ABCS Antenna for Wireless Body Area Network at 26 GHz

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Abstract. The paper presents the design and investigation of a wearable textile antenna (receiver) and transmitter antenna operating in the wireless body area network (WBAN) of 26 GHz band for 5G mobile networks. The wearable antenna with an overall size of 30 mm x 40 mm x 1.26 mm achieves good impedance matching, high gain, and directive radiation pattern. Both antennas were designed using CST Microwave Studio to validate the simulation results. A rectangular radiating patch comprises a Shieldit electrotextile situated on one side of a non-conductive substrate panel with the ground plane. The bed sheet cotton fabric is used as the non-conductive substrate due to its widespread use in daily clothing with a dielectric constant is 3.2 and the loss tangent is 0.0027. In addition, the wearable antenna successfully achieved the high gain and efficiency of 12 dB and 90.83% respectively. Moreover, the antenna operating at 26 GHz with -40.48 dB return loss, which is less than the -10 dB in requirement. The simulated results show that this proposed wearable antenna is best suited for wireless body area network applications. Hence, the wearable antenna is simple, compact and easy to fabricate.

1. INTRODUCTION

In recent years, body-worn wireless networking (wearable antenna) that are made of fabric or textile antenna has developed rapidly, specifically designed to function while worn on the body [1]. It is predicted that various wearable devices will be part of the Internet of Things (IoT). In particular, with the recent advances in IoT technology, a wearable antenna has prominent potential in various application areas (healthcare, emergency, communication, monitoring) [2]. The development of wearable antennas is gaining popularity among researchers as they could play a key role in fifth-generation (5G) mobile communication systems [3]. Therefore, one of the dominant research topics for the wearable antenna is a wearable, fabric-based antenna integrated into clothing, highly reliable and efficient.

In general, the requirements of wearable antenna for all modern applications require high gain, wide impedance bandwidth, compactness, low-cost, lightweight, integration into the fabric, high radiation efficiency and high isolation [4]. Hence, the significance of high gain and high return loss are highlighted in this paper. Many researchers are focus on investigating ceramic and microstrip antenna, spiral antenna, dipole antenna and inverted-F antenna for wearable antenna [5]-[6]. Rectangular antenna shape has been chosen in this research not only facile to design but additionally capable of engendering wide bandwidth. The bandwidth of a rectangular antenna is slightly higher due to its larger physical area where the higher-order modes are widely separated in the case of a rectangular patch antenna [7]. Furthermore, the design of the rectangular patch is simple, and its electromagnetic simulation takes less time. For the convenience of the user, wearable antennas must be hidden and of low profile.

Therefore, a textile rectangular microstrip patch antenna is best suited for any wearable application as radiating perpendicular to the planar structure and the ground plane shields the body tissue efficiently. The wearable antennas can be worn by teenagers, the elderly and athletes for monitoring. To fully develop textile-based technology, the dielectric properties of fabrics need to be quantified. A textile antenna consists of a radiating conductive patch on one side of a dielectric substrate and a ground plane on the other side [8]. The design of a textile antenna requires knowledge about selecting a suitable conductive textile, and the substrate is a main point for the antenna design.

A conductive textile such as Zelt, Pure Copper Taffeta Fabric and shieldit [9] is regularly used as the radiating element (electrotextile). Meanwhile, four of the most commonly used fabrics, such as organic cotton [10], jeans, viscose and lycra are act as substrates to accommodate a wide selection of everyday use textiles (Figure 1a-d) [11]-[12]. The varied porosity of the textiles can be seen in the Figure 1; these air voids have an effect on the variation of the effective permittivity. The dielectric constant of the air ($\varepsilon_r = 1$) is lower than the fabrics, lowering the total dielectric constant and increasing the dissipation factor value (tan δ). As for this research, we are using a bed cotton sheet to design wearable antenna with a relative permittivity of 3.2 and a loss tangent of 0.0027 as the substrate due to high relative permittivity this makes it even more conformable for on body applications.

