Gain Enhancement for Multiband Fractal Antenna Using Hilbert Slot Frequency Selective Surface Reflector

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***Abstract*- In this paper, the gain enhancement for a multiband antenna with Hilbert fractal slot in a modified rectangular patch is presented. The composite structure including a wide slot, a Hilbert fractal slot with 1st iteration, and modified rectangular patch used as additional resonators producing multi-resonant frequencies are developed. The antenna gain can be enhanced by using frequency selective surface (FSS) reflector. The proposed FSS is optimized to control the phase and the magnitude of S-parameters of reflection and transmission characteristics over a bandwidth suitable for multiband antenna. FSS layer has been designed and employed with a unit cell of Hilbert fractal slot. Experimental results show good multiband operation at the frequency ranges of 870 – 960 MHz, 1710 – 1880 MHz, 1.85 – 1.99 GHz, 1.92 – 2.17 GHz, 2.3 – 2.36 GHZ and 2.4 – 2.485 GHz, respectively. Finally, the designed antenna can operate and cover the applications of GSM, DCS, PCS, UMTS, WiMAX and WLAN IEEE802.11 b/g. Moreover, the antenna gains at the operating frequencies of 0.9, 1.8, 1.92, 2.045 and 2.45 GHz are 7.607, 10.41, 9.54, 8.67 and 7.98 dBi, respectively.**

I. INTRODUCTION

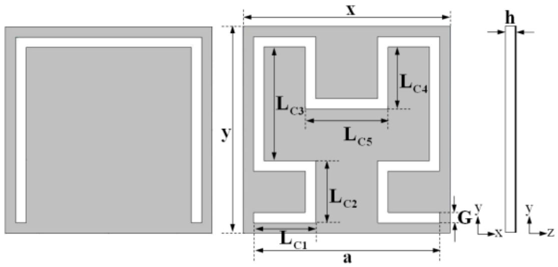
Over the years, we have seen unprecedented growth in wireless communication applications. Multiband and wideband antennas are compatible for wireless communication systems. Recent advances in the designing method of multiband antenna are recognized using several methods. Firstly, multi-resonators [1] generated multi-resonant frequencies. For instant in [2], the multiband antenna was created by adding bow-tie patches and a modified fractal loop to the sides and bottom of a strip line for the applications of DCS 1800, WLAN(IEEE802.11 b/g), WiMAX and IMT advanced system. Secondly, the antenna [3] was fabricated to improve the band-notch characteristic by cutting u-slots on the patch for dual and multiband applications. In [4], designing and analyzing the fractal antennas for multi-band operation are researched by inserting Hilbert fractal slit in both sides of the rectangular stub in order to create the multiband antenna by using the technique of wideband antenna with multiple notch frequency. Another method, the development of the multiband antenna could be also achieved with the using of fractal concepts. The fractal geometries have been researched including Sierpinski, Koch and Hilbert shapes [5]. The Hilbert geometry is a space-filling curve, since with a larger iteration, and it was trying to fill the area. Mostly, self similarity property of fractal shapes is used to design of multiband operations.

There is a long history of development for technology of frequency selective surfaces (FSSs) [6-7]. FSSs are periodic structures of infinite identical cells which have different behaviors as low pass, high pass, band pass or band stop filter characteristics [8]. In [9], adequate designs of FSSs allow to control the phases of reflection and transmission characteristics over a wide bandwidth by designing with a slot antenna for enhancing the gain of ultra wideband antennas.

In this paper we present a gain enhancement for a multiband fractal antenna with FSS reflector. The multi-resonators are produced to response the multiband operation. A wide slot is employed on the ground plane of antenna designs for 1st operating frequency band. A modified rectangular patch and a modified Hilbert fractal slot are created for 2nd and 3rd operating frequency ranges, respectively. The operating frequencies can be controlled by varying electrical length of Hilbert fractal slot and the coupling value between both edges of wide slot and modified rectangular patch. However, impedance matching of the antenna is graceless for operating frequencies as without FSS reflector. Therefore, the designed FSS is applied to allow significant improvement in the gain over the all impedance bandwidth. The effective parameters of the proposed antenna will be investigated by using the CST software.

