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RESEARCH PAPER

CPW-fed H-tree fractal antenna for WLAN, WIMAX, RFID, C-band, HiperLAN, and UWB applications

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This paper presents three iterations of a coplanar waveguide-fed H-tree fractal antenna. Increasing the number of iterations allows us obtaining a multi-band and broad-band behavior. The proposed antennas are a good solution for wireless local area networks IEEE802.11 a/h/j/n/ac/y, worldwide interoperability for microwave access system IEEE802.16, radio frequency identification, C-band, high performance radio LAN, and ultra wideband applications. The simulations were performed in FEKO 6.3. The measurements were performed by the network analyzer HP 8719C.

Keywords: Antenna design, Modeling and measurements, Antennas and propagation for wireless systems

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I. INTRODUCTION

With the multiplication and miniaturization of telecommunications systems and their integration in restricted environments, such as smart-phones, tablets, cars, airplanes, and other embedded systems. The design of compact multi-band and broadband antennas with high gains and a good efficiency becomes a necessity.

For designing this kind of antennas, a lot of techniques are used:

(1) designing multi-band antennas operating in several frequencies bands. Several studies have been made to design this kind of antennas using fractal geometries or adding slots to the radiating elements [1–7].
(2) designing UWB antennas operating in the frequencies bands exceeding 500 MHz or having a fractional bandwidth of at least 0.20. The UWB wireless communication occupies a bandwidth from 3.1 to 10.6 GHz (based on the FCC "Federal Communication Commission") [8–17].
(3) designing antennas with a broad-band behavior, a high gain, and a good efficiency using some special materials [18–21].

One of the interesting techniques used to design miniaturized antennas with multi-band and broad band behavior is the fractal geometry, because it is a simple technique based on the auto-similarity, the most known techniques used are: MINKOWSKI, KOCH, Tree, HILBERT, SIERPINSKI, APOLLONIUS circles, CANTOR Set… [16, 22, 23].

In this paper, we study the behavior of a coplanar waveguide (CPW)-fed H-tree fractal slot antenna versus the iteration numbers. The simulation is done by FEKO 6.3 based on the method of the moment (MoM) [24]. The measurements are done by the HP 8719C 50 MHz-13.5 GHz Network Analyzer.

II. LITTERATURE REVUE OF THE TREE FRACTAL ANTENNAS

A) The generation of Tree fractal geometry

To generate this kind of fractal structure, we apply the following steps:

(1) For the initiator or "iteration 0", the structure has three branches, the vertical one is the "parent" the two others are the "Childs" with an inclination (θ).
(2) At each iteration, the same shape is generated with a reduction factor "h" (Fig. 1).

In the fractal structures, we use another dimension concept known as "the Hausdorff dimension" which defined by the equation (1) [25, 26].

$$d = \frac{\ln(n)}{\ln(R)}, \tag{1}$$

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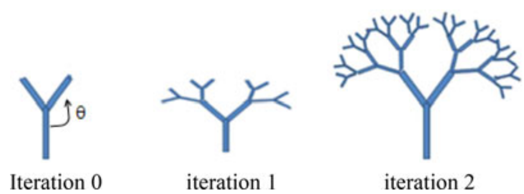

Fig. 1. The three first iterations of the Tree fractal structure.

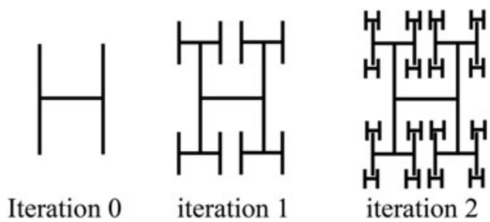

Fig. 2. The three first iterations of the H-tree fractal structure.

where the fractal is formed of "n" copies whose size has been reduced by a factor of "R".

For the Tree structure, if the reduction factor $R = 2$, the Hausdorff dimension is given by the equation (2).

$$d = \frac{\ln(n)}{\ln(R)} = \frac{\ln(4)}{\ln(2)} = 2. \qquad (2)$$

B) The generation of H-tree fractal geometry

The H-tree geometry is a modified Tree geometry with the same concept (Fig. 2). The initiator is a structure like the letter "H". On each iteration, we create four copies of the previous iteration with a reduction factor "R".

