Circularly Polarized Metamaterial Based Fractal Wearable Antenna for Wireless Applications

[1] Mehaboob Mujawar, [2] Bhagyashree Goudar, [3] Kaveri Basarakod and[4] Aishwarya Kalal
[1,2,3,4] Bearys Institute of Technology, Mangalore, Karnataka, India

Article Info
A. Haldorai et al. (eds.),*2nd International Conference on Materials Science and Sustainable Manufacturing Technology,* Advances in Computational Intelligence in Materials Science.
Doi:https://doi.org/10.53759/acims/978-9914-9946-9-8_4

Abstract - The design of wearable fractal antenna on the spiral shaped Metamaterial (MTM) substrate suitable for Industrial, Scientific and Medical (ISM) (2.4-2.45GHz) frequency bands is presented in this paper. To reduce the SAR value a spiral metamaterial meander is introduced in the ground plane. High-Frequency Structure Simulator (HFSS) software was used to design the antenna. Maximum allowedSpecific Absorption Rate (SAR) value is 1.6 W/Kg which indicates that the wearable antennas are safe for human. Jeans substrate is used to design the antenna. The reflection coefficient of the antenna is -27 dB and the Voltage Standing Wave Ratio (VSWR) of the antenna is 1.05. The SAR value of the proposed antenna when placed on Phantom neck is 0.78 W/Kg, which makes it suitable for wearable applications.

Keywords - Metamaterial, Wearable, ISM, SAR, Gain, VSWR, Reflection Coefficient, Circular Polarization.

I. INTRODUCTION

Antennas play important vital role for better performance of wireless communication system. It does not matter whether it is a mobile phone, complex radar system and satellite communication system. Antennas are eyes and ears of the wireless communication system. they are our links with the space. Nowadays, in many of the field especially in antenna field, metamaterials are used for improving gain and bandwidth. Metamaterials are artificial materials having electromagnetic properties which are not existing in the nature. A synthetic composite material with a structure such that it exhibits properties not usually found in natural materials, especially a negative refractive index. Metamaterials can be classified on the basis of $\varepsilon \, and \, \mu$ in four quadrants.it is introduced by victor veselago a Russian physicist. The metamaterial used as a metallic mesh of thin wires for obtaining value of ε. A single cell Split Ring Resonator (SRR) has a pair of enclosed loops with splits in them at opposite ends. The loops are made of non-magnetic metal like copper and have a small gap between them. the loops can be concentric or square and gapped as needed. Reactive impedance surface is used for implementing broad band microstrip antennas. High impedance surface is also used to generate the broadband antennas.A high-permittivity dielectric substrate with strong walls, shorting pins, some deformation, similar to how fractal geometry works, and other methods are used to miniaturize microstrip antenna technology. However, these techniques have drawbacks such limited bandwidth and low gain.

The use of electromagnetic meta-materials for antenna design is a novel approach that designers are very interested in. The use of meta-materials in antenna design can increase other antenna properties, such as boosting bandwidth, raising gain, or producing multiband frequencies of operation, in addition to drastically reducing the size of the antenna. One of the novel materials made up of the arrangement on the surface of the dielectric substrates is called a meta-material. Because of this, meta-materials' physical characteristics are more dependent on their structures than on the individual parts that make them up. The term "metamaterial" is borrowed from the Greek. It is a word combination made up of the words "meta" and "material." Where "meta" refers to something above and beyond the ordinary, altered, or advanced. Wearable sensors equipped with antennas that can monitor a person's health, as well as their performance in sports, during exercise, and other activities, are gaining a significant amount of popularity. These types of applications could make use of the ON-body and OFF-body sensors that are a part of Wireless Body Area Networks (WBANs). The ISM band is regarded as the band that is most ideally suited for WBANs since it does not need a license and it provides a sufficient amount of bandwidth. In order to communicate local data from the sensor nodes to the central module, these sensor nodes make use of antennas that are worn on the body. According to [13], in order to achieve their basic requirement of flexibility, body worn antennas must be constructed of textile and electro (e)-textile materials.

Textile and electronic textile antennas are easy to integrate into clothing or to wear directly on the body without limiting mobility. This makes them ideal for wearable technologies. Microstrip patch antennas are the least expensive, conformable, and low profile antennas for wearable applications, according to research that has been published [13].

