype have also been performed. The radiation pattern of the proposed antenna will be also evaluated. The organization of this paper is as follows. In Section 2, a brief explanation on the modified fractal

slot antenna will be issued. Then, the antenna parameters will be investigated in Section 3. Afterward, simulation and measured properties of the proposed antenna will be discussed in Section 4. Finally, the results are discussed in Section 5.

2. ANTENNA DESIGN

In this section, a fractal slot antenna fed by CPW [30] was created by applying the Minkowski fractal concept in [31] to generate the initial generator model [29] at both sides of inner patch of the antenna, as shown in Fig. 1(a). The altitude of initial generator model as shown in Fig. 2 varies with W_p . Usually, W_p is smaller than $W_s/3$ and the iteration factor is [32].

$$\eta = \frac{W_p}{W_s/3}; \quad 0 < \eta < 1 \quad (1)$$

Normally, the appropriated value of iteration factor $\eta = 0.66$ was used to produce the fractal slot antenna. However, the fractal slot antenna fed by CPW in Fig. 1(a), as reviewed in [30], cannot independently control each resonant frequency. Therefore, it has been modified by eroding the inner metallic patch, as illustrated in Fig. 1(b), in order to independently control each resonant frequency and support the operating frequency bands of DCS 1800, WiMAX, IMT advanced systems, and WLAN 5.25 GHz.

The configuration of the proposed antenna, as illustrated in Fig. 1(b), is the modified fractal slot antenna fed by CPW. The antenna composes of the modified inner metallic patch, which is fed by a 50Ω CPW line with a strip width W_f and gap g_1 , and an outer metallic patch. In the paper, the antenna is fabricated on an economical FR4 dielectric substrate with a thickness of 1.6 mm (h), relative permittivity of 4.1 (ϵ_r) and loss tangent of 0.019. The entire dimensions of the antenna are 53.40 mm \times 75.20 mm. The 50Ω SMA connector is used to feed the antenna at the CPW line. The important parameters, which affect the resonant frequencies of 1.74 GHz, 3.85 GHz, and 5.05 GHz, compose of S_u , S , and S_L . The fixed parameters of the proposed antenna are following: $h = 1.6$ mm, $W_{G_1} = 53.37$ mm, $W_{G_2} = 38.54$ mm, $L_{G_1} = 75.20$ mm, $L_{G_2} = 34.07$ mm, $L_{G_3} = 39.75$ mm, $W_s = 32.57$ mm, $g_1 = 0.5$ mm, $g_2 = 2.3$ mm, $W_t = 0.94$ mm, $L_t = 21.88$ mm, $W_f = 3.5$ mm, $L_f = 14.50$ mm, $W_1 = 25.92$ mm, $W_2 = 11.11$ mm, $W_3 = 16.05$ mm, $W_4 = 3.7$ mm, and $s_1 = s_2 = s_3 = 3.55$ mm. The important parameters of S_u , S , and S_L will be investigated and observed at the alternation of the operating frequency bands by using

the full wave method of moment (MOM) software package, IE3D, in the next section.

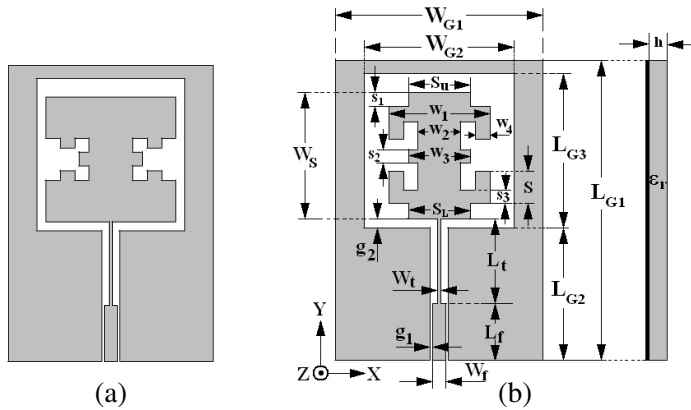


Figure 1. The schematic diagrams, (a) the fractal slot antenna and (b) the modified fractal slot antenna.

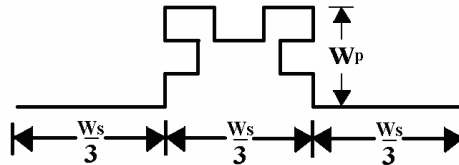


Figure 2. The initial generator model for the proposed antenna.

