Design and development of an H-shaped wearable antenna for medical and wireless applications using textile materials

DOI: 10.35530/IT.077.04.202543

GURUPRASATH RENGARAJAN NAGARAJAN RAMALINGAM

ABSTRACT – REZUMAT

Design and development of an H-shaped wearable antenna for medical and wireless applications using textile materials

The main goal of this research is to design, develop, and fabricate a small H-stub antenna suitable for contemporary wireless communication systems. The antenna's 46 mm × 30 mm × 1.6 mm dimensions make it perfect for uses where weight and size are crucial limitations. By functioning well at 2.5 GHz to 12 GHz frequencies that correspond to important bands in modern wireless technologies, the suggested antenna exhibits triple-mode capability. The antenna employs innovative design techniques, including a parasitic strip and a reconfigurable ground plane slot, to accomplish efficient energy distribution across the antenna, incorporating H-shaped stubs that extend from the ground. Using a thick Teflon, yarns, and FR4 substrate ensures that the antenna meets the needs of modern wireless communication systems and also boosts bandwidth. Despite its small size, the antenna's adaptability comes from its ability to retain high efficiency and dependability over various frequency bands. Performance tests verify that the antenna can provide broad bandwidth, high radiation efficiency, and steady operation, all of which are in line with the changing needs of next-generation wireless communication. As Internet of Things (IoT) applications proliferate in today's communication networks, there is an increasing need for tiny antennas. IoT applications widely use microstrip patch antennas due to their compatibility. Because it is designed to function at a frequency of 2.5 GHz to 12 GHz, it may be used for IoT applications. It is designed to be used as an integrated antenna in an IoT device and is composed of a variety of H shapes. The main findings of this study show that, in comparison to a conventional antenna, the optimised shaped antenna enhanced bandwidth, gain, and return loss.

Keywords: *H-shaped, textile, gain, return loss, radiation pattern, VSWR*

Proiectarea și dezvoltarea unei antene purtabile în formă de H pentru aplicații medicale și wireless folosind materiale textile

Scopul principal al acestui studiu este proiectarea, dezvoltarea și fabricarea unei antene mici, în formă de H, potrivite pentru sistemele contemporane de comunicații wireless. Dimensiunile antenei de 46 mm × 30 mm × 1,6 mm o fac perfectă pentru utilizări în care greutatea și dimensiunea sunt limitări cruciale. Funcționând bine la frecvențe cuprinse între 2,5 GHz și 12 GHz, care corespund benzilor importante din tehnologiile wireless moderne, antena sugerată prezintă capacitate triplă de funcționare. Antena utilizează tehnici inovatoare de proiectare, inclusiv o bandă conductoare și un slot reconfigurabil în planul de masă, pentru a realiza o distribuție eficientă a energiei pe întreaga suprafață a antenei, încorporând ramificații în formă de H care se extind de la planul de masă. Utilizarea unui substrat gros de Teflon, fire și FR4 asigură faptul că antena îndeplinește cerințele sistemelor moderne de comunicații wireless și, de asemenea, sporește lățimea de bandă. În ciuda dimensiunilor sale mici, adaptabilitatea antenei provine din capacitatea sa de a menține o eficiență și o fiabilitate ridicate pe diverse benzi de frecvență. Testele de performanță confirmă faptul că antena poate oferi o lățime de bandă largă, o eficiență ridicată a radiațiilor și o funcționare constantă, toate acestea fiind în conformitate cu nevoile în continuă schimbare ale comunicațiilor wireless de ultimă generație. Pe măsură ce aplicațiile Internet of Things (IoT) proliferează în rețelele de comunicații actuale, există o nevoie tot mai mare de antene minuscule. Aplicațiile IoT utilizează pe scară largă antene microstrip de tip patch datorită compatibilității lor. Deoarece este proiectată să funcționeze la o frecvență cuprinsă între 2,5 GHz și 12 GHz, aceasta poate fi utilizată în aplicații IoT. Este concepută pentru a fi utilizată ca antenă integrată într-un dispozitiv IoT și este compusă dintr-o varietate de forme de tip H. Principalele concluzii ale acestui studiu arată că, în comparație cu o antenă convențională, antena cu formă optimizată a îmbunătățit lățimea de bandă, câștigul și pierderea de retur.

Cuvinte-cheie*: formă de H, textil, câștig, pierdere de retur, diagramă de radiație, VSWR*

INTRODUCTION

In order to provide wearable sensors more flexibility, flexible substrates such as polymers, plastics, paper, textiles, and fabrics are now required. The basic aim is to examine the bending, flexibility, and tendency to accept deformation of polymer materials. This research starts by providing a chronological summary of the flexible materials that have been used during the last several decades. To enable new applications via wireless connection, it is projected that the IoT will eventually support a wide variety of technologies. Materials need to be pliable and bendable for wearable IoTs to work. The mechanical, electrical, and physical properties of several popular polymer substrates are examined in this work. It also examines the effects of bending on the radiation performance of polymer-substrate antenna designs. Rogers RT/Duroid, liquid crystal polymer (LCP), polyimides (PI), polyethylene terephthalate (PET), polydimethylsiloxane (PDMS), and polytetrafluoroethylene (PTFE) are a few of the flexible materials that have been examined. These materials are used in the antennas of the IoTs. The S-parameters, resonant frequency deviation, and impedance mismatch with the feedline of flexible polymer substrate microstrip antennas are all closely examined in this work. These flexible polymer substrates may be used in general IoT applications and future wearable electronics. Flexible electronics are becoming essential for biological applications with complex curvilinear geometries and applications requiring flexible displays [1–5].

In response, researchers have tried to increase the flexibility of electrical devices by experimenting with a range of materials as substrates, such as polymers, plastic, paper, textiles, and fabrics. The capacity of various materials to bend, twist, and/or crumple is determined by their individual qualities. Because of their bendability and flexibility, these materials may be used in designs for future smart electronics systems as well as IoT applications. The bending properties of various materials are crucial for several electrical and communication applications. Examples of these include developments in flexible antennas, smart tags, and wearable technology [6–10].

In actuality, flexible displays and antenna systems are now widely used in business, healthcare, the military, and personal communication. These versatile devices are frequently used in aviation, RFID tagging applications, and health monitoring systems. Flexible circuits, such as thin sheets of carbon nanotubes on plastic substrates, provide a lightweight and conformal architecture. These flexible integrated circuits have a wide range of potential uses in embedded systems and other electronics domains, and several varieties of flexible RFID tags are currently widely used. Active-matrix displays, stretchy power sources, and stretchy organic solar cells, which may double as biological sensors, are recent examples of flexible electronics. Other novel applications recently introduced to the market include skin-like sensing robotic systems, electronic paper, flexible displays and touch screens [11–15]. Smart clothes and fashion are becoming increasingly popular. The past ten years have seen a rise in the popularity of smart attire. The electronic fibres that make up smart shirts and jackets enable the user to answer four out of twenty-five calls and listen to music and entertainment shows. With their smart clothing, the user can take pictures or videos using the built-in camera. Smart watches, smart jewellery, smart shoes, and wristbands are a few examples of wearable technology that are becoming more and more popular.

Since flexible communication systems are in great demand and wearable sensors and gadgets are evolving at an exponential pace, several new problems have arisen as a result of the exceptional performance requirements. The frequent example of wearable electronics with flexible antennas serves as a pertinent illustration for this work. The flexible antennas must thus be tiny, light, robust, heat and moisture-resistant, and above all extremely flexible without compromising the radiating properties. As a result, the primary focus of our study is on the seamless integrity and flexibility of flexible antennas. Conventional antennas are usually built by manufacturers using conductive wires or rigid substrates engraved with metal patterns. Stretching, folding, or twisting these antennas results in permanent deformation, if not shattered. This implies that they are not suitable for applications requiring a high degree of flexibility. Flexible antennas, due to their great degree of flexibility, have directly addressed this problem. Other advantages include their ease of integration with other microwave components, light weight, low energy consumption, ease of manufacturing, affordability, and widespread availability as substrate films. The concept of flexible wearable antennas emerged from the steady evolution of the Flexible Electronic System (FES). An increasing number of physical objects, wirelessly linked via antennas, form the IoT. The IoT affects transportation, the health and agriculture industries, industrial automation, and above all, emergency responses to natural disasters [16–20].

The IoT enables information sharing and decision-making based on objects connected to algorithms. IoT devices are now improving people's lives and expanding the scope of business uses. For instance, smart homes enable homeowners to switch on and off devices such as TVs, alarm systems, monitoring systems, and heating systems, as well as remotely and wirelessly control the temperature of particular rooms. Passive antennas, which are available in a range of materials, are used in almost all mobile electronic devices nowadays. Flexible antennas are becoming more and more popular because they provide a number of advantages over traditional rigid antennas. Their ability to combine conventionally sturdy materials with lightweight, thin, and low-profile designs is what makes them appealing. Standard antennas are 50–70% bigger and heavier than flexible antennas, rendering them less appropriate for small and lightweight applications. Flexible antennas provide a more efficient solution for contemporary wireless systems, particularly in portable and wearable devices where dimensions, weight, and flexibility are essential design factors. The size may be further reduced to around 90% of its initial size for a certain frequency by using a flexible substrate, such as a polymer, in place of hard printed boards. Flexible antennas are not only very lightweight and robust, but they can also tolerate high mechanical loads. Conductive materials can transfer electricity with little loss or emit energy in the form of electromagnetic (EM) waves. When the antenna has to be distorted from its typical straight posture, the materials must be able to withstand material deterioration and have bending capabilities, meaning they must be able to bend, crumple, and stretch without impairing the antenna's functionality [21–25].

The material utilised for the conductors must be able to withstand repeated pressure, and low resistance and high conductivity are still crucial components of these conductors' electrical characteristic qualities required for flexible wearable technology, such as RFID tags and flexible antennas, and for flexible electronic systems in general. The designed antenna with the support of conductive materials needs to be highly elastic, deformable, and conductive in addition to having a high bending, adhesion, and textile integration capability. They should simultaneously have minimal moisture absorption, resistance, and moisture content. Out of 50 experimental works that are studied on flexible antennas, we chose 20 for qualitative analysis in order to provide the reader with a comprehensive picture of the whole area for the range of various frequencies and applications. We carry out these investigations in a variety of settings and use a range of manufacturing and experimental methods.

