

Design Analysis on Wearable Patch Antenna for Wireless Applications

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Abstract— In today's world, the compactness of wireless systems has made possible the utilization of wearable patch antennas in plenty of programs and is currently one of the quickest developing technologies around the globe. In general, many of the wearable patch antennas use textile material as their substrate. In commercial terms, the available textile materials and their properties has a far larger influence on the functionality of wearable antennas. These antennas are intended to be a component for the clothing which can fulfill various communication applications such as mobile computing, tracking, public safety and navigation. The wearable antennas which use textiles as their substrate often has a lower dielectric constant compared to some others for its efficiency. The latest studies on such antennas have sparked significant interest regarding the usage of wireless body area network (WBAN) applications. This study discusses recent advancements in the area of antennas which can be worn, including their designs, materials employed, and effective results for diverse wireless applications.

Index Terms— Wearable antennas, S11 parameters, VSWR, textile, wireless

I. INTRODUCTION

Communication continues to keep individuals connected in a global community. In typical wearable systems, the major components that take up a lot of space are batteries and antennas. Nonetheless, the size and shape of the wearable computer system are reducing as electronic components have advanced in recent years. As a result, the antennas are now made out of textile materials. Furthermore, antennas embedded into garments utilizing fabric give an option to manufacturing with several rigid substrates (Mohamadzade et al., 2019). Moreover, wearable textile systems are also valuable for tracking, public safety and navigation (N. Singh et al., 2015). Because of the wide range of uses for wearable antennas, it may be viewed as another key stage in the widespread computing concept, in which information is easily available from everywhere.(Dutta, Chaudhury, et al., 2023; Dutta, Gupta, et al., 2023; Shukla et al., 2015)

Wearable textile antennas are microstrip antennas with a textile substrate. The wearable textile antenna is popular and widespread due to traits such as less weight, durability, smaller size, vibration resistance, and shock resistance (Daya Murali et al., 2014)(Watanabe & Iwasaki, 2012). However, this antenna has a limited bandwidth and is susceptible to temperature and humidity. Such disadvantages eventually diminish the gain of an antenna, and therefore its efficiency. The materials utilized in the design framework determine the construction regarding the fabric of wearable antenna, as shown in Fig.1.

As a result, because the substrate's qualities have an immediate effect upon the antenna's performance, good textile substrate selection is crucial to developing an effective antenna(Abbas et al., 2020)(Mandal et al., 2013). In the

future years, the wearable market is expected to increase at an exponential rate. The market is predicted to develop at a rate of more than 20% per year in the following five years, reaching more than 40 billion EUR by 2028. Wearable shipments are expected to reach 222.3 million per year by 2021, up from 113.2 million in 2017 and a total market value of \$70 billion in 2019. Furthermore, the COVID-19 epidemic had a significant impact on the evolution of wearable devices, which was pushed by the adoption of various crowd-sensing and contact-tracing platforms. Wearables are likely to proliferate steadily over the next few decades.(Ometov et al., 2021)

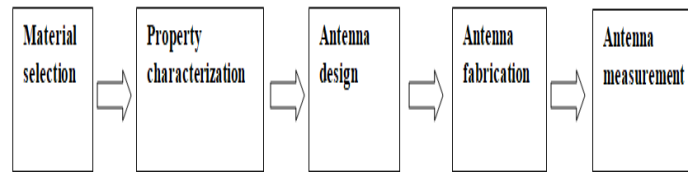


Fig.1 A typical approach for wearable and flexible antennas

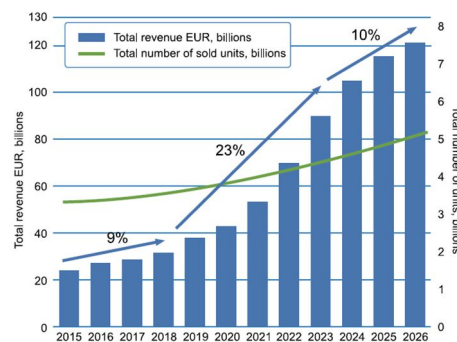


Fig.2 A wearable technology growth prediction (Ometov et al., 2021)