II. THE HILBERT FRACTAL SLOT FSS DESIGN

The two simply structures of FSS with the 0 iteration and the 1st iteration of Hilbert fractal slot are shown in Fig. 1(a) and Fig. 1(b), respectively. The magnitudes and phases of the s-parameters for the 0 iteration and the 1st iteration of Hilbert fractal slot are shown in Fig. 2(a) and Fig. 2(b), respectively. A unit cell has been designed to achieve the band stop responses. The highly reflective surface affects to the gain of the antenna. As seen in Fig. 2, the suitable magnitude and phase of the s-parameters are the key part for the gain enhancement. As the unit cell of Hilbert fractal FSS with 0 iteration designed, the magnitude of S-parameters reflect effectively at the frequency ranges of 1.06 – 2.05 GHz and 2.18 – 2.60 GHz. Furthermore, the phases of Hilbert fractal FSS with 0 iteration at operating frequencies of 0.9, 1.8, 1.92, 2.045 and 2.45 GHz are -155.126, -178.552, 177.805, 165.381, and 179.131 degree, respectively as shown in Fig. 2(a). As the unit cell of Hilbert fractal FSS



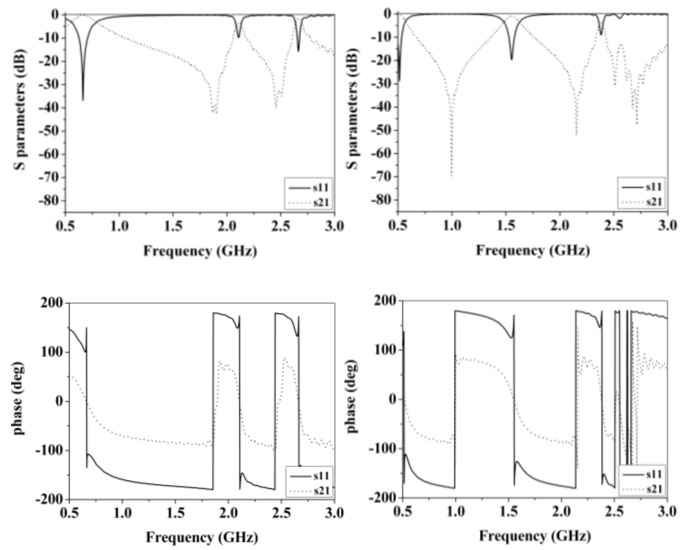
(a) (b)

Fig. 1 Unit cell of Hilbert fractal FSS layer with (a) the 0 iteration (b) the 1st iteration.

with 1 iteration designed, the magnitude of S-parameters conspicuously shifted to lower frequency due to the extending electrical length of Hilbert fractal slot. Especially, the magnitude can reflect effectively the frequency ranges of 670 – 1360 MHz, 1710 – 2.23 GHz and 2.4 – 2.51 GHz. Furthermore, the phases of Hilbert fractal FSS with 1st iteration at operating frequencies of 0.9, 1.8, 1.92, 2.045 and 2.45 GHz are -177.002, -165.940, -172.573, -177.350, and -172.072 degree, respectively, as shown in Fig. 2(b). Also, the 1st iteration of Hilbert fractal slot is chosen because the simulated results have the higher reflectivity and the suitable reflection phase (negative phase) that can satisfy for frequency ranges of 870 – 960 MHz, 1710 – 1880 MHz, 1.85 – 1.99 GHz, 1.92 – 2.17 GHz, and 2.4 – 2.485 GHz. Also, the physical parameters of Hilbert fractal slot on unit cell are achieved for x = 60 mm, y = 60 mm, L_{c1} = 17 mm, L_{c2} = 18 mm, L_{c3} = 33 mm, L_{c4} = 16 mm, L_{c5} = 19 mm and g = 2 mm. The FSS is printed on FR4 substrate with relative permittivity of ε_r = 4.2, thickness of h = 1.6 mm, and the unit cell with its size of 60× 60 mm^2.

