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Bandwidth enhancement of modified square fractal microstrip patch antenna using gap-coupling

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ABSTRACT

Narrow bandwidth is a major constraint of microstrip antennas. This paper illustrates the design of a gap coupled modified square fractal microstrip patch antenna which has been designed to overcome this limitation. The intended design has an impedance bandwidth of 85.42% around the resonant frequency of 1.844 GHz. This antenna can be simultaneously used for Bluetooth, WLAN and WiMAX applications. IE3D Zeland simulation software has been used for the simulation of the proposed design.

1. Introduction

Microstrip Patch Antennas have always been a source of attraction for the researchers due to their highly desirable attributes such as low profile structure, light weight, conformal shape, cost-effectiveness, high efficiency, ease of installation, small volume, and compatibility with microwave integrated circuits (MIC) and monolithic microwave integrated circuits (MMIC) [1,2]. These qualities have resulted in wide applications of microstrip patch antennas in radar, satellite and mobile communications. However microstrip patch antennas suffer from a major limitation of very low impedance bandwidth, typically about 5% bandwidth with respect to central frequency.

Extensive research has been carried out in the past two to three decades in an attempt to increase the bandwidth of patch antennas. These bandwidth enhancement techniques include use of Frequency Selective Surface [3,4], use of low dielectric substrate, use of multiple resonators, use of thicker substrate [5], employing stacked configuration [6] and use of slot antenna geometry [7,8]. Singh et al. [9] proposed a T-slot rectangular patch antenna with an impedance bandwidth of 25.23%. Aneesh et al. [10] demonstrated that an S-shaped Microstrip patch antenna can achieve a bandwidth of 21.62%. Mulgi et al. [11] proposed a wideband gap-coupled slot rectangular microstrip array antenna with an impedance bandwidth of 26.72%. Khanna and Srivastava [12] designed a square patch antenna with modified edges and square fractal slots with a bandwidth of 30%. Tyagi and Vyas [13] designed a slotted U-shaped microstrip antenna with PBG structure which has an impedance bandwidth of 35%. Kajla et al. [14] proposed a microstrip patch antenna combining Crown and Sierpinski fractal slots which has a bandwidth if 44%. Gupta et al. [15] showed that an impedance bandwidth of 63.3%, 72.10% and 37.5% can be achieved using two, three and six slit-slotted circular patch antennas respectively. Numerous other geometries have been developed to improve the bandwidth of conventional patch antennas, for instance, square-ring slot antenna [16], inverted and non-inverted V-shaped slotted trapezoidal patch antenna [17], a U-shaped slot in an equilateral triangular patch antenna [18], circular patch antenna with a diamond shaped slot [19] and a transmission line fed crescent patch antenna [20]. Various other fractal geometries that have been explored in the previous works by researchers include the Koch Snowflake fractal monopole antenna [21], a rhombic patch monopole antenn awith modified Minkowski fractal geometry [22], a novel broadband fractal Sierpinski shaped microstrip antenna [23], a wideband Sierpinski shaped slot antenna [24] and the Giuseppe Peano fractal antenna [25]. The Giuseppe Peano fractal is

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basically a space-filling curve, generally applied to the boundary or edges of the patch to achieve antenna miniaturization and multi-band characteristics [26,27].

This paper elaborates the design of a gap-coupled modified square fractal microstrip patch antenna using co-axial feeding technique which operates in the frequency range of 1.68–4.16 GHz i.e. 85.42% around the resonant frequency of 1.844 GHz. This antenna has been designed for simultaneous use in Bluetooth, WLAN and WiMAX applications.

2. Fractal antenna

A fractal antenna [28–30] can be described as an antenna that uses a fractal, self-similar design to increase the perimeter (both internal and external) of the material that is able to transmit or receive electromagnetic radiation within a given total surface area or volume. The term fractal means broken or irregular fragments. Fractals are commonly made up of multiple copies of themselves at varied scales. They possess the unique qualities of self-similarity and space-filling property. Fractal antennas offer certain advantages such as large bandwidth, improved VSWR, miniaturization of antenna, multiband and wideband performance. It has been observed that as the order of iteration increases, the resonant frequency of the fractal antenna decreases. Such antennas suffer from certain limitations such as complicated fabrication and designing as well as low gain in some cases.