Wireless body area network (WBAN) technology possesses a chance to deliver a rare chance for widespread fitness monitoring in operating rooms, ambulances, emergency rooms, homes, clinics etc, thus allowing the prevention of several diseases with the help of early recognition and doctors to offer people with effective suggestions on how to enhance their health (Jayabharathy & Shanmuganantham, 2019; Patel & Wang, 2010). Over the past decade, in a range of fields, notably military, medical and entertainment, there currently are signs of growing concern regarding the dependability of WBAN frameworks, particularly wearable technology. The capacity to transmit wirelessly to or from the body utilizing amenable and wearable antennas is an important component of this wearable technology (Le & Yun, 2020; Yan & Vandenbosch, 2016). As a result, such antennas acts as an important part in on-body wireless communications also are receiving a lot of interest for research. Because these antennas work in near contact to a person's body, the load effect caused by the lossy characteristic of human tissues, along with their higher conductivity and dielectric constants, causes the creation of an extremely efficient radiation antenna difficult. This issue is complicated further by the need and demand for these antennas to have qualities that are light in weight, maintenance-free, inexpensive in cost, and easy to install.(Chen et al., 2022) The patch antenna is a significant research topic for wearable antennas for WBAN applications because to its comparatively strong directivity as a consequence of the broad level of the ground utilized in its construction. Aside from directivity, MPAs possess numerous significant benefits for on-ground wearables, the most important of which are the low price, ease in manufacturing, and the relative isolation attained between the element that radiates and the body. The ground plane causes a substantial decrease in energy accepted by the element that radiates and the body. (Ramesh Garg, 2001). Patch antennas, on the other hand, have a poor bandwidth and could require to be rather big if they are to prove resistant against body disturbance (Ma et al., n.d.).

As wearable antennas have evolved, the majority of antenna research has been around flexible materials. The qualities of the components utilized can have an impact on the antenna's behaviour. The thickness of substrate and its permittivity, for example, affect the frequency range and effectiveness of a planar microstrip antenna. Prior to them being employed in wearable antennas, textiles need to be characterized (Ashyap et al., 2018; Potey & Tuckley, 2020). Electrotexiles comprise of conducting fabrics created by weaving conductive metals or polymeric threads into typical textiles. These materials are suitable for wearable applications because they are wearable, durable, and flexible. The conducting fabric is designed to have a low and continuous electrical resistance in order

to minimize losses. Since it's necessary for the antenna to remain folded over the fabric, its components also have to be flexible. Substrate selection is critical for a fabric or wearable antenna to prove durable for a certain applications. Textiles, in general, possess a low dielectric constant, that reduces surface wave losses hence enhancing the impedance bandwidth of the antenna (Ferreira et al., 2017; Gupta et al., 2010).

Metamaterials that consist of high impedance surfaces (HIS), artificial magnetic conductor (AMC) surfaces and electromagnetic band-gap (EBG) structures, nonetheless, have come forward as plausible proposals for wearable antennas (Najumunnisa et al., 2022; Turpin et al., 2014). Metamaterials are man-made materials with qualities that are not present in nature. They are made up of multiple discrete parts made of conventional small elements like polymers and metals, however the components are frequently arranged in recurrent designs (George et al., 2013). In broad terms, metamaterials have a number of enticing qualities. They have the potential to improve the total compatibility while decreasing radiation from small antennas, as well as lower the specific absorption rate (SAR) within the skull. This issue can be made use of to minimize the accepted power in the body's tissues.(Hwang & Chen, 2006).

The paper is further organized as follows: Section II, discusses and presents the characteristics of the textiles used as substrates for the antenna design. Section III focuses on the different patch designs used by researchers in the past for the efficient performance of wearable antennas. Finally in Section IV, the results obtained by the previous studies are discussed along with the conclusion of this paper.

