A Multiband CPW-Fed Slot Antenna with Fractal Stub and Parasitic Line

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Abstract. *This paper presents a multiband CPW-fed slot antenna with fractal stub and parasitic line. The conventional wideband slot antenna with fractal stub is modified by inserting the parasitic line surrounding the fractal stub that affects the attribution to be a multiband operation suitable for some applications in wireless communication systems. The parasitic line surrounding the fractal stub can generate a dual-notched frequency that can be controlled by varying the parameters of the parasitic structure. The lengths of slit and stub on both sides of the parasitic line can control the lower and higher notched frequencies, respectively. Additionally, the prototype of the proposed antenna can operate and cover the applications of DCS 1800, WiMAX IEEE 802.16, WLAN IEEE 802.11a/b/g, and IMT advance systems.*

Keywords

Multiband slot antenna, fractal stub, parasitic line.

1. Introduction

Nowadays, wireless communication systems are increasingly developed to support demands of people. Many current communication systems are coming with several operating bands. Therefore, antenna design needs many requisitions including low profile, low cost, compact size, and multiband operation. The multiband operation is the most important requisition for producing antennas used for multiple wireless communication systems on one device.

Generally, there are two methods of antenna design to achieve the multiband operation. For the first method, the multiband antenna is generated by using multi-resonators that each resonator radiates independently electromagnetic wave at each operating frequency. In [1], the conventional monopole CPW-fed antenna was developed by inserting the inverted L-pair of slits on a T-shaped ground plane and putting a U-shaped parasitic element to excite higher and lower operating frequencies, respectively. The multiband monopole antenna using three resonators was proposed in [2], that resonators in different shapes of strip line, bow tie, and loop operated at different resonance frequencies. In [3], it is clearly seen that combining of monopole and loop antennas could produce the reconfigured antenna with dual-band operating frequency. However, it has been found that using these multiband design techniques, the antenna characteristics could not be easily adjusted due to the effects of mutual couplings between resonators. Another method for designing multiband operation is modification or reconfiguration of a conventional wideband antenna structure to generate notched frequency bands. This technique can assist filtering out undesired frequencies for avoiding interference and essentially relieves the requirement of filtering components. In [4], the wideband monopole antenna was modified by creating the pair of slits on a ground plane and a slot on an elliptical radiating patch, resulting in two notched frequency bands or multiband operation. The notched frequency of multiband antenna was also created and experimented by inserting several slits and slots on a radiating patch of wideband monopole antenna [5]. In [6], the notched frequency bands could be increased as a number of U-shape slots on the radiating patch antenna increased. These methods are flexible to produce the desired multiband antennas and easy to adjust some antenna characteristics such as impedance bandwidth and operating frequency.

Furthermore, the multiband antenna can be also achieved by using fractal geometry technique. The Minkowski and Sierpinski fractal geometries were used to generate multiband monopole antennas [7], [8]. The fractal geometries generate harmonic frequencies that most of radiation patterns at each harmonic frequency are unstable. In [9], the patch monopole antenna with modified Minkowski fractal geometry for multiband operation was proposed. The antenna structure is very complex, resulting in difficulties of impedance matching and resonance frequency adjusting. However, the self-similarity property of fractal shape is popular method to generate multiband

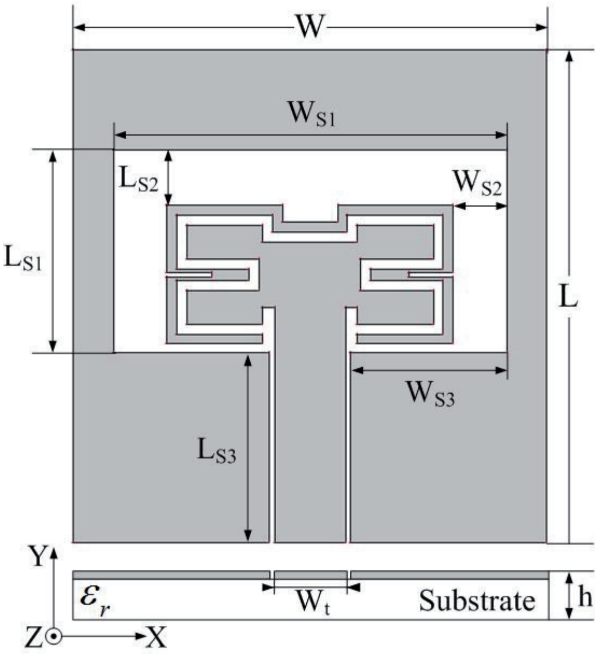


Fig. 1. The proposed slot antenna structure.

operation because its structure can contain multi-path of effective electrical length for resonating at multi-frequency in one structure, resulting in compact size.