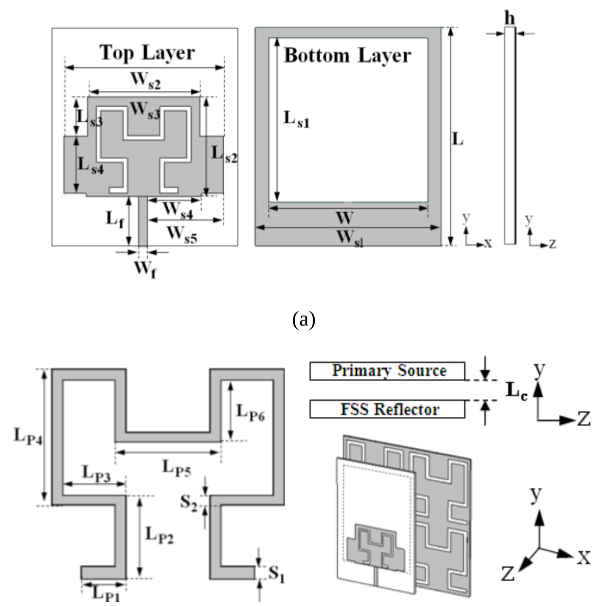
III. Multiband Antenna With FSS Reflector

The geometry of proposed antenna with FSS reflector is shown in Fig. 3(a). The antenna is printed on FR4 substrate with relative permittivity of ε_r = 4.2, thickness of h = 1.6 mm, the antenna size of 85×72.5 mm^2, and the Hilbert fractal slot FSS reflector with its size of 120×120 mm^2. The proposed antenna with Hilbert fractal slot FSS reflector consists of the wide slot, the modified rectangular patch with adding a modified Hilbert fractal slot, and Hilbert fractal slot FSS reflector. First, the wide slot is created by etching a slot on the ground plane to operate at the first operating frequency band (860 – 964 MHz). Next, the 2nd operating frequency band (1.71 – 2.17 GHz) is produced by compounding the harmonic of the first resonant frequency and the resonant frequency created from the modified rectangular patch with electrical length of λ/4. Additionally, the patch is still increasing the matching efficiency and bandwidth enhancement of 2nd operating frequency band. Finally, the modified fractal slot in rectangular patch with Hilbert geometry of 1st iteration is created to operate at 3rd operating frequency band (2.25 – 2.49 GHz). The modified 1st iteration Hilbert shape is shown in Fig. 3(b). However, adding FSS reflector occurs a better matching and a



(a) (b)

Fig. 2 Simulated magnitudes and phase of S-parameters (S_{11} and S_{21}) for unit cell of Hilbert fractal FSS layer with (a) the 0 iteration (b) the 1st iteration.



(b) (c)

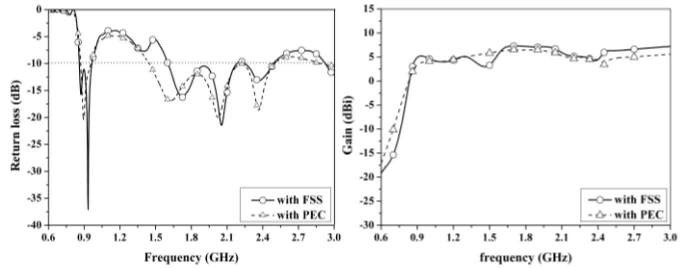
Fig. 3 Configuration of the proposed antenna with (a) the top layer and the bottom layer, (b) the modified Hilbert Fractal slot structure and (c) FSS reflector.

