Flexible Antenna Design for Wearable Telemedicine Applications

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Abstract— In this article, an antenna design based on the printed patch of three strip lines which are excited with a microstrip line has been proposed and implemented for wearable telemedicine devices. The proposed antenna is fabricated using conductive copper tape of 35 μm thickness and printed on a flexible photo paper to suit the telemedicine applications. It has a physical dimension of $40 \times 35 \times 0.635\,\mathrm{mm}^3$ for operation at the frequency of 2.45 GHz within ISM bands. The proposed antenna design is simulated and optimized by Computer Simulation Technology of Microwave Studio software (CSTMWS), and then it was experimentally validated. A good agreement between the simulated and measurements has been achieved. The proposed antenna performances in terms of radiation efficiency, radiation patterns, and return loss are evaluated. According to the obtained results, the proposed antenna shows an excellent computability to wearable telemedicine devices.

1. INTRODUCTION

Flexible antennas are strong, lightweight antennas that can withstand some mechanical stress. The rigidity resulting from form factor and weight considerations is one of the main obstacles to the technological advancements of next-generation IoT-related devices [1]. The development of telemedicine technology has created new healthcare opportunities [2]. Due to their capability to wirelessly monitor and transmit data, wearable telemedicine devices in particular have grown in popularity. This has made it possible to remotely monitor patients' health conditions [3]. Small, adaptable, and effective antennas that can function at the 2.4 GHz ISM band are needed for the creation of wearable telemedicine devices [4]. Wi-Fi, Bluetooth, and Zigbee are just a few of the wireless communication technologies that use the unlicensed ISM band. Flexible antennas are crucial components in wearable telemedicine applications as they enable wireless communication between the wearable device and external systems [5], such as monitoring stations or smartphones. The design of flexible antennas should take into account the unique requirements and challenges posed by wearable telemedicine applications [6], including size constraints, durability, and performance [7].

The main key aspects the must be considered in design any flexible antenna for wearable telemedicine applications are given as:

1. Frequency selection: Determine the frequency band(s) suitable for the intended telemedicine application, considering factors like data transmission requirements and regulations. Common frequency bands include 2.4 GHz (Wi-Fi, Bluetooth), 868/915 MHz (RFID, IoT), and cellular bands [8].
2. Compact size: Wearable devices often have limited space for antenna integration. Miniaturization techniques like meandering, fractal geometries, or planar inverted F-antennas (PIFAs) can help achieve compact antenna designs without sacrificing performance [9].
3. Flexibility and durability: Wearable devices require antennas that can withstand bending, stretching, and twisting without performance degradation. Flexible substrates such as polyimide or liquid crystal polymer (LCP) can be used to ensure mechanical flexibility and durability [10].
4. Multiband operation: Depending on the application, it may be necessary to support multiple frequency bands for different wireless technologies or communication protocols [11]. Design techniques like impedance matching networks, frequency-selective surfaces, or multiple resonant elements can be employed for multiband operation [12].
5. Wearable integration: Antennas should be seamlessly integrated into wearable devices without causing discomfort to the user [13]. Embedding the antenna within the wearable fabric or using conductive inks for printing antennas directly on flexible substrates are potential integration methods [14].
6. Efficiency and radiation pattern: The antenna should have high radiation efficiency to ensure reliable wireless communication [15]. Careful design of the antenna structure, such as optimizing ground plane size and shape, can improve efficiency. Additionally, the radiation pattern should be well-controlled to minimize signal distortion due to body effects or nearby objects [11].
7. SAR considerations: Specific Absorption Rate (SAR) is an important safety consideration for wearable devices, as they are in close proximity to the human body [12]. Antenna design should aim to minimize SAR levels by optimizing radiation patterns, antenna placement, and grounding techniques [5].
8. Performance testing: Once the antenna is designed, it should be thoroughly tested in realistic operating conditions [6]. This includes evaluating key parameters like impedance matching, gain, radiation efficiency, and bandwidth [9].

