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Tungsten disulfide based wearable antenna in terahertz band for sixth generation applications

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ABSTRACT

Wireless communication networks could become quicker and more dependable as sixth generation (6G) antennas develop. One difficult development in the field of wearable technology is wearable textile antennas. Wearable textile antennas require flexible building materials, primarily textiles with planar structures. This study will concentrate on the design and specification of microstrip rectangular patch antennas that use a variety of fabrics as the substrate, such as lycra, polyester, and washed cotton. Using two-dimensional (2D) materials in the terahertz (THz) range, the study presented here will help in the construction of appropriate wearable antennas. This work may significantly improve materials science and engineering by investigating and using 2D materials, such as tungsten disulfide, in antenna design. The suggested antennas' resonance frequencies are 1.1254 THz for polyester substrates, 4.4019 THz for washed cotton, and 2.9861 THz for lycra substrates. For substrate materials such as lycra, polyester, and washed cotton, the measured return loss was -44.92 dB, -38.17 dB, and -20.75 dB. This study could lead to the creation of new technologies and materials, such tungsten disulfide, which would have far-reaching uses outside of wearable electronics and provide significant advantages for society.

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1. INTRODUCTION

The rapid evolution of wireless communication technologies has driven the demand for innovative antenna designs to support emerging applications, particularly in the context of wearable electronics. The demand for small, effective, and adaptable antennas is growing as we approach the launch of the sixth generation of wireless networks, or 6G. Using the special qualities of two-dimensional (2D) materials, this thesis explores the field of 6G antenna design for wearable devices [1]. Every new generation of wireless technology, including 6G, has the potential to be revolutionary. With its ultra-low latency, enormous data throughput, and seamless connectivity for a wide range of devices, including wearable electronics, 6G is expected to surpass the capabilities of its predecessors. Wearable technology is becoming a part of daily life, which means that antennas need to be small and able to provide high-performance connectivity in a variety of settings [2].

Even though 2D materials have a lot of potential for antenna design, there are still obstacles to overcome and knowledge gaps regarding their efficient use. Not only must antennas be made smaller, but power consumption, flexibility, and manufacturability must also be considered when integrating them into wearable technology. For best results, it is also necessary to handle the complicated electromagnetic interactions that exist between the human body and antennas [3]. This work seeks to contribute to the advancement of 6G antenna design by proposing innovative solutions grounded in the use of 2D material. By leveraging the intrinsic properties of tungsten disulfide, we aim to develop antennas that are not only compact and lightweight but also exhibit enhanced performance in terms of efficiency and bandwidth. To meet the growing demand for high-speed and reliable wireless communication, 6G antennas are finding particular utility in various real-time health monitoring applications. Wearable antennas serve numerous purposes, including GPS navigation, military applications, fitness tracking for athletes, telemedicine, satellite communication, digital watches, and radio frequency identification (RFID) [4], [5].

Due to wearable antenna's widespread accessibility, the THz frequency range is used for the development of wearable antennas. The wearable antenna should be discrete and low profile for the user's comfort. This requires a reasonable fusion of the antenna components used in everyday attire. For applications involving wearable antennas [6]–[8], microstrip patch antenna [9] may be the best option [10]. Fabric materials are considered a feasible resource for design because they are readily available and frequently used in daily life by all humans. Because the ground plane of the antenna effectively protects the body tissues and radiates vertically to the planar structure [11], microstrip patch designs are the most often used for wearable applications. As a 2D material tungsten disulfide is used. Due to its crucial chemical and physical features, the transition metal di-chalcogenide (TMDC) tungsten disulfide (WS2) has garnered a lot of attention as a 2D layered material. It is appealing for these applications because it has a band gap between 1.3 and 2.2 eV, which is well within the range of solar materials. Its 2D layered structure enables doping with additional atoms or molecules in between weakly linked layers to adjust and tune its electronic characteristics. Additionally, the structure and subsequently the electrical properties of the object can be changed by applying external force [12].

Since thermoelectric materials can directly transform waste heat into useful electricity, they have great potential for energy conversion applications. Thermoelectric devices efficiency is critically dependent on the figure of merit (ZT), which is determined by the interplay of electrical conductivity (σ), seebeck coefficient (S), and thermal conductivity (k). Achieving high values of S and σ along with low k is crucial for realizing high-performance thermoelectric devices. Tungsten disulfide (WS2) has garnered attention due to its inherently high seebeck coefficient (3.5×102∼9.5×102 μV/K) but limited electrical conductivity (10−2∼10−1 S/m), resulting in a low ZT value (~0) [13].

A 2D substance recognized for its extraordinary strength, flexibility, and electrical conductivity. Graphene has attracted interest as a possible contender for use in antenna applications, notably in the THz frequency range, due to its exceptional conductivity and capacity to support surface plasmon modes. Due to its link to higher atmospheric absorption, the frequency band between 12.2 and 13.8 THz offers both opportunities and difficulties. Despite this restriction, the authors contend that THz communication systems are appealing for applications like WLAN antennas due to the ultrahigh bandwidth they offer [14]. In this work, micro-strip patch antennas have been designed using tungsten disulfide as a patch of the antennas for THz range wearable applications. Here different types of substrate material have been used to observe the performance parameters of the antenna.

2. METHOD

2.1. Proposed antenna design

The computer simulation technology (CST) studio is used to develop and emulate the suggested antenna. As a microstrip patch antenna, the recommended antenna requires specific geometrical and simulation parameters for its design in CST studio. After the computation of geometrical parameters, the design of the suggested antenna can be modeled in the CST studio. We followed the procedure of designing microstrip patch antenna utilizing different types of fabrics such as wash cotton, polyester, lycra as the antenna's substrate. The geometry of the proposed rectangular microstrip patch antennas as shown in Figure 1.

