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Original Article

Denim-Based Wearable Textile Antenna for WiMAX, Telemetry, and X-Band Applications

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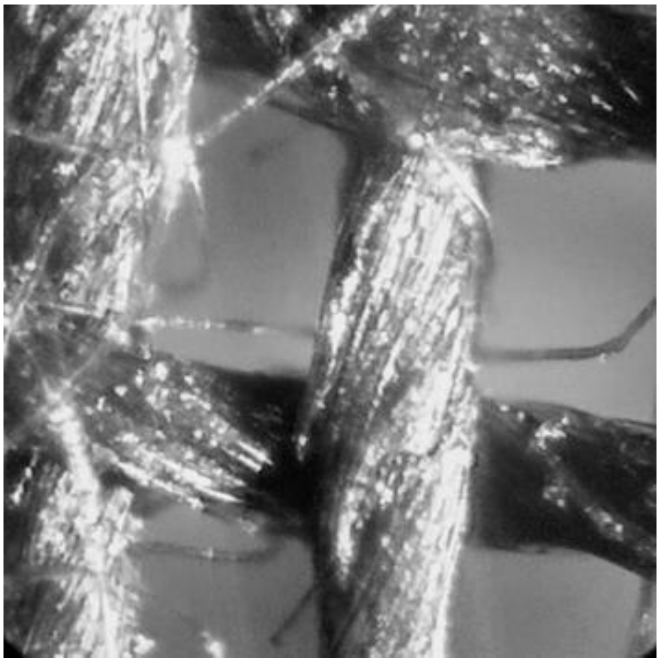
Abstract *- This research details the construction and performance evaluation of a textenna employing denim as a substrate. The antenna's conducting layers are constructed from conductive textile materials. A comparative material study was conducted to identify the optimal substrate for the wearable antenna, assessing four possible materials: (a) yarn, (b) polyester, (c) denim, and (d) conductive fabric. The investigation of surface shape and electrical characteristics resulted in the identification of denim as the superior substrate, attributed to its advantageous mechanical flexibility and compatibility with conductive fabrics. The antenna is engineered to work at 3 specific bands: 1.5 for telemetry, 3.3 for WiMAX, and 7.5 GHz for X-band frequencies. The patch design draws inspiration from the distinctive morphology of a cactus, hence augmenting the antenna's radiating properties and efficiency. Experimental findings indicate that the denim-based textile antenna exhibits superior performance across the designated frequency ranges, rendering it exceptionally appropriate for wearable communication systems across several applications, including medical monitoring, wireless communication, and radar.*

Keywords *- Body wireless communication, Conductive fabric, Denim textile, Military and medical applications, Flexibility.*

1. Introduction

With the ultrafast progression of wireless communication technology and the increasing demand for wearable electronics, great attention has been devoted to the development of textile antennas. These new types of antennas can be woven into fabrics, resulting in data and communications woven into the fabric of our clothing, paving the way for systems as varied as personal health monitoring systems, smart clothing, and improved communication systems for military personnel. Fabrication of antennas on mechanically hard substrates usually introduces constraints in the form of comfort and flexibility, leading to challenges in using such designs in wearable scenarios. Textile antennas, on the other hand, offer the advantages of flexibility, lightweight, and the ability to conform to the human body, making them an ideal solution for wearable communication systems [1-7]. The design of textile antennas presents a significant challenge in selecting suitable materials for the substrate and conductive layers. The substrate material is essential in influencing the mechanical properties, flexibility, and overall performance of the antenna. The substrate must possess characteristics such as lightweight, durability, and flexibility while also ensuring electrical properties that support effective antenna operation. Conductive materials that constitute the radiating elements of the antenna must be compatible with the selected substrate. These materials should provide low resistance and high conductivity while maintaining the antenna's flexibility and wearability [8-11]. This study centers on the design and fabrication of a textile antenna, utilizing denim fabric as the substrate and incorporating conductive textiles for the radiating elements. Denim, a widely accessible fabric, is recognized for its strength, adaptability, and capacity to endure everyday use, positioning it as an ideal option for wearable applications. Before finalizing denim as the chosen substrate, an extensive material analysis was performed to evaluate four possible substrates: (a) cotton, (b) polyester, (c) denim, and (d) conductive fabric. This analysis involved assessing the surface morphology, flexibility, and electrical properties of each material to determine the most suitable substrate for the antenna [12-16]. 1.5 GHz for telemetry, 3.3 GHz for WiMAX, and 7.5 GHz for X-band applications are the frequencies that operate the antenna, and the choice of those frequencies is determined by the applications that are intended to use it. The antenna is adaptable enough to be used for a variety of applications in the actual world since these frequency bands encompass a wide range of communication and radar systems. Cactus-shaped structures are well-known for their capacity to radiate energy effectively and to keep their structural integrity intact across a wide range of situations. The design of the patch antenna was inspired by these structures. Not only does this one-of-a-kind design increase the radiation qualities of the antenna, but it also makes it more adaptable to a variety of settings and gestures, which is an essential quality for applications that include wearable technology.



