Design and Fabrication of Multi-band Wearable Fractal Antenna for Telehealth Applications

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Abstract. In this paper, a Multi-band Wearable Fractal Antenna is fabricated for Telehealth Applications. The projected antenna substrate is made from a flexible Jeans textile material. The dielectric properties of this textile can be measured by two different methods. Also, a folded copper tape is used to fabricate the projected wearable antenna. Further, the projected antenna under the bent conditions is studied in details. The specific absorption ratio (SAR) is also studied in this paper. The projected antenna is simulated by CST simulator version 2018 and measured by Agilent8719ES VNA. Finally, there is a large convergence between the measured and the simulation results.

1. Introduction

Health care is an important human right and it should not be considered a benefit for the only some [1]. However, little resources and funding cuts are dangerously affecting public services in many places, as well as health care [2]. Therefore, telemedicine is considered as one of the solutions for a reduction of the public costs related to health care, while still providing support for the elderly and ensuring a good quality of life [3]. On the other hand, the wearable compact antenna with better performance and multi-bands working frequencies is one of the main trends in modern medical wireless communications systems [3]. One of the most important techniques used to reduce the antenna’s dimensions and achieved the multi-bands working frequencies is the fractal geometries. A fractal is a fragmented or split geometric shape that can be subdivided into parts; each of this is a reduced-size copy of the whole [4]. There are more benefits for the fractal antennas and the most
important of them; its trade-off between the antenna performance (good efficiency, large bandwidth, and high gain) and the antenna dimensions (compact size) [4].

In this paper, the second iteration wearable fractal antenna is designed which based on the rectangular shape. The antenna substrate is made from jeans of textile material. So, to determine the dielectric properties for Jeans textile material (relative permittivity ($\varepsilon_r$) and dielectric loss tangent ($\tan\delta$)), two different experimental methods are used in this paper to confirm the results: a DAK (Dielectric Assessment Kit) method and microstrip ring resonator method. The projected 2nd iteration wearable fractal antenna is operated at three resonance frequencies which is suitable for WiMax, WiFi and satellite applications. Due to the continues movement of the human body, the wearable antenna impossible to be flat at all times, so the projected antenna under the bent conditions is studied in details. Also, the SAR values at all resonance frequencies are investigated to make sure that the projected antenna in this paper is operated safely closed to the human body.

2. Determination of the Jeans dielectric properties

Firstly, in this paper DAK (Dielectric Assessment Kit) equipment is used for dielectric measurements such as permittivity, loss tangent. It is the solution for all applications where the dielectric measurements are required [5]. The results of this equipment are tabulated in Table 1.

| Substrate Material | dielectric constant ($\varepsilon_r$) | loss tangent ($\tan\delta$) |
|--------------------|------------------------------------|---------------------------|
| Jeans              | 1.78                               | 0.085                     |

Now, the second method in this paper is called a microstrip ring resonator method [6] as shown in Figure 1. This ring is simulated and fabricated to obtain other results to confirm the results obtained by the first method. The results for this method are tabulated in Table 2. Furthermore, the digital screw gauge is used to measure the thickness of the jeans textile is 0.6 mm.

![Figure 1](image_url)
Table 2. The Experimental Results for the Ring Resonator Model

| Textile Material | The Microstrip Ring Resonator Method |
|------------------|--------------------------------------|
|                  | Mode | Resonance Frequency (GHz) | S21 (dB) | dielectric constant ($\varepsilon_r$) | loss tangent ($\tan \delta$) |
| Jeans            | n=1  | 4.26                       | -35.5    | 1.73                                  | 0.077                         |
|                  | n=2  | 8.89                       | -36.9    | 1.69                                  | 0.073                         |

3. The Rectangular Wearable Fractal Antenna Geometry

The 2nd wearable fractal antenna structure depends on the rectangular shape. The basic geometry is called as; “initial iteration” is a rectangle. Next, the 1st iteration geometry is constructed by etching an ellipse on the center of the basic rectangular and then putting inside it a secondary rectangle smaller than the basic rectangular and contacts the edges of elliptical by its corners. Similarly, the 2nd iteration geometry can be obtained by the same process of the 1st iteration geometry and also the extra iterations [7].

Figure 2 represents the geometries and the simulated $S_{11}$ for the three antenna structures. Also, in Table 3 there is the required dimension which used to design both of the patch and the ground plane and some of the characteristics for the Jeans substrate. Furthermore, the radiation patterns of the projected 2nd iterations of the fractal wearable microstrip antenna in E-plane ($\Phi = 0^\circ$) and H-plane ($\Phi = 90^\circ$) are plotted in Figure 3.

