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Comparative Study of Fractal Structures as Tuning Stub in Slot Antenna

Sushil Kakkar*, Shweta Rani**
*(ECE Department, Bhai Gurdas Institute of Engineering & Technology, Sangrur, Punjab
Email: kakkar778@gmail.com)
** (ECE Department, GZSCCET, MRSPTU, Bathinda
Email: shweta.ece@mrsptu.ac.in)

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Abstract:

This paper gives a comparative study of resonant behavior of the different fractal geometries used as tuning stub in planar slot antenna. This analysis includes sierpinski carpet, sierpinski gasket and Koch fractal structures. It has been observed that out of these three presented antennas, sierpinski carpet has given Ultra-wideband (3.50-13.41 GHz) features with better return loss and input impedance. The self-affine and space filling properties of fractals have been exploited for wireless communication systems.

Keywords **— Antennas, Fractals, UWB.**

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I. INTRODUCTION

Advance telecommunication system requires antennas with wider bandwidth and smaller dimensions [1]. Ultra-wideband (UWB) systems enable personal area network wireless connectivity since the Federal Communications Commission (FCC) released the frequency band from 3.1 to 10.6 GHz for high data rate communication in 2002 [2]. Besides the demand for small size and compact profile antennas, broadband antennas are often required in order to cover simultaneously several bands. The necessity for multiple-single frequency antennas is not required when a single antenna can operate in ultra-wideband region that can cover multi-band applications, [3]. To design an antenna to operate in the UWB band is quiet challenging one because it has to satisfy the requirements such as ultra wide impedance bandwidth, omnidirectional radiation pattern, high radiation efficiency, constant gain, low profile, compact and easy manufacturing. Interestingly the planar slot antennas with CPW feeding posses the above said features hence CPW fed planar slot antennas are identified as the most promising design for wideband wireless applications [4, 5]. In addition these days' fractal geometries are also getting interest of antenna design engineers to develop UWB antennas [6-8]. This paper investigates design and comparison of CPW fed rectangular slot antenna with different fractal geometries as tuning stub.

II. DESIGN AND STRUCTURE

The proposed antenna structures are designed with FR4 substrate having dielectric constant of 4.4 and height 1.6 mm. These structures have used CPW feeding technique which consists of a 50 Ω transmission line having width of 2.4 mm. There is a gap of 0.5 mm between the single feed strip and the coplanar ground plane. The length of the patch of proposed antenna, L = 10.73 mm and width, W = 10.73 mm, Length of the ground plane, Lp = 28 mm and width of the ground plane, Wp = 21 mm. The space between patch and ground plane is 1.6 mm. The different fractal shapes like sierpinski carpet, sierpinski gasket and Koch curve has been used as tunings stub in the rectangular slot for the proposed designs. The dimensions of the rectangular slot are length, Ls = 15 mm and width, Ws = 16.8 mm. The 50Ω impedance is achieved by adjusting width of the inner conduct and the gap width between the ground plane and the inner conduct. For better resonance performance parameters, good impedance matching is required and it can be calculated using equation (1) and (2) [1].

$$\varepsilon_{eff} = \frac{(\varepsilon r+1)}{2} + \frac{(\varepsilon r-1)}{2}\left[\frac{1}{\sqrt{1+12h/w}}\right] \quad (1)$$

$$Z_o = \frac{120\,\pi}{\sqrt{\varepsilon eff}\left[\frac{w}{h}+1.393+0.667\ln\left(\frac{w}{h}+1.444\right)\right]} \text{ for } \frac{w}{h} \geq 1 \quad (2)$$

Iterated function systems (IFS) have always been an efficient way to design accurate fractal structures [6]. The transformations for different iteration can be achieved using equation (3).

$$w\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} r\cos\theta & -r\sin\theta \\ r\sin\theta & r\cos\theta \end{bmatrix}\begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} e \\ f \end{bmatrix} \quad (3)$$