For the H-tree structure, if the reduction factor $R = 2$, the Hausdorff dimension is given by the equation (3).

$$d = \frac{\ln(n)}{\ln(R)} = \frac{\ln(4)}{\ln(2)} = 2. \qquad (3)$$

C) The use of the Tree fractal on the design of the antennas

The Tree Fractal structures are used in many works for the antennas design with good performances.

In 1986, according to our investigations, KIM has published the first paper on Fractal geometries antennas [27]. In 1999, WERNER studied the effect of the number of iterations on the behavior of fractal antennas in general and in particular of the tree structures [28]. In 2004, PETKO studied the 3D-Tree fractal antennas and found out the relationship between the geometry parameters and the performances of this kind of fractal structures [29]. In 2009, He studied the array of Tree fractal antennas and he demonstrated that we can have better results with this technique [30]. In 2011, POURAHMADAZA created modified patch antennas fed by microstrip lines and having the shape of "PYTHAGORE TREE". He demonstrated that by increasing the number of iterations we can have miniaturized antennas with more resonance frequencies, an ultra wideband behavior, good efficiency, and better matching [31]. In 2013, DUMOND studied experimentally the Random 2D-Tree fractal antennas and he demonstrated that with this kind of structures, we can have antennas with good performances, multi-band and UWB behavior [32]. Also, NASER-MOGHADASI has introduced a miniaturized Tree fractal structure operational for all the UWB applications, he also set up parasite elements in order to eliminate some frequencies bands [33]. VARADHAN proposed a tri-bands Tree fractal antenna for the radio frequency identification (RFID) applications [3]. LIU proposed another structure with a high gain for the UHF-RFID, this antenna is composed of a traditional patch and another layer composed of a four Tree fractal elements [34].

In the next section, three iterations of a CPW-fed H-tree antenna will be simulated and measured.

III. ANTENNA DESIGN

To design the first iteration of CPW H-tree structure, we start from the first iteration of a CPW tree fractal antenna designed by VARADHAN [3]; this structure is a tri-band antenna with three resonant frequencies $f_{r1} = 3.6$ GHz, $f_{r2} = 5.8$ GHz, and $f_{r3} = 8.2$ GHz.

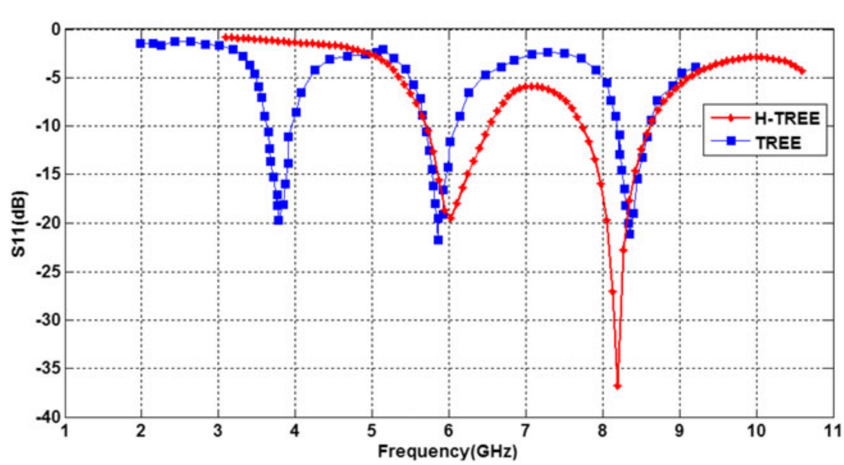

Fig. 3. The S_{11} parameter versus the frequency for the H-tree and the tree structures.

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Table 1. The difference between the gains.

Frequency (GHz)	Tree [3] (dB)	H-tree (our results) (dB)
5.8	2.7	4
8.2	2.6	3.4

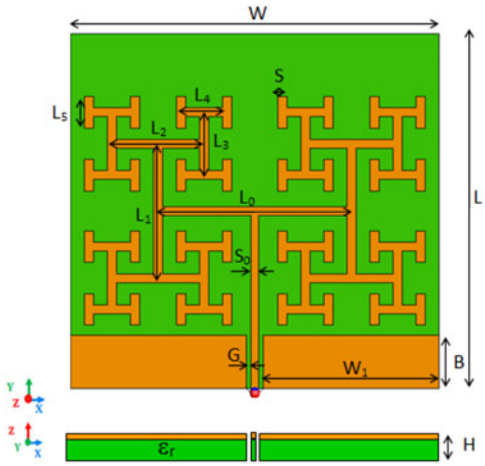

Fig. 4. The geometry of the CPW-fed H-tree Fractal Antenna.