When discussing microstrip antennas, the word "textile" refers to a design in which the substrate is created from a textile material, such as cotton, felt, flannel fabric, or denim. Another example of a textile material that might be used is denim.

Circular polarization(CP)

Circular polarization is preferred over linear polarization as many of the applications mainly focus on circularly polarized antennas.When the electric field is continuously rotating along360^0, it is referred to as circular polarization. Two orthogonal components with equal amplitude and 90^0 out of phase are required for generating CP emission. When tip of the electric field vector rotating in clockwise direction, it is referred to as left hand circular polarization. When tip of the electric field vector rotating in anticlockwise/counterclockwise direction, it is referred to as right hand circular polarization.Feeding methods for circular polarization include, dual feed and single feed. Dual feed CP antennas in phase quadrature needs external hardware phase splitter to generate two orthogonal signal with equal amplitude and 90^0out of phase. it occupies lot of board space and with external hardware cost of the system also increases. To overcome this single feed CP antenna are developed. Single feed antennas are used for obtaining electric field. By making some alteration to the patch and by introducing asymmetric to the structure two orthogonal modes are generated for CP radiation.

Fractals in antenna design

A fractal is a self – similar design to maximize the length or increase the perimeter of material that can receive or transmit electromagnetic radiation within a given total surface area or volume. The fractal concept is used to obtain the CP in microsrtip antennas. Fractals are generally formed by iterative process. It is used to increase the electrical length of the patch. Fractal curves are divided into two types namely mass fractal-sierpinsk and boundary fractal-koch. When the self similarities are occurring on the surface of the patch, it is referred as mass fractal.When the self similarities are occurring along the boundaries of the patch, it is called boundary fractal. Fractals have space filling properties.

Human Phantom Modeling

For the purpose of conducting ON-body evaluation of the wearable antenna, a heterogeneous cylindrical body component that simulates the human arm and leg has been developed. This component is comprised of four layers of skin, fat, muscle, and bone. The arm that is in the worst possible condition has a radius of 40 millimeters, the arm that is in the best possible condition has a radius of 60 millimeters, and the leg has a radius of 70 millimeters. Different frequencies bring out different dielectric properties and conductivities in different tissues, including muscle, fat, and bone.

Specific Absorption Rate (SAR)

When the antennas are worn on top of a human arm with a specified radius, the radiation that is aimed towards the user body is absorbed in it. The specific absorption rate, or SAR, is an important measurement that reflects the amount of power absorbed by the body relative to its mass. The SAR is calculated using a tissue volume that is 10 grams in total (ICNIRP, European standard). With regard to this criteria, a safe threshold is two watts per kilogram measured over ten grams of tissue.