A. Sierpinski Carpet as Tuning Stub

Sierpinski carpet microstrip patch antenna of different iteration orders can be designed by dropping elements on the patch as sierpinski carpet, whose iteration factor is 1/3, without changing the physical parameters of the patch [7]. Fig. 1 shows the 1st and 2nd iteration of the proposed geometry in which sierpinski carpet has been used as tuning stub

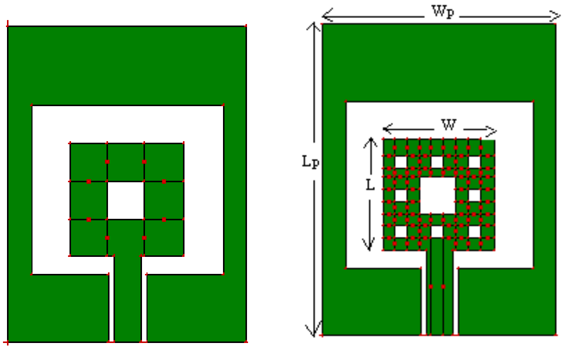


Fig. 1 Proposed geometry with sierpinski carpet as tuning stub for 1st and 2nd iteration.

IFS used to obtain the transformations for the generator are :

$$W_1\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{bmatrix} \frac{1}{3} & 0 \\ 0 & \frac{1}{3} \end{bmatrix}\begin{pmatrix} x \\ y \end{pmatrix} \quad (4)$$

$$W_2\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{bmatrix} \frac{1}{3} & 0 \\ 0 & \frac{1}{3} \end{bmatrix}\begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} 0 \\ \frac{1}{3} \end{pmatrix} \quad (5)$$

$$W_3\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{bmatrix} \frac{1}{3} & 0 \\ 0 & \frac{1}{3} \end{bmatrix}\begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} 0 \\ \frac{2}{3} \end{pmatrix} \quad (6)$$

$$W_4\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{bmatrix} \frac{1}{3} & 0 \\ 0 & \frac{1}{3} \end{bmatrix}\begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} \frac{1}{3} \\ \frac{2}{3} \end{pmatrix} \quad (7)$$

$$W_5\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{bmatrix} \frac{1}{3} & 0 \\ 0 & \frac{1}{3} \end{bmatrix}\begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} \frac{2}{3} \\ \frac{2}{3} \end{pmatrix} \quad (8)$$

$$W_6\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{bmatrix} \frac{1}{3} & 0 \\ 0 & \frac{1}{3} \end{bmatrix}\begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} \frac{2}{3} \\ \frac{1}{3} \end{pmatrix} \quad (9)$$

$$W_7\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{bmatrix} \frac{1}{3} & 0 \\ 0 & \frac{1}{3} \end{bmatrix}\begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} \frac{2}{3} \\ 0 \end{pmatrix} \quad (10)$$

$$W_8\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{bmatrix} \frac{1}{3} & 0 \\ 0 & \frac{1}{3} \end{bmatrix}\begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} \frac{1}{3} \\ 0 \end{pmatrix} \quad (11)$$

B. Sierpinski Gasket as Tuning Stub

The sierpinski gasket consists of a series of scaled triangles having a scaling of r = ½ [4]. Fig. 2 shows the 1st and 2nd iteration of the proposed geometry in which sierpinski gasket has been used as tuning stub.

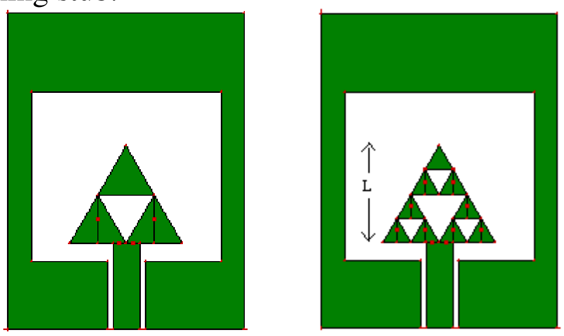


Fig. 2 Proposed geometry with sierpinski gasket as tuning stub for 1st and 2nd iteration