II. PROPERTIES OF SUBSTRATE TEXTILE MATERIALS

Textiles frequently have dielectric value (ϵ_r) values between 1 and 2 because they are extremely permeable substances with a relative permittivity that's near one. Surface wave losses induced by guided wave propagation via substrates are reduced by a low dielectric constant. Reducing the dielectric value raises the spatial waves, which enhances impedance bandwidth of the antenna. Furthermore, decreasing the substrate permittivity raises the resonance frequency of the antenna, allowing for an efficient and high-gain antenna (Atanasova & Atanasov, 2020; V. K. Singh et al., 2015). "Thickness" is another important feature in textiles(Di Natale & Di Giampaolo, 2020). The degree of thickness of an antenna's dielectric material is critical in the construction of wearable antennas. To maximize the bandwidth of a planar antenna with fixed relative permittivity, the thickness of the substrate is able to be raised. As a result, it can obtain greater profits Furthermore, the width of the material that acts as dielectric must be determined (Potey & Tuckley, 2018; B. Roy et al., 2013). An antenna's loss tangent ($\tan(\delta)$) has a significant impact upon its frequency response and gain. The gain of an antenna and the bandwidth of a MPA both decrease as the tangent loss increases. In general, a rise in loss tangent lowers the operational efficiency of a microstrip antenna (J.C Wang, 2016; P. Puttaswamy, 2014).

In Paper (Kumar et al., n.d.) , the researchers describe the simulation and the design of a wearable antenna employing a flexible textile substrate, as well as the evaluation of several antenna performance factors. This research aims to demonstrate a miniature UWB antenna layout with a general antenna size of 20mm x 22mm x 1.07mm. The planned dual-band antenna's resonance frequencies are 4.450 and 8.750 GHz, with a large fractional bandwidth of 103.50%within the ultra-wide frequency band. The microstrip patch textile antenna described here is small, durable, and flexible, making it an excellent pick for use as a on-body antenna for communication for WBAN applications and wireless health tracking systems. The textile substrate used in this study is “Jeans” having a dielectric constant of 1.7. Figure 3 depicts the proposed UWB antenna design.

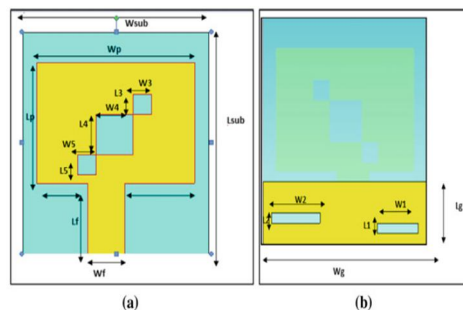


Fig.3 Antenna Design proposed. a) Slotted Patch antenna, b) Partial Ground Structure(Kumar et al., n.d.)

Another study (Wang & Li, 2018), made use of the textile “Denim” as their substrate. The antenna designed was a wearable dual band antenna within ISM band at 2.450GHz and 5.80GHz. When Denim was used as a substrate

to design the antenna it was found to have a dielectric constant of 1.54 and a width of 0.05mm. The dimensions of the antenna taken were 46x16 mm. Fig.4 and Fig.5 below shows the layout of the proposed wearable antenna on the substrate.

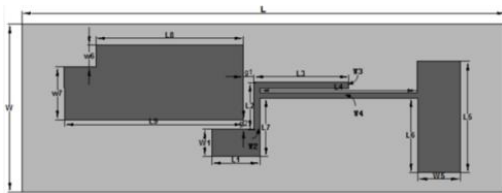


Fig.4 Layout of dual band proposed textile antenna
(Wang & Li, 2018)

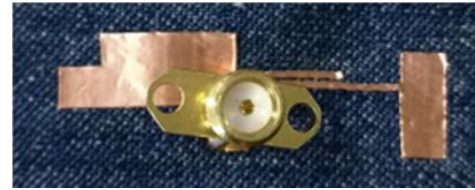


Fig.5 Fabricated antenna on denim (Wang & Li, 2018)

Another paper in 2018 (S.-H. Li & Li, 2018), experimented on the same ISM range and used “Denim” as their substrate but with a thickness of 25mm and the antenna having dimensions of 42x13 mm for wearable device applications. Fig.6 shows the fabricated design of the antenna on denim as its substrate and Fig.7 displays the model of a wearable antenna on a human body.

