INTL JOURNAL OF ELECTRONICS AND TELECOMMUNICATIONS, 2019, VOL. 65, NO. 4, PP. 551-556
Manuscript received December 9, 2018; revised September, 2019. DOI: 10.24425/ijet.2019.129812

A Sierpinski Carpet Five Band Antenna for Wireless Applications

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***Abstract*—A compact Sierpinski Carpet square fractal multiband antenna operating at 3.9 (WiMAX) /6.6 (Satellite TV) /8.1/10.7/11.8 GHz (X-band) is presented. The proposed Microstrip Patch Antenna (MSPA) consists of a Sierpinski Carpet square fractal radiator in which square slots are etched out and a tapered microstrip feed line. The Sierpinski Carpet square fractal patch modifies the current resonant path thereby making the antenna to operate at five useful bands. Impedance matching at these bands are solely achieved by using Sierpinski square slot and tapered feedline, thus eliminating the need of any external matching circuit. The dimensions of the compact antenna is $32 \times 32 \times 1.6\ mm^3$ and exhibits S_{11}<-10dB bandwidth of about 4.8% (4.01-3.82 GHz), 2.1% (6.62-6.48 GHz), 2.7% (8.24-8.02 GHz), 2.1% (10.77-10.54 GHz) and 21% (12.1-11.60 GHz) with the gain of 7.57/3.91/3.77/6.74/1.33 dB at the operating frequencies 3.9/6.6/8.1/10.7 and 11.8 GHz, respectively under simulation analysis carried out by using HFSS v.13.0.**

***Keywords*—Sierpinski carpet, WiMAX, X-band, Current distribution**

I. INTRODUCTION

THE period of Microstrip Patch Antenna (MSPA) began in the year 1953 by G.A. Deschamps, it took about 20 years to acknowledge for all intents and purposes because of characteristic imperfections. Assist examinations made by Robert .E. Munson and others utilizing low loss soft materials and the creation of Printed Circuit Board (PCB) made ready for a viable antenna in 1970s [1]. Microstrip antenna has heaps of favorable circumstances like minimal effort, low profile, low power prerequisite and so on. Therefore, as of late, wideband with high gain framework has made more consideration among the antenna researchers. MSPA have moreover a few hindrances, for example, low gain, low bandwidth, and low efficiency and so on. The MSPA comprises of a thin radiating patch on one side of dielectric substrate and has a ground plane on the back side. The patch is commonly made of material like copper or gold, the radiation patch and feed lines are typically photo etched on dielectric substrate. A Thick substrate with lesser dielectric constant increment the bandwidth and antenna proficiency yet, but this will build the measure of energy caught in the substrate, then again, thin substrate with higher dielectric constant diminishes antenna size [2-3]. The transmission limit of the antenna can be controlled by using the dielectric permittivity of the material and patch estimations [4]. MSPA has wide area of employments for military applications, for instance, TV, radio telecom, mobile systems, RFID, Wi-Fi, Wi-Max, GPS, warships, RADAR, common imaging, rocket direction, 5G and GSM [5-9]. Notwithstanding the way that, MSPA being a common choice for the recently referenced applications, inconvenience rises in downsizing the patch antenna. For instance, inconvenience in keeping up tradeoff between execution (i.e., radiation characteristics and resonant mode action) and size of the patch. Regardless, a survey of the literature reports a couple multiband strategies, for instance, defected ground structures (DGSs), fractalization, utilization of metamaterial, Slots, Planar inverted-F antenna (PIFA), responsive impedance surfaces (RIS), stacking capacitors and inductors etc. [10-12].

In this paper we a compact multiband antenna loaded with Sierpinski square fractals slots for operation at 3.9/6.6/8.1/10.7/11.8 GHz (five bands) with the radiation efficiencies of 94%/64%/60%/65%/81% and corresponding reflection coefficient (S11 (dB)) values of, -12.94/-10.82/-11.25/-14.6/-19.9 respectively. The Sierpinski carpet is a plane fractal firstly investigated by Wacław Sierpiński in 1916. The procedure of subdividing a shape into littler duplicates of itself, evacuating at least one duplicate, and proceeding with recursively can be reached out to different shapes. Cell phone and Wi-Fi fractal antennas have been delivered a couple of emphases of the Sierpinski carpet. Because of their self-similitude and scale invariance, they effectively suit numerous frequencies. They are additionally simple to create and littler than ordinary antennas of comparable execution, along these lines being ideal for pocket-sized cell phones.