3. Gap coupling

The concept of gap coupling [11,31–34] is used to enhance the bandwidth of patch antenna and also to achieve dual frequency operation. In a gap-coupled structure, as shown in Fig. 1, a parasitic patch and a feed patch are placed close to each other. The feed patch is excited by a feeding technique where as the parasitic patch gets excited through the gap-coupling between the two patches. If the resonant frequencies of these two patches are close to each other, then a broad bandwidth can be achieved. If the dimensions of the feed patch and the parasitic patch are same, then the gap coupled structure creates two different resonant frequencies.

4. Co-axial or probe feed

This is a very common technique used to feed a microstrip patch antenna. As shown in Fig. 2, the inner conductor of the co-axial connector extends through the dielectric and is soldered to the radiation patch where as the outer conductor remains connected to the ground plane. This feeding technique has a major advantage that the feed can be applied at any desired location inside the patch to achieve proper impedance matching. Co-axial feeding technique allows easy fabrication and offers low spurious radiation.

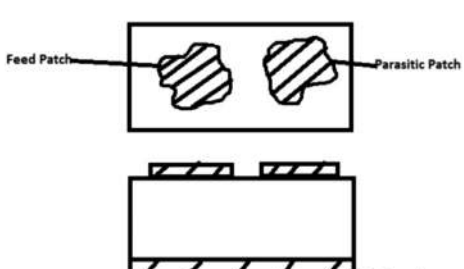

Fig. 1. Two gap-coupled microstrip patch antennas.

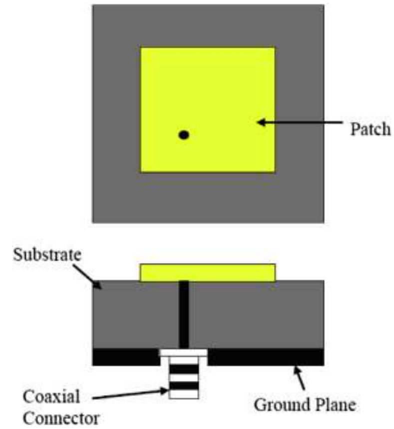

Fig. 2. Probe fed microstrip patch antenna.

5. Bandwidth improvement

The following two techniques have been employed to improve the impedance of the conventional microstrip patch antenna:

5.1. Fractal geometry

A fractal antenna possesses the unique feature of self-similarity. A self-similar set is a set that contains scaled down copies of itself. This property is responsible for the multiband and wideband characteristics of the fractal antenna. A basic square fractal antenna has been designed to achieve wideband characteristics (Fig. 3).

5.2. Gap-coupled structure

In order to introduce gap-coupling for further bandwidth enhancement, the basic square fractal antenna has been modified by introducing parasitic square patches in each iteration (Fig. 4).

6. Description of the proposed antenna design

The proposed antenna has been designed on FR4 glass epoxy substrate with dielectric constant of 4.4, loss tangent of 0.0013 and substrate thickness of 1.6 mm. The simulation performance of the suggested gap-coupled patch antenna has been analyzed by using IE3D simulation software [35]. The design specifications are as follows (Table 1):

6.1. Base shape of basic square fractal antenna

In the base shape, a square feed patch of side length 28 mm has been taken on a finite ground plane of side 50 mm. A square slot of side length 14 mm (half the size of basic square patch) has been embedded in the center of this square feed patch. The Fig. 5(a) shows the structure of the base shape of the basic square fractal antenna. Fig. 5(b) demonstrates that the base shape has dual frequency bands of 36.67% (1.67–2.42 GHz) and 24.7% (3.82–4.9 GHz) with return losses −22.63 dB and −11.83 dB at resonant frequencies 1.864 GHz and 4.3 GHz respectively. A VSWR of 2.4 and 1.689 are available at 1.864 GHz and 4.3 GHz respectively.

