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Super Wideband Wearable Fractal Antenna For Wireless Communication

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ABSTRACT: A fractal antenna is an antenna that uses a fractal, self-similar design to maximize the length, or increase the perimeter (on inside sections or the outer structure), of material that can receive or transmit electromagnetic radiation within a given total surface area or volume. Such fractal antennas are also referred to as multilevel and space filling curves, but the key aspect lies in their repetition of a motif over two or more scale sizes, or "iterations". Fractal antennas can obtain radiation pattern and input impedance similar to a longer antenna, yet take less area due to the many contours of the shape. Fractal antennas are a fairly new research area and are likely to have a promising future in many applications. Wireless mobile communication systems require increased bandwidth for data and voice applications. Wearable electronics has many applications in the field of telemedicine, sports, military and tracking systems. In this paper wideband wearable fractal antenna with line feed is designed using ANSYS Electronic Design Kit (HFSS v17) software. Proposed antenna works from 4.3GHz to 30 GHz wideband. Proposed antenna can be used for Ultra Wide Band applications.

KEYWORDS: fractal; super-wideband; ultra-wideband; wearable antenna

I.INTRODUCTION

Wearable antenna is latest technology that has application in many fields of wireless communication. Many researchers have been performed for the use of different types of fabrics and polymers as the substrate materials which has least thickness and can be folded very easily. AN antenna which is appropriate to wear is called wearable antenna. In other words, these antenna serves as part of clothes, whose function are directly related to telecommunication communication systems which can be used in radar application, remote computing and communication responsibilities related to safety of public [1]. Flexible antennas become more attractive in the recent developments of wearable computing to integrate the wireless functions in the clothing. This technology is used for the goal of wearable electronics and antennas. Textile antenna is one of the most attractive and critical edge investigation areas of recent era. Body wearable antennas should be hidden [2]. This antenna is very flexible and compact in size that is why it cannot interrupt the movement of the wearer. Different textile/cloth based materials are used to manufacture these antennas such as cotton, fleece fabric, foam, nomex, nylon, polyester, conducting ribbon, insulated wire, conducting paint, copper coated fabric, geo textile [3]. These antennas have been fabricated on the various textile substrates for body centric communication systems that cover Wi-Fi, Wi-Max, WLAN, HYPER LAN, BAN, Bluetooth and SWB applications [4]. Wearable antennas need to be flexible, hidden and light weight, considering the convenience of the user. Therefore, textile wearable antennas have become the focus of many antenna research efforts due to their flexibility, durability, and suitability for a extensive variety of applications such as wireless medical or wireless communication applications and objects surveillance [5]. In recent years, wearable electronics engineering has been gaining. Different types of antennas have been designed for wearable purpose in the form of bendable metal patches. Textile materials are used as substrate for the design of these antennas [6]. A large number of research papers are available in literature on the design, application and fabrication of these antennas and wearable electronics communication systems [7]. Electrically conducting materials are required for ground plane and microstrip patch for the design of wearable antennas. These conducting materials should have a low and stable electric resistance (1ohm/square) in order to minimize the losses. Thus for achieving the necessary performance of these antennas, conducting properties of the materials plays a significant role in antenna design and fabrication.

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The commercial use of frequency bands from 3.1 to 10.6 GHz was approved for Ultra Wide Band (UWB) system by Federal Communications Commission (FCC) in 2002 [8]. The frequency range above 10 GHz is called Super Wide Band (SWB), in late 1950s and early 1960s; a family of SWB antennas was developed by Rumsey et.al, which was classified as a class of frequency- independent antennas [9]. Recently, there are many monopole antennas are proposed for the SWB applications [10]. By merging the UWB and SWB technology with textile technology, UWB and SWB antennas using clothing material like polyester which is suitable for wearing applications is proposed in this paper. Unlike in the previous design of wearable antennas only the UWB technology is used, but now the proposed antenna presented in this paper works on both the UWB and SWB communication applications.

