engineering proceedings

Proceeding Paper

A Compact CPW-Fed Textile-Substrate-Based Half-Circula Spike Monopole Antenna †

Rajesh Katragadda [1,*] and Palasetti Appala Nageswara Rao [2]

[1] Department of ECE, A.U.TDR-HUB, Andhra University, Visakapatnam 530003, Andhra Pradesh, India
[2] Department of ECE, Gayatri Vidya Parishad College for Degree and P.G Courses (A), Andhra University, Visakhapatnam 530045, Andhra Pradesh, India; drnageswararao@gvpcdpgc.edu.in
* Correspondence: rajesh.k@nriit.edu.in
† Presented at the International Conference on Recent Advances on Science and Engineering, Dubai, United Arab Emirates, 4–5 October 2023.

Abstract: A coplanar-waveguide-type fed half-circular spike-shaped monopole antenna is designed on textile substrates and analyzed in this paper. The most suitable textile substrate is identified in this work by testing the current model performance characteristics on silk, jeans and cotton fabrics and is presented this analytical study. The cotton material model provided a bandwidth of 9.4 GHz, the silk material provided a 9.2 GHz bandwidth and the jeans material provided 9.1 GHz. A maximum gain of 9.5 dB was attained for 3.6 GHz of the 5G band and 8.2 dB for 5.8 GHz of the WLAN band. The antenna is prototyped on cotton substrate, bending analysis is also performed at 15 degrees, 30 degrees and 45 degrees in vertical and horizontal conditions and we find satisfactory results for the specified application. Compact, wearable antennas with varied performance are in demand as wireless communication systems evolve. The antenna is designed for wearable and textile-integrated wireless communication. The textile substrate makes the antenna flexible and can be integrated into garments, wearable gadgets and smart textiles. This paper describes how to choose textile materials and design a half-circular spike monopole antenna. Electromagnetic simulations evaluate the antenna's impedance matching, radiation pattern and bandwidth. The CPW feedline is designed to efficiently transfer power to the antenna, improving performance. This study also examines the antenna's longevity and resilience in textile materials, addressing real-world issues like bending and washing. This examination verifies the antenna's wearable functionality and reliability.

Keywords: circular spike; jeans; cotton substrate; silk; textile; monopole antenna

Citation: Katragadda, R.; Rao, P.A.N. A Compact CPW-Fed Textile-Substrate-Based Half-Circula Spike Monopole Antenna. *Eng. Proc.* **2023**, *59*, 149. https://doi.org/10.3390/engproc2023059149

Academic Editors: Nithesh Naik, Rajiv Selvam, Pavan Hiremath, Suhas Kowshik CS and Ritesh Ramakrishna Bhat

Published: 9 January 2024

1. Introduction

The need for flexible and compact antennas in wearable communication applications is growing as per the demand from the healthcare industry [1]. The communication module requirements are increasing day by day with the advent of sophisticated analytical active and passive components. Antennas are one of the key components in any communication system, and without them, the reception and transmission of signals is unimaginable [2].

Several serrated antennas have been designed by active researchers for the purpose of multiband, wideband and ultra-wideband applications [3]. CPW-fed monopole, u-slot and array antenna models have been designed by engineers for GPS (Global Positioning System), LTE (Long-Term Evolution), Wi-Fi (Wireless Fidelity) and WLAN (Wireless Local Area Network) applications [4]. Slot-loaded antennas with circular polarization and suitable for WiMAX (Worldwide Inter-operability for Microwave Access) and commercial communication applications have been produced by designers [5]. Few designs for vehicular communication applications and medical communications have been designed for integration with IoT (Internet of Things) devices [6].

An antenna optimized for use with wearable communication systems is a coplanar waveguide-fed half-circular spike monopole antenna mounted on a textile substrate [7]. Its portability, light weight and ease of incorporation into clothes make it well suited for use in healthcare monitoring, sports tracking, military equipment, smart clothing and other related fields [8]. These antennas enhance the form and function of wearable electronics by being low-profile and easy to wear, as well as providing better signal quality than previous designs [9].

Few researchers have designed antennas for wearable communication applications with the help of copper tapes, conductive fabrics and conductive threads for WBAN and ISM (International Safety Management) band applications [10]. Reconfigurable antennas with pattern, polarization, frequency and hybrid reconfigurability are achieved in few designs by engineers with PIN (personal identification numbers), varactor diodes and liquid crystal compound loading [11]. Square slot ring resonator-based notch band antennas have been designed by scientists for ultra-wideband and medical communication applications [12].