As mentioned, using wideband and notch techniques to design multiband antennas is simple and flexible, therefore it is very interested. In order to produce wideband antenna, the slot antenna structure is very popular. In [10], the conventional CPW-fed slot antenna could improve the impedance matching easily by varying dimension of a rectangular stub. The fractal slot antenna in [11] was designed to support wideband operation, which modifying of ground plane affected to impedance matching at lower frequency band. In [12], the slot antenna with fractal stub was proposed, whose operating bandwidth could be controlled by electrical length of stub. It can be concluded that the slot antenna structure is very attractive for creating a wideband antenna because it is easy to match impedance and to control bandwidth.

This paper proposes a multiband CPW-fed slot antenna with a fractal stub and a parasitic line. The multiband operation of antenna is produced by modifying a conventional CPW-fed wideband in [12] using a fractal geometry on a rectangular stub to control bandwidth. In order to create a notched frequency of wideband slot antenna, a resonator in shape of slot, slit, or parasitic line can be usually employed [13-14]. However, this research uses a parasitic line surrounding the fractal stub to obtain two notched bands on the wideband operation. The behavior of notched bands is similar to harmonic frequency on the antenna structure. Additionally, two notched frequencies can be adjusted freely by changing the effective parameters of the notch parasitic line. The proposed antenna covers the application bands of DCS 1800 (1710-1880 MHz), WiMAX (3.3-3.8 GHz), WLAN (2.40-2.484 GHz/5.15-5.35 GHz), and IMT advanced system or 4th generation mobile communication system (3.4 - 4.2 GHz). The effective parameters of antenna will be investigated by simulation that uses the full wave method of moment (MOM) software package, IE3D program. The prototype antenna with optimum values of all parameters will be fabricated and experimented. Finally, the antenna results will be verified and discussed.

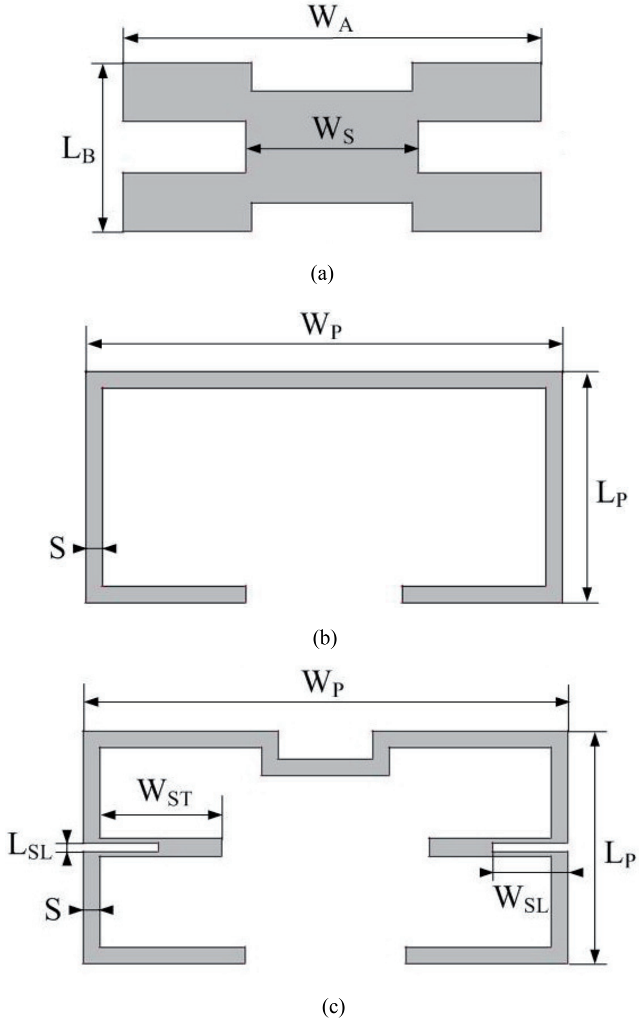


Fig. 2. The section of antenna structure with (a) the modified 1st iteration fractal stub, (b) the notch parasitic line without fractal shape and (c) the notch parasitic line with fractal shape that is in accordance with the modified fractal stub.