II. ANTENNA DESIGN

The design of 0th, 1st and 2^{nd} iterations of wearable fractal antenna are shown in Fig. 1. The proposed novel wearable fractal antenna with the dimensions of 20 x 20 mm is designed on width W_f and length L_f of the microstrip feed line to get the 50 ohm characteristic impedance are fixed at 1.9 x 4.1 mm, respectively. Due to the fractal iteration on the patch of the antenna the bandwidth of the antenna will be increased [11]. The fractal patch on the upper side of the substrate has a distance from the ground plane is Z =0.5mm. The width of the ground plane W_g = 20 mm and is equal to the width of the substrate and length L_g = 3.47 mm. To get the best performance of the proposed antenna, it was simulated on the Ansoft HFSS V13 software. In order to optimize the final design many aspects has been considered, like to improve the impedance bandwidth by introducing rectangular notch (Slot S1) at the feeding position in the semi-elliptical ground plane. The geometry of the proposed wearable antenna with defected ground plane is shown in Fig. 2 and its parametric values are shown in Table 1.

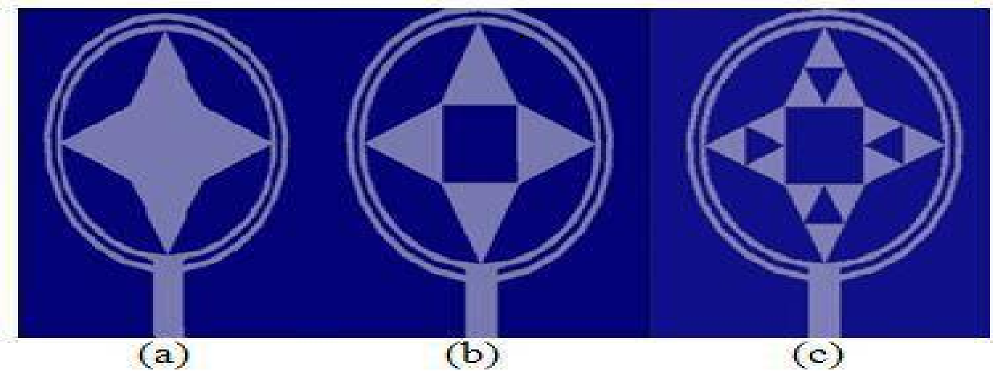

Fig.1. (a) 0^{th} (b) 1^{st} and (c) 2^{nd} iterations of proposed wearable fractal antenna

