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AN UWB WEARABLE MIMO ANTENNA FOR BIOMEDICAL AND IOT APPLICATIONS

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Abstract : This work presents the design of a novel, low-profile ultra-wideband textile Multiple Input Multiple Output (MIMO) antenna for wearable biomedical and Internet of Things (IoT) applications. The proposed antenna employs a monopole structure with strategically placed triangles and parallel slots on the radiation patch, contributing to an enhanced bandwidth of 159% from 1.64 to 8.83 GHz, with an average realized gain of 3.37 dBi. The antenna is designed on a jeans ($\varepsilon r = 1.7$, $\tan \delta = 0.0025$) textile substrate with dimensions of $60 \times 50 \times 1$ mm³. A comparison of the proposed antenna parameters, such as bandwidth, average realized gain, and radiation pattern, is carried out with existing antennas in the literature. Additionally, the proposed antenna is investigated on the human body, and its specific absorption rate (SAR) for human tissue specimens is examined. The designed proposed MIMO antenna could be useful for wearable applications.

Index Terms – Textile antenna, ultra-wideband antenna, wearable technology, and biomedical and IoT

Introduction

Electronic devices that are worn on the body or embedded in clothing or jewellery, or implanted in the body, are known as wearable technology. Fitness tracking, health monitoring, communication, and entertainment are some of the applications that these devices can be used for. These devices are small, lightweight, and comfortable to wear. Fitness trackers, smartwatches, and smart glasses are some examples of wearable technology that are worn on the body. The devices are capable of tracking a user's physical activity, monitoring vital signs like heart rate, and providing notifications of incoming calls and messages. Smart clothing, such as shirts and pants embedded with sensors, are another example of wearable technology that can be used to monitor health, such as posture and breathing, and provide haptic feedback to wearers to improve their movements.

Wearable technology implants include heart pacemakers, cochlear implants, and deep brain stimulators. They are used to treat various medical conditions and can be controlled wirelessly.

In short, wearable technology is the term for electronic devices that can perform a variety of activities when they are placed on the body, stitched into jewellery or clothing, or implanted within the body. Fitness tracking, health monitoring, communication, and entertainment are just a few of the many ways in which wearable technology can be employed. The future of wearable technology is expected to bring more advanced and sophisticated devices, with a wider range of applications.

The wearable microstrip antenna devices are designed to operate at different frequencies such as ultra-high frequency (UHF), microwave, and millimetre-wave frequencies. These antennas are designed to be integrated into different types of materials, like textile and rubber, to make them more comfortable to wear.

The growing number of wearable has led to demand for lightweight, flexible, fully textile, or optically transparent wearable antennas which can be integrated into clothing or accessories.Depending on the wearable device application (e.g., health care, sports, advertising), antennas can be directly mounted on a human arm, forearm, back, chest, leg, or neck or integrated into a garment or accessory. Due to the presence of the human body, wearable antenna design is very complicated; antennas must meet electrical (bandwidth, radiation efficiency, gain), mechanical (low profile, flexible, lightweight), manufacturing (low cost, simple structure), and safety requirements (specific absorption rate (SAR) below the worldwide standard limits) [2, 3] to be applicable in Internet of Things (IoT) wearable devices.

The assessment of the absorption of electromagnetic energy by human tissues is an important topic to be considered. So are the health risks that could arise as a consequence of exposure to electromagnetic fields (EMFs) produced by a wearable antenna placed on or very close to the human body (24 h/7 days a week) [8]. In the frequency range of 100 kHz to 6 GHz, the SAR is defined as an indication of how much electromagnetic energy is absorbed by human tissues. The SAR limits for local exposures in the considered frequency range were established in recent ICNIRP guidelines and IEEE C95.1-2019 standard. Several previously reported works on fully textile and optically transparent wearable antennas showed that the simulated peak 1 g and 10 g average SAR generated from the antennas in a homogeneous flat phantom, in the chest, upper arm, and the wrist of the HUGO human body model [7], in a multilayer cylindrical human body model [6] and in a forearm phantom [5] varied from 0.22 to 0.533 W/kg (SAR 1 g) and from 0.148 to 0.695 W/kg (SAR 10 g), at 2.45 GHz at a net input power of 100 mW.

