Design of 2.4 GHz E-Textile Monopole Antenna for Wearable Technology

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Abstract

The design and study of a flexible monopole antenna are presented in this work. The proposed antenna design operates in the Industrial Scientific Medical (ISM) band at frequencies between 2.4 and 2.5 GHz, which makes it appropriate for wearable technology. The proposed antenna can be used with wireless technologies including 2.4 GHz RFID and Wi-Fi. An antenna is made from a flexible material. The radiating patch is a conductive fabric with a conductivity of 1250 S/m. The felt is used as the substrate with a dielectric constant of 1.38. The antenna is designed and analyzed by CST Microwave Studio with and without a human body. The antenna simulates and measures at the chest and arm to consider the effect of a human body on the designed antenna. The radiation pattern, the $|S_{11}|$ and gain are measured to verify the antenna performances. The results illustrate that the proposed antenna is appropriated for wearable technology using for frequency between 2.4 GHz and 2.5 GHz.

Keywords: Antenna, Flexible Material, Wearable Technology

1. Introduction

With the advancement of wireless communication technology, wearable technology becomes a device of the future and it is expected to be an integral part of the Internet of Things or IoT [1–2]. Many applications which are based on a wearable device is launched such as wristwatches, life jackets, fitness bands, breast cancer detection sensors and many others [3–4]. Most of the wearable technology is related to wireless communication devices because the device is almost on the human body which is not suitable for communication with a wired connection.

However, in wireless communication, the antenna plays an important role in transmitting and receiving a signal [5]. The antenna should be designed and developed appropriately for specific applications [6]. The frequency band of the application and the desired radiation pattern and gain are very important parameters to the antenna design [7]. Hence, the antenna for wearable technology should consider both the electrical properties and physical properties. The wearable antenna should be flexible and can be operated when the antenna is attached to a human body [8–10]. For this reason, wearable antenna design becomes a challenging issue.

Many types of antenna are developed nowadays but there are just some types of antenna that are appropriate for wearable technology. The 2.4 GHz textile antenna using E-shape with a microstrip feed line technique is presented in [11]. Because a lot of wearable technology is on the human body; hence, the human effect should be considered. Microstrip patch antennas can have a reduced impact when placed on the human body, according to J.G. Santas *et al* [12]. The skin, fat and muscle of a human are relatively high dielectric; therefore, it can affect the radiation characteristics and the impedance matching of the antenna.

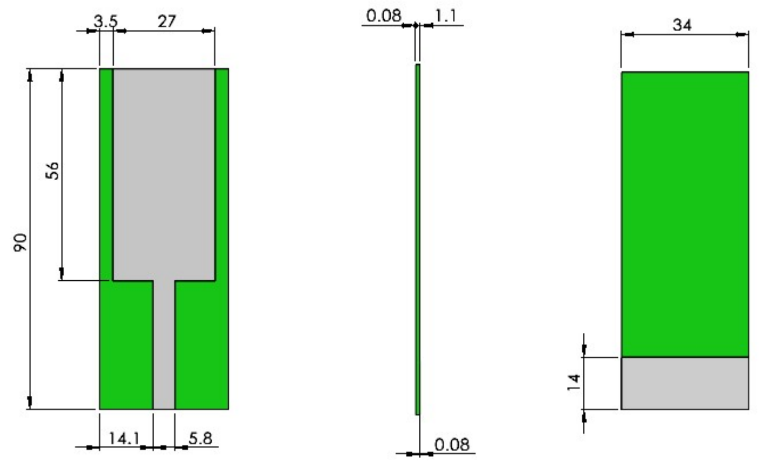
In this work, the antenna is designed and analyzed by a microwave simulation program [13]. The antenna is flexible and made from conductive fabric and felt. The operating frequency is from 2.4 GHz to 2.5 GHz which is in the ISM bands [14]. The antenna was fabricated and tested with-without a human to verify the operability of the designed antenna.

2. Antenna Design

An initial antenna design is based on a monopole antenna. The antenna is designed at the centre frequency of 2.45 GHz. The initial size of the antenna is 29 mm x 70 mm. The CST Microwave Studio program is used for simulation and optimization of the antenna structure. In this part, the antenna is designed in free space (without a human body).