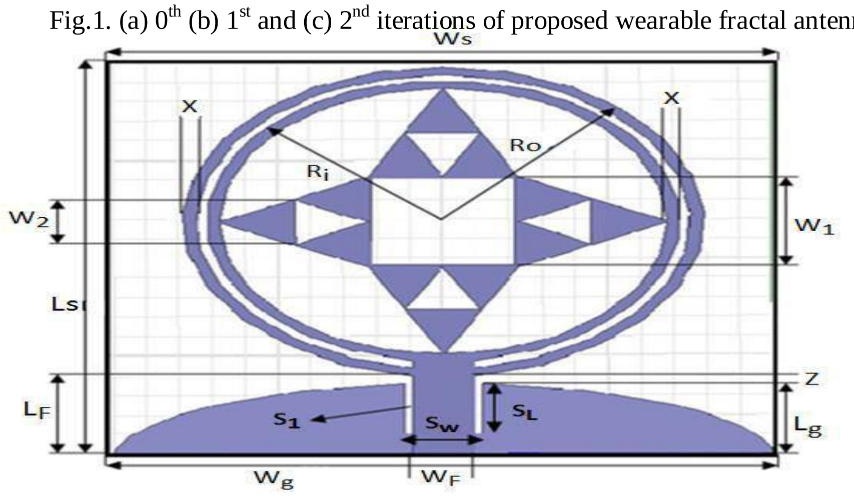

Fig.2. Geometry of proposed wearable fractal antenna

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To provide a reasonable comparison between two wideband antennas (especially UWB antenna), The authors have used and index term that will allow antenna engineers to identify if their planar antenna design (compared against the other design) is very much compact in size and wide in bandwidth. Here, to determine both the compactness and wideband characteristics of a planar antenna, we use this index term that named the bandwidth dimension ratio (BDR). This index term will indicate how much operating bandwidth (in percentage) can be provided per electrical area unit [12]. The equation is written as where is the wavelength of the lower-edge frequency of the band that meets the 10-dB return loss. Here, a larger BDR will indicate that the design antenna is smaller in dimension and wider in bandwidth [13]. The results of the comparison between the proposed MSTF and the other good designs, presented in[14] (all references antenna cover the UWB spectrum), are summarized. The antenna performances such as ratio bandwidth, 10-dB bandwidth, electrical dimension, and BDR are listed. The measured results of the parameter of the designed antenna are presented. The 10-dB bandwidth of the proposed antenna is 190% (1–30 GHz) and 193% (0.5–30 GHz) for the measured antenna, and a ratio band of 30:1 and 60:1respectively calculated. From the simulation and measured results. It is observed that the impedance bandwidth increases as the fractal iterations are increased, and simulation and measured results are compatible. Thus, we have maximum impedance bandwidth for SWB applications up to now. Measured results of the radiation patterns of the corresponding proposed MSTF antenna at 3.6, 7, 15, and 30 GHz are depicted. It is seen that the MSTF antenna provides omnidirectional radiation pattern sin the H-plane and stable patterns in the form of figure-eight in the E-plane. The simulated and measured peak gain variation of the proposed MSTF is displayed. Here, a raising gain from 14 to 30 is manifest with small area.

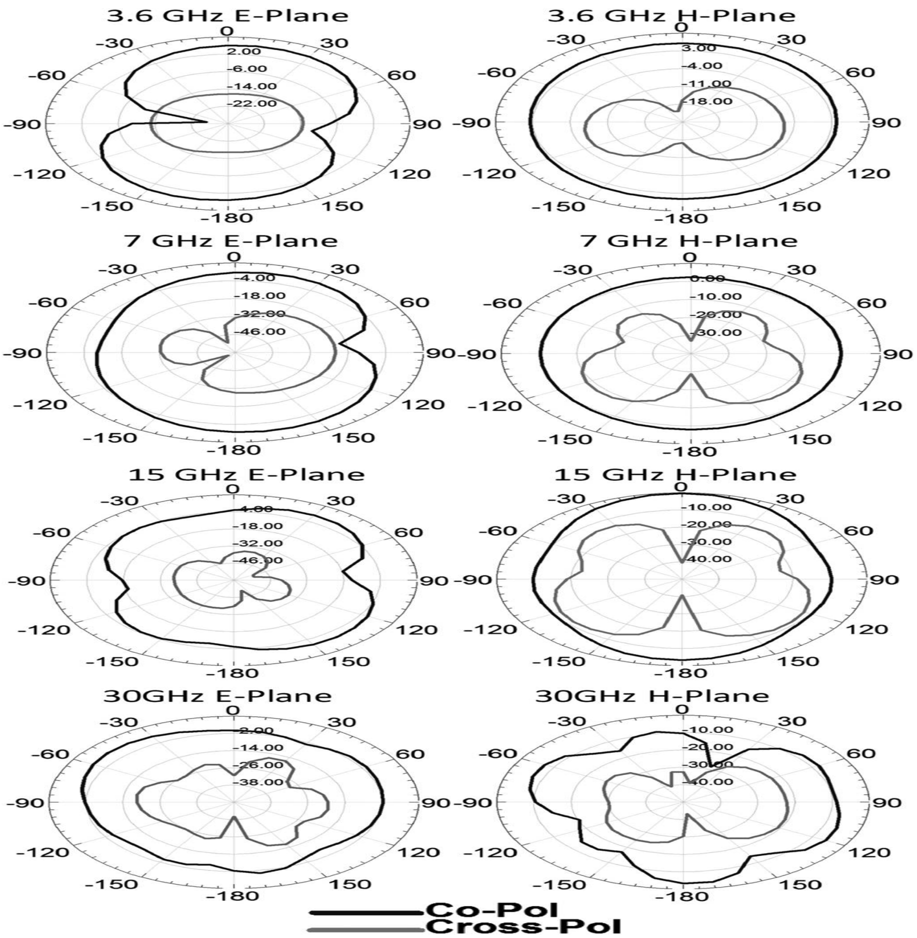

Fig.3. Measured E (xz)-plane and the H (yz)-plane radiation patterns of pro-posed MSTF antenna at 3.6, 7, 15, and 30 GHz.

