A new printed multiband fractal triangular antenna for wireless application

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Article Info

Article history:

Received Jan 31, 2023
Revised Jul 30, 2023
Accepted Aug 15, 2023

Keywords:

Fractal
High-frequency structure simulator
Multiband antenna
Slit antenna
Triangle shaped resonator
Wireless application

ABSTRACT

This letter investigates the properties of a novel multi-band fractal antenna with a triangular geometry that can expand its bandwidth, provide multiband functionality, and enable the best smart antenna technology. The antenna employs an FR4 as support with dimensions of 75×75 mm^2 and a thickness of 1.6 mm. A microstrip line with an impedance of 50 ohms feeds the patch. The high-frequency structure simulator (HFSS) is applied to develop and simulate the patch. The vector network analyzer AVR ROHDE and SCHWARZ ZVB20 carried out the experimental tests of the prototype antenna. The suggested antenna's simulation results show that it runs on five main frequency bands: 1.840 GHz, 2.770 GHz, 2.940 GHz, 4.330 GHz, and 5.790 GHz, with a high gain that can exceed 6.01dB and an efficiency of 82%. In the operational bands, the voltage standing wave ratio (VSWR) is between one and two. The results from the simulation and the experiment are extremely similar.

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1. INTRODUCTION

Recent advancements in wireless technologies encourage antenna downsizing, which has the advantages of being low cost, lightweight, less fragile, low profile, and easier to build. As communication technologies advance, there is a growing demand for small antennas that operate in several bands and/or wideband and have high radiation efficiency and gain [1].

Various approaches for generating multiband operations to adapt to development requirements can be found in the literature [2]–[11] [12]–[21] [22]–[26]. To address wireless local area network WLAN, worldwide interoperability for microwave access WiMAX, and GSM spectrum applications, a variety of strategies are proposed to generate multi-band and/or wideband operations and have been widely used in small devices like handheld PCs, smartphones, and other portable electronic equipment [2]–[6]. Fractal antennas are one approach for reducing size and giving a multiband/wideband feature at a low cost. Fractals refer to segments that are broken or uneven and feature self-similarity or self-affinity within their geometrical structure [7]. For multiband operation, many fractal antenna approaches (Minkowski [8], [9], Sierpinski [10], Hilbert curves [11], fractal tree antennas [12], [13], Cantor [14], shaped fractals [15]–[18], slotted antenna [19], [20], and koch curves [21]) have been proposed in the literature. A small, miniature star fractal antenna for wireless applications with a gain that can approach 4.85 dB was described by Nejdi *et al.* [22]. Idris *et al.* [23]

presented a multiband/wideband reconfigurable antenna that operates at six frequencies: 1.7, 2.6, 3.5, 5.2, and 7,5 GHz. WWAN/LTE smartphone applications using a decoupled multiband dual-antenna system by [24]. PIFA antenna operates in 3 frequency bands (1.53-1.70 GHz), (2.54-2.47 GHz) for mobile communications, including GPS, bluetooth, and WiFi was presented by [25]. Alibakhshikenari *et al*. [26], a dual-polarized is suggested for use in 5G sub-6 GHz wireless networks with an average radiation efficiency of 82.6% and a gain of 7.5 dBi. Alibakhshi-Kenari *et al*. [27] describe an unique miniaturized (UWB) antenna based on (CRLH) metamaterial unit cells for contemporary wireless communication applications. The antenna is sufficiently small 15×7.87×1.6 mm^3 to fit into the majority of portable communication devices.

The authors of this research, afford a fractal antenna using an FR4 substrate as support. The proposed model has radiation properties well also may be employed in a range of wireless communication technology such as GSM, WiMAX, and WLAN having an overall size of 75×75×1.6 mm^3. The antenna is capable of working at five different frequencies 1.840 GHz, 2.770 GHz, 2.940 GHz, 4.330 GHz, and 5.790 GHz. The multiband patch is a triangular form, with a reduction factor of 1/2 and a sequence of minuses from a decagon form and welds to a triangle piled inside. A rectangular slot is included in the ground plane. This architecture makes it possible to obtain excellent impedance adaptability.

