A Novel Design of Wideband Koch like Sided Sierpinski Square Carpet Multifractal Antenna

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Abstract **─** This paper reveals Koch Like Sided Sierpinski Square Carpet Multifractal Antenna (KLSSSCMA) having wideband features and comprises a new hybrid geometry using Sierpinski carpet and Koch curve geometries. The antenna is designed using square patch having dimensions 29.4 mm × 29.4 mm over Roger RT/Duroid substrate having height equal to 3.18 mm and dimensions 48.48 mm × 48.48 mm. The proposed antenna is analyzed and simulated using FEM (Finite Element Method) based Ansoft HFSS^{TM} v.13 software successfully up to fourth iteration. Simulation results show that KLSSSCMA has wideband characteristics from 2 to 8 GHz that covers S and C bands for WiMAX, WPAN, WLAN and Wi-Fi applications. The projected antenna is capable of achieving a good impedance bandwidth with S_{11} less than -9 dB over the whole range of BW and also exhibits almost stable radiation patterns.

Index Terms **─** Carpet, fractal, gain, Koch curve, patch, VSWR.

I. INTRODUCTION

This paper focuses on the generation of Koch Like Sided Sierpinski Square Carpet Multifractal (KLSSSCM) geometry. As in earlier studies, the fractal antenna geometries are inspired by nature. They possess features of fractals that exist in nature [1]. The proposed geometry also represents the hybrid structure of two geometries [2]. A lot of research has been done on individual fractal geometries using different techniques with exciting features such as wide band, miniaturize size, multiband resonance behavior etc. The recent trend towards the combination of two geometries with different methods is being popular as studied in the literature [3-5]. Multifractal geometries reserved the merits and overcome the limitations of mono fractals. Since these multi fractals have not been used broadly in antenna design structures, therefore this is an encouraging topic in fractal structures and needs to be examined and technologically advanced in more depth. Fractal antenna engineering is a new kind of antenna design technology [1] that gives a lot of scope for research to enhance the performance of designed antenna. This concept gives better response in terms of bandwidth, enhancement in radiation pattern, lesser reflection coefficient, multi-resonance, miniaturization of antenna size and also wideband / UWB [4-6]. Due to self-similar and space filling properties, fractal and multifractal antennas reveal multiband, wideband and miniaturization of antenna size [7-11]. Different techniques have been applied to fractal antenna yet to attain more bandwidth. A planer multiband Koch snowflake fractal antenna for cognitive radio [12], wideband square gap coupled fractal antenna [13], CPW feed KLSSHCMF monopole antenna [3], UWB monopole based on Sierpinski carpet fractal shape slot antenna [14], microstrip patch antenna designed with Sierpinski and Koch fractal geometries [15], star-shaped microstrip wideband antenna [16] and ultra-wideband hexagonal fractal antenna using Koch shape with an enhancement in bandwidth [17] have been designed to optimize the performance of antenna. In this paper, the Koch curve and Sierpinski carpet geometries are united together to design KLSSSCMA. The proposed antenna is fed by coax probe feed at the right upper corner. Feed position is optimized to match the impedance of feed to the antenna. The effect of substrate height on bandwidth is also analyzed. The final iteration $S_2 K_2$ of KLSSSCMA is fabricated and tested.

II. ANTENNA DESIGN

The KLSSSCMA is designed up to 4th iteration. Roger RT/Duroid 5880 (TM) material having thickness 3.18 mm is used as the substrate. This material provides a higher gain and more bandwidth depending on the substrate thickness. The specifications of RT/Duroid substrate material are mentioned in Table 1. Resonant frequency of 3.2497 GHz is chosen for the proposed antenna that lies in S-band with multiple applications that enables it to operate the antenna in S as well as in C-bands of the communication field. Transmission line model is used to calculate the dimensions of the patch as this model is an easy and correct model for rectangular microstrip patch antenna.