3. PARAMETER STUDY

This section presents the investigation on the effects of important parameters, including S_u , S , and S_L . The fractal slot antenna without modified slot in [30] has only covered the operating frequency bands of 1.51–1.68 GHz and 3.3–5.2 GHz. In order to enhance the operating frequency band for the applications of DCS 1800, WiMAX, IMT advance system or 4G mobile communication system, and WLAN IEEE 802.11a, the antenna has been modified as illustrated in Fig. 1(b).

For this studied design, the initial parameters of the antenna configuration have been selected to be $S = 4.751$ mm and $S_L = 16.050$ mm. Then, the parameter S_u has been alternated ($S_u = 11.112$, 16.050, and 20.989 mm) in order to investigate the effect on the return

loss, as shown in Fig. 3. This figure shows that the antenna has three resonant frequencies. As the parameter S_u increased, it can be seen that the first resonant frequency slightly shifts to the left, while the second and third resonant frequencies do not significantly affect. As

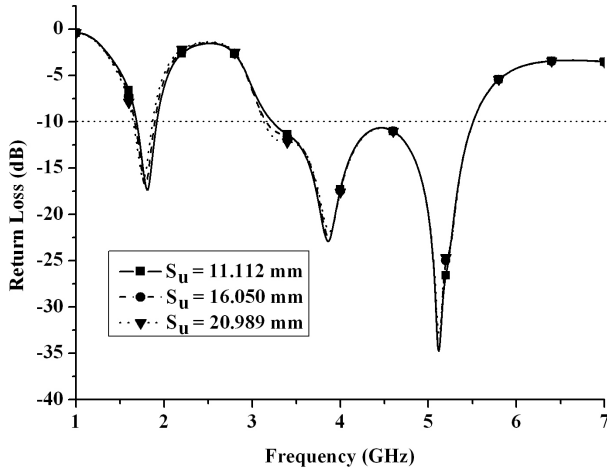


Figure 3. Simulated return losses for various S_u with $S = 4.751$ mm and $S_L = 16.050$ mm.

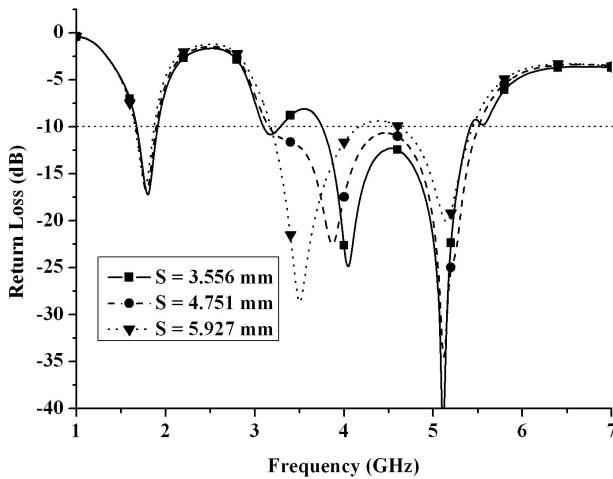


Figure 4. Simulated return losses for various S with $S_u = 16.050$ mm and $S_L = 16.050$ mm.

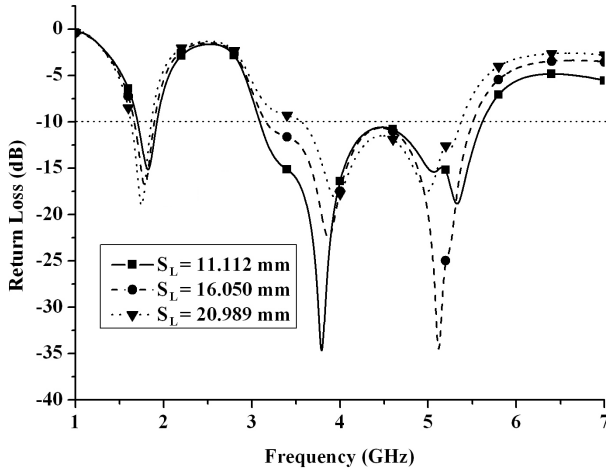


Figure 5. Simulated return losses for various S_L with $S_u = 16.050$ mm and $S = 4.751$ mm.

observed in Fig. 3, the sufficient parameter $S_u = 16.050$ mm should be selected to cover the operating frequency band for the application of DCS 1800 (1.71–1.88 GHz) and further design the configuration in the next step.