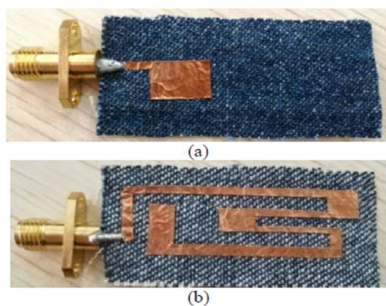


Fig.6a Top and b) Back view of the suggested antenna
(S.-H. Li & Li, 2018)

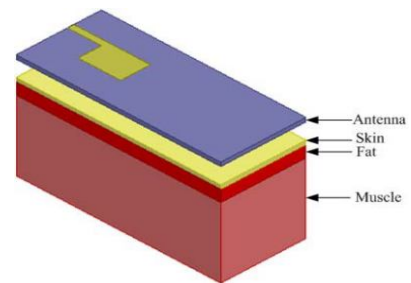


Fig.7 Model of a wearable antenna on a human body
(S.-H. Li & Li, 2018)

Another study (Amit et al., 2019) presents us with the comparison of 3 textile substrates named - Jeans, flannel and cotton each having dielectric constants of 1.7 and thickness 1mm. The proposed antenna was designed with a dimension of 33x35 mm and at the frequency band of 3-10 GHz and 4-9 GHz. The antenna that is suggested is intended for use in health tracking applications. Fig.8 shows the UWB antenna, and it being placed on a human body phantom.

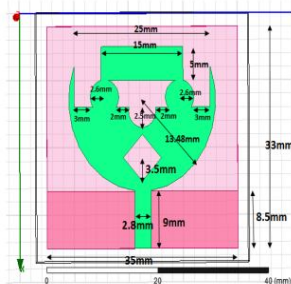


Fig.8 a) Proposed antenna.
(Amit et al., 2019)

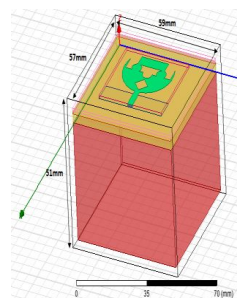


Fig.8 b) Proposed antenna on body phantom
(Amit et al., 2019)

A recent study (Chen et al., 2023), shows that for wireless body area networks (WBAN), a miniaturized textile microstrip antenna is proposed. The UWB antenna has a denim substrate to minimize surface wave losses. The monopole antenna, which is made up of a revised circular radiation patch and an off-centered defective ground construction, increases the impedance BW and enhances radiation distribution in a tiny 20x30x1.4 mm³ antenna. The frequency boundary impedance BW was measured to be 110% (2.850-9.810 GHz). At 6 GHz, the highest gain was calculated to be 3.280 dBi based on the measured values. The size of the antenna had decreased by 62.50% in contrast to standard wearable antennas of reduced sizes (R. Li et al., 2022). The textile antenna is made from a

substrate named - "Denim" having width of 1.0mm. The denim fabric is distinguished by its ease of incorporation into human clothes. Due to a technical flaw, copper was unable to be printed upon denim fabric. The copper has been encased on a flexible board made up of FPC. Given a width of 1.0 mm, FPC exhibits a loss tangent = 0.00280 and a dielectric constant = 3.10.

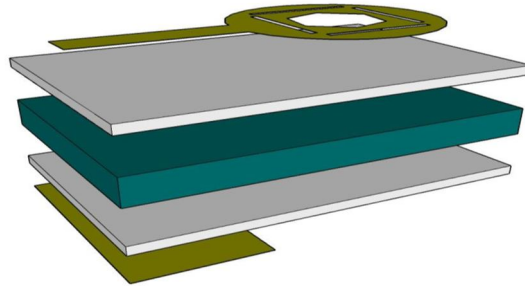


Fig.9 Layers of the wearable antenna designed (Chen et al., 2023)

The Table 1 below compares all the characteristics of the textile substrates used and dimensions of proposed antennas in the studies done in the past few years.