2. Antenna Modelling

The half-circular spike antenna is designed according to wavelength-based analysis [13]. Achieving a maximum gain of 9.5 dB at 3.6 GHz (5G band) and 8.2 dB at 5.8 GHz (WLAN band) for an antenna has substantial effects on its performance in different applications.

- ➢ **5G (3.6 GHz): high gain (9.5 dB):** This gain level implies that the antenna can better focus its 5G radiation pattern, enhancing signal strength [14].
- ➢ **Practical effects: enhanced coverage:** In 5G networks, where higher frequencies are employed, a high gain at 3.6 GHz is essential for greater coverage and signal stability, especially in urban areas with obstacles.
- ➢ **Reduced interference:** Higher gain reduces signal interference and enhances the antenna's stability in congested spectrum conditions [15].
- ➢ **Wireless band (5.8 GHz):** good gain (8.2 dB): While lower than in the 5G band, 8.2 dB is still a reasonable WLAN gain. Practical effects: better data speeds: The increased gain at 5.8 GHz boosts WLAN data speeds and signal strength. Faster and more dependable Wi-Fi connections benefit from this. Extended range: WLAN devices at 5.8 GHz in homes and offices have better range and coverage, minimizing dead zones and improving user experience [16].

The dimensional characteristics presented in this section are shown in Figure 1. Initially, the antenna was designed on an FR4 (flame retardant4) rigid substrate, and after that, they were transformed to textile substrate material [17]. Silk, jeans and cotton substrates are used in the design of the antenna in simulations, and the cotton-substrate-based model is finalized based on the performance characteristics for prototyping and testing and scaling shown in Table 1 and taken reference from [18].

(1) Project a 50 f2 CPW line on a substratum with permittivity En Compute Eeff = (£r + 1)/2 where Eeff is the real permittivity of the substratum.
(2) L and W of the substratum SL = Sw = 0.33.
(3) Here Sw = 2Gw + 2G + W.
(4) 1/2 of the G-plane GW = 0.15 Xc.
(5) Break amongst F-line and G-line G = 0.005 cc.
(6) F-plane thickness W = 0.02 Xc.
(7) Notched arc component distance S1 = 0.03 Xc and S2 = 0.05 Xc.
(8) Range R = 0.037 Xc.

Table 1. Scaling parameter.

Sl	Sw	Gw	W	G	r	S1	S2
60 mm	60 mm	13.7 mm	2 mm	0.5 mm	3.4 mm	3.6 mm	4.6 mm

(**a**) (**b**) (**c**)

Figure 1. Half-circular spike monopole antenna: (**a**) simulated, (**b**) FR4 prototype, (**c**) cotton prototype.

3. Impacts on the Antenna's Performance

According to the experiments with silk, jeans and cotton, each material has unique features that can affect antenna performance:

Silk: Description: Silk is a lightweight, silky natural fiber. Electrical insulation, dielectric constant and flexibility are its strengths. Silk is useful for wearable antennas because of its light weight and flexibility [19]. However, its high dielectric constant affects antenna impedance and resonance frequency [20]. To avoid detuning and impedance mismatch, silk substrate antenna designers must account for this in their models.

Jeans: Features: Cotton denim is a tough fabric used to make jeans. Its dielectric constant is low, and it is moderately flexible. Antenna effect: Jeans are durable enough for antenna applications that must withstand mechanical stress or wear. Lower dielectric constants reduce radiation efficiency and modify resonance characteristics, affecting antenna performance. Designers should consider antenna compensation to optimize performance.

Cotton: Features: Cotton is a popular natural fiber thanks to its breathability, comfort and adaptability. It is soft, flexible and pleasant. Cotton's softness and elasticity make it appealing for wearables. Its modest dielectric constant and moisture-absorbing characteristics can somewhat affect antenna performance. Moisture can modify cotton's dielectric characteristics and antenna resonance frequency. During design and operation, designers should consider these factors.

Designers and operators should consider these factors. For antenna experimentation, textile substrate choice is crucial due to each material's unique properties. Silk, denim and cotton vary in terms of their dielectric constant, elasticity and durability. Radiation efficiency, antenna impedance and resonance frequency are affected by these qualities. To optimize antenna performance based on substrate, designers must carefully evaluate textile qualities and use appropriate design and tuning strategies.