6.2. First iteration of basic square fractal antenna

In the first iteration of a simple square fractal antenna, four square slots, each of side length 7 mm (half of side of square slot of base shape) are embedded in the center of the outer sides of the

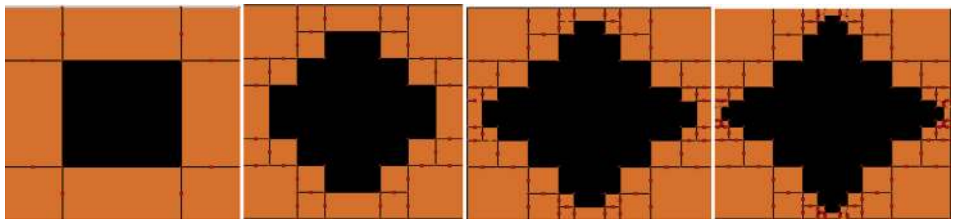

Fig. 3. Base shape and first three iterations of basic square fractal antenna.

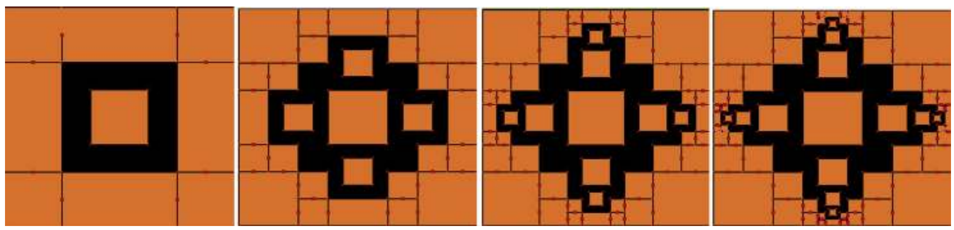

Fig. 4. Base shape and first three iterations of modified square fractal antenna with parasitic patches.

Table 1
Antenna design specifications.

S. No.	Parameters	Value
1.	Dielectric constant ε_r	4.4
2.	Substrate height	1.6 mm
3.	Loss tangent	0.0013
4.	Square patch length	28 mm
5.	Ground plane length	50 mm

main square slot. The geometry of the first iteration has been shown in Fig 6(a). Fig 6(b) illustrates the return loss v/s frequency plot of the first iteration which shows a bandwidth of 80% (1.67 GHz −3.9 GHz) at resonant frequency 1.844 GHz. A return loss of −35.97 dB and a VSWR of 1.032 are available at the resonant frequency.

6.3. Second iteration of basic square fractal antenna

In the second iteration of a simple square fractal antenna, a square slot, each of side length 3.5 mm (half of side of square slot of first iteration) is employed in the center of the outer sides of the four square slots of first iteration. Fig. 7(a) and Fig. 7(b) illustrate the design and return loss v/s frequency graph of the second iteration of basic square fractal antenna. The antenna shows a bandwidth of 73.9%(1.67 GHz–3.63 GHz) at resonant frequency 1.824 GHz. A return loss of −31.87 dB and a VSWR of 1.052 are available at the resonant frequency.

6.4. Base shape of modified square fractal antenna with parasitic patches

As shown in Fig 8(a), in order to apply the concept of gap coupling for bandwidth enhancement, a parasitic square patch of side length 7 mm has been introduced in the centre of the square slot of base shape of basic square fractal antenna. Fig 8(b) demonstrates that this antenna has dual frequency bands from 1.69 to 2.43 GHz (35.92%) and 3.78–4.86 GHz (25%) around the resonant frequency 1.864 GHz and 4.29 GHz respectively. Return losses of −22.7 dB and −11.78 dB and VSWR of 1.158 and 1.695 are available at resonant frequencies 1.864 GHz and 4.296 GHz respectively.

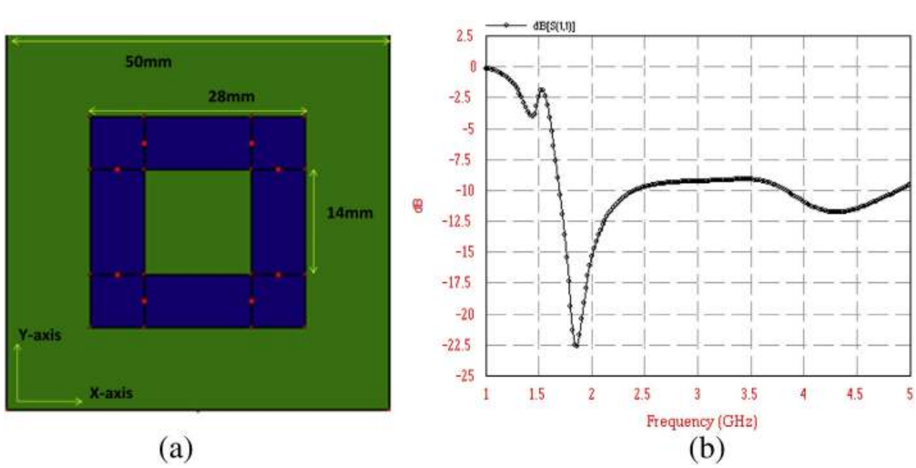

Fig. 5. (a) Geometry of base shape of basic square fractal antenna (b) return loss v/s frequency plot of base shape of basic square fractal antenna.