wide frequency bandwidth at whole resonant frequencies. The antenna with Hilbert fractal slot FSS reflector is shown in Fig. 3(c). The effect of the return loss for the proposed antenna is depicted in Fig. 4(a). The impedance bandwidths are comprehensive for the requirement bandwidth of 1st and 2nd operating frequency bands as the proposed antenna with FSS as incomprehensive bandwidth of 1st and 2nd operating frequency for the antenna with PEC. Furthermore, the gains of proposed antenna with Hilbert FSS reflector are higher than the PEC case as shown in Fig.4 (b). Moreover, the simulated far-field radiation patterns at the centre frequency of 2.45 GHz with the PEC reflector are graceless compared with the FSS reflector as illustrated in Fig.5. In order to study antenna parameters affecting to multiband operations, the optimum parameters of the proposed antenna are the following: W = 72.5 mm, W_{s1} = 62 mm, W_{s2} = 54 mm, W_{s3} = 38 mm, W_{s4} = 22 mm, W_{s5} = 29.5 mm, L = 85 mm, L_{s1} = 64 mm, L_{s2} = 33.75 mm, L_{s3} = 13.5 mm, L_{s4} = 19.25 mm, L_f = 17 mm, W_t = 3 mm, L_{p1} = 6.2 mm, L_{p2} = 11.5 mm, L_{p3} = 9 mm, L_{p4} = 19 mm, L_{p5} = 10 mm, L_{p6} = 14 mm, S_1 = 2 mm , S_2 = 1.5 mm, and the gap between the two layer of L_c = 46.775 mm (L_c is cavity high).

In order to obtain optimized parameter values, the significant parameters mainly affecting to resonant frequencies including L_{s3}, and L_c will be observed and varied as fixing the other parameters to investigate the effects on return loss, as depicted in Fig. 6. First, as the L_{s3} varied (L_c = 46.775 mm) shown in Fig. 6(a), it can be seen that the parameter affects to the 3rd operating frequency band resulting from altering coupling values and electrical length between both side edges of wide slot and modified rectangular patch. Additionally, the return losses of level 1st and 2nd frequency bands are altered by the coupling effect. Then, as the parameter L_c varied (L_{s3} = 13.5 mm) depicted in Fig. 6(b), it can be clearly seen that the parameter affects to the all of operating frequency band due to the coupling value between the proposed antenna and the FSS reflector on impedance matching. Also, three resonant frequency ranges are exhibited with a good matching for L_c = 46.775 mm and covering the requirement bandwidth. As illustrated in Fig. 7, the gain alters as varying parameter L_c due to the changing phase between the FSS reflector and the radiating antenna. Especially, the best result of gain is obtained by the sufficiently reflection phase between the FSS reflector and the radiating antenna.

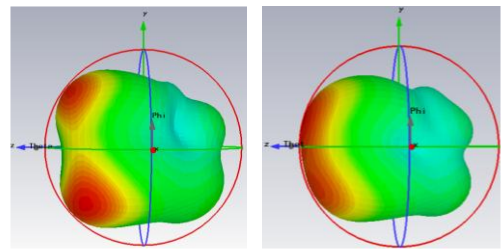
IV. RESULTS AND DISCUSSION

The antenna prototype is illustrated in Fig.8. The proposed antenna is placed at 46.775 mm above the Hilbert fractal slot FSS reflector, corresponding to $0.146\lambda_0$, $0.292\lambda_0$, $0.312\lambda_0$, $0.332\lambda_0$, and $0.398\lambda_0$ with the resonant frequency of 900 MHz, 1800 MHz, 1.92 GHz, 2.045 GHz, and 2.45 GHz, respectively. The simulated and measured return losses of the proposed antenna are illustrated in Fig. 9(a). It is explicitly seen that the difference between simulated and measured return losses of antenna occurred due to the etching process. The antenna gains at 900 MHz, 1800 MHz, 1.92 GHz, 2.045 GHz, and 2.45 GHz are 7.607, 10.41, 9.54, 8.67, and 7.98 dBi, respectively, as shown in Fig. 9(b). The measured far-field radiation patterns in X-Z and Y-Z planes at the centre frequency of each operating band are good directional radiation patterns, as illustrated in Fig.10. The maximum beams at all operating frequencies in X-Z plane are occurred at 0 degree. As the maximum beams in Y-Z plane at 900 MHz, 1800 MHz and 1.92 GHz are occurred at 0 degree, whereas at 2.045 MHz and 2.45 GHz are occurred at 30 degree.



