

# Development of Augmented Low-Cost, Compact, and Flexible Textile Antenna

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**Abstract** – This paper presents a compact, low-cost, flexible textile antenna fabricated on a readily available denim substrate. Inspired by the Algerian Special Forces logo, the antenna features a distinctive shape and demonstrates robust single-band performance suitable for wireless local area networks applications. The fabricated prototype demonstrates excellent agreement between simulated and measured results. The simulated results show a maximum gain of 4.3 dB at 5.5 GHz and a peak efficiency of 85% in free space, with a  $-10$  dB impedance bandwidth of approximately 10% (5.3–5.85 GHz). The antenna's conformal nature and stable performance under bending and proximity to the human body make it well-suited for wearable applications. This cost-effective design offers a promising solution for integration into various consumer electronics, including potential applications in enhanced workforce management, secure access control, and identification.

## 1. Introduction

The rise of wearable technology has driven the need for advanced antenna designs that enhance both performance and user experience. Textile antennas have emerged as a key solution for wearable electronics, offering flexibility, comfort, and easy integration into garments and accessories like shirts, jackets, and hats. Their adaptability makes them ideal for the Internet of Things and 5G networks, replacing bulky conventional antennas. Patch antennas are particularly suitable for near-body communication because of their high isolation, low profile, durability, and cost-effectiveness [1, 2].

Textiles provide advantages over conventional materials, such as lower permittivity, reduced weight, and better bending behavior, ensuring seamless integration while maintaining communication efficiency. Beyond functionality, textile antennas also offer aesthetic benefits, complementing different fashion styles and making wearable technology less intrusive.

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Their applications range from health monitoring to body area networks and enhanced personal communication [3, 4].

For optimal performance, textile wearable antennas must be lightweight, compact, cost-effective, efficient, robust, and safe for the user, with low specific absorption rate (SAR) levels [5]. Despite their many advantages, challenges such as impedance mismatch due to bending can affect bandwidth and radiation patterns. Extensive research has explored different textile substrates, including denim [6], cotton [7], felt [8], fleece [9], leather [10], and polyamide [11], all of which have low dielectric constants that help minimize surface wave losses and improve impedance bandwidth.

The direct integration of antennas into garments has attracted significant interest from both academia and industry due to its security benefits and discrete design. A notable advantage is the ability to embed antennas within logos, maintaining visual appeal while ensuring effective communication. With continuous advancements, textile antennas are poised to revolutionize wearable electronics, enabling more personalized and connected experiences [6, 12].

This study presents a novel, compact, wearable antenna designed for seamless integration into a vest-like garment, enabling communication within the 5.5-GHz frequency band, targeting applications in wireless body area networks (WBAN), industrial, scientific, and medical bands, and wireless local area networks (WLAN). The proposed antenna incorporates a distinctive visual design inspired by the Algerian Special Forces logo fabricated on a readily available denim substrate. This approach leverages the inherent properties of textile materials to achieve a compact, lightweight, and cost-effective solution for wearable communication systems. The antenna is designed for efficient operation at 5.5 GHz, exhibiting resonance across the 5.3-GHz to 5.85-GHz range. Comprehensive analysis and optimization of key performance parameters, including  $-10$  dB impedance bandwidth, radiation efficiency, realized gain, and side lobe levels, are conducted to achieve superior performance. Furthermore, the antenna's resilience to mechanical deformation is assessed through experimental testing, evaluating its performance under various bending radii.