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Table 1: Substrate specifications

Relative dielectric constant (ε_r)	2.2
Loss tangent	0.0009
Substrate thickness (h)	3.18 mm
Acceptable frequency range	<10 GHz

Equations (1) to (4) are used to calculate the width and length of the patch as described in transmission model. These equations give the values of width and length of patch as 29.4 mm each respectively. The information of 'ε_r', the resonant frequency 'f_r' and height of substrate 'h' is required to calculate other parameters. Practical width of a radiating patch as in [18] is given by:

$$W = \frac{1}{2 f_r \sqrt{\mu_0 \varepsilon_0}} \sqrt{\frac{2}{\varepsilon_r + 1}} = \frac{v_0}{2 f_r} \sqrt{\frac{2}{\varepsilon_r + 1}}, \quad (1)$$

where v_0 denotes the velocity of light in free-space. The effective dielectric constant of microstrip antenna [18] is given by:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}}. \quad (2)$$

Table 2: Design parameters of antenna

S. No	Parameters	Dimension (mm)
1	Width of patch (W_P)	29.4
2	Length of patch (L_P)	29.4
3	Effective dielectric constant ε_{reff}	1.995
4	Width of substrate	48.48
5	Length of substrate	48.48
6	Width of centermost block in S_1 K_1 (W_1)	9.8
7	Length of centermost block in S_1 K_1 (L_1)	9.8
8	Width of other 8 blocks in S_2 K_1	3.267
9	Length of other 8 blocks in S_2 K_1	3.267

Once W is calculated using Equation (1), consider the extension in actual length of patch due to fringing effect as in [18] and is given by:

$$\Delta L = h\frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.25\right)\left(\frac{W}{h} + 0.8\right)}. \quad (3)$$

After calculating the extended length of patch, the actual length of patch is determined as in [18] as:

$$L = \frac{1}{2 f_r \sqrt{\varepsilon_{reff}}\sqrt{\varepsilon_0 \mu_0}} - 2\Delta L. \quad (4)$$

Dimensions of ground plane are calculated using Equations (5) and (6):

$$\text{Length of ground } L_g = 6h + L, \quad (5)$$

$$\text{Width of ground } W_g = 6h + W. \quad (6)$$

The calculated dimensions are shown in Table 2.

A. IFS (Iterative Function System) for first iteration of proposed geometry

IFS used to generate the Koch curve geometry on Sierpinski carpet sides. The initiator is required to generate the IFS of geometry using a set of affine transformation matrices. IFS for standard Koch curve is given in [9] and IFS for standard Sierpinski carpet geometry is given in [21]. The proposed IFS for the first iteration geometry of the proposed antenna is given by a set of W_1 to W_{16} matrices given as follows:

$$W_1\begin{pmatrix}x'\\y'\end{pmatrix} = \begin{bmatrix}\frac{1}{12} & 0\\ 0 & \frac{1}{12}\end{bmatrix}\begin{bmatrix}x\\y\end{bmatrix} + \begin{bmatrix}0\\0\end{bmatrix},$$

$$W_2\begin{pmatrix}x'\\y'\end{pmatrix} = \begin{bmatrix}\frac{1}{24} & -\frac{\sqrt{3}}{24}\\ -\frac{\sqrt{3}}{24} & \frac{1}{24}\end{bmatrix}\begin{bmatrix}x\\y\end{bmatrix} + \begin{bmatrix}\frac{1}{12}\\0\end{bmatrix},$$

$$W_3\begin{pmatrix}x'\\y'\end{pmatrix} = \begin{bmatrix}\frac{1}{24} & \frac{\sqrt{3}}{24}\\ -\frac{\sqrt{3}}{24} & \frac{1}{24}\end{bmatrix}\begin{bmatrix}x\\y\end{bmatrix} + \begin{bmatrix}\frac{1}{18}\\ \frac{\sqrt{3}}{24}\end{bmatrix},$$

$$W_4\begin{pmatrix}x'\\y'\end{pmatrix} = \begin{bmatrix}\frac{1}{12} & 0\\ 0 & \frac{1}{12}\end{bmatrix}\begin{bmatrix}x\\y\end{bmatrix} + \begin{bmatrix}\frac{1}{6}\\0\end{bmatrix},$$