It is very important to note that designing antennas for wearable telemedicine applications can be a complex task that requires expertise in antenna theory, electromagnetics, and RF design. Simulations using software tools like CST Studio Suite, HFSS, or FEKO can aid in the design process, followed by prototyping and testing to validate the performance. Collaborating with an experienced RF engineer or antenna specialist can greatly facilitate the development of an effective and reliable flexible antenna for wearable telemedicine applications [7].

Here a simple prototype antenna with flexible configuration has been proposed and experimentally validated, which may suit the applications of RFID tag, smart card systems, and wearable telemedicine devices operating below 12 GHz band such as WiMAX, Wi-Fi, lower band of 5G spectrum, and ISM radio band [4].

2. ANTENNA DESIGN SPECIFICATIONS AND RESULTS

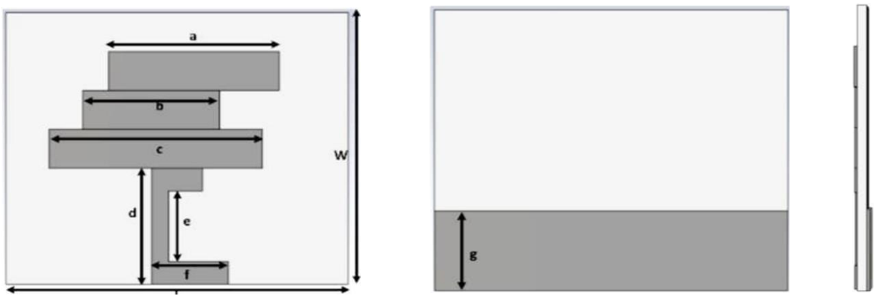
The proposed antenna is fed with a basic microstrip line that serves as the foundation for the initial design. The antenna substrate has a low-profile thickness with a feed line of 15 mm length and total substrate size of $40 \times 35\,\text{mm}^2$. The substrate thickness is 0.6 mm of photo paper, while, the radiating parts are made of copper tape 35 µm thickness. The proposed antenna dimensions and geometrical details are given in Figure 1 and Table 1.

In Section 3, the optimization process of the proposed antenna design has been elaborated.

The proposed miniaturized antenna model with flexible capability is implemented by applying a photo paper substrate of 0.6 mm thickness with a copper patch that is based on three strips of 35 µm thickness which makes it applicable for an interbody telemedicine system. 3D electromagnetic CST Microwave Studio software package is invoked to design and study the performance parameters of the proposed antenna. The antenna performance in terms of the reflection coefficient (S_{11}) and radiation properties are tested in two different scenarios based on flat and curved conditions. The proposed antenna occupies an area of $40 \times 35 \times 0.6\,\text{mm}^3$. The fabricated antenna design which is exhibited in Figure 2 provides a fractional bandwidth of 8% from 2.33 GHz to 2.53 GHz.

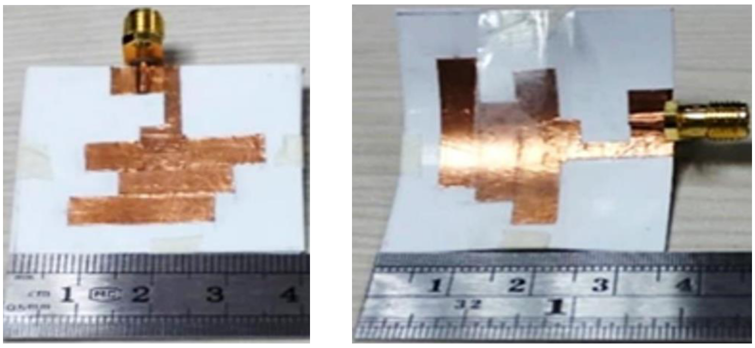
Table 1: Geometrical details and dimensions.