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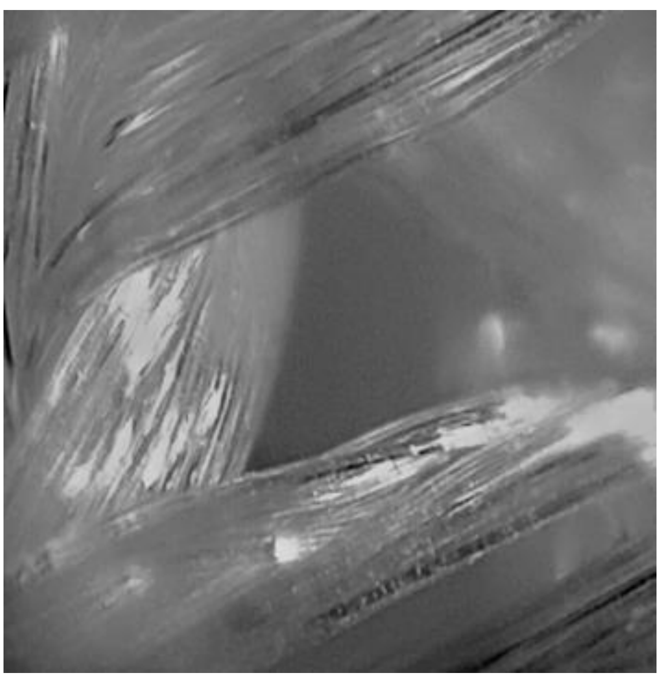

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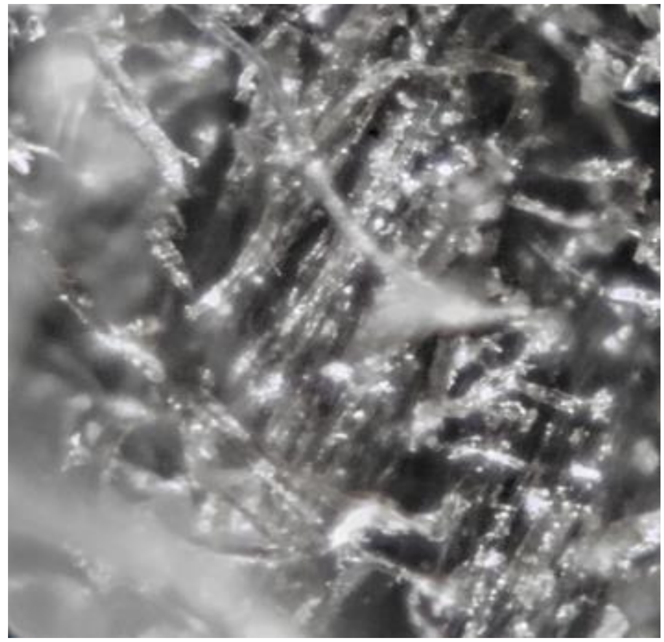