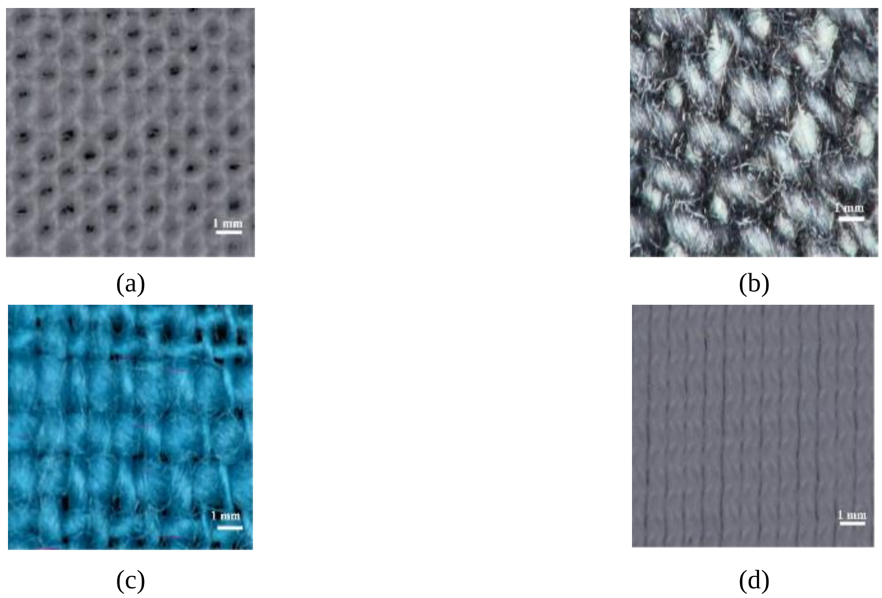

FIGURE 1. Textile substrates: (a) Cotton; (b) Jeans; (c) Viscose and (d) Lycra.

The values of dielectric constant and dissipation factor for the four textile substrates measured using the resonant method of cavity perturbation are given in Table 1 below. They provide advantages such as low cost, low profile, lightweight, integration into clothing and shielding effect of/from the body due to the ground plane [13]-[14].

TABLE 1. Dielectric properties of fabrics.

Fabric	Dielectric constant	Tangent
Bed sheet cotton	3.2	0.0027
Jeans	1.62	0.018
Viscose	1.64	0.016
Lycra	1.68	0.008

The rest of the paper is organized as follows. The three elements of textile rectangular microstrip patch antenna design is presented (radiating patch, ground plane, and dielectric substrate) in Section 2. The numerical results and discussion are presented in Section 3. All antenna simulations were performed using computer simulation software (CST Microwave Studio). To conclude, concluding remarks are given in Section 4.

2. ANTENNA DESIGN PROCEDURE

In ambient backscattered communication systems (ABCS), an antenna is an essential component that receives backscattered signals [15]. A transceiver in ABCS consists of three main components such as harvester, backscatter transmitter and backscatter receiver. The receiver and transmitter are connected to the same antenna. Moreover, the transmitter and receiver operate in the same frequency band of the cellular system [16]. Figure 2 shows the structure of ABCS, which consists of transceiver A and transceiver B by modulating and reflecting the signals of the ambient radio frequency (RF). Therefore, two antennas are proposed in this paper consisting of a wearable antenna (transmitter) and a receiver antenna in the transceiver system of the ABCS components.

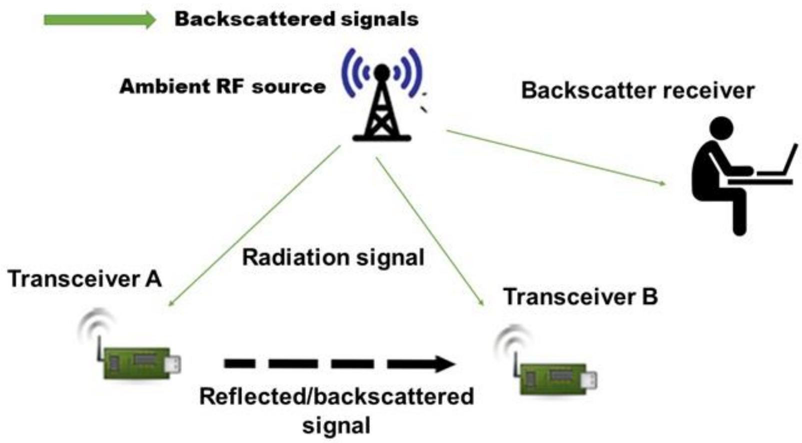

FIGURE 2. Ambient backscatter communication system components.

