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Bending analysis of Compact geometry Monopole Antenna for Wearable Applications

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ABSTRACT

This work describes a compact monopole antenna design including bending analysis. The antenna has a variable return loss of -41dB and a bandwidth of 1422MHz for the lower microwave band resonance of 4.52GHz. The bending analysis along the X, Y axis planes are performed at different phases. V2X high-speed wireless communication, 5G WLAN, 5G-NR frequencies, fifth-generation Sub-6GHz (5G) smartphone apps, and C-band wearable applications are all intended uses for the designed antenna. With a thickness of 24 x 29 x 0.254 mm³, the substrate exhibits compact geometry. Through simulations employing tissue that resembles a human arm model, a gain value of 3.64dBi with SAR values that remain within the allowable range are also attained.

KEYWORDS *: DWearable, 5G, Low weight, Antenna, Compact, Flexible.*

INTRODUCTION

A growth is found in the requirement of wearable devices that can track bodily functions due to the shrinking of electronic systems [1], making wearable health management systems a very desirable area for researchers to study. This is because, when integrated into smart clothing, wearable technology can perform well enough to replace a number of medical devices [2].

LITERATURE REVIEW

Researchers created a range of compact antennas with sufficient performance in order to implement such technology [3]. However, a number of practical antenna design requirements, including compact size, low weight, power consumption, and flexible structure can be used in wearable devices for biomedical applications [4]. Thus, the use of many microstrip antennas, which are among the most sought types for wearable applications when installed in near-closeness to the human body [5].

In addition to wearable devices, flexible antenna designs are also proposed for millimeter wave applications, wireless power transmission, and 5G wireless communications to work with next-generation flexible electronics. A flexible broadband antenna based on Rogers RO4835T is proposed in [6] communication systems in 5G sub-6GHz band. Hexagonal split-ring resonators are recommended because the radiating element offers broadband capability for sub-6 GHz, preventing interference problems in the frequency range. Without sacrificing antenna performance, these resonators may be circumscribed independently.

For systems equipped with RFID tags, a design for a flexible, transparent antenna that operates across multiple bands is given in [7]. This design demonstrates wireless power transfer in both radiation field scenarios, operating at resonant frequencies of 13.56MHz and 2.45GHz, respectively. A flexible antenna which consists of a rectangular patch embedded within a flexible PDMS substrate is studied in [8]. As challenging environments such as channel imbalance and body attenuation effects draw growing attention, wearable antennas must operate effectively within particular frequency bands to be used in different communication based wireless protocols. The prevalence of these frequency bands varies, including 2.4GHz and 5.8GHz-ISM bands, UWB (3.1–10.6 GHz), and up-and-coming 5G bands (24–40 GHz) [9-13]. Architectures are chosen according to the use case, yet wideband and multiband

designs are commonly adopted so that several functions—such as GPS, Bluetooth, LTE cellular connection, and Wi-Fi which can operate at the same time. This allows the antenna to adapt with ease across various communication protocols.

Considerable focus was given to employing flexible and semi-flexible materials during fabrication of wearable nodes[14]. Thanks to major breakthroughs in wearable antenna technologies, their application in implantable devices has grown remarkably [15]. Nevertheless, antennas with low frequencies while keeping them miniaturized for wearable devices, all without compromising radiation efficiency and gain, remains among the most pertinent challenges in present days [16]. To account this problem, a variety of methods are pursued to shrink wearable antennas, including reactive loads [17], high-permittivity materials [18], vias [19], shorting posts [20], and fractal geometries that lengthen the current path [21]. The antenna functioning with close attention to how different its positions particularly the remoteness between the fabric material and skin are studied in [25]. For wearable applications, particularly with flexibility nature of substrate along with its design, structure are thoroughly examined in [26], focusing on their role in WBAN and medical-health technology, with highlighting the need to sustain optimal performance under human-body contact and also in mechanical deformation condition. The paper [27] discusses the novel materials employed in wearable electronics devices.

The objective reported in this paper is to create a simpler antenna that is compact in size, offers a reasonably wide bandwidth, and maintains acceptable Specific Absorption Rate (SAR) levels for wearable uses. The wearable antenna's design is detailed in section II. In section III, the findings are discussed, with conclusion in section IV, followed by acknowledgments and references at the end.

WEARABLE ANTENNA DESIGN

A compact microstrip flexible wearable antenna featuring a circular patch engraved I-shape structure in the centre of the radiating patch, alongside an outer circular cut patch next to it, excited using a line-feed method with a partial copper acting as ground on the other side of substrate is shown in fig.1. The suggested antenna employs Rogers RT Duriod 5880 as the substrate, and the radiating patch is constructed using copper with a thickness of 0.035 microns.