II. LITERATURE SURVEY

Novel compact circularly polarized square microstrip antennawas proposed in paper [1]. Advantage of this antenna is the reduction in size of 36% as compared to the conventional corner-truncated square microstrip antenna at a given operating frequency. Axial ratio bandwidth of 0.84% was achieved. Disadvantageof this antenna was the generated 3-dB AR bandwidth, which is very narrow <1%.Which is insufficient for modern day applications.Circularly polarized U-Slot antennas are proposed in paper [2]. Advantages of this antenna are CP bandwidth increased up to 1%. Minimum AR value is high 0.5dB. Drawback of this antenna is narrow 3-dB AR bandwidth <1% and volume of the antenna is also very high. Compact asymmetric –slit microstrip antennas for circular polarization are proposed in paper [3]. Advantage of this antennais that the return loss, AR and gain of the antenna do not depend on slit shape,but only dependent on area of the slits.Conclusion is that the measured 3-dB axial-ratio bandwidth of the antenna prototype is around 0.5% and narrow AR bandwidth. Asymmetric multiband Koch CP antenna is proposed in paper [4]. The first frequency band at 2.45GHz is mainly excited due to the strong current distribution along the fractal boundary curves of the patch and by the boundaries of the embedded slot. The strong current distribution on the fractal curves of the patch excites 3.4GHz resonance mode. The third frequency band of 5.8GHz is generated by the embedded fractal slot at the center of the patch. In this study [12], a flexible dual band (2.4 GHz, 5.2 GHz) wearable dipole antenna was developed and tested for return loss, gain pattern, and specific absorption rate (SAR) under two orthogonal bending situations (E, H-plane) on various human body regions (arms, leg). In order to make the design flexible and conformable, the material felt, which is used in clothing, was employed as a dielectric, and Zelt was used as a conducting patch in both of the antenna modules. By ensuring that the resonant frequencies are kept at the levels that were stipulated, its design prevented the antenna from being out of tune when used in wearable situations (2.4 GHz and 5.2 GHz). In addition, the gain was boosted from the conventional design by as much as 4.45 decibels (dBi). Using a design that is based on metamaterials results in a factor ten reduction in the extremely high value of specific absorption rate (SAR) that is produced by the conventional omnidirectional wearable dipole. This is yet another one of the dipole's disadvantages. As a consequence of this, the specific absorption rate (SAR) was reduced by 83.3% and 92.8% for 2.4 GHz and 5.2 GHz, respectively, due to the improved isolation capabilities of the EBG ground plane in comparison to a standard substrate. This brought it down to levels that were acceptable, which are defined as less than 2.0 W/Kg over 10 g of tissue. As a consequence of this, the dual band dipole that is based on metamaterials is compact, has a low profile, is flexible, and performs better than its conventional counterpart in applications that include wearable technology. In addition to being put to use in private talks, it may also be put to use in combat, rescue operations, and the diagnosis of medical conditions. The textile material must not suffer from any decrease in quality, have a reasonable price tag, and be easily obtainable on the market. In the research that was conducted, fashion designers utilized a variety of common clothing materials. Some of these materials included denim jeans, flannel fabric, Bermuda cotton, felt material and protective clothing in the research that has been done, electro-textile has been employed for the conducting or radiating component of an antenna. The e-textile that makes up a conducting portion has to be able to fulfill certain criteria, including low and consistent resistivity (1 ohm/sq.), homogeneity throughout the whole antenna surface, flexibility, and inelasticity. Sheildit Super, Flectron, and Zelt are three examples of popular electro textiles. Zelt is considered to be superior to other materials because to its very high surface conductivity, which is 1 e+ 006 S/m, and extremely low surface resistance, which is 0.01 ohm/sq. It is necessary to find a solution to potential problems linked with the word "flexible," such as bending and crumpling, for the antenna to perform well. Fabrics that are flexible can never be entirely flattened out. As a consequence of this, textile antennas will undergo stretching and crumpling, which will change the electrical length or area of the antenna, causing it to no longer fulfill the primary purpose for which it was designed. The significant and revolutionary advancements in shrinking do not enable the use of the high-profile antenna that contributed to the increase in the cost of electronic gadgets. As a result of these qualities, researchers are striving to design antennas that are low-profile and low-cost, with the goal of making them compatible with compact electronic devices. Because of the exhaustive research and development that was done in the field of microstrip antenna, scientists were able to design an antenna that had a low profile, was extremely effective, and was suitable for wireless applications in the field of communication engineering. These investigations resulted in the development of a planar antenna that is compatible with monolithic microwave integrated circuits, as well as being cost-effective, efficient, low profile, and low scattering (MMICs). They demonstrated a wide variety of applications at frequencies ranging from 100 MHz to 50 GHz. Constant research is being done on patch antennas in order to meet the requirements of wireless communication, which include reducing their size, improving their efficiency, raising their gain, and reducing the number of spurious signals they produce, among other things. There have been many different suggestions made to minimize the size of a patch antenna in order for it to function at a certain frequency.

III. ANTENNA DESIGN

The proposed antenna has been designed using HFSS software. Circularly polarized metamaterial based fractal wearable antenna has been designed for wireless applications. Jeans substrate was used to design the antenna. The spiral shaped metamaterial unit cell has dimensions of $28 \times 28mm^2$. The gap between the spiral is 2mm as shown in **Fig1**. The Metamaterial based fractal antenna structure is shown in **Fig2. Fig2(a), 2(b)** and **2(c)** shows first, second and third iteration respectively. The dimensions of the proposed antenna are listed in **Table1.**