I. EXISTING METHOD

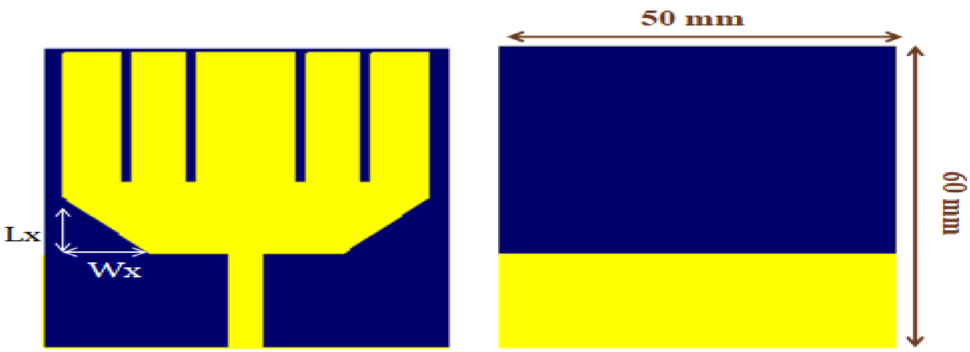
The existing antenna is based on a monopole structure, where two triangles and a few parallel slots are cut at the bottom corners and top edge of the radiation patch, respectively, to achieve an optimized ultra-wide bandwidth and a reduced size of the antenna. Polyester fabrics and conductive Copper taffeta, which are universally available on the market, are selected to construct the antenna. Thus, the fabricated prototypes well suit the needs of wearable applications, where flexible components are required to conform to the curved human bodies. The overall size of the antenna measures 70×50 mm2.The measured results show that the antenna prototype can realize a bandwidth of 109% from 1.198–4.055 GHz with a realized gain of 2.9 dBi. Furthermore, the on-phantom measurements show that there is limited effect on the operating bandwidth and realized gain of the antenna when it is working in the proximity to human bodies. The antenna is used to monitor the recovery process of a bone fracture that is emulated by a body mimicking phantom with a size-varying blood strip. The time domain reflection coefficient of the antenna varies significantly with the size of the fracture introduced, which demonstrates the applicability of the antenna for such use scenarios in microwave medical imaging. . The preliminary antenna geometry is based on a basic monopole structure awhich consists of a radiation patch, a ground plane, and a 50-Ω coplanar-waveguide (CPW) feedline.

Table 1 Dimensions Of The Existing Antenna

Parameter	Value (mm)	Parameter	Value (mm)
Substrate Length	70	Patch Width	45
Substrate Width	50	Slot Length	22
Substrate Height	0.5	Slot Width	1.5
Feed Length	29	LX	4.5
Feed Width	1.5	WX	12.5
Patch Length	40		

II. PROPOSED ANTENNA DESIGN

The antenna is designed and simulated with the finite element software CST MWS software. The proposed antenna geometry is based on a basic monopole structure as depicted in Figure. 1, which consists of a radiation patch, a ground plane, and a 50-Ω coplanar-waveguide (CPW) feedline.



(a) (b)

Figure. 1 The proposed antenna configuration, (a) top-layer, and (b) bottom-layer

The final geometrical parameters of the antenna are listed in Table 2. The antenna has dimensions of 60 x 50 x 1 mm^3 for Biomedical and IOT applications. Whereas the electrical characteristics of a wearable electronic system predominantly hinge upon the conductive materials employed, the flexibility and softness are primarily attributed to the properties of the substrates. In wearable antennas, substrates effectively insulate the antennas from direct contact with the epidermis, thereby minimizing the influence of the human body on antenna performance. Conversely, in wearable circuits, substrates are not imperative for functional maintenance but serve to enhance system stability and mitigate potential risks associated with poorly biocompatible conductors. In the domain of wearable antennas, fabrics have emerged as viable candidates to provide adequate antenna metrics. Therefore, the wearable substrate for proposed design is selected as jeans with dielectric constant of 1.7.