2. Antenna Design

The proposed antenna has been designed and fabricated on an inexpensive FR4 substrate with relative permittivity of $\varepsilon_r = 4.2$ and thickness of $h = 0.8$ mm. The fundamental slot antenna consists of a fractal stub with an overall dimension of 10x25 mm $(L_B \times W_A)$. A 50 Ω CPW-fed line is used for exciting the antenna that it has the strip width (W_t) and distance gap of 7.2 mm and 0.48 mm, respectively. To create the multiband operation on a wideband slot antenna, the conventional wideband antenna with fractal stub of 1st iteration [12] as shown in Fig.2 (a), is

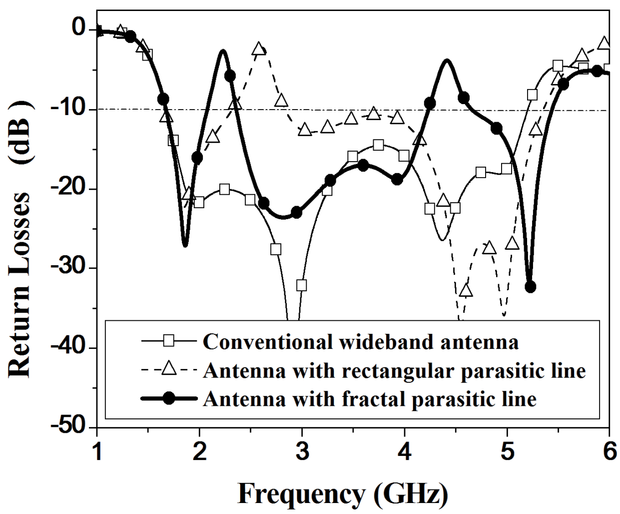
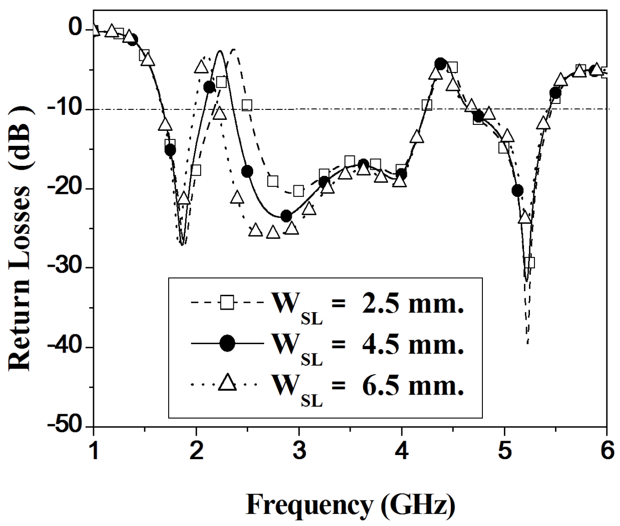


Fig. 3. Simulated return loss results of conventional wideband slot antenna and the proposed slot antenna with different parasitic lines.

