

Research Article

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Development and Performance Assessment of a Textile-Based Wearable Antenna for WBAN Applications

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Abstract: This study presents a compact wearable antenna intended for wireless body area network (WBAN) applications. The antenna is realized on a denim textile substrate with overall dimensions of $46 \times 55 \times 1$ mm³, and its performance is evaluated using a commercial full-wave EM solver. Under the $S_{11} < -10$ dB criterion, the simulated impedance bandwidths extend from 2.05 to 4.67 GHz and from 5.78 to 8.94 GHz. The design resonates at 2.45 GHz and 7.88 GHz, delivering realized gains of 2.43 dBi and 3.60 dBi at the two bands. The total efficiencies reach 97.62% at 2.45 GHz and 90.0% at 7.88 GHz. These outcomes verify that the suggested structure is a strong candidate for practical wearable implementations.

Keywords: Flexible antenna, Textile antenna, Wearable antenna, Wireless body area network (WBAN)

1. Introduction

With the rapid growth of wireless technologies, wearable antennas have become a core enabling element of Wireless Body Area Networks (WBAN) [1]. Extensive research has led to wearable antennas being adopted in diverse scenarios including sports/fitness devices, military links, medical monitoring, and activity-tracking platforms [2], [3], [4], [5], [6]. The WBAN can be viewed as a short-range communication framework where sensors and personal devices are positioned on the body or embedded into garments [7]. For such systems, textile-based wearable antennas that can be stitched onto or incorporated within garments are particularly appealing. They offer low cost, simple fabrication, low weight, mechanical flexibility, and straightforward integration into clothing [8], [9].

In the literature, many different wearable antenna configurations have been reported using textile or other flexible materials. These include planar monopole antennas [10], [11], E-shaped monopole textile structures [12], planar inverted-F antennas [13], [14], reconfigurable antennas [15], metamaterial-based surface antennas [16], high impedance surface antennas [17], [18], and substrate-integrated waveguide (SIW) antennas [19], [20]. However, many of these designs still exhibit narrow impedance bandwidths or relatively low gain.

Wearable antenna designs often rely on textile materials, which can be used either as the underlying substrate or integrated into the conductive configuration. Due to their low dielectric permittivity, limited loss tangent, and thin profile, these materials mitigate surface-wave effects and thereby enhance the antenna's radiation performance [21], [22]. Among the fabrics commonly employed for this purpose are felt [10], [23] and denim (jeans) [24], [25], [26], [27].

Key considerations in the design of wearable antennas include the operating frequency, achievable impedance bandwidth, flexibility, overall size, and gain. Among these, the physical dimensions of the antenna are especially important, as they affect both radiation performance and user comfort. For real-world wearable applications, the antenna should be compact enough to be easily integrated into portable devices or directly mounted on the body [28].

In this study, a compact, low-cost, and dual-band, wearable antenna intended for WBAN applications

is presented, operating at 2.45 GHz and 7.88 GHz. A flexible textile substrate of denim (jeans) is used in the antenna design. The antenna is designed and examined using electromagnetic (EM) simulation software. The proposed wearable antenna's (PW-ANT.) performance is characterized in terms of gain, efficiency, and radiation patterns. Owing to its compact size, good flexibility, and high gain, the proposed dual-band design is a strong candidate for practical wearable antenna applications.

2. Antenna Design

2.1. Antenna Design Configuration

A microstrip patch antenna typically consists of a metallic ground plane, a dielectric layer, and a radiating patch. This class of antennas is favored because of its low weight, thin profile, and ease of integration with microwave circuits [29], [30]. Their planar geometry also permits straightforward mounting on the human body, which makes them attractive for wearable technology. Since these antennas have a flat profile, they can be comfortably mounted on the human body and are therefore well suited for wearable devices [31].