However, considering the limitations, we grouped several experiments with almost equivalent physical characteristics and similar frequency ranges [26–30]. We also examine how previous studies compare the resonant frequency variations, gain, and reflection coefficients of antennas fabricated from flexible polymer substrates. Polymers from previous articles, such as PI, PET, PTFE, PDMS, and LCP, with certain modifications, are examined in this table. It also analyses the radiation characteristics for a specific application and illustrates the effects of bending on return loss, resonant frequency, and antenna gain. PI is the most often used of these five polymers as a flexible antenna substrate. Commercially, Kapton is a variant of PI. Because of its exceptional thermal stability and great electrical, chemical, and physical balance, we chose polyimide Kapton as the antenna's substrate. They discovered that there was an 80 MHz shift in the resonant frequency, or 0.36% of the 2.45 GHz resonant frequency. When compared to the flat example, the resonant frequency changes by the greatest 0.4% at the trial resonance frequency, which is less than 50 MHz.

When the antenna is bent to a smaller size of 9 mm, with silver nanoparticles serving as the conductor and Kapton (200 HN) as the base, it shifts frequencies by 1.1 GHz at maximum. The increase in directivity at 8.8 GHz results in a 3 dB increase in return loss.

Similarly, various flexible antennas employ Kapton (500 HN), which is roughly 130 mm thicker than Kapton (200 HN) but has a lower resistivity and a larger dissipation factor (209). A compact Kapton-based inkjet-printed multiband flexible antenna with convex and concave bending at a maximum level of 59 mm. The antenna operates in the following four wide frequency bands: 1.2 GHz, 2.0 GHz, 2.6 GHz and 3.4 GHz. Convex bending has no noticeable frequency shift, but concave bending exhibits a 3% frequency shift toward the lower end across all frequency bands. At higher centre frequencies, the gain rises with convex bending of up to 59 mm because of the increase in directivity that results from the antenna experiencing this greater curvature [31–33]. In Kapton 500 HN, a tiny, flexible antenna for WLAN and upper UWB applications, is coated with parylene-C to increase its flexibility without significantly altering its gain and return losses. Wearable flexible antennas have the potential to crumple, which might reduce their radiation effectiveness. Kapton 500 HN is an efficient polymer that can withstand high crumpling levels of up to 5.5 mm, according to this research.

DESIGN OF H-SHAPED ANTENNA

The performance of the suggested antenna at a high operating frequency of 2.5 to 12 GHz with a maximum gain of 8.2 dBi is the main focus of the research. Teflon and yarns have been used extensively in applications that need substrate flexibility and transparency. The antenna is bent; the frequency shift is minimal for flexible W-BAN antennas. The completely adjustable antennas with flexible antennas were created to function at 5.5 GHz and 10.5 GHz, proving.

The reflections are the same for bends of 60 degrees or greater. This extensive assessment emphasises a thorough comparative examination of both chemical and thermal characteristics of the flexible materials. The substrates of flexible antennas in the past provide a useful reference to better match their compatibility with certain wearable applications when choosing the right substrate for flexible antennas. One crucial feature of IoTs is their adaptability, which calls for adaptable antennas for communication. The article includes an overview of the bending process and an examination of the characteristics of several materials.

The article gives a summary of the bending process and presents the materials. This works well for adaptable IoT applications. Flexible antennas have the following properties: directivity, gain, and return losses. The performance of the suggested antenna is greatly impacted by degradation. Here, the behaviour of these flexible antennas with various substrates under various folding circumstances with the lowest curvature radiation was observed. There is a noticeable effect on the antenna. There is too much distortion in the radiation to get acceptable outcomes. It is determined that the radiation's properties have a specific amount of curvature and are too twisted to provide useful results. It could be beneficial to share the antenna's low-profile forward radiation, which takes advantage of the electromagnetic bandgap or subpar ground structure is shown in figure 1.

When utilised near angled surfaces, the antennas bend or flex, which might alter their reflecting qualities:

$$W = \frac{V_o}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \quad (1)$$

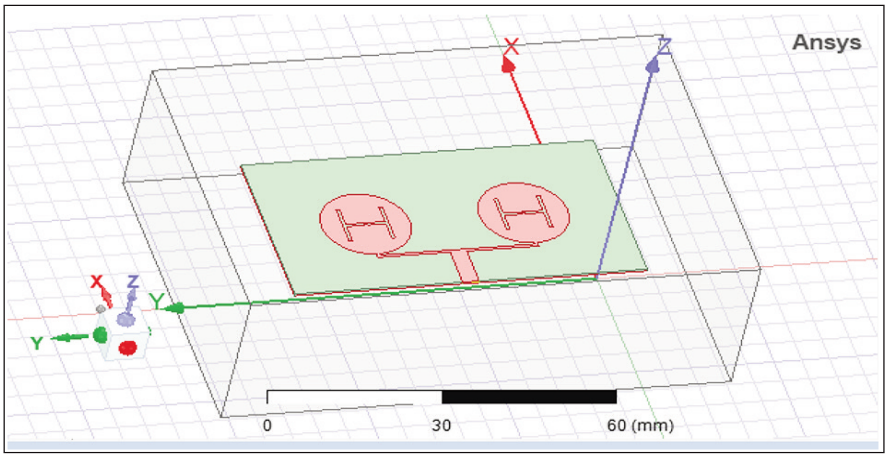

Fig. 1. H-shaped antenna structure

The antennas are tested for bending in a range of bending situations to make sure they work as intended, since they are made on flexible substrates. Antenna parameters are shown in table 1. The Teflon-based material commonly used in antenna design is polytetrafluoroethylene (PTFE), which is a high-quality insulating material known for its low dielectric constant, low loss tangent, and excellent heat resistance. PTFE is often augmented with glass fibres or ceramics to improve mechanical strength, particularly in printed circuit board (PCB) applications. In RF and antenna applications, conductive yarns, including silver-coated nylon, carbon-based fibres, and metallic threads, are often used. These threads function as conductive pathways or structural reinforcement in flexible or textile-based antennas.

It is crucial to test textile antennas under a range of bending situations to determine how their characteristics change as they are twisted, since they are likely to be bent or otherwise moulded to a certain surface throughout the activity. The substrate, backplane, front panel, and encapsulation are the four primary components that comprise flexible electronic devices (FES). FES is composed of flexible materials such as textiles, conductive foils, polymers, plastics, and laminates. Selecting the appropriate "substrate", the first part that forms the basis of the whole circuit, is essential. The second component is the backplane, which is a printed circuit board (PCB) with slots for connecting electrical components. The third section, the front panel, is usually a sheet of metal that secures the pieces and allows for certain adjustments to the system components.

In table 1, the dimensions 46 mm × 30 mm × 1.6 mm represent the overall antenna size, specifying its length, width, and thickness, respectively. The substrate is listed as Teflon and Yarn; it is important to specify the type of yarn used. The yarns incorporated are conductive, composed of metallic threads, which enhance the antenna's electrical performance and flexibility. Including these details in table 1 will provide clearer insight into the antenna's construction and material properties for better comprehension and reproducibility. The last component is an encapsulating layer that protects the electronics by covering them. Flexibility is necessary for all of the FES components; otherwise, it would disrupt their normal functioning. Devices worn on the person and those in the surroundings may communicate with the Wireless Body Area Network (WBAN). Flexible wearable antennas and smart tags, such as radio frequency identification (RFID) tags, are examples of these wearable devices. The WBAN, which combines FES

$$L = \frac{V_o}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \quad (2)$$

where V_o is the speed of light, ε_{reff} – effective permittivity, $2\Delta L$ – extension in length, W – width, f_r – resonating frequency and ε_{reff} – effective radiated power.

$$f_r = \frac{c}{2L\sqrt{\varepsilon_r}} = \frac{1}{2L\sqrt{\varepsilon_0\varepsilon_r\mu_0}} \quad (3)$$

Where ε_0 is the permittivity of free space, ε_r is the permittivity of the dielectric substrate, and μ_0 is the permeability of free space. The operating frequency of a patch antenna, considering L and W, is given by L – length of the patch and c – velocity of light:

$$f_r = \frac{c}{2\sqrt{\varepsilon_{reff}}}\left[\left(\frac{n}{L+2\Delta L}\right)^2 + \left(\frac{m}{w+2\Delta w}\right)^2\right]^{1/2} \quad (4)$$

where $n = 1$, $m = 0$.

$$f_{r(nm)} = \frac{c}{2(L+2\Delta L)\sqrt{\varepsilon_{reff}}} \quad (5)$$

$$\varepsilon_{reff} = \frac{\varepsilon_{r+1}}{2} + \frac{\varepsilon_{r-1}}{2}\left[1 + 12\frac{h}{w}\right]^{-1/2} \quad (6)$$

$$\Delta L = 0.412h\frac{\left(\varepsilon_{reff}+0.3\right)\left(\frac{w}{h}+0.264\right)}{\left(\varepsilon_{reff}-0.258\right)\left(\frac{w}{h}+0.8\right)} \quad (7)$$

$$W = \frac{(W_L - W_H)}{2}\cdot\frac{(W_L + W_H)}{2} \quad (8)$$

Table 1

ANTENNA PARAMETERS		
Sl. No	**Parameters**	**Range**
1	Antenna size (mm)	46 × 30 × 1.6
2	Length (mm)	9.403
3	Width (mm)	12.67
4	Input impedance (ohm)	50
5	Dielectric constant (mm)	4.8
6	Dielectric height (mm)	2.2
7	Substrate	Teflon, Yarn

with readily connected body-worn electronics, is evolving to allow users to wear antennas and smart tags instead of carrying them about. Thus, the development of flexible wearable electronics on a flexible substrate, including smart tags and antennas, is an interesting area that needs more investigation.