After that, we modify this structure to have an H-tree structure ($\theta = \pi/2$). Figure 3 shows the difference between the S_{11} parameters of the Tree and the H-tree structures.

We observe that the modified structure is a bi-band antenna with two resonant frequencies $f_{r1} = 5.8$ GHz and $f_{r2} = 8.1$ GHz. Also, the simulated gain and the -10 dB bandwidth of the H-tree structure are very important. Table 1 shows the difference between the gains of the two structures for two frequencies 5.8 and 8.2 GHz.

In the following, we will analyze the behavior of three iterations of the H-tree structure.

As shown in Fig. 4, the proposed antenna is printed on a FR4 dielectric substrate of relative permittivity $\varepsilon_r = 4.3$, thickness $H = 1.6$ mm, loss tangent 0.025 and fed by a CPW transmission line with a signal strip width S_o and a gap distance G between the signal strip and the ground plane. Several studies have used this mode of feeding because it is one of the techniques to increase the bandwidth of the antennas [4, 6, 10].

For a reduction factor $R = 2$, the generation of the different iterations of the H-tree Fractal antenna (Fig. 5) is based on a simple formula (4):

$$L_i = \frac{L_o}{\sqrt[i]{2}} [35]. \tag{4}$$

The other parameters are as follow:
$W = 40$ mm, $L = 40$ mm, $B = 4$, $G = 0.5$ mm, $L_o = 20$ mm, and $S_o = 0.8$ mm.

A parametric study is based on the variation of the parameter S.

All the simulations and the measurements are done in the band of 3.1–10.6 GHz.

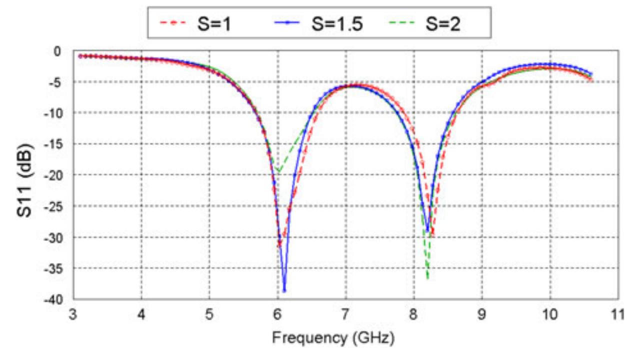

Fig. 6. Simulated S_{11} versus frequency graph of the antenna (first iteration).

IV. RESULTS AND DISCUSSIONS

A) The first iteration

For the first iteration of the CPW-fed H-tree fractal antenna, the variation of simulated S_{11} parameter versus the frequency for some values of S is shown in Fig. 6. Table 2 summarizes for each value of S, the resonant frequencies, the S_{11} values on the resonant frequencies, the -10 dB bandwidths, the maximum and minimum gains.

We note that for this first iteration, the simulated structures are dual-band antennas with two resonant frequencies and all the bandwidths exceed 500 MHz.

The antenna with the parameter $S = 2$ is manufactured and measured. Figure 7 shows the comparison between simulated and measured S_{11} parameter. Figure 8 shows the 3D-Total Gain pattern of the antenna for the frequencies 5.8 and 8.2 GHz.

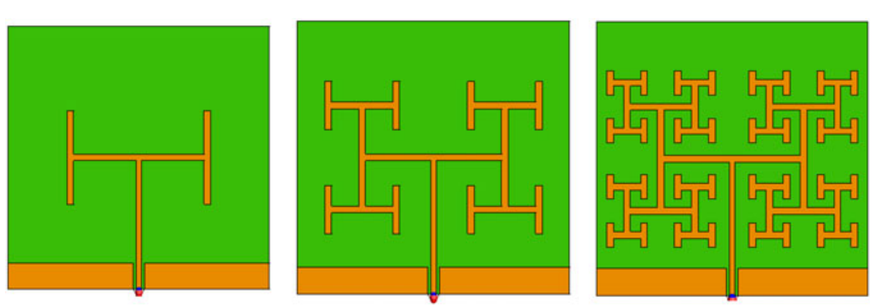

Fig. 5. The three iterations of the H-tree fractal Antenna.