A. Motivation

The adoption of MSPA relies on the device unit cost, hence increasing the desirability for low-cost solution. Planar antennas serve as excellent candidates in devices such as portable electronics, tablets etc., due the compact integrability feature. Additionally, planar antennas find extensive applications in designing communication systems and their corresponding counterparts due to the former's compatibility with monolithic microwave integrated circuits. This paper deals with the design and analysis of low cost planar Sierpinski carpet fractal antennas loaded with fractal slots for adoption in the future communication devices.

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B. *Antenna Design Equations*

The width and the length of the proposed antenna can be calculated by the following design equations

$$W = \frac{\lambda_o}{f_o\sqrt{(\varepsilon_r+1)/2}} \quad (1)$$

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

$$L = \frac{\lambda_o}{f_o\sqrt{\varepsilon_{reff}}} - 2\Delta L \quad (3)$$

$$\frac{\Delta L}{h} = 0.412\,\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \quad (4)$$

II. DESIGN OF MULTIBAND ANTENNA

The proposed antenna structure is modeled on FR4 substrate (*height =1.6 mm*, $\varepsilon_r = 4.4$ *and* $\delta = 0.02$) with compact size of 32×32 mm^2, as detailed in Fig. 1. The proposed design consists of the ground plane and radiating patch loaded with Sierpinski Carpet square fractal antenna as shown in Fig. 1. The Sierpinski Carpet square fractal is engraved on the front patch (basically a radiator) of the antenna. The detailed Sierpinski Carpet square fractal antenna dimensions are illustrated in Table 1. The introduction of this Sierpinski Carpet square fractal modifies the electrical flow length way as a result of which antenna works in multiband mode with the frequencies of 3.9/6.6/8.1/10.7/11.8 GHz. The designed patch antenna is excited by microstrip feed line to achieve good impedance match at the operating bands.

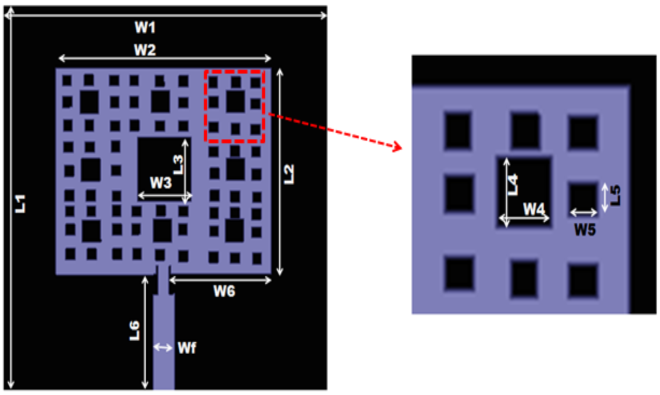


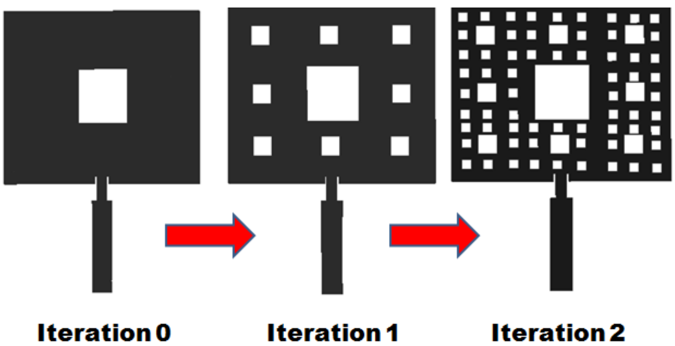
Fig. 1. Physical layout of the proposed antenna

Table I
DIMENSIONS OF THE PROPOSED DESIGN

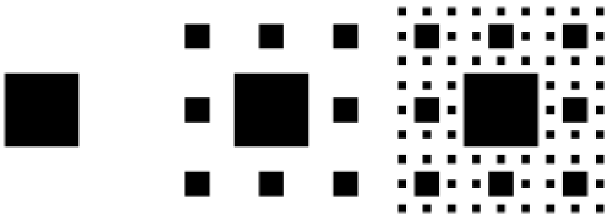
PARAMETERS	DIMENSIONS (mm)
L1	32
W1	32
L2	16
W2	20
L3	5
W3	5
L4	1.75
W4	1.75
L5	0.87
W5	0.87
L6	11
W6	9.3
Wf	2

So as to accomplish the set target, the plan development of the proposed structure is given in Fig. 2(a) and (b) and their S_{11} results are shown in Fig. 3. Initially, an ordinary square patch antenna of size 32 × 32 mm^2 is planned. This antenna shows great attributes with S11 < −10 dB.