TABLE I COMPARISON OF SUBSTRATE PROPERTIES

Ref.	Substrate	Freq. Band (GHz)	ϵ_r	h (mm)	Application
(Kumar et al., n.d.)	Jeans	3.1-10.6	1.7	1	UWB Devices
(Wang & Li, 2018)	Denim	2.45 & 5.8	1.54	0.05	ISM & Wearable
(S.-H. Li & Li, 2018)	Denim	2.45 & 5.8	1.54	25	Wearable devices
(Amit et al., 2019)	Flannel	4-9 3-10	1.7	1	Monitoring of Health
	Cotton				
	Jeans				
(Chen et al., 2023)	Denim	2.850-9.810	1.6	1	Wearable & WBAN

In the above Table.1, It compares all the textile substrates along with their dielectric constant and width used in the previous literature studies and their applications. In a few studies, Denim has been selected as their substrate but the frequency band ranges are different for each such as 2.45-5.8 GHz, 2.85-9.8 GHz. Similarly, studies have also used Jeans having a dielectric of 1.7 with frequency bands being between 3.1-10.6 GHz.

III. WEARABLE PATCH ANTENNA DESIGN

In this section, the analysis of several patch antennas has been discussed which presents us a various different result. Each microstrip patch antenna can have a different dimension and slots etched into it to have the final parameters to be suitable and compatible to the applications it is intended to. By alternating through these shapes and substrates, results such as gain, bandwidth, field radiation and several other parameters can be enhanced or optimized.

Two different substrates were employed in this study (Mohan & Suriyakala, 2017) to present an analysis on the UWB antenna output attributes in accordance with the patch antenna having a rectangular structure. UWB antennas that are small in size for two substrates were developed in the proposed study, with a focus on inexpensive, fire-proof FR4 and denim substrates. Because these antenna configurations satisfied the UWB antenna specifications, it became apparent how the FR4-based antenna attained a reflection coefficient of (3.80-10.90) GHz, whereas with an omnidirectional radiation pattern, a return loss of (2.60-9.80) GHz was exhibited in a structure made of the material -"Jeans". The antenna's structure is produced with the help of the FR-4 substrate having a dielectric constant of 4.40 with a substrate height of 1.60mm. The "Jeans" fabric has a dielectric constant of 1.670 and a width of 1mm. A 50.0-ohm microstrip line powers the radiator. In the shape of a staircase, two slots were inserted on each sides of the intended patch antenna. This is introduced to improve Bandwidth optimization. Figure 10

depicts an improved patch antenna that includes two slits. To increase the performance attributes of the proposed antenna, a notch is included.

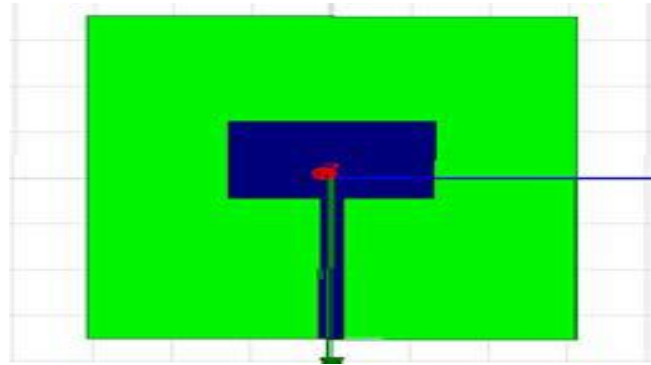


Fig.10 Rectangle Patch Antenna (Mohan & Suriyakala, 2017)

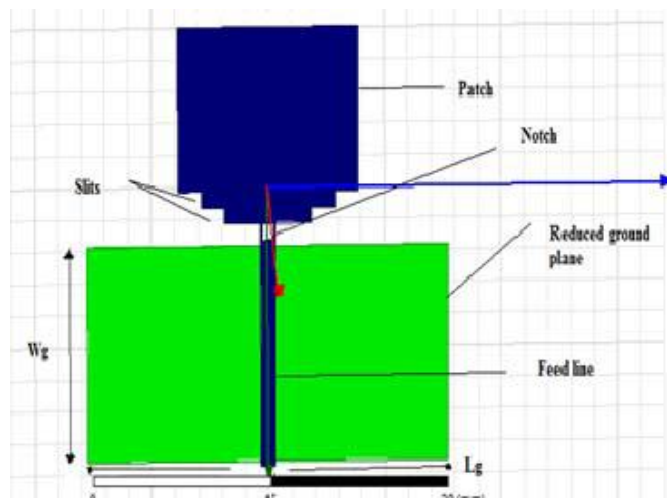


Fig 11 Proposed antenna after insertion of slits and Notches (Mohan & Suriyakala, 2017)