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Table 2. Simulated bandwidths and the gains for the antenna (first iteration).

S (mm)	Resonant frequencies (GHz)/S_{11} (dB)	(−10 dB) bandwidth: from–to	Gain (dB)* min–max
1	$F_{r1} = 6/-32$	950 MHz:5.65–6.6	2.6–4
	$F_{r2} = 8.2/-30$	800 MHz:7.82–8.62	3.5–4
1.5	$F_{r1} = 6.1/-39$	840 MHz:5.66–6.5	3.1–4
	$F_{r2} = 8.2/-29$	870 MHz:7.7–8.57	3.5–3.7
2	$F_{r1} = 6/-20$	800 MHz:5.7–6.5	3.2–4
	$F_{r2} = 8.2/-37$	890 MHz:7.74–8.63	3–3.4

*The gain is simulated on the (−10 dB) bandwidth.

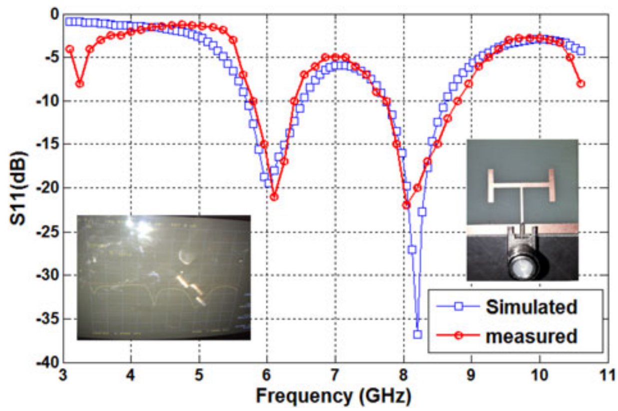

Fig. 7. Simulated and measured S_{11} versus frequency graph of the antenna (first iteration).

In comparison with the Three-band CPW-fed tree fractal antenna designed by VARADHAN [3], the proposed CPW-fed H-tree fractal antenna is a dual-band antenna for the 5.8 and 8.2 GHz RFID applications, and its gain is much better. This structure is also a good solution for the 5.9 GHz wireless local area networks (WLAN) IEEE802.11p, a part of 5 GHz WLAN IEEE 802.11 1/h/j/n/ac and 5.8 GHz worldwide interoperability for microwave access system (WIMAX) IEEE802.16 applications.

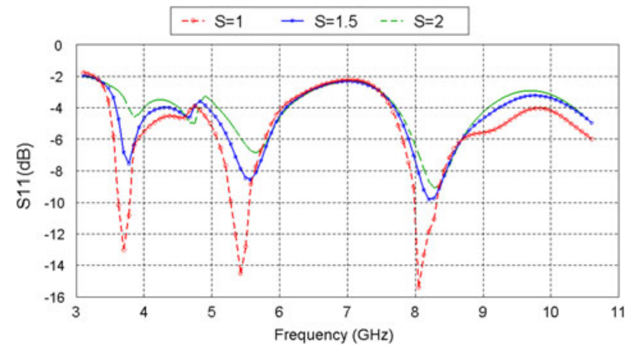

Fig. 9. Simulated S_{11} versus frequency graph of the antenna (second iteration).

B) The second iteration

For the second iteration of the CPW-fed H-tree fractal antenna, the variation of simulated S_{11} parameter versus the frequency for some values of *S* is shown in Fig. 9. Table 3 summarizes for each value of *S*, the resonant frequencies, the S_{11} values on the resonant frequencies, the −10 dB bandwidths, the maximum and minimum gains.

We note that for this second iteration, the simulated structures are tri-band antennas with three resonant frequencies.

The antenna with the parameter $S = 1$ is manufactured and measured. Figure 10 shows the comparison between the simulated and the measured S_{11} parameter. Figure 11 shows the 3D-Total Gain pattern of the antenna for the frequencies 5.3 and 8.3 GHz.

This antenna is a good solution for 3.6 GHz WLAN IEEE802.11y, 3.6 and 8.2 GHz RFID, 5.4 GHz HiperLAN, and C-band applications.