The evolution design steps of the proposed configuration are displayed in Fig. 2 and their S_{11} results are exhibited in Fig. 3. In these design development steps the impact of adding different slots to the radiator is contemplated. In the initial step, a square patch antenna with a square slot of dimension W3XL3 is planned as shown in arrangement "iteration 0" of Fig. 2(a). It tends to be seen that in Fig. 3, this antenna produces resonance at four frequency band. In setup "Iteration 1" of Fig. 2 the presentation of other square slots of dimension W4XL4 changes the surface current which tends the antenna to work at four bands other than the bands because of "Iteration 0" (Fig. 3). However, just four band activity is accomplished from these designs. Along these lines, to expand the quantity of working band "Iteration 3" is incorporated as exhibited in Fig. 2. The etching of these square slots further disturbs the surface current dispersion which will in general enhances the overall current length path, hence making "Iteration 2" to work at 3.9, 6.6, 8.1, 10.7 and 11.8 GHz individually. At last by utilizing this arrangement (i.e. "Iteration 2") the designed antenna works at 3.9 GHz (WiMAX), 6.6 GHz (Satellite TV), 8.1/10.7 and 11.8GHz (X-band) with great impedance coordination, as exhibited in Fig. 3. Hence from the proposed antenna design the previously mentioned goal of accomplishing multiband nature from the Sierpinski Carpet square fractal antenna is effectively accomplished. Additionally it very well may be noticed that the proposed antenna has measurement of just 32×32×1.6mm^3, in this manner, making it easy to coordinate with different remote gadgets.



(a)



(b)

Fig. 2. Design Evolution

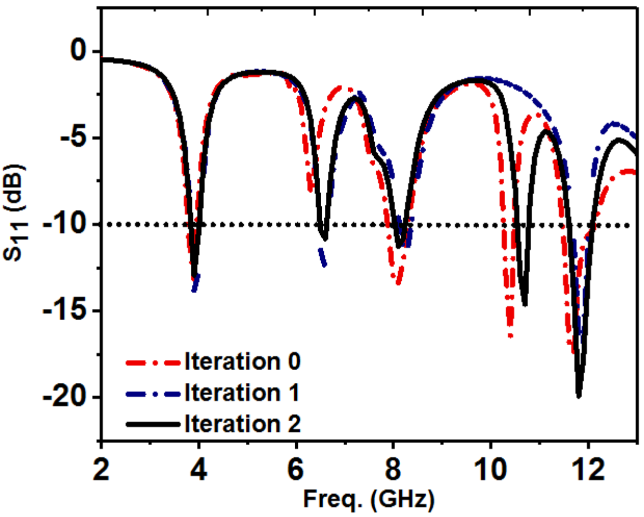


Fig. 3. S_{11} Evolution plot of the proposed antenna

III. RESULTS

Antenna design simulation structure outlined in Fig. 1 is performed using HFSS v.13.0 on widely and available low cost FR4 substrate with ε_r of 4.4 and height of 1.6mm. The computed S_{11} (reflection coefficient) of the proposed antenna is depicted in Fig.4. It can be clearly seen that, multiband operation is obtained at 1st resonance at 3.9 GHz and correspondingly 5th resonance occurs at 11.8GHz. Antenna simulated bandwidth at -10dB for 3.9/6.6/8.1/10.7/11.8 GHz are 190/140/220/230/500 MHz respectively. The accomplished bandwidth is adequate to serve the necessity of WiMAX (3.9 GHz), Satellite TV (6.6 GHz) and X-band (8.1/10. 7/11.8 GHz) applications.

A. *VSWR and Input Impedance*

The VSWR (voltage standing wave ratio) of the proposed antenna design structure is presented in Fig. 5. It is clearly noticed that the antenna achieves the required VSWR values of 1.58/1.80/1.75/1.45/1.22 for all the resonating frequencies 3.9/6.6/8.1/10.7/11.8 GHz, respectively.