Section 1 contains the introduction and a review of the literature. The model parameters of the suggested antenna are interpreted in the section 2. About section 3 contains the results and discussion, while section 4 has the conclusion.

2. ANTENNA DESIGN

This letter's substrate is FR-4, the size of the board is 75×75 mm^2, 1.6 mm in thickness which has 4.4 a dielectric constant. In Figure 1 the monopole fractal triangular antenna is built on a top plane. On the underside of the substrate, the ground plane with the rectangular thickness slot of one mm is engraved. As illustrated in Figure 1, this study proposes a fractal triangular patch antenna fed by a microstrip line with a mixture of decagon slots and triangular plane integration using a one-half reduction factor. Multiband operation is possible with this configuration. The antenna structure's parameters are listed in Table 1.

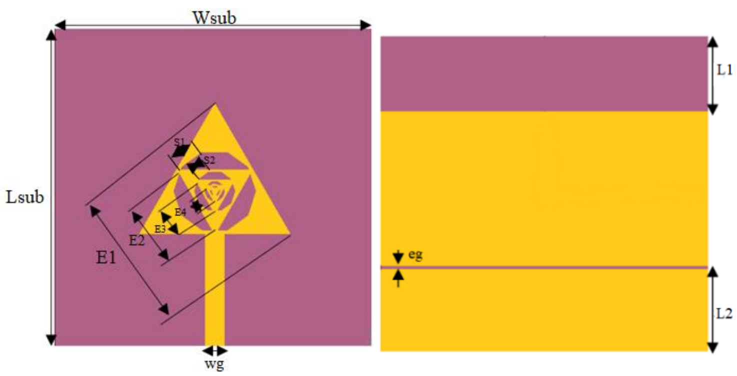
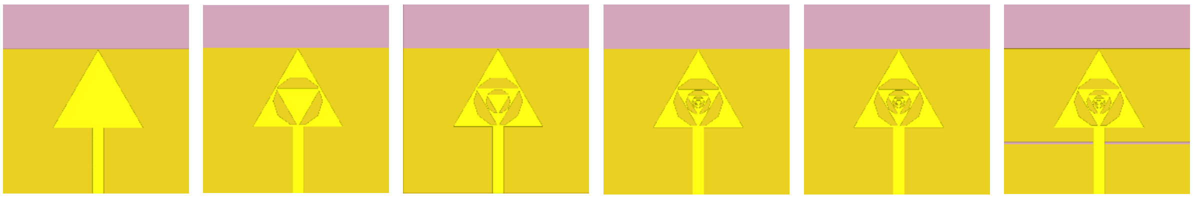


Figure 1. The suggested fractal antenna's parameters

Table 1. Ultimate size of fractal antenna proposed

Parameter	Wsub	Lsub	Wg	Eg	L1	L2	E1	E2	E3	E4	S1	S2
Values (mm)	75	75	4.95	1	20	22.5	22.5	22	10	5	6.798	3.399

The basic triangular antenna is depicted in iteration zero in Figure 2(a). To focus on the initial iteration illustrated in Figure 2, a decagon shaped slot is created, the integration of a triangle copper plane follows. Four iterations are undertaken to generate the suggested antenna, as shown in Figures 2(a) to (f) the transmission line model is used in this article to produce an impedance supply. For the objective of simulating and optimizing the patch, ansys software (HFSS) is adopted. Also, the subsequent alteration to the patch divides the primary current flow into a number of secondary directions, which in turn produces various resonators, resulting in multiband operation. The partial ground plane removal minimizes the back lobe radiation by preventing surface wave diffraction from the antenna ground plane's edges. The resonant frequency is moved to the lower side when the gap line is integrated into the resonator and expands in size electrically.