Due to their low weight, affordability, and tiny size, planar antennas are becoming an essential component of modern biomedical equipment. The deployment of medical technologies like body area networks, remote health monitoring, and microwave imaging systems depends on these antennas. The antennas used in the above-described applications need to meet certain specifications and be constructed from lightweight, human-safe materials. Wearable antennas are used to measure a person's health by attaching them to their body. Therefore, the performance of the antenna, including its radiation characteristics throughout the operating frequency bands, should not be affected by the proximity of a human body. This study aims to highlight the effects of human body proximity on wearable antenna performance. The several kinds of flexible antennas that have been suggested for use in biological applications are also examined in this study. It describes the challenges of developing wearable antennas, how to choose a flexible material that is suitable for their creation, and the proper manufacturing methods. The future directions in this quickly developing field are also highlighted in this study. Flexible antennas are the cornerstone for implementing next-generation wireless communication devices for monitoring and health safety applications. The total effectiveness of the antenna will be greatly impacted by the physical changes and water absorption of the body. The design of these antennas is influenced by the operating environment, transmission strength, and operational frequency range.

However, the antenna's total performance is entirely determined by the dielectric material. Based on its capacity to retain its characteristics under certain circumstances, including bending, crumpling, and stretching impacts, the dielectric material employed in the antenna design was selected. The conductive materials on the dielectric material's top and lower layers are very resilient to deterioration and mechanical deformation. Understanding the electromagnetic characteristics of the material, such as the substrate thickness, permittivity, and loss tangent, is crucial for the creation of wearable antennas. Both conductive and non-conductive textiles, also referred to as electro-textiles, are commonly found in wearable materials. Non-conductive textile materials, including felt, silk, nylon, leather, washed cotton, denim, polymer, fleece, and paper, are often utilised in the production of wearable antennas to minimise their weight and profile.

A high-performance antenna system that may be worn on or off the body and connect with nearby devices can be made possible using conductive fabric materials. To make conductive textile (e-textile) materials, we mix ordinary textiles with conductive metals or polymer threads. Taffeta, Shieldith, Zelt, Flectron, and pure copper are examples of conductive textiles. Because of their durability and flexibility, these materials are suitable for use on the body and provide a substantial contribution to the wearable context. To build a high-performance antenna system, we need a lightweight and flexible substrate. The AUWB [Aero Ultra-Wide Band] health monitoring system tracks a variety of daily activities that support a healthy lifestyle by using several wearable sensors at various locations and distances. Furthermore, polarisation mismatches are caused by human body movement, and most wearable antennas have linear polarisation.

The closeness of wearable antennas to the human body has an impact on the antenna's gain, bandwidth, driving point impedance, and efficiency.

The analysis of the polynomial regression:

$$Y = w_0 + w_1 t_1 + w_2 t_2 + \dots + w_n t_n \tag{9}$$

The analysis of the multivariate regression analysis:

$$Y = w_0 + \sum_{a_1=1}^{t} w_1 t_1 a_1 + w_1 \sum_{a_1=1}^{t} w_2 t_2 a_2 + \dots + w_n \sum_{a_1=1}^{t} w_n t_n a_n \tag{10}$$

here w_1, w_2 are polynomial regression coefficient, a – input variable, Y – output variable, w_0 – intercept, w_n – weight matrix.

Second polynomial $T_1 = R_s$, $t_2 = K_s$ and $t_n = F_s$:

$$Y = w_0 + w_1 R_s + w_2 K_s + \dots + w_n F_s \tag{11}$$

Algorithm 1

Input x,y

Initialize $w_0[|W_t|_1=R_s]$, $W_1[|W_t|_2=R_s]$, $W_n[|W_t|_n=F_s]$

While |M|-|T|>M or |M|-|K|>N do

$A_1' = |W_t^T a_1'|$

While |M|-|F|>M-1 or |M|-|K|>N-1 do

$A_2' = |W_t^T a_2'|$

Set $W_{1,2}=0$

End while

Output w_t, w_n

This technique delineates a procedure for the iterative update and optimisation of weight parameters using conditional evaluations. Initially, three sets of weights are established: the first two using a reference state and the last one employing a final state condition. The program thereafter initiates an outer loop that persists as long as the disparity between certain data set sizes surpasses established criteria. This indicates that the algorithm is seeing convergence or equilibrium among variables like model size, training data, or critical performance metrics. Within the outer loop, a transformation or activation is performed on the existing weights, presumably to assess performance or intermediate outcomes. If further size criteria between sets remain unfulfilled, a nested loop is initiated. Within this inner loop, an additional transformation is calculated, presumably to further refine or optimise the model. At this level, two particular weights are recalibrated to mitigate bias or interference from preceding stages.

The loops guarantee that weight changes persist until the model stabilises or meets the specified criteria. Upon meeting all requirements, the algorithm terminates, yielding revised weight values. The approach is intended to repeatedly enhance a model's internal parameters to attain an optimum condition based on structural and performance restrictions. Algorithms are pivotal in the Internet of Things (IoT), facilitating data processing, decision-making, and efficient communication among smart devices. Algorithms in an IoT system often link to multiple physical and digital entities. This category encompasses sensors (e.g., temperature, motion, humidity), actuators (e.g., motors, switches), microcontrollers, communication modules (e.g., Wi-Fi, Bluetooth, Zigbee), cloud platforms, and data analytics instruments. Each component creates or utilises data that algorithms must evaluate, interpret, or reply to instantaneously.

To enhance clarity, the author could include a succinct description of IoT. The Internet of Things (IoT) is described as a network of networked devices that may gather and exchange data to execute intelligent activities autonomously, without direct human involvement. This concept elucidates that algorithms are not independent entities; they are integrated inside or associated with devices functioning in physical contexts. Defining the Internet of Things (IoT) aids in determining the components that must interface with the algorithm, including the sensors that provide data, the actuators it governs, and the means of communication with cloud services. This viewpoint facilitates a more lucid comprehension of the system's architecture and the function of each component in realising intelligent capabilities.

Wearable antennas have garnered a lot of attention recently because of their attractive features and the potential for creating wireless communication systems that are portable, lightweight, affordable, and multifunctional. The use of lightweight materials and revolutionary developments in nanomaterial research has enabled the widespread use of wearable antennas. One-dimensional (1-D) nanomaterials known for their exceptional electrical conductivity and mechanical strength are carbon nanotubes (CNTs). While maintaining some of the antenna's electromagnetic properties, CNTs may be utilised in wearable antennas to increase the mechanical stability and lifetime of the device. CNTs, for instance, provide a balance between mechanical strength and flexibility in sports and health monitoring systems. AgNWs combine the exceptional electrical conductivity of silver with the versatility of nanoscale dimensions. Wearable antennas frequently use AgNWs to improve electromagnetic performance, particularly in terms of gain and bandwidth.

High-frequency broadband communication applications, such as wireless sensor networks with high resolution and fast data transmission, are especially well-suited for AgNWs. Graphene, a two-dimensional (2-D) carbon material, is well recognised for its exceptional electromagnetic properties and mechanical strength. Graphene is the perfect material for uses that need both strong physical strength and excellent electromagnetic performance, like better environmental sensing and health monitoring systems. We have also introduced several wearable textile antennas to fully integrate wearable systems into protective apparel and smart clothing. Shieldit, Flectron, and non-conductive textile substrates, such as Cordura layers, felt, cotton/polyester, fleece fabric, and flexible pad foam, are frequently seen in protective clothing. There has been a lot of work put into antenna designs that don't have bad soldering connections and that use antenna topologies that are less affected by changes in the thickness of the non-conductive layer and the conductivity and permittivity of textile materials.

The field of sheet waveguides offers a novel communication technique. This research examines examples of sensor, personal, and body area network applications, to replace a portion of wired communication with a new field that relies on wireless communication, taking into account the communication range. Whether indoors or out, ubiquitous sensor networks that are usable at any time and location are gaining popularity. It is consequently challenging to establish a single network for everything, as the number of apps keeps growing. Infrastructure technology that supports wireless sensor networks is necessary because they vary depending on the applications. Applications that accept wearable material as a sheet-like waveguide enable effective transmission. Since multiple sensors can be affixed to the human body, a smart suit composed of conductive fabric is a fantastic option for an auxiliary BAN transmission line. This allows for simultaneous power supply and sensor data collection. This opens up the possibility of using it to transmit information for military and disaster relief purposes.

RESULTS AND DISCUSSION

Human body communication (HBC) systems use a wearable antenna made of electrodes that come into contact with the body's surface to excite radio-frequency impulses inside the body. Like other wireless circuits, these antennas' input impedance properties are crucial design factors for boosting transmission efficiency and lowering signal reflection. In this study, we address how variances among actual human subjects can affect the input impedance characteristics of a wearable antenna prototype. We compare the analytical results with data from real people in the 1–100 MHz range. For the simulations, we used a real human arm model. From simulations of input impedance characteristics from antennas worn on the wrists of male and female models with dry and wet skin, it looks like there isn't much difference in impedance between the sexes. For frequencies higher than a few MHz, the skin's moisture content has minimal effect. Additionally, we propose a simplified rectangular prism model to examine the thickness of the bodily tissues. Individual variations in impedance are mostly caused by variations in the thickness of the skin and fat layers, according to comparisons of measured input impedances. Additionally, the model allows us to design the antenna prototypes without experiments involving several subjects. The reflection coefficient of the proposed antenna was evaluated from 2.5, 6.3, 7.7 and 9.7 GHz and attained a return loss of –15.23, –22.02, –17.56 and –33.72 dB. Notably, the average radiation path of the antenna at the H-plane bends over the y-plane, deviating from the normal. The related antenna output, however, remained constant under bending circumstances. Additionally, there was a substantial difference between simulation and calculation due to the influence of the tiny ground plane on the feeding cable.

The VSWR of the proposed antenna was evaluated from 2.5, 6.3, 7.7 and 9.7 GHz and attained values of 1.62, 1.17, 1.3 and 1.02. The results showed that bending curvatures had a major effect on the cost and cumulative dispersion of radiation. Notably, the entire antenna architecture was examined in three general locations: the wrist, arm, and chest. The fact that the antenna's front-to-back radiation density drops with increasing bending curvature is a beneficial feature for WBAN applications. The bandwidth remained almost constant in every situation that was examined.

