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Design of a Novel Wearable Textile Antenna for Enhanced Performance in Medical and Wireless Applications

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Abstract -Wearable textile antennas have gained significant attention in recent years due to its growing demand.They are portable and integrating these antennas into textiles enhance wearability and comfort. In this project we explore the design and optimization of a horn-shaped wearable textile antenna for resonance in the ISM (Industrial, Scientific, and Medical) band and diverse commercial wireless applications.The antenna will be designed on a jeans substrate with a relative permittivity (εr) of 1.6 and having physical dimensions of 50×80×0.56 mm3. In terms of performance, the proposed antenna will be analyzed by observing the parameters like Return loss,Gain and VSWR.These wearable antennas are used in medical field to remotely monitor the blood pressure,heart rate and temperature of the patient.This antenna also works for WiFi,WiMAX,ISM and C-band applications.The desired antenna will be simulated using CST Microwave Studio.
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Keywords— *Microstrip patch antenna, ISM band, Multiband.*

I INTRODUCTION

The burgeoning demand for wearable and flexible electronics necessitates lightweight, comfortable, and efficient antennas seamlessly integrated into clothing and accessories. Textile antennas, utilizing various substrates, offer comfort and concealability, catering to diverse applications such as wireless systems, medical monitoring, and defense. Prior research showcases the versatility of textile antennas, including microstrip patch designs tailored to specific substrates like jeans for ISM band applications. This paper aims to design an antenna for the ISM band using jeans substrate's permittivity and loss tangent values, with copper tape as the radiating element. CST Microwave Studio facilitates design, while a Vector Network Analyzer validates performance. The proposed horn-shaped patch antenna operates at multiple frequencies, leveraging slots for multiband functionality. With potential applications in health monitoring and wireless communication, the antenna demonstrates efficacy across WiFi, WiMAX, ISM, and C-band frequencies. Simulation and measurement results validate its effectiveness, paving the way for diverse wireless applications.

II Design Equations

STEP 1 :Calculation of the Width of patch (W).

$$w = \frac{c}{2f_0\sqrt{\frac{\varepsilon_R+1}{2}}} \qquad (2.1)$$

STEP 2: Calculation of Effective Dielectric Constant

$$\varepsilon_{eff} = \frac{\varepsilon_R+1}{2} + \frac{\varepsilon_R-1}{2}\left[1+12\left(\frac{h}{w}\right)\right]^{1/2} \qquad (2.2)$$

STEP 3: Calculation of Actual Length of Patch(L)

$$L = leff - 2\Delta l \qquad (2.3)$$

$$l_{eff} = \frac{C}{2f_0\sqrt{\varepsilon_{eff}}} \qquad (2.4)$$

$$\Delta l = 0\cdot 412h\frac{\left(\varepsilon_{eff}+0.3\right)\left(\frac{W}{h}+0.265\right)}{\left(\varepsilon_{eff}-0.258\right)\left(\frac{W}{h}+0.8\right)} (2.5)$$

where

c is free space velocity of light (3× 108 m/s).

εr is dielectric constant of the substrate.

fr is resonant frequency for the current design.

W is smaller, Bandwidth and gain are directly proportional to the W of the antenna will decrease and vice versa.

Utilizing specific formulas allows for the extraction of fundamental design metrics essential for enhancing antenna performance. Employing Computer Simulation Technology (CST), an advanced electromagnetic simulation tool, enables rigorous refinement of these metrics. Through meticulous optimization, the resulting values are systematically organized and presented in tabular form, serving as a tangible representation of the exhaustive efforts dedicated to the design process. This comprehensive methodology ensures thorough examination and fine-tuning of each aspect of the antenna's performance, leading to optimal functionality.