(a) (b) (c) (d) (e) (f)

Figure 2. Shows the progression of the fractal patch design: (a) initiator, (b) iteration 1, (c) iteration 2, (d) iteration 3, (e) iteration 4, and (f) the proposed

Figure 3 displays the return loss simulation results, which demonstrate the resonant frequencies for various iterations of the fractal patch. With a bandwidth of 0.30 [5.60, 5.90] GHz, the initiator antenna produced only one resonance frequency. Figure 2(b) shows that the first iteration also produced a single resonant frequency with a return loss of -13.1 dB and a bandwidth of 0.21 [5.28, 5.51], allowing the WLAN band to be covered. After simulating the second iteration, three resonance frequencies with returns losses of -12.69 dB, -23.49 dB, and -16.01 dB were determined, with bandwidths of 0.15 [2.81, 2.96] GHz, 0.19 [4.31, 4.50] GHz, and 0.06 [5.94, 6.01] GHz, respectively for C-band applications. For the third iteration, it obtained 4 resonance frequencies with a loss return reaching -32.09 dB. Table 2 includes a summary of all these findings.

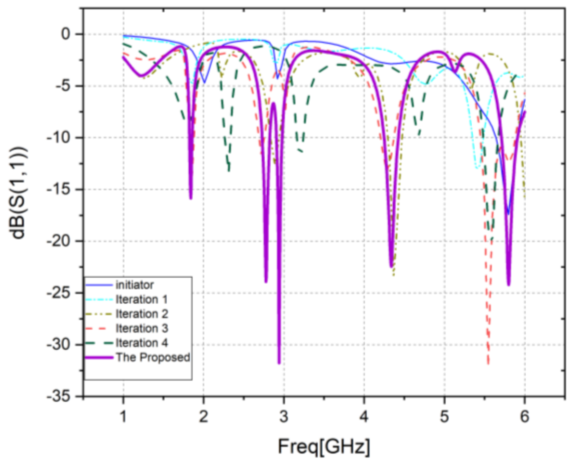


Figure 3. Comparison of the S11 at various phases of development

Table 2. Displays the resonant frequencies in detail for each iteration, as well as the antenna bandwidth for various frequencies

The iterations	Frequency number	Loss return dB	Bandwidth GHz
Initiator	1	-17.50	0.30 [5.60, 5.90]
Iteration 1	1	-13.1	0.21[5.28, 5.51]
Iteration 2	3	-12.69	0.15 [2.81, 2.96]
		-23.49	0.19 [4.31, 4.50]
		-16.01	0.06 [5.94, 6.01]
Iteration 3	4	-13.7	0.06 [1.82, 1.88]
		-11.70	0.12 [2.66, 2.78]
		-13.30	0.20 [4.18, 4.38]
		-32.09	0.45 [5.44, 5.89]
Iteration 4	3	-13.05	0.10 [2.26, 2.36]
		-11.7	0.15 [3.12, 3.27]
		-20.05	0.36 [5.44, 5.70]
The proposed	5	-15.89	0.04 [1.82, 1.86]
		-23.91	0.10 [2.72, 2.82]
		-31.78	0.08 [2.90, 2.98]
		-22.45	0.18 [4.24, 4.42]
		-24.21	0.21 [5.70, 5.91]

3. RESULTS AND DISCUSSION

To ensure that the findings from the simulation and the experiment agree, the antenna is then constructed and analyzed using a vector network analyzer. The proposed antenna fabrication structure is exposed in Figures 4(a) and (b). Table 3 displays the simulations at the 5 resonant frequencies of 1.84 GHz, 2.77 GHz, 2.94 GHz, 4.33 GHz, and 5.79 GHz for return losses of -15.85 dB, -23.90 dB, -31.77 dB, -22.45 dB, and -24.21 dB, respectively, can show the resonance peaks of the suggested antenna. Gain measurements for the recommended antenna are 1.38 dB, 2.67 dB, 6.01 dB, 3.71 dB, and 3.72 dB. The simulation results show that the impedance bandwidths of the five operational bands are 38.31 MHz, 96.21 MHz, 71.10 MHz, 178.70 MHz, and 200.10 MHz, respectively.