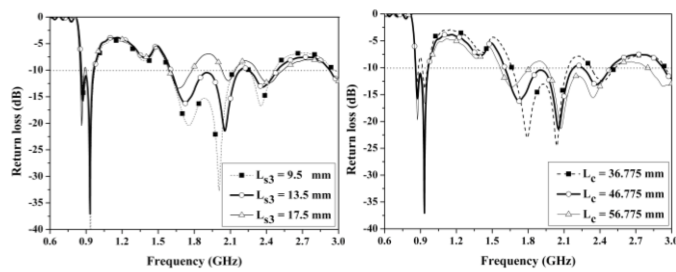
(a) (b)

Fig. 4 (a) The return losses and (b) the gains of the proposed antenna with FSS and with PEC.



(a) (b)

Fig. 5 The far-field radiation patterns at 2.45 GHz of (a) PEC and (b) FSS.



(a) (b)

Fig. 6 Simulated return loss results of effective parameters (a) L_{s3} and (b) L_c.

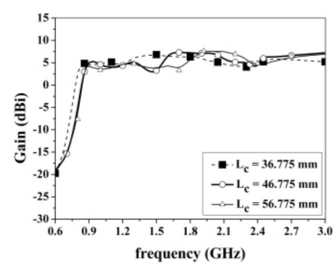


Fig. 7 The gains of effective parameter L_c.

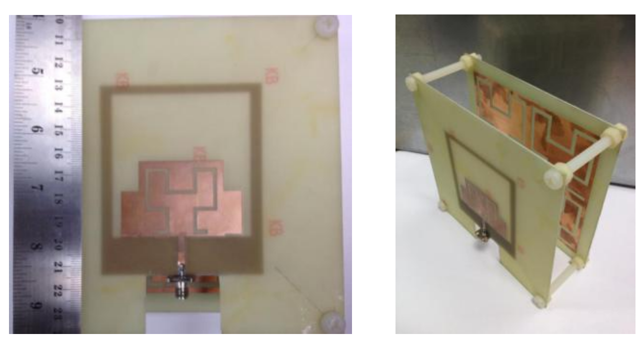
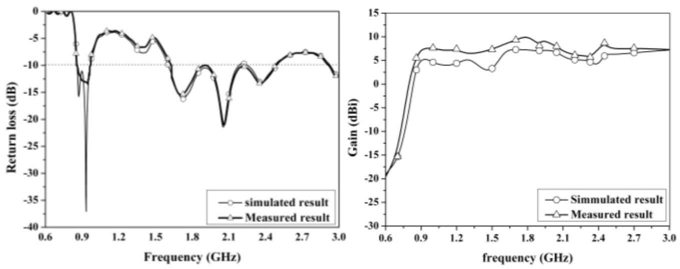


Fig. 8 Prototype of the proposed antenna.



(a) (b)

Fig.9 (a) The measured return losses, (b) The measured gains of the simulated and measured return losses of the proposed antenna.

Additionally, our antenna has high gain as improving the efficiency of radiation pattern with the operating frequency band of (859 - 962 MHz), (1605 - 2180 MHz), and (2.252 - 2.490 GHz) for the applications of GSM, DCS, PCS, UMTS, WiMAX, and WLAN IEEE802.11 b/g.

