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DESIGN TRENDS IN ULTRA WIDE BAND WEARABLE ANTENNAS FOR WIRELESS ON-BODY NETWORKS

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ABSTRACT

The recent significant researches on Ultra Wide Band Wearable Antenna (UWBWA) for Wireless on-Body Area Networks (WBAN) are elucidated in this paper. The most sought technology by industrialist and academicians is UWB due to its enriched features such as low cost, high data rates, low energy requirements, high operating bandwidth and radiation efficiency. The wearable, fabric-based antenna is the prime research area in antennas for body-centric communications. This paper provides a thorough understanding of the available methods in designing the UWBWAs for wireless on-body area networks highlighting the merits and demerits. It also offers an insight and scope to explore new antenna designs that augur to meet the ever-growing demands of the UWBWA applications.

Keywords: wireless body area networks (WBAN), ultra wide band wearable antenna (UWBWA), body-centric wireless communication systems (BWCS).

1. INTRODUCTION

Wireless Body Area Network (WBAN) is also known as Wireless Body Sensor Network of wearable components. WBAN is the foremost key component in the infrastructure for patient centred healthcare applications and it can be wearable or implanted. Wearable WBANs are considered for both medical and non medical applications. WBAN technology provides an unparalleled opportunity for ubiquitous concurrent healthcare and fitness monitoring in ambulances, emergency rooms, clinics, homes and support to people with disabilities [1]. In the recent years, there has been increasing anxiety about the safety of wearable electronics over a host of applications including medical, entertainment and military. WBAN allows wireless communication from or to the body via wearable and conformal antennas. Therefore wearable antennas play a crucial role in wireless on-body centric communications and draws significant attention in research. As wearable antennas function in close proximity to the human body, the loading effect due to the lossy nature of body tissues coupled with their high conductivity and dielectric constants, makes the design of high radiation efficiency antenna a challenging one. Therefore the requirements of wearable antenna for modern applications are light weight, low cost, almost maintenance-free and no installation [2].

Ultra Wide Band (UWB) technology based wireless systems and devices with the frequency allocation of 3.1-10.6 GHz by FCC (Federal Communications Commission) support low output power, low cost and high data rate (110-200 Mbps) applications over short ranges (4-10 m) [3,4]. The UWB signal uses Orthogonal Frequency Division Multiplexing (OFDM) as the modulation scheme to accomplish wide frequency band. UWB antennas must be electrically small and inexpensive without compromising on their performance. It can be efficiently used for WBAs due to its large bandwidth and ultra low power consumption. The low transmitted power in UWB systems limits the applications to short range or to moderate data rate. The objective is to find solutions that make the best possible use of radiated and received power for the future commercial realization of UWB communication systems [5].

Body-Centric Wireless Communication Systems (BWCS) is the brain of future communications. It is classified as on-body, off-body and in-body communications as shown in Figure-1. On-body communication is the communication between wearable devices. The communication between an external and an on-body device is termed as off-body communication. In-body communication is the communication using implantable devices or sensors inside the body. Among these, implantable antennas face more challenges due to the poor and intricate in-body working environment [6].

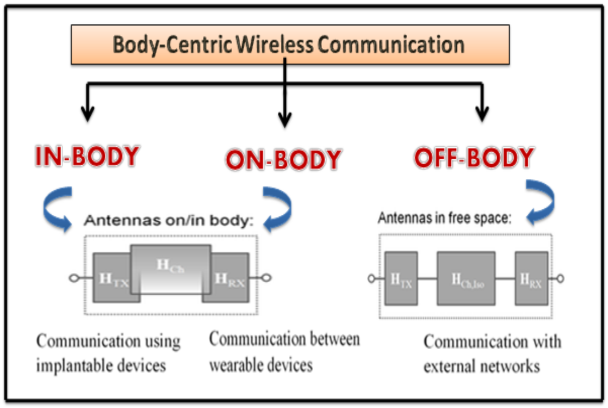


Figure-1. Description of body-centric wireless communication.

One of the foremost research topic in antennas for BWCS is wearable, fabric-based antennas. It is applicable in many employment segments such as fire armed forces, military and paramedics. The wearable antennas can also be applied for monitoring the health of all age group people including sportsmen. Textile antenna provides a wearable boundary between human and the machine. Designing of textile antenna requires the awareness on electromagnetic properties such as permittivity and loss tangent of the textile material [7].Conductive textile materials such as Flectron, pure copper, Zelt and Polyester taffeta fabrics have been regularly used as the radiating element while non-conductive textile materials such as fleece and silk have been used as substrates.