IFS used to obtain the transformations for the generator are:

$$W_1\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{bmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{bmatrix}\begin{pmatrix} x \\ y \end{pmatrix} \quad (12)$$

$$W_2\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{bmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{bmatrix}\begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} \frac{1}{2} \\ 0 \end{pmatrix} \quad (13)$$

$$W_3\begin{pmatrix}x'\\y'\end{pmatrix}=\begin{bmatrix}\frac{1}{2} & 0\\ 0 & \frac{1}{2}\end{bmatrix}\begin{pmatrix}x\\y\end{pmatrix}+\begin{pmatrix}\frac{1}{4}\\ \frac{\sqrt{3}}{4}\end{pmatrix} \qquad (14)$$

C. Koch curve as tuning stub

The classical structure of Koch curves starts with a straight line, called the initiator. This is partitioned in to three equal parts, and the segment at the middle replaced with two other segments of same length. This process is repeated in the generation of higher iterated structure [7, 8]. Fig. 3 shows the 1st and 2nd iteration of the proposed geometry in which Koch curve has been used as tuning stub.

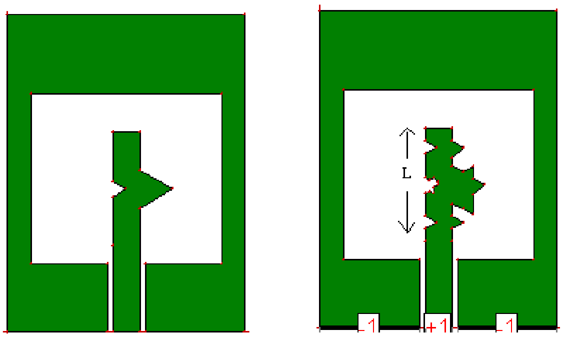


Fig. 3 Proposed geometry with Koch curve as tuning stub for 1st and 2nd iteration

IFS used to obtain the transformations for the generator are [7]:

$$W_1\begin{pmatrix}x'\\y'\end{pmatrix}=\begin{bmatrix}\frac{1}{3} & 0\\ 0 & \frac{1}{3}\end{bmatrix}\begin{pmatrix}x\\y\end{pmatrix} \qquad (15)$$

$$W_2\begin{pmatrix}x'\\y'\end{pmatrix}=\begin{bmatrix}\frac{1}{3}\cos 60^\circ & -\frac{1}{3}\sin 60^\circ\\ \frac{1}{3}\sin 60^\circ & \frac{1}{3}\cos 60^\circ\end{bmatrix}\begin{pmatrix}x\\y\end{pmatrix}+\begin{pmatrix}\frac{1}{3}\\ 0\end{pmatrix} \qquad (16)$$

$$W_3\begin{pmatrix}x'\\y'\end{pmatrix}=\begin{bmatrix}\frac{1}{3}\cos 60^\circ & -\frac{1}{3}\sin 60^\circ\\ \frac{1}{3}\sin 60^\circ & \frac{1}{3}\cos 60^\circ\end{bmatrix}\begin{pmatrix}x\\y\end{pmatrix}+\begin{pmatrix}\frac{1}{2}\\ \frac{1}{2}\sin 60^\circ\end{pmatrix}$$

(17)

$$W_4\begin{pmatrix}x'\\y'\end{pmatrix}=\begin{bmatrix}\frac{1}{3} & 0\\ 0 & \frac{1}{3}\end{bmatrix}\begin{pmatrix}x\\y\end{pmatrix}+\begin{pmatrix}\frac{2}{3}\\ 0\end{pmatrix} \qquad (18)$$