Next, the effect of important parameter S is investigated by varying parameter $S = 3.556$, 4.751, and 5.927 mm, while the other parameters $S_u = 16.050$ mm and $S_L = 16.050$ mm are selected. The results of varying parameter S are illustrated in Fig. 4. As the parameter S increased, the third resonant is slightly shifted to the right, while the first resonant frequency slightly shifted to the left. However, when varying the parameter S , it can be clearly seen that the second resonant frequency is mainly affected. This parameter controls the level of return loss in the second resonant frequency, resulting in the coupling effect in the slot of the proposed antenna. Also, the suitable parameter $S = 4.751$ mm is chosen in order to enhance the impedance bandwidth and cover the operating frequency bands of 3.2–5.5 GHz for the applications of WiMAX (3.3–3.8 GHz), IMT advance system or 4G mobile communication system (3.4–4.2 GHz), and WLAN IEEE 802.11a (5.15–5.35 GHz).

In addition, the simulation results of the return loss for various the parameter S_L ($S_L = 11.112$, 16.050, and 20.989 mm) is also illustrated in Fig. 5, which the appropriate parameters $S_u = 16.050$ mm and $S = 4.751$ mm are considered to cover the operating frequency band of 3.2–5.5 GHz. As illustrated in Fig. 5, it can be obviously seen that with

increasing in the parameter S_L , the first and third resonant frequencies decrease while the second resonant frequency increases. The level of the return losses in the second and third resonant frequencies are fluctuated due to the coupling effect in the radiating slot of the proposed antenna. Therefore, the befitting impedance bandwidth to cover the operating frequency bands of 1.71–1.88 GHz and 3.2–5.5 GHz is found when the parameter $S_L = 16.050$ mm.

Consequently, the optimal parameters, $S_u = 16.050$ mm, $S = 4.751$ mm, and $S_L = 16.050$ mm, are chosen for investigating the electric field distribution, radiation pattern, and gain at each resonant frequency in the next section. The parameter studies of the proposed antenna are summarized in Table 1.

4. EXPERIMENTAL RESULTS

From observation of various parameters, they affect the operating frequency bands of the proposed antenna in the previous section. Hence, the suitable parameters, as following, $h = 1.6$ mm, $W_{G_1} = 53.37$ mm, $W_{G_2} = 38.54$ mm, $L_{G_1} = 75.20$ mm, $L_{G_2} = 34.07$ mm, $L_{G_3} = 39.75$ mm, $W_s = 32.57$ mm, $g_1 = 0.5$ mm, $g_2 = 2.3$ mm, $W_t = 0.94$ mm, $L_t = 21.88$ mm, $W_f = 3.5$ mm, $L_f = 14.50$ mm,

Parameters (mm)		
S_u	S	S_L
11.112		
16.050	4.751	16.050
20.989		
	3.556	
16.050	4.751	16.050
	5.927	
		11.112
16.050	4.751	16.050
		20.989

Table 1. Summary of parameter study for the proposed antenna.

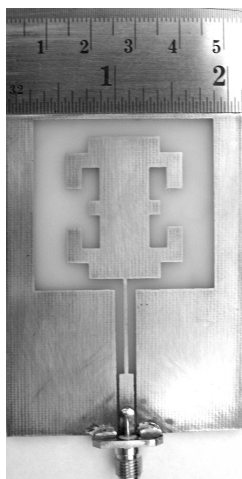


Figure 6. Photograph of the proposed antenna with appropriate values of $S_u = 16.050$ mm, $S = 4.751$ mm, and $S_L = 16.050$ mm.

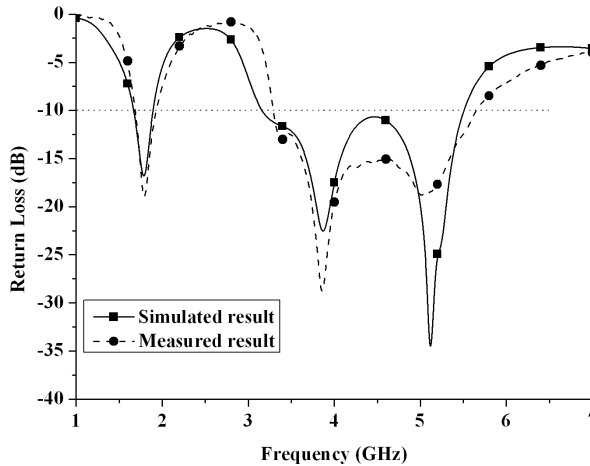


Figure 7. Simulated and measured return losses for the proposed antenna.