## 2. Antenna Design and Simulated Results

Figure 1 details the evolution of the design and presents the final antenna configuration. The antenna is constructed on a common denim substrate ( $\epsilon_r = 1.7$ ,  $\tan \delta = 0.025$ , thickness = 0.7 mm). The radiating patch

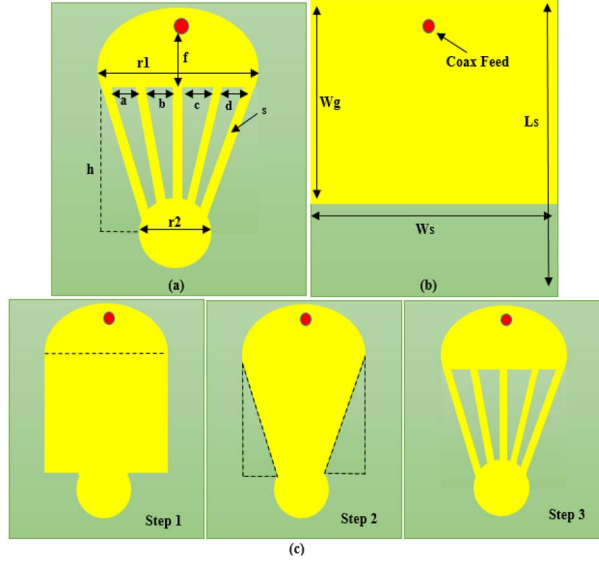


Figure 1. Illustration of the designed antenna. (a) Top view, (b) Bottom view, and (c) step-by-step evolution of the antenna structure.

and ground plane are realized using 0.035-mm thick copper. A standard 50- $\Omega$  coaxial feed line is employed for excitation. The overall dimensions of the proposed antenna are 30 mm  $\times$  26 mm  $\times$  0.7 mm.

The design process initiates with a circular patch element, followed by a rectangular element directly beneath it and a smaller circular element below the rectangle (Stage 1, Figure 1). This initial configuration, incorporating a coaxial feed at the top of the larger circle and a partial ground plane on the opposite side of the substrate, exhibits a single resonant frequency near 5.7 GHz with a return loss of  $-6$  dB. In Stage 2, the patch geometry is modified to approximate a parachute-like profile. Two opposing, equal-sized triangular slots are introduced onto the patch surface, resulting in a design inspired by the Algerian Special Forces logo. This geometric adjustment shifts the resonant frequency to approximately 5.9 GHz, with a significantly improved

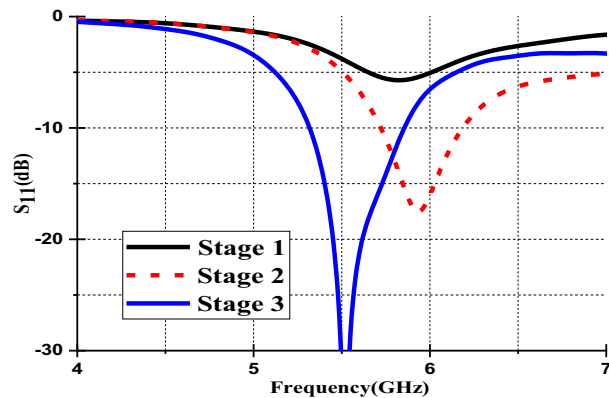


Figure 2. Simulated  $S_{11}$  results affect the evolution steps.

Table 1. Dimensions of the designed antenna in millimeters

Parameters	Value	Parameters	Value
Ls	30	a	03
Ws	26	b	3.3
Wg	20	c	3.3
r1	16	d	03
r2	06	s	01
h	16	f	6.5

return loss of  $-17.5$  dB. Further optimization (Stage 3, Figure 1) involves the incorporation of several quadrilateral slots, representing the spaces between parachute cords, culminating in the final antenna design. This final modification yields a single resonant frequency at 5.5 GHz with excellent impedance matching, achieving a return loss of  $-45$  dB. The reflection coefficients for each design iteration are presented in Figure 2, and the final antenna parameters are summarized in Table 1.

A parametric study of the antenna geometry is crucial for understanding its influence on performance. The coaxial feed position significantly impacts the impedance matching of the proposed antenna. Figure 3 illustrates the effect of varying the feed point. These results indicate that optimal impedance matching is achieved when the feed is located at the top of the larger circle rather than on the right or left sides.

### 3. Antenna Fabrication and Measurement Results

The proposed antenna is fabricated on a readily available denim substrate, and a photograph of the prototype is depicted in Figure 4. The reflection coefficient was measured using the E8362B vector network analyzer. The measured  $S_{11}$  is shown in Figure 5. The measured results are in excellent agreement with the simulation results.