$$W_5\begin{pmatrix}x'\\y'\end{pmatrix} = \begin{bmatrix}0 & -\frac{1}{12}\\ \frac{1}{12} & 0\end{bmatrix}\begin{bmatrix}x\\y\end{bmatrix} + \begin{bmatrix}\frac{1}{4}\\0\end{bmatrix},$$

$$W_6\begin{pmatrix}x'\\y'\end{pmatrix} = \begin{bmatrix}-\frac{\sqrt{3}}{24} & -\frac{1}{24}\\ \frac{1}{24} & -\frac{\sqrt{3}}{24}\end{bmatrix}\begin{bmatrix}x\\y\end{bmatrix} + \begin{bmatrix}\frac{1}{4}\\ \frac{1}{12}\end{bmatrix},$$

$$W_7\begin{pmatrix}x'\\y'\end{pmatrix} = \begin{bmatrix}\frac{\sqrt{3}}{24} & -\frac{1}{24}\\ \frac{1}{24} & -\frac{\sqrt{3}}{24}\end{bmatrix}\begin{bmatrix}x\\y\end{bmatrix} + \begin{bmatrix}\frac{1}{4} - \frac{\sqrt{3}}{24}\\ \frac{1}{8}\end{bmatrix},$$

$$W_8\begin{pmatrix}x'\\y'\end{pmatrix} = \begin{bmatrix}0 & -\frac{1}{12}\\ \frac{1}{12} & 0\end{bmatrix}\begin{bmatrix}x\\y\end{bmatrix} + \begin{bmatrix}\frac{1}{4}\\ \frac{1}{6}\end{bmatrix},$$

$$W_9\begin{pmatrix}x'\\y'\end{pmatrix} = \begin{bmatrix}-\frac{1}{12} & 0\\ 0 & -\frac{1}{12}\end{bmatrix}\begin{bmatrix}x\\y\end{bmatrix} + \begin{bmatrix}\frac{1}{4}\\ \frac{1}{4}\end{bmatrix},$$

$$W_{10}\begin{pmatrix}x'\\y'\end{pmatrix} = \begin{bmatrix}-\frac{1}{24} & -\frac{\sqrt{3}}{24}\\ -\frac{\sqrt{3}}{24} & -\frac{1}{24}\end{bmatrix}\begin{bmatrix}x\\y\end{bmatrix} + \begin{bmatrix}\frac{1}{6}\\ \frac{1}{4}\end{bmatrix},$$

$$W_{11}\begin{pmatrix}x'\\y'\end{pmatrix} = \begin{bmatrix}-\frac{1}{24} & \frac{\sqrt{3}}{24}\\ \frac{\sqrt{3}}{24} & -\frac{1}{24}\end{bmatrix}\begin{bmatrix}x\\y\end{bmatrix} + \begin{bmatrix}\frac{1}{8}\\ \frac{1}{4} - \frac{\sqrt{3}}{24}\end{bmatrix},$$

$$W_{12}\begin{pmatrix}x'\\y'\end{pmatrix} = \begin{bmatrix}-\frac{1}{12} & 0\\ 0 & -\frac{1}{12}\end{bmatrix}\begin{bmatrix}x\\y\end{bmatrix} + \begin{bmatrix}\frac{1}{12}\\ \frac{1}{4}\end{bmatrix},$$

$$W_{13}\begin{pmatrix}x'\\y'\end{pmatrix} = \begin{bmatrix}0 & \frac{1}{12}\\ -\frac{1}{12} & 0\end{bmatrix}\begin{bmatrix}x\\y\end{bmatrix} + \begin{bmatrix}0\\ \frac{1}{4}\end{bmatrix},$$

$$W_{14}\begin{pmatrix}x'\\y'\end{pmatrix} = \begin{bmatrix}\frac{\sqrt{3}}{24} & \frac{1}{12}\\ -\frac{1}{24} & -\frac{\sqrt{3}}{24}\end{bmatrix}\begin{bmatrix}x\\y\end{bmatrix} + \begin{bmatrix}0\\ \frac{1}{6}\end{bmatrix},$$