$W_1 = 25.92$ mm, $W_2 = 11.11$ mm, $W_3 = 16.05$ mm, $W_4 = 3.7$ mm, and $s_1 = s_2 = s_3 = 3.55$ mm, $S_u = 16.050$ mm, $S = 4.751$ mm, and $S_L = 16.050$ mm, are chosen to implement the prototype antenna by etching into chemicals. The prototype of the proposed antenna is shown in Fig. 6. The simulated and measured return losses of the antenna are illustrated in Fig. 7. It is clearly observed that the measured return loss of the antenna slightly shifts to the right because of the inaccuracy of the manufacturing process by etching into chemicals. However, the measured result of proposed antenna still covers the operating bands of 1.71–1.88 GHz and 3.2–5.5 GHz for the applications of DCS 1800, WiMAX, IMT advance system or 4G mobile communication system, and WLAN IEEE 802.11a.

The simulation results of electric field distribution on the modified fractal slot of the proposed antenna at the resonant frequencies of 1.74 GHz, 3.85 GHz, and 5.05 GHz are simulated and analyzed by IE3D simulation software package, as shown in Fig. 8. For the excitation at 1.74 GHz, as illustrated in Fig. 8(a), the vertical and horizontal components of the electric field are dominant to propagate the radiation patterns of co-polarization and cross-polarization in X - Z plane and Y - Z plane, which are observed in the slot of top, middle, and bottom sections. Obviously, it can be seen that the parameters S_u , S , and S_L , as discussed in the previous section, correlate to the effect of the electric field, which propagate the radiation patterns in all sections of the slot. Therefore, the parameters S_u , S , and S_L influence with the resonant frequency 1.74 GHz.

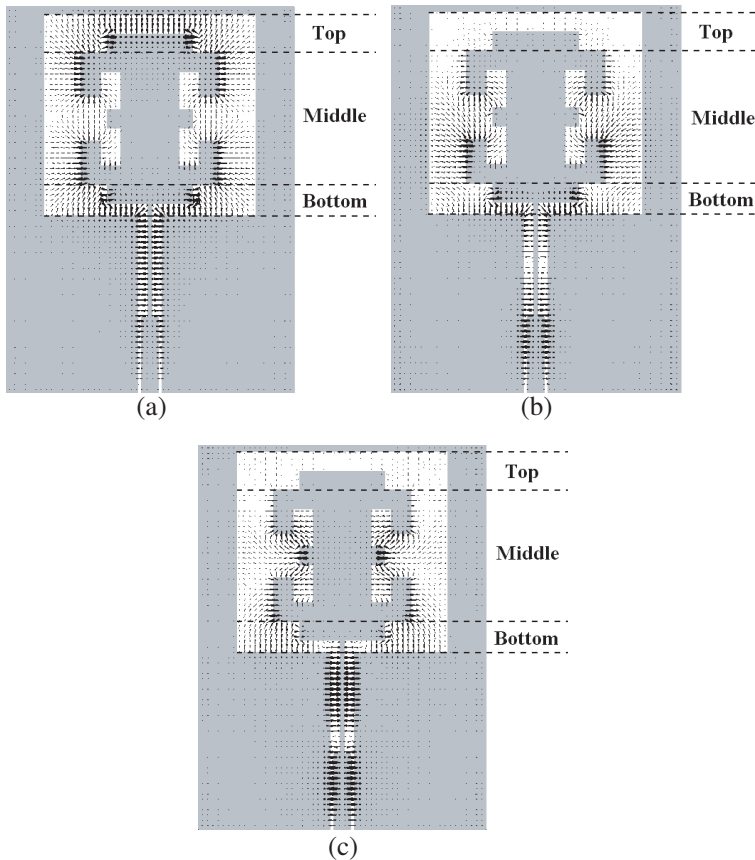


Figure 8. Simulated IE3D results of the electrical field on the radiating modified fractal slot of the proposed antenna at (a) 1.74 GHz, (b) 3.85 GHz, and (c) 5.05 GHz.

As shown in Fig. 8(b), the vertical and horizontal components of the electric field mostly occurs in the middle and bottom sections of slot at the resonant frequency 3.85 GHz. It can be clearly seen that both components of the electric field depend on the parameter S and S_L , as mentioned in Section 3, to propagate the electric pattern at the resonant frequency 3.85 GHz. Also, Fig. 8(c) illustrated that the electric field appears in the middle and bottom sections of the slot, which depend on the parameters S and S_L . It is obviously found that the horizontal component of the electric field is mostly found in the middle section of the slot, while the vertical component of the electric field mostly occurs in the bottom section of the slot. Clearly,

it reveals that the mostly horizontal component of the electric field causes the extensive cross polarization in the higher resonant frequency at 5.05 GHz.