2.2. Properties of tungsten disulfide

The patch material used for the proposed antenna is a 2D material. By exploring and utilizing 2D materials like tungsten disulfide in antenna design, our project can contribute to the advancement of materials science and engineering. The structure of tungsten disulfide (WS2) displays a trigonal prismatic arrangement, with each layer being made up of two layers of hexagonally aligned sulfur (S) atoms on either side of a layer formed by tungsten (W) atoms in a hexagonal alignment [15], [16]. The single WS2 layer has a thickness of 3.2. These layers are separated from one another by an empty gap measuring 2.96. Through single-crystal electron diffraction, the lattice parameter 'a' is found to be 3.154. Each layer has robust covalent connections, such as W-W, S-S, and W-S interactions. Meanwhile, the van der waals kind of connection between adjacent layers is weaker. A single W atom and two S atoms combine to form the basic building block, which has a trigonal prismatic shape [17], [18]. Tungsten disulfide has high carrier mobility, excellent mechanical flexibility, good thermal stability, tunable electrical properties. The properties needed to create tungsten disulfide as patch material in CST studio are given in Table 1. And for the preparation process of the antenna is illustrated in Figure 2(a) shows the SEM image and Figure 2(b) shows the TEM image of tungsten disulfide at different magnitudes.

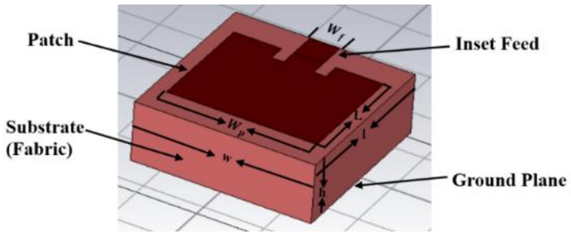
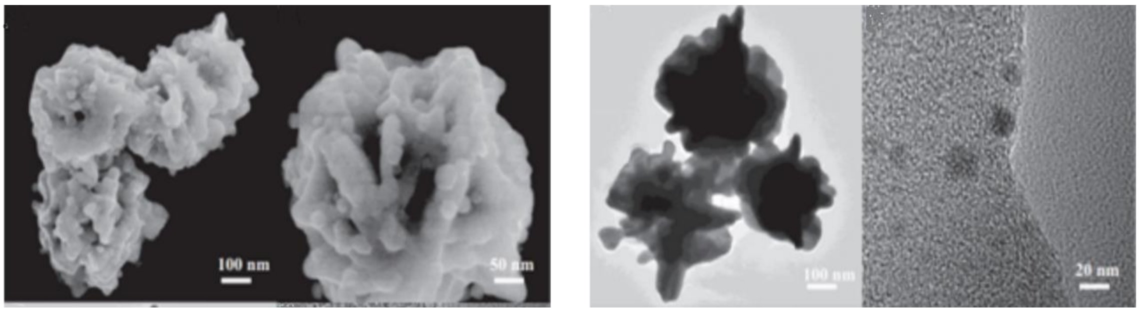


Figure 1. Geometry of the proposed rectangular microstrip patch antennas

Table 1. Properties of tungsten disulfide for antenna design [12], [13], [19]

Parameters	Value
Epsilon, ε_r	5.1
Mu (diamagnetic material)	1
Electric conductivity	0.1 [S/m]
Density (Rho)	6530 [kg/m^3]
Thermal conductivity	31.8 [W/K/m]
Heat capacity	0.255 [kJ/K/kg]
Diffusivity	0.00001919 [m^2/s]
Young's modulus	302400 [kN/mm^2]
Poisson's ratio	0.22



(a) (b)

Figure 2. Preparation process of: (a) the SEM images of WS2 nano flowers and (b) the TEM images of WS2 nano-flowers [20]

2.3. Substrate material

Lycra, polyester, and washable cotton are the substrate materials used in the design of wearable antenna. Flexibility is the primary benefit of using lycra, polyester, or washable cotton as a substrate. Moreover, it is easily accessible in the market and utilized in everyday fabrics. The following are the material properties that Table 2 lists.

Table 2. Properties of substate materials [21]–[26]

Material type	Dielectric constant (εr)	Loss tangent tan σ
Wash cotton	1.51	0.025
Polyester	1.44	0.01
Lycra	1.50	0.0093

2.4. Dimensions of patch antenna

When creating an antenna design that produces efficient results, the patch antenna's dimensions are crucial. Table 3 presents the estimated parameters of the proposed patch antenna model for several substrate materials, including lycra, polyester, and washable cotton. All the parameters are in micrometer (μm) range.