III. RESULTS AND DISCUSSION

A. *Resonant Performance Characteristics*

The resonant properties of these planar space filling fractal structures are consider for comparing their effect, on used as tuning stub for rectangular slot antenna. The specific geometries analyzed include sierpinski carpet, sierpinski gasket and Koch fractal antenna. All of these antennas are analyzed using method of moment based IE3D software. The physical and resonant properties of these antennas are detailed in Table. 1 Graphical comparison of each antenna's return loss, voltage standing wave ratio (VSWR) and input impedance are shown from Fig. 4 to Fig. 7. In examining the resonant properties of these geometries it is first evident that only the sierpinski carpet produces ultra wide band features which are expected from the CPW fed rectangular slot tuning stub antennas. This is primarily a function of the fact that the sierpinski carpet covers more patch area when similar dimensions have been taken for all the presented geometries. This occupied patch area and location of the tuning stub causes the antennas to exhibit such a different resonant properties. Another important point to note is that the resonant characteristics of these geometries become more deteriorated with the increase of iterations. Evidence of this is provided by creating the first and second iteration order of all these geometries and their resonant properties are validated by simulations which are shown from Fig. 8 to Fig. 10.

TABLE. 1
RESONANT PROPERTIES OF 2ND ITERATIONS

Fractal Geometry	*Resonant Frequency(GHz)*	*Retun Loss (dB)*	*VSWR*	*Input Impedance (Ohms)*
Sierpinski carpet	3.939	-13.39	1.544	63.61
	6.848	-40.89	1.018	50.4
	10.85	-22.7	1.086	52.5
	12.91	-19.98	1.223	47
Koch	3.818	-12.07	1.664	62.07
	11.82	-10.19	1.895	86.65
Sierpinski gasket	7.091	-11.07	1.776	37.83

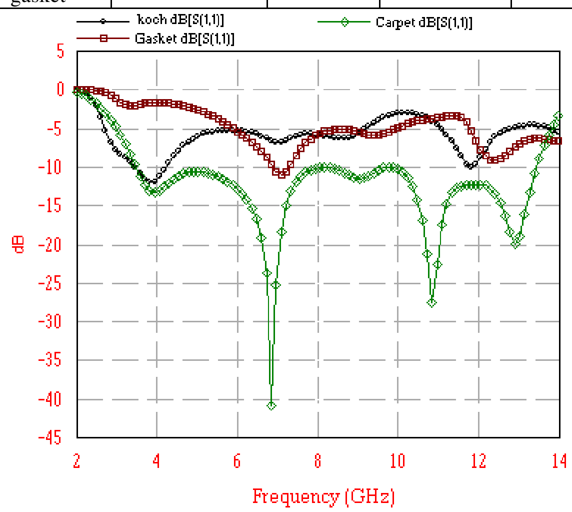


Fig. 4 S-parameters of all the three geometries for 2nd iterations.