2.1. Prototype of Flexible Monopole Antenna

The antenna structure is shown in figure 1. The size of the antenna is 34 mm x 90 mm. The substrate is felt with a dielectric constant of 1.38. The thickness of the substrate is 1.1 mm. The radiating patch was made from E-textile which is a conductive material. The conductivity of the material is 1250 S/m with a thickness of 0.08 m. These materials have flexible characteristics; therefore, the antenna becomes a flexible antenna structure.



(a) Front view (b) Side view (c) Back view

Figure 1 The simulated antenna structure

2.2 Simulation Results of the Antenna

The simulated $|S_{11}|$ of the antenna is illustrated in figure 2. The antenna can be operated, covering the desired frequency band from 2.4 GHz to 2.5 GHz. The impedance bandwidth is 0.6 GHz from 2.1 GHz to 2.7 GHz.

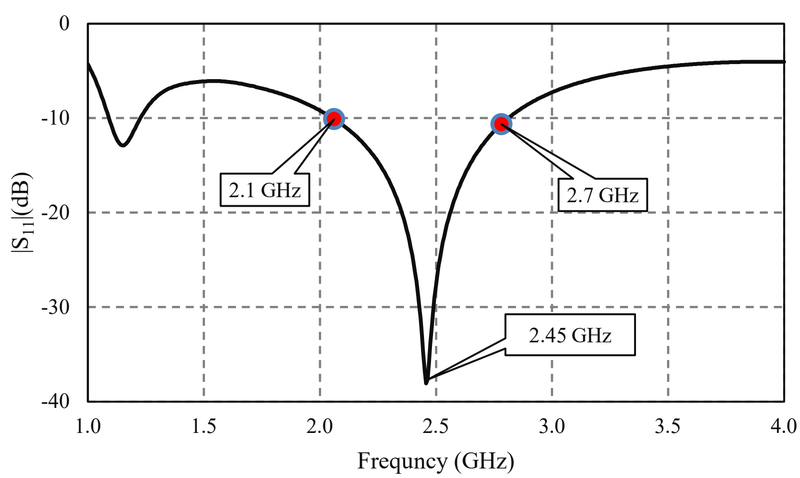
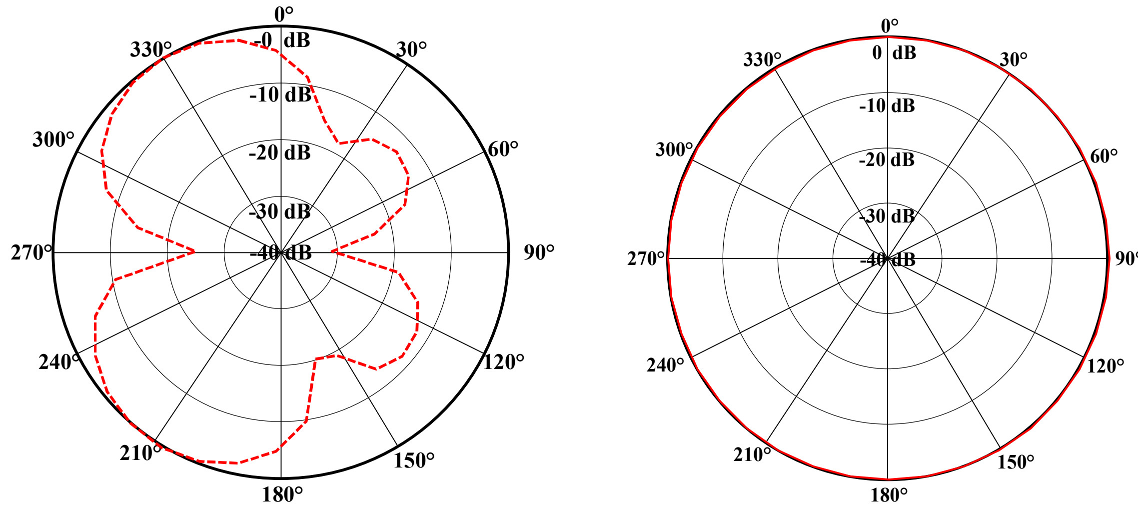


Figure 2 Simulated $|S_{11}|$ of the antenna



(a) E-plane (b) H-plane

Figure 3 Simulated radiation pattern

The simulated radiating characteristics are in figures 3(a) and 3(b). In E-plane and H-plane, the antenna radiates a symmetrical beam. From the simulated results, it is obvious that the antenna without the human body effect can operate very well. However, the wearable antenna is used on the human body; therefore, the effect of the human on the antenna characteristics should be considered.