C) The third iteration

For the third iteration of the CPW-fed H-tree fractal antenna, the variation of simulated S_{11} parameter versus the frequency for some values of *S* is shown in Fig. 12. The Table 4 summarizes for each value of *S*, the resonant frequencies, the S_{11} values on the resonant frequencies, the −10 dB bandwidths, the maximum, and minimum gains.

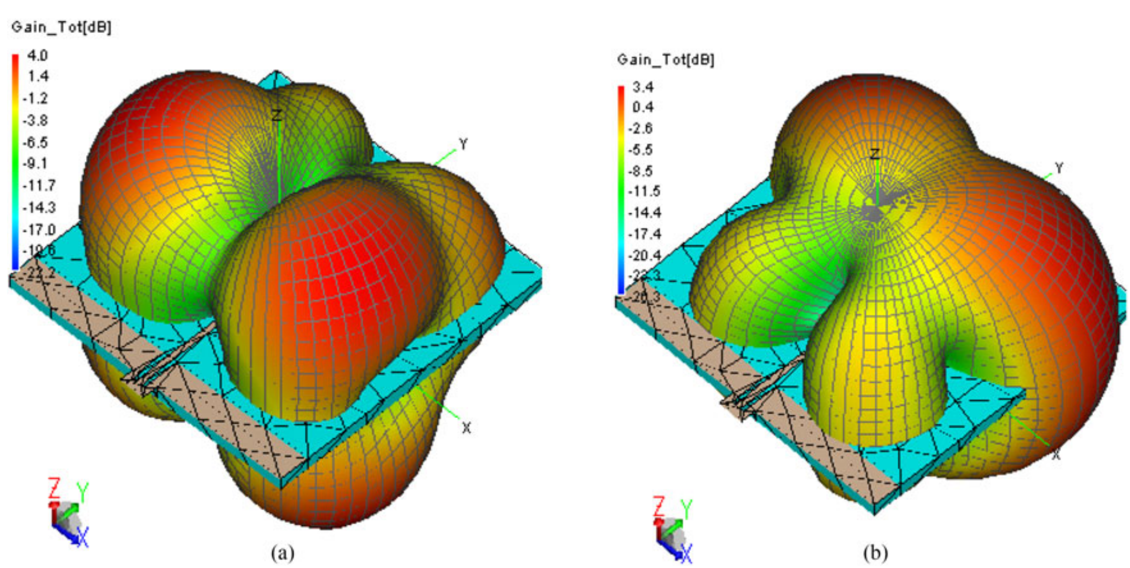

Fig. 8. the 3D Total Gain pattern for the frequencies 5.8 and 8.2 GHz. (a) $f = 5.8$ GHZ (maximum gain = 4 dB) (b) $f = 8.2$ GHZ (maximum gain = 3.4 dB).

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Table 3. Simulated bandwidths and the gains for the antenna (second iteration).

S (mm)	Resonant frequencies (GHz)/S_{11} (dB)	(−10 dB) bandwidth: from–to	Gain (dB)* min–max
1	F_{r1} = 3.66/−13	200 MHz: 3.5–3.7	0.1–0.3
	F_{r2} = 5.42/−14.3	200 MHz: 5.3–5.5	2.3–3.1
	F_{r3} = 8.12/−15.8	350 MHz: 8–8.35	0.9–1.3
1.5	F_{r1} = 3.7/−7.5	–	–
	F_{r2} = 5.6/−8.5	–	–
	F_{r3} = 8.2/−9.8	–	–
2	F_{r1} = 3.8/−4.8	–	–
	F_{r2} = 5.66/−6.9	–	–
	F_{r3} = 8.3/−9	–	–

*The gain is simulated on the (−10 dB) bandwidth.

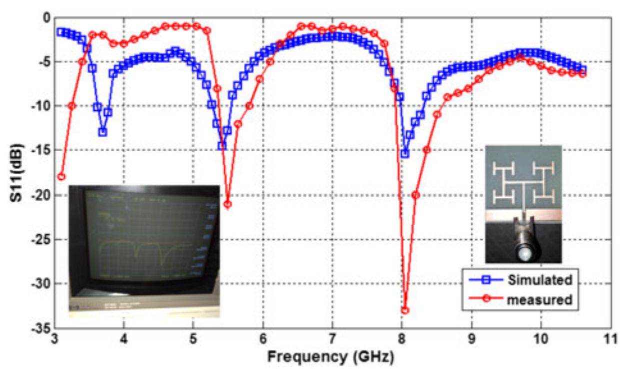

Fig. 10. Simulated and measured S_{11} versus frequency graph of the antenna (second iteration).