$$W_{15}\begin{pmatrix}x'\\y'\end{pmatrix}=\begin{bmatrix}-\frac{\sqrt{3}}{24} & \frac{1}{24}\\ -\frac{1}{24} & -\frac{\sqrt{3}}{24}\end{bmatrix}\begin{bmatrix}x\\y\end{bmatrix}+\begin{bmatrix}\frac{\sqrt{3}}{24}\\ \frac{1}{8}\end{bmatrix},$$

$$W_{16}\begin{pmatrix}x'\\y'\end{pmatrix}=\begin{bmatrix}0 & \frac{1}{12}\\ -\frac{1}{12} & 0\end{bmatrix}\begin{bmatrix}x\\y\end{bmatrix}+\begin{bmatrix}0\\ \frac{1}{12}\end{bmatrix}.$$

Then generator curve is achieved as follows:

$$A = W_1 U W_2 U W_3 U W_4 U W_5 U W_6 U W_7 U W_8 U W_9 U W_{10} U W_{11} U W_{12} U W_{13} U W_{14} U W_{15} U W_{16}$$

B. IFS for the second iteration of the Koch curve

$$W_1\begin{pmatrix}x'\\y'\end{pmatrix}=\begin{bmatrix}\frac{1}{3} & 0\\ 0 & \frac{1}{3}\end{bmatrix}\begin{bmatrix}x\\y\end{bmatrix}+\begin{bmatrix}0\\1\end{bmatrix}, W_2\begin{pmatrix}x'\\y'\end{pmatrix}=\begin{bmatrix}\frac{1}{6} & -\frac{\sqrt{3}}{6}\\ \frac{\sqrt{3}}{6} & \frac{1}{6}\end{bmatrix}\begin{bmatrix}x\\y\end{bmatrix}+\begin{bmatrix}\frac{1}{3}\\0\end{bmatrix},$$

$$W_3\begin{pmatrix}x'\\y'\end{pmatrix}=\begin{bmatrix}\frac{1}{6} & \frac{\sqrt{3}}{6}\\ -\frac{\sqrt{3}}{6} & \frac{1}{6}\end{bmatrix}\begin{bmatrix}x\\y\end{bmatrix}+\begin{bmatrix}\frac{1}{2}\\ \frac{\sqrt{3}}{6}\end{bmatrix},$$

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

Hence, generator curve can be calculated as:

$$A = W_1 U\, W_2 U W_3 U\, W_4.$$

C. Design steps for KLSSSCMFA

Step 1: Design a simple square conventional patch antenna using the above calculated dimensions. This is 0th iteration or S_0 K_0 iteration as depicted in Fig. 1 (a).

Step 2: By applying 1st iteration of Sierpinski carpet to the square patch, the geometry is called Sierpinski first iteration S_1. The 1st iteration of Koch curve on square sides is denoted as K_1. The patch is divided into 9 congruent squares each having side 9.8 mm. Then centermost square is selected and Koch curve is applied on each side of the central square. This final structure is cut from the patch to make complete iteration S_1K_1, as shown in Fig. 1 (b).

Step 3: For iteration 2, the remaining all 8 squares are divided into 9 more congruent squares each having side of 3.267 mm. Among all these squares, the centermost square is selected and is called Sierpinski iteration S_2. As in 1st iteration, apply the Koch curve K_1 on each side of all squares to generate the complete structure for iteration 2. All these eight structures as in iteration 1st are cut from the patch to design the complete 2nd iteration of the proposed geometry as shown in Fig. 1 (c). Koch curve is the type of self-similar fractal structure and can be repeated on each line or side of the square by dividing the side length into three parts and on the center part equilateral triangle is made each having side equal to the length of central part [19].

Step 4: For the third iteration, choose 1st iteration having S_1 and K_1 structure and apply Koch curve K_2 further on each side lengths. The structure is denoted as S_1 with K_2 geometry (third iteration) as obtained denoted in Fig. 1 (d).

