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Bharamappa Irappa Kattimani (navyabk2012@gmail.com)
VSM Institute of Technology https://orcid.org/0000-0002-6193-9789
Rajendra R Patil
GSSS Institute of Engineering Technology for Women

Research Article

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Design and Fabrication of Sierpinski Square Fractal Microstrip Patch Antenna with Parasitic Elements for Wideband Applications

Bharamappa Kattimani [1*] **, Rajendra R Patil** [2]

1Department of Electronics and Communication Engineering, VSM's SRKIT, Nipani,

navyabk2012@gmail.com

2Department of Electronics and Communication Engineering, GSSSIETW, Mysuru

rajendra.nano@gmail.com

Abstract

The narrow bandwidth of a microstrip antenna is one of its key drawbacks. This work shows how a dual-layer stacked and parasitic arrangement, together with the effect of fractal designs, can provide wide bandwidth and high gain qualities in a microstrip patch antenna. For wideband applications, the proposed antenna design in stacked construction has a total bandwidth of 750MHz for S_{11} -10dB. In order to reduce the antenna size, the Sierpinski square carpet fractal is used. This antenna exhibits a lower resonance frequency due to the space-filling property of fractal geometry. The resonance frequency of this patch antenna drops as iteration and iteration factors rise, according to experimental results. Wideband functioning is achieved with a size decrease of 70.1%. The proposed antenna design exhibits a 6.98dB gain. These qualities of wideband and higher gain make the proposed antenna an excellent one for wideband applications.

Keywords: Fractal Microstrip patch Antenna (FMPA), Bandwidth, Gain, Return Loss.

1. Introduction

In today's world of expanding wireless communication, personal communication devices require increasingly compact and multiband antennas. These conditions can be met with the use of fractal antennas [1]. Fractal antennas are defined as the antennas which are capable of retaining the same shape under recursive transformations, which is an inherent self-similarity property shared by many fractals [2]. With a peak value of 8.2dB at 5.7GHz, the gain in the bandwidth region was improved. The major goal of this article is to develop a square-shaped fractal antenna that is small in size and can operate in multiple bands with high gain and increased bandwidth. A parasitic patch is used to increase gain and bandwidth. Fractal geometries have been used to reduce the size of antennas.[3-5]. As we all know, the microstrip patch antenna (MPA) is frequently utilized due to its low profile, but it also has significant drawbacks, such as limited bandwidth and gain. An overview of numerous ways for increasing bandwidth (BW) and gain is presented here. A) Gain and bandwidth increase of a microstrip antenna utilizing multiple layers dielectric substrate with partial substrate removal. B) Using a material that reflects light. C) Parasitic elements are used. D) EBG (electromagnetic bandgap) substrates [6-7]. In a microstrip patch antenna, a dielectric substrate separates the radiating and ground patches. MPAs are used in a variety of wireless communication applications. Reduced weight, ease of manufacture, low cost, and low profile are just a few of the benefits of these antennas. These antennas have incredibly low radiation levels and are also quite compact. Microstrip patch antennas, on the other hand, have some disadvantages including a narrow bandwidth, low gain, and low efficiency [8-12].