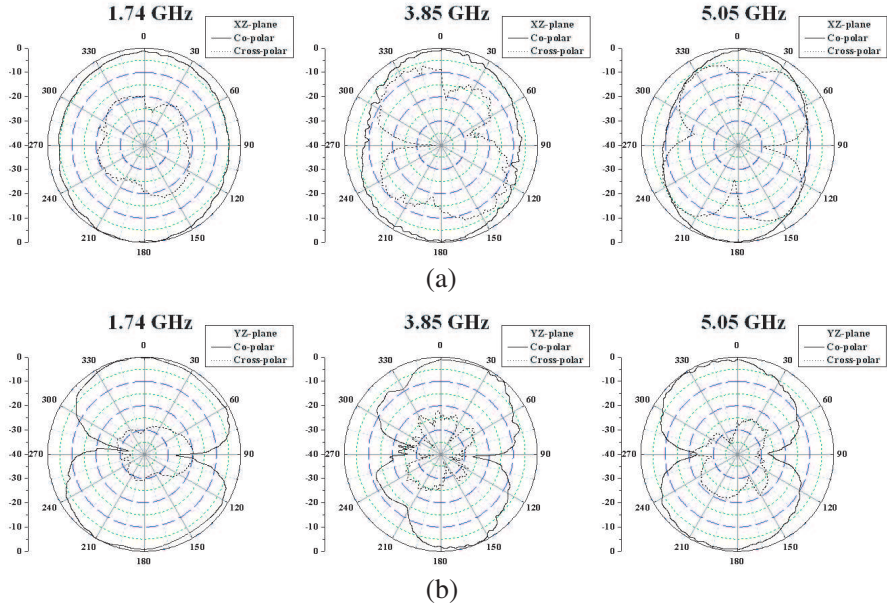


Figure 9. Measured radiation patterns of the proposed antenna with $S_u = 16.050$ mm, $S = 4.751$ mm, and $S_L = 16.050$ mm at 1.74 GHz, 3.85 GHz, and 5.05 GHz for (a) X - Z plane and (b) Y - Z plane.

Figures 9(a) and (b) illustrate the measured X - Z plane and Y - Z plane radiation patterns at the resonant frequencies of 1.74 GHz, 3.85 GHz, and 5.05 GHz. The measured radiation patterns of all resonant frequencies are similar to the bi-directional radiation patterns. The X - Z plane radiation patterns are depicted in Fig. 9(a). When increasing frequency, it can be clearly observed that the magnitude of cross-polarization increases due to the increased horizontal component of the electric field, which is the significant increase of the cross polarization radiation. Nevertheless, the HPBW of co-polarization still decreases. In Fig. 9(b), the maximum gains of radiation patterns in Y - Z plane are approximately occurred at 0 and 180 degrees, at the resonant frequencies of 1.74 GHz, 3.85 GHz, and 5.05 GHz. In addition, the peaks of simulated and measured antenna gains are shown in Fig. 10. The results depict that the average gains of simulated and measured results are approximately 2 dBi at each operating frequency

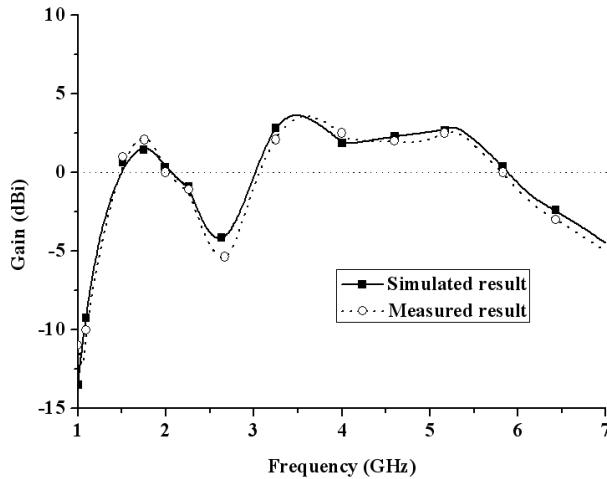


Figure 10. Simulated and measured gains of the proposed antenna.

band for the applications of DCS 1800, WiMAX, IMT advance system or 4G mobile communication system, and WLAN IEEE 802.11a.

5. CONCLUSION

In this paper, a modified fractal slot antenna fed by CPW has been demonstrated. The configuration parameters of the antenna have been varied to improve the impedance bandwidth for multiband wireless communication applications including DCS (1.71–1.88 GHz), WiMAX (3.3–3.8 GHz), IMT advance system or 4G mobile communication system (3.4–4.2 GHz), and WLAN IEEE 802.11a (5.15–5.35 GHz). Moreover, the radiation patterns at each operating frequency are almost similar to bi-directional, which is an advantage of the fractal concept over the conventional multiband antenna.

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