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Paiyanoor-603 104, Tamil Nadu, India

Design and Analysis of a Novel Five Face Fractal Antenna for UWB Wireless Applications

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Abstract—The objective of this paper is to design and analyze a novel Five Face Fractal Antenna (3FA), for Ultra Wideband (UWB) wireless applications. Fractal technique is being used to overcome the limitations of microstrip antenna. The proposed antenna has been designed on FR-4 substrate with Ɛr=4.4, thickness h=1.6 mm and circular patch of 8.5 mm radius. The overall size of the antenna is 34×32 mm^2. The impedance bandwidth of the proposed antenna is 7.90GHz ranging from 3.24 GHz to 11.14 GHz with a maximum gain of 4.83 dB and efficiency of 93.55%. Analysis of this antenna is done using High Frequency Structured Simulator (HFSS). The simulated radiation pattern of the proposed antenna has been observed as nearly omni-directional in azimuth plane. The proposed 3FA can be used for Wireless Personal Area Network (WPAN), Wireless Body Area Network (WBAN) and Home network applications utilizing UWB radio technology.

I. INTRODUCTION

In the present scenario of wireless communication, People demand high data rate and reliable communication. In February 2002, the Federal Communication Commission (FCC)'s allocation of frequency band from 3.1GHz to 10.6GHz under unlicensed band for commercial use [1] has attracted the attention of many of the scientists and researchers to work on short range high-speed communication application. After this release, there has been a rapid development in UWB wireless communication. To avoid interference with the existing narrowband communication system, FCC has assigned an EIRP of – 41.3dBm/MHz for indoor/outdoor communication system. This has created antenna design as the hot topic to attract researcher's attention. After the release of 7.5GHz of spectrum for unlicensed use, there has been a variety of applications developed for indoor/outdoor communication, ground penetrating radar system, wall and through wall imaging, surveillance and medical imaging [2].

For UWB Communication system, antenna is one of the most critical component to be realized in order to have a good system performance. Considering this, many antenna came into existence such as Vivaldi antenna which is a directional antenna which makes it unsuitable for indoor communication, bi-conical antenna limits its application because of its size. To overcome these limitations, microstrip antenna came into existence which has low profile, light weight, low cost, conformal shaping, high efficiency and simplicity in fabrication. Microstrip antenna too has its disadvantages like narrow impedance bandwidth [3-4]. Need for wider operating bandwidth and reduced size, Fractal geometry is being used. Fractal is recursive in nature and it appears to be irregular at all scales of length [5]. Fractals have self-similarity property which overlaps multiple resonant frequency to provide a wider bandwidth. It also has a space filling property which leads to the miniaturization of antenna elements [6-7]. There are various fractal shapes such as Hilbert Curve [8], Sierpinski carpet [9], Koch curve [10] etc. which provide narrow bandwidth. Various wideband fractal antennas [11] have been reported till date.

This paper presents a novel design of microstrip fed Five Face Fractal (3FA) Antenna which has several advantages like low profile, compact size, low manufacturing cost and

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easy fabrication. N notch and a ground slit have been introduced in order to achieve the desired UWB characteristics as defined by FCC. The radiation pattern of our proposed antenna is nearly omni-directional and this antenna is useful for UWB applications, WPAN, home network applications, WBAN.

II. ANTENNA GEOMETRY

In this paper, The Five Face Fractal (3FA) antenna printed on circuit board has been proposed. The proposed antenna has been constructed from conventional microstrip monopole antenna as depicted in figure 1. The radiating patch and the partial ground plane are printed on the top and the bottom of the FR-4 substrate, with the thickness of 1.6mm and relative permittivity 4.4, respectively. The dimensions of the substrate are 34×32mm^2 and the size of the ground plane is 12×32mm^2. Circular patch has been used in order to provide multiple resonant frequency and omni-directional radiation pattern.

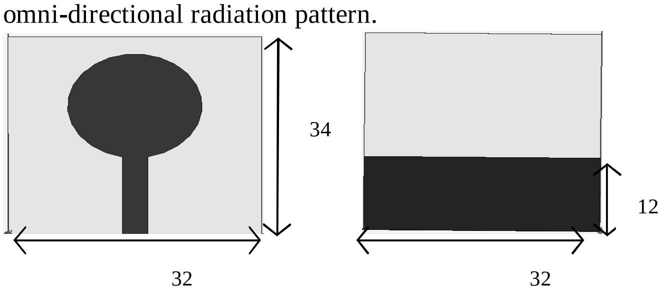


Figure 1: Microstrip antenna (a) Front view (b) Back view (All dimensions are in mm)