Various Communication Bands

The bandwidth values of 9.4 GHz on cotton, 9.2 GHz on silk, and 9.1 GHz on jeans relate to their alignment with communication bands. Broadband values show how well antennas on each substrate transmit and receive signals within specified frequency ranges. They coordinate with communication bands.

Cotton (9.4 GHz): Cotton's bandwidth means the antenna can cover more frequencies. This is appropriate for multi-band devices that need flexibility and communication across multiple frequency bands.

Silk (9.2 GHz): Despite its lower bandwidth, silk spans a wide frequency range. This matches Wi-Fi (2.4 GHz and 5 GHz) and several cellular bands, making it appropriate for wireless communication equipment.

Jeans (9.1 GHz): Denim's limited bandwidth may limit frequency coverage. Reduced bandwidth may help IoT or customized wireless protocols.

4. Analysis

The behavioral study of the designed antenna with respect to their performance characteristics is described in this section. Figure 2 presents the reflection coefficient S11 of the antenna on three different substrates. The cotton material model provided a bandwidth of 9.4 GHz, the silk material provided a 9.2 GHz bandwidth and the jeans material provided 9.1 GHz. The VSWR (voltage standing wave ratio) values are also presented for the same in Figure 3. The voltage standing wave ratio (VSWR) is an important metric in RF and microwave engineering, notably for antennas and transmission lines. Impedance matching with reflection characteristics is illuminated by quantifying power transfer efficiency between a transmission line (or cable) and an antenna.

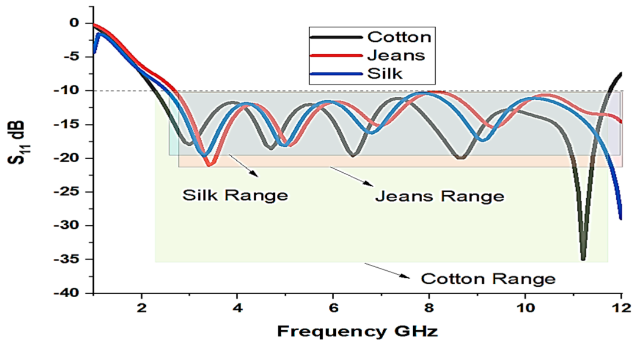


Figure 2. Scattering parameter S11 vs. frequency for textile substrates.

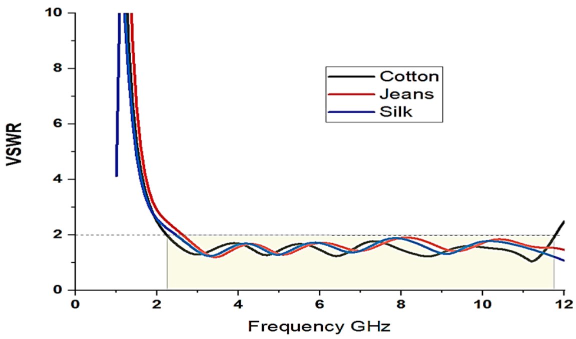


Figure 3. VSWR curve for three materials.

The ratio of transmission line maximum to minimum voltage is VSWR. Complete power transfer without reflection is achieved with a 1:1 VSWR. Impedance mismatch and reflected power rise with VSWR, indicating poor matching. The importance of VSWR for antenna impedance matching and reflection can be described as follows:

Power transfer efficiency: A low VSWR (near to 1:1) indicates that the antenna matches the transmission line's characteristic impedance. Maximum signal strength and minimum signal loss require this.

Low reflection: A low VSWR indicates little RF signal reflection back to the source. Reflections from high VSWR values degrade signals, interfere and limit coverage.

Impedance matching: VSWR shows how well antenna, transmission line and system impedance match. Impedance matching optimizes signal transfer without reflections.

In order to optimize antenna and transmission line performance, engineers and operators use VSWR measurements. Adjusting antenna dimensions or employing matched networks can reduce VSWR to boost efficiency.

Protection: High VSWR values may indicate system damage, such as a detached antenna part. Regular VSWR monitoring detects and fixes faults quickly, preventing equipment damage.

A 2:1 ratio is shown for the operating bands where the reflection coefficient value shown is less than 10 dB with good impedance matching.