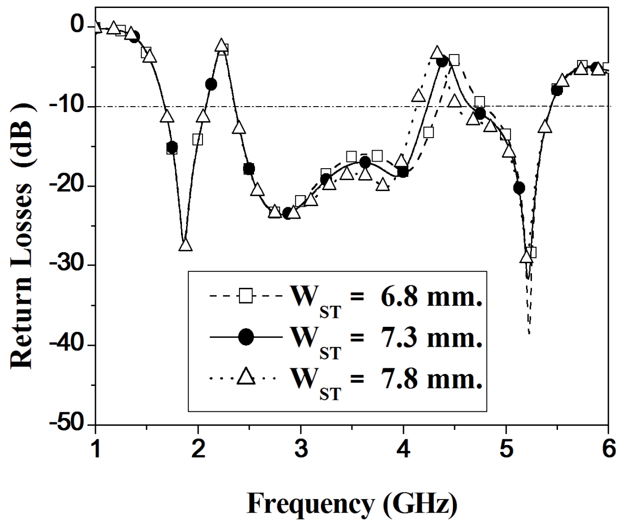
chosen because the bandwidth of slot antenna with 1st iteration fractal stub can satisfy and support the wireless communication systems without any difficulty. The parasitic line has been then added to the proposed antenna in order to generate notched frequencies. First, the open loop parasitic line with rectangular shape as shown in Fig 2(b) is used to surround the modified fractal stub generating a single notch frequency at 2.60 GHz. Next, the open loop parasitic strip line is modified by changing its shape from the simple rectangular shape to a fractal shape that is in accordance with the fractal stub. This creates the slits on both sides in horizontal axis with the dimension of $L_{SL} \times W_{SL}$, as depicted in Fig.2(c). The width of fractal parasitic line and gap between the edge of fractal stub and fractal parasitic line are set to be 1 mm. The details of the overall antenna structure are displayed in Fig. 1. The open loop fractal parasitic line can produce two notched frequencies at 2.2 GHz and 4.4 GHz. Comparison of simulated return loss results of the conventional wideband slot antenna and the proposed slot antenna with different parasitic lines is in Fig. 3. In order to study antenna parameters affecting to dual notched frequencies, the effective parameters of W_{SL}, W_{ST}, and W_S on the notch parasitic line and the fractal stub will be observed. It can be seen that the optimum parameters of the proposed slot antenna are following: W = 48 mm, L = 50 mm, W_{S1} = 39.8 mm, L_{S1} =20.6 mm, W_{S2} = 5.42 mm, L_{S2} = 5.64 mm, W_{S3} =15.84 mm, L_{S3} = 19.28 mm, W_P =29 mm, L_P = 14 mm, L_{SL} = 0.3 mm ,and S=1 mm.

3. Parametric Study

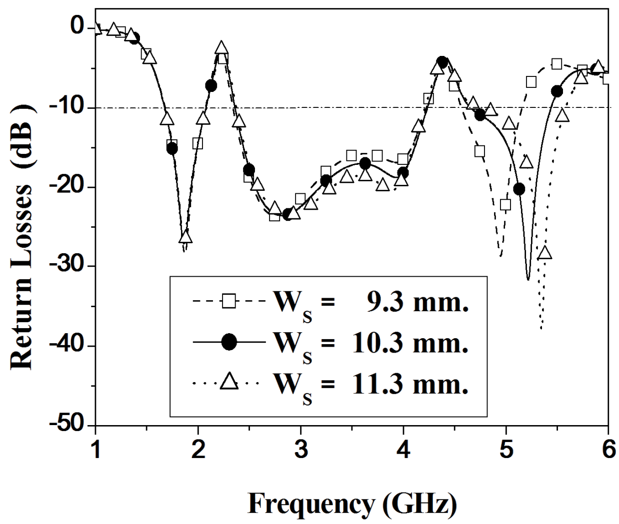
This section presents the study of important parameters to clearly understand behaviors of the proposed antenna and to obtain optimized key values. The significant parameters mainly affecting to notched frequencies including W_{SL}, W_{ST} and W_S will be observed These effec-



(a)



(b)



(c)

Fig. 4. Simulated return loss results from the investigation of effective parameters of (a) W_{SL} ,(b) W_{ST}, and (c) W_S.

tive parameters are investigated by varying one parameter at a time when fixing the other parameters. The initial parameters of the proposed antenna have been selected to be W_S = 10.3 mm and W_{ST} = 7.3 mm. First, the parameter W_{SL} has been varied (W_{SL} = 2.5, 4.5, and 6.5 mm.) in the order to investigate the effects on the return losses, as results are depicted in Fig. 4(a). From the results, the varying of W_{SL} parameter affects to the first notched frequency of multiband operation. As the W_{SL} increased, the first notched frequency is shifted to lower frequency. However, this parameter affects to return loss level in the second resonance bandwidth, resulting from coupling values on the slits in the middle section of parasitic line.

Next, the effective parameter W_{ST} is investigated by alternating parameter W_{ST} = 6.8 and 7.8 mm as the other parameters W_S = 10.3 mm and W_{SL} = 4.5 mm. The results of alternating parameter W_{ST} are depicted in Fig. 4(b). When the parameter W_{ST} is increased, the second notch frequency is shifted to lower band frequency due to extending of coupling effect between parasitic line and stub. From the results, it can be clearly seen that the second notched frequency is mainly affected.