Step 5: To design the fourth iteration geometry, chose 2nd iteration as base geometry and apply K_2 on all 8 congruent squares. Last iteration S_2 K_2 is known as final design of the proposed antenna as shown in Fig. 1 (e).

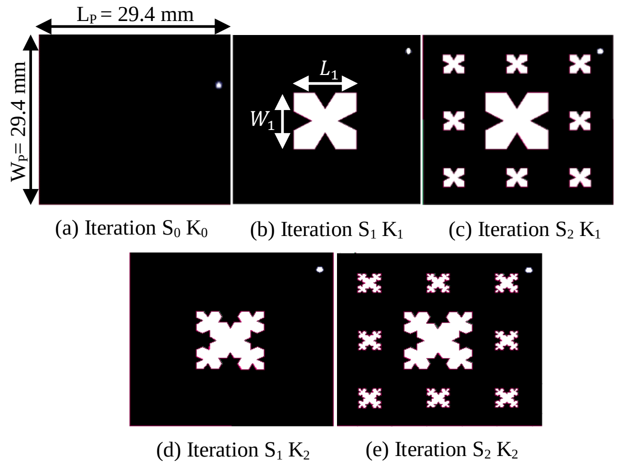

Fig. 1. Design of KLSSSCMA.

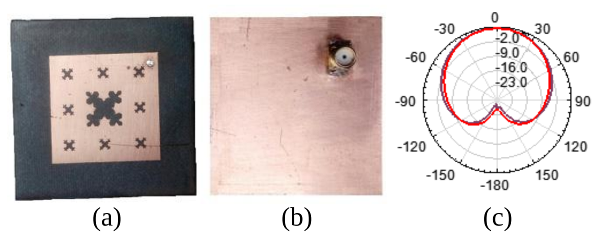

Fig. 2. (a) Fabricated patch, (b) ground plane, (c) radiation pattern of S_0 K_0 iteration at 3.2 GHz.

III. RESULTS AND DISCUSSIONS

To design the proposed antenna, it is simulated using High-Frequency Simulator Software (HFSS) successfully and all the performance parameters are analyzed thoroughly. S_{11} (dB) parameter is observed concisely for all the proposed iterations. Figures 2 (a) and 2 (b) show the photographic front view and back view of the fabricated S_2 K_2 iteration with probe feed.

A. Simulated results

Figure 3 represents S_{11} (dB) versus frequency plots for all iterations of the proposed antenna. In this figure S_0 K_0, S_1 K_1, S_2 K_1, S_1 K_2 and S_2 K_2 show the impedance matching behavior. S_0 K_0 iteration resonates at one frequency f_1=3.2 GHz with S_{11}= -29.27 dB.

The bandwidth is 1.593 GHz between 2.8350 GHz to 4.4280 GHz covering small portion of both S and C bands range. The S_1K_1 iteration gives multi resonance behavior at f_1=3.2 GHz, f_2=4.6 GHz and f_3=7.6 GHz frequencies and possess S_{11} values of -39.48 dB, -30.38 dB and -25.67 dB respectively at these frequencies. There is improved BW having value 2.3867 GHz between first two peaks and 1.7572 GHz BW between later peaks. Sierpinski S_2 iteration preserves the multi-resonance behavior of the first iteration with a small shift in all frequency peaks towards lower side due to fractal shaped slots in the geometry. This geometry represents the multifractal geometry with f_1=3.1 GHz, f_2=4.3 GHz and f_3=7.5 GHz. These three peaks have S_{11} values of -20.37 dB, -20 dB and 7.5 dB respectively. Bandwidth becomes 2.6188 GHz at first two peaks and 1.9249 GHz at third peak. It is clear that as the number of iterations is increased, bandwidth also improves. This $S_2 K_1$ iteration of antenna also covers S and C bands for multiple applications having BW=50.81% for first band and 23.147% for second band. For iteration $S_1 K_2$, Koch curve is applied on all sides of $S_1 K_1$ geometry. Further frequency shift in lower side is to consider at f_1=3.0 GHz, f_2=4.2 GHz and f_3=7.3 GHz with S_{11} values of -16.25 dB, -16.34 dB and -11.59 dB respectively. The bandwidth parameter is enhanced to 61.93% between first two peaks and to 34.26% between last peaks. Now K_2 structure is applied to $S_2 K_1$ base geometry that gives a new shape called $S_2 K_2$ iteration of KLSSSCMFA. This gives wide bandwidth of 5.5299 GHz from 2.3040 GHz to 7.8339 GHz and covers the bands of WLAN, WiMAX, WPAN, Wi-Fi, satellite communication and military applications. Bandwidth becomes 70.589% as shown in Fig. 3. For all iterations, bandwidth, S_{11}, gain and VSWR are tabulated in Table 3.