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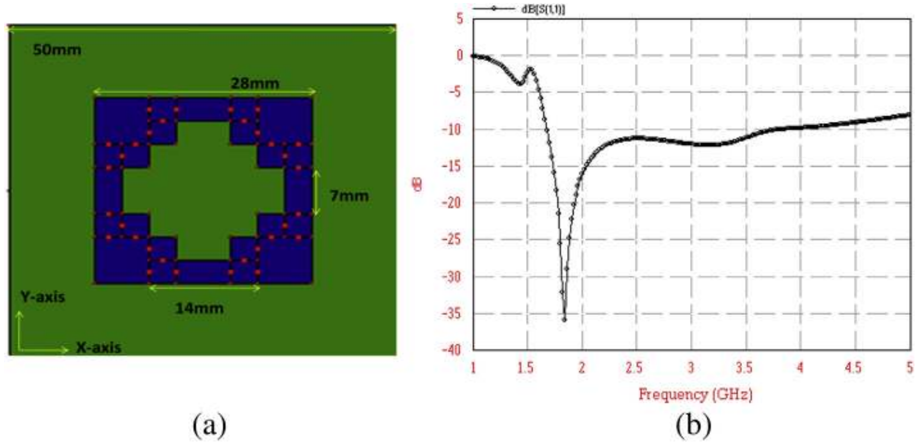

Fig. 6. (a) Geometry of first iteration of basic square fractal antenna (b) return loss v/s frequency plot of first iteration of basic square fractal antenna.

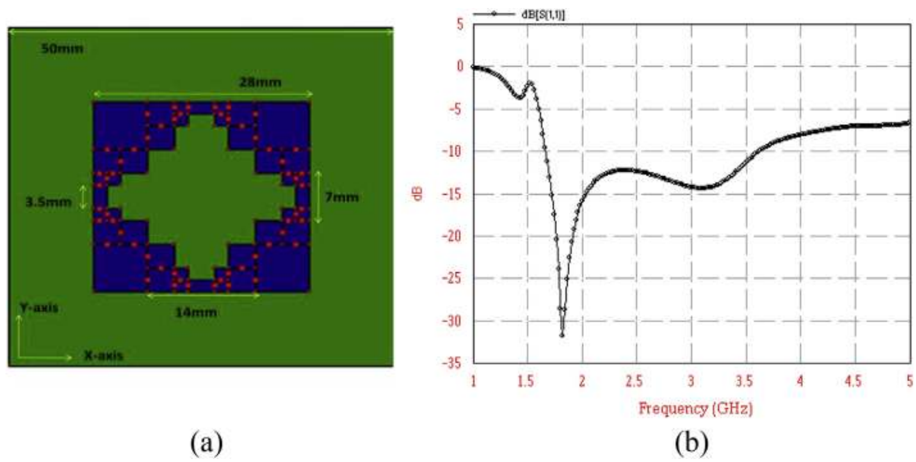

Fig. 7. (a) Geometry of second iteration of basic square fractal antenna (b) return loss v/s frequency plot of second iteration of basic square fractal antenna.