The designing of circular patch antenna involves determining the radius and effective radius according to the operating frequency, dielectric constant, and substrate height. The equations comprise [22].

$$a = \frac{F}{\left\{1+\frac{2h}{\pi \epsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right)+1.77726\right]\right\}^{\frac{1}{2}}} \quad (1)$$

where,

$$F = \frac{8.791\times10^{9}}{f_r\sqrt{\epsilon_r}} \quad (2)$$

and determining effective dielectric constant for fringing estimation.

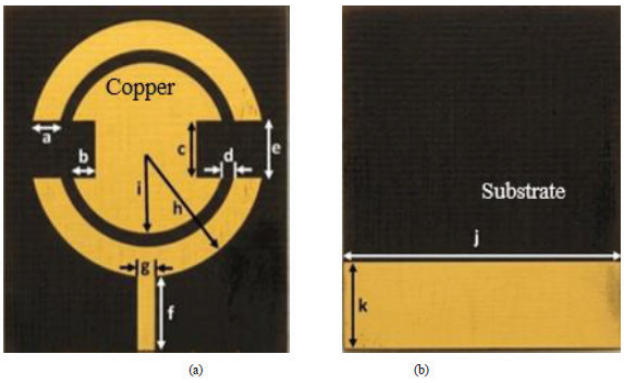


Fig.1. Design of antenna. a) Front view, b) Back view

The antenna layout illustrated in fig. 1 features an external circular patch with a radius of h=11.6 mm on a Rogers RT 5880 flexible substrate (with εr = 2.2, tanδ = 0.0009, Hs = 0.254 mm), which is energized by a 50-Ω coaxial probe. This antenna includes an I-shaped inner circular patch at the center, which has a radius of i=9.2mm for the radiation structure. The yellow shade indicates the copper layer, where as brown area represents the substrate layer in figure 1 illustrating the front and back layers. The different parameters employed in the antenna design along with their sizes are a= 2.62mm, b= 2.61mm, c= 5.1mm, d= 1.02mm, e= 5.1mm, f= 5.60mm, g= 1.52mm, h= 11.4m, i= 9.1mm, j= 26mm, k= 4.73mm.

BENDING ANALYSIS RESULTS

Simulation study is carried out on the proposed antenna design. For this purpose, the S_{11} (return loss) spectra and radiation patterns of the proposed antenna were measured across resonant frequency band under different bending conditions in simulation environment. Afterward, the same set of design was repeated with the antenna positioned near the phantom arm tissue model. Measurements of the proposed antenna were taken over the frequency range of 3 GHz to 6 GHz. For performing simulations, the CST Studio Suite software is used, and the antenna results, encompassing the reflection coefficient of bending examination of the antenna, Specific Absorption Rate (SAR), and VSWR are incorporated in this section. The S_{11} response shown in Fig.2 illustrates stable impedance matching and a wide impedance bandwidth of 1422 MHz, achieving a return loss of -41dB at 4.52GHz. The simulated bandwidth ranges from 4.053 GHz to 5.475 GHz. The suggested antenna for wearable use is created with an emphasis on compact devices such as smartwatch applications or for the case of wearable clothes or devices. When this kind of device is used on arm, it experiences a degree of conformability or bending nature. So, the bending characteristic is studied and the antenna's performance in this case should stay near-to steady, or results should be similar to those of the antenna in a typical situation without any bending situations.

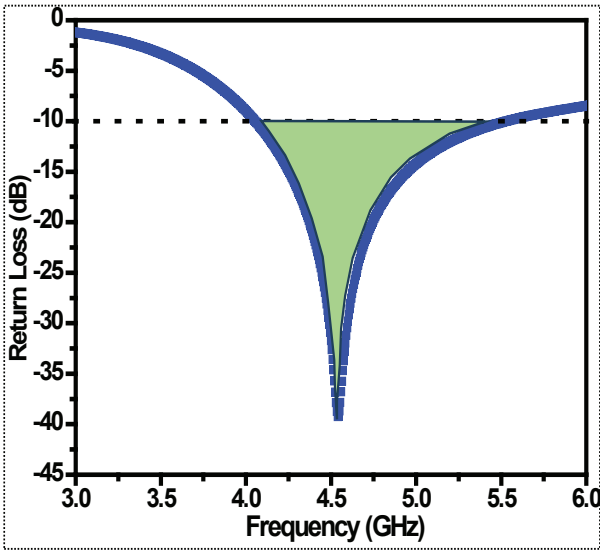


Fig. 2. Reflection Coefficient of designed patch [23]

Consequently, the suggested antenna is curved along the x- and y-axis. Simulation results show that, the antenna is curved in the x-direction at a 90◦ angle and has a bending radius in steps of 20 mm. Since the antenna is designed for hand-worn use, a tighter bending radius was considered. Fig. 3 (a) illustrates the curved design of the wearable antenna from an isometric perspective, while the top and bottom perspectives are also displayed respectively.