a) Receiver antenna design

Figure 3 shows a textile rectangular microstrip patch antenna with small and compact dimensions of 30 mm x 40 mm x 1.26 mm. The textile rectangular microstrip patch antenna is chosen and designed due to its low profile and low cost fabrication [17]. This antenna is bonded to a piece of bed sheet cotton fabric as the substrate with the thickness of 1.26 mm. The high dielectric constant materials reduced the size of the antenna. All the parameters are simulated by using CST Microwave Studio software. The dimensions of the patch and feedline of the antenna were calculated using the equations cited in [18] and tabulated in Table 2.

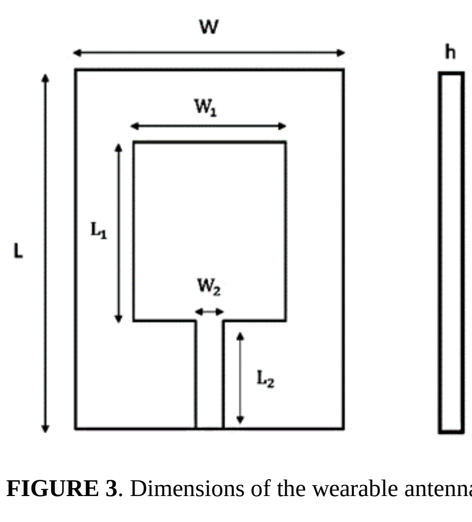

FIGURE 3. Dimensions of the wearable antenna.

TABLE 2. Dimensions of the proposed antenna.

Parameter	Value (mm)	Parameter	Value (mm)
W	30	W_2	3
L	40	L_2	12
W_1	17	h	1.26
L_1	20		

Figure 4 shows the front view of the antenna, which consists of a waveguide port in three basic layers. The first layer consists of a radiating patch (shieldit). The characteristics of Shieldit is a high-quality flame retardant fabric for radio frequency (RF) [19], with a thickness of 0.04 mm, relative permittivity (ε_r) of 1.22, and a loss tangent of 0.016. "Shieldit Super" consists of a polyester substrate coated with conductive nickel and a non-conductive hot melt adhesive [9]. It has the advantages of excellent shielding and low corrosion. It is also easy to cut, sew and can be ironed onto cotton or other fabric. The second layer consists of a dielectric substrate and the feed lines are usually photo etched onto the dielectric substrate (bed sheet cotton fabric).

FIGURE 4. Front view of the receiver antenna.

Finally, the third layer consists of the ground plate. Copper is commonly used as a partial ground to achieve good directivity and wide bandwidth. In this paper, we have proposed shieldit as a ground plate since it is for wearable application, and it is also able to increase the antenna gain by reflected the direction of antenna pattern. Figure 5 shows an antenna topology was chosen consisting of textile rectangular microstrip patch antenna made of bed sheet cotton substrate with shieldit as a radiating patch and ground plate.

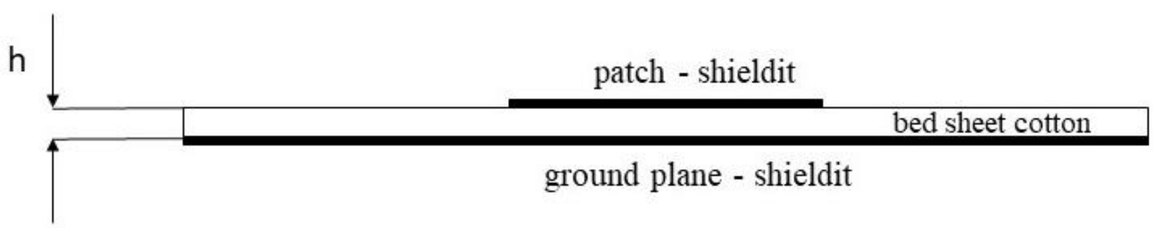

FIGURE 5. Side view of receiver antenna.

b) Transmitter antenna design

Figure 6 shows a conventional microstrip antenna with small and compact dimensions of 18 mm x 18 mm x 0.1 mm with a relative dielectric constant (ε_r) of 3.55 and a loss tangent of 0.0027. It is bonded to a piece of Rogers R04003C as the substrate with the thickness of 0.1 mm. The dimensions of the patch and feedline of the antenna were calculated using the equations cited in [18] and tabulated in Table 3.