Fig. 6 represents the antenna input impedance which is about (31.7+2.04j),(27.7+2.09j),(53.1-29.17j),(72.6-3.0j) and (42.8+6.0j) at the operating frequencies of 3.9/6.6/8.1/10.7/11.8 GHz, respectively.

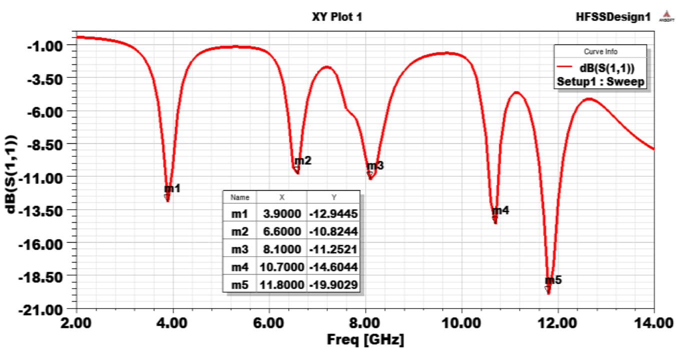


Fig. 4. Simulated S_{11} (reflection coefficient) of the proposed design

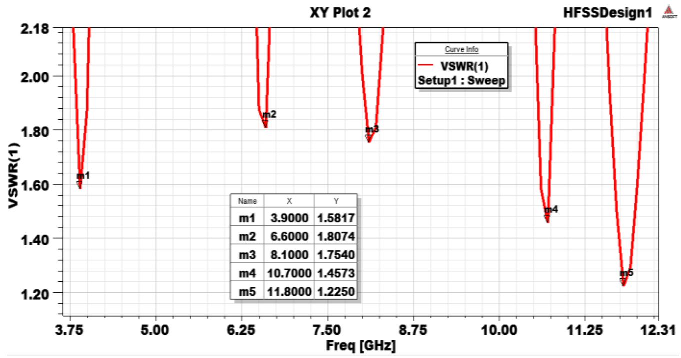


Fig. 5. VSWR plot of the proposed antenna

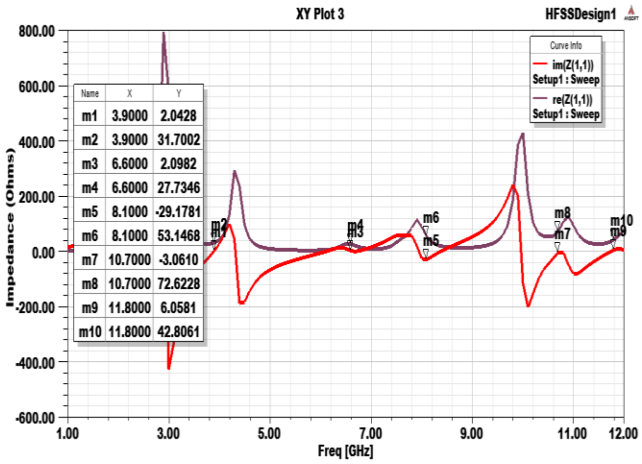
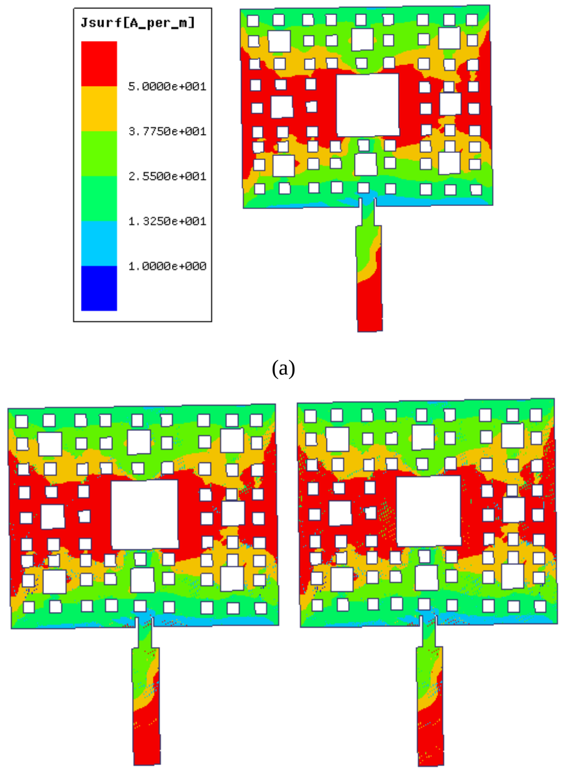
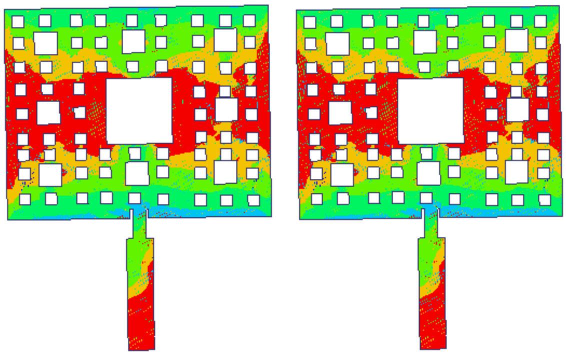