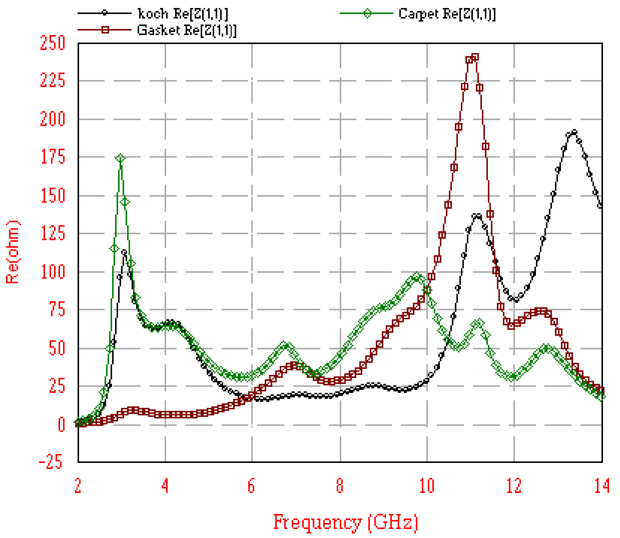


Fig. 5 Real Input Impedance of all three geomeries for 2nd iteration

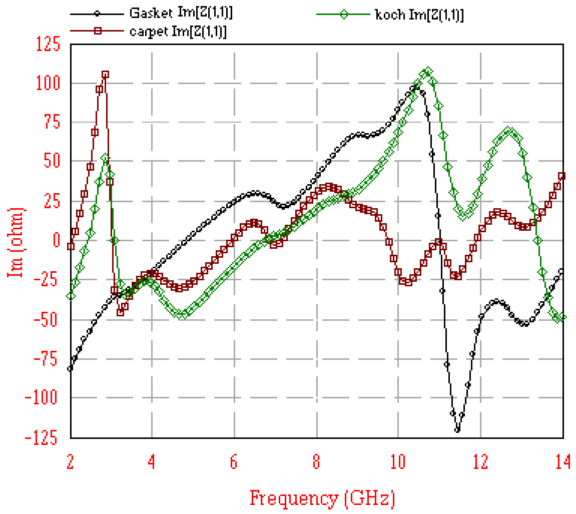


Fig. 6 Imaginary Input Impedance of all three geometries for 2nd iteration

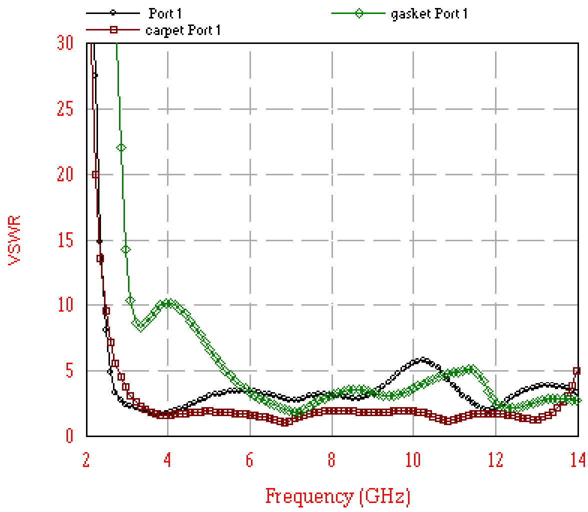


Fig. 7 VSWR of all the three geometries for 2nd iteration.