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The measured results of the S_{11} parameter of the designed antenna are presented. The 10- dB bandwidth of the proposed antenna is 190% (1–30 GHz) and 193% (0.5–30 GHz) for the measured antenna, and a ratio band of 30:1 and 60:1 respectively calculated. From the simulation and measured results, it is observed that the impedance bandwidth increases as the fractal iterations are increased, and simulation and measured results are compatible. Thus, we have maximum impedance bandwidth for SWB applications up to now. Measured results of the radiation patterns of the corresponding proposed MSTF antenna at 3.6, 7, 15, and 30 GHz are depicted. It is seen that the MSTF antenna provides omnidirectional radiation pat-terns in the H-plane (yz-plane) and stable patterns in the form of figure -eight in the E-plane (xz- plane). The simulated and the measured peak gain variation of the proposed MSTF is displayed. Here, a raising gain from 14 to 30 is manifest with small fluctuation in intermediate frequencies. The gain is stable along 1–14 GHz of the antenna operating band. Also, radiation efficiency is presented. We see that good adjustment is available between simulated and measured results. In designing UWB and SWB antennas, it is not sufficient to evaluate the antenna performance in traditional parameters such as S_{11} , gain and radiation patterns, etc. In order to verify the capability of the proposed MSTF antenna to operate as a UWB or SWB antenna, it is necessary to achieve a consistent group delay. The group delay needs to be constant over the entire band as well [15], [16]. Measurement of group delay is performed by exciting two identical prototypes of the MSTF antenna kept in the far field for two orientations: side by side and face to face. The separation between the identical MSTF monopole antenna pairs was 1 m. It indicates magnitude of group delay for side -by-side and face -to- face orientations of the MSTF antenna. It is observed that the group delay variation is less than 0.1 ns for side- by - side and 0.2 ns for face-to-face orientations over SWB. It is also interesting to mention that MSTF is invented by the authors for the first time. It is observed that in comparison to other fractal and SWB antennas, we have exciting results and very compact dimension having both SWB and fractal properties.

III. MONOPOLE ANTENNA CONFIGURATIONAND DESIGN

As illustrated in Fig. 1, the cardioid-shaped conductor–backed plane is placed under the radiating fractal patch and is also symmetrical with respect to the longitudinal direction. The conductor–backed plane perturbs the resonant response and also acts as a parasitic structure, electrically coupled to the fractal monopole. The cardioid patch has a length of R_1, width of R_2, and a distance of G to the ground plane, printed on the back surface of the substrate. Note that G stands for the distance of cusp and ground plane. The name cardioid comes from the heart shape of the curve. The cardioid is given by the following parametric equations:

$$x(t) = 2r_1(\cos(t) - 0.5\cos(2t))$$
$$y(t) = 2r_2(\sin(t) - 0.5\sin(2t)).$$

Ultra wideband signals will have some significance in on body communications and there is much work underway to characterize the path loss and dispersion properties. On-body propagation channel measured was performed using a cpw-fed UWB antenna. For this measurement, a matrix of measurement points is used for reliable and efficient channel characterisation and modelling with minimum distance between Tx and Rx of 10cm. Different antenna positions and various angular orientations are applied with reference to the transmit antenna on the right waist. When comparing impulse performance of the antenna placed on the body at different angular position, a minimum fidelity of 60% can be obtained. The probability density function of measured path loss data for all body postures and all antenna orientations fitted well to a normal Gaussian distribution with a high scaling (σ =14.5) value. This variation is due to body geometry changes, including angular positions, which verifies the rapidly changing on-body environment. Also, radiation efficiency is presented. We see that good adjustment is available between simulated and measured results. In designing UWB and SWB antennas, it is not sufficient to evaluate the antenna performance in traditional parameters such as S_{11} , gain and radiation patterns, etc. In order to verify the capability of the proposed MSTF antenna to operate as a UWB or SWB antenna, it is necessary to achieve a consistent group delay. The group delay needs to be constant over the entire band as well. Measurement of group delay is performed by exciting two identical prototypes of the MSTF antenna kept in the far field for two orientations: side by side and face to face. The separation between the identical MSTF monopole antenna pairs was 1 m. Thus, we have maximum impedance bandwidth for SWB applications up to now. Measured

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results of the radiation patterns of the corresponding proposed MSTF antenna at 3.6, 7, 15, and 30 GHz are depicted. It is seen that the MSTF antenna provides omnidirectional radiation pat-terns in the H-plane (yz-plane) and stable patterns in the form of figure -eight in the E-plane (xz- plane).