We note that for this third iteration, the simulated structures are tetra-band antennas with 5 resonant frequencies and some of the bandwidths exceed 1.4 GHz.

The antenna with the parameter $S = 1$ is manufactured and measured. Figure 13 shows the comparison between the simulated and the measured S_{11} parameter. We observe that the measurement is different to the simulation. Such a difference between the simulation and experimental results can probably be ascribed to the fabrication imperfections (like inaccuracy in the milling and etching processes and connector soldering).

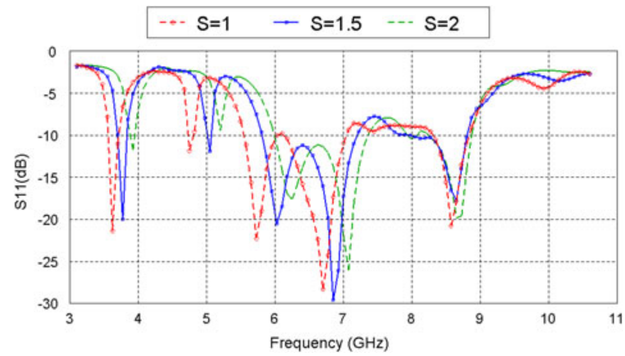

Fig. 12. Simulated S_{11} versus frequency graph of the antenna (third iteration).

Table 4. Simulated bandwidths and the gains for the antenna (second iteration).

S (mm)	Resonant frequencies (GHz)/S_{11} (dB)	(−10 dB) bandwidth: from–to	Gain (dB)* min–max
1	F_{r1} = 3.6/−21.5	160 MHz:3.58–3.74	0.1–0.3
	F_{r2} = 4.75/−11.5	150 MHz:4.7–4.85	0.1–0.3
	F_{r3} = 5.74/−22.3	1.46 GHz: 5.54–7	1–2.8
	F_{r4} = 6.71/−28.4		
	F_{r5} = 8.57/−21	510 MHz: 8.34–8.85	0.1–0.8
1.5	F_{r1} = 3.7/−20	200 MHz:3.65–3.85	0.1–1
	F_{r2} = 5.05/−12	80 MHz:5–5.08	0–0.1
	F_{r3} = 6.04/−21	1.43 GHz:5.78–7.2	1.2–1.9
	F_{r4} = 6.83/−29.8		
	F_{r5} = 8.62/−17.8	1.01 GHz:7.8–8.81	0.1–1.8
2	F_{r1} = 3.92/−11.7	80 MHz:3.86–3.94	0.1–0.2
	F_{r2} = 5.2/−9	–	–
	F_{r3} = 6.2/−17.8	1.42 GHz:5.96–7.38	1.9–2.8
	F_{r4} = 7.08/−26		
	F_{r5} = 8.7/−20	700 MHz: 8.2–8.9	0.1–2.8

*The gain is simulated on the (−10 dB) Bandwidth.