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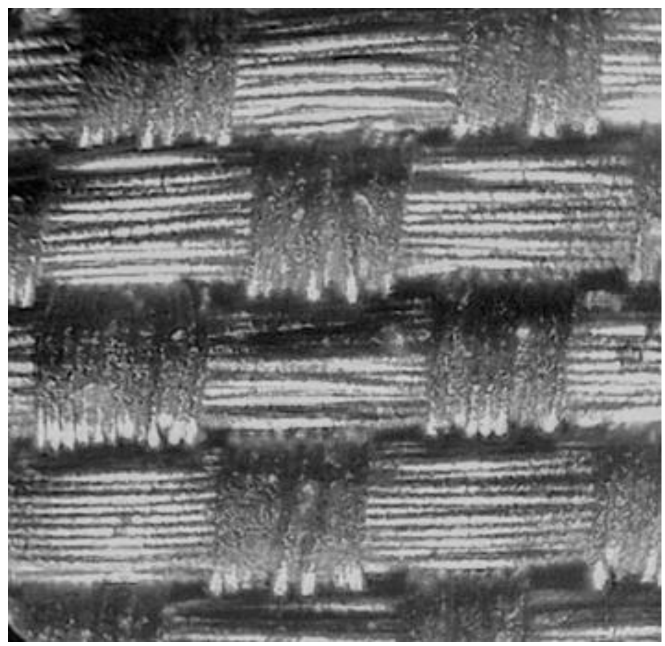


(d)

Fig. 1 Electron microscope images at 200-micrometer resolution: (a) Yarn, (b) Polyester, (c) Denim, and (d) Conductive fabric.

This study explores the denim-based textile antenna's intricate design, material choice, and performance assessment. We investigate how a flexible, long-lasting, and high-performing antenna is produced by combining conductive textile layers with a denim substrate. The work contributes to the development of smart textiles and next-generation wearable technologies by offering insightful information on the possibilities of incorporating textile antennas into wearable communication systems.

2. The Antenna Design

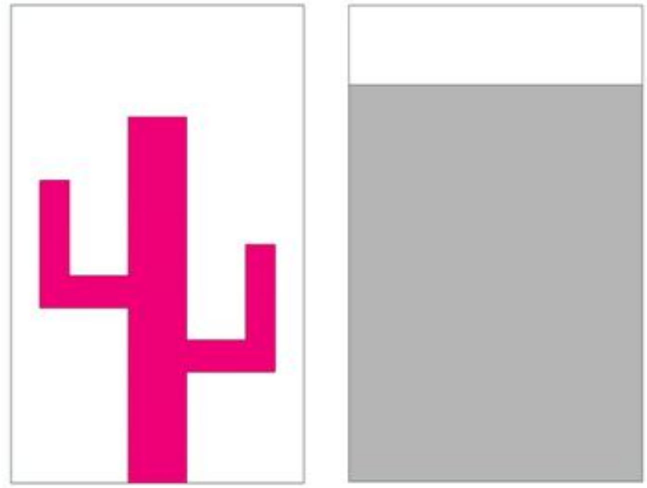
A thorough assessment of different textile materials, such as cotton, polyester, denim, and conductive fabric, was performed to identify the most appropriate substrate for this research. The main objective was to evaluate the structural, mechanical, and electromagnetic characteristics of these fabrics to confirm their suitability for the intended application. Figure 1 demonstrates that most of the analyzed textile samples, with the exception of denim, exhibit significant air voids distributed among the prominent fiber bundles. The voids present within the fabric's structure significantly impact the dielectric constant, surface roughness, and the overall electromagnetic characteristics of the substrate. Air gaps may influence the mechanical stability and durability of the material, particularly when subjected to fluctuating environmental conditions, including temperature and humidity.

Denim demonstrated a compact and uniform structure, which minimized air voids and provided improved stability. Circumstances like thickness, plasticity, facilitation of integration with conductive layers, and the complete textenna performance must be considered during the selection process. This structural morphology leads to poor stability and very low stiffness, making it unsuitable for frequent bending and crumpling circumstances.