Figure 1 shows the geometric topology of the PW-ANT. The PW-ANT. utilizes a flexible denim substrate with $\epsilon_r = 1.7$, $\tan \delta = 0.026$, and thickness $h = 1\text{mm}$. Both the radiating patch and the ground plane are formed using 0.035 mm-thick conductive copper tape. The PW-ANT has an overall size of $46\text{mm} \times 55\text{mm} \times 1\text{mm}$. The antenna comprises a circular patch fed by a 3.64 mm-wide microstrip line, which provides connection to a 50 Ohm SMA-connector. The optimized values of the geometrical parameters with the help of CST studio [32] are $W = 46$, $L = 55$, $r_a = 6$, $r_b = 12.5$, $r_c = 17.5$, $r_d = 6.25$, $v = 2.5$, $W_f = 3.64$, $L_f = 11$, $W_g = 42$, $L_g = 10.75$, $W_{gs} = 3.5$, $L_{gs} = 3.75$ (All lengths in millimeters).

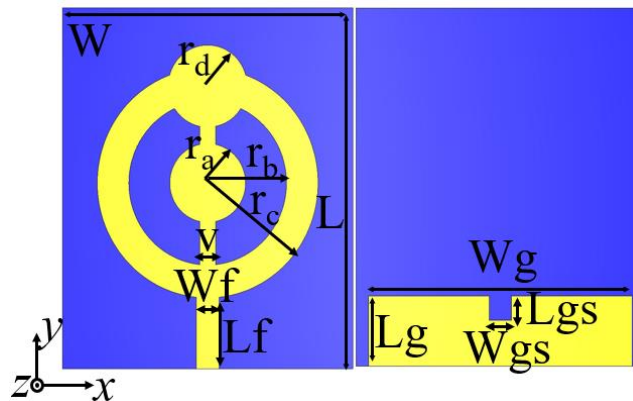


Figure 1. Geometric topology of the PW-ANT.

Figure 2 demonstrates the step-by-step development of PW-ANT. together with the simulated S_{11} curves for each configuration. When the circular patch is hollowed and a conductive path is added at its center, Case-2 yields enhanced radiation characteristics relative to Case-1. Case-3 exhibits impedance matching properties that differ slightly from those of Case-2 in the lower frequency region. In order to realize the required frequency bands, the geometry used in Case-3, which incorporates a central circular feature on the patch and a center slot in the ground plane, is chosen as the final design.

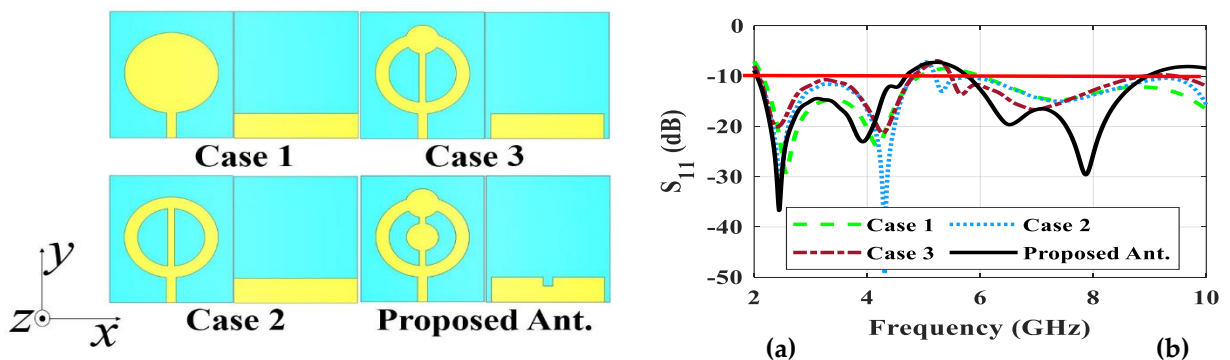


Figure 2. PW-ANT design process (a) and simulated S_{11} responses (b)

3. Results and Discussions

The analysis began by simulating the antenna geometry. The reflection coefficient (S_{11}) was computed in CST Microwave Studio [32]. The simulated S_{11} response of the PW-ANT. in free space is presented in Fig. 3. The highest resonance frequencies within the antenna's operating bands are 2.45, and 7.88 GHz. The simulated bandwidth $S_{11} < -10$ dB for the PW-ANT is 2.05-4.67GHz and 5.78-8.94GHz. The simulated S_{11} parameter results of the PW-ANT, as depicted in Fig. 3.