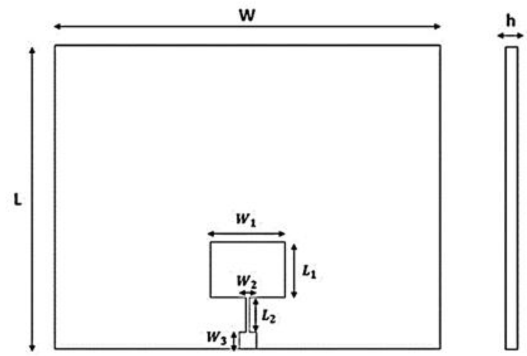

FIGURE 6. Dimensions of the transmitter antenna.

TABLE 3. Dimensions of the antenna.

Parameter	Value (mm)	Parameter	Value (mm)
W	18	W_2	0.15
L	18	L_2	1.78
W_1	3.82	h	0.1
L_1	2.92	W_3	0.72

Figure 7 shows the front view of the antenna, which consists of a waveguide port in three basic layers. The first layer consists of a radiating patch (copper). The dimensions of the port are [$6W_2$ x (5h + 0.035)]. The easiest way to define the area of a port is select structural elements such as points/edges/areas before opening the port definition dialogue box. The second layer consists of a dielectric substrate and the feed lines are usually photo etched onto the dielectric substrate (Rogers R04003C). Finally, the third layer consists of the ground plate. Copper is commonly used as a partial ground to achieve good directivity and wide bandwidth.

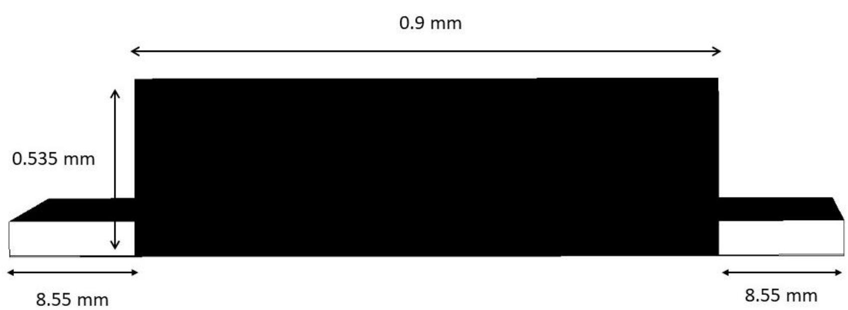

FIGURE 7. Front view of the transmitter antenna.

Figure 8 shows an antenna topology was chosen consisting of textile rectangular microstrip patch antenna made of Rogers R04003C substrate with copper as a radiating patch and ground plate.

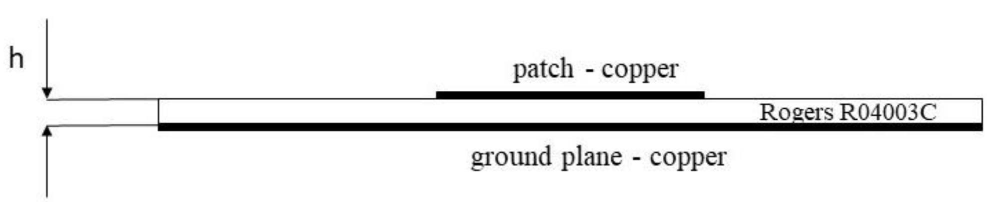

FIGURE 8. Side view of transmitter antenna.