2. Literature Survey

A miniature microstrip Patch Antenna (MPA) is its small size in conjunction with the well-known advantages of an MPA (cost, profile, weight). However, there is a big constraint on the bandwidth limitation either in a miniature antenna or in an MPA. The proposed solution to overcome such a problem is to couple a miniature parasitic resonator to the miniature active patch forming a wideband small stacked microstrip patch antenna [13]. The effect of a dual-layer staked structure configuration with the influence of fractal designs on a microstrip square patch antenna fed with 50Ω coaxial cable, for attaining both wide bandwidth and high gain. The results of the 2nd iterated fractal patch demonstrate that the gain of the antenna is 10.13 dB with 94.64% radiation efficiency whereas the impedance bandwidth for S11<-10dB achieved is 0.80GHz (4.89%) which is 0.30GHz wider than that achieved for basic square patch[14]. A stacked structure of Sierpinski Gasket fractal geometry applied to an equilateral triangular microstrip patch antenna was designed with fractal shapes being excoriated from both the radiating patch surfaces. In addition, the stack structures make possible simultaneous dual-band performance of the antenna. The return loss of the fabricated antenna indicates a −10 dB impedance bandwidth of 64 MHz at the 2.4 GHz band and impedance bandwidth of 500 MHz at the 5.8 GHz band [15]. A stacked structure of complementary Sierpinski gasket fractal geometry applied to an equilateral triangular microstrip patch antenna was designed with fractal shapes being excoriated from both the radiating patch surfaces. The return loss of the fabricated antenna indicates a -10 dB impedance bandwidth of 100 MHz at the 3.5 GHz band and impedance bandwidth of 150 MHz at the 5.8 GHz band [16]. A U-shaped slot etched on each leaf of the four-leaf clover and a parasitic element of four disks placed above the dual-polarized element are introduced to realize the bandwidth enhancement. The bandwidth enhanced dual-polarized antenna achieves a bandwidth of 67% (1.39–2.8 GHz) for reflection coefficients <-15 dB with an isolation of >30 dB.[17]. A wideband dual-polarized slot antenna is presented. An H-shaped slot in an infinite ground plane is used as the initial structure for further optimization design. To enhance the bandwidth of the antenna, geometry of the slot antenna is then modified based on the clear physical insights obtained from the modal analysis. In addition, two pairs of differentially-fed capacitive coupling elements are introduced to excite the first two modes of the slot and an integrated wideband feeding network is designed. The bandwidth of the proposed antenna is enhanced from 17% to 46% [18]. A microstrip patch antenna that works at a frequency of 5.2 GHz is designed. The gain and directivity of the antenna are intended to be optimized by using MTM structures and the ANN method is used to determine the most suitable MTM structure [19]. A miniaturized and gain enhanced AVA-MS array with impedance bandwidth of 24.1–28.5 GHz is proposed, which meet the frequency bands of 24.75–27.5 GHz and 27.5–28.35 GHz for future 5G mmWave communication applications. The AVA-MS array has a lower cutoff frequency of 24.1 GHz and a higher gain of 9.35–12 dB in comparison with the AVA array, whose gain is 8.5–11.2 dB in the frequency band of 24.75– 28.35 GHz[20].

2. Antenna design procedure

The conventional microstrip patch antenna is designed to resonate at 9.54GHz. The width of the antenna can be calculated by using

$$W = \frac{c}{2f_o\sqrt{\frac{\varepsilon_r+1}{2}}} \tag{1}$$

Effective Dielectric Constant is calculated

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+12\frac{h}{w}\right)\wedge -1/2 \tag{2}$$

Where

ε_r is the relative permittivity

The effective length of the patch is obtained

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{reff}}} \tag{3}$$

C is the velocity of light, fo is the resonance frequency

Length extension of the patch can be calculated

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)\left(\frac{w}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{w}{h}+0.8\right)} \tag{4}$$

The actual length of the patch is obtained

$$L = L_{eff} - 2\Delta L \tag{5}$$

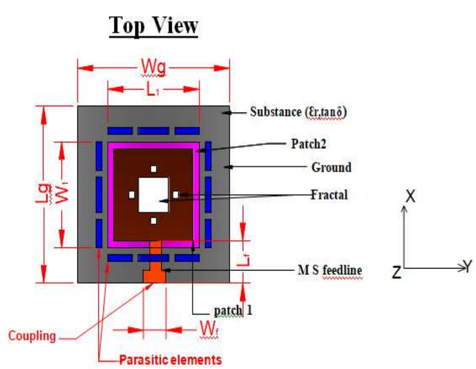
Width and length of substrate can be calculated

$$L_s = L + 2 * 6h \quad (6)$$
$$W_s = w + 2 * 6h \quad (7)$$

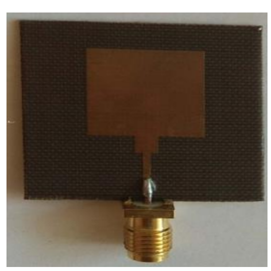
The taconic as substrate material with dielectric constant (ε_{e1}) 3.2 and tangent loss (tanδ) 0.002 with thickness h=0.8mm is used. The copper material is used for the radiating patch with a thickness of 0.03mm. The substrate and ground plane are in rectangular shape with a dimension of Wg=Ws=34.93mm and Lg=Ls=36.55mm.. The antenna is designed to achieve a 50Ω impedance matching. The microstrip line feeding is used with a transformer, the length of the transformer is =8mm. The conventional antenna configuration, similarly schematic diagram of the proposed microstrip patch antenna is as shown in Fig.1 (a, b, c & d). The stacking structure configuration is employed in the proposed antenna design to improve the antenna's performance, particularly to expand the antenna's impedance bandwidth. The proposed design uses a two-layer stacking structure that contains the radiation patch and the parasitic patch, which are electromagnetically connected at a distance of hz = 3 mm between them. The parasitic elements are used around the patch, hence it is called parasitic patch. This is placed above the Glass Epoxy (FR4) dielectric substrate with dielectric constant (ε_{e2}) 4.4 with thickness h=1.6mm. The prototypes of conventional and proposed microstrip antenna are fabricated using commercially available glass epoxy FR4 and Taconic substrates with dielectric constants are 4.4 & 3.2 are as shown in Table I. The prototype antennas are measured using automatic VNA (Vector Network Analyzer) and in an anechoic chamber. One of the most attractive techniques to improve MPA (microstrip patch antenna) is adding a parasitic element to the driven element, especially the gain and bandwidth. When parasitic elements are used, electromagnetic energy is coupled from the driven patch to it by the main of both space and surface waves, and any two parasitics must have a small gap between them.

