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A compact multiband wearable fractal antenna for medical and wireless applications

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Abstract - A multiband microstrip patch wearable antenna based on fractal geometry is introduced for ISM band and other wireless applications. The proposed antenna is compact size antenna with 0.56mm textile substrate thickness. The proposed fractal wearable antenna resonates at 2.27 GHz, 4.3 GHz, 6.8 GHz, 8.16 GHz and 9.9 GHz frequencies. It attains high gain of 4.64 dB, 5.54 dB, 5.34 dB and 2.43 dB at 2.45 GHz, 4.3 GHz, 6.8 GHz and 9.9 GHz resonance frequencies respectively. The antenna has a stable radiation pattern at the resonance frequencies. The antenna provides percentage impedance bandwidth of 21.09 % (2.08 GHz to 2.67 GHz), 10.6 % (4.07 GHz to 4.53 GHz), 21.5 % (6.51 GHz to 7.25 GHz), 11.04% (8.6 GHz to 7.7 GHz)and 21.7 % (8.72 GHz to 7.55 GHz). The proposed wearable antenna acts as multiband antenna applicable for ISM band, WLAN, WiMAX, WiFi, INSAT and Radio altimeters, C-band and Satellite TV applications.

Index Terms - ISM band, Microstrip, Textile, Wearable

INTRODUCTION

Wearable technology demand has been growing rapidly and vast researches are being done in this field. Today there is a trend and liability on the smart clothing is increasing day by day. The wearable technology has applications in the medical, defence, safety, WiFi, WiMax and many other fields. There is increasing demand of tracking, health safety and public safety devices worn in the form of wearable devices [1,2]. In recent years, the wearable electronics has paved its ways towards Wireless Body Area Network (WBAN) based systems [3].The wearable antenna plays a vital role in the wearable technology.

The wearable antennas can be designed using different types of substrate materials. In the textile antennas, the substrate material taken is any textile material like jeans, cotton, fleece, silk, polyester etc.as a substrate. The textile antennas are preferred as they are comfortable to wear and highly flexible. The antennas are designed by using patches of different shapes and configurations like T,E,H,A,Y,U, triangle, square and triangular shapes, etc.[4].

ISM (Industrial, Scientific, and Medical) radio frequency bands are designated for medical and commercial wireless applications. The commonly accepted band worldwide is 2.45 GHz ISM band. There are numerous research papers have been published in the field of wearable antennas using different substrate for ISM band and other wireless aplications. The textile antennas designed so far are only single band and dual band antennas working in ISM band [5-7]. Nowadays there is a demand of the multiband wearable antennas and various antennas has been designed using conventional substrates [8-9]. The textile wearable antennas working as multiband antenna has been designed using different textile substrates [10]. But the textile antennas acting as multiband antenna using common jeans substrate are very rare. Earlier the textile antennas used complex EBG, metamaterial structures to attain desired resonance bands and the wide bandwidth [11-12]. In case of wearable antennas, large bandwidth in the compact and inexpensive antennas is the basic requirement these days.

Since fractal geometries are based on two primary properties of space filling and self-similar properties which help the fractal geometries to provide multiband, miniaturization and wide-bandwidth features. In fractal antennas, for same resonance frequency the miniaturization is achieved by different iteration orders. The iterations cause increase in the current flowing path and therefore decreases the physical size of an antenna [13-14]. The performance of the antenna does not get deteriorated with the miniaturization feature of the fractal geometry.

In this paper the fractal wearable textile based antenna is designed. There are various researches done on the fractal geometry but mostly FR4 substrate is used for the antenna design. But in this paper, the widely available textile jeans material is used as a substrate for the proposed fractal wearable antenna design. The proposed antenna is designed by manipulation in the Sierpinski Gasket fractal geometry which provides better antenna performance characteristics. The proposed antenna is applicable for various wireless and medical applications.

The paper is organized in different sections. The section provides the brief introduction of the wearable and the fractal antenna design geometries. The design of the proposed wearable textile antenna is presented in Section II. In the Section III, the simulated analysis of the antenna design is illustrated followed by the conclusion.

ANTENNA DESIGN AND ANALYSIS

A compact microstrip patch antenna has been designed with jeans textile substrate and the copper material for the patch and the ground. The dielectric constant and the loss tangent of the jeans textile material is 1.6 dielectric constant and 0.0631 respectively [15]. The physical dimensions of the patch (LxW) are 24.01 x 53.68 mm2, calculated with the help of mathematical equations of the microstrip patch antenna design [16].

The microstrip patch antenna design is accomplished by following steps:

Step 1: Calculation of the Width of patch (W)

The width of patch

$$W = \frac{c}{2\mathrm{fr}}\sqrt{\frac{2}{\varepsilon\mathrm{r}+1}} \qquad (1)$$

c is free space velocity of light (3×10^8 m/s)

εr is dielectric constant of the substrate

f_r is resonant frequency for the current design

W is smaller, Bandwidth and gain are directly proportional to the W of the antenna will decrease and vice versa.