Correspondingly, fig. 4 illustrated the proposed antenna under conformal conditions along the y-axis at a 90◦ angle, with a bending radius of 20 mm per step beginning at 40 mm, applying the same bending angle and radius as those utilized for the x-axis. Along both axes, the bent antenna's reflection characteristics match closely those of the simulated antenna that has no bending. As the simulation results in Fig. 4 show, the proposed antenna, when bent along both axes, the antenna functions across the 3.8 GHz to 5.3 GHz range (wideband) suitable for wearable applications and Sub-6 GHz 5G applications.

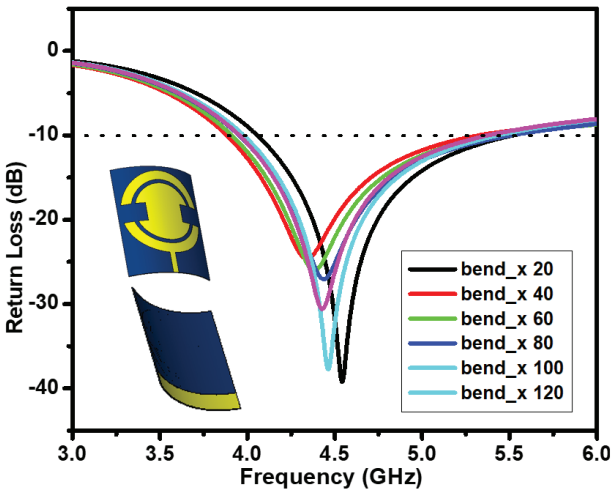


Fig. 3. Reflection Coefficient of antenna bend on x-axis

When the antenna was subjected to the bending effects, it exhibited insignificant changes in terms of the S_{11} aspect, as seen in Figures 3 and 4. This variation in the frequency and bandwidth results from the current motion on the patch structure and the side cuts along the x-axis, and also from the line feed point.

Because the proposed study involved the use of wearable devices, a SAR investigation was also carried out to examine radiation leaking from the antenna into human tissue. This examines the consequences

of radiation absorbed within the human arm. For the simulation, the input power level was set at 1 mW. The proposed antenna design in order to achieve minimal leakage into human tissue is achieved by placing a feed port near to the feeding line. Here, the antenna was positioned close to the human arm mimic phantom, at a distance of 0 mm. It should be noted that, a bending effect of 90◦ as flat case was taken into account. The Specific Absorption Rate (SAR) measures how much radiofrequency energy is taken in by human tissue. It is determined by averaging over a specific mass of 1 gram. The SAR limit in US is 1.6 W/kg for 1 gram of tissue, which corresponds to 2 W/kg in Europe for 10 grams of tissue.

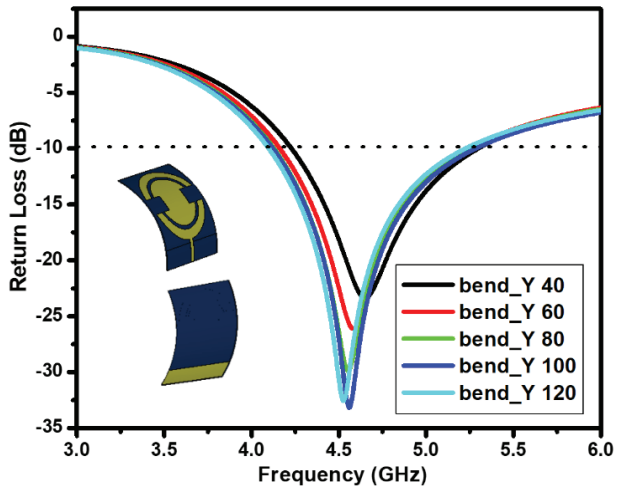


Fig. 4. Reflection Coefficient of antenna bend on Y-axis

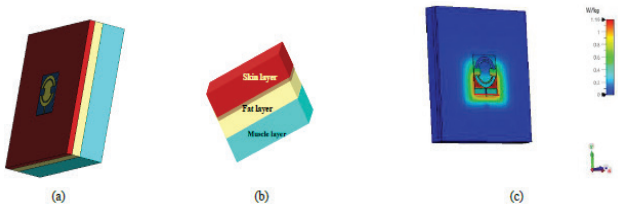


Fig. 5. (a)Human tissue layers, (b) layered colours and (c) SAR at 1g. [23]