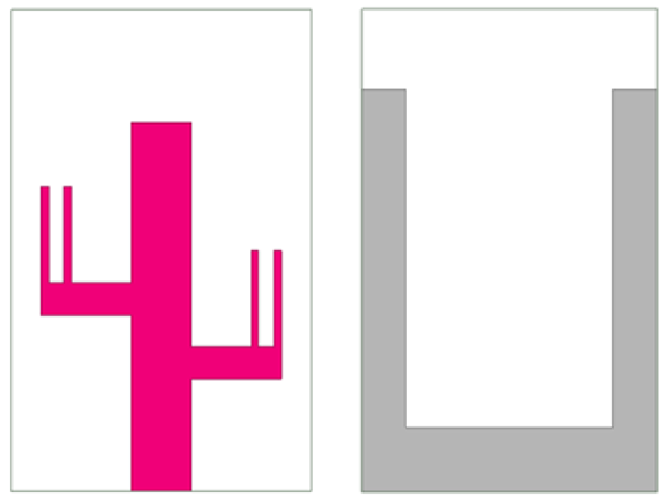
Hence, the robust fibre intervention-based denim fabric was chosen as a proper textile substrate. As viewed in Figure 1(d), the conductive layers of the textenna were realized using a fabric made of nylon with conductive properties. The proposed antenna design takes inspiration from the shape of a cactus tree, resulting in a cactus-shaped structure. A denim textile material has been utilized in the development of the antenna with dimensions of 30×20×1.6 mm^3. The propounded textenna geometric characteristics were performed using the Ansys HFSS-built R22 package.

In the first iteration, as seen in Figure 2(a), initially a cactus-shaped four-sided formation was created as a patch element. The central rectangular structure has dimensions of 23 mm in length and 4 mm in width. This structure was attached with two ‘L’ shaped elements, which were placed opposite to each other. The ground structure was taken as a partial rectangular element. This particular model operates at 8.5GHz frequencies, enhancing the fringing fields. In iteration 2, as seen in Figure 2(b), two rectangular slots were opened on both sides of the ‘L’ shaped structure with a width of 1mm.

This alteration results in making two finger-like structures. The structure in the ground plane was converted as a ‘U’ shaped defective milled construction, as confirmed in Figure 2(c). As illustrated in the figure, one more rectangular slot was opened on the primary radiating structure of 2 mm and a rectangular structure was launched in the base level with dimensions of 20mm dimension and 4mm width.



(a)



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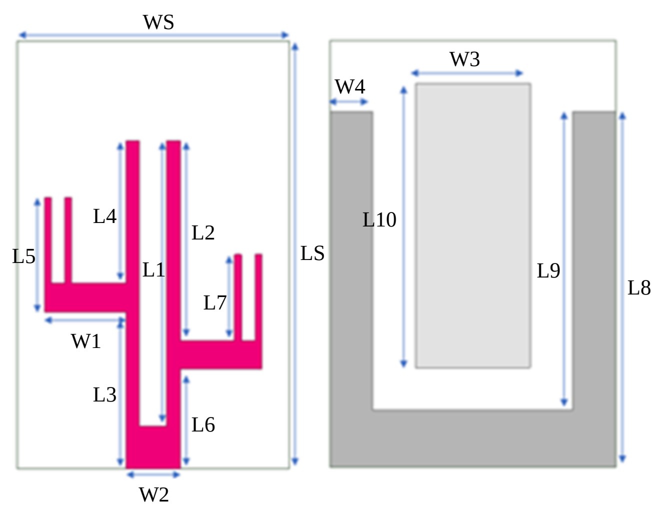


(c)

Fig. 2 Propounded textenna model concerning development stages: (a) Stage 1, (b) Stage 2, and (c) Stage 3.