Parameters	Value (mm)	Parameters	Value (mm)
L	40	c	25
W	35	d	15
a	20	e	12
b	16	f	5



(a) (b) (c)

Figure 1: The optimized design, (a) top-view, (b) back-view, and (c) side-view.



(a) (b)

Figure 2: Antenna prototype, (a) flat profile, and (b) bended profile.

3. DESIGN METHODOLOGY

The flexible antenna is designed and optimized by CST Microwave Studio environments with 3D full wave simulations for both flat and bended scenarios. In this regard, the antenna passes three initial steps to reach the optimal design as seen in Figure 3. We found that the first step shows a frequency resonance at 3.9 GHz with oriented radiation pattern. Then, the proposed study is shifted to the next movement as step 2. It is found at this stage the antenna resonates at 4.5 GHz. The last step which is the optimized one presents a combination of the first two steps as third step. In this case, it is observed that the proposed antenna resonates at 2.45 GHz which is fit with the goal of this work.

4. FABRICATION AND MEASUREMENT SETUP

The antenna is fabricated using a flexible photo paper substrate and conductive copper tape. The simulation results of the proposed antenna show a reflection coefficient of better than -20 dB with an impedance bandwidth of 0.2 GHz from 2.4 GHz to 2.6 GHz, as seen in Figure 4(a). Figure 4(b) shows the radiation pattern of the antenna is omnidirectional in the azimuth plane and directional in the elevation plane. The simulation results also show that the antenna has a maximum gain and radiation efficiency of 2.24 dBi and 75% occurred at 2.45 GHz.

To proof the antenna for wearable applications, it is bended (rolled) on a cylinder to measure the effects of bending on the antenna's performance parameters. The results plotted in Figure 4 show that in this case a reflection coefficient of better -15 dB at the same resonance frequency

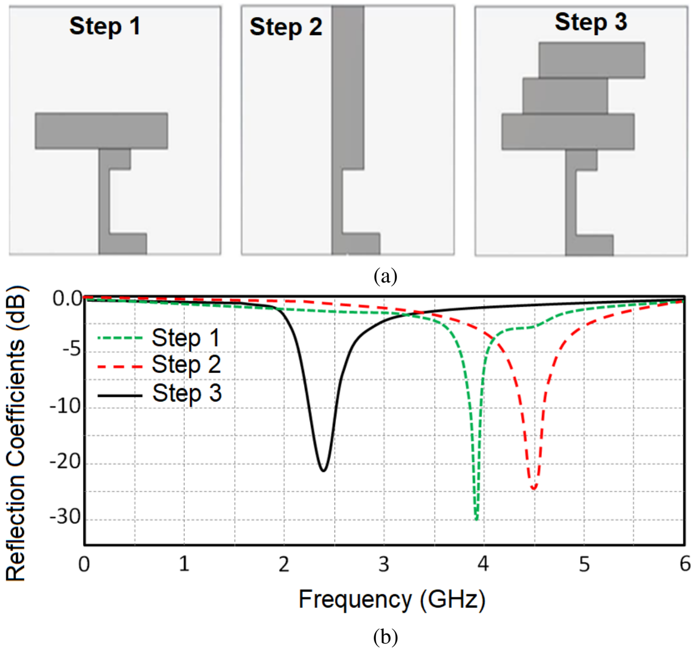


Figure 3: Design steps and characteristics of the proposed flexible antenna, (a) design steps, and (b) reflection coefficients ($S_{11} < -10\,\text{dB}$).