The results demonstrated that for all operational frequency ranges from 2.5 to 12 GHz and all bending radii of the wearable antenna, the realised reflection coefficients were less than 10 dB. For every bending radius, the conformal UWB antenna's reflection coefficient response was the same. Thus, the recommended antenna design is the ideal choice for UWB wearable applications because of its thickness, durability, and flexibility. However, a little change in the cardboard used to cover the antenna during the compatibility test might account for the calculated findings. Furthermore, there's a chance that the cardboard itself has certain dielectric properties, which would undoubtedly alter the operating frequency. The antenna achieves a gain of 8.27 dBi in the ISM medical range, with a value greater than 20 dB. It is clear that it has outstanding efficiency even under a range of bending situations and has no impact on human safety since the SAR value is less than 0.15 W/kg, which is much lower than the normal implementation level. The flow chart of the proposed antenna is shown in figure 2.

Researchers evaluated and compared how well complementary structures integrated with the human body. Two body-worn antennas were highlighted: a meandering slot antenna with an ungrounded surface and a printed patch antenna with a meandering ground. This work shows that magnetic antenna designs, including meandering slot printed antennas, are favoured for wearable systems, even if similar structures are practically the same in non-wearable systems. By making careful design decisions, the susceptibility of these antennas near the human body may be greatly decreased.

Wireless technology plays a key role in the development of flexible and elastic electronics, which has attracted attention in response to the rising need for devices that are compact, light, and comfortable. Microstrip antennas have emerged as desirable alternatives in the wireless technology sector due to their high degree of flexibility and complex bending electronics construction. However, the flexibility of microstrip antennas often leads to a decrease in their conductivity and radiation efficiency. To solve this problem, we suggested two designs: the arch-shaped microstrip antenna and the stretchy mesh microstrip antenna. Both antennas use conductive materials to cover a silicone substrate. Depending on the bending condition, the resonance frequency of the antennas varies. However, the variation is determined by the strain of the antenna element. The resonance frequency of the meshed microstrip antenna decreases as the antenna strain increases. The strain of the arching antenna must be greatly decreased in order to increase its resonance frequency. The microstrip antenna's resonance frequency rises 8.5 and 5.5 times, respectively, indicating that it is more susceptible to strain than the other one.

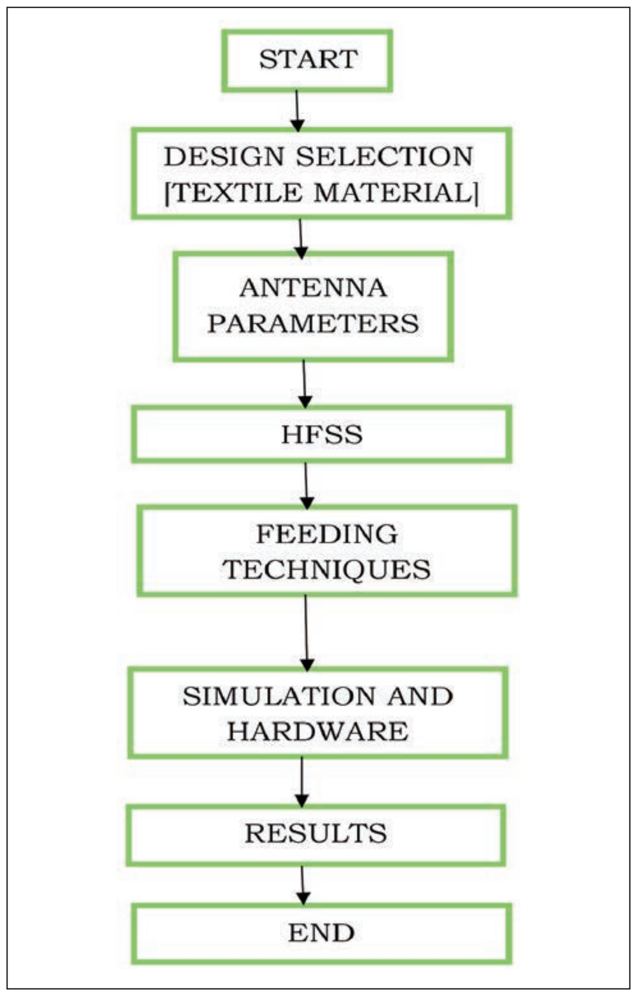

Fig. 2. Flow chart of the proposed antenna

Consequently, the following research questions and significant topics are enumerated for more investigation in this field: enhancing the present production and measurement processes' accuracy and effectiveness; introducing to the market novel yarns and conductive fabrics with reduced resistance or increased conductivity; introducing novel manufacturing methods or new flexible materials for embroidered apparel; Based on substrate materials, we are presenting new body-operated antenna sensors for a range of uses. Additional research in the domains of materials science and systems engineering is still required for the substantial practical deployment of wearable antennas. Biomedical applications may use novel materials like graphene compounds and conductive ink on textile substrates to enhance the functionality of antennas as sensors. These cutting-edge materials are fascinating components of the next generation of antenna designs. Flexible wearable antennas have received a great deal of interest from the scientific and business worlds. This presents certain research challenges. Researchers might focus their efforts on making the present manufacturing and measurement processes more accurate and efficient. Researchers can improve yarn and textile materials' conductivity by using innovative techniques. The simulated H-shaped antenna structure is shown in figure 3.

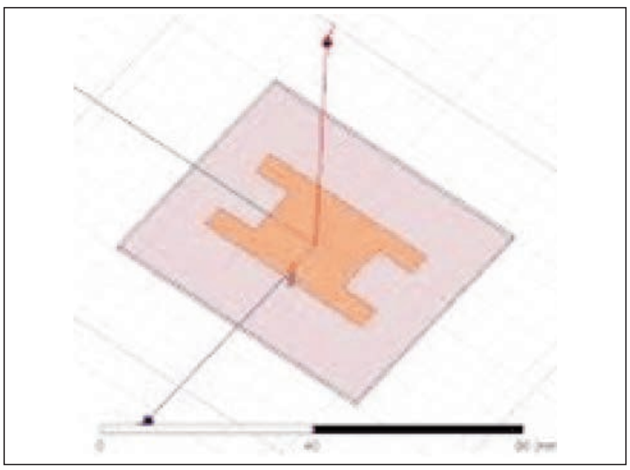

Fig. 3. H-shaped antenna structure

Wireless communication relies heavily on antennas as they facilitate the transmission and reception of signals across various frequency bands. These frequency bands include RFID (radio frequency identification), X-band, S-band, and the IoT. The antenna works well because it can be used with different frequencies, and the results from simulations and measurements agree very well. An interconnected network of physical objects that communicate online is known as the Internet of Things (IoT). Its goal is to enable intelligent, smooth communication and automation among devices for greater convenience and efficiency. Smart cities, wearable technology, industrial automation, smart homes, and healthcare monitoring are all examples of IoT applications. IoT devices operate in different frequency bands. Long-range, low-power communication (LPWAN) is made possible by sub-1 GHz frequencies like 433 MHz and 868 MHz; Zigbee and Bluetooth technologies allow for short-range communication using the 2.4 GHz band, and faster data rates and shorter-range applications use the 5.8 GHz spectrum. For worldwide IoT connectivity, cellular networks such as LTE-M, NB-IoT, and 5G function in several bands. Technologies like Sigfox and LoRa provide low-power, long-range solutions for particular Internet of Things applications by utilising a variety of sub-1 GHz bands.

The ideal technique for creating textile wearable antennas with superior production precision for wearable applications is screen and inkjet printing. A screen-printed interface layer was used to reduce the surface roughness of the polyester/cotton mixture, making it simpler to print a persistent conducting surface. Custom designs can still be generated rapidly for low-volume orders by doing away with the need for a screen and printing antennas straight from the finished design. Inkjet printing, a widely used technology, also enables an extremely fine resolution for improved production. The feeding mechanism of the antenna, in terms of compactness, is shown in figure 4.

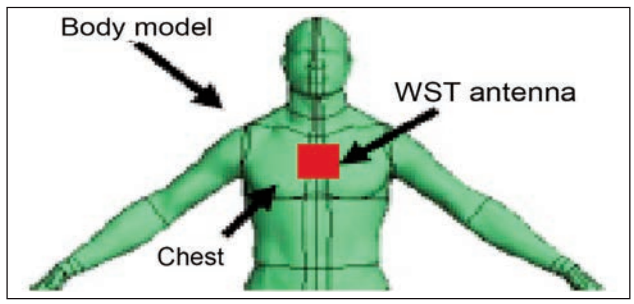

Fig. 4. Body model of the wearable devices

$X_{n,i} = Random(0, 1) \cdot (X_{n,i}^{u} - X_{n,i}^{L}) + X_{n,i}^{L}$

i= 1,2,3,……..D and n = 1,2,3,……N

Where X_i^L is the lower bound of the variable X_i

Where X_i^U is the upper bound of the variable X_i

$V = X_{r1} + F(X_{r3} - X_{r2})$

Where F = Scaling factor

r1,r2,r3 are random solutions

Where (0<r1,r2,r3<N) And r1≠r2≠r3

Donor vectors are generated without involving the target vector.

Algorithm 2

Step 1: Set the generation counter G=0, and randomly initialise a population of NP individuals X. i Initialise the parameter F, CR.

Step 2: Evaluate the fitness for each individual in P.

Step 3: while the stopping criteria are not satisfied, do

for i= 1 to NP

select randomly a≠b≠c≠d≠i

for j=1 to D

j rand = rand (1,0) * D

if rand (0 ,1)≤CR or j= = jr and then

$U_{l,h} = X_{r1} + F(X_{r2} + X_{r3})$

else

$U_{l,h} = X_{l,h}$

end if

```
        end for
        end for
        for i= 1 to N-1 do
        Evaluate the offspring U I,h
        if U I,h is better than P I,h then
        P I,h = U I,h
        end if
        end for
Memorise the best solution achieved so far
Step 4: end while
End
```

Running comments

1. Bring in the necessary libraries.
2. Determine how many elements, or antennas, there are in the array.
3. Indicate the distance between the antenna array's components.
4. Indicate the components' phase angle.
5. The variables are allocated with array factor equations and design equations.
6. We provide plotting commands for outputs, patterns, or graphs.
7. Launch the software application.
8. If there are problems, debug them.
9. Examine the antenna array's dual-beam emission pattern.