3. RESULTS AND DISCUSSIONS

In this section, the wearable and transmitter antenna results are presented based on return loss, VSWR, efficiency, and gain. The antenna is then simulated and analysed in the CST Microwave Studio software. The reflection coefficient or return loss describes how much an electromagnetic wave is reflected due to a discontinuity in the transmission medium. It is often referred to as S_{11}. Figure 9 shows the reflection coefficient graph plot of the wearable antenna simulated in free space. It can be shown that the wearable antenna provides a good impedance matching $|S_{11} < -10 \text{ dB}|$ for a frequency of 26 GHz despite having other S-parameters peaks at about 19 GHz, 21 GHz and 24 GHz. Therefore, the proposed wearable antenna has a high return loss which is achieved at -40.48 dB. The designed antenna is best suited for the wireless body area network.

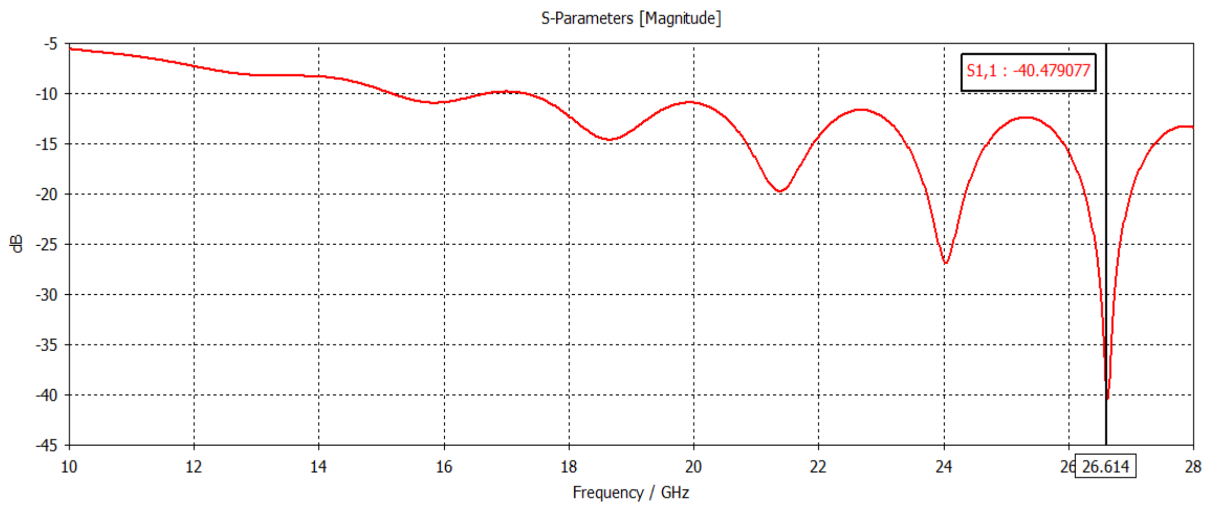

FIGURE 9. Return loss plot of the wearable antenna as the receiver.

The VSWR indicates the quality of the impedance matching. Figure 10 shows small VSWR graph plot of the wearable antenna at 26 GHz. In this case, the VSWR is 1.12, so less power is reflected from the antenna, which is the best ideal. The smaller the VSWR is, the better the antenna is matched to the transmission line and the more power is delivered to the antenna.