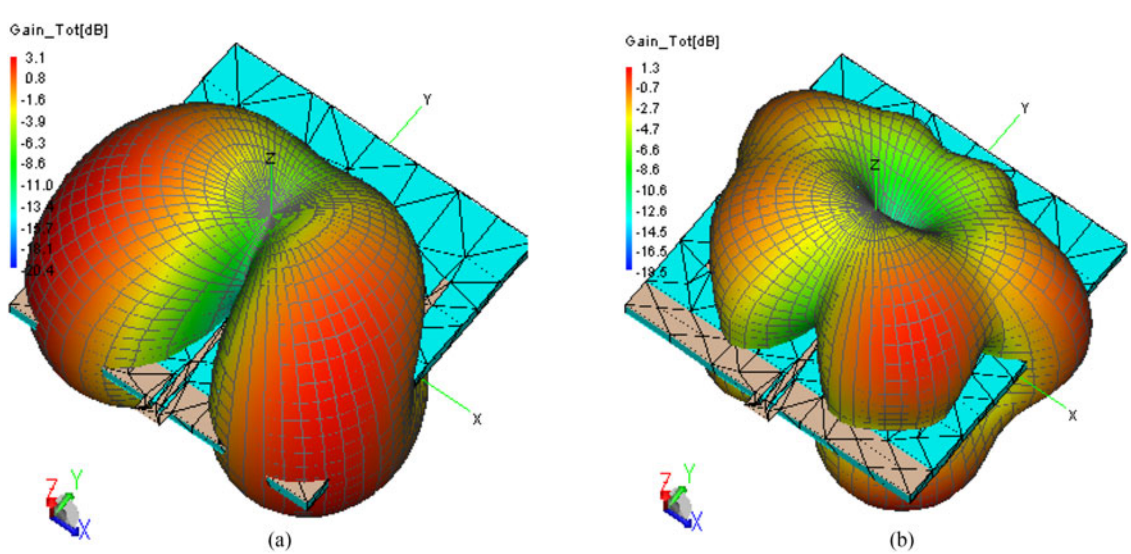

Fig. 11. the 3D Total Gain pattern for the frequencies 5.3 and 8.3 GHz. (a) $f = 5.3$ GHZ (maximum gain = 3.1 dB) (b) $f = 8.3$ GHZ (maximum gain = 1.3 dB).

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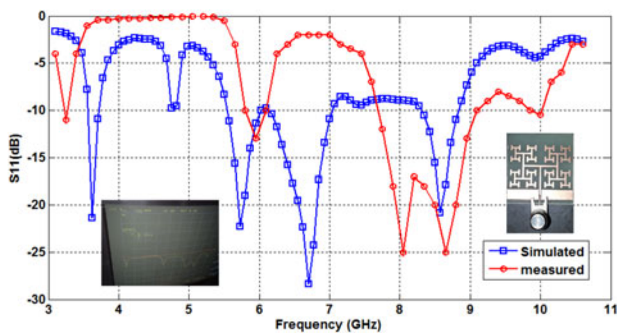

Fig. 13. Simulated and measured S_{11} versus frequency graph of the antenna (third iteration).

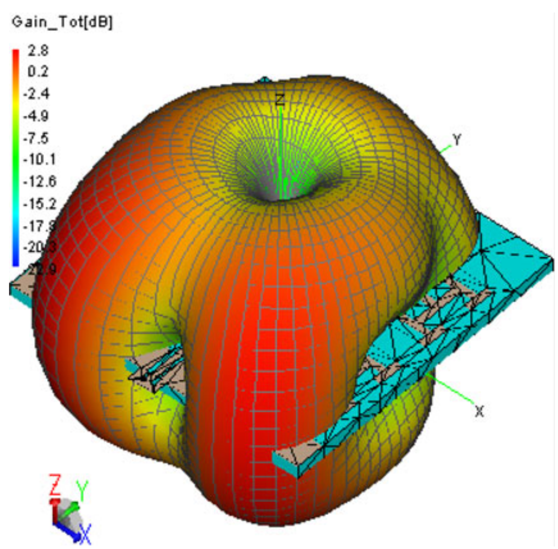

Fig. 14. the 3D Total Gain pattern for the frequency 6 GHz (maximum gain = 2.8 dB).

Figure 14 shows the 3D-Total Gain pattern of the antenna for the frequency 6 GHz.

This antenna is a good solution for 3.6 GHz WLAN IEEE802.11y, 3.6 and 5.8 GHz RFID, 5.8 GHz WIMAX IEEE802.16, 5.9 GHz WLAN IEEE 802.11p, and C-band applications.

V. CONCLUSION

The fractal concept is a one of the better solutions to design miniaturized broadband and multi-band antennas. The use of the CPW-fed technique increases the bandwidth of the antennas, and it is very easy to manufacture because the antenna is designed on one face of a printed circuit board (PCB).

Increasing the number of iteration of the CPW-fed H-tree fractal antenna allows obtaining a low profile antenna with a multi-band and broadband behavior.

For some configurations of the proposed structures, the antennas operate in many applications, such as WLAN IEEE802.11 a/h/j/n/ac/y, WIMAX IEEE802.16, RFID, C-BAND, HiperLAN, and UWB applications.

Also, more refinement can be done to obtain antennas with better performances and good matching.

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