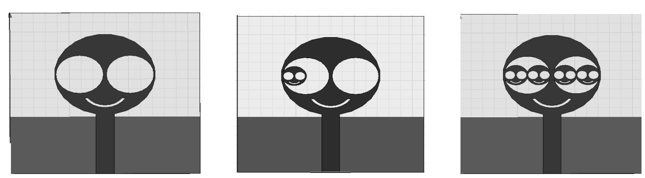
The radius of the circular patch is 8.5mm for resonant frequency of 4.7GHz which has been calculated from the given formula taking fringing effect into considerations where, f_r is in Hz and h in cm.

$$a = \frac{F}{\left\{1 + \frac{2h}{\pi \epsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}^{1/2}}$$

Where,

$$F = \frac{8.791 \times 10^9}{fr\sqrt{\varepsilon r}}$$

This is called the initiator or Zeroth Iteration. The dimension of the microstrip feed line is 12.64×3.08mm^2 and is calculated using transmission line model equation [14] to achieve 50 ohm line impedance. The first iteration of the proposed fractal antenna is created by subtracting two circles of radius 4mm whose centre lies on the diameter of the main radiating patch (8.5mm) i.e. the Zeroth iteration. The arc has been drawn by subtracting one-fourth of the ring of thickness 0.5mm. This is first iteration fractal element which resembles smiling human face as shown in figure 2(a). For second iteration, the circle representing the face is drawn with radius 2.1mm and its centre lies on the diameter of the main radiating patch. The two circles of radius 0.9mm representing the eyes for the second iteration is subtracted from the respective face. The arc thickness for second iteration is 0.25mm. This is the second iterative fractal element as shown in figure 2(b). This fractal element has been repeated four times in order to increase the electrical length (figure 2(c)).



(a) (b) (c)

Figure 2: (a) First Iteration (b) Second Iteration (c) Space filing

The number of iterations can be repeated up to infinite number of times but, this cannot be done due to fabrication complexity and constraints. As the desired UWB characteristics have been obtained after the second iteration, this has been finalized to be fabricated on the FR-4 substrate with εr=4.4, h=1.6mm and dielectric loss tangent tan δ=0.02, relative permeability=1, lande G factor=2 and ΔH=0.

III. ANTENNA WITH 'N' NOTCH AND GROUND SLIT

Figure 3, shows the geometry of the proposed antenna with 'N' notch and ground slit in order to obtain the desired UWB characteristic. The antenna consists of two iterative fractal element with microstrip feed line. Microstrip feed line is the most widely used planar

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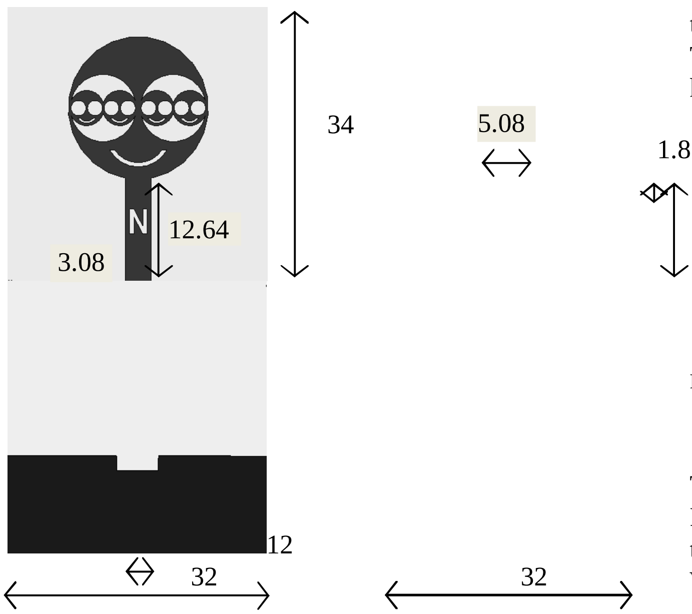
transmission line which is directly connected to the edge of the patch in order to provide input to the radiating patch. In this type of feed, radiating patch is on one side of the substrate and the partial ground plane on the other side. Ground plane is used to complete the circuit and to reflect the waves from the radiating patch.