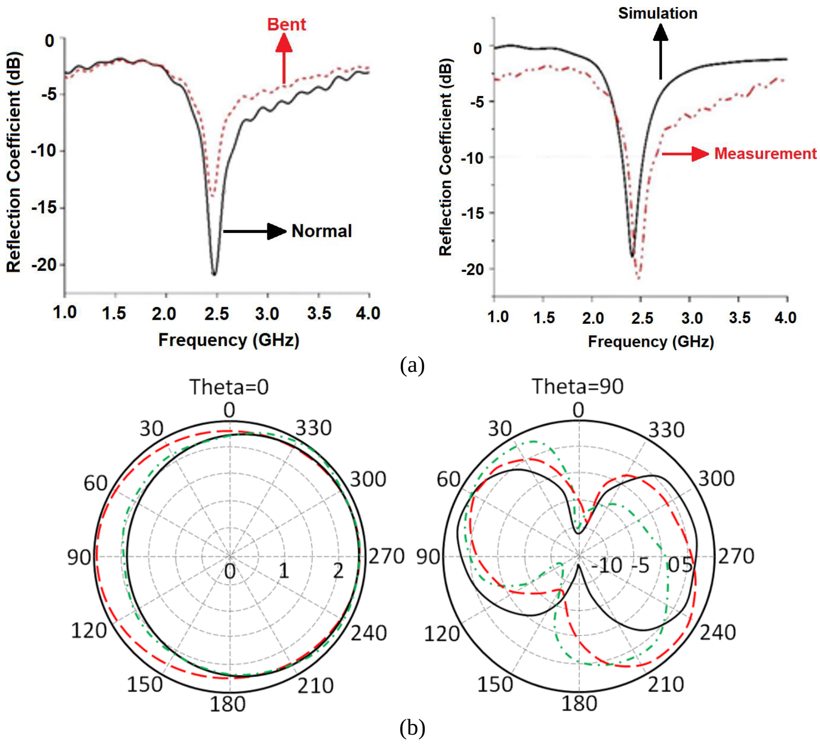


Figure 4: (a) Simulated and measured reflection coefficient results ($S_{11} < -10\,\text{dB}$) for flat and bended cases, and (b) radiation patterns in azimuth plane (left side) and elevation plane (right side).

of 4.5 GHz compared with the normal case has been achieved. In addition, the maximum gain of the antenna is found 2.1 dBi with a radiation efficiency of 72% at this resonance frequency point. Therefore, a good agreement between normal and bent cases has been obtained, which confirms the flexibility of the proposed design methodology for wearable telemedicine devices.

The antenna is measured using vector network analyzer as seen in Figure 5. The experimental measurements are involved after performing the calibration analysis in short, 50 Ω load, and open to ensure accuracy in terms of magnitude and phase performance.

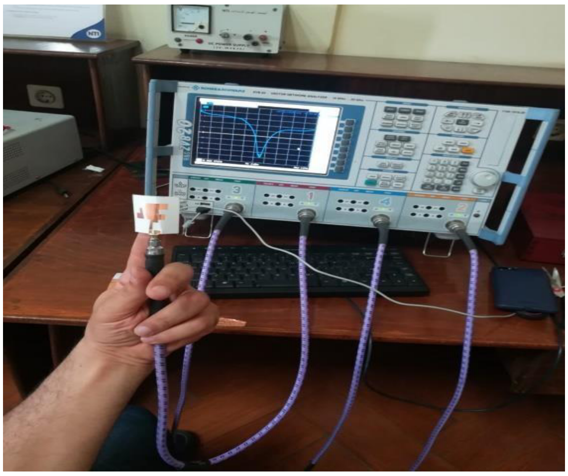


Figure 5: Measurement setup.

5. CONCLUSION

In this paper, a flexible antenna design has been demonstrated for wearable telemedicine applications at 2.45 GHz ISM-band. The antenna is constructed of a flexible substrate with a conductive patch from copper tape. The simulation results have been experimentally validated. The performance parameters such as reflection coefficients and radiation properties in both normal and bended cases have been achieved and analyzed. This analysis show that the bending has not significant effects on the antenna's performances that confirms the flexibility of the proposed design method. Therefore, the proposed antenna with benefits of small size, high performances, simple and flexible layout, ow-profile is found to be suitable for wearable telemedicine devices for remotely monitor patients' health.

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