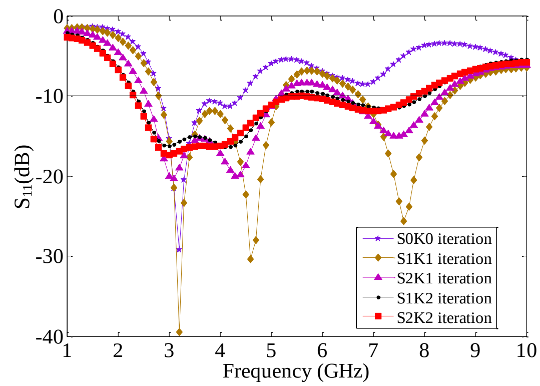

Fig. 3. A comparison of S_{11} values of KLSSSCMFA for $S_0 K_0$, $S_1 K_1$, $S_2 K_1$, $S_1 K_2$ and $S_2 K_2$ iterations.

Table 3: Simulation results of all performance parameters of KLSSSCMFA

S. No.	Frequency (GHz)	S_{11} (dB)	VSWR	Gain (dB)	Lower Frequency (GHz)	Upper Frequency (GHz)	Bandwidth (GHz)	Bandwidth %
$S_0 K_0$ iteration	3.2	-29.27	1.0712	+4	2.8350	4.4280	1.593	5.9756
$S_1 K_1$ iteration	3.2	-39.48	1.0215	+6	2.7995	5.1866	2.3867	46.024
	4.6	-30.38	1.0624	+4				
	7.6	-25.66	1.1099	+7	6.7287	8.4873	1.7572	20.720
$S_2 K_1$ iteration	3.1	-20.37	1.2118	+7	2.5350	5.1540	2.6188	50.81490
	4.3	-20.0	1.2221	+4				
	7.5	-15.05	1.4291	+8	6.4026	8.3310	1.9249	23.147
$S_1 K_2$ iteration	3.0	-16.25	1.3636	+8	2.3488	6.1706	2.9081	61.9356
	4.2	-16.34	1.3595	+4				
	7.3	-11.59	1.7146	+8	5.2569	7.9979	1.827	34.269
$S_2 K_2$ iteration	3.0	-17.30	1.3136	+9	2.3040	7.8339	5.5299	70.589
	4.0	-16.22	1.3651	+6				
	7.0	-11.88	1.6831	+8				

For the proposed KLSSSCMFA, Voltage Standing Wave Ratio (VSWR) is observed in the desired range (1 to 2) for all iterations as depicted in Fig. 4.

B. Measured results

S_{11} parameter of final iteration of the proposed antenna is measured using Vector Network Analyzer to validate simulated results generated by HFSS. Figure 5 represents a comparison between simulated and measured results for $S_2 K_2$ iteration. The measured results and the simulated results are almost similar.

Table 4 shows a comparative data of simulated and measured results in terms of S_{11} and bandwidth.

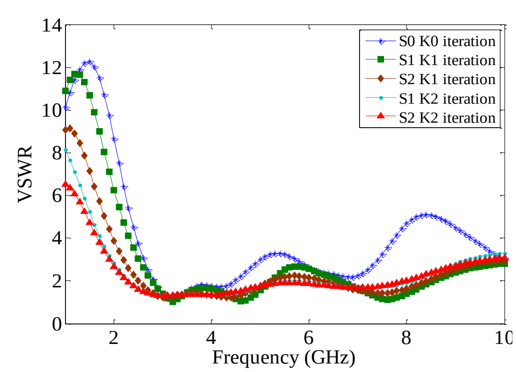

Fig. 4. A coparison of VSWR values of $S_0 K_0$, $S_1 K_1$, $S_2 K_1$, $S_1 K_2$ and $S_2 K_2$ iterations.