6.5. First iteration of modified square fractal antenna with parasitic patches

In the first iteration of a modified square fractal antenna, four parasitic square patches, each of side length 3.5 mm (half of side of square slots of first iteration of basic square fractal antenna) are introduced in the centre of the four square slots of the first iteration of basic square fractal antenna. Fig 9(a) shows the geometry of the first iteration of modified square fractal antenna. Fig 9(b) shows that the antenna has an impedance bandwidth of 85.42% (1.67–4.16 GHz) around the resonant frequency 1.844 GHz. Minimum return loss of −36.89 dB and VSWR of 1.029 are available at 1.844 GHz

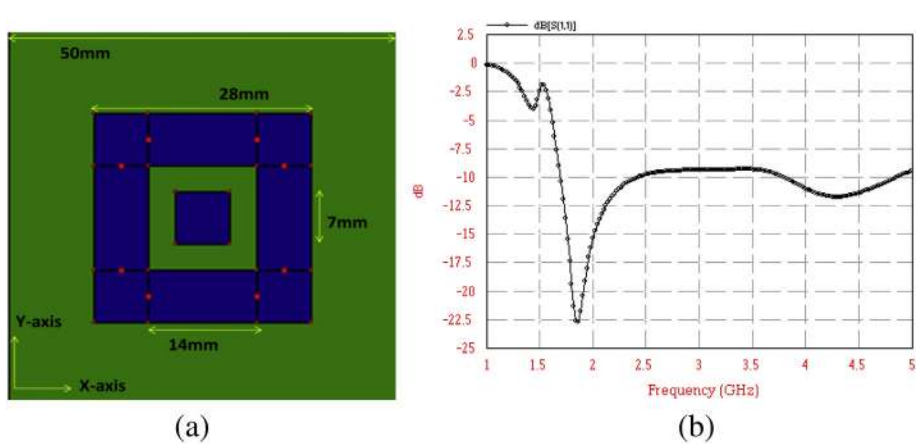

Fig. 8. (a) Geometry of base shape of modified square fractal antenna (b) return loss v/s frequency plot of base shape of modified square fractal antenna.

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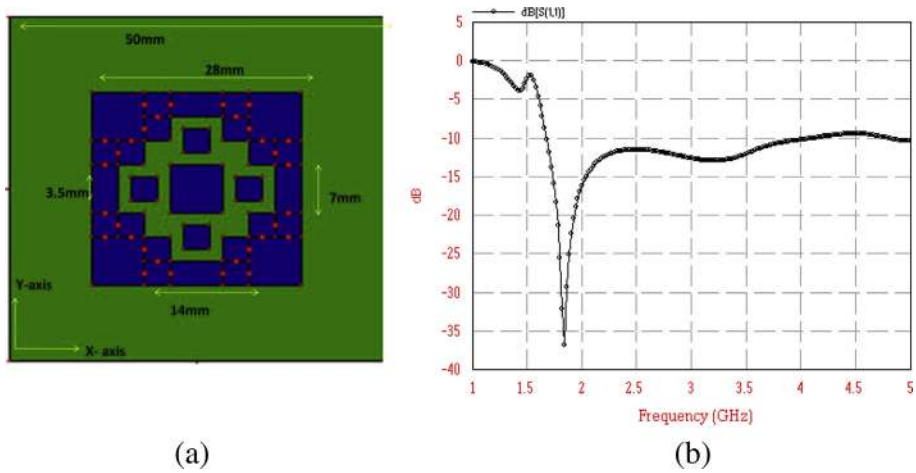

Fig. 9. (a) Geometry of first iteration of modified square fractal antenna (b) Return loss v/s frequency plot of first iteration of modified square fractal antenna.

6.6. Second iteration of modified square fractal antenna with parasitic patches

In the second iteration of a modified square fractal antenna, four parasitic square patches, each of side length 1.75 mm (half of side of square slots of second iteration of basic square fractal antenna) are introduced in the centre of the four square slots of the second iteration of basic square fractal antenna. Fig 10(a) illustrates the structure of the second iteration of the modified square fractal antenna with parasitic patches. Fig 10(b) shows that in the second iteration, the antenna has an impedance bandwidth of 75.1% (1.67–3.68 GHz) around the resonant frequency 1.824 GHz. Minimum return loss of −31.15 dB and VSWR of 1.057 are available at 1.824 GHz.

6.7. Comparison between different geometries

Table 2 shows a comparison between the various parameters of the six proposed geometries of fractal antenna.

7. Simulation results of the proposed design

This section illustrates the simulated results of the most optimum proposed design i.e. first iteration of the modified square fractal antenna with parasitic patches.