The SAR value is highly important, as it demonstrates how back radiation affects human tissue. If it surpasses the recommended limit set by the FCC and ICINPR, it will damage the tissues of the human body. To examine this, a region of skin, fat, and muscle keeps dimensions constant at 50 × 50 mm². The thickness of these layers, namely skin, fat and muscle, is kept at 2 mm, 3 mm, and 8 mm respectively. The antenna is modeled and evaluated on the skin, while the dielectric constant stays at 41.4 with thermal conductivity measuring 0.88 S/m, representing human biological tissues, are employed in the simulations as given in Fig.5(a). The fig. 5 (b) shows the different layers of the tissue considered for the study. The specific absorption rate (SAR) analysis using this confirms safe operation at 4.52 GHz, with a 1-g measurement of 1.19 W/kg for the arm-tissue model, well below the IEEE/IEC limits of 1.6 W/Kg, as shown in Fig. 5(c). The antenna also shows enhanced gain, with a slight improvement in the on-body case (i.e., 3.64 dBi simulated), likely due to favorable interaction with the body surface modeled as phantom layers in the design. Figure 6 illustrates the VSWR plotted against frequency, revealing that the antenna attains a VSWR value below 1.5, which indicates improved impedance matching and reduced power being reflected back toward the source.

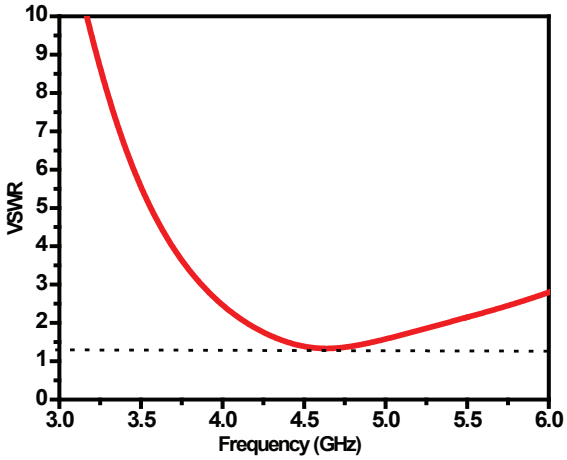


Fig. 6. Plot of VSWR Vs frequency for the proposed design

Figure 7a, b shows the 2D and 3D radiation characteristics of the designed antenna depicting that the antenna exhibited the nearly broadsided radiation pattern at the desired resonance frequency.

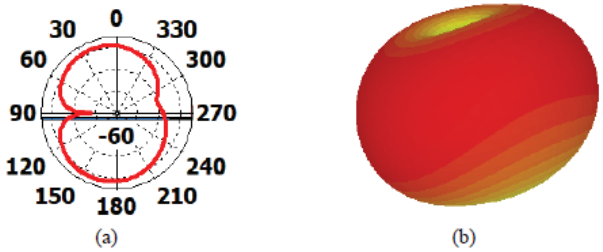


Fig. 7 a)2D, b)3D radiation characteristics

USES OF WEARABLE ANTENNAS

The demand from users for wearable devices has expanded swiftly with the emergence of modern monitoring systems. In particular, their presence within the healthcare system is growing quickly, which is expected to benefit society positively. Physiological conditions serve as vital health indicators, and tracking them could effectively permit the early identification of any type of disease. Smart wearable applications would lessen significant health difficulties, including disease management and expense. Typically, clinical equipment used for measurement is not wearable; therefore, researchers have concentrated on distinctive smart configurations that would make wearable devices possible with a low profile, robustness, and strong performance. The IEEE 802.15 group has acknowledged standard applications for body-centric communications [24].

CONCLUSION

This study presents a compact wideband wearable antenna that achieves a gain of 3.64dBi, shows a bidirectional radiation pattern, and offers a broad impedance bandwidth of 1422MHz at 4.52GHz, which makes it suitable for wearable applications. Using CST simulation studio, the SAR performance of the proposed antenna was assessed and determined to be 1.19W/Kg, a value considerably lower than the standard 1.6W/Kg. Future work could be carried out with a metasurface or AMC in order to achieve improved bandwidth and gain results.

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