Its performance was practically measured under varying bending conditions to evaluate the impact of

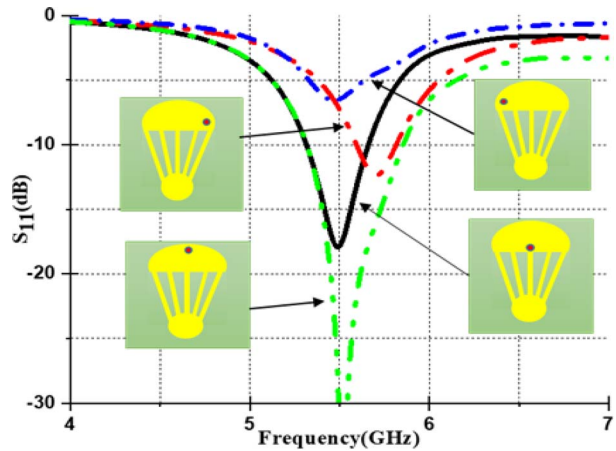


Figure 3. Effect on the reflection coefficient through variation of the position of the coax feed.

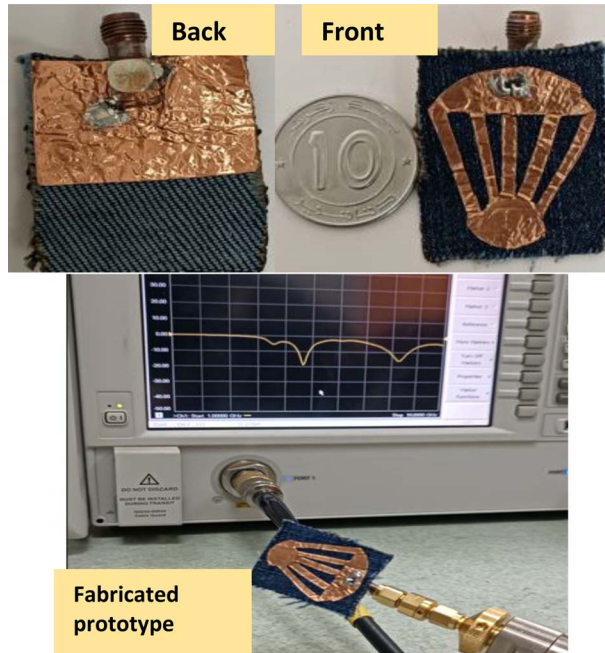


Figure 4. Fabricated prototype and reflection coefficient measurement on the vector network analyzer.

bending and conformability on the proposed wearable antenna. The antenna was placed on a polystyrene cylinder (dielectric constant  $\epsilon \approx 1$ ) with diameters of 70 mm, 80 mm, 100 mm, and 140 mm to realize different curvatures, as shown in Figure 6a. The measured reflection coefficient ( $S_{11}$ ) remained robust across the bending variations, showing minimal deviation, as depicted in Figure 6b.

#### 4. Antenna Performance Close to the Human Body

The schematic of the simulated antenna analysis is conducted using a four-layered stacked human tissue model, as shown in Figure 7. When the wearable antenna