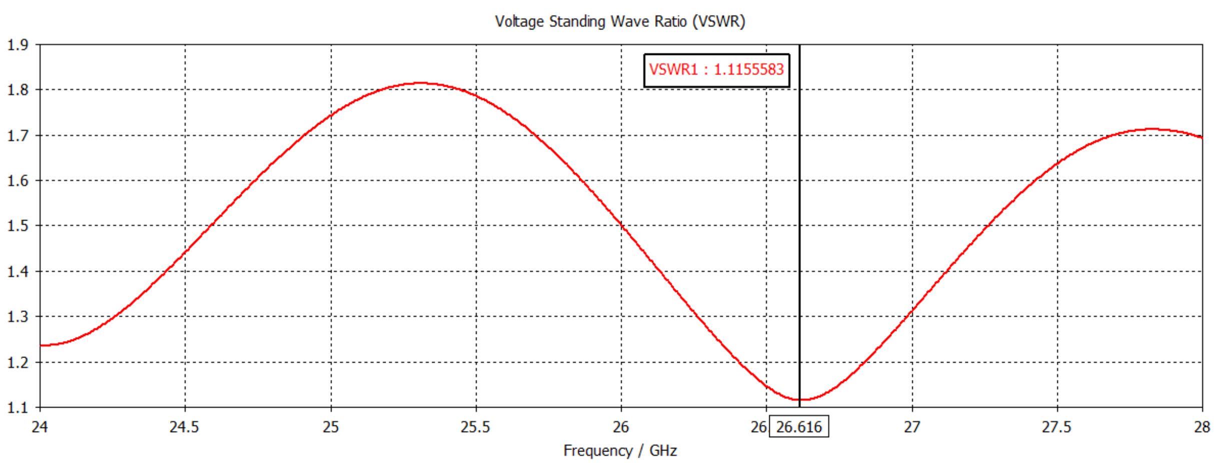

FIGURE 10. VSWR plot of the wearable antenna.

The directivity gain is a measurement of the ability of an antenna to concentrate radiation in a particular direction. Figure 11 shows a high directivity gain of the wearable antenna at 26 GHz. In this paper, the directivity gain is 15.4 dB, so that the signal strength can be increased and provides a more precise way of targeting radio signals. Therefore, a high gain antenna is essential for long-range wireless networks in communication systems.

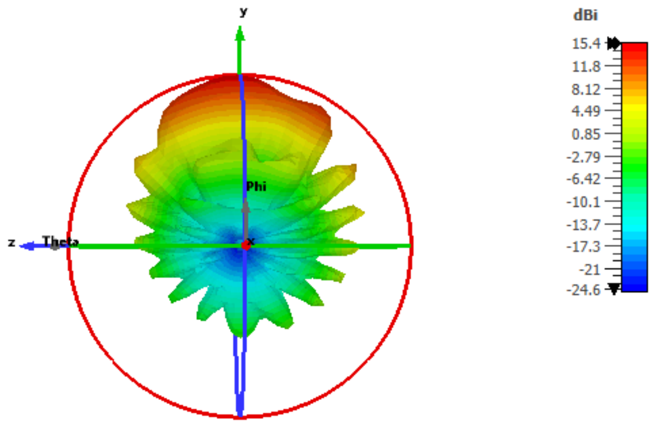

FIGURE 11. Directivity gain of the wearable antenna.

Antenna efficiency is the ratio of power radiated (Prad) by the antenna to the power supplied (Ps) to the antenna. The antenna efficiency is achieved at 96.66%. An ideal antenna has 100% antenna efficiency. It transmits all the power fed to it. But in the real world, a good antenna radiates only 50 to 60% of the power supplied to it. Table 4 shows the directivity, gain and efficiency of the proposed wearable antenna. The gain and efficiency enhancement of 75% and 2.75% are achieved compared to the previous design in [19].

TABLE 4. Radiation parameters of the wearable antennas at 26 GHz.

Radiation parameters	Simulated
Directivity (dB)	15.4
Gain (dB)	15.3
Efficiency (%)	96.66

Figure 12 shows the reflection coefficient graph plot of the transmitter antenna simulated in free space. It can be seen that the antenna provides a good impedance matching ($|S_{11} < -10\,\mathrm{dB}|$ for a frequency range of 26 GHz. Therefore, the proposed transmitter antenna has a high return loss which is achieved at -30.331 dB. The designed antenna is best suited for the wireless body area network.