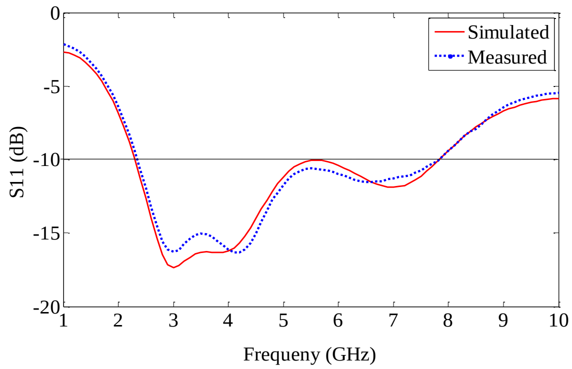

Fig. 5. Simulated and measured S_{11} (dB) versus frequency plot of the proposed antenna.

Table 4: A comparison of measured and simulated results

Frequency (GHz)	Simulated		Measured	
	S_{11} (dB)	**BW (GHz)**	**S_{11} (dB)**	**BW (GHz)**
3.0	-17.35	5.5299	-16.25	5.400
4.0	-16.22		-16.12	
7.0	-11.88		-11.28	

C. Radiation pattern

It represents the field power distribution of an antenna in E and H planes at given frequencies. Fractal nature always tends to give stable radiation pattern. 2D radiation pattern of the proposed antenna first iteration (S_0 K_0) is shown in Fig. 2 (c). Radiation patterns for S_1 K_1, S_2 K_1, S_1 K_2 and S_2 K_2 at corresponding peaks are shown in Fig. 6, Fig. 7, Fig. 8 and Fig. 9 respectively.

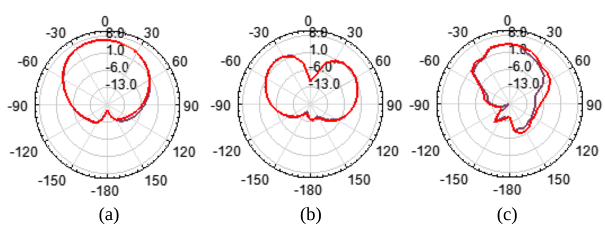

Fig. 6. Radiation patterns of S_1 K_1 iteration at: (a) 3.2 GHz, (b) 4.6 GHz, and (c) 7.6 GHz.

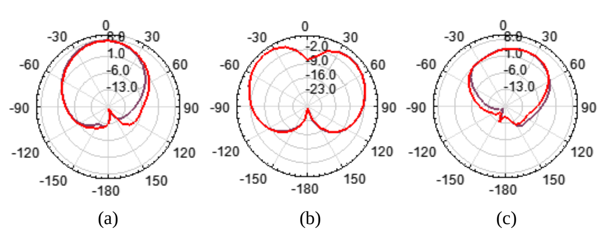

Fig. 7. Radiation patterns of S_2 K_1 iteration at: (a) 3.1 GHz, (b) 4.3 GHz, and (c) 7.5 GHz.

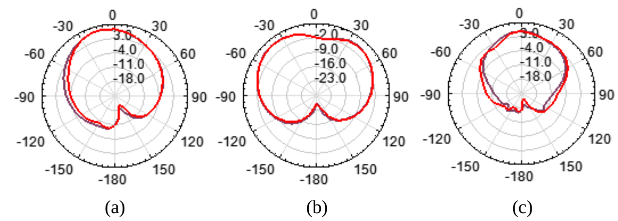

Fig. 8. Radiation patterns of S_1 K_2 iteration at: (a) 3.0 GHz, (b) 4.2 GHz, and (c) 7.3 GHz.