. The antenna is designed to operate at ultrawide band which means that the centre resonance frequency should be 2.4 GHz. Now, ε_r into 1.7, H=1 mm, Z_0=50Ω, and t= 0.035mm.

$$W = \frac{c}{2f_0}\sqrt{\frac{2}{\epsilon_r+1}} \qquad (3.1)$$

$$L = L_{eff} - \Delta L \qquad (3.2)$$

where c is the speed of the light, f_0 is the resonant frequency of the monopole antenna, L,W, L_{eff} and ΔL are the length, width, effective length, and extended length of the radiation patch, respectively. L_{eff} and ΔL are considered due to the fringing fields

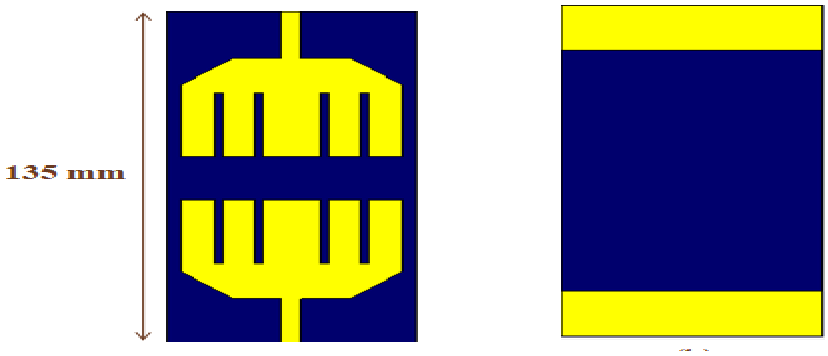


Figure. 2 Design model of the proposed two port antenna

The 3D view of the proposed two port antenna is displayed in Figure. 2. The proposed design is arranged on a jeans dielectric with permittivity 1.7 and loss tangent 0.025 which has an overall dimension of 135 × 50 mm^2. The dual-polarized parallel slot antenna elements with the reduced size of 60× 50 mm^2 are placed at the corners of the substrate. The radiation elements have similar return loss performances providing high impedance matching (around -27.7 dB reflection coefficients) at 1.64 GHz to 8.83 GHz.

Table 2 The final design parameters

Parameter	Value (mm)	Parameter	Value (mm)
Substrate Length	60	Patch Width	20.5
Substrate Width	50	Slot Length	26
Substrate Height	1	Slot Width	1.5
Feed Length	19	LX	11
Feed Width	4	WX	10.5
Patch Length	40	Slot Length	26

III. RESULTS AND DISCUSSIONS

The simulated S-parameters including the reflection coefficient (S_{nn}) and the mutual coupling (S_{nm}) characteristics of the designed dual-polarized MIMO antenna array are shown in Figure. 3 and 4. Clearly, the radiation elements have similar return loss performances providing high impedance matching (around -27.7 dB reflection coefficients) at 1.64 GHz to 8.83 GHz.

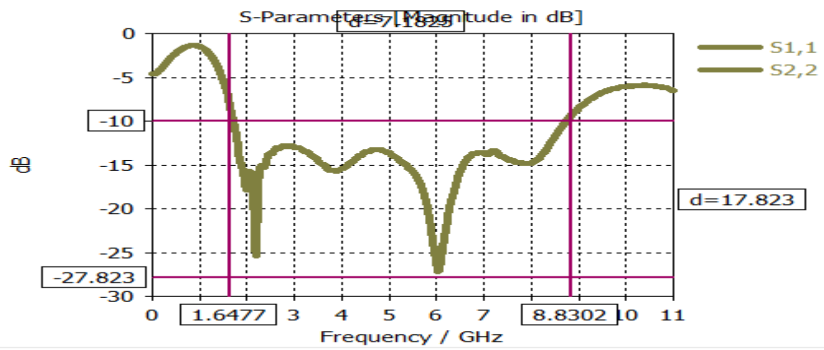


Figure. 3 S_{11}-parameter plot of the proposed two port antenna

Furthermore, as shown in Figure. 4, the mutual coupling function of the antenna elements (less than −15 dB) are good enough to avoid the loss of radiation performance for the wearable antenna. Employing the slot radiators on the proposed MIMO array configuration not only exhibits sufficient bandwidth but also provides almost symmetrical radiation patterns to cover the top and bottom regions of the body.