Fig. 11 shows the variation of return loss with frequency for the proposed design. The intended design has an impedance bandwidth of 85.42% (1.67–4.16 GHz) around the resonant frequency 1.844 GHz. Minimum return loss of −36.89 dB and VSWR of 1.029 are available at 1.844 GHz

Fig. 12 demonstrates the relationship between gain and frequency. A gain of 3.31 dB is available at 1.844 GHz. Fractal antennas

Table 2
Comparison between various parameters of the six proposed geometries.

Geometry	Resonant frequency (GHz)	Bandwidth (GHz)	Return loss S_{11} parameter (dB)	VSWR
Base shape	1.864 GHz	1.67–3.68 GHz = 36.67%	−22.63 dB	2.4
	4.3 GHz	3.82–4.9 GHz = 24.7%	−11.83 dB	1.689
Iteration 1	1.844 GHz	1.67–3.9 GHz = 80%	−35.97 dB	1.032
Iteration 2	1.824 GHz	1.67–3.63 GHz = 73.9%	−31.87 dB	1.052
Base shape with parasitic patch	1.864 GHz	1.69–2.43 GHz = 35.92%	−22.7 dB	1.158
	4.296 GHz	3.78–4.86 GHz = 25%	−11.78 dB	1.695
Iteration 1 with parasitic patch	1.844 GHz	1.67–4.16 GHz = 85.42%	−36.89 dB	1.029
Iteration 2 with parasitic patch	1.824 GHz	1.67–3.68 GHz = 75.1%	−31.15 dB	1.057

The above table clearly indicates that the first iteration of the modified square fractal antenna with parasitic patches can be considered as the most optimum design since it has maximum bandwidth of 85.42% with optimum values of VSWR and return loss.

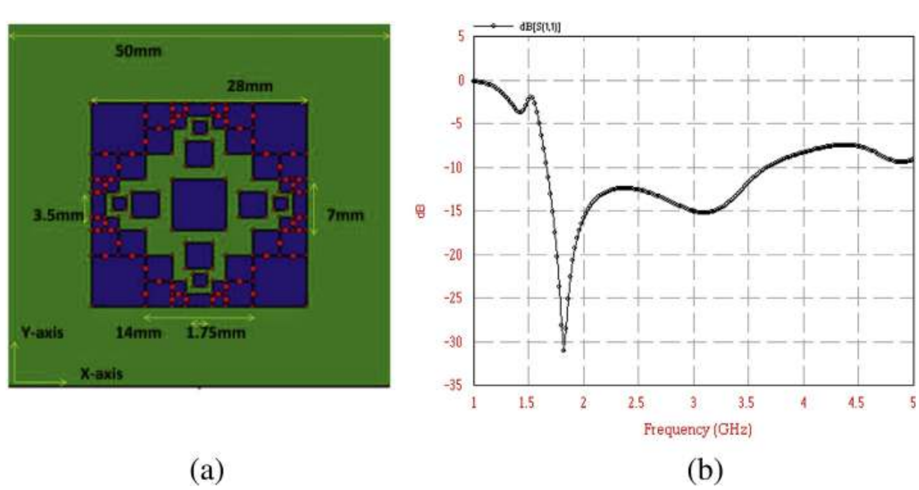

Fig. 10. (a) Geometry of second iteration of modified square fractal antenna (b) return loss v/s frequency plot of second iteration of modified square fractal antenna.

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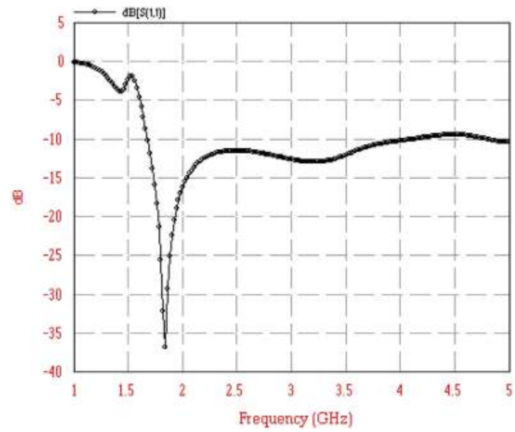

Fig. 11. Return loss v/s frequency graph for proposed geometry.

are generally employed for antenna miniaturization and wideband/broadband characteristics. They suffer from the limitation of low gain in some cases as the product of gain and bandwidth is constant. Thus a trade off exists between the two. In this work, an attempt has been made to enhance the bandwidth, hence the gain has been compromised.