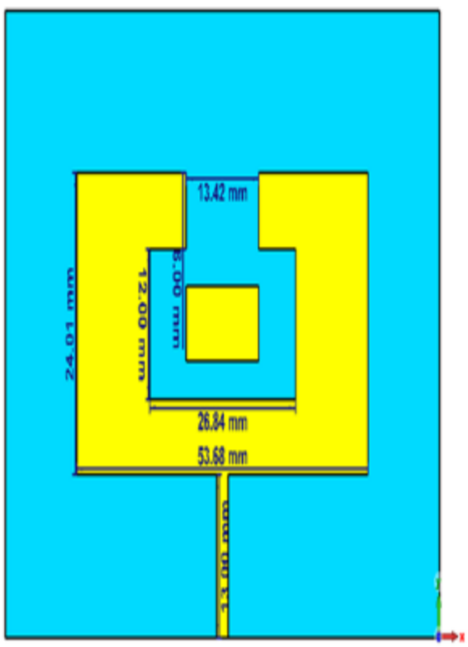

Figure1: *Front view*

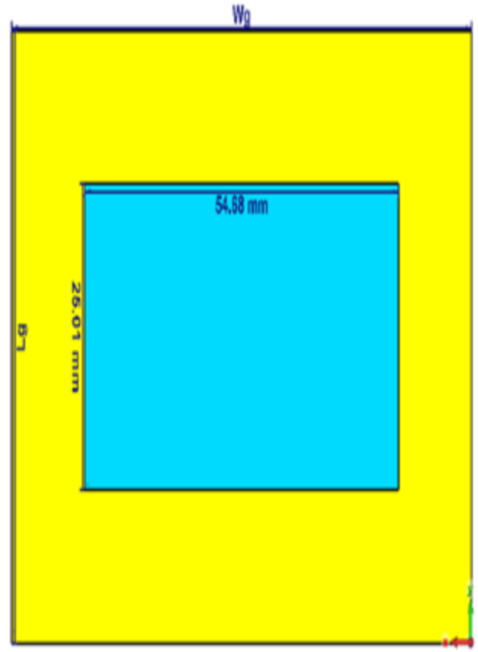

Figure 2: *Back view*

Table 1: *Dimensional parameters for the proposed antenna design*

Antenna parameters	Dimensions (mm)
Length of patch (1t)	24.008
Width of patch (wt)	53.675
Height of the patch (ht)	0.035
Width of feedline (Wf)	2.113
Length of feedline(Lf)	13
Width of ground (Wg)	80
Length of ground (Lg)	50
Width of substrate (Ws)	80
Length of substrate (Ls)	50
Height of substrate (hs)	0.56
Length of slot in the ground	25.01
Width of slot in the ground	54.68

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III Design of Textile Antenna

This section delves into the architectural blueprint of the rectangular horn-shaped microstrip patch antenna. The design process kicks off by utilizing the metrics outlined in Table-1 as foundational guidelines for crafting an optimized antenna configuration. Harnessing the capabilities of Computer Simulation Technology (CST), the antenna design is meticulously crafted, integrating precise dimensions and parameters to ensure peak performance. Figures 3 and 4 present comprehensive front and rear views of the antenna design, offering detailed visualizations of the intricate layout and configuration achieved through CST simulation. These graphical representations provide invaluable insights into the structural nuances and geometrical complexities of the designed antenna.

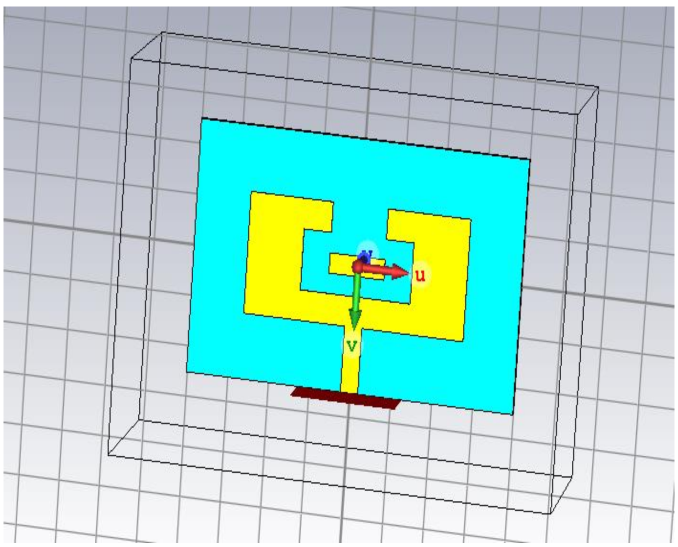

Figure 3: *Front view of textile antenna*

From figure 3 we can see that the position and dimensions of slots etched from the patch or the ground plane significantly impact the resonating frequency of the antenna. By optimizing the slot dimensions and positions within the antenna geometry, resonance bands can be controlled effectively. Slot positions on both the patch and ground plane play crucial roles in antenna performance. These slots are optimized to achieve the desired resonance frequency, such as the 2.45 GHz ISM band.