Table 3. Patch antennas design value

Parameters	Wash cotton	Polyester	Lycra
Substrate width, w (μm)	800	400	300
Substrate length, l (μm)	800	400	300
Substrate thickness, h (μm)	100	100	100
Antenna width, Wp (μm)	600	350	250
Antenna length, L (μm)	450	300	200
Ground thickness, t (μm)	60	30	0.0035
Transmission line width, Wf (μm)	150	50	50
Inset width (μm)	60	50	20
Inset length (μm)	100	80	30

2.5. Equation for the patch antenna

The equations need to calculate the parameters for this work is given [27]–[29]

a. The effective dielectric constant (1):

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+12\times\frac{h}{w}\right)^{-0.5} \tag{1}$$

b. Microstrip patch antenna width (2):

$$W_p = \frac{c_0}{2f_r\sqrt{\frac{\varepsilon_r+1}{2}}} \tag{2}$$

c. Extended length (3-5):

$$\Delta L = 0.412\frac{\left(\frac{W}{h}+.264\right)\left(\varepsilon_{reff}+.3\right)}{\left(\varepsilon_{reff}-.258\right)\left(\frac{W}{h}+.813\right)} \tag{3}$$

$$L_{ext} = \frac{c_0}{2f_r\sqrt{\varepsilon_{reff}}} \tag{4}$$

$$L = L_{ext} - 2\Delta L \tag{5}$$

d. Feed line width (6):

$$W_f = \frac{7.48h}{e^{\left(z_0\frac{\sqrt{\varepsilon_r+1.41}}{87}\right)}} - 1.25t \tag{6}$$

3. RESULTS AND DISCUSSION

The CST studio antenna simulation tool is used to simulate the suggested wearable patch antenna using the simulation settings listed in Table 3. 2D material-based antenna have been designed for THz applications by using different types of substrate material such as wash cotton, polyester, and lycra. As the patch of the antenna, tungsten disulfide was used as a 2D material. Tungsten disulfide has high carrier mobility, excellent mechanical flexibility, good thermal stability, and tunable electrical properties. Return loss is a measurement of the power of the reflected wave or signal that the antenna is sending to or receiving from the transmitter. Antenna return loss parameters that are good for a certain application and level of performance are determined by these factors. It is generally acknowledged that a return loss of -10 dB or more is acceptable for most antenna systems. The voltage standing wave ratio (VSWR) measures how well high-frequency power travels from a source down a transmission line to a load, like an antenna from a power amplifier along a transmission line [30]. The bandwidth for the VSWR should be close to 1 to get better performance [31]. Farfield (FF) is thought to begin at a distance of rff = $2D$ 2 /λ, where λ is the wavelength and D is the radiation source's largest dimension. When the antenna takes up relatively little space within the radiating apparatus, this criterion can, however, be unduly conservative [32]. Geometry of the proposed rectangular microstrip patch antennas is given in Figures 3 to 5, specifically Figures 3(a), 4(a) and 5(a). The dissipating parameters (S11) return loss of the simulated antennas for different types of substrate material such as wash cotton, polyester and lycra are illustrated in Figures 3(b), 4(b) and 5(b) accordingly. Geometry of the proposed antennas, return loss, peak gain, simulated VSWR was given in Figures 3 to 5 for wash cotton, polyester, lycra as the substrate material and a comparison of these three antennae was given in result comparision section.

3.1. Wash cotton as a substrate material

Figure3 (a) shows the geometry of the design antenna when wash cotton is used as a substrate material and Figures 3(b), 3(c) and 3(d) illustrate return loss, VSWR and peak gain of the proposed antenna respectively. The value of the minimum return loss curve attained at 1.1254 THz is - 20.75 dB for wash cotton as the substrate of the antenna which is acceptable because a return loss of -10 dB or more is acceptable for most antenna systems [30], [33], [34]. A measure of the quality of the impedance match is VSWR. The VSWR value attained at 1.1254 THz in the suggested antenna is 1.20. The peak gain of this antenna is 9.23 dBi.

3.2. Polyester as a substrate material

For polyester as a substrate material, Figure 4(a) shows the geometry of the design antenna and Figures 4(b), 4(c) and 4(d) shows the return loss, VSWR, and peak gain, respectively. When polyester serves as the antenna's substrate, a -38.17 dB minimum return loss curve value is attained at 4.4019 THz. The impedance match's quality can be determined via VSWR and the bandwidth for the VSWR should be close to 1 to get better performance [31]. The VSWR value at 4.4019 THz for the proposed antenna is 1.03. This antenna's maximum gain is 8.44 dBi.

3.3. Lycra as a substrate material

Figure 5(a) shows the geometry of the design antenna and Figures 5(b), 5(c) and 5(d) illustrate return loss, VSWR and peak gain correspondingly, when the patch antenna's substrate is made of lycra. The antenna substrate made of lycra achieves a minimal return loss curve value of -44.92 dB at 2.9861 THz. A measure of the quality of the impedance match is VSWR. At 2.9861 THz, the proposed antenna achieves a VSWR value of 1.01. The peak gain of this antenna is 14.4 dBi.