The stages for the simulation are as follows:

Step 1: Installing Python software is step one.
Step 2: Launch Python IDLE shell version 3.9.
Step 3: Press Ctrl+N to create a new file.
Step 4: Import the necessary libraries, which are matplotlib from math, pylab, and pyplot.
Step 5: Set the settings to their starting values
- The quantity of components, or antennas
- The distance between the components (S)
- The components' phase angle (Phi)

Step 6: The variables are allocated to the array factor equations and design equations.
Step 7: Perform the directivity normalisation
Step 8: Plotting instructions are provided based on the syntax for the graphs and patterns.
Step 9: Give the program a name and save it in the designated place.
Step 10: Click Fn+F5 to launch the software application.
Step 11: Debug any issues that may have occurred.
Step 12: Examine the dual-beam radiation pattern to determine whether or not it has good directivity.
Step 13: If normalised directivity is not improved, optimise the patterns by varying the parameters, i.e., N, S, and Phi. This process is similar to a trial-and-error approach.
Step 14: The optimum output is achieved by repeatedly changing the settings until the best directivity is achieved.

This approach delineates the Differential Evolution (DE) process, a population-centric optimisation method extensively used for addressing intricate numerical challenges. The process starts with Step 1, whereby the generation counter G is set to zero, and a population of NP people is formed randomly. The mutation factor (F) and crossover rate (CR) are established at this phase. In Step 2, the fitness of each person is assessed according to a specified objective function. In Step 3, the fundamental evolutionary process begins and persists until a stopping requirement, such as a maximum number of generations or a convergence threshold, is satisfied. For each person, four unique people, a, b, c, and d, are randomly chosen from the population. A trial vector is produced by mutation and crossover operations. The progeny's fitness is then assessed. If the progeny outperforms its progenitor, it supplants it in the subsequent generation. This selection approach guarantees convergence to an optimum solution. The optimal answer is retained each generation for the final result.

When felt and Teflon are used on the antenna to improve performance, a deformed ground structure is added to the rectangular patch antenna to improve impedance matching. The reflection coefficient of the proposed antenna is shown in figure 5. Using Teflon as the antenna's substrate results in a better gain of 7.8 dB, but using felt yields a gain of 8.2 dB. These structures make the current path longer, which changes the frequency from a higher to a lower resonance. Bio-implantable device antennas employ Teflon fabric because of its precision and flexibility. The VSWR of the proposed antenna is shown in figure 6.

The method involves inserting H-shaped slots into a rectangular patch antenna to increase bandwidth. The slits and slots offer a modest bandwidth of <=1 GHz, according to the comparison study. By truncating the patch at the corners, this problem can be resolved, and bandwidth can be effectively increased from lower to higher than with conventional bandwidth improvement techniques. Systems for IoT, 5G, medical, and future communication require small, environmentally friendly, and effective broadband sensors and antennas. This article presents new dual-polarised and linear antennas for 5G, 6G, medical equipment, Internet of Things (IoT) systems, and healthcare monitoring sensors. Developing effective, small, affordable antennas and sensors is a key objective in the assessment of medical, 5G, and smart wireless communication devices. By attaching an energy-harvesting device to the antenna, passive and active sensors can also run on their own power by absorbing electromagnetic radiation and recharging the wearable sensor's battery.

The metamaterial technologies used in this work look at small, broadband, and useful antennas and sensors for 5G, 6G, and IoT, healthcare, and communication systems. The new, effective meta-fractal sensors and antennas optimise the system's dynamic range and electrical properties. Wearable medical sensors and equipment are used to monitor heartbeat, blood pressure, sugar levels, temperature, and other daily hospital tasks, including patient care and sleep habits. People use wearable technology to send, track, and monitor personal health information.

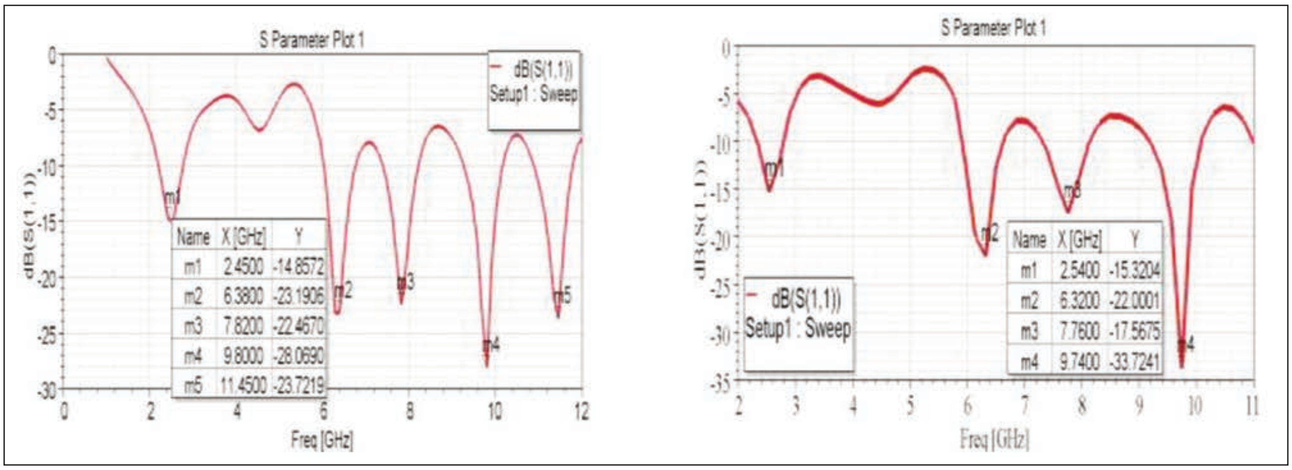

Fig. 5. Reflection coefficient of the proposed antenna

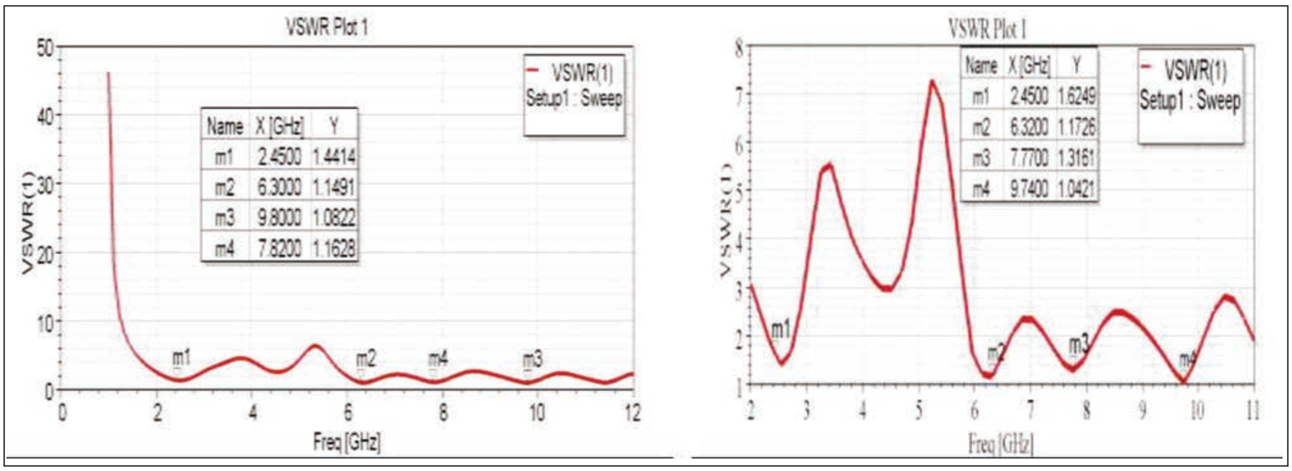

Fig. 6. VSWR of the proposed antenna

These medical devices are able to track vital signs like temperature, sweat, sleep patterns, and cardiac rate. To understand how well the proposed H-stub antenna works and operates on multiple frequencies, it's very important to look at how the current flows through it. The surface current is focused in various areas of the antenna structure at each resonant frequency, 7.5 GHz, demonstrating how well the design supports triple-mode operation. At 7.5 GHz, the main patch and the longer H-shaped stub segments, which serve as resonators at lower frequencies, are where the majority of the current is focused. This observation implies that resonance at this band is greatly influenced by the stubs' physical length. The current changes and intensify throughout the middle portions of the parasitic strip and the intermediate stub sections at 5.5 GHz. This experiment demonstrates how the ground plane adjustments and parasitic elements help to fine-tune the coupling processes and resonant behaviour. The current is mostly contained close to the feed line, patch edges, and open ends of the H-shaped slots at the higher frequency of 7.5 GHz, suggesting that these components are responsible for high-frequency resonance. A thick Teflon and FR4 substrate promotes improved electromagnetic coupling and wider bandwidth, which affects the current flow is shown in figure 7. The variance in current pathways at various frequencies demonstrates the antenna's capacity to isolate and control many resonances via compact design.

The colour gradient in the present distribution of the suggested antenna indicates the strength and amplitude of the surface current traversing the antenna's construction. Generally, warmer hues such as red and yellow signify areas of elevated current density, while cooler hues like blue and green denote regions of decreased current density. This picture facilitates

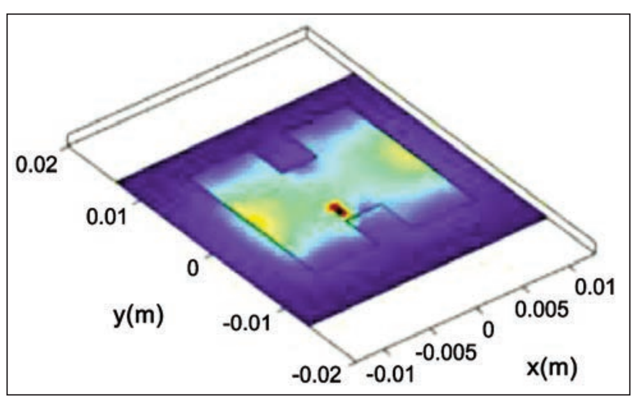

Fig. 7. Current distribution of the proposed antenna

the identification of active components of the antenna during operation, including the H-shaped stubs and parasitic elements where current is focused. Understanding the current distribution is important for improving antenna performance because it explains how well the antenna radiates energy and how the design affects bandwidth and efficiency.