. (a) (b)

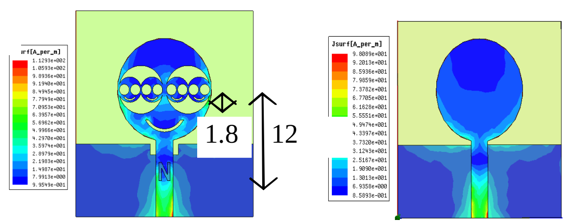
Figure 3: 3FA Antenna (a) Front view (b) Back view (All dimensions are in mm)

Firstly, a middle slit of dimension 1.8×5.08 mm^2 is introduced in the ground plane in order to eliminate the notched band ranging from 4.7GHz to 6.22GHz. After the introduction of middle slit, antenna also began to operate on higher frequency component which resulted in the interference with the other communication systems. To overcome this, N-notch is introduced of width 0.5mm and height 3mm. A parametric study, with respect to slot width and length has been carried out, in order to obtain desired UWB characteristics.

The current is generally distributed along the circumference of the circular patch. This states, that the current density is minimum in the middle area, therefore, the current distribution will not be affected, even if any changes are made. The effective length of the current path can be increased by performing iterations. Thus, the first resonant frequency will shift from 4.7GHz to 4.1GHz and thus, the size of the antenna will be reduced. Figure 4 shows the current distribution of circular radiating patch with and without fractal geometry.

From the figure it can be inferred that the current distribution is maximum in the feed line and the edges of the circular patch of different iterations which enhances the radiation characteristics.

To achieve the desired UWB characteristics, optimization has been performed with different antenna parameters.

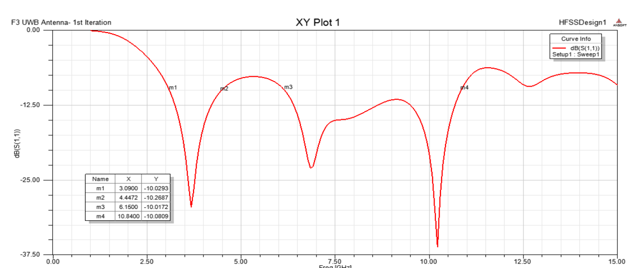


(a) (b)

Figure 4: Current Density (a) 3FA Antenna (b) Zeroth Initiator

IV. RESULT AND SIMULATION

The Five Face Fractal antenna (3FA) has been designed of FR-4 substrate with ε_r=4.4 and thickness h=1.6mm with the length of N-shaped notch L=3mm and width of notch W=0.5mm and overall width of notch is 2.08mm. This antenna has been simulated using HFSS (High Frequency Structured Simulator) based on FDTD technique. Two iterations are implemented and their return loss characteristic is shown in Figure 5. Dimensions and specifications of the substrate and the feed line are kept constant. Any changes in the return loss, efficiency gain and surface current distribution is due to slit and notch [12-13].



(a)

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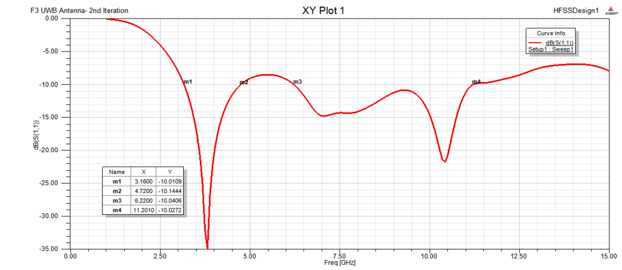

(b)

Figure 5: Return loss graph (a) First Iteration (b) Second Iteration

From the graph (Figure 5(b)), we can infer that, band notch is introduced in the frequency range from 3.1GHz to 10.6GHz. To remove this notched band i.e. from 4.72GHz to 6.22GHz, slit in the ground plane is introduced. Figure 6, shows the return loss graph of the fractal antenna with ground slit which removes the notched frequency band.

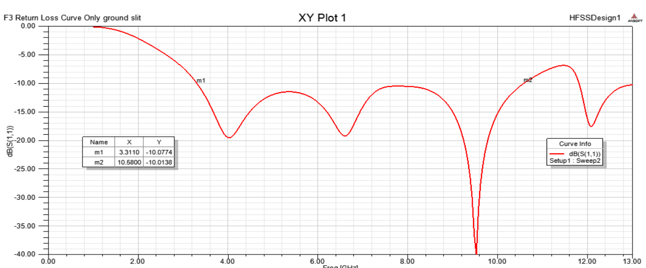

Figure 6: Return Loss graph With Ground Slit

From the graph (Figure 6), it can be inferred that the slit allows antenna to operate on higher frequency component greater than 10.6GHz. Figure 7, shows the return loss graph of fractal antenna with N notch in feed line which eliminates the higher operating frequency component.