4.1. Antenna's Performance and Suitability for Wearable Scenarios

The performance and application of a wearable antenna must be considered after bending studies at 15 degrees, 30 degrees and 45 degrees. The electrical properties of a bent antenna can alter drastically. The resonance frequency may change slightly with a 15-degree antenna bend. Thus, wearables with minimal bending can use it, but at a 30-degree bend, the antenna's performance may worsen, reducing signal reception and radiation efficiency. Flexibility may be unsuitable for wearables that need constant connectivity. The antenna's performance may suffer when bent at 45 degrees. For such large bending, wearable devices need highly flexible antenna designs or imaginative positioning to maintain transmission quality. Examining antennas' bending angles is crucial for wearable applications. Antenna design and location for wearable applications must include the likelihood of performance deterioration from bending to 30 or 45 degrees.

Antenna design requires several trade-offs when choosing textile substrates and studying their performance. Key factors: Materials: Choose a textile substrate with flexibility, durability and washability. Stretchy fabrics may not serve as antennas. When using less flexible materials with higher signal transmission, designers must balance these needs. Textile substrate electrical properties affect antenna efficiency. Flexible and squishy materials are good for wearables but may not perform well antenna-wise. Signal propagation may need designing for substrate discomfort. Fiber substrate and frequency range affect antenna performance. Certain materials favor or attenuate certain frequencies. Substrates must match wearable device communication frequencies. Production: Harder textile substrates may cost more to work with. Some designers must balance performance and fabrication. Comfort is essential for wearable hardware. Wearable materials that convey signals well are uncomfortable. Performance and comfort must be balanced. Fabrics must withstand moisture, temperature and wear. Rugged textiles may be important despite poor antenna performance. Form factor affects substrate choices for wearable devices. Compact design or form considerations limit textile substrates. Textile substrates for wearable antennas offer less flexibility, comfort, manufacturability and performance. To fulfil technical and user goals, engineers must balance these factors.

The antenna's resilience and wearability are shown in the bending study results at 15-, 30- and 45-degree angles:

15-Degree Bend: The antenna performs well at a 15-degree bend, retaining signal reception and radiation efficiency. This versatility allows the antenna to withstand wearable device bending forces like in wristbands and clothes.

30-Degree Bend: Performance decreases at a 30-degree bend. However, the antenna still has tolerable detuning and signal quality. To maintain communication, wearables that flex moderately throughout regular use need this adaptability.

45-Degree Bend: Though performance decreases, the antenna remains resilient at a 45-degree bend. The antenna's ability to function shows its adaptability in difficult settings, even if this level of bending is rare in wearables. Bending research shows the antenna's durability and wearability. It is ideal for wearable applications that require flexibility and durability since it can bear regular bending forces and maintain consistent communication.

The model dimensions are shown in Table 1.

The radiation analysis of the proposed antenna is presented in Figure 4. In the E- and H-planes, the three-dimensional radiation is represented with a graphical pattern and showing a peak gain of more than 12 dB. The total radiation analysis of the 3D view presented in Figure 4c, projecting the gain of 9.5 dB with a distributive pattern. A 2D pattern of the same is presented at 5.8 GHz for the proposed antenna in Figure 5. The elevation pattern shows monopole-like and azimuthal shows omni-directional radiation. A peak gain of 12 dB, an average gain of 9.5 dB and a radiation efficiency of over 79% affect antenna system signal strength, coverage and energy efficiency. Signal strength: Enhanced signal reception: A 12 dB peak gain indicates the antenna can capture and enhance incoming signals. Signal reception improves, making it useful in weak or distant signal sources. Boost: The antenna's 9.5 dB average gain indicates strong signal amplification. Increased signal strength and reliability reduce signal dropouts and interference. Coverage: A higher-gain antenna can transmit and receive signals over a larger region. This is useful for long-range communication and large-area IoT deployments. Higher gain: Antennas with higher gain may penetrate walls and foliage better, improving coverage in difficult locations. Saving energy: Less transmission power: High-gain antennas focus the broadcast signal, saving transmission power. The transmitting gadget uses less energy.