As shown in Fig. 13, this antenna has achieved a radiation efficiency of 97.58% which is significant.

Fig. 14 and 15 represent the 2D radiation pattern of the proposed antenna in E-plane and H-plane respectively.

8. Experimental results and discussion

The proposed antenna i.e. the first iteration of the modified square fractal antenna with parasitic patches has been fabricated and the experimental results have been investigated. The prototype

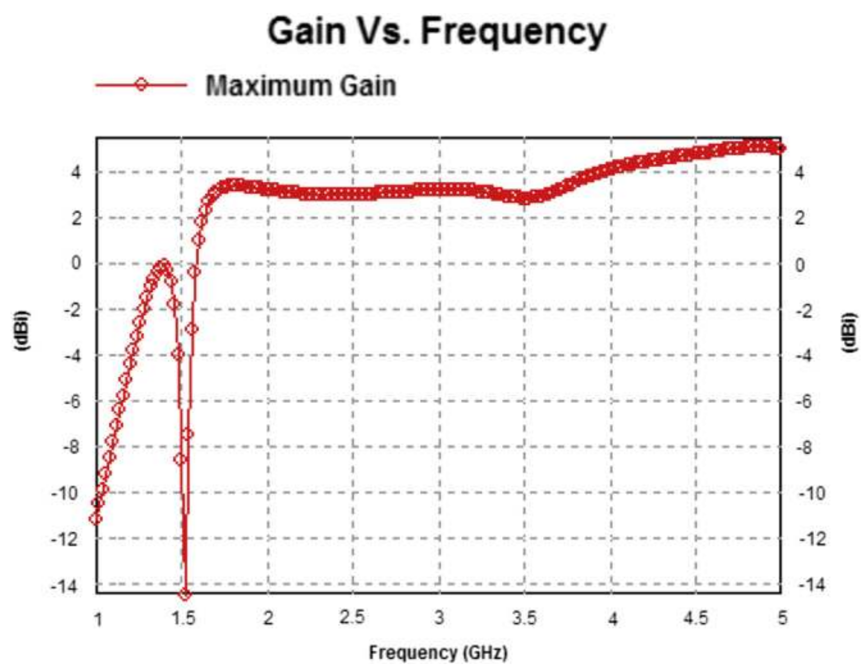

Fig. 12. Gain v/s frequency plot.

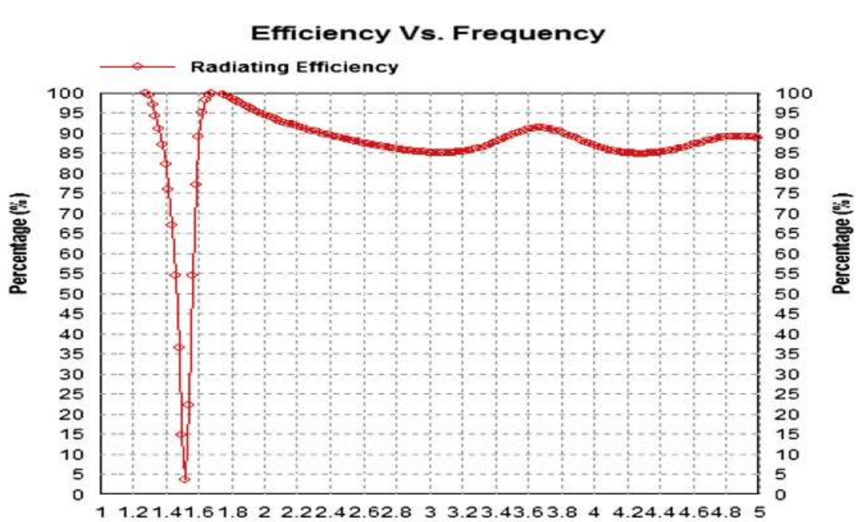

Fig. 13. Radiation efficiency of the proposed antenna.