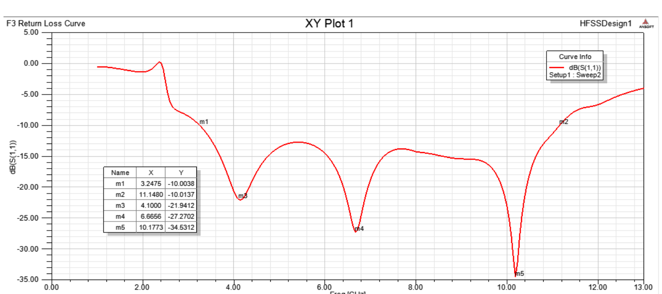

Figure 7: Return loss graph With N notch and ground slit

Figure 8, shows the variation of the slit length at 1.6mm, 1.8mm, 2.0mm and 2.2mm.

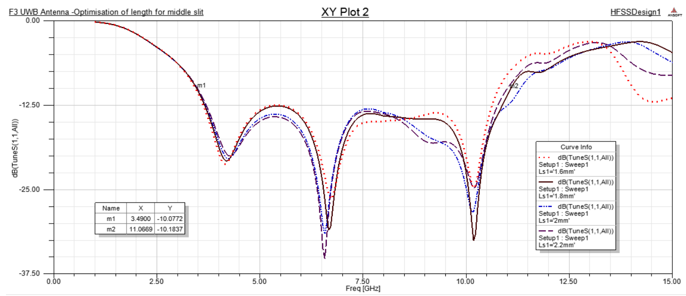

Figure 8: Variation of slit length

Figure 9, shows the variation of slit width for different values at 3.08mm, 4.08mm, 6.08mm and 7.08mm. Slit length of 1.8mm and width 5.08mm is taken due to better return loss and impedance bandwidth.

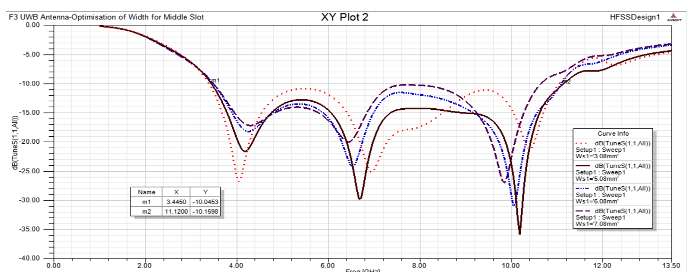

Figure 9: Variation of slit width

The return loss graph for different notch length is shown in figure 10. It can be seen that as length increases from 2mm to 5mm, impedance bandwidth decreases.

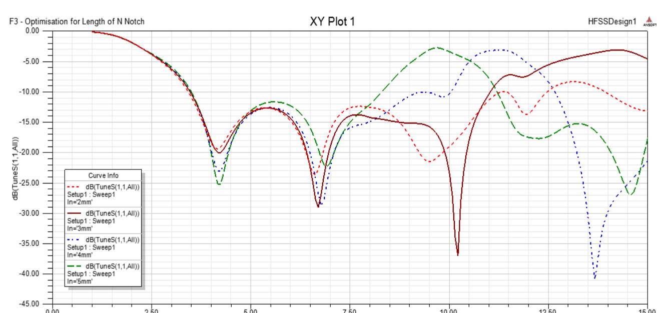

Figure 10: Variation of length of N notch

Figure 11 shows variation of the notch width for width 0.3mm, 0.5mm and 0.7 mm. N notch of length 3mm and

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width 0.5mm is taken after analyzing the optimization graph to achieve the desired UWB impedance bandwidth.

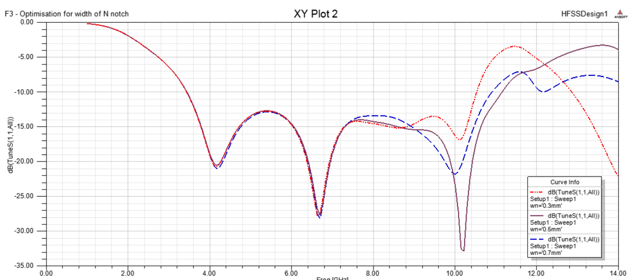


Figure 11: Variation of width of N notch

The VSWR of the Five Face Fractal (3FA) antenna with 'N' notch and modified ground plane is as shown in Figure 12. When N-notch of length 3mm and width 0.5mm is introduced, the antenna bandwidth (2:1 VSWR, or about -10dB return loss) of 3.24–11.14 GHz (figure 7) can be achieved for the UWB applications.