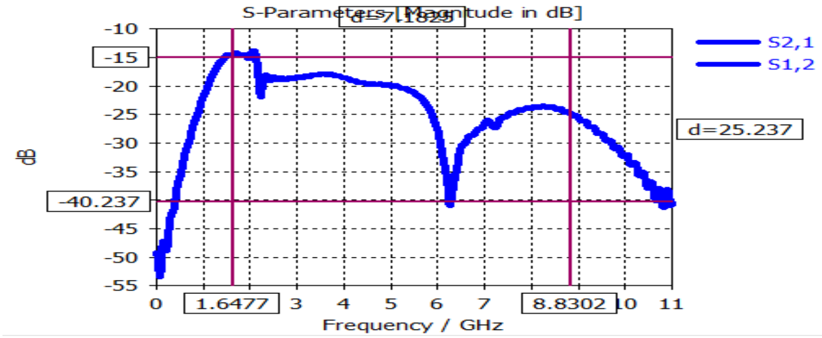


Figure. 5 S_{21}-parameter plot of the proposed two port antenna

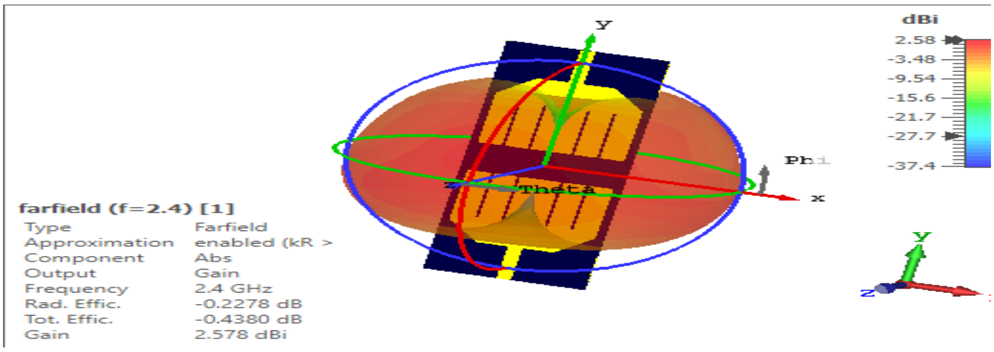


Figure. 6 Gain of the proposed two port antenna at 2.4 GHz

As shown in Figure. 5, and 6, the antenna elements can provide high directivity radiation patterns covering the top and bottom sides of body and improving the coverage efficiency function.