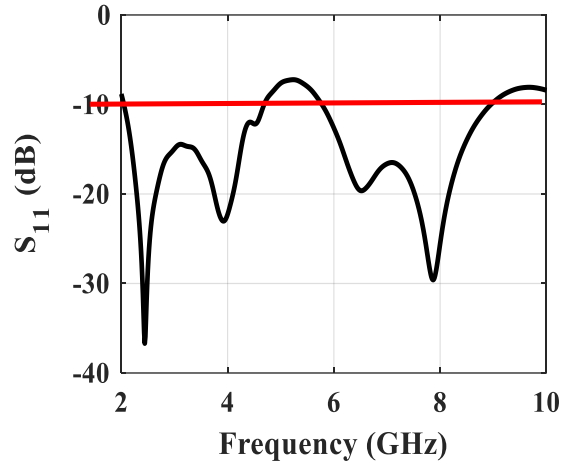


Figure 3. Simulated S_{11} response of the PW-ANT.

After the S_{11} analysis, the realized gain, total efficiency, radiation patterns, and surface current behavior of the antenna were further investigated. Figure 4 shows the simulated far-field radiation patterns of the PW-ANT at 2.45GHz and 7.88 GHz for the principal planes $\varphi = 0^\circ$ and $\varphi = 90^\circ$. In the plots, the blue curves represent the $\varphi = 0^\circ$ plane, while the black curves correspond to the $\varphi = 90^\circ$ plane. The surface current distributions at both resonant frequencies are given in Fig. 5. The results indicate that the current paths change with frequency for each resonance. It is also observed that the surface currents are mainly concentrated along the edges of the antenna and around the junction regions of the feed line.

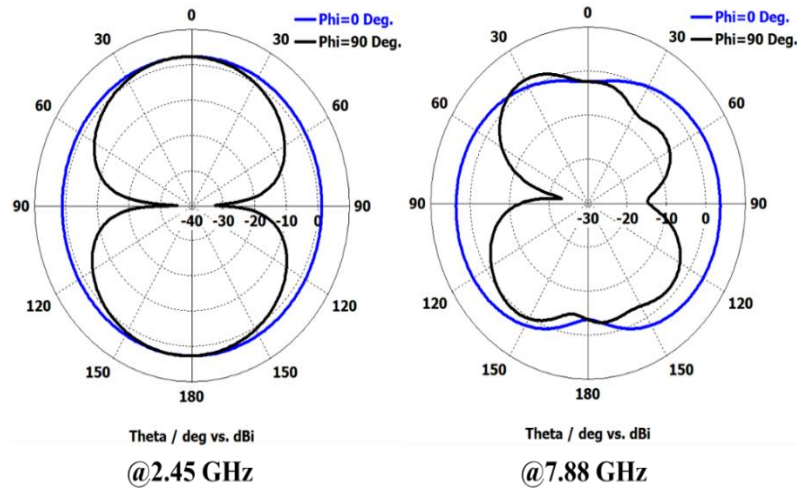


Figure 4. The far-field radiation patterns at $\Phi=0$ deg. and $\Phi=90$ deg. for the frequencies 2.45 GHz, and 7.88 GHz of the PW-ANT were analyzed.