3. The Antenna on Human Body

The human body is devided into 3 layers from the simulations. The simulated antenna is located at the arm and chest of the human model with the electrical properties in table 1.

Table 1 The conductivity and dielectric properties of fat, skin and muscle of the human [15].

Parameter	Fat	Skin	Muscle
Conductivity (S/m)	0.1	1.56	1.71
Dielectric Constant	5.29	42.9	52.8

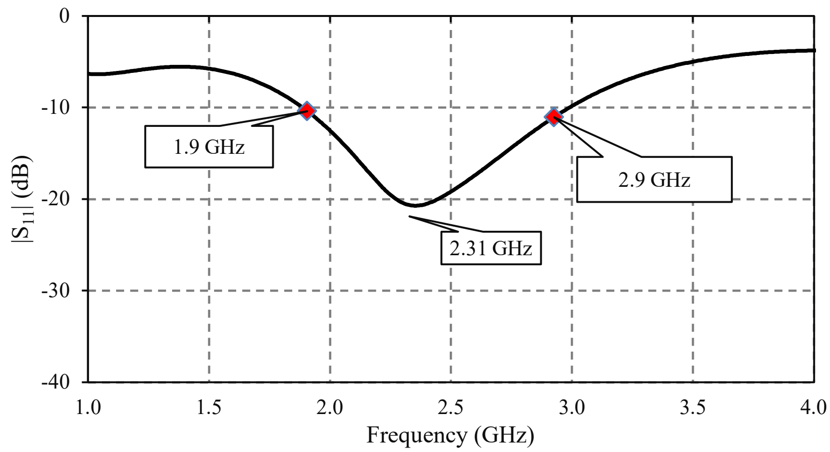


Figure 4 Simulated $|S_{11}|$ of the antenna located on the arm

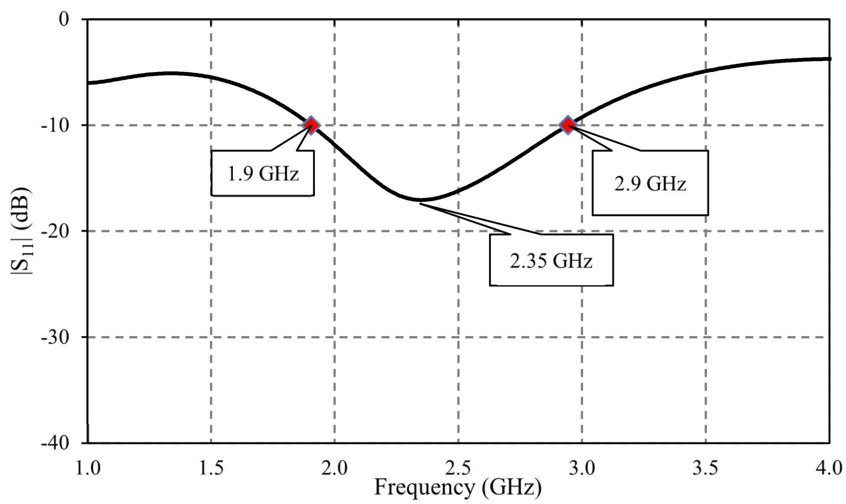


Figure 5 Simulated $|S_{11}|$ of the antenna located on the chest

From figures 4 and 5, it is illustrated that the impedance bandwidth is still effective even though the effect of the arm and chest is included. The antenna can be operated from 1.9 GHz to 2.9 GHz, covering the proposed bandwidth.

The radiation considered at 2.45 GHz, when the antenna is attached to the arm and chest are respectively presented in figure 6 (a)-(d). The results show that the radiation characteristic of the antenna is changed from a bi-directional to a directional radiation pattern. It can be concluded that the arm and chest have little effect on the antenna impedance matching but they have a strong effect on the radiation characteristic of the designed monopole antenna. The antenna radiation pattern changes depending on the body part under consideration. The changed characteristics such as impedance, radiation pattern, and gain of the antenna are caused by the fact that human skin is a lossy material with a high dielectric constant. The high dielectric constant of the human body may decrease the efficiency of the antenna.