The notch is stated as altering the capacitance level between the patch and decreased ground plane to regulate the impedance bandwidth and return loss. Figure 11 depicts a patch antenna with a notch introduced. Another study (Turkmen & Yalduz, 2018), displays an antenna that functions at frequencies ranging from 2.20-17.0GHz and within the UWB frequency range. Figure 10 depicts the layout of the planned antenna's front, rear, and bottom side perspectives, as well as detailed dimensions in millimeters. Jeans textile material with a dielectric constant (ϵ_r) of 1.680, tangent loss ($\tan \delta$) of 0.01 and thickness of 1mm was chosen as a substrate. Copper having a thickness of 0.02 mm was utilized for the conducting components of the antenna (the radiator patch and ground plane). Figure 11a depicts the radiator patch as well as feedline structure from an antenna's front perspective. A microstrip feedline having a size of $W_f \times L_f$ (3.50 mm x 24.250 mm) that has a fifty ohm impedance and SMA port feeds the antenna. The geometric structure of the radiator patch comprises square and circular patches.

TABLE II MPA PARAMETERS

Description	Unit (mm)	Description	Unit (in mm)
Substrate width (W_s)	45.0	Feed width (W_f)	3.50
Feed length (L_f)	24.0	Ground length (L_g)	24.250
Thickness (h)	1.0	Ground Width (W_g)	45.0
Antenna Width (W)	22.0	Radius (r)	13.0
Antenna Length (L)	22.0	W_{gs}	3.60
Substrate Length (L_s)	60.0	L_{gs}	3.250

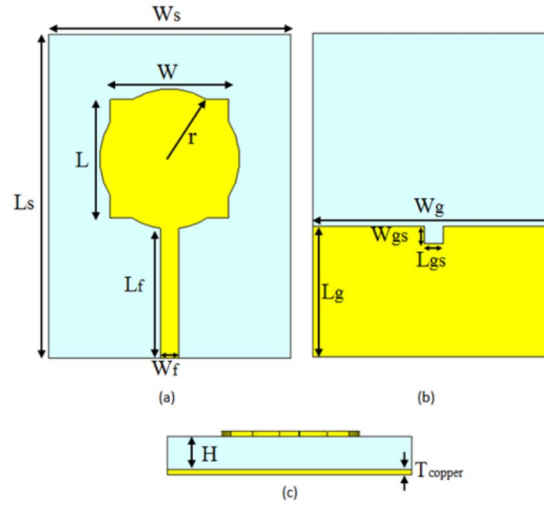


Fig.12 Designed Antenna a) Front b) Back c) Side view (Turkmen & Yalduz, 2018)

Similarly, (Yin et al., 2019) introduces a proposed antenna having an overall dimension of 40x32x1 mm and a simple structure. Figure 13 depicts the suggested monopole wearable antenna construction. The antenna's basic structure and planar characteristics make it easier to adapt to the human body. A Coplanar Waveguide (CPW) feeds the antenna, and the antenna's reception unit resembles a semi-circular metal patch having radius R_1 . Printing over the uppermost layer that covers the dielectric substrate produces both the receiving unit as well as the radiating patch, allowing for a single-layered production technique. Table 3 and Figure 13 presents the parameters of the MPA.