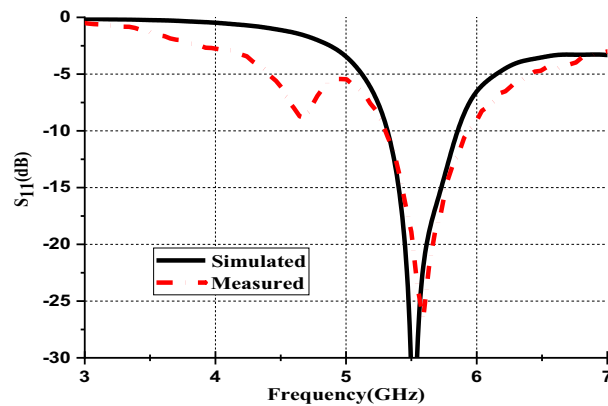
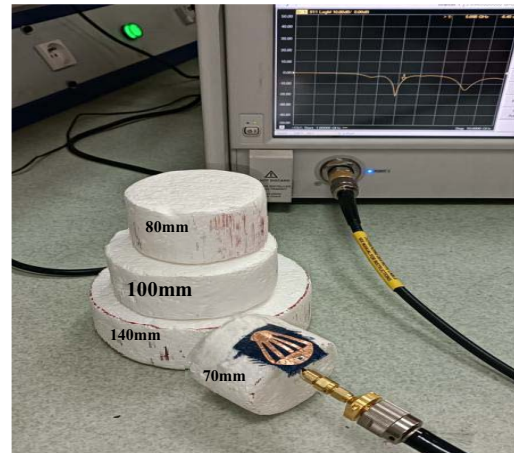
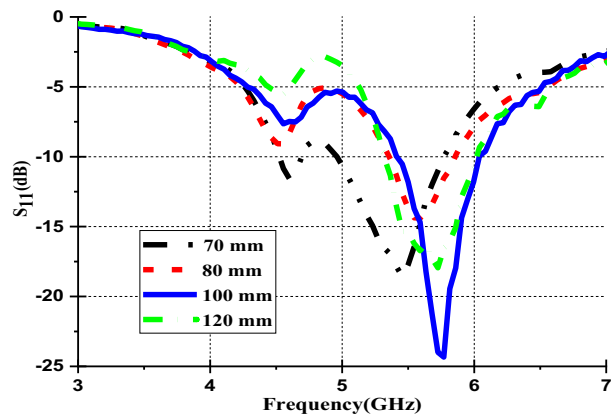


Figure 5. Measured versus simulated reflection coefficient of the proposed antenna.



(a)



(b)

Figure 6. (a) Fabricated prototype deformed by different curvatures. (b) Measured reflection coefficient of the proposed antenna under different curvatures.

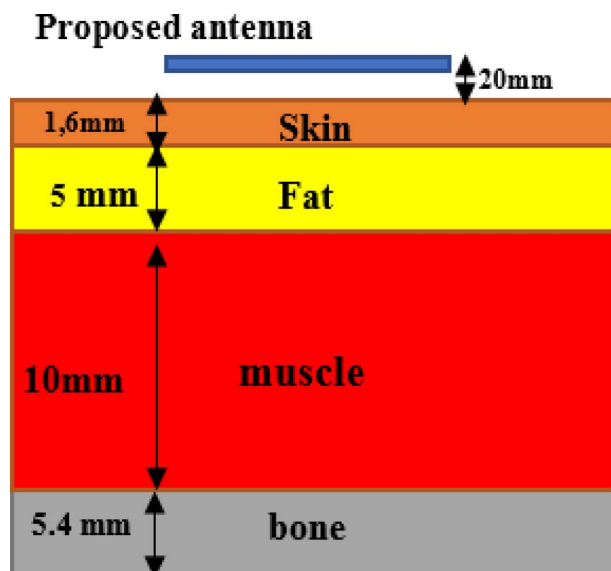


Figure 7. Four-layer rectangular human body arm area model.

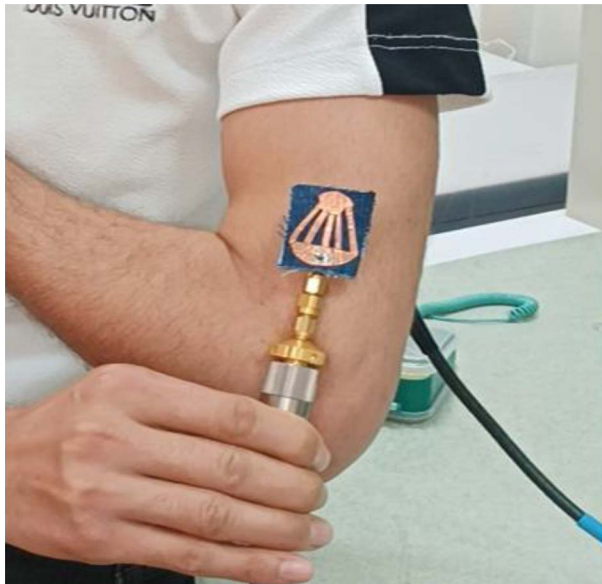


Figure 8. Placement of the fabricated antenna on the human arm.