Fig. 6. Simulated input impedance

B. *Current Distributions*

The current distributions at the surface of the antenna at the different operating frequencies are illustrated in Fig. 7.



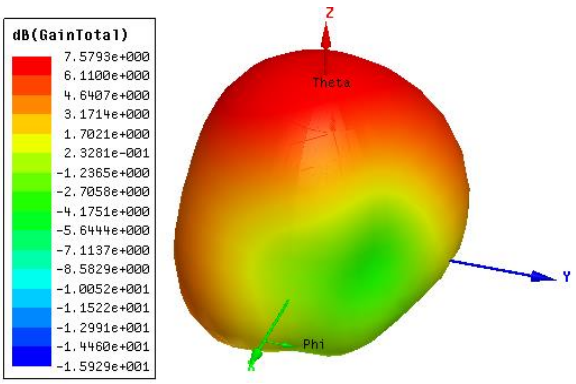


(d) (e)

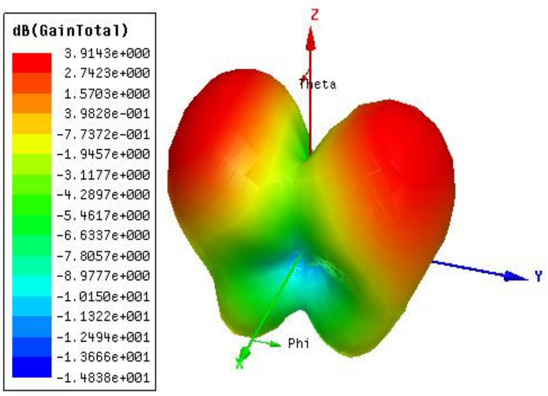
Fig. 7. Distribution of surface Current at (a) 3.9, (b)6.6, (c) 8.1, (d) 10.7, and (e)11.8 GHz

C. Gain

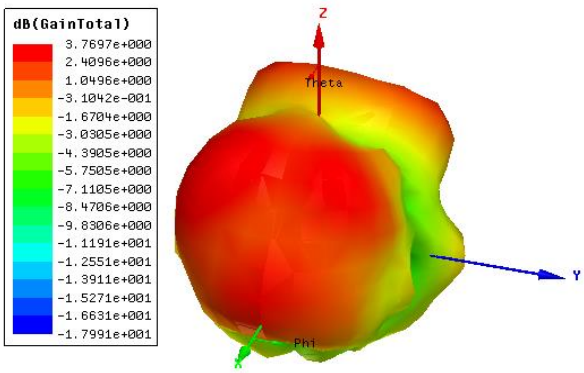
The 3D gain plots for proposed design are given in Fig. 8. The antenna exhibits good gain at all the resonant frequencies even though it has a compact size. At 3.9/6.6/8.1/10.7/11.8 GHz a gain of about 7.57/3.91/3.77/6.74/1.33 dB are obtained respectively.