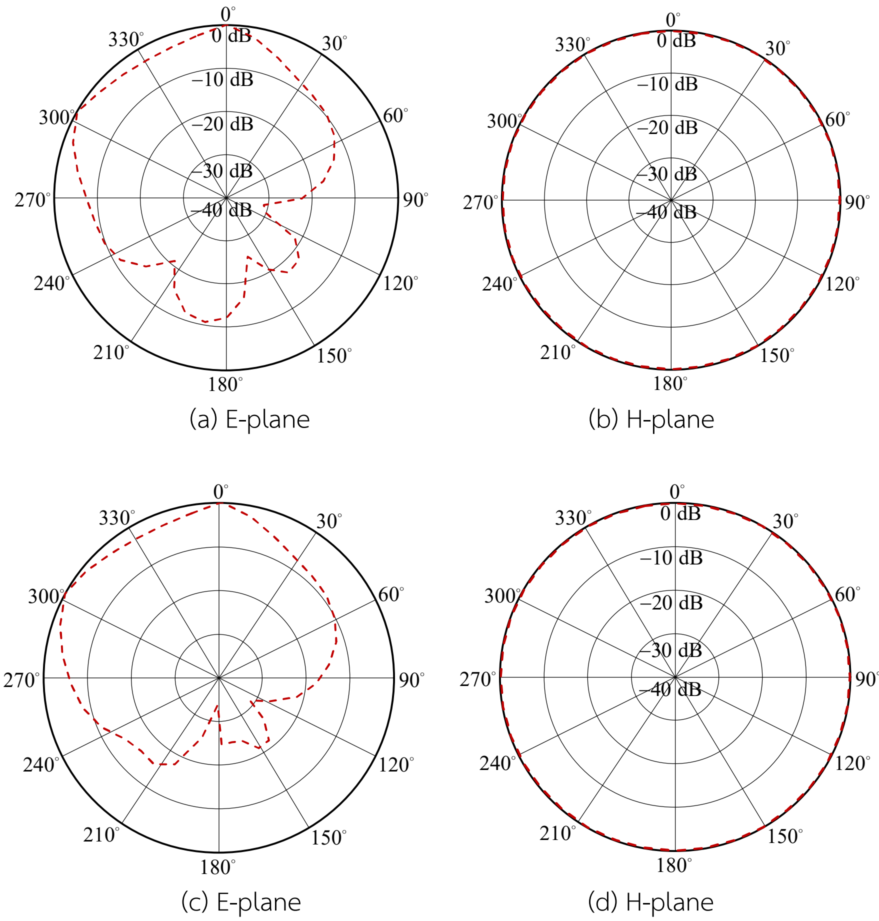


Figure 6 Simulated radiation patterns (a)-(b) located on the arm and (c)-(d) located on the chest

4. Fabrication and Measurement

Figure 7 depicts the proposed E-textile antenna. The antenna structure can bend to suit the human body because the antenna material is based on flexible textile. The antenna characteristics are measured by Network Analyzer. The antenna size is 34 mm x 90 mm with a thickness of 1.1 mm. The radiating patch size is 32 mm x 54 mm with a thickness of 0.08 mm. The ground plane size is 34 mm x 14 mm with a thickness of 0.08 mm.

(a) Front (b) Back

Figure 7 Fabricated Antenna

The measured and simulated results of the antenna without a human body are compared in figure 8. The antenna can operate from 2.2 GHz to 2.7 GHz. At 2.45 GHz, the $|S_{11}|$ is -38.9 dB. The measured result and the simulated result are in the same trend. In figure 9, the measured operating frequency when the antenna is located on the arm is from 2.1 GHz to 2.6 GHz, which covers the desired operating frequency. At the centre frequency of 2.45 GHz, the $|S_{11}|$ is -28.62 dB.