(a)

(b)

Figure 4. The manufactured antenna: (a) front side and (b) back side

Table 3. The proposed antennas simulation result

Resonance frequency (GHz)	Bandwidth (MHz)	Reflection coefficient (dB)	Gain (dB)
1.84	38.3	-15.85	1.38
2.77	96.2	-23.90	2.67
2.94	71.1	-31.77	6.01
4.33	178.7	-22.45	3.71
5.79	200.1	-24.21	3.72

Figure 5 depicts the five frequency bands worth of simulations that can reveal the resonance peaks of the proposed antenna: 1.84 GHz, 2.77 GHz, 2.94 GHz, 4.33 GHz, and 5.79 GHz, with return losses of -15.85 dB, -11.25 dB, -29.21 dB, -22.09 dB, and -20.07 dB, respectively, in measured results. A 5 bands antenna covering 1.81-1.85 GHz, 2.76-2.82 GHz, 2.90-2.98 GHz, 4.24-4.44 GHz, and 5.75-6 GHz can be achieved through bandwidth.

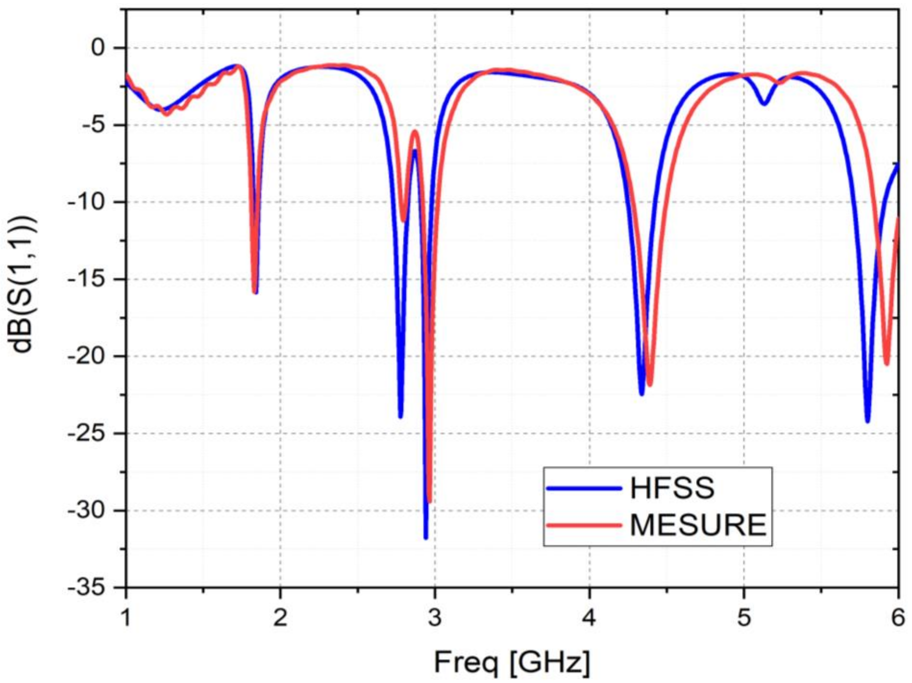


Figure 5. Comparison of simulated and measured S11

Table 4 illustrates the simulated and measured frequency band spanned by the suggested antenna. The measured and simulated findings are very similar because of the effect of actual substrate materials and experimental parameters. The measured S11 is sometimes a little superior to the simulated values (2.480 to 2.880 GHz) and (4.250 to 4.960 GHz), and there is a gap between them for the last band. A comparison of the findings from simulations and experiments demonstrates that the two outcomes are identical.