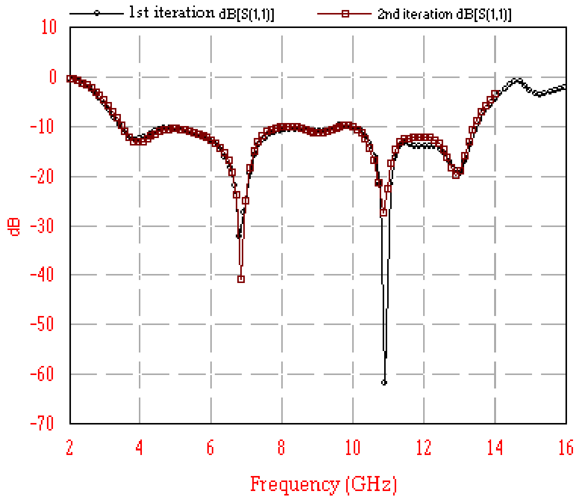


Fig. 8 S-parameters of Sierpinski carpet for 1st and 2nd iterations

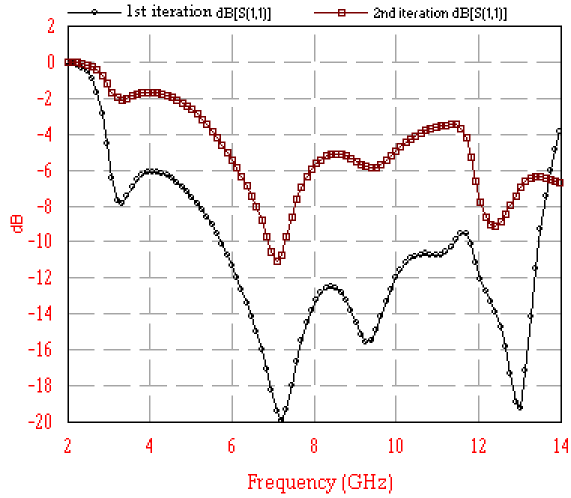


Fig. 9 S-parameters of Koch fractal for 1st and 2nd iterations

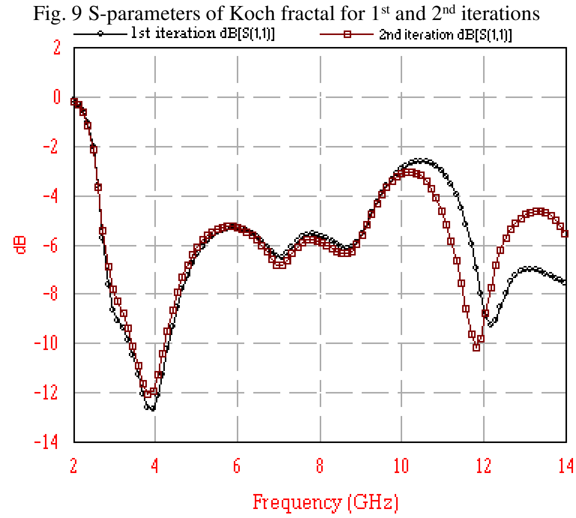
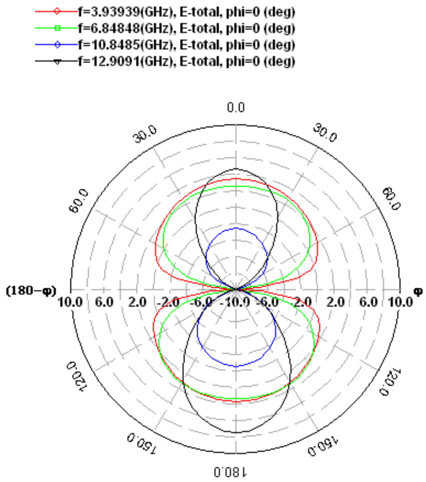
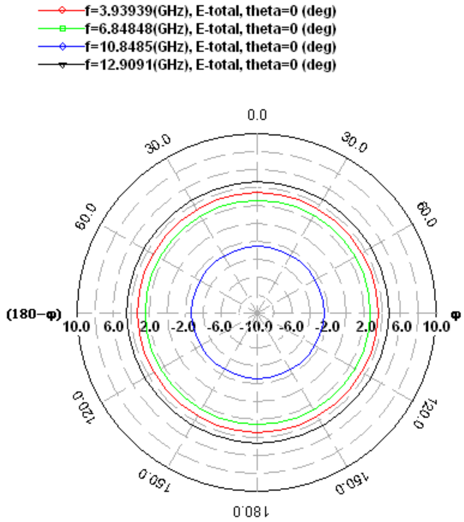


Fig. 10 S-parameters of Sierpinski gasket for 1st and 2nd iterations

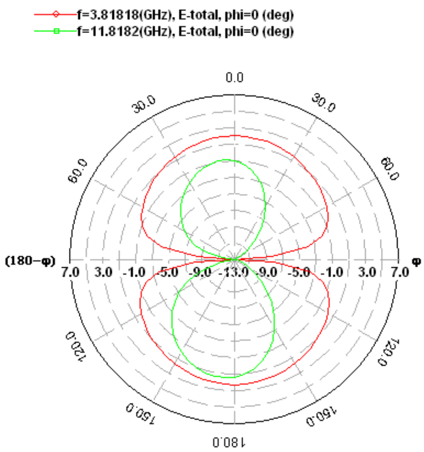


(a)

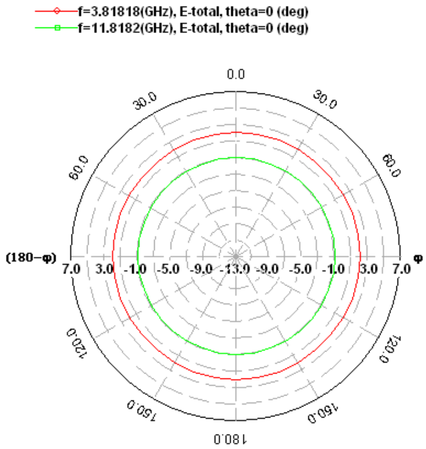


(b)