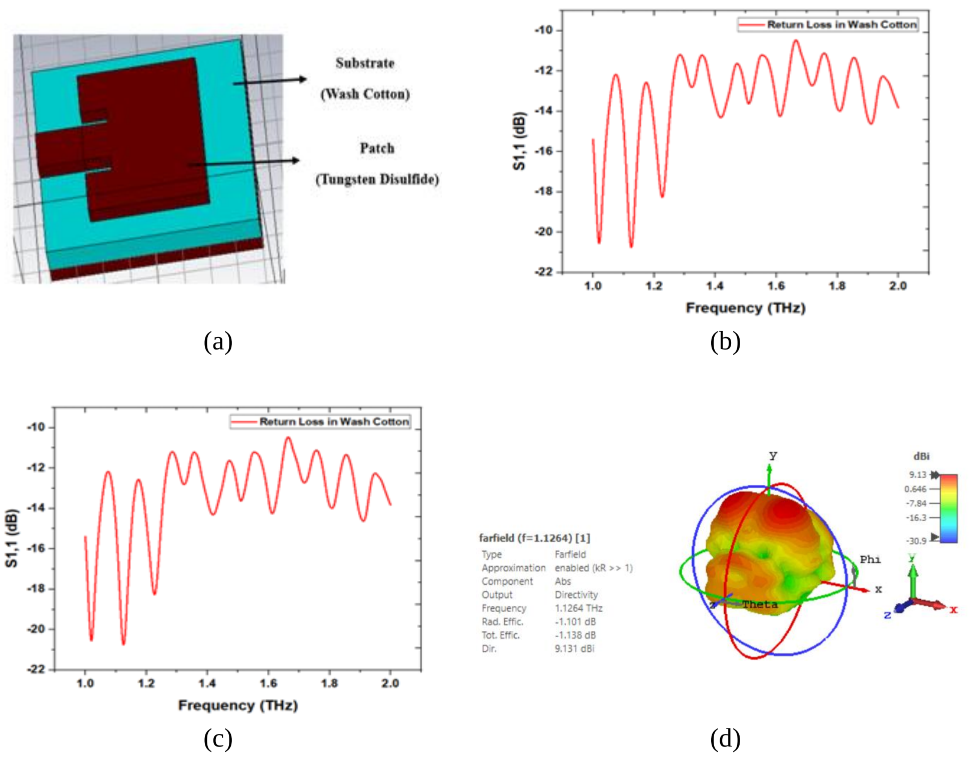


Figure 3. Wash cotton as a substrate material: (a) geometry of the proposed rectangular microstrip patch antenna; (b) simulated return loss of - 20.75 dB at 1.1254 THz; (c) simulated VSWR of 1.20 at 1.1254 THz; and (d) simulated antenna 3D radiation pattern at 1.1254 THz (wash cotton)

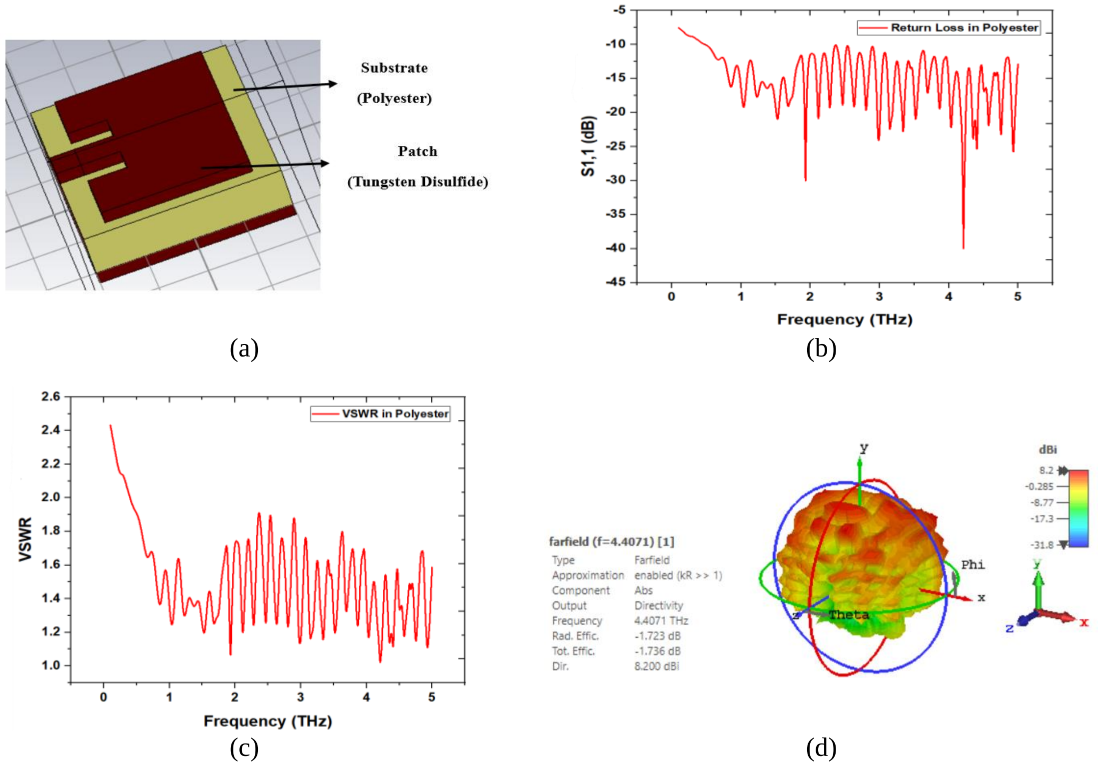


Figure 4. Polyester as a substrate material: (a) geometry of the proposed rectangular microstrip patch antenna; (b) simulated return loss of - 38.17 dB at 4.4019 THz; (c) simulated VSWR of 1.02 at 4.4019 THz; and (d) simulated antenna 3D radiation pattern at 4.4019 THz (polyester)