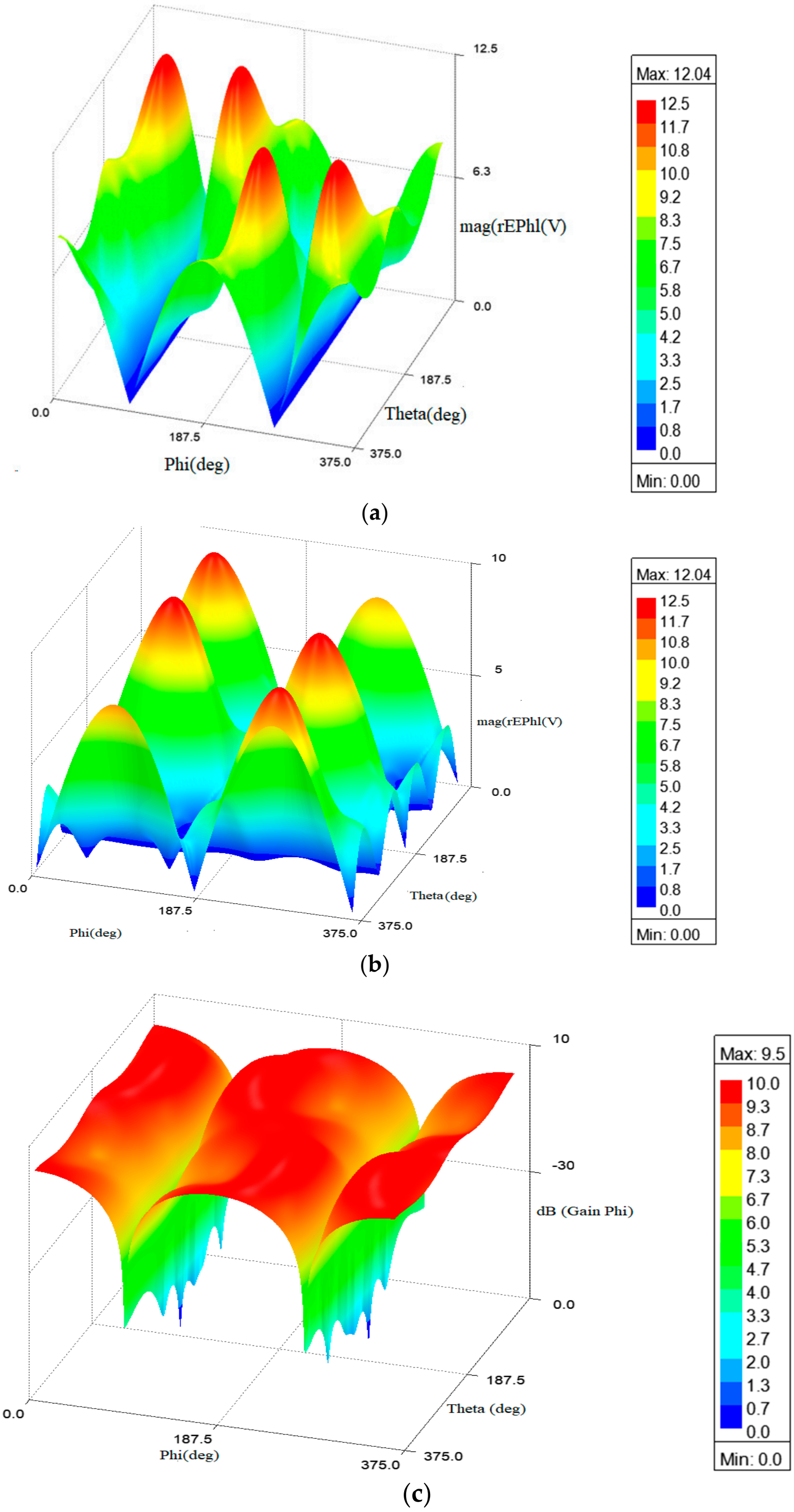
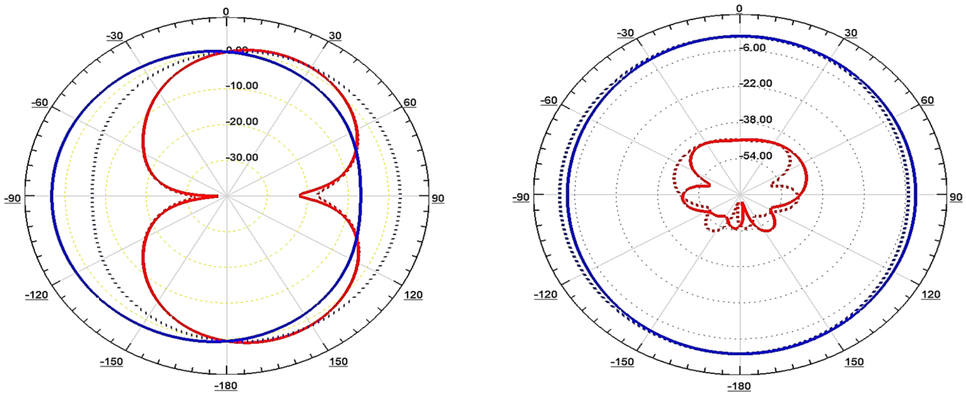