Fig. 11 Simulated radiation Pattern of sierpinski carpet for second iteration (a) E-plane (b) H-plane

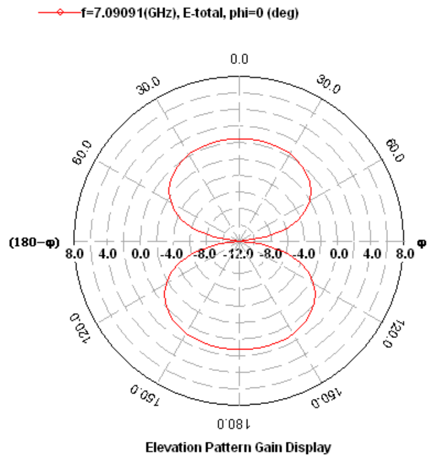


(a)

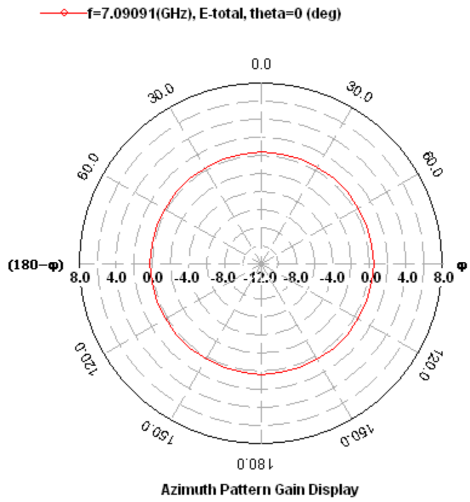


(b)

Fig. 12 Simulated radiation Pattern of Koch fractal for second iteration (a) E-plane (b) H-plane



(a)



(b)

Fig. 13 Simulated radiation Pattern of sierpinski gasket for second iteration (a) E-plane (b) H-plane

B. Radiation Patterns and Gain

The radiation characteristics of proposed geometries are shown from Fig. 11 to Fig. 13 and it has been observed that all these structures exhibit similar behavior in corresponding E and H-plane. The radiation pattern in E-plane is symmetrical to antenna axis whereas it has nearly omnidirectional pattern in H-plane. The simulated gain of proposed antenna with sierpinski carpet as tuning stub, in the operating band is shown in Fig. 14. It is seen that the gain remains above 2 dBi in the almost entire band. The maximum achievable gain for the specific geometry is 9.16 dBi at 11.82 GHz.

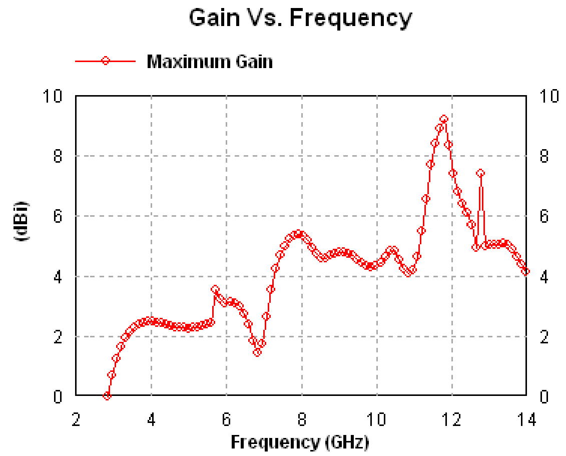


Fig. 14 Simulated Gain of sierpinski carpet for second iteration

IV. CONCLUSIONS

Design and comparison of CPW fed rectangular slot antennas with different fractal geometries as tuning stub is presented in this paper. This research work gives an effective idea for the design of tuning stub slot antenna. It has been shown that sierpinski carpet as tuning stub exhibit a better electrical behavior with reduced size for UWB wireless applications.

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