Table 3. Dimensions of the projected Antenna and The Characteristics of Jeans Substrate

| Ground Dimensions | The Patch Dimensions |
|-------------------|----------------------|
| $A_g$  | $B_g$  | $A_p$  | $B_p$  | $A_f$  | $B_f$  | $A_1$  | $B_1$  | $A_2$  | $B_2$  | $M_1$  | $N_1$  | $M_2$  | $N_2$  |
| 57    | 50    | 37    | 30    | 3     | 10    | 15     | 18.5   | 7.5    | 9.25   | 12     | 11.85  | 6      | 5.9     |

The Jeans Substrate Characteristics

| Dielectric Constant ($\varepsilon_r$) | Loss Tangent ($\tan \delta$) | Thickness (mm) |
|--------------------------------------|-------------------------------|-----------------|
| 1.78                                 | 0.085                         | 0.6             |
As of Figure 2, the projected 2\textsuperscript{nd} iteration fractal wearable microstrip antenna has three resonance frequencies can be operated in various applications. The first frequency band from 3 to 3.315 GHz with return loss -20.142 dB, gain 4.3 dB and efficiency 66.7%, this band can be used in WiMax for modern wireless applications. The second frequency band from 5.503 to 6.03 GHz with return loss -21.77 dB, gain 5.3 dB and efficiency 75.2%, this band can be used in WiFi for modern wireless applications the third frequency band from 6.44 to 7.07 GHz with return loss -18.7 dB, gain 3.44 dB and efficiency 64.9%, this band can be used in satellite applications.

Figure 2. The three structures of Rectangular Wearable Fractal Antenna: (a) geometry and (b) simulated $S_{11}$ with the Frequency.

Figure 3. Radiation Pattern for the antenna in H and E-planes at 3.3, 5.8 and 6.7 GHz
4. Experimental Results and Discussion

Considering that the simulation results of the 1st iteration are very close to the simulation results of the 2nd iteration as shown in Fig. 3 and this simple difference was the result of small dimensions. So, to facilitate the process of manufacturing as it is done manually without machine intervention was manufactured the 1st iteration instead of the 2nd iteration. The fabricated geometry of the projected antenna is shown in Figure 4. The measured and simulated $s_{11}$ of the projected crown rectangular fractal antenna is plotted in Figure 5. From Figure 5, the simulated and experimental results are close to each other but there is a little shift due to the manufacturing process.

![Prototype of the Projected Crown Fractal Antenna: (a) Top, and (b) Bottom Views](image)

**Figure 4.** Prototype of the Projected Crown Fractal Antenna: (a) Top, and (b) Bottom Views

![Measured and Simulated S11 with Frequency for the Projected Wearable Antenna](image)

**Figure 5.** Measured and Simulated S11 with Frequency for the Projected Wearable Antenna.

5. Bending Effect on the Antenna Impedance Characteristics

To study the bending effect on the impedance characteristics of the projected antenna, this antenna is bent around curved surfaces with typical diameters of the human arm and shoulder as respectively 150 mm and 200 mm [8]. The results for wearable fractal projected antenna for a flat position and for both bending diameters are shown in Figure 6. From these results, found that the resonant frequency remains approximately stable for a certain amount of bending.
Figure 6. $S_{11}$ for the projected antenna in a flat position and two different bending diameters.

6. SAR Calculation

As a result of the projected antenna is a body-worn antenna, the amount of power that absorbed by the human body tissues must be calculated to ensure that projected antenna is operated safely closed to the human body. The specific absorption ratio (SAR) value is calculated to quantify the power absorbed per unit mass of tissues [9]. This value must be satisfied the international safety standards (FCC & ICNIPR). Figure 7 illustrates the SAR distribution results for the projected fractal wearable antenna. These results are tabulated in more details in table 4. From these results, found that the SAR values are very low.

Figure 7. SAR distribution on human voxel model at (a) 3.3, (b) 5.8, and (c) 6.7 GHz.

Finally, this design is compared with newly published work in the literature. These results are tabulated in Table 5.
Table 4. Maximum SAR values for the projected antenna by FCC and ICNIPR standards

| Resonance Frequency (GHz) | SAR value (w/kg) 10g | SAR value (w/kg) 1g |
|--------------------------|---------------------|---------------------|
|                          |                     |                     |
| 3.3                      | 0.144               | 0.352               |
| 5.8                      | 0.0867              | 0.237               |
| 6.7                      | 0.235               | 0.384               |

Table 5. Comparison between this work and other published works

| Ref. | Resonant Freq. | Substrate material | S_{11} (dB) | Gain (dB) | SAR Study | Bending study |
|------|----------------|--------------------|-------------|-----------|-----------|--------------|
|      |                |                    |             |           |           |              |
| [10] | 3.75           | FR4                | -21.3       | 3.12      | Fabrication | No study, No study |
|      | 4.27           |                    | -20.1       |           |           |              |
|      | 6.81           |                    | -18.7       |           |           |              |
| [11] | 2.7            | Jeans              | -23.6       | 4.1       | Fabrication | No study, study |
|      | 1              |                    | -19.2       | 1.35      |           |              |
|      | 3.3            |                    | -20.14      | 4.3       |           |              |
|      | 5.8            |                    | -21.77      | 5.3       |           |              |
| This work | 6.7          | Jeans              | -19.9       | 3.44      | Fabrication | study, study |

7. Conclusion

This paper presented a multi-band fractal antenna printed on jeans substrate for telehealth applications. The design evolution is clear from rectangular monopole antenna till the proposed multiband fractal antenna. In order to determine the dielectric properties of Jeans material, two different experimental methods are used in this paper to confirm the results, where there was a great convergence of results of the two methods. The projected antenna is fabricated to operate at three frequencies 3.3, 5.8, and 6.7 GHz at the same time and with good performance for WiFi and WiMax applications over body area network and also satellite applications. Furthermore, bending the antenna on the human arm and shoulder are investigated where the results were very close to the flat position. Also, SAR values proved that the projected wearable fractal antenna can be operated safely near the human body.
8. References

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