is placed in proximity to the human body, such as on the arm (illustrated in Figure 8), it emits electromagnetic radiation, part of which may be absorbed by the body while another portion may be reflected. Therefore, it is crucial to assess the resulting changes in the antenna's performance and their potential effects on the human body. The antenna operates with an input power of 0.5 W within this model. The dielectric properties at 5.5 GHz are calculated using [6, 12, 13]. The results in Figure 9 demonstrate that the proposed antenna maintains its performance regardless of the body part it is placed on. Furthermore, it effectively covers the required frequency band for measurements on these organs.

The SAR denotes the quantity of electromagnetic radiation absorbed by bodily tissues when subjected to an electromagnetic field. The Federal Communication Commission requires SAR values less than 1.6 W/kg for 1 g of

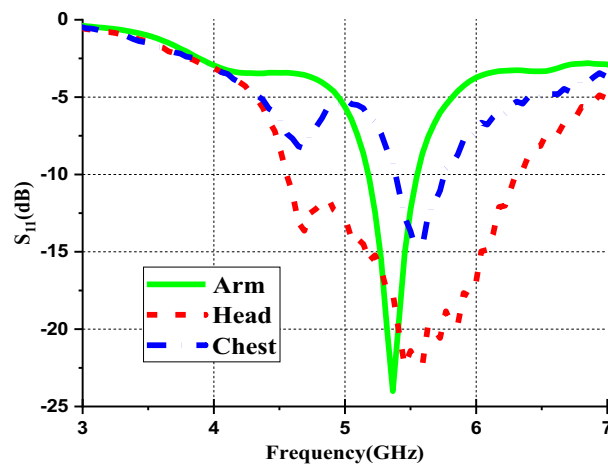


Figure 9. Measured the reflection coefficient of the proposed antenna under different human body organs.

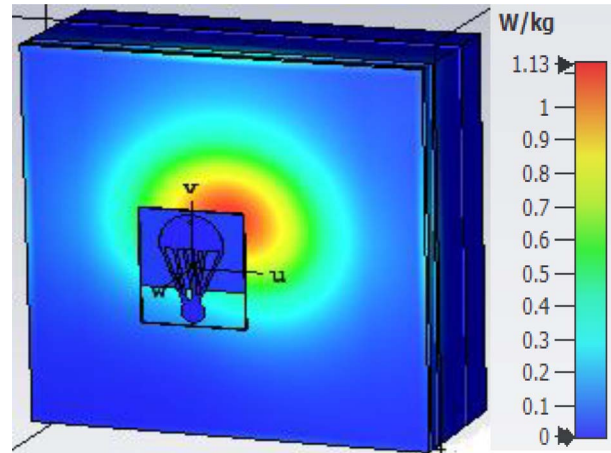


Figure 10. SAR analysis at 5.5 GHz.

tissue and 2 W/kg for 10 g. The theoretical calculation of this parameter is presented as follows [1-4]

$$SAR = \frac{\delta E^2}{\rho} \quad (1)$$

Figure 10 illustrates the antenna's SAR values at different frequencies. As shown, the SAR remains within safe limits for user applications involving proximity to the body. At 5.5 GHz with an input power of 0.5 W, the 10-g averaged SAR 1.13 W/kg ( $< 2$  W/Kg).

Figure 11 presents the 3D radiation pattern of the antenna on the human body model. In free space, the antenna achieves a peak gain of 4.3 dBi and a radiation efficiency of 85% at the target frequency. As shown, the proposed antenna also achieves a simulated gain of 6.02 dB when the proposed antenna is placed on the human body.