Additionally, varying the effective parameter W_S results in Fig. 4(c). The parameters W_{ST} and W_{SL} are defined to be 7.3 mm and 4.5 mm, respectively. The third resonant frequency is shifted to higher band frequency as the parameter W_S is increasing from 9.3 to 11.3 mm. While the parameter W_S is changed, it affects to electrical length on the edge of fractal stub that usually affects to impedance bandwidth at higher band frequency of the wideband slot antenna. Moreover, as the result, it has been clearly found that changing of W_S does not affect to the center frequency of the both notched frequencies.

Therefore, the optimal values of effective parameters including W_{SL} = 4.5 mm, W_{ST} = 7.3 mm, and W_S = 10.3 mm are obtained, resulting in the operating frequency bands of 1.67 – 2.07 GHz, 2.35 – 4.23 GHz, and 4.65 – 5.43 GHz for the applications of DCS 1800 (1710 – 1880 MHz), WiMAX (3.3 – 3.8 GHz), WLAN IEEE802.11a/b/g (2.40-2.484 GHz/5.15-5.35 GHz), and IMT advanced system or 4th generation (4G) mobile communication system (3.4 – 4.2 GHz).

4. Results and Discussion

From investigation of various parameters of the modified fractal stub and the parasitic line, they affect the operating frequency bands of the proposed antenna in previous section. Hence, the suitable parameters as following: h = 0.8 mm, W = 48 mm, L = 50 mm, W_{S1} = 39.8 mm, L_{S1} =20.6 mm, W_{S2} = 5.42 mm, L_{S2} = 5.64 mm, W_{S3} = 15.84 mm, L_{S3} = 19.28 mm, W_P =29 mm, L_P = 14 mm, L_{SL} = 0.3 mm, S=1 mm, W_{SL} = 4.5 mm, W_{ST} = 7.3 mm, and W_S = 10.3 mm are chosen for implementing the prototype antenna by using milling machine and etching processes. The proposed antenna prototype is depicted in Fig. 5. The simulated and measured return losses of the proposed antenna are illustrated in Fig. 6. It is obviously seen that small difference between simulation and measured return losses of the antenna occurs because of the manufacturing

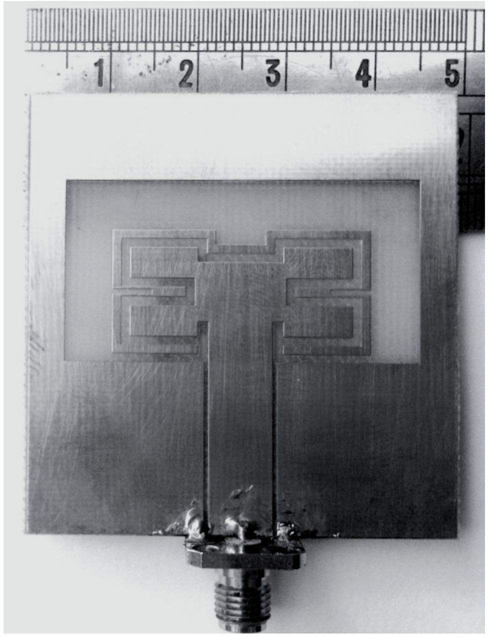


Fig. 5. Photograph of the fabricated multiband slot antenna.

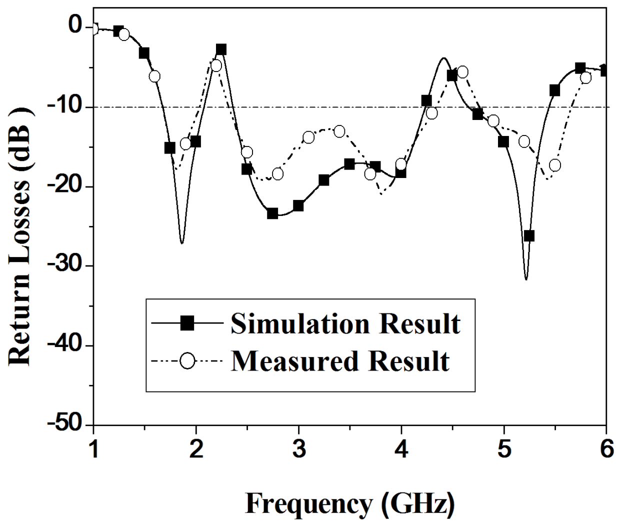
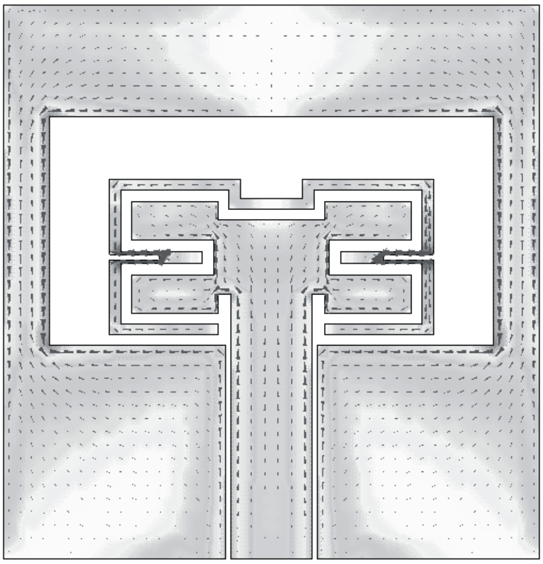