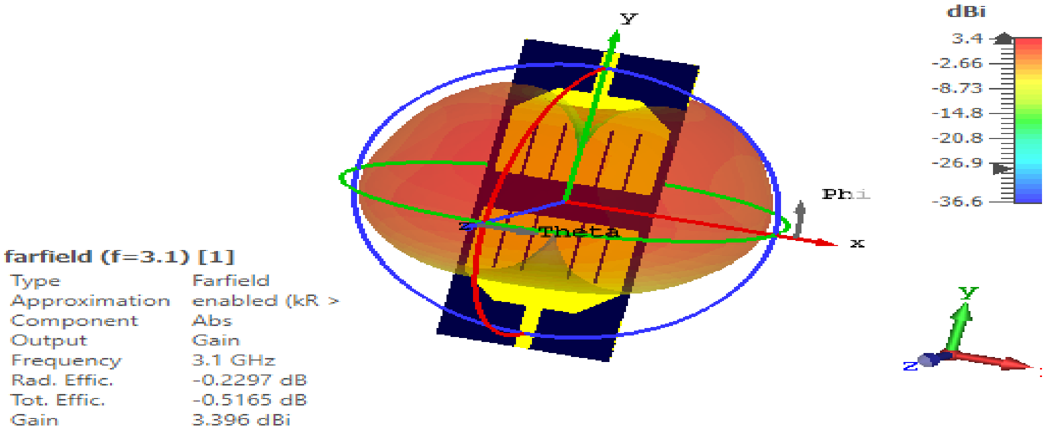


Figure. 7 Gain of the proposed two port antenna at 3.1 GHz

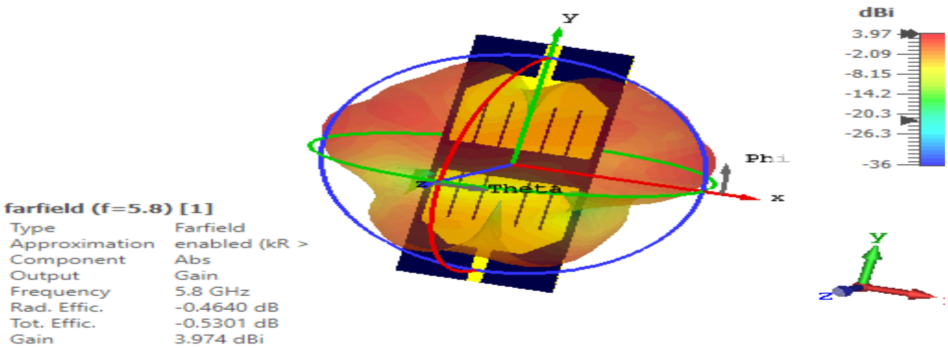


Figure. 8 Gain of the proposed two port antenna at 5.8 GHz

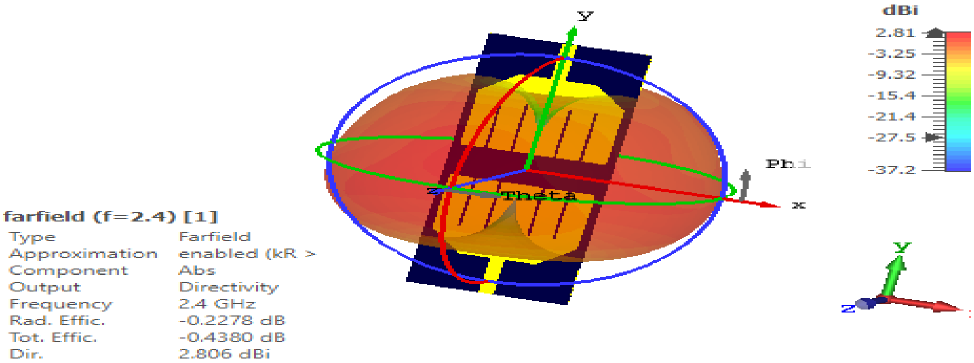


Figure. 9 Directivity of the proposed two port antenna at 2.4 GHz

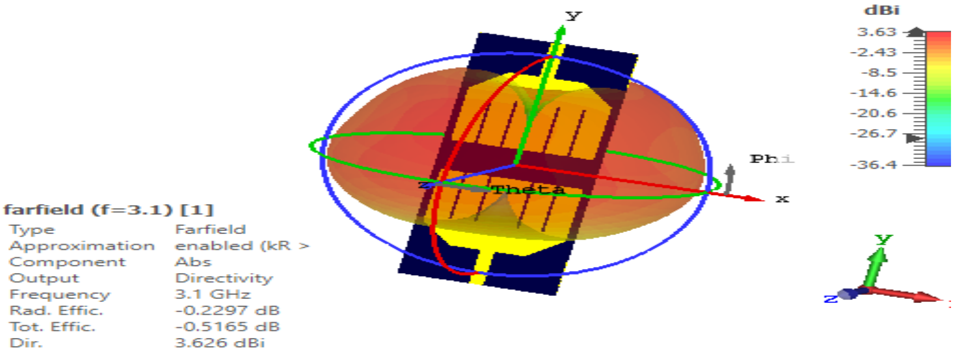


Figure. 10 Directivity of the proposed two port antenna at 3.1 GHz

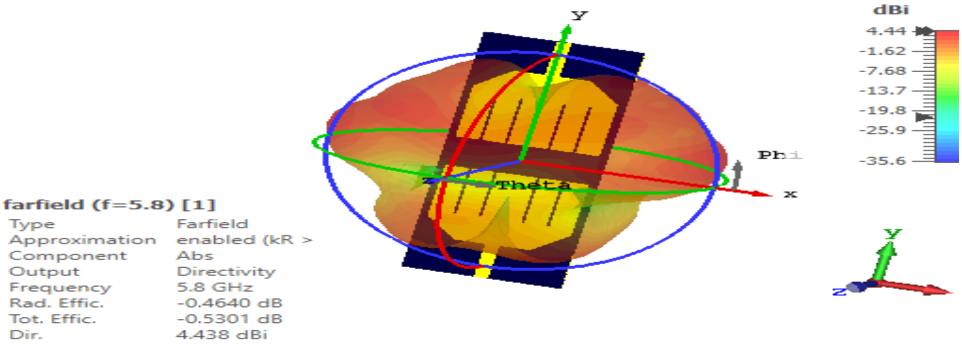


Figure. 11 Directivity of the proposed two port antenna at 5.8 GHz

Figure. 6 to Figure. 11 displays the 3D top-views of the radiation patterns for each antenna elements deployed in the proposed two port antenna. It can be seen, each top side of the substrate can be covered by the radiation patterns of the radiators. At the same time, due to the dual-polarized characteristic of the antenna elements, different polarizations for each region of the body can be achieved which make the MIMO antenna system suitable for the future biomedical and IoT applications. As illustrated, the antenna elements have high radiation efficiencies. They also provide more than 75% total efficiencies at the resonance frequency (2.4, 3.1 and 5.8 GHz). Furthermore, for the frequency range from 1.64 to 8.83 GHz (ultra wide band), maximum 80% efficiency characteristics have been achieved for the radiators of the proposed two port antenna.

SAFETY ASSESMENT