TABLE III MPA PARAMETERS

Description	W	W_1	L	L_1	L_2	L_3
Unit (mm)	40.0	04.90	32.0	06.60	0.50	1.50
Description	R_1	R_2	S	T	g	d_1
Unit (mm)	10.40	18.40	01.20	07.50	0.50	1.00

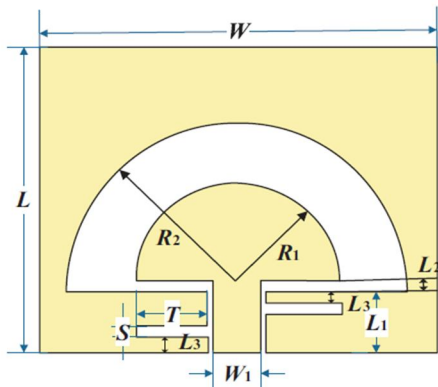


Fig.13 Dimension structure of antenna proposed

(Yin et al., 2019)

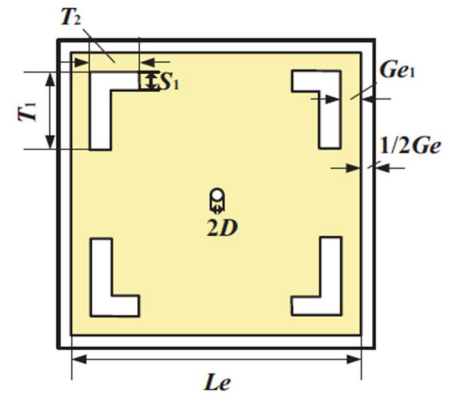


Fig.14 AMC Structure proposed (Yin et al., 2019)

To span the 2.450GHz ISM band, the antenna's impedance bandwidth is improved via merging of the circular and asymmetric slots. The antenna is composed of flexible polyimide material ($r = 3.50$, $\tan = 0.002$). To optimize antenna performance, ANSYS HFSS adjusts the antenna structure using the finite element method. Table 4 and Figure 14 displays the AMC design parameters.

TABLE IV AMC PARAMETERS

Parameter	Ge	Ge1	Le	T1	T2	D	S1
Unit	1.0	2.0	28.90	8.0	5.0	1	2.0

Figure 15 shows the complete and proposed design of the wearable antenna with the AMC at the back of the MPA.

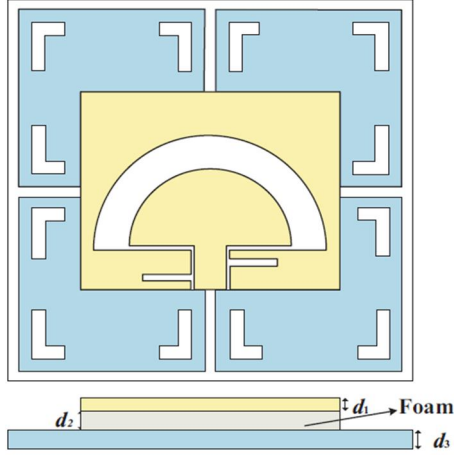


Fig.15 Final proposed antenna design

(Yin et al., 2019)

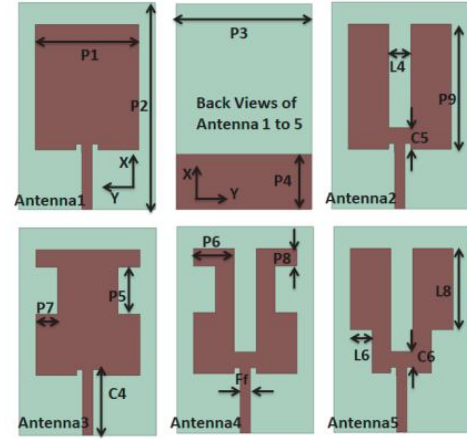


Fig.16 Proposed Antenna designs steps (A. Roy et al., 2023)