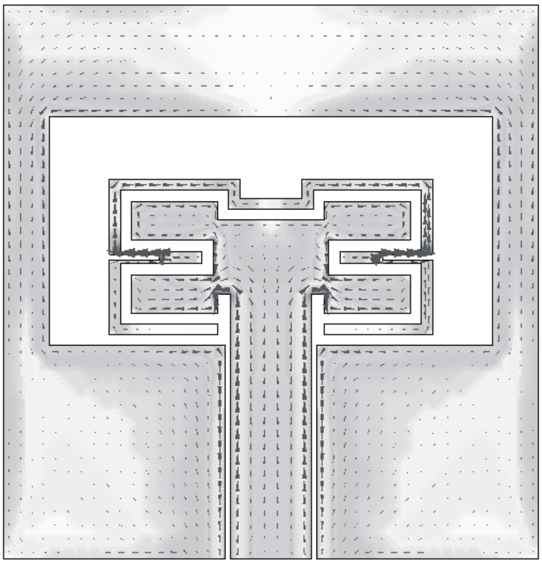
Fig. 6. Simulated and measured return loss results of the proposed multiband slot antenna.

process and the effect of an SMA connector to feed the antenna. However, the measured result of the proposed antenna can support the operation bands of DCS 1800, WiMAX, WLAN IEEE 802.11 a/b/g, and IMT advanced system or 4th generation mobile communication system.

In order to clearly see behavior of the proposed antenna that creates the dual notched frequency in the conventional wideband slot antenna, the simulated current distributions at the operating and notched frequencies of 1.8 GHz, 2.2 GHz, 3.5GHz, 4.4GHz and 5.2GHz are investigated by IE3D simulation software package, as the



(a)



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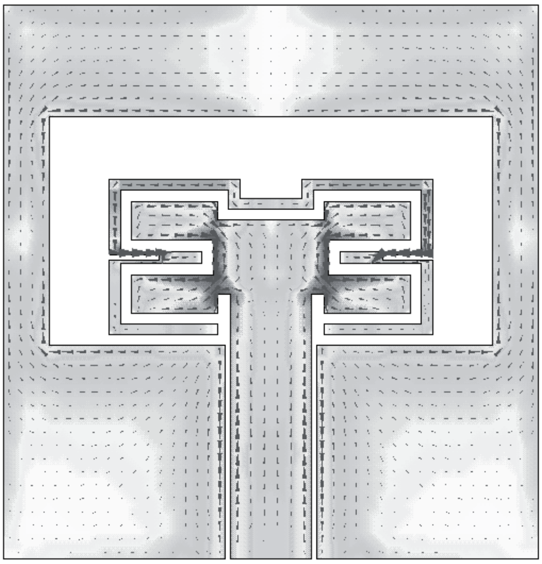