V. CONCLUSION

In this paper, the gain and impedance bandwidth enhancement of the multiband antenna with Hilbert fractal slot in rectangular patch has been presented. The FSS is designed by using 1st iteration of Hilbert fractal geometry. The sufficiently reflection magnitude and phase affect to enhancement of the gains. Additionally, the gains are 7.607, 10.41, 9.54, 8.67, and 7.98 dBi at operating frequencies of 900 MHz, 1800 MHz, 1.92 GHz, 2.045 GHz and 2.45 GHz, respectively, covering applications of GSM(870–960 MHz), DCS(1710–1880 MHz), PCS(1.85–1.99 GHz), UMTS(1.92–2.17 GHz), WiMAX(2.3–2.36 GHz) and WLAN IEEE802.11 b/g(2.4–2.485 GHz). Moreover the radiation patterns are still directional patterns at all of operating frequency bands.

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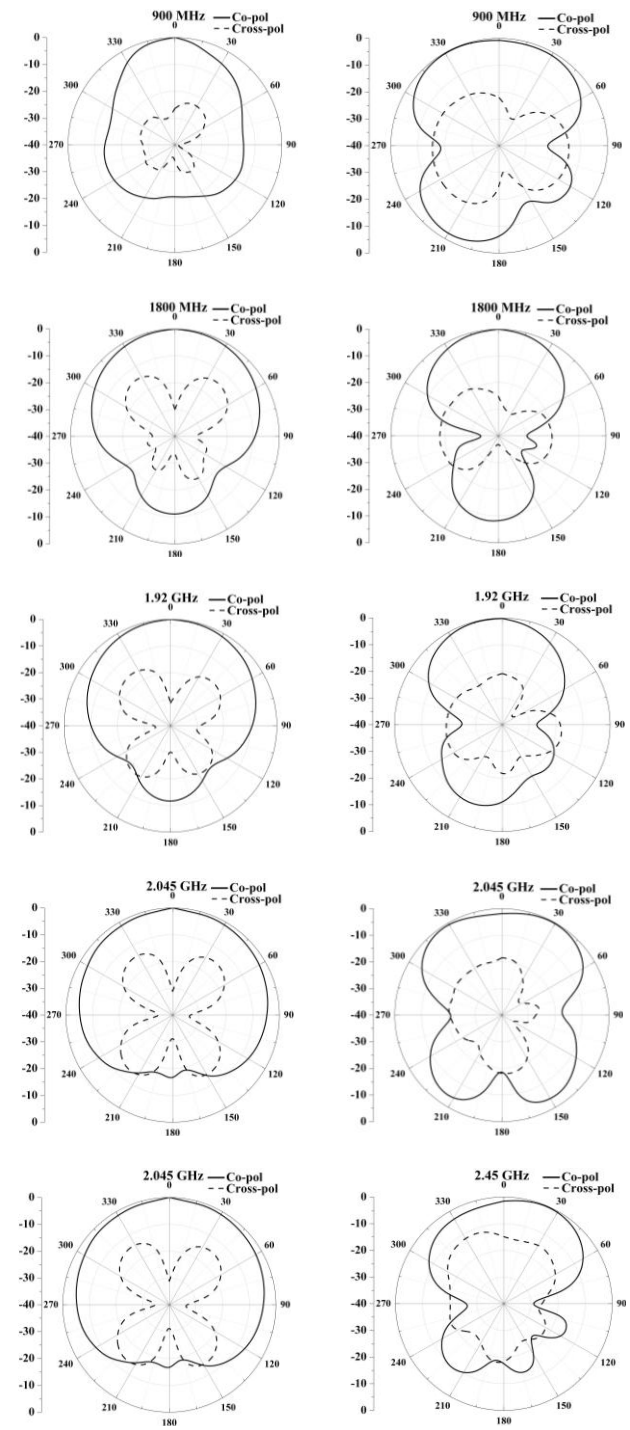

(a) (b)

Fig.10 The measured radiation patterns in (a) X-Z plane and (b) Y-Z plane.

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