Specific Absorption Rate (SAR) is a measure of how transmitted RF energy is absorbed by human tissue. The SAR is calculated by averaging (or integrating) over a specific volume (typically a 1 gram or 10 gram area). According to the IEEE C95.1-2019 standards, the SAR value for 1g/10g of human tissue should be less than 1.6/2.0 W/kg . For an input power of 0.01 W, the simulated SAR values for 1g of tissue were found to be 0.56 W/Kg at 2.4 GHz.

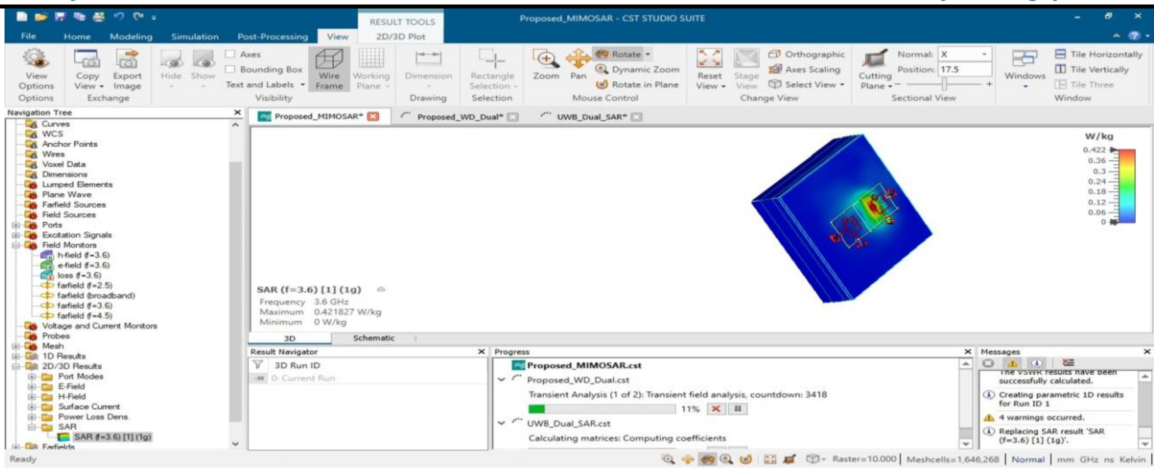


Figure. 12 SAR measurement on CST MWS software

Table 3 Comparative Analysis of the proposed antenna with the reported antennas

Ref.	Antenna Size (L × W × H) (m^3)	Operating Band (GHz)	Antenna type	Fractional Bandwidth (%)	Avg. Realized Gain (dBi)
[1]	80 × 45 × 1.6	1.25-2.4	Omnidirectional	63	2.5
[10]	70 × 50 × 0.5	1.198-4.055	Omnidirectional	109	2.85
Proposed	**60 × 50 × 1**	**1.7 - 8.8**	**Omnidirectional**	**135**	**3.37**

IV. CONCLUSION

Based on the obtained results, it can be concluded that, the proposed antenna has a compact size with a simple configuration, and it operated 1.64–8.83 GHz band with Average radiation efficiency of 91.5%, and high level of impedance matching, where VSWR is less than 2 and the return loss is better than -10 dB.

Therefore, the proposed textile monopole antenna can be operated with good performance at the desired band (1.64–8.83 GHz), and it can be used for Biomedical and IoT Applications. An UWB wearable textile MIMO antenna offer a combination of high performance, flexibility, comfort, and cost-effectiveness, making them ideal for various biomedical monitoring and IOT connectivity requirements.

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