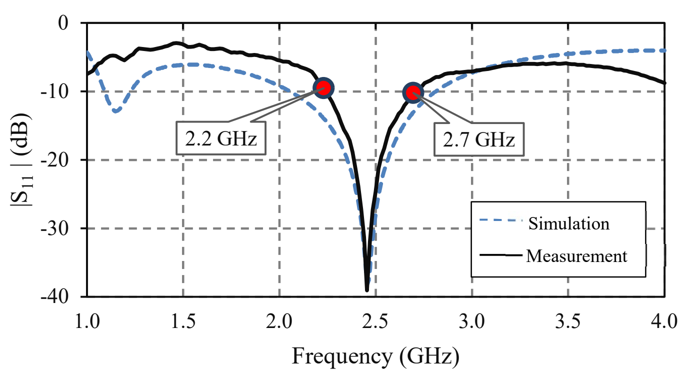


Figure 8 Measured $|S_{11}|$ of the antenna without a human body

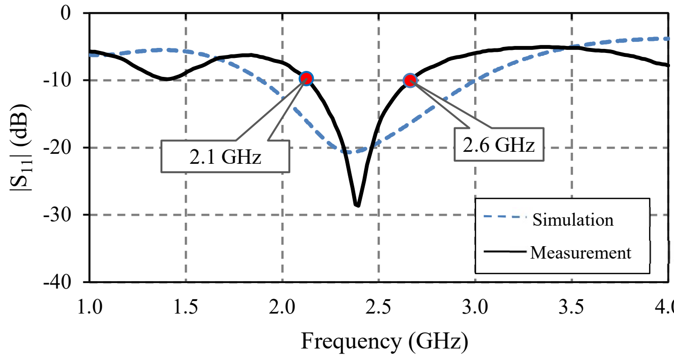


Figure 9 Measured $|S_{11}|$ of the antenna located on the arm

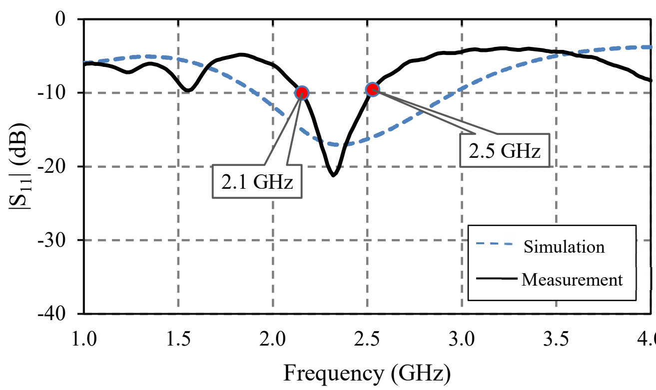
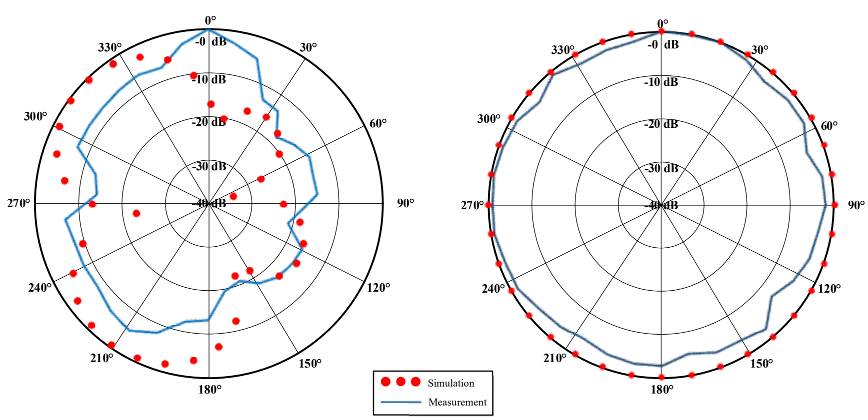


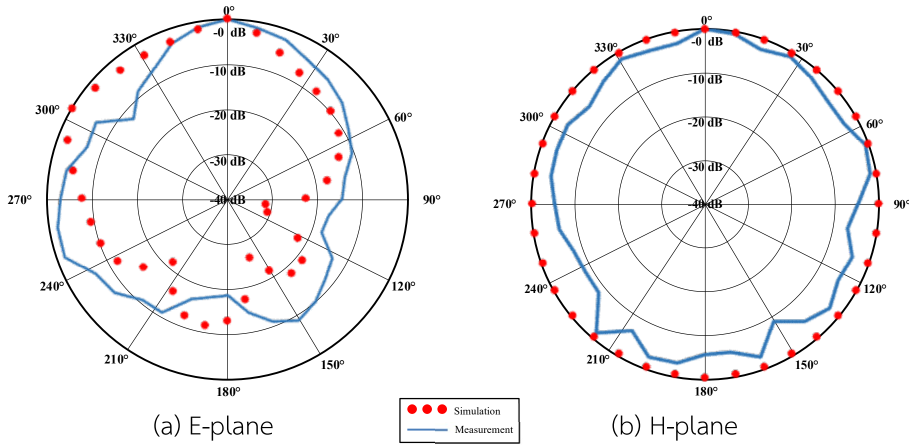
Figure 10 Measured $|S_{11}|$ the antenna located on the chest

The effect of the antenna attached to the chest on the $|S_{11}|$ is illustrated in figure 10. The impedance bandwidth of the measured result becomes narrower than that of the simulated result with the operating frequency between 2.1 GHz and 2.6 GHz. Considering the centre frequency of 2.45 GHz, the $|S_{11}|$ is -21.25 dB.