Table 4. simulated and measured frequency band defined by the suggested patch

	Bandwidth (GHz)	Covered band
HFSS result	[1.824:1.859]	GSM/WLAN/WiMAX
	[2.731:2.825]	
	[2.908:2.979]	
	[4.242:4.424]	
	[5.710:5.910]	
Measures result	[1.824:1.859]	
	[2.761:2.823]	
	[2.908:2.281]	
	[4.247:4.498]	
	[5.751:6.00]	

The suggested antenna gain goes from 1.3 dB to 6 dB for all operational bands as shown in Figure 6. It might be shown that the proposed patch performs well in terms of peak gain and radiation efficiency. Negative gain indicates that the antenna has significant losses in that direction. the transmit power will be significantly reduced in that direction, approaching negative gain. The antenna's effectiveness is quite high (82%) in Figure 7 The antenna gain is a function of both its directivity and radiation efficiency, thus if gain declines, efficiency also declines.

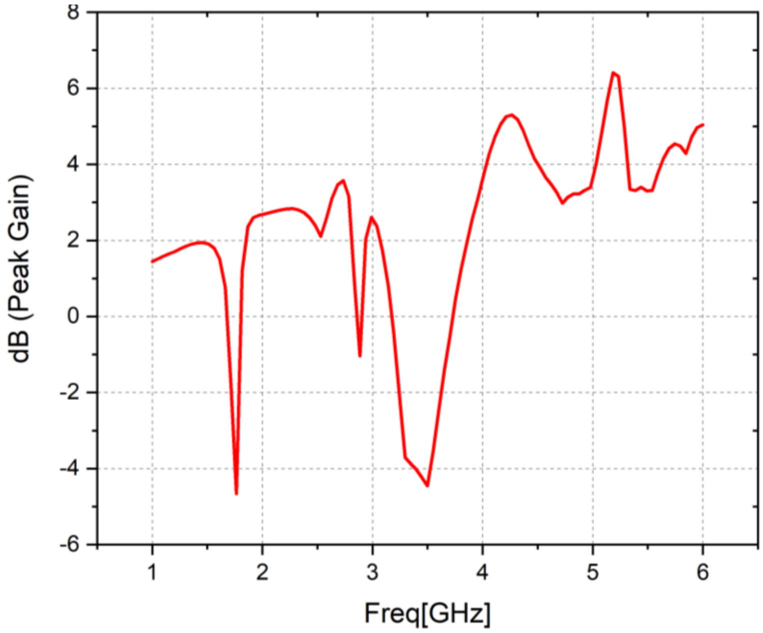


Figure 6. Antenna peak gain simulation

The far-field radiation parameters of the proposed five-band antenna have also been studied. At 1.840 GHz, 2.770 GHz, 2.940 GHz, 4.330 GHz, and 5.790 GHz, respectively, Figure 8 depicts the simulated radiation patterns in both planes E and H. Figure 8 shows that in the H plane, the radiation patterns are omnidirectional in the lower operating frequencies Figures 8(a)–(d), and directional in the higher operating frequencies in Figure 8(e), indicating that the FR4 substrate is not stable. Because the radiation patterns in the E plane have an “8” shape in Figures 8(a) and 8(b), it is evident that they are bidirectional in Figure 8(c). The radiation patterns in Figures 8(d) and 8(e) are quasi-omnidirectional.