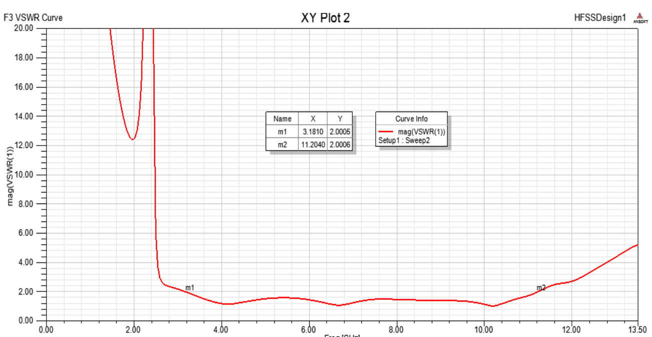
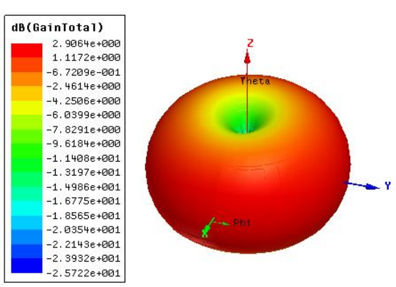
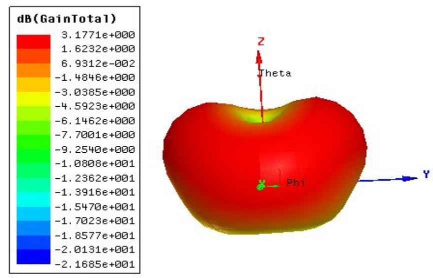


Figure 12: VSWR curve for 3FA Antenna

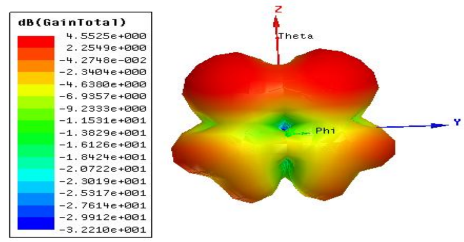
The simulated radiation patterns of this 3FA antenna have been calculated using high frequency structured simulator at frequency 4.1GHz, 6.7GHz and 10.18GHz.



(a)



(b)



(c)

Figure 13: Radiation Pattern at frequency (a)4.1GHz (b)6.7GHz (c)10.18GHz

Figure 13 shows the variation of antenna gain with frequency. The radiation pattern in azimuth plane is nearly omni-directional at lower frequency.

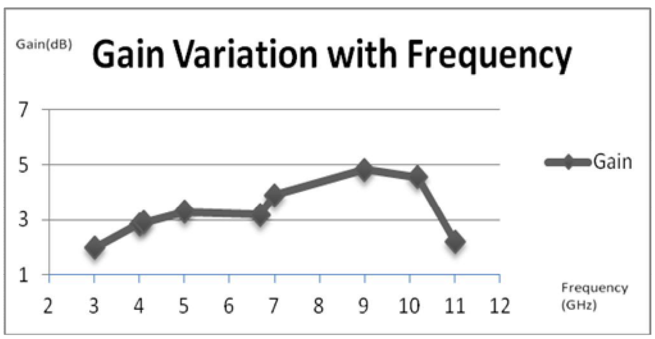


Figure 13:Variation of Gain with frequency

Thus the omni-directional radiation pattern with the desired gain can be used for the indoor UWB applications as WPAN, WBAN and home network application.

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V. CONCLUSION

A compact microstrip fed novel Five Face Fractal Antenna (3FA) has been proposed, designed and fabricate. The antenna has a circular patch of radius 8.5mm and thickness 0.05mm, iterated twice and printed on FR-4 substrate with dimensions 32×34×1.6 mm^3 with nearly omni-directional radiation pattern and operating band ranging from 3.24GHz to 11.14GHz (VSWR<2) with an impedance bandwidth of 7.90GHz. A complete parametric study has been performed in order to obtain an optimal design with each parameter investigated carefully. A middle slit in the ground plane and an N-notch in feed has been introduced in order to improve the return loss curve, impedance bandwidth and to eliminate the operation in higher frequency bands. The presented antenna is very simple, low profile, small in size, easy to fabricate, low cost and can be integrated with MMIC/MICs. This antenna can be used in UWB wireless communication systems, Wireless Personal Area network(WPAN), Home network application and Wireless Body Area Network(WBAN).

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