2.1. Effect of Stacking:

As illustrated in Fig.1, to maintain the effect of a stacking structure, a parasitic patch with the same size and material properties as the radiating MPA has been introduced and electromagnetically coupled at a 3mm distance for bandwidth enhancement. When employed in stacking configuration exhibits at 5.7GHz. The antenna has a total bandwidth of 750MHz and a gain 6.98dB is suitable for wireless applications. In the absence of stacking and parasitic configuration on conventional MPA (microstrip patch antenna) at 9.54GHz. We observed a bandwidth of 470MHz and gain 6.1dB. It is observed that with a combination of the stacked and parasitic and fractal in microstrip antenna, then we observed bandwidth enhancement from (470 to 750) MHz and gain increased from 6.1dB to 6.98dB is as shown in Fig.4.it has a great impact on the impedance bandwidth, a gain of the proposed antenna.



(a)



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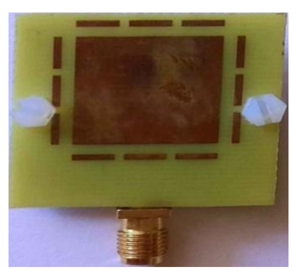

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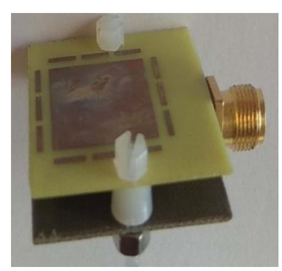
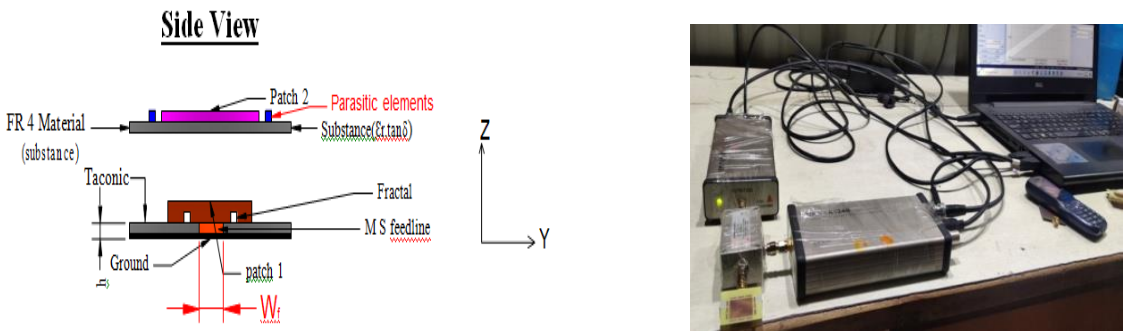


(e)



(b) (f)

Fig.1. Schematic diagram of proposed microstrip patch antenna (a) Top view (b) Side view. Wg= 34.93 mm, Lg=36.55mm, L_1=15.01mm, W_1=13.39mm, t=0.03mm, h=0.8mm, ε_{r1}=3.2, ε_{r2}= 4.4, L_f= 8mm, Wf= 1mm, (c) & (d) & (e) Fabricated Conventional and proposed microstrip patch antenna,(f) Experimental setup of proposed antenna.