Step 2: Calculation of effective dielectric constant (ϵ_{reff}).

$$\epsilon\mathrm{REFF} = \frac{\epsilon r+1}{2} + \frac{\epsilon r-1}{2}\left[1+12\frac{\mathrm{H}}{\mathrm{W}}\right]^{\frac{-1}{2}} \qquad (2)$$

h is height or thickness of the substrate.

Step 3: Calculation of the length extension ΔL, which is given by

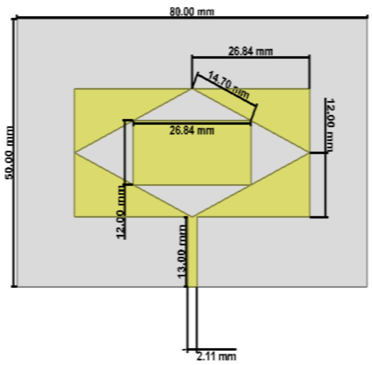
$$\triangle L = 0.412h\frac{(\epsilon\mathrm{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\epsilon\mathrm{reff}-0.268)\left(\frac{W}{h}-0.8\right)} \qquad (3)$$

Step 4: Calculation of the length of patch

$$L = Leff - 2\triangle L \qquad (4)$$

L_{eff} is calculated as

$$Leff = \frac{c}{2fr\sqrt{\epsilon reff}} \qquad (5)$$



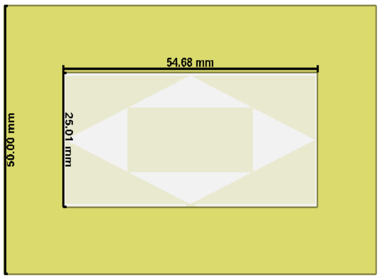


Figure 1: The geometrical structure of the proposed fractal antenna design

The dimensional geometry of the proposed antenna is shown in Figure 1. The thin jeans textile substrate of 0.56mm is used for the antenna design. The proposed antenna dimensions are 50 x80x 0.56mm^3. The feedline used for the microstrip patch antenna design is 13x2.11mm^2. The adhesive copper tape is used for the radiating patch and the ground plane of the fabricated antenna. The thickness of the adhesive copper tape is 0.035mm.

Table 1: Dimensions of the rectangle and the diamond

Iteration No.	Dimensions of the rectangle/square
1	24.01 x 53.68 mm^2
2	29.4 x 29.4 mm^2
3	12 x 26.84 mm^2

The proposed fractal wearable textile antenna is designed by using modified Sierpinski Gasket fractal geometry. In the iteration 1, the proposed antenna is designed by etching diamond shape in the rectangular patch. In the iteration 2, the rectangle is added in the diamond slot as so on for further iterations.

SIMULATED PERFORMANCE ANALYSIS RESULTS

I. S-Parameters

The proposed fractal antenna is designed and simulated on CST Microwave Studio 2018.The proposed antenna resonates at 2.27 GHz, 4.3 GHz, 6.8 GHz, 8.16 GHz and 9.9 GHz with reflection coefficient of -14.67 dB, -15.68dB, -28.81dB, -33.4dB and -14.61dB respectively as shown in Figure 2. The antenna provides percentage impedance bandwidth of 21.09 % (2.08 GHz to 2.67 GHz), 10.6 % (4.07 GHz to 4.53 GHz), 21.5 % (6.51 GHz to 7.25 GHz), 11.04% (8.6 GHz to 7.7 GHz) and 21.7 % (8.72 GHz to 7.55 GHz).The proposed wearable antenna acts as multiband antenna applicable for ISM band, WLAN, WiMAX, WiFi, INSAT and Radio altimeters, C-band and Satellite TV applications.

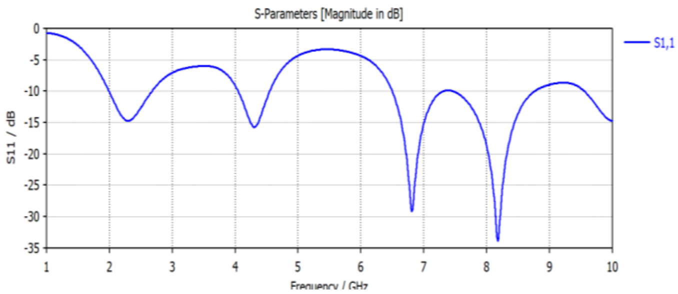
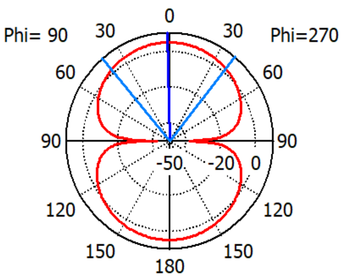


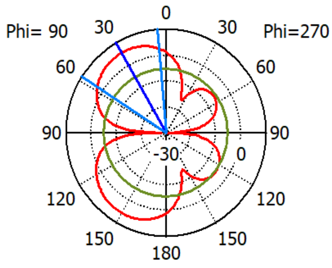
Figure 2: The simulated reflection coefficient vs frequency graph of the proposed antenna

II. Radiation Pattern

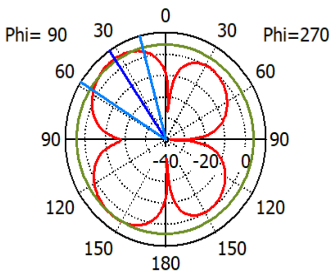
The radiation pattern is illustrated in Figure 4. It is predicted from the Figure 4 that the antenna provides desired omnidirectional pattern x-y plane. The wearable antenna requires providing omnidirectional pattern as it is attached to the human body, so the antenna acts as a moving object in all the directions.