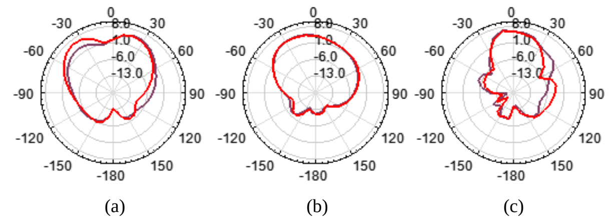

Fig. 9. Radiation patterns of S_2 K_2 iteration at: (a) 3.0 GHz, (b) 4.0 GHz, and (c) 7.0 GHz.

D. Effect of height of substrate on bandwidth

The effect of substrate height (h) on bandwidth (BW) of the proposed antenna is observed. To obtain wideband behavior of the antenna, the height of substrate is varied from 1.6 mm to 3.3 mm as shown in Fig. 10. At lower value of h the proposed antenna shows multiband behavior (three peaks 2.9 GHz, 4.5 GHz and 9.2 GHz). As h is increased, the bandwidth at these peaks increases. At h=2.9 mm, out of these three peaks, two peaks (2.9 GHz and 4.5 GHz) are combined.

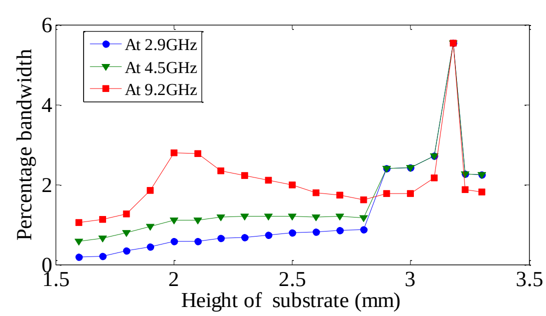

Fig. 10. Variation of bandwidth with height of substrate.

But at h=3.18 mm all three peaks combine and start showing wideband behavior. Beyond this height, bandwidth again starts to decline. Thus, h=3.18 mm substrate height is an optimum height for the design of the proposed antenna.

A comparison of results of the proposed antenna in terms of gain and bandwidth with previous antennas available in literature is shown in Table 5. From this table it is clear that a maximum bandwidth of 6.9 GHz is obtained by Pharwaha et al. at the cost of low gain 4.41 dB [21]. A maximum gain of 5.8 dB is obtained by Lin et al. at the cost of small bandwidth 66 MHz [20].

Table 5: A comparison of the proposed antenna with other fractal antennas

Author	Gain (dB)	Center Frequency (GHz)	Bandwidth (GHz)
Daotie [3]	5.11	2.50	4.00
Shrestha [11]	2.64	2.45	0.60
Srivastava [13]	3.31	1.84	2.39
Lin [20]	5.80	1.57	0.66
Pharwaha [21]	4.41	3.72	6.90
Wang [22]	5.00	3.00	4.00
Proposed antenna	9.00	3.00	5.53

The proposed antenna has more bandwidth than antennas of Daotie et al. [3], Shrestha et al. [11], Srivastava et al. [13], Lin et al. [20], and Wang et al. [22]. It also has more gain than these antennas.

IV. CONCLUSION

The proposed geometry of KLSSSCMA combines the Sierpinski carpet and Koch curves successfully. $S_2 K_2$ iteration is designed, simulated and fabricated. A wideband range of frequency 5.6 GHz is obtained and has considerable gain (4 dB to 9 dB) over the whole band. KLSSSCMFA covers WLAN, Wi-Max, WPAN, Wi-Fi, satellite communication for uplink and downlink and military applications of S and C bands. The radiation pattern of all iterations at peaks shows the hemisphere pattern with consistency. Variation in substrate height impacts bandwidth parameter and is optimized. For further work, different methods can be applied for modifications in the proposed antenna. Neural network can be implemented for this proposed geometry to optimize different parameters using training data. Curve fitting and Particle Swarm Optimization (PSO) techniques can also be implemented to optimize the geometry of the proposed antenna. This antenna can also be designed for higher iterations using optometric analysis.

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