TABLE I
Conventional and proposed antenna substrate material used specifications

Antenna	**substrate** $\varepsilon_{r1}, \varepsilon_{r2}$	**Dielectric constant**	**Air gap height**
Conventional (9.54GHz)	Taconic	3.2	
Proposed (5.7GHz)	Taconic	3.2	3mm
	Glass Epoxy FR4 material	4.4	

3. Results and discussion

The simulated outcomes of the conventional and proposed antennas are analyzed and discussed in this section. High-Frequency Simulation Software -V15 has been used to simulate the with and without the influence of dual-layer stacked and parasitic configurations up to the second iteration. All the three geometrical designs, which are conventional (basic) MPA, 1st iterated patch, and the 2nd iterated patch.

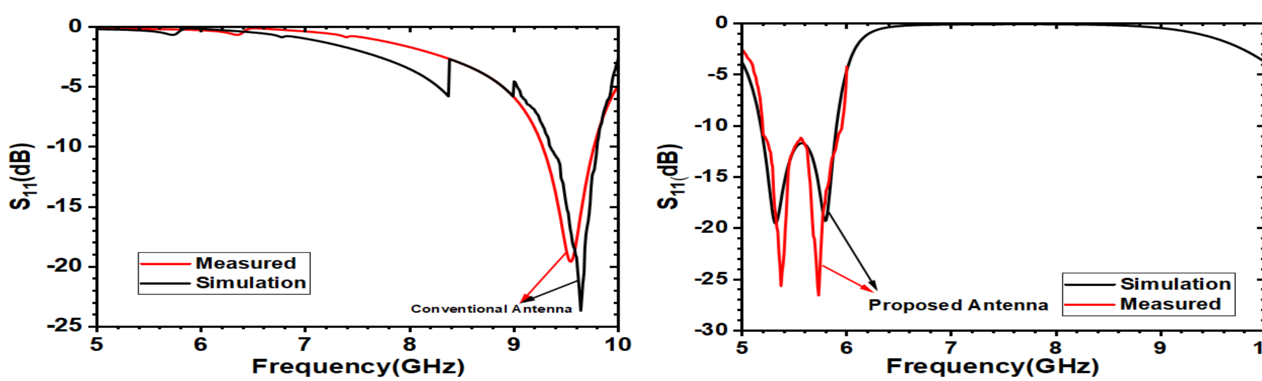
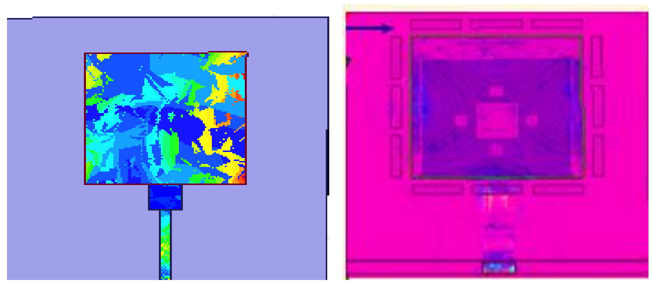


Fig.2. Simulated and measured return loss characteristics of (a) Conventional (b).proposed microstrip patch antenna.

The amount of power that is lost to load and does not return as reflection is referred to as return loss. The simulated return loss for the conventional antenna at 9.54GHz is -23.6dB. Similarly, the measured return loss -19.6dB is observed in Fig. 2(a). The simulated value of the proposed MPA has a peak gain of 6.1dB at 5.73GHz as shown in Table III. The simulated return loss for the proposed MPA at 5.73GHz is -19.27dB. Similarly, the measured return loss -26.54dB is observed from Fig. 2(b). The measured value of the gain of proposed MPA the peak gain is 6.98dB at 5.73GHz. Fig. 2 shows the simulated and measured return loss, demonstrating that the bandwidths are in accord. The shift in resonance frequency was confirmed, and the variation could be explained by the FR4-permittivity uncertainty.



(a) (b)

Fig.3 current distribution (a) conventional MPA and (b) Proposed fractal microstrip antenna.

In the designed conventional microstrip patch antenna we observed in Fig. 3(a) no Sierpinski carpet fractal is used. The surface current distribution is very much maximum over the entire surface of the MPA. Conventional microstrip patch antenna has a quarter-wave transformer for impedance matching. Once the input impedance i.e. 50Ω gets matched more current flows in the antenna. The patch resistivity increases because of increasing the surface resistance, but surface resistivity is more effective on bandwidth, gain and return loss. In the proposed design we observed in Fig. 3(b) Sierpinski carpet fractal used in the driven patch, by introducing the fractal resonance frequency goes on decreasing from (9.54 to 5.73) GHz. The bandwidth of the antenna depends on the air gap between the driven patch and the parasitic patch through this gap electromagnetic coupling is developed. Due to the coupling less current flow and resistivity increase as increasing surface resistance the bandwidth of the antenna increases from (470 to 750)MHz In stacked design, the two different dielectric materials are used one is Taconic and another one is FR4 material. The proposed antenna gain depends on the substrate material used, but in the driven patch, the less dielectric constant Taconic substrate whereas in parasitic patch FR4 material is used. Therefore the gain of the proposed antenna is increased from (6.1 to 6.98) dB. The above-mentioned improved results we observed as shown in Table.III.