A recent study (A. Roy et al., 2023), demonstrates a wearable ultra-wideband antenna with a tiny notch band based on a jeans substrate. First, on a jeans substrate, a rectangle type antenna element is designed to function over a wide frequency range and supports mobile connections at 4.40-4.990GHz and exhibits notch functionality for WLAN channels.(Grandhi Venkata & Kalva, 2022). Antenna 1 is the designation of the antenna. Figure 4 depicts top and rear perspectives of the antenna. The analysis of this initial antenna reveals a band range of 2.70-4.630 GHz, which isn't considered to be appropriate. As a result, it has been modified to maintain the same ground plane. A slit in a rectangular shape is etched across the centre of the patch to expose a large portion of one side. Antenna 2 is the name given to the improved antenna. Figure 4 depicts the antenna's front perspective. According to the S11 (dB) curve, the frequency band above 2.650-4.760 GHz is likewise bad. As illustrated in the diagram, the third antenna is created by changing Antenna 1. It is discovered by severing two rectangular portions from the patch's upper right and left edges. It runs at frequencies ranging from 2.690 - 5.80 GHz. It even depicts the lack of an adequate band deployment. As a result, Antenna 4 is created, which is a hybrid of Antennas 2 and 3. Antenna 5 was built by redesigning Antenna 2. Both lower sides have two outside parts removed.

IV. PREVIOUS LITERATURE RESULTS

The results of the tests are shown in this section, previously discussed studies will be compared to display how, just by changing the substrate material or having a different design, the results of the antenna could vary greatly. By comparing the previous studies, it will help us gain insight on ways to increase the design's accuracy and efficiency of patch antennas for wearable applications in the future.

In the Table above, the various different results for the antenna parameters which has been designed previously have been compared where it presents that in (Kumar et al., n.d.; A. Roy et al., 2023; Turkmen & Yalduz, 2018), jeans have been used as the textile substrate and have shown return loss of -44.25dB at 8.75 GHz, -33dB at 5GHz and -35dB at 9.80GHz respectively. It is seen that as the resonating frequency increased the gain also increased to 4.81 dB with a bandwidth of 4.4-4.99 and 5.15-5.85GHz. In (Chen et al., 2023; S.-H. Li & Li, 2018; Wang & Li, 2018), Denim has been selected and has achieved return loss of -27dB, -32dB, -32.5dB respectively which is less than that of jeans but have a high resonating frequency. The bandwidth ranges are within the ISM bands. In (Amit et al., 2019; Mohan & Suriyakala, 2017; Yin et al., 2019), the substrates selected are Flannel, FR-4 and Polyamide

respectively having return loss of -22dB,-30dB and -13.62 dB , within which polyamide shows the highest gain of 7.47 dB at 2.42-2.46 GHz of bandwidth.

TABLE V COMPARISON OF PREVIOUS STUDY RESULTS

Ref.	Substrate	Return Loss (in dB)	Gain (in dB)	BW (GHz)
(Kumar et al., n.d.)	Jeans	-44.25 (8.75GHz)	3.01	3.4-10.7
(Wang & Li, 2018)	Denim	-27.0 (2.75GHz)	-	2.4-2.48 5.7-5.85
(S.-H. Li & Li, 2018)	Denim	-32.0	6.34	2.42-2.48
		-35.0	4.7	5.72-5.85
(Amit et al., 2019)	Flannel	22.0 (at 5GHz)	-	4.0-9.0
	Cotton			
	Jeans			
(Chen et al., 2023)	Denim	-32.5 (8.20GHz)	3.280	2.85-9.81
(Mohan & Suriyakala, 2017)	FR-4	-30.0 (4.45GHz)	4.0	3.8-10.9
(Turkmen & Yalduz, 2018)	Jeans	-33.0 (5GHz)	-	3.4-10.7
(Yin et al., 2019)	Polyamide	-13.62 (2.45GHz)	7.470	2.42-2.46
(Kumar et al., n.d.; A. Roy et al., 2023; Turkmen & Yalduz, 2018)	Jeans	-35 (9.80GHz)	4.81	4.4-4.99 5.15-5.85

V. CONCLUSION

This paper presents an organized review on wearable antenna and the textile materials and designs used to design them. It has been discusses as how this technology has been used by researchers in the previous studies for various applications using various materials. This paper also discusses about the various approaches taken for designing the wearable antennas and how they have attained efficient results. These results can further be improved by choosing textile substrates having lower dielectric constants and combine other technologies/design such as the (Defected Ground Structure) technology to enhance the gain and bandwidth. Various different shape of slots could be etched into the patch along with the use of various different available feeding techniques.

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