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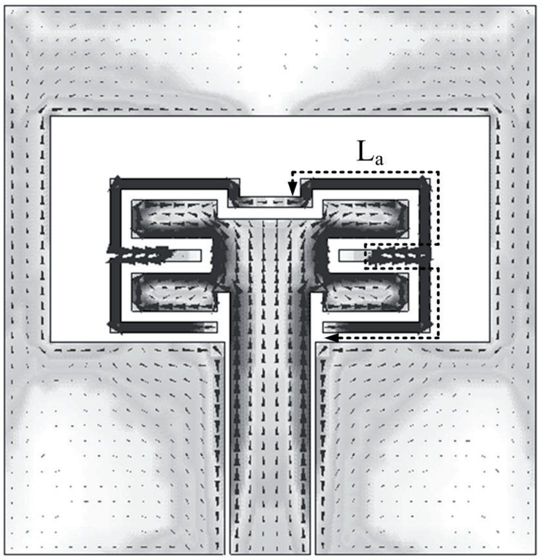
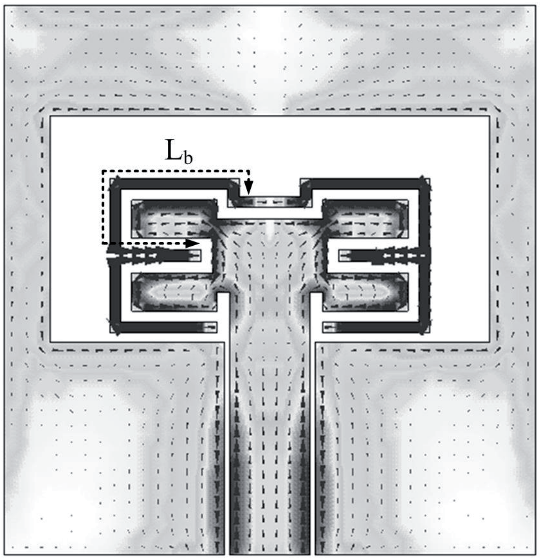


(d)



(e)

Fig. 7. Simulation result of current distribution at operating frequency of (a) 1.8 GHz, (b) 3.5 GHz, (c) 5.2 GHz and at notched frequency of (d) 2.2 GHz and (e) 4.4 GHz.

results illustrated in Fig. 7. It has been found that the weak current distributions in the parasitic line of the proposed antenna at operating frequencies are obtained, as shown in Figs.7 (a-c). Usually, the electric fields of the conventional slot antenna propagate to ground plane around the stub that current density is distributed on the ground plane at operating frequency. However, more currents are in the parasitic line at notched frequencies, as shown in Figs.7 (d-e). While the parasitic line is inserted into the slot between the stub and ground plane, the electric fields are induced to the parasitic line instead of the ground plane at both notched frequencies. This causes the main current flowing in the parasitic line. The current on the parasitic line produces the electric fields, resulting in the appropriate distortion of electric fields between fractal stub and parasitic line to re-