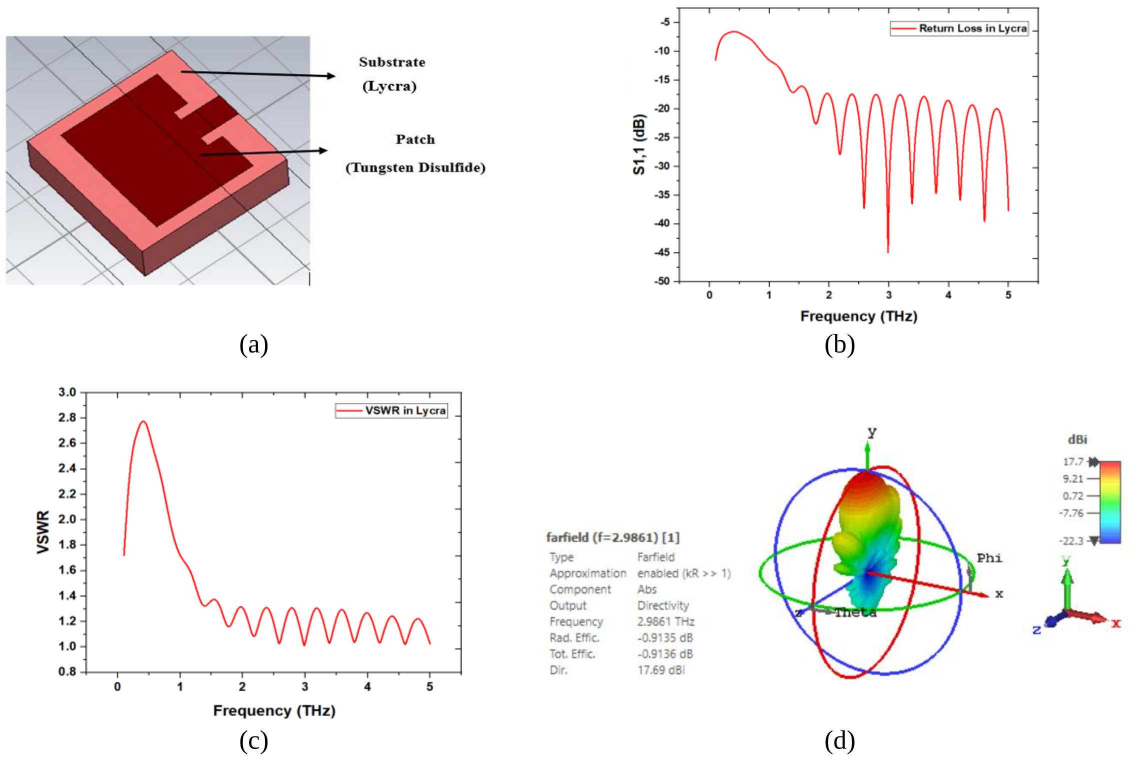


Figure 5. Lycra as a substrate material: (a) geometry of the proposed rectangular microstrip patch antenna; (b) simulated return loss of - 44.92 dB at 2.9861 THz; (c) simulated VSWR of 1.01 at 2.9861 THz; and (d) simulated antenna 3D radiation pattern at 2.9861 THz (lycra)

3.4. Properties of human body tissue and specific absorption rate

Table 4. shows the properties of human body tissue. Skin is 2 mm in thickness and fat is 8 mm in a human phantom muscle model. Figure 6 depicts the antenna when Lycra is used as a substrate material that has been implanted on that model to monitor its performance in a biological setting. Figure 6 illustrates the measurement of the S11 parameter at resonance frequency following the implantation of the antenna on phantom tissue to confirm the biocompatibility of the planned antenna. The resonance frequency in this investigation was found to be 2.11 THz when Lycra is used as the textile material of the antenna, which is in the sixth-generation band.

Table 4. Properties of human body tissue

Tissue	Permittivity	Conductivity	Loss tangent	Density
Skin	31.29	5.0138	0.2835	1100
Fat	5.28	0.1	0.19382	1100