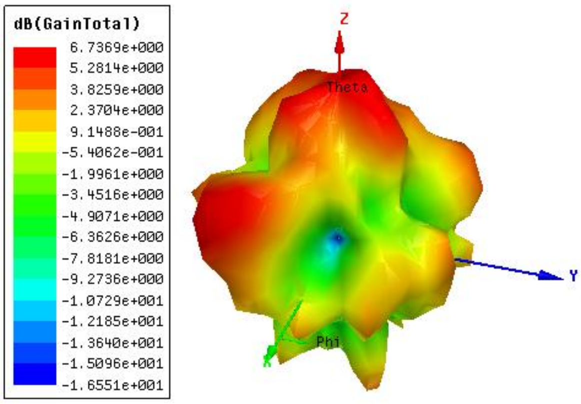
(a)



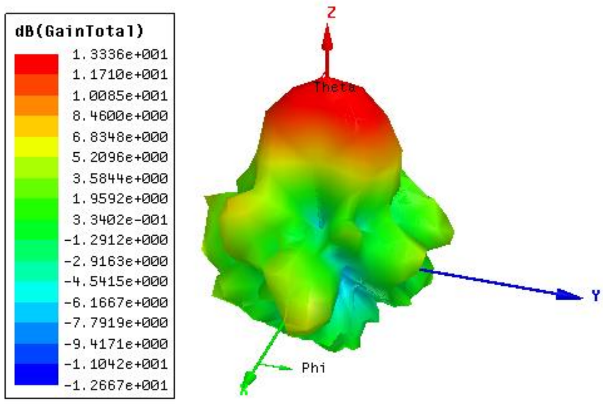
(b)



(c)



(d)

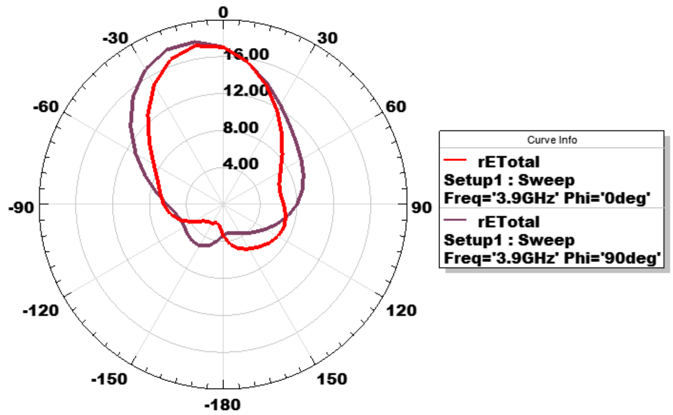


(e)

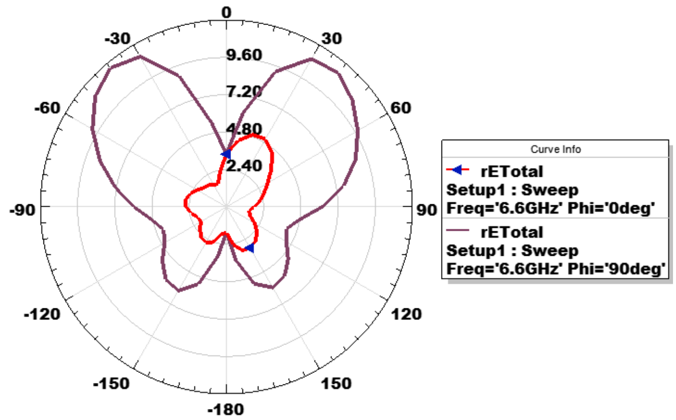
Fig. 8. Simulated Gain at (a) 3.9, (b)6.6, (c) 8.1, (d) 10.7, & (e) 11.8 GHz

D. Radiation Pattern

The radiation pattern for the designed antenna for Phi=0^0 and 90^0 for all the resonating frequency bands are presented in Fig.9.



(a)