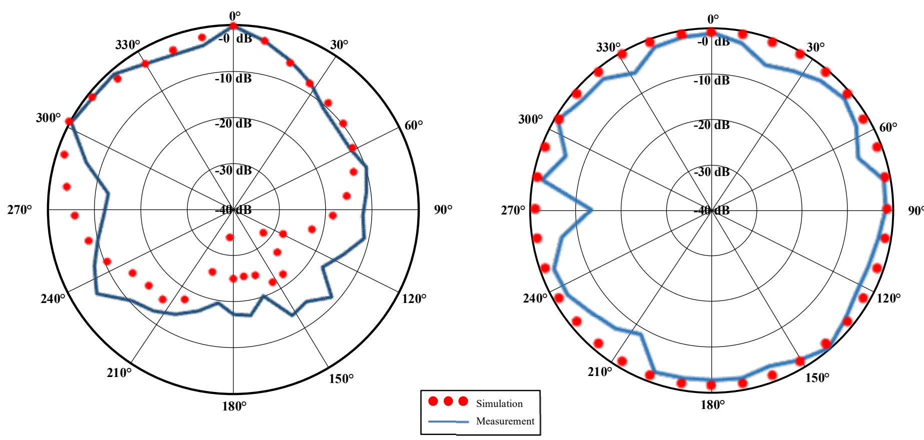
(a) E-plane (b) H-plane

Figure 11 Measured radiation pattern of the antenna without the human body



(a) E-plane (b) H-plane

Figure 12 Measured radiation pattern of the antenna located on arm



(a) E-plane (b) H-plane

Figure 13 Measured radiation pattern of the antenna on chest

One of the important antenna characteristics is the antenna radiation pattern because it can show the antenna directional characteristic. The radiation pattern in the case of comparing the simulated and measured results without a human body is shown in figure 11. The direction of the antenna is slightly changed but it is still in the same trend. However, considering when the antenna is located on the human body in figures 12 and 13, the patterns are slightly different from the results in figure 11 (without a human body). From that compared results, it can be concluded that the chest and arm of a human body affect the antenna radiation properties. The measured results and the simulated results are different because in the simulation the authors used the human model just a simple human model in which the body is divided into 3 layers that are skin, fat and muscle. An organ, bone and cloth are not included in the simulation model. However, the designed antenna still works properly.

Table 2 The measured antenna gain

Gain	Chest	Arm	Free-space
Simulation	-2.97 dBi	-2.47 dBi	4.36 dBi
Measurement	-2.02 dBi	-1.52 dBi	3.18 dBi

The antenna gain is tabulated in table 2. The gain of the antenna has greatly affected the human body. That can be caused by the degradation of the radiation efficiency and the reflection efficiency (mismatch) when the antenna is placed on high dielectric material such as the human body.

5. Conclusion

The E-textile monopole antenna is presented in this work. The antenna is designed for wearable technology and is located on the human body at the arm and chest. The flexible antenna structure is made of conductive fabric with a conductivity of 1250 s/m and felt with a dielectric constant of 1.38. The operating frequency range of the proposed antenna is from 2.2 GHz to 2.7 GHz without a human body. When combining the effects of the human body structure, the antenna has an operating frequency from 2.2 GHz to 2.6 GHz. According to the measured results, the presented antenna impedance bandwidth covered the proposed operating frequency band of 2.4-2.5 GHz. The results show that the human body has a minor effect on $|S_{11}|$ due to the dielectric constant of the human body. However, the radiation pattern is considerably changed when the antenna is located on the human body such as the characteristics and the direction of the main beam. The antenna radiation pattern will differ when installed on different human parts due to differences in human part shape, which will directly affect antenna propagation. When placed on human parts, the antenna gain is greatly reduced because human skin has a relatively high dielectric value, which may reduce the antenna radiation efficiency. The measured results show that the proposed antenna is appropriated for wearable technology which is used in the arm and chest of the human.

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