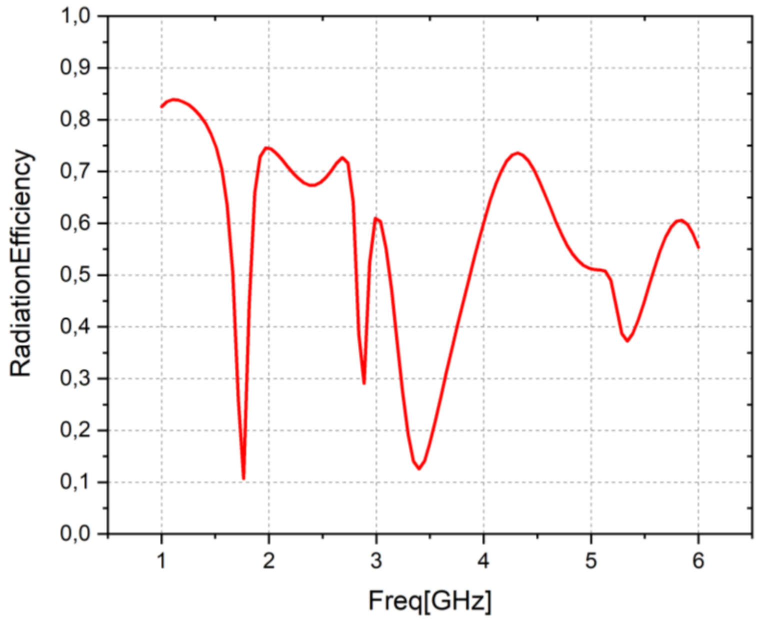
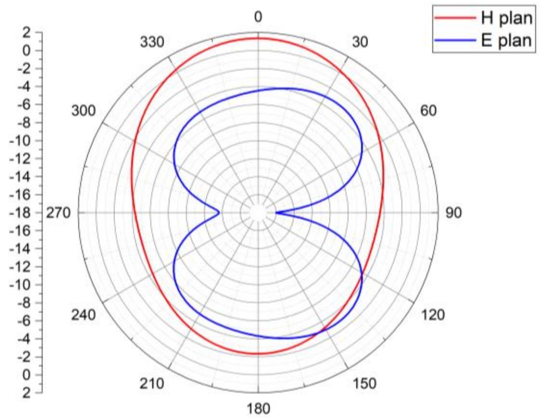
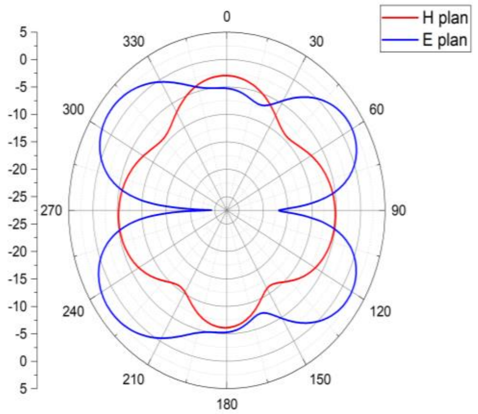


Figure 7. Antenna radiation efficiency simulation

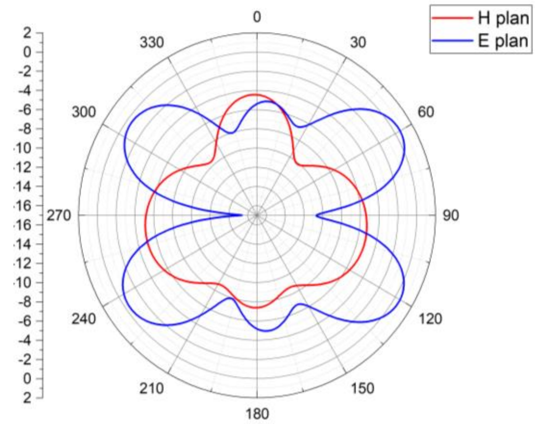
To clarify the phenomenon behind this multi-band performance, Figures 9(a) to (e) displays the simulated current distribution of the suggested patch at :1.840 GHz, 2.770 GHz, 2.940 GHz, 4.330 GHz, and 5.790 GHz. The current is well dispersed throughout the patch and on the slit, as shown in Figures 9(a) and 9(b). Under the triangle patch and the slot, the surface current at 2.77 GHz is approximately similar. The current flows around the slot are more dominant than the triangle for the fourth frequency. Furthermore, at the frequency of 5.79 GHz, the surface currents surrounding all of the patch antennas are almost similar, as shown in Figure 9(d). It is obvious from the results of Figure 9 that the slot has an essential function in the generation of resonant frequencies.