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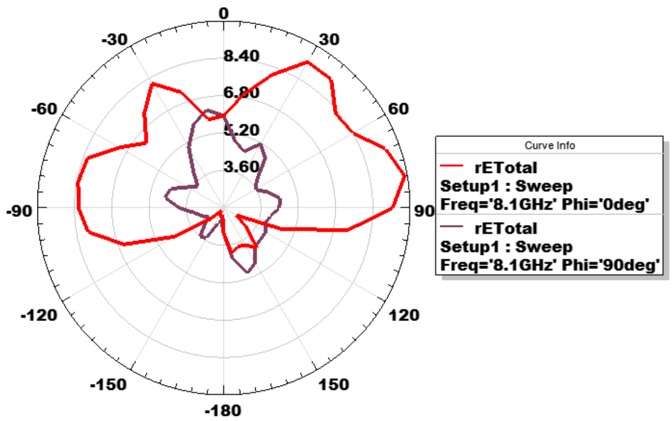
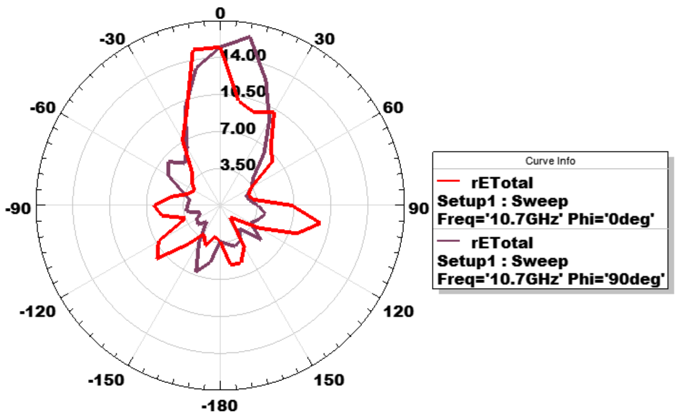
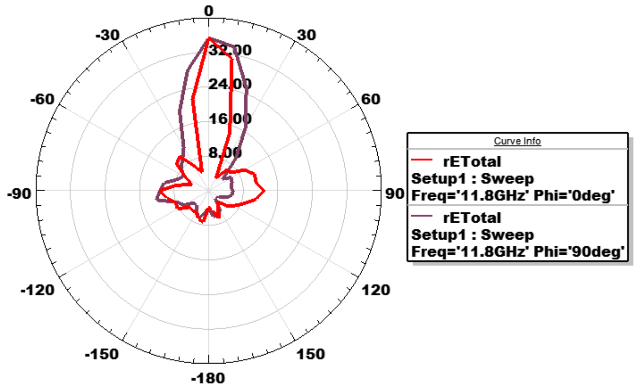


(c)



(d)



(e)

Fig. 9. Simulated radiation pattern at (a) 3.9, (b)6.6, (c) 8.1, (d) 10.7, and (e) 11.8 GHz

To demonstrate the upside of the proposed design with the other comparative sorts accessible in the literature a correlation is made and is displayed in Table 2. From the table it very well may be obviously examined that the proposed structure has more prominent favourable position as far as size, number of working groups, and transfer speed over its counterparts.

Table II
COMPARATIVE ANALYSIS OF THE PROPOSED CONFIGURATION

Ref.	Size (mm^2)	No. of Bands	Freq. of Operation (GHz)	% BW	Appl.
[2]	20 × 20	4	2.65/5.20/6.75/7.30	3/2.3/1.2/1.37	WiMAX /WLAN/ SAT. TV
[4]	27 × 16	2	2.4/5.2	13.4/3.7	WLAN
[8]	49 × 35	2	1.8/2.4	--	GPS/Wi-Fi
[9]	9 × 12	3	2.5/3.4/5.7	6.45/ 3.03/5.9	WiMAX/ WLAN
[11]	13.5 × 13.5	2	4.04/6.56	--	C-Band
[12]	35 × 40	3	2.9/5.4/8.8	4.16/ 5.71/ 10.25	WLAN/ WiMAX/ X-Band
[16]	40 × 40	2	4.45/6.9	6.02/ 2.89	C-Band
Prop	**32 × 32**	**5**	**3.9/6.6/8.1/ 10.7/11.8**	**4.8/2.1/ 2.7/2.1/21**	**WiMAX/ WLAN/ X-band**

IV. CONCLUSION

This research paper presents a compact Sierpinski Carpet square fractal slot antenna with five frequency bands (i.e. 3.9/6.6/8.1/10.7/11.8 GHz). It utilizes Sierpinski carpet square fractal shape that makes the antenna to radiate in five bands. The tuning range of the antenna is about 4.8% (4.01-3.82 GHz), 2.1% (6.62-6.48 GHz), 2.7% (8.24-8.02 GHz), 2.1% (10.77-10.54 GHz) and 21% (12.1-11.60 GHz) with the gain of 7.57/3.91/3.77/6.74/1.33 dB at the operating frequencies 3.9/6.6/8.1/10.7 and 11.8 GHz, respectively under simulation. The proposed configuration produces better outcomes as far as gain, radiation pattern, VSWR is in the scope of 1– 2, great reflection coefficient and impedance coordinating for all the frequency bands. Also, it is easy to plan and fabricate. Good impedance matching, acceptable radiation performances and good gain makes the proposed configuration an attractive candidate for WiMAX, Satellite TV and X-band applications.

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