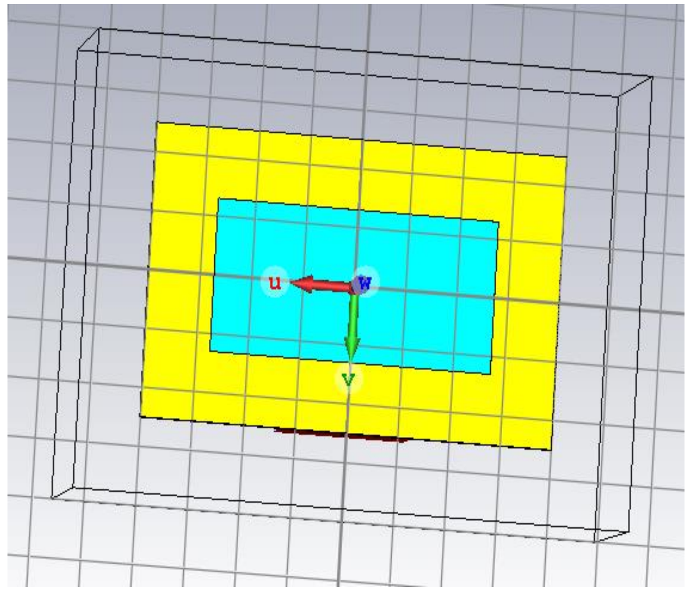

Figure 4: *Back view of textile antenna*

Figure 4 presents a comprehensive panoramic view of the ground structure, offering a detailed depiction from a specific perspective angle. Notably, it highlights the port as a prominent rectangular structure within the visualization. It's crucial to note that the detailed design composition, encompassing all essential components, is thoroughly illustrated across Figures 3 and 4. Together, these visual representations provide a nuanced portrayal of the antenna's architectural complexities, offering valuable insights into its overall design configuration and spatial orientation.

At its essence, the design predominantly incorporates two key materials: copper, serving as the primary conductor, and jeans substrate, utilized as the dielectric material. Copper, prized for its excellent electrical conductivity, is strategically employed to craft the antenna's radiating elements and feed structures. This selection ensures efficient transmission and reception of electromagnetic signals, thereby optimizing the antenna's performance. In contrast, jeans substrate, a widely used substrate material known for its dielectric properties, offers essential support and insulation. Its incorporation ensures the structural integrity and stability of the antenna while preserving optimal signal propagation characteristics. This deliberate choice of materials underscores the meticulous attention paid to the antenna's design considerations.

IV Performance Evaluation

This section conducts an in-depth analysis of the results obtained from CST simulations, focusing on crucial parameters essential for understanding return loss, particularly S-parameters, Voltage Standing Wave Ratio (VSWR), and far-field radiation plots. S-parameters serve as foundational elements in microwave engineering, elucidating the intricate behavior of linear electrical networks. They encapsulate the complex relationship between incident and reflected waves at each port of the network, offering profound insights into signal transmission and reflection dynamics.

Supplementing S-parameters, VSWR emerges as a pivotal metric derived from these parameters, providing a quantifiable measure of power transfer efficiency between the antenna and transmission line. It delineates the ratio of maximum voltage to minimum voltage along the transmission line, thus serving as a crucial indicator for impedance matching and signal fidelity. Concurrently, return loss, typically expressed in decibels (dB), serves as a fundamental gauge of antenna performance, measuring the magnitude of reflected power relative to incident power at the antenna port. Its importance lies in its ability to signify impedance matching quality, with lower return loss values indicating superior efficiency and enhanced impedance matching.

Recognizing the intricate interplay between these parameters underscores the symbiotic relationship between antenna design, electrical performance, and signal propagation. Through meticulous analysis of these outcomes and their respective thresholds, engineers can iteratively refine antenna designs to achieve optimal performance while adhering to stringent design specifications and performance criteria. Moreover, the inclusion of far-field radiation plots provides a visual representation of the antenna's radiation pattern, offering critical insights into its directional characteristics and coverage area.

This comprehensive assessment of results not only facilitates a thorough evaluation of the antenna's performance but also serves as a guiding beacon for further optimization endeavors aimed at meeting and surpassing desired specifications and operational requirements.

S-PARAMETER RESULTS:

S11 parameter, also known as the reflection coefficient, is a measure of how much power is reflected from an antenna compared to how much is incident upon it. It's often represented in terms of magnitude and phase.

When designing an antenna, achieving a low S11 value is desirable because it indicates that the antenna efficiently transfers power from the transmission line (feedline) to the radiating elements, rather than reflecting it back. This is crucial for maximizing the antenna's performance and ensuring good impedance matching with the transmission line and the surrounding environment.

The S11 characteristics of the antennas would involve analyzing the reflection coefficient at different frequencies, particularly focusing on the ISM band around 2.45 GHz. The S11 characteristics would show how well each antenna design performs in terms of impedance matching and efficiency at the desired resonance frequency.

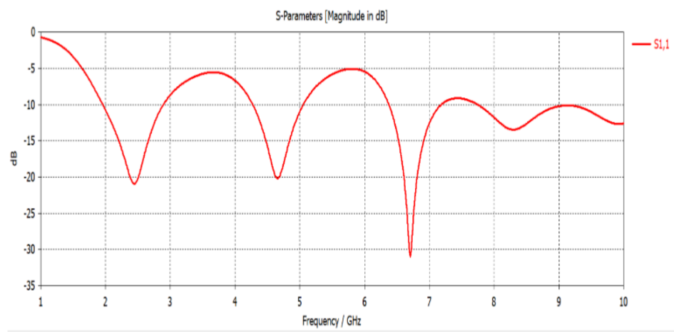

Figure 5*: S11 Parameter plot with respect to frequency.*

For example, the above Fig likely depicts graph or plot illustrating the S11 characteristics of the given wearable textile antenna. The graph would show how the reflection coefficient varies with frequency for each antenna design. The goal would be to observe low S11 values within the ISM band, indicating good performance and suitability for the intended application.