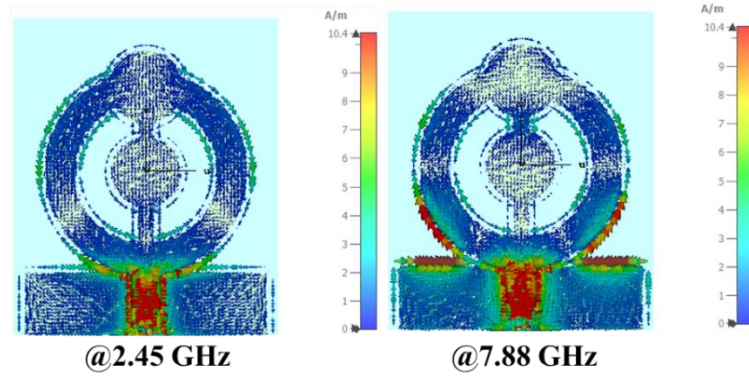


Figure 5. Simulation of the PW-ANT.'s surface current distributions for resonant frequencies 2.45GHz, and 7.88GHz

The frequency-dependent realized gain is plotted in Fig. 6. The PW-ANT. provides realized gains of 2.43dBi at 2.45GHz and 3.60dBi at 7.88GHz. The total efficiency response in Fig. 7 remains approximately between 74% and 98% within the operating bands. The total efficiencies of 97.62% and 90.0% are achieved at 2.45GHz and 7.88GHz, respectively. These outcomes show that the PW-ANT. offers very good performance in terms of both realized gain and total efficiency.

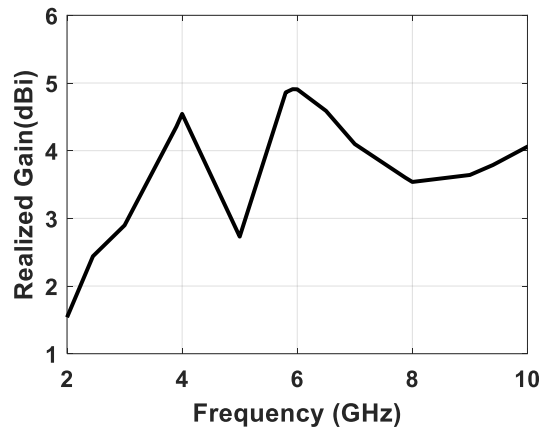


Figure 6. The simulated realized gain of the PW-ANT.

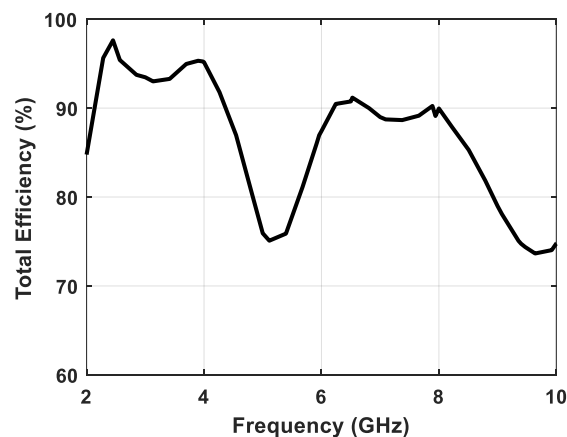


Figure 7. The simulated total efficiency (%) of the PW-ANT.

4. Conclusion

This work has presented a compact dual-band textile wearable antenna for WBAN applications. The PW-ANT. is implemented on a denim substrate with physical dimensions of $46 \times 55 \times 1\text{mm}^3$, and its performance is evaluated using commercial EM simulation software. In addition to S11 performance,

realized gain, radiation patterns, surface current distributions, and total efficiency were examined. The results show that the PW-ANT., which exhibits high efficiency, and high gain, offers important advantages for WBAN applications. It is expected that the presented antenna design and the corresponding findings will contribute to the wearable antenna literature and provide useful guidance for antenna designers.

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Conflicts of Interest: The author declares no conflict of interest.

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