There is a significant advancement in military wearable technology. Sensors and equipment that track soldiers are examples of wearable military technology. Soldiers can use boot inserts to measure their weapon grip effectiveness. In a variety of settings and climates, wearable sensors can track and evaluate soldiers' health and performance. They can also determine how geography influences soldiers' performance. Sports and fitness are important aspects of life. Professional and amateur athletes use sports equipment such as headgear, shoes, bats, and balls, along with wearable athletic sensors and devices. Sportswear can be made with wearable sports sensors integrated into the fabric. The GPS and Bluetooth-enabled gadgets give coaches access to real-time data so they can track and evaluate the athlete's performance. The gain plot of the proposed antenna is shown in figure 8.

An important performance metric that shows how well an antenna transforms input power into radio waves in a particular direction is its gain. The gain of the suggested H-shaped antenna has been assessed throughout its working frequencies, demonstrating reliable and effective radiation properties appropriate for contemporary wireless communication applications. The antenna attains a modest gain of around 5.5 to 8.5 dBi at 5.5 to 5.8 GHz, respectively, as shown in figure 9. Compact antennas that operate at lower frequencies and have tiny physical sizes in relation to wavelengths often have this amount of gain. For applications like GSM and IoT systems that need wide coverage, the H-shaped structure allows for efficient current distribution despite its small size, allowing for a respectable gain while preserving an omnidirectional radiation pattern. The H-shaped architecture, which more efficiently directs current over the radiating surface, supports the improved impedance matching and more efficient resonant behaviour that provides the increased gain at this frequency. As a result, the antenna is appropriate for mid-band uses, including mobile broadband, 3G, and 4G. This is explained by the directed character of the radiation pattern at this frequency, as well as the higher radiation effectiveness. Strong, concentrated radiation is made possible by the tiny but optimised H-shaped design, which is very advantageous for high-speed data applications like LTE and early 5G installations. The effectiveness and dependability of the suggested fabricated H-shaped antenna for multi-band wireless communication are shown in figure 10 by its constant gain performance across all three bands. It is a great option for tiny, high-performance wireless systems because of its capacity to sustain decent gain levels despite its small form size. The photocopy of the H-Shaped antenna is shown in figure 11.

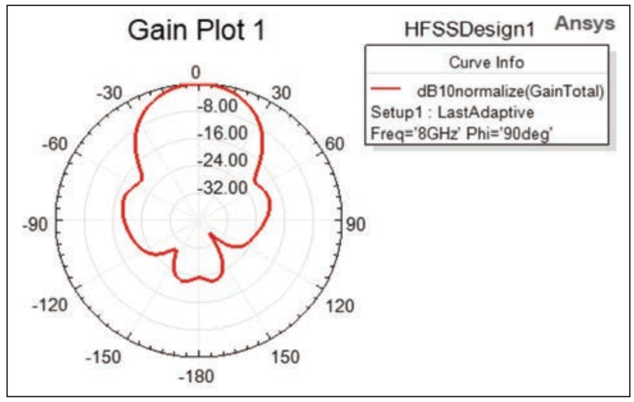

Fig. 8. Gain plot of the proposed antenna

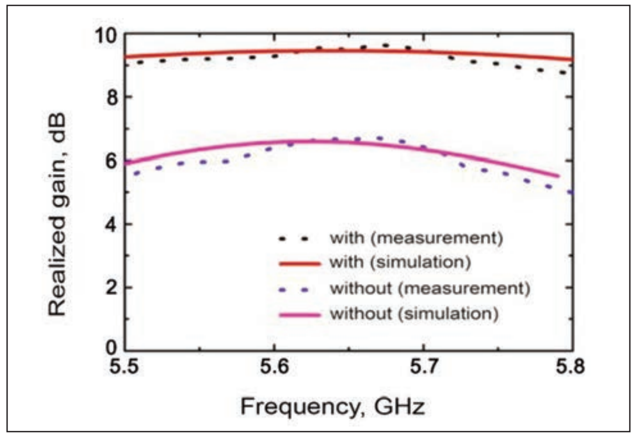

Fig. 9. Gain of the proposed antenna

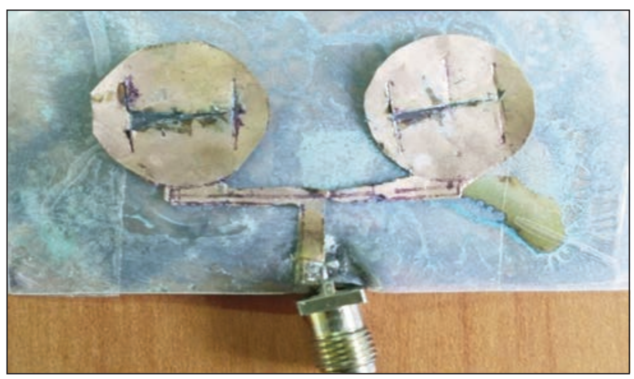

Fig. 10. Fabricated H-shaped antenna

The antenna has H-shaped stubs and a reconfigurable ground plane slot, which are metamaterial-inspired configurations that provide multi-band functionality and improved energy distribution. These metamaterial components modulate electromagnetic waves to enhance bandwidth, gain, and radiation efficiency within a compact design. Utilising novel materials and structural designs, the antenna fulfils the stringent requirements of next-generation wireless communication and sensing applications, providing improved flexibility and performance across many frequency bands.

Fig. 11. Photocopy of the H-shaped antenna

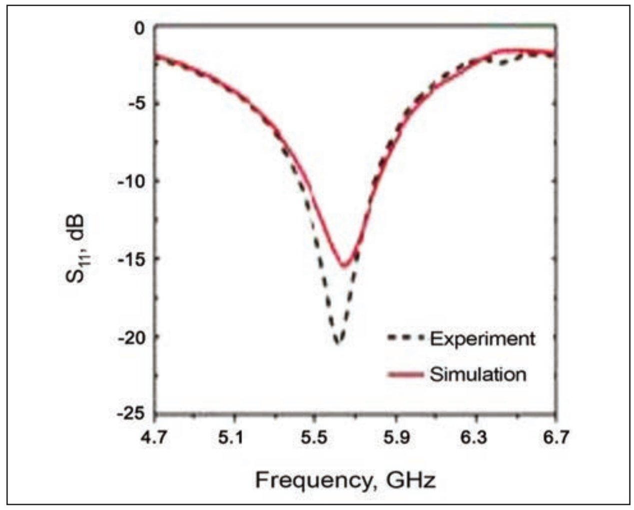

Fig. 12. Reflection coefficient of the experiment and simulation output

Copper foil is often used for antenna manufacturing owing to its superior electrical conductivity, flexibility, and simplicity of patterning. The use of copper foil guarantees effective signal transmission and reduces losses, which is crucial for sustaining high radiation efficiency across the antenna's operational frequency spectrum. Moreover, the compatibility of copper foil with substrates like Teflon and FR4 renders it optimal for the fabrication of small, dependable antennas. This selection enhances the antenna's performance objectives, including wide bandwidth and consistent operation for wireless communication applications.

The experimental and simulation output of the reflection coefficient is shown in figure 12. The radiation pattern of the proposed H-stub antenna is very important for how well it works at different frequencies and is key to determining if it is suitable for modern wireless communication systems. At its operational frequencies of 2.5, 6.3, 7.7 and 9.7 GHz, the antenna displays unique radiation characteristics that demonstrate its triple-mode capability and its well-optimised construction is shown in figure 13. For low-frequency wireless communication when broad coverage is crucial, the antenna's almost omnidirectional emission pattern in the H-plane (horizontal plane) at 9.7 GHz is perfect. Although the radiation is more directed in the E-plane (elevation plane), it still has a comparatively wide coverage area. This architecture supports applications like GSM and Internet of Things devices that require consistent signal delivery. The E-plane and H-plane radiation patterns begin to show a slight directionality, which helps improve signal strength and lessen interference. The changes to the parasitic strip and slot help direct the radiation to produce stronger and more controlled emission angles, resulting in better resonance effects and this behavior. Point-to-point communication and high-data-rate applications like LTE and 5G benefit from the antenna's more directional capabilities at 5.5 GHz, especially in the E-plane.

The improvement in gain and directivity at this frequency demonstrates efficient radiation

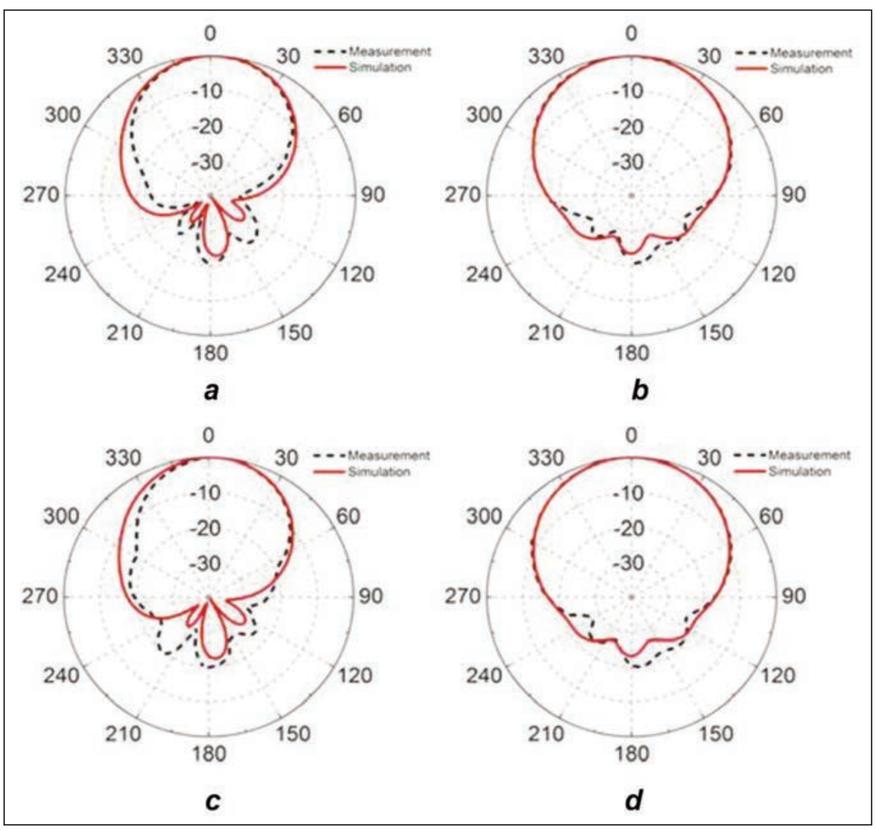

Fig. 13. Radiation pattern of the proposed antenna

despite the antenna's small size. The radiation pattern's stability and minimal distortion across all frequencies demonstrate good impedance matching and less back lobe radiation. These consistent, frequency-dependent radiation patterns demonstrate the outstanding adaptability of the suggested H-stub antenna, which makes it a strong contender for incorporation into broadband and portable wireless communication systems, as shown in figure 14.