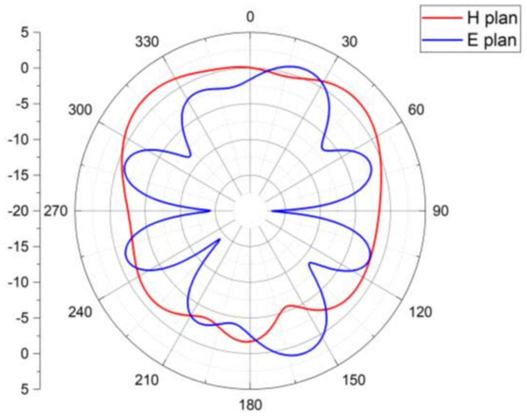
(a)



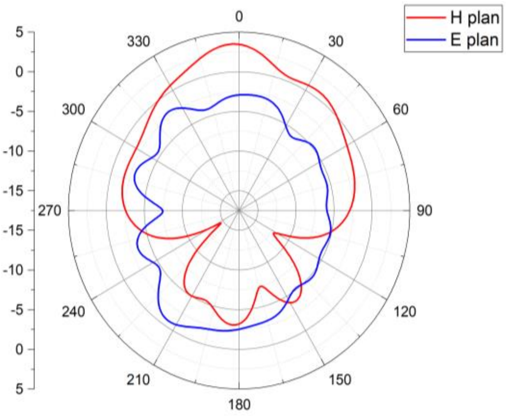
(b)



(c)



(d)



(e)

Figure 8. Far-field radiation of the proposed antenna in planes E and H: (a) 1.840 GHz, (b) 2.770 GHz, (c) 2.940 GHz, (d) 4.330 GHz, and (e) 5.790 GHz