Figure 4. E-plane, H-plane and total 3D radiation: (**a**) explains radiation pattern of E plane; (**b**) explains H plane; (**c**) explains E and H plane radiation patterns.

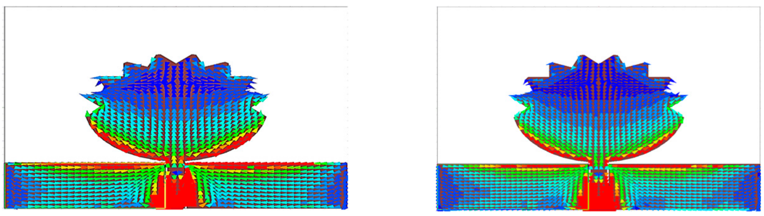


(**a**) ___ Co-Pol (Simulated), --- Co-Pol (Measured) (**b**) ___ Cross-Pol (Simulated), --- Cross-Pol (Measured)

Figure 5. Radiation in polar coordinates (E- and H-plane) at 5.8 GHz.

Higher energy efficiency from a high-gain antenna can increase the battery life of battery-powered devices like wearables and IoT sensors. Remote or hard-to-reach equipment needs this. Here Figure 4a explains radiation pattern of E plane, Figure 4b explains H plane and Figure 4c explains E and H plane radiation patterns. Finally, an antenna design with a peak gain of 12 dB, an average gain of 9.5 dB and a radiation efficiency of over 79% improves signal strength, coverage and energy efficiency. Figure 5a is radiation pattern of E plane and Figure 5b Radiation pattern of H plane.

The surface current distribution presented in Figure 6 projects the portion of the radiating surface participating in radiation. The lower portion of the radiating patch and upper portion of the ground is radiating more, and the feedline is also supporting with high intensity. Figure 6a is radiation pattern of E plane and Figure 6b Radiation pattern of H plane.



(**a**) (**b**)

Figure 6. Surface current at 3.6 GHz and 5.8 GHz: (**a**) radiation pattern of E plane; (**b**) Radiation pattern of H plane.

4.2. The Importance of Prototyping the Antenna: The Antenna Should Be Prototyped on Cotton for Numerous Reasons

1. Real-world testing simulates the antenna's performance in clothing or accessories.
2. Cotton, like other textiles, varies in thickness, density and dielectric characteristics. Cotton prototyping analyzes how real-world material differences affect antenna performance.
3. Comfort and wearability: Cotton is a typical clothing fabric; thus, the antenna's integration into cotton must be comfortable and flexible.
4. Usability: Antennas must be both functional and user-friendly. Cotton prototypes give customer feedback on comfort, usability and esthetics.
5. Ecological considerations: Cotton biodegrades. The antenna's cotton performance follows eco-friendly design standards.

Validating antenna design requires comparing actual results to simulation findings. It helps find differences between idealized simulations and real-world performance. A solid design matches simulations and real-world outcomes nicely. The final antenna can be adjusted and improved to fulfill performance objectives in wearable communication devices.

4.3. Wearable Communication Applications

A radiation efficiency over 79% and max gain of 12 dB and 9.5 dB would be significant for wearable communication applications. When used properly, the wearable antenna's 12 dB gain can focus and amplify signals in certain directions, enhancing signal strength. Reliable communication in difficult conditions or over vast distances requires this. An average gain of 9.5 dB shows that the wearable antenna functions well in varied settings. Wearable tech needs consistency because it moves often. Peak and average increases improve wearable communication device coverage with reliability. Moving should improve signal reception and reduce dropouts. Power efficiency: A 79% radiation efficiency means communication uses more energy than heat. This increases battery life and power usage for limited-power wearable gadgets.