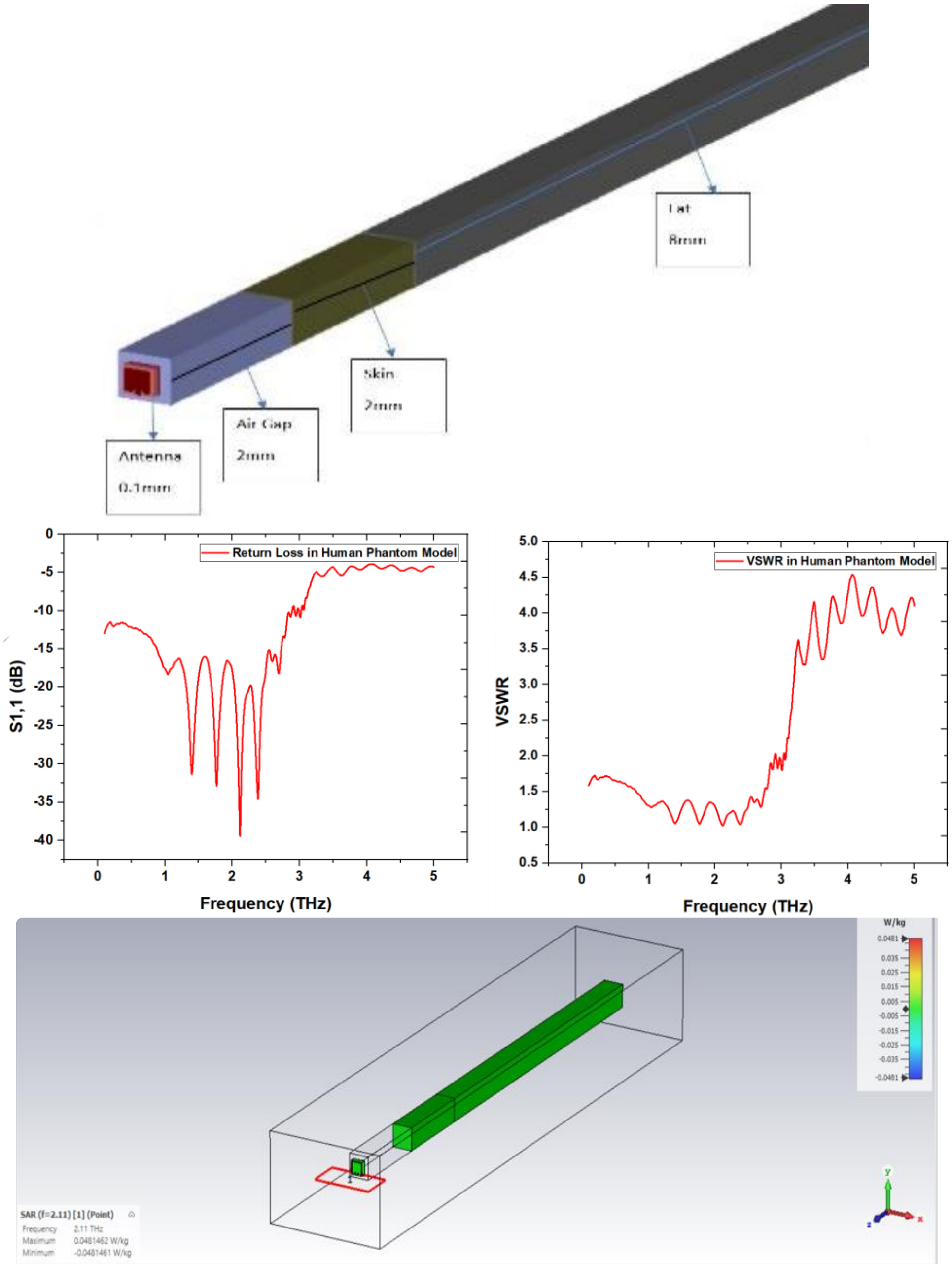


Figure 6. Suggested wearable patch antenna for the lycra model using a human phantom model

In Figure 6 the VSWR is also observed on human tissue and found to be 1.02 at resonant frequency of 2.11 THz, which is good for impedance matching. SAR which stands for specific absorption rate, is a measurement of how quickly the human body absorbs energy when exposed to RF energy. SAR is a crucial quality in terms of safety. According to the IEEE/IEC 62704-1 standard, the 10-g averaged SAR should not be greater than 2W/kg, which is the limit given by federal communications commission (FCC), and ICNIRP guidelines [33]–[37]. According to the FCC, its criteria include reasonable safety margins. SAR is determined the rate of energy absorption by human body, when RF energy is exposed. SAR value of the simulated antenna is 0.048 W/kg at 2.11 THz when lycra is used as a substrate material.

3.5. Comparison with other related works

The results of a wearable patch antenna are compared with those of other comparable works in Table 5. From the table, the proposed antennas have the resonant frequency range of 1.12-4.40 THz. On the other hand, the related paper works have a resonant frequency range of 2.4-2.45 GHz. Return loss, gain and VSWR of the proposed antenna is -20.75 dB, 9.23 dB, 1.20 respectively whereas paper [38] has the return loss of -10.68dB, gain of 4.53 dB. So, the proposed antenna shows better performance compared with the paper [38] when wash cotton is utilized as a material substrate. The loss on return, peak gain and VSWR of the proposed antennas are better than that of the [39], [40] when polyester and lycra are used as a substrate material respectively.

Table 5. Comparison with other related works

Substrate materials	Resonant frequency	Return loss (dB)	Gain (dB)	VSWR
Wash cotton	1.12 THz	-20.75	9.23	1.20
Polyester	4.40 THz	-38.17	8.44	1.03
Lycra	2.98 THz	-44.92	17.4	1.01
Wash cotton [38]	2.4 GHz	-10.68	4.53	1.83
Polyester [39]	2.45 GHz	-10.52	7.81	1.84
Lycra [40]	2.45 GHz	-31	6.8	1.09

4. CONCLUSION

The wearable antenna proposed in this research has multiple applications, including military, navigation, and medical monitoring. The patch antenna that is rectangular was designed with tungsten disulfide as a 2D. Tungsten disulfide has unique properties. Different types of textile material such as wash cotton, polyester and lycra were used as the substrate of these patch antenna. The measured return loss for wash cotton is -20.75 dB at 1.1254 THz, for polyester is -38.17 dB at 4.4019 THz and for lycra is -44.92 dB at 2.9861 THz. SAR value of the simulated antenna when lycra is used as a substrate material is 0.048 W/kg at 2.11 THz which is suitable for human body. The most effective method for implementing wireless body area network communication is using wearing antennas.

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REFERENCES

[1] S. A. A. Hakeem, H. H. Hussein, and H. W. Kim, “Vision and research directions of 6G technologies and applications,” *Journal of King Saud University-Computer and Information Sciences*, vol. 34, no. 6, pp. 2419–2442, 2022, doi: 10.1016/j.jksuci.2022.03.019.

[2] C. De Alwis *et al.*, “Survey on 6G Frontiers: Trends, Applications, Requirements, Technologies and Future Research,” *IEEE Open Journal of the Communications Society*, vol. 2, pp. 836–886, 2021, doi: 10.1109/OJCOMS.2021.3071496.

[3] S. M. Ali, C. Sovuthy, M. A. Imran, S. Socheatra, Q. H. Abbasi, and Z. Z. Abidin, “Recent advances of wearable antennas in materials, fabrication methods, designs, and their applications: State-of-the-art,” *Micromachines*, vol. 11, no. 10, p. 888, 2020, doi: 10.3390/mi11100888.

[4] H. R. Khaleel, H. M. Al-Rizzo, D. G. Rucker, and T. A. Elwi, “Wearable Yagi microstrip antenna for telemedicine applications,” in *IEEE Radio and Wireless Symposium, RWW 2010-Paper Digest*, IEEE, pp. 280–283, 2010, doi: 10.1109/RWS.2010.5434177.