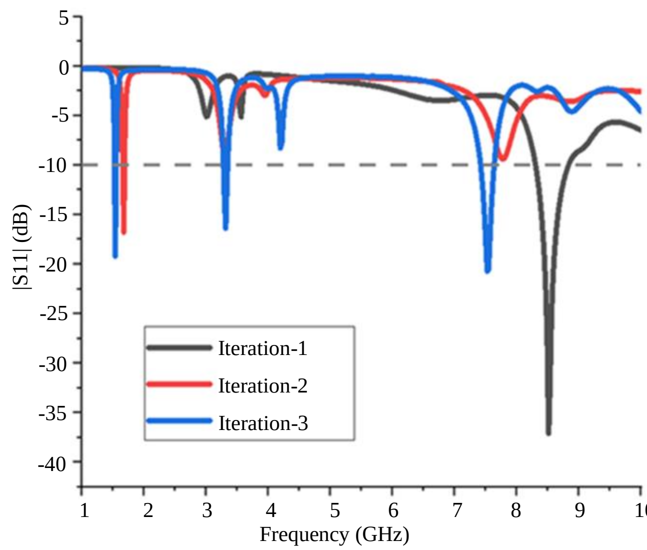


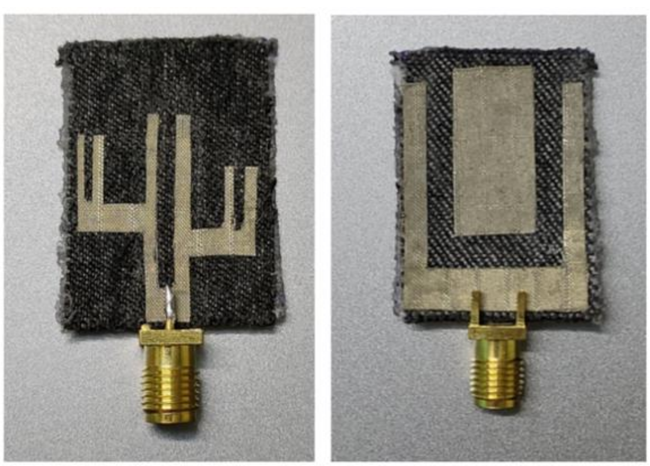
Fig. 3 Proposed antenna model simulated S11 concerning design steps 1, 2, and 3

This particular design operates at regularities of 1.6, 3.4, and 7.5 Ghz at X-Band, WiMAX and Telemetryfrequency bands as demonstrated in Figure 3. The detailed psychological sizes in millimetres are L.1-20, L.2-14, L.3-11, L.4-10, L.5-8 mm, L.6-7, L.7-5, L.8-25, L..9-21, W.1-6, W.2-4, W.3-8, W4-3. The fabricated prototype is illustrated in Figure 4(a).

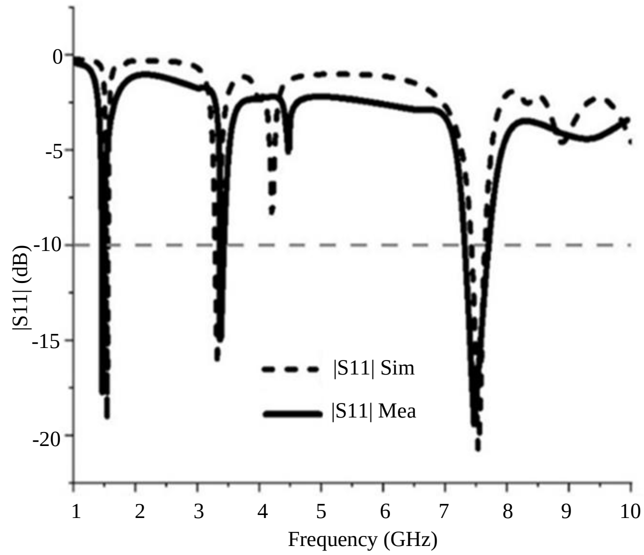
3. Results and Discussion

3.1. S-Parameters

Measurements were conducted for a prototype antenna within an anechoic chamber. An Anritsu-MS2037C network analyzer was commissioned to validate the functioning bands of the textenna. The initial phase of this testing method was measuring |S11|, which signifies the extent of reflected power resulting from an impedance mismatch. The prototype antenna depicted in Figure 4(b) functions at three distinct frequencies concurrently: 1.5, 3.3, 4.2, and 7.5 GHz, spanning the Telemetry, Wimax, n77, and X-bands.