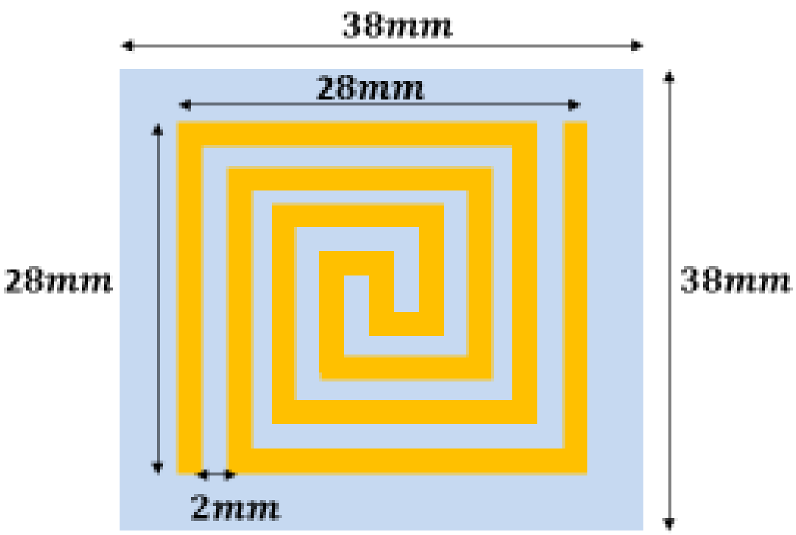

Fig1. Spiral shaped Metamaterial Unit cell

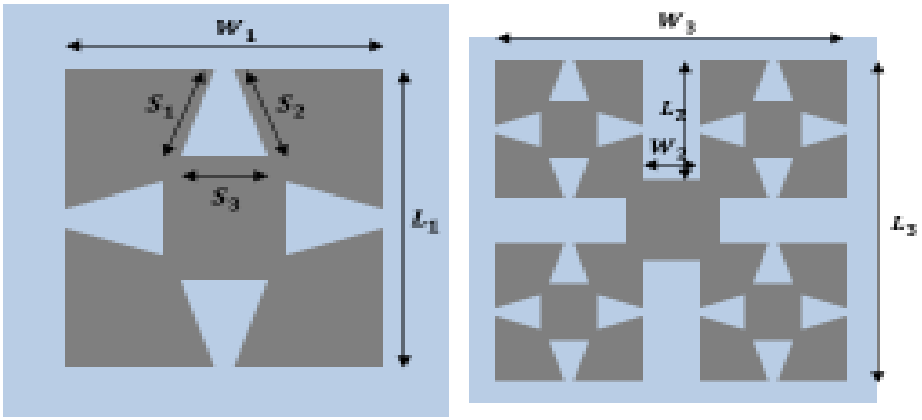

Fig2(a). First Iteration **Fig2(b).** Second Iteration

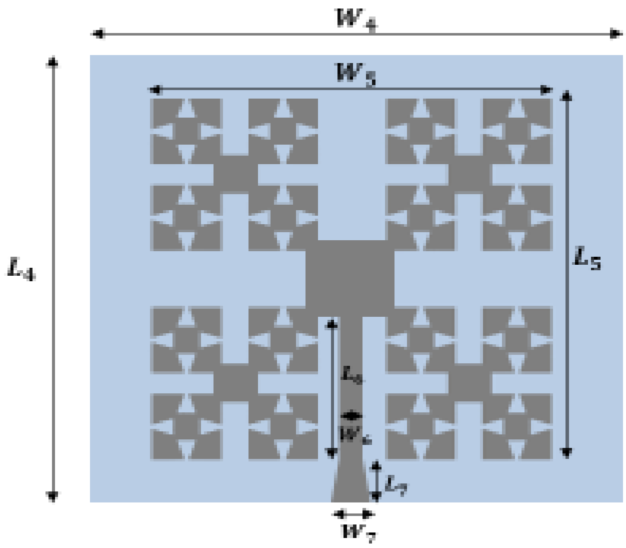

Fig2(c). Third Iteration

Fig2. Metamaterial based fractal antenna structure

Table1. Dimensions of the Proposed Antenna

Dimensions	Units in mm	Dimensions	Units in mm
S_1	2	L_4	38
S_2	2	W_4	38
S_3	1.5	L_5	28
L_1	5	W_5	28
W_1	5	L_6	11.8
L_2	4.8	W_6	1.4
W_2	2	L_7	4
L_3	12	W_7	1.8
W_3	12	-	-

IV. RESULTS

As can be seen in **Fig3**, the reflection coefficient of the antenna is -27 dB. The VSWR characteristics of the proposed antenna can be seen in **Fig4**. The VSWR of the antenna is 1.05. The SAR value of the proposed antenna when placed on Phantom neck is 0.78 W/Kg as observed in **Fig5**.