[5] M. Ikram, K. Sultan, M. F. Lateef, and A. S. M. Alqadami, “A Road towards 6G Communication—A Review of 5G Antennas, Arrays, and Wearable Devices,” *Electronics (Switzerland)*, vol. 11, no. 1, p. 169, 2022, doi: 10.3390/electronics11010169.

[6] S. Purohit and F. Raval, “Wearable -Textile Patch Antenna using Jeans as Substrate at 2.45 GHz,” *International Journal of Engineering Research and Technology*, vol. 3, no. 5, pp. 2456–2460, 2014.

[7] S. J. Chen, T. Kaufmann, and C. Fumeaux, “Wearable textile microstrip patch antenna for multiple ISM band communications,” in *IEEE Antennas and Propagation Society, AP-S International Symposium (Digest)*, IEEE, pp. 1860–1861, 2013, doi: 10.1109/APS.2013.6711588.

[8] C. Parmar and S. Joshi, “Wearable textile patch antenna for on-body communications,” in *Global Conference on Communication Technologies*, IEEE, pp. 921–924, 2015, doi: 10.1109/GCCT.2015.7342796.

[9] G. Demirbas and E. Akar, “Design and Interpretation of Microstrip Patch Antenna Operating at 2.4GHz for Wireless WI-FI Application,” *European Journal of Science and Technology*, 2022, doi: 10.31590/ejosat.1084151.

[10] S. Sankaralingam and B. Gupta, “Development of textile antennas for body wearable applications and investigations on their performance under bent conditions,” *Progress In Electromagnetics Research B*, vol. 22, no. 22, pp. 53–71, 2010, doi: 10.2528/PIERB10032705.

[11] S. Sankaralingam and B. Gupta, “Determination of dielectric constant of fabric materials and their use as substrates for design and development of antennas for wearable applications,” *IEEE Transactions on Instrumentation and Measurement*, vol. 59, no. 12, pp. 3122–3130, 2010, doi: 10.1109/TIM.2010.2063090.

[12] S. Roy and P. Bermel, “Electronic and optical properties of ultra-thin 2D tungsten disulfide for photovoltaic applications,” *Solar Energy Materials and Solar Cells*, vol. 174, pp. 370–379, 2018, doi: 10.1016/j.solmat.2017.09.011.

[13] S. Kim, H. Bark, S. Nam, H. Choi, and H. Lee, “Control of Electrical and Thermal Transport Properties by Hybridization of Two-Dimensional Tungsten Disulfide and Reduced Graphene Oxide for Thermoelectric Applications,” *ACS Sustainable Chemistry and Engineering*, vol. 6, no. 11, pp. 15487–15493, 2018, doi: 10.1021/acssuschemeng.8b03949.

[14] R. Bala and A. Marwaha, “Characterization of graphene for performance enhancement of patch antenna in THz region,” *Optik*, vol. 127, no. 4, pp. 2089–2093, 2016, doi: 10.1016/j.ijleo.2015.11.029.

[15] R. Tenne, L. Margulis, M. Genut, and G. Hodes, “Polyhedral and cylindrical structures of tungsten disulphide,” *Nature*, vol. 360, no. 6403, pp. 444–446, 1992, doi: 10.1038/360444a0.

[16] H. Jiang, “Electronic band structures of molybdenum and tungsten dichalcogenides by the GW approach,” *Journal of Physical Chemistry C*, vol. 116, no. 14, pp. 7664–7671, 2012, doi: 10.1021/jp300079d.

[17] J. A. Wilson and A. D. Yoffe, “The transition metal dichalcogenides discussion and interpretation of the observed optical, electrical and structural properties,” *Advances in Physics*, vol. 18, no. 73, pp. 193–335, 1969, doi: 10.1080/00018736900101307.

[18] W. J. Schutte, J. L. De Boer, and F. Jellinek, “Crystal structures of tungsten disulfide and diselenide,” *Journal of Solid State Chemistry*, vol. 70, no. 2, pp. 207–209, 1987, doi: 10.1016/0022-4596(87)90057-0.

[19] A. Falin *et al.*, “Mechanical Properties of Atomically Thin Tungsten Dichalcogenides: WS2, WSe2, and WTe2,” *ACS Nano*, vol. 15, no. 2, pp. 2600–2610, 2021, doi: 10.1021/acsnano.0c07430.

[20] H.-B. Wang *et al.*, “Tungsten Disulfide Nano-Flowers/Silver Nanoparticles Composites Based Electrochemical Sensor for Theophylline Determination,” *Journal of The Electrochemical Society*, vol. 162, no. 7, pp. B173–B179, 2015, doi: 10.1149/2.0941507jes.

[21] P. M. Potey and K. Tuckley, “Design of wearable textile antenna with various substrate and investigation on fabric selection,” in *2018 3rd International Conference on Microwave and Photonics*, IEEE, pp. 1–2, 2018, doi: 10.1109/ICMAP.2018.8354539.

[22] U. Afruz and M. A. Kabir, “Design of Wearable Microstrip Patch Antenna for Wireless Body Area Network,” *24th International Conference on Computer and Information Technology*, vol. 9, no. 9, 2021, doi: 10.1109/ICCIT54785.2021.9689901.

[23] G. Christina, A. Rajeswari, M. Lavanya, J. Keerthana, K. Ilamathi, and V. Manoranjitha, “Design and development of wearable antennas for tele-medicine applications,” in *International Conference on Communication and Signal Processing*, IEEE, pp. 2033–2037, 2016, doi: 10.1109/ICCSP.2016.7754532.