(a)



(b)

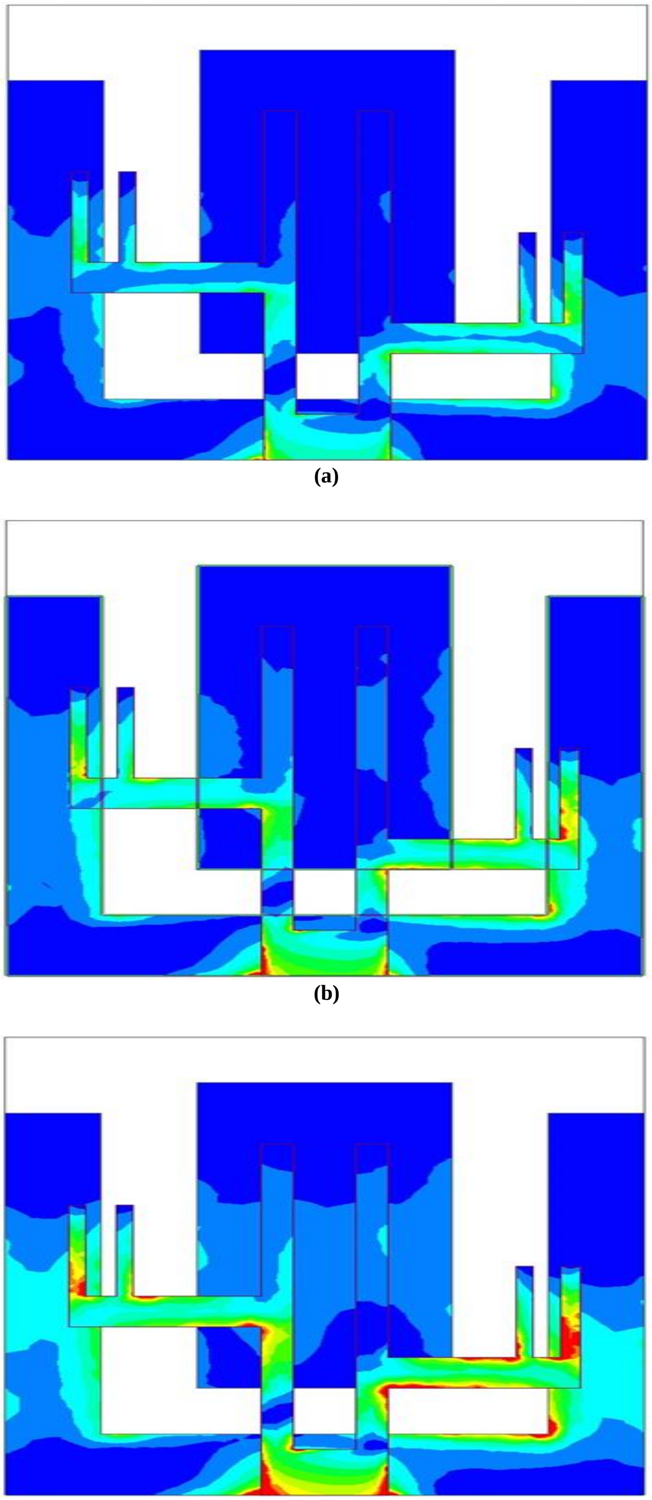
Fig. 4(a) Prototype model, and (b) Modelled and calculated S11 plot.

The empirical observations of the reflection coefficient values correspond with those derived from software simulations. This signifies that the antenna design and optimization were executed accurately, yielding satisfactory performance at the designated frequencies. It is essential to acknowledge that additional testing and validation may be necessary to comprehensively measure the textenna's execution, including the measurement of its gain, effectiveness, and radiation pattern.

3.2. Surface Current Densities

Surface current density is fundamental in the analysis and design of electromagnetic devices like antennas and waveguides. Specifically, this is the induced amount of electric current per unit area on the surface of a conductor under an electromagnetic field. Any performance characteristic of the device, such as radiation efficiency, impedance, and gain, depends on the behavior and the distribution of current densities on the surface. Antenna design typically relies on surface current density, as it determines the electromagnetic waves that will be radiated and affect the antenna's capacity for signal transmission or reception. In the case of materials that are textile substrates or transparent conductors, the surface current density also shows how effective the interaction between the conductive layer and the substrate is. Suitable for optimal radiation and minimum losses, i.e. a real antenna is a high surface current density on a uniform area (this surface current exists up to the electrically small areas created by the conductive layer). In this section, as shown in Figure 5, the surface current densities of multiple designs are investigated through active frequencies to determine their potential for real-world applications. According to the analysis, differences in current distribution were influenced by properties of the conductive material, including conductivity, thickness, and surface uniformity.