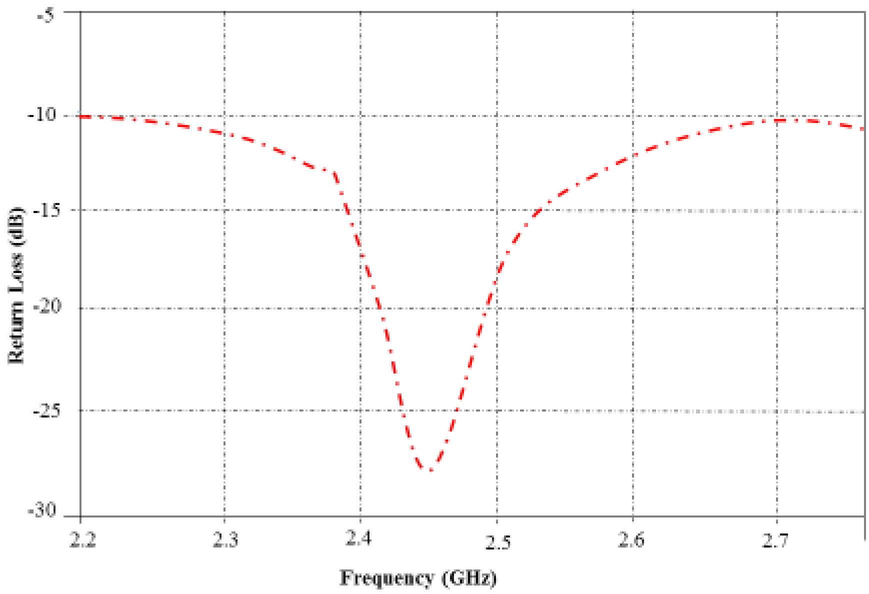

Fig3. Return loss Characteristics for the proposed antenna

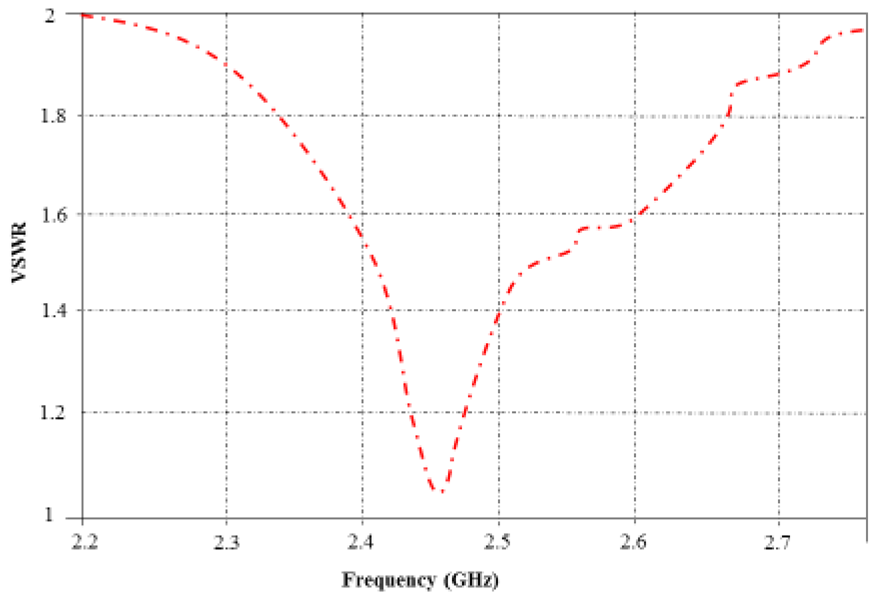

Fig4. VSWR characteristics for the proposed antenna

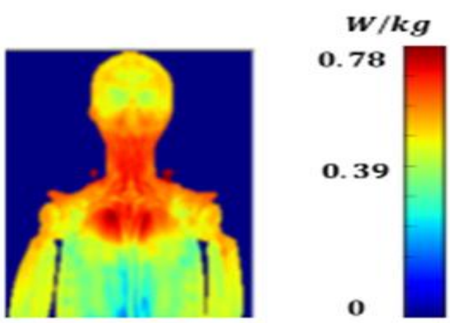

Fig5. SAR analysis of the proposed antenna when placed on Neck

V. CONCLUSION

In this paper, we have designed circularly polarized metamaterial-based fractal wearable antenna for wireless applications. Jeans substrate was used to design the antenna. The reflection coefficient of the antenna is -27 dB and the VSWR of the antenna is 1.05. The SAR value of the proposed antenna when placed on Phantom neck is 0.78 W/Kg, which makes it suitable for wearable applications.