Analyzing the S11 characteristics allows antenna designers to assess and compare the performance of different designs, enabling them to refine and optimize antenna geometries for specific frequency bands and applications.

VSWR RESULTS:

Figure 6 showcases the VSWR plot, drawing attention to the VSWR values at frequency: 2.4GHz.

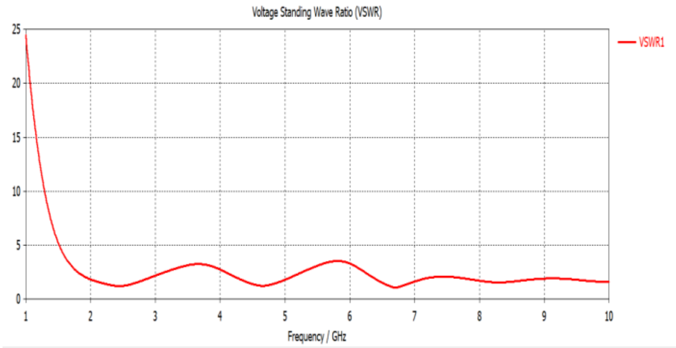

Figure 6: *VSWR of proposed antenna at 2.45 GHz*

These values are crucial indicators of the effectiveness of power transfer between the antenna and transmission line. A VSWR value nearing 1 indicates optimal impedance matching and minimal signal reflection, while higher values suggest impedance mismatches and potential signal degradation. Understanding these VSWR values is pivotal as they validate the antenna's performance and its suitability for operation at designated frequencies, guaranteeing reliable signal transmission and reception capabilities.

FAR-FIELD RESULTS:

Illustrated in Figure 7 is the far-field plot, presenting a comprehensive depiction of the far-field radiation pattern specifically at 2.4GHz.

The far-field region, also known as the radiation zone, is the region far away from the antenna where the electromagnetic fields radiated by the antenna behave as waves propagating through free space. In this region, the electromagnetic fields

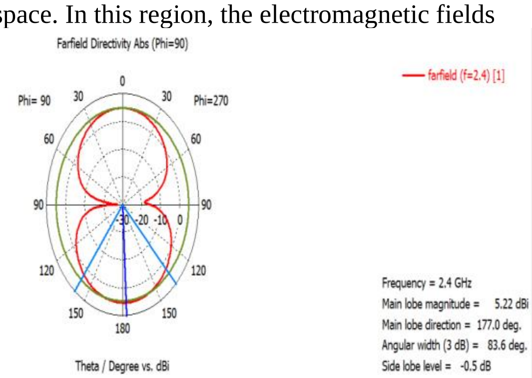

Figure 7: *Far-Field plot at 2.4 GHz*

propagate independently of the antenna structure and behave similarly to waves in open space.The far-field region begins at a distance from the antenna where the radiated fields have a well-defined direction and polarization, and their magnitudes follow the inverse square law, which states that the intensity of the fields decreases inversely with the square of the distance from the antenna.For wearable antennas, understanding the far-field region is important because it helps in optimizing the antenna's performance and minimizing its interaction with the human body. In the near-field region, which is closer to the antenna, the fields are more complex and can be significantly affected by the presence of nearby objects, such as the wearer's body, other electronic components, or surrounding structures. This can lead to distortion, detuning, and inefficiency in the antenna's operation.By designing antennas that primarily radiate in the far-field region, engineers can ensure better performance, improved efficiency, and reduced interference from surrounding objects. This is particularly important for wearable devices where space is limited, and the proximity to the human body can significantly affect antenna performance.

V CONCLUSION

The proposed textile horn-shaped multiband wearable antenna is designed to operate within the ISM band (2.4–2.48 GHz), WiFi (2.45 GHz), WiMAX (3.3–3.9 GHz), and C-band (6.57–6.8 GHz). Constructed using a jeans substrate and copper tape as the radiating patch and ground plane, respectively, this antenna achieves multiband functionality within a compact dimensional geometry, thanks to its thin textile substrate of 0.56 mm thickness.The antenna design incorporates horn-shaped slots in the patch and a partial ground plane, leveraging CST Studio for intensive simulation. Unit cell simulations utilize boundary conditions, while the metasurface contributes negative refractive index and permittivity values.

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