5. Challenges or Limitations

Wearable communication devices employing the specified antenna configuration may have various issues: Small size and form factor: Wearable gadgets make antenna miniaturization difficult while maintaining performance. Design should balance size and function. Stretching: Wearables often bend and flex, which might affect antenna performance. Challenges include antenna efficiency under varying bends. Signal interference and electrical device interference plague wearables. The antenna must resist interference and perform reliably. Wearables use Bluetooth, Wi-Fi and cellular. Managing several frequency bands is tough for the antenna. Small batteries in wearables require effective antenna design to save power. Antenna integration: Ergonomics and esthetics make antenna integration problematic in wearables. Wearables require cost-effective and reliable mass production, which may challenge specialized antenna designs.

A potential application for the suggested antenna design is IoT and healthcare. Integration with IoT: Small and versatile, the antenna connects several sensors and smart items to IoT devices. Smart home, environmental and asset tracking solutions can boost IoT ecosystem connectivity and efficiency. Healthwear: The antenna design might be utilized in wearable devices to remotely monitor patients, track vital signs and relay real-time medical data to experts. Applications increase patient care and reduce hospital strain. The antenna could help fitness trackers and sports performance monitors. Continuous data collection and processing are needed for tracking and insights. Disabled people may benefit from wearable antennas. Connectivity is needed for real-time hearing aids and smart eyeglasses for the visually impaired. Smart clothes for gesture detection, location monitoring, communication and healthcare could use this antenna design. They could be fashionable and safe. Safety and efficiency in the industrial IoT can be improved through wearable antennas. Workers' IIoT devices can share environmental, equipment and health data, improving safety and efficiency. Emergency services: Wearable antennas could help frontline responders communicate during key missions.

6. Conclusions

A half-circular monopole with coplanar waveguide feeding is presented in this paper for wideband communication system applications. The modeled structure was tested on three textile substrates: jeans, silk and cotton material. The cotton material model provided a bandwidth of 9.4 GHz, the silk material provided a 9.2 GHz bandwidth and the jeans material provided 9.1 GHz. The VSWR values also showed a 2:1 ratio for the operating bands where the reflection coefficient shown was less than 10 dB, with good impedance matching. A peak gain of 12 dB and average gain of 9.5 dB is attained with radiation efficiency of more than 79%. The prototyped antenna exhibits similar characteristics to the simulation results.