TABLE 1. PARAMETRIC VALUES OF PROPOSED ANTENNA

Parameters	Description	Values
Ws=Wg	Width of the substrate	20 mm
Ls	Length of the substrate	20 mm
Lg	Length of the ground plane	3.6 mm
Ri	Radius of the inner ring	7.2 mm
Ro	Radius of the outer ring	7.8 mm
W_F	Width of the feed line	1.9 mm
L_F	Length of the feed line	4.1 mm
W_1	Width of the triangle	4.6 mm
W_2	Width of the inner triangle	2.3 mm
Z	Distance between patch and ground Plane	0.5mm
X	Space between the circles	0.4 mm

The return losses v/s frequency curves of 0th, 1st and 2nd iterations of proposed wearable antenna with simple semi-elliptical ground plane are shown in Fig.3. It shows that for all the three iterations impedance matching is not proper because it only covers few frequency bands between the frequencies range from 0.1 to 30GHz. To increase the impedance bandwidth further a rectangular slot S1 is introduced at the feeding position in the semi-elliptical ground plane of the 2nd iteration of the proposed antenna which is the final design of the antenna. The effect of impedance bandwidth due to the change in the length S_L and width S_W of the slot S1 keeping other parameters fixed. It is also interesting to notice that the proposed antenna has an area of 625 mm2 (25 mm × 25 mm), which is less than the area of the presented antenna (9025 mm2) in [17] with dimensions of 95 mm × 95 mm and thickness of 1.5 mm.

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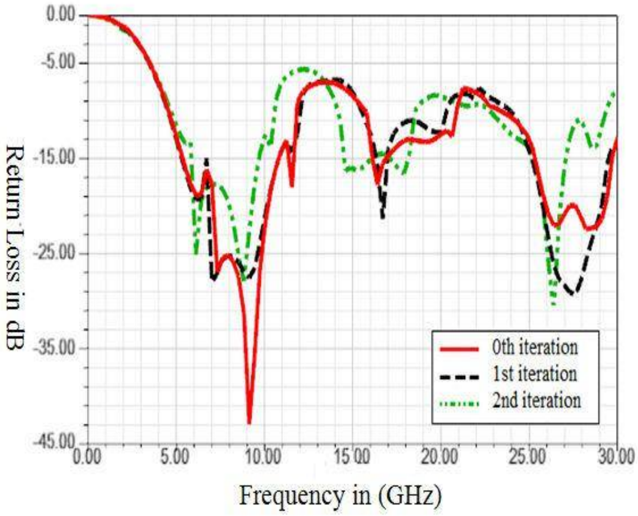

Fig.4. Return loss v/s frequency plot of designed antenna with simple semi-elliptical ground plane

For a given physical length of an antenna, if the density of the electric or magnetic field in a section of the antenna is increased, the antenna's electrical length is also increased, which is called capacitive loading or inductive loading. Based on the over coupling condition between the fractal and cardioid parasitic patches, placing the cardioid parasitic patch increases the electric field density between the fractal and cardioid patches in the substrate, leading to the capacitive loading condition and the increase of electrical length of the antenna.

IV. CONCLUSION

In this paper the novel design of wearable fractal antenna for wideband application is presented. Due to the use of the clothing fabric such as polyester the antenna has satisfied the requirements of antenna for wearing purpose. Due to the compact size of the antenna has less influence on the human body. By using the optimization technique at the defected ground plane the designed antenna works on the frequency range of 4.3 GHz to 29.6 GHz which fulfill the requirements of the UWB and SWB applications. The use of medical implants will increase as the number and capability of nano and micro sensors and devices increases. Communications between implants may then be used to form networks, which improve the system functionality. It could be said that system design will be unique to the implant function required, but for future design and production efficiency through commonality, more systematic studies of antennas and propagation for implant are required. A novel MSTF monopole antenna with a very compact size was presented and investigated. We showed that by increasing the MSTF iteration and optimizing antenna parameters with proper values, a very good impedance matching and improvement bandwidth can be attained. This would be the result of the fractal's space filling and its special layout properties. The operating bandwidth of the proposed MSTF antenna covers the en-tire frequency band from 1 to 30 GHz. Both measured and simulated results suggested that the proposed MSTF antenna can be suitable for UWB and SWB communication applications.

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