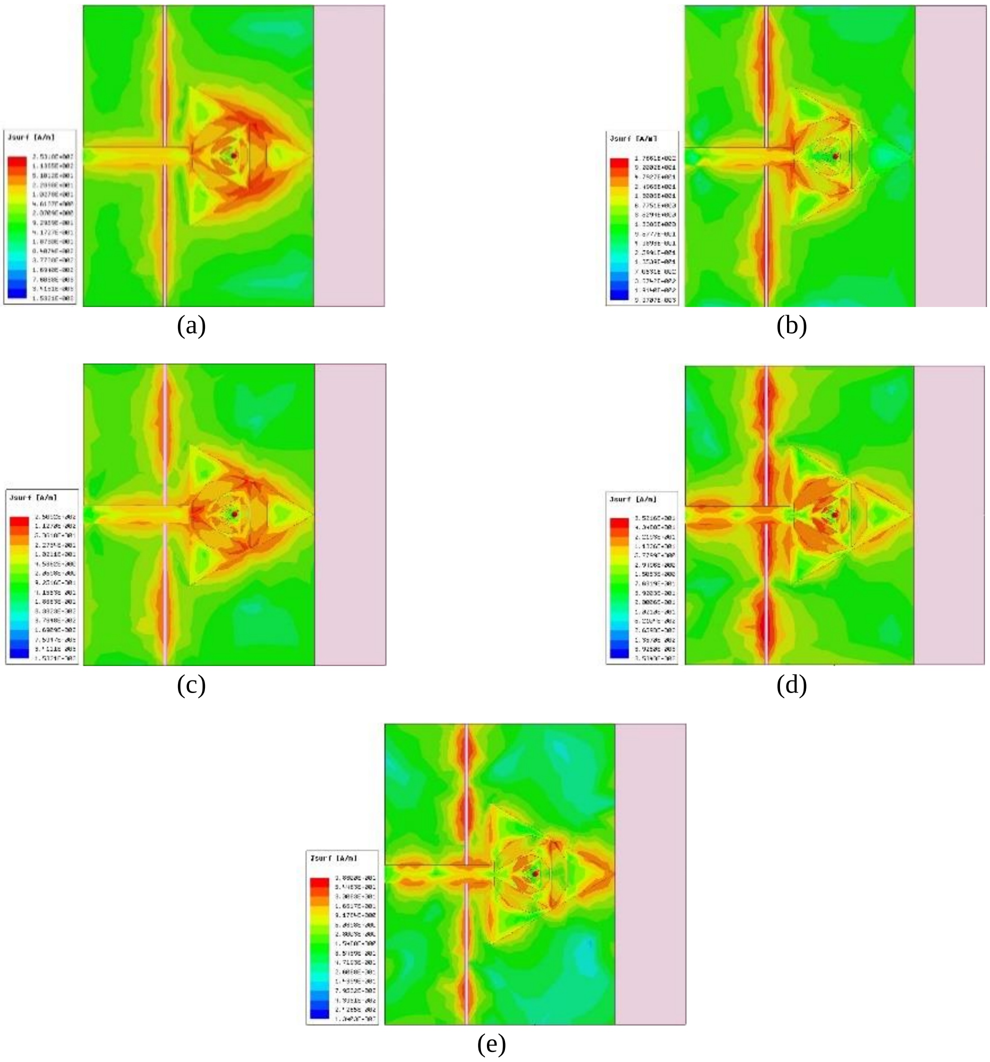

(a) (b) (c) (d) (e)

Figure 9. Antenna surface current simulations: (a) 1.840 GHz, (b) 2.770 GHz, (c) 2.940 GHz, (d) 4.330 GHz, and (e) 5.790 GHz

Table 5 illustrates the properties of the built antenna compared to those of equivalent patches suggested in the literature in the table given. Despite the fact that [6] presents a small antenna, the gain does not surpass 3.2 dB. Lenin *et al.* [16] present a big antenna 100×100 mm^2 with two bandwidths. Gupta *et al.* [17] describes a resonator with a complex geometry, a high dimension, and a poor bandwidth. Despite good results in terms of gain and number of frequencies [23] has a large ground. The patch in [24] operates in two low-gain bands. Despite the fact that [25] antenna is minimal, it has two resonance frequencies: 1.65 GHz and 2.45 GHz with gain not exceeding 3.78 dB. When compared to the mentioned research, it’s clear that the suggested antenna has a significant dimensions and gain advantages.

Table 5. Performance of the proposed antenna compared to comparable antennas in the literature

Ref	Dimension (mm^2)	Resonance frequency (GHz)					Gain (dB)					Efficiency %	Design complexity
		F1	F2	F3	F4	F5	F1	F2	F3	F4	F5		
[6]	75×55	1.57	2.61	3.71	4.08	-	2.64	3.27	2.54	3.23	-	-	Simple
[10]	300×300	1.58	2.51	3.8	-	-	1.2	1.7	2	-	-	-	Simple
[16]	100×100	1.6	2.57	-	-	-	6	7.25	-	-	-	-	Complicated
[17]	108×88	2	3.5	4.9	6.5	-	3.23	4.3	5.95	4.65	-	79	Simple
[23]	50×150	1.7	2.6	3.5	5.2	7.5	0.4	3.94	4.57	5.16	2.43	-	Simple
[24]	95×60	0.85	1.9	-	-	-	0.76	4.5	-	-	-	67	Complicated
[25]	100×55	1.65	2.45	-	-	-	3.78	3.78	-	-	-	-	Complicated
Our antenna	75×75	1.84	2.77	2.94	4.33	5.79	1.38	2.67	6.01	3.71	3.72	82	Simple

4. CONCLUSION

A novel multi-band fractal antenna in the 1.84 GHz to 5.8 GHz range has a resonator in the shape of a triangle that is simulated, built, and measured in this study. It seems the proposed antenna is quite appealing and a good option for multiband applications. In the covered working bands, the recommended patch has good radiation characteristics and a high gain range up to 6.01 dB. A bottom plane with a square slit and a triangular fractal patch assist compensates the antenna, the dielectric constant of the substrate is 4.4, and the dielectric loss tangent is 0.02. The antenna is 75×75×1.6 mm^3 and is suitable for GSM (1.80-1.88 GHz), WIMAX (5.72-5.85 GHz), and WLAN applications (4.82-5.95 GHz). The HFSS software results and the testing information from the model antenna are in good agreement.

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