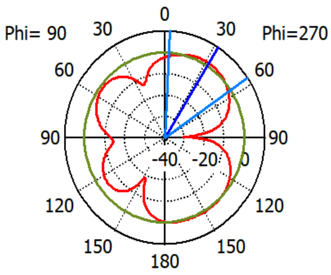
a)



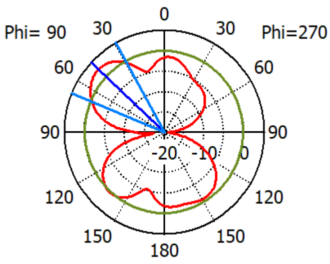
b)



c)



d)



e)

Figure 4: The Radiation pattern of the proposed antenna at a) 2.45 GHz b) 4.3 GHz c)6.8 GHz d)8.16 GHz e) 9.9 GHz resonant frequencies

The proposed antenna attains high gain of 4.64 dB, 5.54 dB, 5.34 dB and 2.43 dB at 2.45 GHz, 4.3 GHz, 6.8 GHz and 9.9 GHz resonance frequencies respectively.

III. Surface Current Density

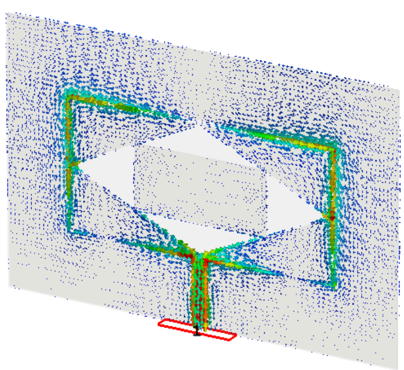


Figure 5: Surface current density at 2.45 GHz frequency

The Figure 5 reveals the surface current density flow at 2.45 GHz resonance frequency which is applicable in desired ISM band. The resonance at 2.45 GHz frequency is achieved mainly due to the corners of the rectangular slots in the patch.

Table 2: Comparison of the proposed antenna with the existing researches

Reference No.	Resonating Frequency (GHz)	Substrate	Thickness of substrate (mm)	Gain (dB)
[17]	2.45, 5.8	Jeans	0.05	2.2 dB at 2.45 GHz, 1.6dB at 5.8GHz
[18]	2.43/2.5	Jeans	0.44	2.3 dB/4.3dB
[19]	2.6/3.8/ 5.3	FR4	1.6	2.98 dBi, 2.58 dBi, and 3.34 dBi at 2.6 GHz, 3.8 GHz, and 5.3 GHz, respectively.
[20]	3.8/ 5.8/7	Jeans	0.7	3.12dBi at 3.8 GHz, 5.50 dBi at 5.8 GHz,5.89 dBi at 7GHz
Proposed Antenna	2.27/ 4.3/ 6.8, 8.16 /9.9	Jeans	0.56	4.64 dB at 2.45 GHz, 5.54 dB at 4.3 GHz, 5.34 dB at 6.8 GHz and 2.43 dB at 9.9 GHz

The Table 2 provides the comparison of the proposed antenna design with the existing work in the field of multiband antenna designs. The proposed antenna resonates at different frequency bands due to its fractal geometry. The antenna provides high gain at the resonance frequencies. In [19], antenna is designed based on fractal geometry using FR4 substrate. The proposed antenna is designed by using thin jeans substrate so that it can be used comfortably as a wearable antenna for the desired ISM band and other wireless applications.

CONCLUSION

In this paper the compact fractal wearable textile antenna is designed using jeans textile material as a substrate. The antenna has a stable radiation pattern at the resonance frequencies. The proposed antenna resonates at 2.27 GHz, 4.3 GHz, 6.8 GHz, 8.16 GHz and 9.19 GHz frequencies. The antenna provides percentage impedance bandwidth of 21.09 % (2.08 GHz to 2.67 GHz), 10.6 % (4.07 GHz to 4.53 GHz), 21.5 % (6.51 GHz to 7.25 GHz) and 21.7 % (8.72 GHz to 7.55 GHz). The antenna provides wide bandwidth for different wireless and medical applications. The proposed wearable antenna acts as multiband antenna applicable for ISM band, WLAN, WiMAX, WiFi, INSAT and Radio altimeters, C-band and Satellite TV applications. The proposed antenna attains high gain of 4.64 dB, 5.54 dB, 5.34 dB and 2.43 dB at 2.45 GHz, 4.3 GHz , 6.8 GHz, 8.16 GHz and 9.9 GHz resonance frequencies respectively.

CONFLICT OF INTEREST

"The authors declare no conflict of interest".

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