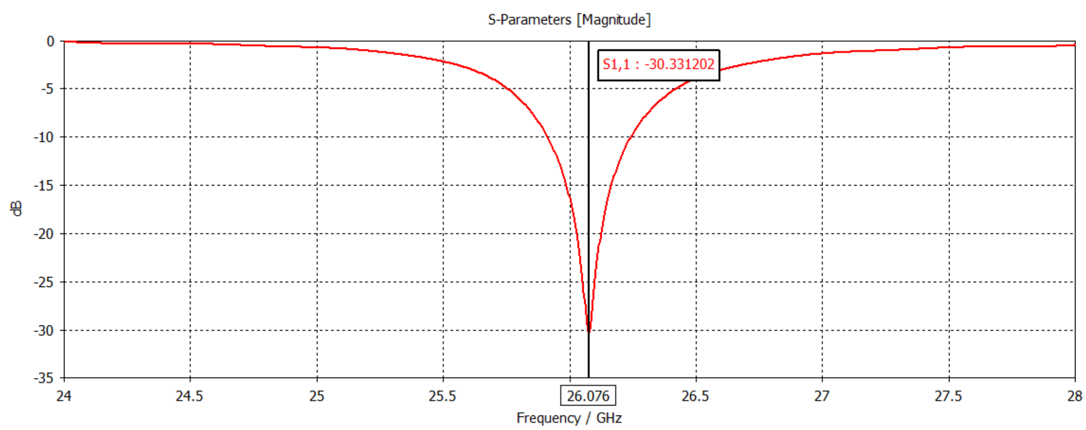

FIGURE 12. Return loss plot of the transmitter antenna.

Figure 13 shows small VSWR graph plot of the transmitter antenna at 26 GHz. In this case, the VSWR is 1.06, so less power is reflected from the antenna, which is the best ideal. The smaller the VSWR is, the better the antenna is matched to the transmission line and the more power is delivered to the antenna. In case of -10 dB bandwidth consideration, the transmitter antenna shows the bandwidth of 330 MHz in Figure 14.

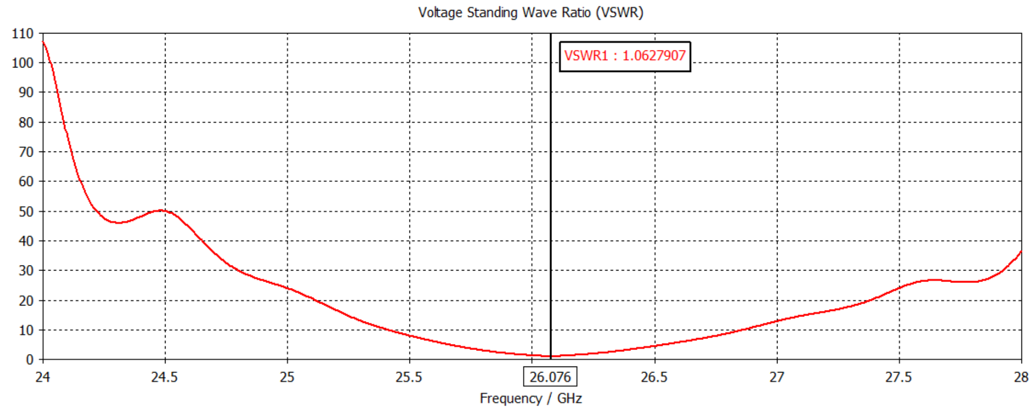

FIGURE 13. VSWR plot of the transmitter antenna.

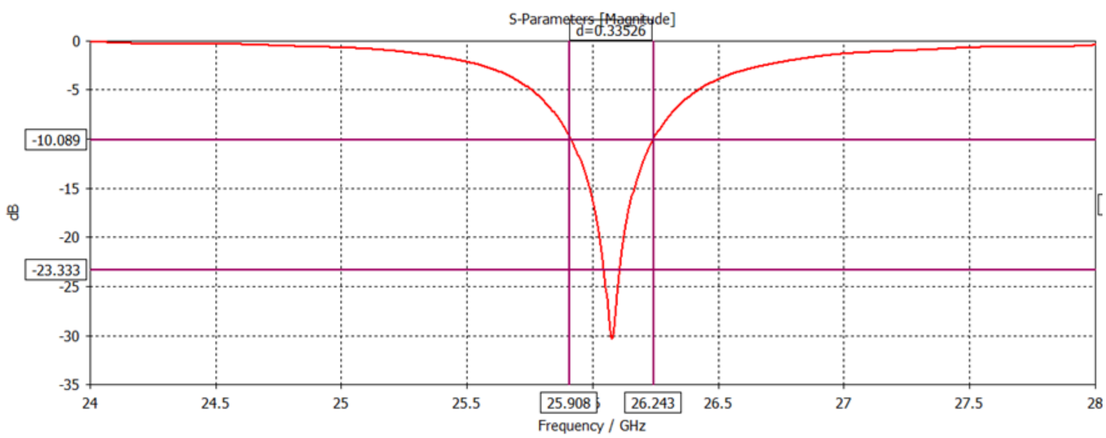

FIGURE 14. The bandwidth calculation for the transmitter antenna.