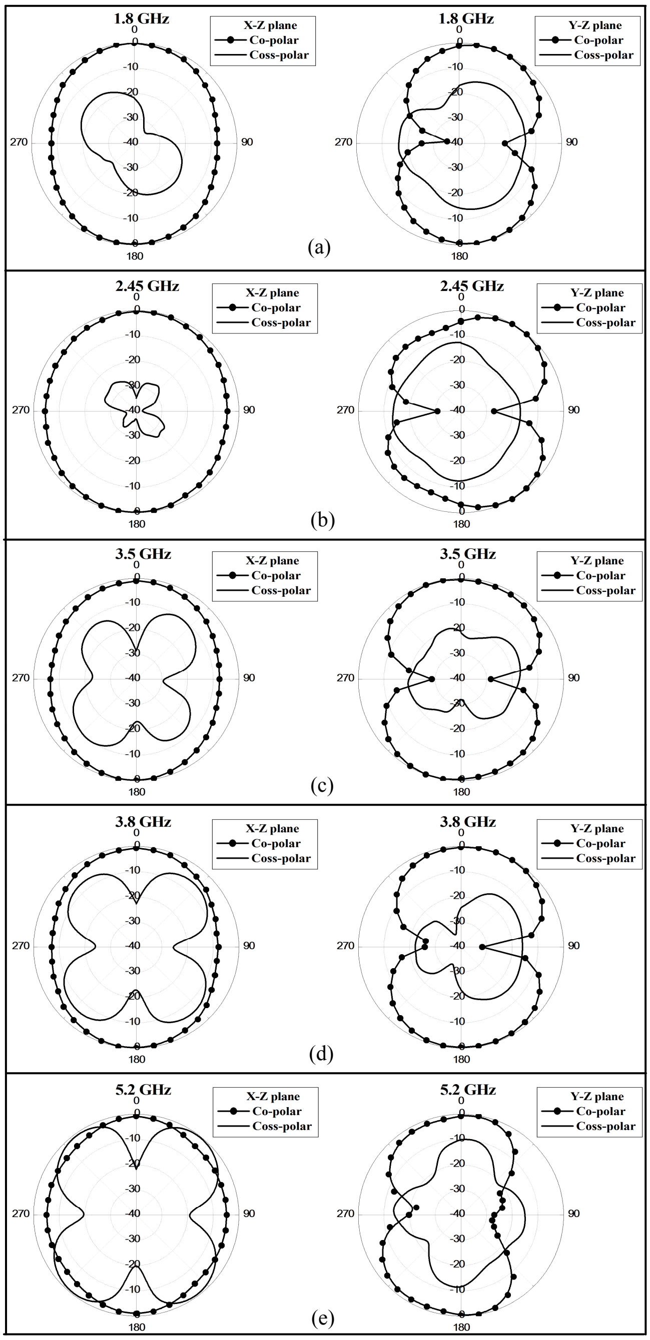


Fig. 8. Measured radiation patterns of the proposed multiband proposed antenna at (a) 1.8 GHz, (b) 2.1 GHz, (c) 3.5 GHz, (d) 3.8 GHz, and (e) 5.2 GHz.

duce the propagation field of the proposed antenna at notch frequencies. The electrical lengths of L_a and L_b on the parasitic line as depicted in Figs. 7 (d) and (e) are approximately $0.5\lambda_g$ at lower and higher notched frequencies of 2.2 GHz and 4.4 GHz, respectively, where the guide wavelength in the parasitic line is given by

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}},$$

when $$\varepsilon_{eff} \approx \frac{\varepsilon_{r\_substrate} + 1}{2}.$$

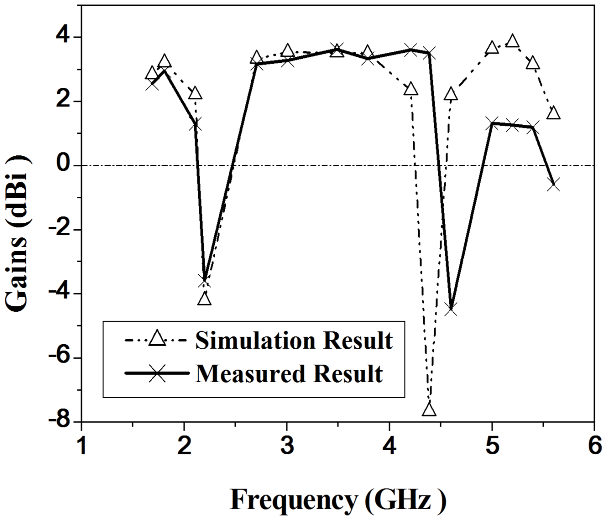


Fig. 9. Simulated and measured peak gains of the proposed multiband slot antenna.

As the result, the occurred dual notch frequency can verify that it is the harmonic notched frequency. However, both notched frequencies of the proposed antenna are still independently adjusted, due to the current density at lower notched frequency is dominant along to the end of slit in the middle parasitic line while the current density at higher notched frequency is dense along to the end of stub.

Additionally, the radiation patterns of the proposed antenna are almost bi-directional in X-Z and Y-Z planes at all operating frequencies as displayed in Fig. 8. However, the cross-polarization patterns in X-Z plane are expanded as frequency increased due to the higher order mode of the operating frequency in the slot antenna and the shifting of resonant frequency. The peaks of the radiation patterns are occurred at 0 and 10 degrees in X-Z plane and Y-Z plane, respectively. The peak gains of simulated and measured results are above 1 dBi, as illustrated in Fig. 9.

5. Conclusion

In this paper, the multiband CPW-fed slot antenna with a fractal stub and a parasitic line is proposed. The conventional wideband slot antenna with a fractal stub is modified to obtain multiband operation by inserting the parasitic line, resulting in the dual harmonic notched frequency in wideband operation. However, the notched frequencies can be adjusted independently by varying the lengths of slit and stub of the parasitic line, resulting in shifting of lower and higher notched frequencies, respectively. Moreover, the third resonant frequency is also controlled by changing the electrical length of the fractal stub. Additionally, the radiation pattern of the proposed antenna is still bi-directional at operating frequencies covering applications of DCS 1800, WLAN IEEE 802.11 a/b/g, WiMAX, and IMT advanced mobile communication system.

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