Author Contributions: Conceptualization was performed by P.A.N.R.; methodology was performed R.K.; validation was performed by P.A.N.R. and R.K.; writing and review was carried out by R.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data can be obtained from the corresponding author on request.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Saikumar, K.; Arulanantham, D.; Rajalakshmi, R.; Prabu, R.T.; Kumar, P.S.; Vani, K.S.; Ahammad, S.H.; Eid, M.M.; Rashed, A.N.; Hossain, M.A.; et al. Design and development of surface plasmon polariton resonance four-element triple-band multi-input multioutput systems for LTE/5G applications. *Plasmonics* **2023**, *18*, 1949–1958. [CrossRef]
2. Vasimalla, Y.; Pradhan, H.S.; Pandya, R.J.; Saikumar, K.; Anwer, T.M.; Rashed, A.N.; Hossain, M.A. Titanium dioxide-2d nanomaterial based on the surface plasmon resonance (SPR) biosensor performance signature for infected red cells detection. *Plasmonics* **2023**, *18*, 1725–1734. [CrossRef]
3. Nejdi, I.H.; Das, S.; Rhazi, Y.; Madhav, B.T.; Bri, S.; Aitlafkih, M. A compact planar multi-resonant multi-broadband fractal monopole antenna for Wi-Fi, WLAN, Wi-Max, Bluetooth, LTE, S, C, and X band Wireless Communication Systems. *J. Circuits Syst. Comput.* **2022**, *31*, 312–324. [CrossRef]
4. Al-Tamimi, H.; Mahid, S. Design of double notch band half-elliptical shape reconfigurable antenna for UWB applications. *Eng. Technol. J.* **2019**, *37*, 85–89. [CrossRef]
5. Yan, Y.; Li, L.; Zhang, J.; Hu, H.; Zhu, Y.; Chen, H.; Fang, Q. Design of Y-type branch broadband dual-polarization antenna and C-type slot line notch antenna. *Prog. Electromagn. Res. M* **2021**, *106*, 105–115. [CrossRef]
6. Lanka, M.D.; Chalasani, S. Development of low profile M-shaped monopole antenna for Sub 6 GHz bluetooth, LTE, ISM, Wi-Fi and WLAN applications. *Int. J. Intell. Eng. Syst.* **2021**, *14*, 159–167.
7. Meher, P.R.; Behera, B.R.; Mishra, S.K. A compact circularly polarized cubic DRA with unit-step feed for bluetooth/ism/wi-fi/wi-max applications. *AEU-Int. J. Electron. Commun.* **2021**, *128*, 153–162. [CrossRef]
8. Sarma, C.A.; Inthiyaz, S.; Madhav, B.T. Design and assessment of bio-inspired antennas for Mobile Communication Systems. *Int. J. Electr. Electron. Res.* **2023**, *11*, 176–184. [CrossRef]
9. Sandeep, D.R.; Madhav, B.T.; Das, S.; Hussain, N.; Islam, T.; Alathbah, M. Performance analysis of skin contact wearable textile antenna in human sweat environment. *IEEE Access* **2023**, *11*, 62039–62050. [CrossRef]
10. Aghoutane, B.; Das, S.; El Faylali, H.; Madhav, B.T.; El Ghzaoui, M.; El Alami, A. Analysis, design and fabrication of a square slot loaded (SSL) millimeter-wave patch antenna array for 5G applications. *J. Circuits Syst. Comput.* **2020**, *30*, 215–221. [CrossRef]
11. Chaitanya, A.V.; Jayaprada, R.; Pavani, M. Circular Monopole Slotted Antenna with FSS for High Gain Applications. *ARPN J. Eng. Appl. Sci.* **2016**, *11*, 1–7.
12. Siva Prasad, B.; Mallikarjuna Rao, P.; T P Madhav, B. Coplanar wave guide fed fork shaped frequency reconfigurable antenna for LTE, Wi-Fi and WLAN applications. *Int. J. Eng. Technol.* **2017**, *7*, 366–372. [CrossRef]
13. Bora, P.; Pardhasaradhi, P.; Madhav, B.T. Design of Microstrip Patch Antenna Based on FSS for 5G and WiMAX Applications. *J. Nano Electron. Phys.* **2021**, *13*, 1–4. [CrossRef] [PubMed]
14. Srilatha, K.; Madhav, B.T.; Anil Babu, B.; Rishikesh Raj, M.; Somala, T.; Nimmaraju, V.; Rao, M.C. Design and analysis of jeans based wearable monopole antenna with enhanced gain using AMC backing. *J. Phys. Conf. Ser.* **2021**, *1804*, 012189. [CrossRef]
15. Madhav, B.T.; JayantthReddyK; Vani, J.; Priyanka, R.R.; Prudhvi Nadh, B.; Rao, M.C. Concentric ring loaded monopole antenna with AMC backed forwearable applications. *J. Phys. Conf. Ser.* **2021**, *1804*, 012191. [CrossRef]
16. Madhav, B.T.; Venkateswara Rao, M.; Anilkumar, T. Conformal band notched circular monopole antenna loaded with split ring resonator. *Wirel. Pers. Commun.* **2018**, *103*, 1965–1976. [CrossRef]
17. Usha Devi, Y.; Rukmini, M.S.; Madhav, B.T. A compact conformal printed dipole antenna for 5G based vehicular communication applications. *Prog. Electromagn. Res. C* **2018**, *85*, 191–208. [CrossRef]
18. Devi, Y.U.; Rukmini, M.S.; Madhav, B.T. Liquid crystal polymer based flexible and conformal 5G antenna for vehicular communication. *Mater. Res. Express* **2018**, *6*, 016306. [CrossRef]
19. Usha Devi, Y.; Boddapati, M.T.; Kumar, T.A.; Sri Kavya Ch, K.; Pardhasaradhi, P. Conformal printed MIMO antenna with DGS for millimetre wave communication applications. *Int. J. Electron. Lett.* **2019**, *8*, 329–343.
20. Wu, S.; Zhao, A.; Zhao, Y. Wideband dipole antenna and array based on liquid crystal polymer for 5G applications. In Proceedings of the 2019 IEEE Asia-Pacific Microwave Conference (APMC), Singapore, 10–13 December 2019.