Figure 15 shows a high directivity gain of the transmitter antenna at 26 GHz. In this paper, the directivity gain is 7.62 dB, so that the signal strength can be increased and provides a more precise way of targeting radio signals. Therefore, a high gain antenna is essential for long-range wireless networks in communication systems.

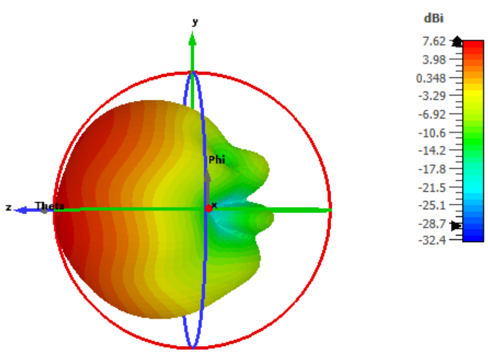

FIGURE 15. Directivity gain of the transmitter antenna.

The antenna efficiency is achieved at 62.09%. An ideal antenna has 100% antenna efficiency. It transmits all the power fed to it. But in the real world, a good antenna radiates only 50 to 60% of the power supplied to it. Table 5 shows the directivity, gain and efficiency of the proposed transmitter antenna. Figure 16 shows a high gain of the transmitter antenna at 26 GHz. In this paper, the gain is 5.56 dB.

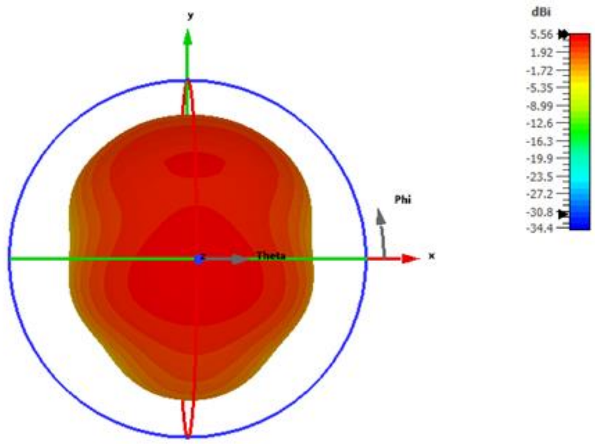

FIGURE 16. Gain of the transmitter antenna.

TABLE 5. Radiation parameters of the transmitter antenna at 26 GHz.

Radiation parameters	Simulated
Directivity (dB)	7.62
Gain (dB)	5.56
Efficiency (%)	62.09

4. CONCLUSION

In this paper, the design and evaluation of a wearable antenna with integration into clothing are investigated. The designed antenna with better performance is proposed with the use of shieldit electrotextile as the radiating patch. In conclusion, the performance of the proposed antenna is improved in return loss, gain and efficiency when shieldit is applied. The wearable antenna has a high return loss of -40.48 dB, the VSWR is 1.12, the directivity gain is 15.4 dB, and the antenna efficiency is 96.66%. The high dielectric constant materials reduced the size of the antenna is best suited for the wearable application due to the wide range of operating frequency and bandwidth. Meanwhile, the receiver antenna also has a high return loss of -30.331 dB, the VSWR is 1.06, the directivity gain is 7.62 dB, and the antenna efficiency is 62.09%. The bandwidth of the transmitter antenna is achieved of 330 MHz. Therefore, the textile microstrip antenna is a suitable candidate for wearable applications, as it can be built using fabric substrate materials. For future work, there will be an experimental analysis of the combination of a wearable textile antenna and a rectifier for harvesting radio frequency (RF) energy in free space. In this case, a rectifier circuit will be designed along with the receiver antenna to convert the received RF energy into direct current (DC). Besides, a wearable textile antenna will be fabricated in the next step to compare with the simulation and experimental results.

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