References

[1]. Wen-Shyang Chen, Chun-Kun Wu, and Kin-Lu Wong, "Novel compact circularly polarized square microstrip antenna," IEEE Transactions on Antennas and Propagation, vol. 49, no. 3, pp. 340–342, Mar. 2001, doi: 10.1109/8.918606.

[2]. K. Y. Lam, K.-M. Luk, K. F. Lee, H. Wong, and K. B. Ng, "Small Circularly Polarized U-Slot Wideband Patch Antenna," IEEE Antennas and Wireless Propagation Letters, vol. 10, pp. 87–90, 2011, doi: 10.1109/lawp.2011.2110631.

[3]. Nasimuddin, X. Qing, and Z. N. Chen, "Compact Asymmetric-Slit Microstrip Antennas for Circular Polarization," IEEE Transactions on Antennas and Propagation, vol. 59, no. 1, pp. 285–288, Jan. 2011, doi: 10.1109/tap.2010.2090468.

[4]. V. Reddy and N. V. S. N. Sarma, "Compact Circularly Polarized Asymmetrical Fractal Boundary Microstrip Antenna for Wireless Applications," IEEE Antennas and Wireless Propagation Letters, vol. 13, pp. 118–121, 2014, doi: 10.1109/lawp.2013.2296951.

[5]. M. Mujawar, D. Vijaya Saradhi, M. Ajmal Naz, and A. Muduli, "Design and performance comparison of arrays of circular, square and hexagonal meta-material structures for wearable applications," Journal of Magnetism and Magnetic Materials, vol. 553, p. 169235, Jul. 2022, doi: 10.1016/j.jmmm.2022.169235.

[6]. M. Mujawar, "Compact Microstrip Patch Antenna Design with Three I-, Two L-, One E- and One F-Shaped Patch for Wireless Applications," Microstrip Antenna Design for Wireless Applications, pp. 57–68, Oct. 2021, doi: 10.1201/9781003093558-7.

[7]. M. Mujawar and T. Gunasekaran, "Multiband Slot Microstrip Antenna for Wireless Applications," EAI/Springer Innovations in Communication and Computing, pp. 23–34, 2022, doi: 10.1007/978-3-030-76636-8_3.

[8]. M. Mujawar, "Arrow Shaped Dual-Band Wearable Antenna for ISM Applications," Wearable and Neuronic Antennas for Medical and Wireless Applications, pp. 163–177, May 2022, doi: 10.1002/9781119792581.ch8.

[9]. M. Mujawar, "Antenna Array Design for Massive MIMO System in 5G Application," Future Trends in 5G and 6G, pp. 321–335, Nov. 2021, doi: 10.1201/9781003175155-18.

[10]. M. Mujawar and S. Pramono, "Textile-based wearable antenna for wireless applications," Printed Antennas, pp. 235–247, Oct. 2022, doi: 10.1201/9781003347057-15.

[11]. M. Mujawar and S. Pramono, "Millimeter Wave Antennas for Wearable Applications," Innovative Smart Materials Used in Wireless Communication Technology, pp. 44–54, Mar. 2023, doi: 10.4018/978-1-6684-7000-8.ch003.

[12]. S. Ullah, J. A. Flint, and R. D. Seager, "Polarisation-dependent electromagnetic bandgap incorporating a slanted sheet via," IET Microwaves, Antennas & Propagation, vol. 5, no. 5, p. 519, 2011, doi: 10.1049/iet-map.2010.0100.

[13]. S. Zhu and R. Langley, "Dual-Band Wearable Textile Antenna on an EBG Substrate," IEEE Transactions on Antennas and Propagation, vol. 57, no. 4, pp. 926–935, Apr. 2009, doi: 10.1109/tap.2009.2014527.