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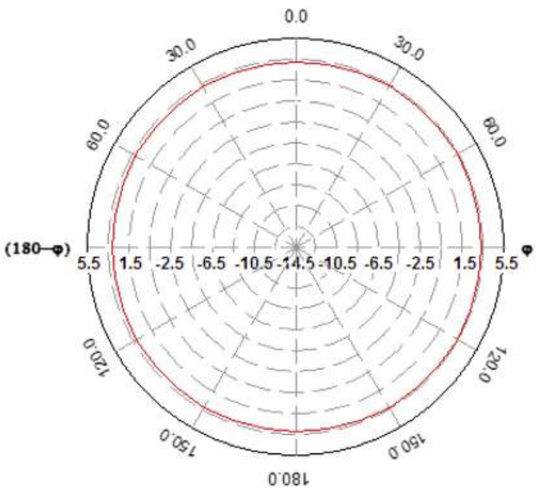

Fig. 14. 2D Radiation pattern of proposed antenna in E-plane.

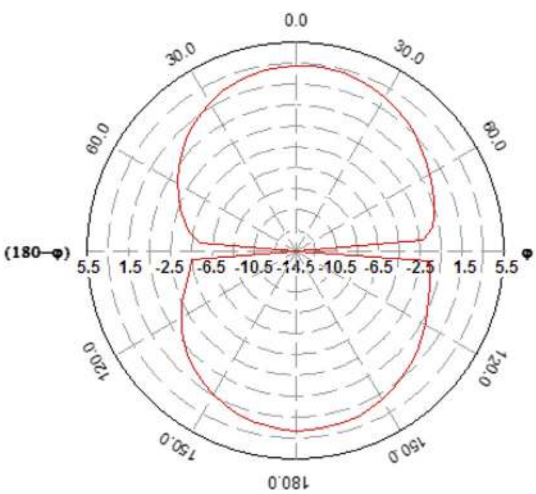

Fig.15. . 2D Radiation pattern of proposed antenna in H-plane

of the suggested design has been illustrated in Fig. 16. This antenna has overall dimensions of 50 × 50 × 1.6 mm and it has been fabricated on glass epoxy substrate with thickness of 1.6 mm and dielectric constant of 4.4.

The experimental results show an impedance bandwidth of 66% around the resonant frequency of 2.1 GHz with lower and upper

Fig. 16. Prototype of the proposed microstrip patch antenna.

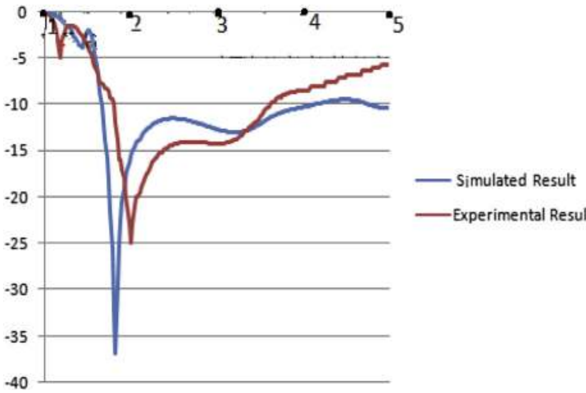

Fig. 17. Comparison between simulation and experimental results for proposed design.

frequencies as 1.9 GHz and 3.77 GHz respectively. The simulation results and the experimental results vary due to fabrication defects that exist in the prototype as the the design is complicated and the entire fabrication has been done manually, yet the proposed design covers the Bluetooth (2.4–2.48 GHz), WLAN (2.4–2.484 GHz), Mobile WiMAX (2.5–2.69 GHz), and WiMAX (3.4–3.69 GHz) applications. The comparison between the simulation and experimental results has been shown in Fig. 17.

9. Conclusion

In this paper a probe fed gap-coupled modified square fractal microstrip patch antenna has been designed to overcome the constraint of narrow bandwidth of the conventional patch antenna. This technique has achieved much better results in terms of bandwidth enhancement as compared to the geometries discussed in the literature. The proposed design has an impedance bandwidth as high as 85.42% around the resonant frequency of 1.844 GHz. This antenna has a VSWR of 1.029 and a return loss of −36.89 which are noticeable results. This antenna, with a gain of 3.31 dB and an antenna efficiency of 97.56%, is simultaneously applicable for Bluetooth (2.4–2.48 GHz), WLAN (2.4–2.484 GHz specified by IEEE 802.11 b/g standards), Mobile WiMAX (2.5–2.69 GHz specified by IEEE 802.16e standards), and WiMAX (3.4–3.69 GHz specified by IEEE 802.11a standards) applications.

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