Like for example, non-uniform current densities could introduce hotspots or decreased efficiency; as such, there would be an imperative to select materials and optimize designs.



(a)

(b)

(c)

Fig. 5 Propounded antenna's apparent current circulations

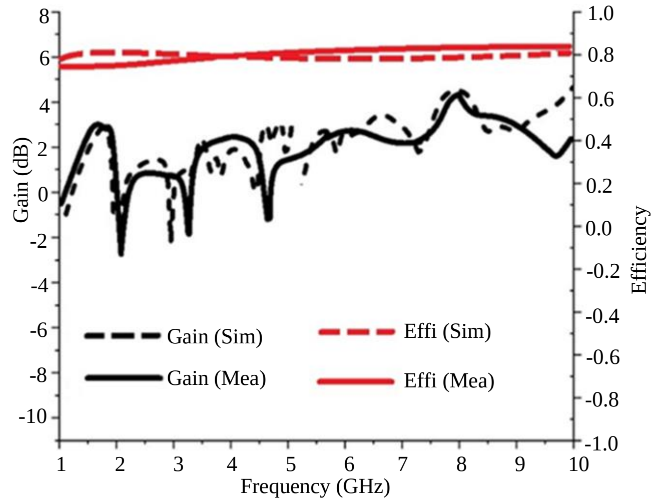


Fig. 6 Modelled and calculated efficiency and gain plot

3.3. Efficiency and Gain

The gain and efficiency of the textenna were assessed in an anechoic chamber and juxtaposed with digital simulations. The findings, shown in Figure 6, demonstrate a top gain of almost 4.9 dB at 7.5 GHz. The antenna's emission proficiency was tested, yielding values of 81%, 82%, and 80% for frequencies of 1.5, 3.3, and 7.5 GHz, respectively.

The results illustrate the suggested textenna has advantageous emission characteristics in the active operating frequencies. Collectively, these findings substantiate the assertion that the advised textenna design is a feasible and efficient selection for claims in Telemetry, Wimax, n77, and X-bands, due to its favorable impedance matching, gain, and radiation efficiency within these frequency ranges. A comparative examination of the suggested antenna with current improvements is presented in Table 1.

4. Conclusion

This research effectively illustrates the development and manufacturing of a textenna utilizing denim as a substrate and conductive textiles for the radiating components. A thorough material investigation revealed denim as the optimal substrate compared to cotton, polyester, and conductive fabric, owing to its enhanced durability, flexibility, and compatibility with conductive materials.

The antenna's distinctive cactus-shaped patch design facilitates effective radiation across many frequencies: 1.5 GHz for telemetry, 3.3 GHz for WiMAX, and 7.5 GHz for X-band applications, underscoring its adaptability for diverse wireless communication systems. The testing findings confirm the efficacy of the denim-based antenna, demonstrating its capacity to sustain excellent performance over the designated frequency ranges while retaining flexibility and wearability. This renders it exceptionally appropriate for various applications, including wearable medical gadgets, wireless communication, and radar systems. The efficacy of this design paves the way for advancements in smart textiles and wearable technology, where comfort, adaptability, and consistent performance are essential. Future research may concentrate on optimizing design for enhanced bandwidth, combining various capabilities, and investigating other fabric substrates to expand the use of textile antennas in new communication technologies.

Table 1. Proposed antennas comparative analysis with some recent literature

S. No.	Substrate	Fabrication	Size	Operating Range	All Textile	Flexible
24	Felt Fabric	SheildIt	47.2 x 31 mm2	2.45 - 3.5 GHz	NO	YES
25	Jean	Copper	45 x 30 mm	2.4 GHz	NO	YES
26	Glass fibre, Cotton	Graphene	50 x 47mm	2–8 GHz	NO	YES
27	Felt fabric	Conductive fabric	42 mm × 75 mm × 1 mm	28 GHz	YES	YES
28	Kevlar	silver-plated copper Elektrisola E-threads	160mm-diameter Archimedean spiral	0.3–3GHz	NO	YES
This Study	Jean	Nylon with E-threads conductive	30 mm×20 mm×1.6 mm	1.5, 3.3, and 7.5 GHz	NO	YES

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