[24] L. A. Aboelmagd, E. Tolba, and Z. A. AbdelAziz, “Chitosan–organosilica hybrid decorated with silver nanoparticles for antimicrobial wearable cotton fabrics,” *Polymer Bulletin*, vol. 80, no. 4, pp. 4229–4243, 2023, doi: 10.1007/s00289-022-04250-x.

[25] M. Pasichnyk, J. Gaálová, P. Minarik, M. Václavíková, and I. Melnyk, “Development of polyester filters with polymer nanocomposite active layer for effective dye filtration,” *Scientific Reports*, vol. 12, no. 1, p. 973, 2022, doi: 10.1038/s41598-022-04829-4.

[26] Y. Huang, Y. Wang, L. Gao, X. He, P. Liu, and C. Liu, “Characterization of stretchable SWCNTs/Lycra fabric electrode with dyeing process,” *Journal of Materials Science: Materials in Electronics*, vol. 28, no. 5, pp. 4279–4287, 2017, doi: 10.1007/s10854-016-6051-7.

[27] S. H. Eshan, R. R. Hasan, A. Al M. Sarker, S. Zabin, R. T. H. Tusher, and M. A. Rahman, “Brain tumor detection by Kapton Polyimide based on-body patch antenna in K band,” in *International Conference on Robotics, Electrical and Signal Processing Techniques*, IEEE, pp. 165–169, 2023, doi: 10.1109/ICREST57604.2023.10070083.

[28] A. G. Derneryd, “A Theoretical Investigation of the Rectangular Microstrip Antenna Element,” *IEEE Transactions on Antennas and Propagation*, vol. 26, no. 4, pp. 532–535, 1978, doi: 10.1109/TAP.1978.1141890.

[29] M. Kara, “A novel technique to calculate the bandwidth of rectangular microstrip antenna elements with thick substrates,” *Microwave and Optical Technology Letters*, vol. 12, no. 2, pp. 60–64, 1996, doi: 10.1002/(sici)1098-2760(19960605)12:2<59::aid-mop3>3.0.co;2-m.

[30] R. R. Hasan *et al.*, “Spin Coated Multi-Walled Carbon Nanotube Patch Antenna for Breast Cancer Detection,” *Advanced Materials Technologies*, vol. 8, no. 24, 2023, doi: 10.1002/admt.202300822.

[31] M. S. Rana and M. M. R. Smieee, “Design and analysis of microstrip patch antenna for 5G wireless communication systems,” *Bulletin of Electrical Engineering and Informatics*, vol. 11, no. 6, pp. 3329–3337, 2022, doi: 10.11591/eei.v11i6.3955.

[32] B. Derat, “5G antenna characterization in the far-field: How close can far-field be?,” in *2018 IEEE International Symposium on Electromagnetic Compatibility and 2018 IEEE Asia-Pacific Symposium on Electromagnetic Compatibility, EMC/APEMC 2018*, IEEE, pp. 959–962, 2018, doi: 10.1109/ISEMC.2018.8393926.

[33] S. H. Eshan, R. R. Hasan, S. M. A. Islam, T. Hasnat, J. Islam, and A. Al Mamun Sarker, “SWCNT based on body patch antenna for lung tumor detection in X band,” in *AIP Conference Proceedings*, p. 120034, 2023, doi: 10.1063/5.0162869.

[34] T. Hasnat, S. A. Islam, S. H. Eshan, R. R. Hasan, J. Islam, and M. A. Rahman, “SWCNT Based On-Body Antenna For Detecting COVID-19 Affected Lung Using 5G-Band,” in *2022 International Conference on Advancement in Electrical and Electronic Engineering, ICAEEE 2022*, IEEE, pp. 1–6, 2022, doi: 10.1109/ICAEEE54957.2022.9836476.

[35] S. Hassan and S. H. Shehab, “Evaluation of an Ultra Wideband (UWB) textile antenna in the vicinity of human body model for WBAN applications,” *2015 IEEE International WIE Conference on Electrical and Computer Engineering*, pp. 195–198, 2016, doi: 10.1109/WIECON-ECE.2015.7443895.

[36] I. S. C. C. 28, IEEE Standards Coordinating Committee, I. S. C. C. 28, and IEEE Standards Coordinating Committee, “IEEE Recommended Practice for Measurements and Computations of Radio Frequency Electromagnetic Fields with Respect to Human Exposure to Such Fields,” *IEEE Standards*, vol. 2002, pp. 103–107, 2003.

[37] J. J. Heikkinen, T. T. Laine-Ma, and M. A. Kivikoski, “Flexible fabric-base patch antenna with protective coating,” in *IEEE Antennas and Propagation Society International Symposium*, IEEE, pp. 4168–4171, 2007, doi: 10.1109/APS.2007.4396459.

[38] H. N. N. B. H. Ramli, N., Noor, S. K., and Zaini, “Design and Analysis of Textile Wearable Antenna Using 100% Cotton at 2.4 GHz for Wireless Applications,” *Networks (ICCECN 2020)*, vol. 1, no. 2, 2020.

[39] J. Dalfiah, M. Ishwariya, and T. Kousalya, “EasyChair Preprint Design of Wearable Textile Antenna for Biomedical WBAN Application using ISM Band Design of Wearable Textile Antenna for Biomedical WBAN Application using ISM Band,”

EasyChair, no. 5240, 2021.
[40] M. I. Ahmed, M. F. Ahmed, and A. E. A. Shaalan, "Novel electrotextile patch antenna on jeans substrate for wearable applications," *Progress In Electromagnetics Research C*, vol. 83, pp. 255–265, 2018, doi: 10.2528/PIERC18030309.

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