TABLE II

COMPARISON WITH PREVIOUSLY PUBLISHED LITERATURE

Ref Pair	Size of Ant. ($L \times H$ mm^2)	BW(MHz)	Gain (dB)
[6]	90.8×25	22.5MHz	3.8
[7]	$\mathbf{75.08 \times 4.9}$	0.95GHz	7.6
[8]	15× 3	780MHz	9.1
[11]	3.45 × 3.21	17.0 GHz	8.72
[12]	8 × 8 × 1.1	5.8GHz	8 dB
Pro	15.01× 3	750MHz	6.98

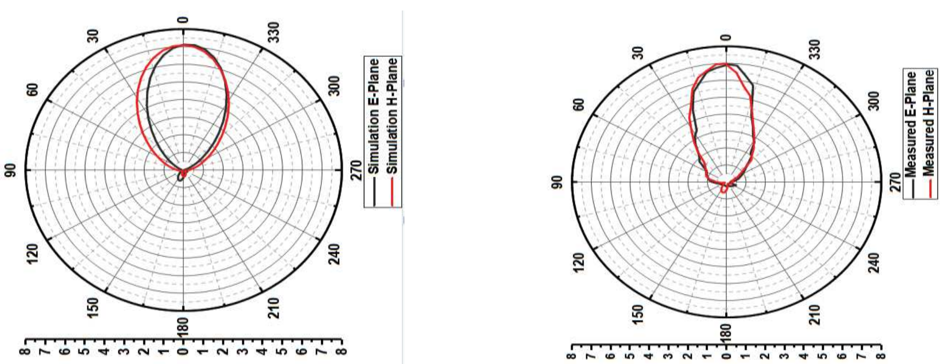
3.1. Comparison and Discussion

The proposed antenna performance is compared as shown in Table II. It is obvious that bandwidth improved up to wideband. The proposed antenna is compared to earlier work that has been published [7], [11], [12] for UWB. The bandwidth of UWB is more than wideband (>500MHz). But the proposed antenna is designed only for wideband application as per requirement. It has improved gain and compact size.

TABLE III

Performance comparison of the antenna

Parameters	**Simulated**	**Measured**
Resonant freq (GHz)	5.79	5.73
Return loss S11 (dB)	-19.27	-26.54
Bandwidth (MHz)	720	750
% of Bandwidth	12.4%	13.08%
% of size reduction	70.1	70.1
Gain (dB)	6.1	6.98



(a) E&H plane simulated radiation pattern of (5.7GHz) proposed antenna

(b) E&H plane measured radiation pattern of (5.7GHz) proposed antenna

Fig.4 Simulated & measured radiation pattern

The simulated antenna was fabricated using the photolithography process; thereafter its radiation pattern (E-field and H-field power pattern) was measured. Figures 4 (a) and (b) show the simulated and measured radiation patterns of the antenna in both the E- and the H-plane at the frequency bands of 5.79 and 5.73 GHz. The simulated and measured radiation patterns for E-plane at both 5.79 and 5.73GHz bands are in close agreement. The measured radiation pattern in H-plane at both 5.79 and 5.73GHz bands is slightly tilted compared with that of the simulated patterns. This may be due to the alignment error. Possible reasons for these disagreements between simulated and measured results may due to the possible presence of interference and noise.

4. Conclusion

It has been concluded that after the incorporation of parasitic and stacking techniques into the structure, bandwidth and gain of an antenna improve remarkably. It is designed and simulated a microstrip patch antenna. The antenna is adjusted at each level to raise the S_{11}, gain, and bandwidth characteristics, and the design is split down into three stages. A conventional antenna is designed to operate at a frequency of 9.54 GHz initially. To achieve the maximum gain and bandwidth possible on the fractal microstrip antenna, parasitic components and stacking techniques are used as a last stage in the process. With a peak value of 6.98dB at 5.7GHz, the gain in the bandwidth region was improved. The proposed antenna has a maximum bandwidth is 750MHz.This antenna covers wideband applications.

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