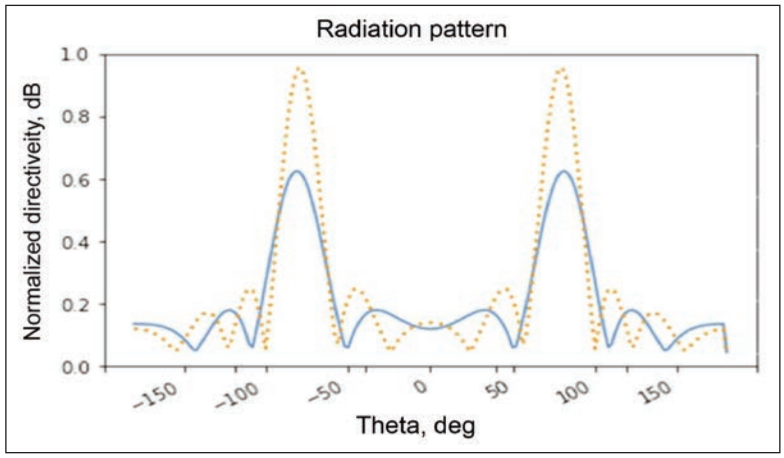

Fig. 14. Radiation pattern of the proposed antenna using Python

The changes in amplitude and phase of the proposed h-stub antenna are important features that reveal how it radiates signals, maintains signal quality, and performs overall at the frequencies of 2.5, 6.3, 7.7 and 9.7 GHz is shown in figure 15. These variances directly impact the antenna's efficiency, beam stability, and suitability for broadband and multi-band wireless applications. The suggested antenna's amplitude keeps its radiation strength comparatively constant across its operating frequencies. The amplitude distribution at 5.5 GHz is well distributed and smooth, suggesting low signal loss and excellent impedance matching. For wide coverage, this range produces a more consistent and omnidirectional radiation pattern. The amplitude starts to show somewhat more concentrated peaks as the frequency rises to 5.5 GHz and 9.5 GHz, especially in the primary radiation direction. Higher frequencies lead to better focus and stronger signals because of this improvement in amplitude response, which is helpful for applications that require high speeds and large amounts of data. To preserve beam coherence and reduce distortion, the phase variation over the radiating surface is also well-behaved. The antenna shows smooth phase transitions throughout the patch and stubs at all three resonant frequencies. The lack of sudden phase changes means the antenna helps reduce phase errors and allows waves to travel effectively. The H-stub antenna's well-controlled amplitude and phase features indicate that it can deliver reliable, high-quality radiation. Because of these characteristics, it may be integrated into contemporary wireless systems that need broadband, low-profile, and effective antenna solutions, guaranteeing reliable communication across many bands and excellent signal performance. The Reflection coefficient with the simulation and fabricated output of the proposed antenna is shown in table 2.

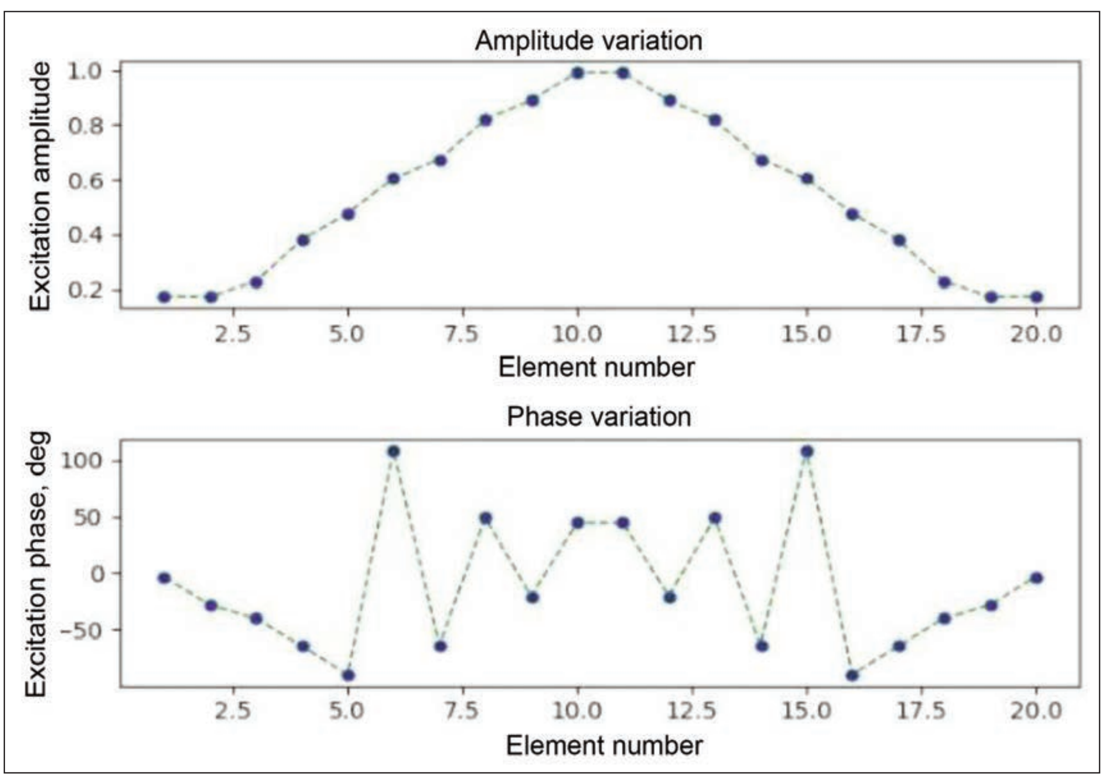

Fig. 15. Amplitude and phase variation of the proposed antenna using Python

Table 2

REFLECTION COEFFICIENT WITH SIMULATION AND FABRICATED OUTPUT OF PROPOSED ANTENNA		
Parameters	**Simulated output**	**Experiment output**
Reflection coefficient	–15.22 dB	–20.02 dB

Table 3

PERFORMANCE ANALYSIS OF THE H-SHAPED PROPOSED ANTENNA						
Frequency (GHz)	**Reflection coefficient (dB)**		**VSWR**		**Gain (dB)**	
	Proposed	**Existing**	**Proposed**	**Existing**	**Proposed**	**Existing**
2.5	–15.22	–12.25 [2]	1.62	1.12 [8]	3.5	2.5 [16]
6.3	–22.02	–20.25 [5]	1.17	1.02 [10]	5.5	3.0 [20]
7.7	–17.56	–15.25 [7]	1.13	1.05 [1]	7.5	4.5 [14]
9.7	–33.72	–2.25 [12]	1.04	1.00 [6]	8.5	5.2 [22]

Performance Analysis of the H-Shaped Proposed Antenna is shown in table 3.

The potential applications of the suggested tiny H-stub antenna in business are substantial, especially within the burgeoning fields of wireless communication and the Internet of Things (IoT). With the rising integration of smart gadgets, wearable technologies, and embedded systems in many sectors, there is an escalating need for compact, efficient antennas capable of functioning over broad frequency ranges. This antenna, measuring 46 mm x 30 mm x 1.6 mm and operating within a frequency range of 2.5 GHz to 12 GHz, is well-suited for incorporation into IoT devices, smart home systems, industrial automation, and healthcare monitoring applications. Consumer electronics use antennas in smartphones, tablets, and wireless headphones to enhance bandwidth and improve signal quality. In logistics and supply chain management, it facilitates asset monitoring and RFID systems, guaranteeing dependable data transfer even in congested conditions. Companies engaged in autonomous cars, drones, or robots may use their superior radiation efficiency and consistent performance for real-time communication. Moreover, the antenna's versatility and enhanced gain render it appropriate for 5G applications, smart city infrastructure, and remote sensing. The antenna offers a cost-efficient, high-performance solution that fosters innovation across several business sectors dependent on wireless communication.

CONCLUSION

In this research, we examine a wearable antenna's input impedance from the perspective of how the impedance varies depending on the body type of the user. First, a realistic human arm model wearing a wearable antenna prototype is used to calculate the input impedance characteristics. A similar trend was observed in both analytical and experimental results across the frequency range of 1 to 100 MHz. The gain is obtained at 8.2 dBi. The reflection coefficient of the proposed H-Shaped antenna is analysed at various frequencies, 2.5, 6.3, 7.7 and 9.7 GHz, and the values of –15.23, –22.02, –17.56 and –33.72 dB. The experiment determined the VSWR value to be less than two, a suitable value for most antenna systems. In addition, we made a simpler rectangular prism model to show how the different properties of each real human subject cause differences in input impedance. Furthermore, we may design the antenna prototype using the rectangular prism model without the need for multiple subject trials. The study's results show that HBC can work when looking at how resistant wearable antennas are to things like changes in skin moisture and tissue structure. The VSWR of the proposed H-Shaped antenna is analysed at various frequencies, 2.5, 6.3, 7.7 and 9.7 GHz, and the values of 1.62, 1.17, 1.3 and 1.04. The results also provide valuable insights for designing HBC systems, which include front-end circuits connected to an antenna and communication frequency bands. Future research will focus on enhancing the wearability of the antenna by investigating extremely flexible substrate materials such as denim, polyfoam, or jeans.