Figure 12 illustrates the two-dimensional radiation patterns of the antenna under both free space and

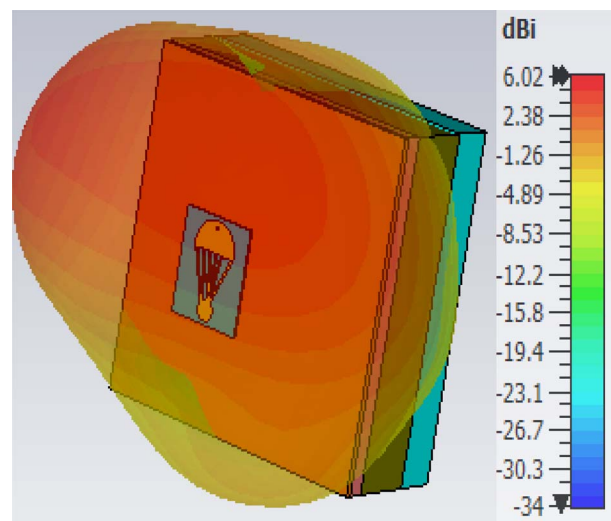


Figure 11. On-body numerical 3D radiation pattern at 5.5 GHz.

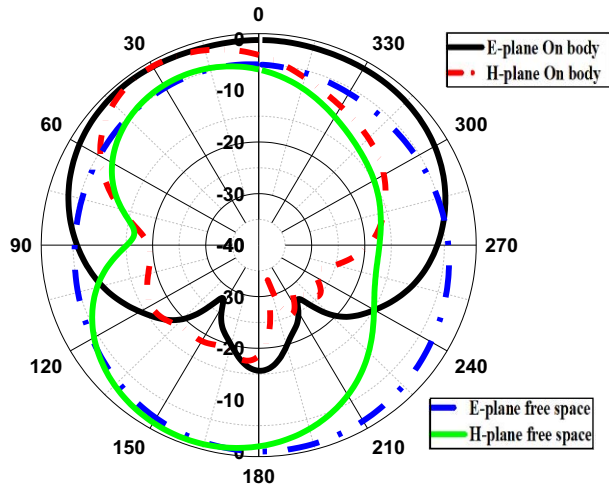


Figure 12. Simulated 2D radiation pattern at 5.5 GHz of the proposed antenna in both the free space and on the body in both E-plane ( $\phi = 0^\circ$ ) and H-plane ( $\phi = 90^\circ$ ).

on-body conditions. In free space, the E-plane radiation pattern exhibits omnidirectional behavior, while the H-plane pattern is bidirectional. When positioned near the human body, the antenna demonstrates a directional radiation pattern in both the E-plane and H-plane, which can be attributed to the reflective effects of human body tissues. A performance comparison of the proposed antenna with other closely related works using a textile material is listed in Table 2.

### 5. Conclusion

This study presents an augmented, compact, flexible textile antenna designed on a jean substrate for WLAN (5.3–5.85 GHz) applications. Featuring a geometry inspired by the Algerian Special Forces logo, the antenna performs excellently in both simulations and measurements, with more than 85% radiation efficiency and a peak gain of 4.3 dBi. It maintains stable performance under bending and shows compliance with SAR limits for wearable use. Despite reduced performance near the human body, the design remains a promising candidate for workforce management and secure identification systems due to its flexibility, efficiency, and safety.

Table 2. Comparison of proposed antenna performance with existing literature

SAR, W/kg	Efficiency, %	Gain, dB	Fr, GHz	Size, mm <sup>2</sup>	Ref
0.4/0.02	34/42	-0.69/7.4	2.4/5.5	44 × 44	Felt [3]
1.09/1.08	65/95	3.4	2.2/5.3	40 × 77	Denim [4]
0.032	67	7.11	2.45	52 × 57	Cotton [7]
0.09	74	6.8	2.4	150 × 54	Fleece [9]
/	71/68/76	1.1/0.9/2	2.4/3.5/4.6	80 × 80	Leather [9]
1.13	85	4.3	5.5	30 × 26	Our work

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