ACKNOWLEDGEMENTS

I want to express my gratitude to Dr. Nagarajan Ramalingam, my supervisor, who helped me with my research study.

REFERENCES

[1] Schmid, W., Fan, Y., Chi, T., Golanov, E., Regnier-Golanov, A.S., Austerman, R.J., Podell, K., Cherukuri, P., Bentley, T., Steele, C.T., *Review of Wearable Technologies and Machine Learning Methodologies for Systematic Detection of Mild Traumatic Brain Injuries*, In: J. Neural Eng., 2021, 18, 041006

[2] Steiner, L.A., Czosnyka, M., Piechnik, S.K., Smielewski, P., Chatfield, D., Menon, D.K., Pickard, J.D., *Continuous Monitoring of Cerebrovascular Pressure Reactivity Allows Determination of Optimal Cerebral Perfusion Pressure in Patients with Traumatic Brain Injury*, In: Crit. Care Med., 2002, 30, 733–738
[3] Schmid, M.B., Reister, F., Mayer, B., Hopfner, R.J., Fuchs, H., Hummler, H.D., *Prospective Risk Factor Monitoring Reduces Intracranial Hemorrhage Rates in Preterm Infants*, In: Dtsch. Ärzteblatt Int., 2013, 110, 489–496
[4] Chen, C.-J., Ding, D., Ironside, N., Buell, T.J., Southerland, A.M., Testai, F.D., Woo, D., Worrall, B.B., *Intracranial Pressure Monitoring in Patients with Spontaneous Intracerebral Hemorrhage*, In: J. Neurosurg., 2019, 132, 1854–1864
[5] Szwargulski, P., Wilmes, M., Javidi, E., Thieben, F., Graeser, M., Koch, M., Gruettner, C., Adam, G., Gerloff, C., Magnus, T., *Monitoring Intracranial Cerebral Hemorrhage Using Multicontrast Real-Time Magnetic Particle Imaging*, In: ACS Nano, 2020, 14, 13913–13923
[6] Karstensen, J.G., Ebigbo, A., Bhat, P., Dinis-Ribeiro, M., Gralnek, I., Guy, C., Le Moine, O., Vilmann, P., Antonelli, G., Ijoma, U., *Endoscopic Treatment of Variceal Upper Gastrointestinal Bleeding: European Society of Gastrointestinal Endoscopy (ESGE) Cascade Guideline*, In: Endosc. Int. Open, 2020, 8, E990–E997
[7] Peng, X., Xia, X., Xu, X., Yang, X., Yang, B., Zhao, P., Yuan, W., Chiu, P.W.Y., Bian, L., *Ultrafast Self-Gelling Powder Mediates Robust Wet Adhesion to Promote Healing of Gastrointestinal Perforations*, In: Sci. Adv., 2021, 7, eabe8739
[8] El Gharbi, M., Fernández-García, R., Ahyoud, S., Gil, I., *A Review of Flexible Wearable Antenna Sensors: Design, Fabrication Methods, and Applications*, In: Materials, 2020, 13, 3781
[9] Mahmood, S.N., Ishak, A.J., Saeidi, T., Alsariera, H., Alani, S., Ismail, A., Soh, A.C., *Recent Advances in Wearable Antenna Technologies: A Review*, In: Prog. Electromagn. Res. B, 2020, 89, 1–27
[10] Yang, M., Ye, Z., Ren, Y., Farhat, M., Chen, P.-Y., *Recent Advances in Nanomaterials Used for Wearable Electronics*, In: Micromachines, 2023, 14, 603
[11] Won, P., Jeong, S., Majidi, C., Ko, S.H., *Recent Advances in Liquid-Metal-Based Wearable Electronics and Materials*, In: iScience, 2021, 24, 102698
[12] Ates, H.C., Nguyen, P.Q., Gonzalez-Macia, L., Morales-Narváez, E., Güder, F., Collins, J.J., Dincer, C., *End-to-End Design of Wearable Sensors*, In: Nat. Rev. Mater., 2022, 7, 887–907
[13] Ling, Y., An, T., Yap, L.W., Zhu, B., Gong, S., Cheng, W., *Disruptive, Soft, Wearable Sensors*, In: Adv. Mater., 2020, 32, 1904664
[14] Jan, M.A., Khan, F., Khan, R., Mastorakis, S., Menon, V.G., Alazab, M., Watters, P., *Lightweight Mutual Authentication and Privacy-Preservation Scheme for Intelligent Wearable Devices in Industrial-CPS*, In: IEEE Trans. Ind. Inform., 2020, 17, 5829–5839
[15] Hashim, F.F., Mahadi, W.N.L.B., Abdul Latef, T.B., Othman, M., *Bin Key Factors in the Implementation of Wearable Antennas for WBNs and ISM Applications: A Review WBNs and ISM Applications: A Review*, In: Electronics, 2022, 11, 5270
[16] Alhayajneh, A., Baccarini, A.N., Weiss, G.M., Hayajneh, T., Farajidavar, A., *Biometric authentication and verification for medical cyber physical systems*, In: Electronics, 2018, 7, 436
[17] Abbasi, Q.H., Rehman, M.U., Qaraqe, K., Alomainy, A., *Advances in Body-Centric Wireless Communication: Applications and State-of-the-Art*, In: Institution of Engineering and Technology: Stevenage, UK, ISBN 1849199892, 2016
[18] Negra, R., Jemili, I., Belghith, A., *Wireless body area networks: Applications and technologies*, In: Procedia Comput. Sci., 2016, 83, 1274–1281
[19] Hadjidj, A., Souil, M., Bouabdallah, A., Challal, Y., Owen, H., *Wireless sensor networks for rehabilitation applications: Challenges and opportunities*, In: J. Netw. Comput. Appl., 2013, 36, 1–15
[20] Isa, M.S.M., Azmi, A.N.L., Isa, A.A.M., Zin, M.S.I.M., Saat, S., Zakaria, Z., Ibrahim, I.M., Abu, M., Ahmad, A., *Textile dual band circular ring patch antenna under bending condition*, In: J. Telecommun. Electron. Comput. Eng., 2017, 9, 37–43
[21] Mersani, A., Bouamara, W., Osman, L., Ribero, J.M., *Dielectric resonator antenna button textile antenna for off-body applications*, In: Microw. Opt. Technol. Lett., 2020, 62, 2910–2918
[22] Marterer, V., Radouchová, M., Soukup, R., Hipp, S., Blecha, T., *Wearable textile antennas: Investigation on material variants, fabrication methods, design and application*, In: Fash. Text, 2024, 11, 9
[23] Abdulla, F.A.A., Demirkol, A., *A novel textile-based UWB patch antenna for breast cancer imaging*, In: Phys. Eng. Sci. Med., 2024, 47, 851–861
[24] Ibrahim, N.F., Dzabletey, P.A., Kim, H., Chung, J.Y., *An all-textile dual-band antenna for ble and lora wireless communications*, In: Electronics, 2021, 10, 2967
[25] Parameswari, S., Chitra, C., *Textile UWB antenna with metamaterial for healthcare monitoring,* In: Int. J. Antennas Propag., 2021, 2021, 5855626
[26] Ullah, U., Mabrouk, I.B., Koziel, S., *A compact circularly polarized antenna with a directional pattern for wearable off-body communications*, In: IEEE Antennas and Wireless Propagation Letters, 2019, 18, 12, 2523–2527, https://doi.org/10.1109/lawp.2019.2942147
[27] Sabban, *Small new wearable metamaterials antennas for IoT medical and 5G applications*, In: 14th IEEE European Conference on Antennas and Propagation, EuCAP, 2020, 1–5, https://doi.org/10.23919/EuCAP48036.2020.9136003
[28] Ouyang, Y., Chappell, W.J., *High-frequency properties of electro-textiles for wearable antenna applications*, In: IEEE Transactions on Antennas and Propagation, 2008, 56, 2, 381–389, https://doi.org/10.1109/tap.2007.915435
[29] Ashyap, Y., Zainal Abidin, Z., Dahlan, S.H., et al., *Compact and low-profile textile EBG-based antenna for wearable medical applications*, In: IEEE Antennas and Wireless Propagation Letters, 2017, 16, 2550–2553, https://doi.org/10.1109/lawp.2017.2732355

[30] Raed, S., Daraghma, M., *Design of Microstrip Patch H-Notch Antenna for Vehicle Using Array Systems*, In: Journal of Communications, 2024, 19, 4, 204-210
[31] Vital, D., Bhardwaj, S., Volakis, J.L., *Textile-based large area RF-power harvesting system for wearable applications*, In: IEEE Transactions on Antennas and Propagation, 2019, 68, 3, 2323–2331, https://doi.org/10.1109/tap.2019.2948521
[32] Pathan, T., Karn, R.A., *Compact circular polarized metamaterial-inspired fabric antenna for WBAN applications*, In: Microwave and Optical Technology Letters, 2021, 63, 2651–2655, https://doi.org/10.1002/mop.32958
[33] Mersani, A., Lotfi, O., Ribero, J.M., *Design of a textile antenna with artificial magnetic conductor for wearable applications*, In: Microwave and Optical Technology Letters, 2018, 60, 6, 1343–1349, https://doi.org/10.1002/mop.31158

Authors:

GURUPRASATH RENGARAJAN[1], NAGARAJAN RAMALINGAM[2]

[1]Assistant Professor, Department of Electronics and Communication Engineering,
Gnanamani College of Technology, Tamil Nadu, India

[2]Professor, Department of Electrical and Electronics Engineering,
Gnanamani College of Technology, Tamil Nadu, India
e-mail: krnaga71@yahoo.com
ORCID: https://orcid.org/0000-0002-4990-5869

Corresponding author:

GURUPRASATH RENGARAJAN
e-mail: jcetguru@gmail.com, guruprasathr@gct.org.in
ORCID: https://orcid.org/0000-0001-6654-1860