The paper is organized as follows; Second section represents the overview of the requirements related to the design of UWBWA. Third section examines the different wearable antennas, operating frequency bands, simulation test methods and design environments. Finally, the conclusion is presented in fourth section.

2. UWB REQUIREMENTS AND DESIGN PARAMETERS

Based on the various studies dedicated to evaluating the performance of UWB, the UWB system must provide:

- High gain transmissions in the desired direction
- Low profile
- Broad operating bandwidths for impedance matching
- High transmission efficiency
- Stable transmission patterns and gains
- Consistent group delays

The source pulses and design considerations of the UWB antennas are also based on transfer functions, system efficiency, S parameters, group delay and fidelity.

Design parameters for UWB wearable antenna

The parameters that have to be considered while designing the conventional antennas are radiation pattern, directivity, gain, transmitting power, input impedance, radiation resistance, equivalent height, bandwidth, beam width, polarization, front-back ratio, bit error rate, return loss, thermal noise, reflection co-efficient and efficiency. When designing UWB antenna for wearable applications, the additional parameters to be calculated are transfer function, path loss, group delay, fidelity etc.

While designing wearable antennas, one of the major concerns is choosing the substrate. Typically for flexible and wearable antennas, the substrate materials chosen are textiles or plastics. The textile material has a low relative permittivity (<2), suffers from trapped air and has variable electrical characteristics due to water content. Plastics, for example polypropylene, are not well suited to wearing close to the skin even with the same relative permittivity as that of textile material. Neoprene is a material commonly seen in scuba diving suits and also in sporting clothes [8]. It is durable, has good thermal properties, permittivity greater than 4 and generally reliable in density. Therefore, it has been selected as a good choice for wearable antennas.

Liquid Crystal Polymer (LCP) is a promising applicant for its flexibility, light weight, low loss factor and low cost characteristics [9]. LCP is a recyclable organic substrate which has a uniform relative dielectric constant in the range from 2.9-3.1 over the entire Radio Frequency (RF) band. The extremely low dissipation factor of 0.002 and low water absorption factor of 0.004 makes LCP a perfect choice for circuits operating in special conditions and environments. UWB antennas for body-centric wireless communication have been discussed extensively in the open literature [10-13]. But there is less literature about conformal antennas especially about the bending effect for UWB body centric communications. The bending effect of single band meander antenna on LCP at 5 GHz has been clearly explained by Nevin Altunyurt *et al* [12]. The impact of bending on UWB antenna performance using a copper film, and an AgHT-8 film as substrate has been elucidated by T. Peter *et al* [13].

3. DESIGN METHODOLOGIES OF UWB WEARABLE ANTENNAS

This section details the various development techniques, design methods and implementation of various antenna applications being used in the recent years. The Ultra Wide Band Antennas [14] have been categorized as follows:

- Multiband, Omni UWB Antennas
- Multiband, Directional UWB Antennas
- Omni, Impulse Radiating UWB Antennas
- Directive, Impulse Radiating UWB Antennas

The most preferred wearable antennas integrated into clothing are Microstrip antennas [15- 23] with flexible conductors and substrates. This has led to an increased demand for Electrical Technical Textiles (ETTs). The significant advantages of Microstrip antennas for on-body wearable applications being their ease of construction, cost effectiveness, and has resulted in less energy absorption by the body. The limitation of Microstrip antennas are low bandwidth and relatively larger in size [17]. Sanz-Izquierdo had employed a circular metal nail in some buttons to create the radiating element of the Compact UWB Wearable Antenna for wireless on body applications [23]. An antenna design for UWB wireless communication systems [24] has been presented with time domain characteristics and optimization by Genetic Algorithm. Kumar et al [25] had designed a HEMT-based circuit for the generation of short pulse (Figure-2) which overrides the disadvantages of conventional methods.

Qammer H. Abbasi had presented a review on UWB antennas [26] that detail about antennas to be deployed for body-centric communications, characterization of UWB on-body channels and UWB on body system modelling techniques. A compact and conformal UWB antenna for wearable applications (Figure-3) had been discussed by Md. Hasanuzzaman Sagor [27] that details the possibility of using LCP as a substrate. It addresses the issue of declining performance due to bending in both time and frequency domain.

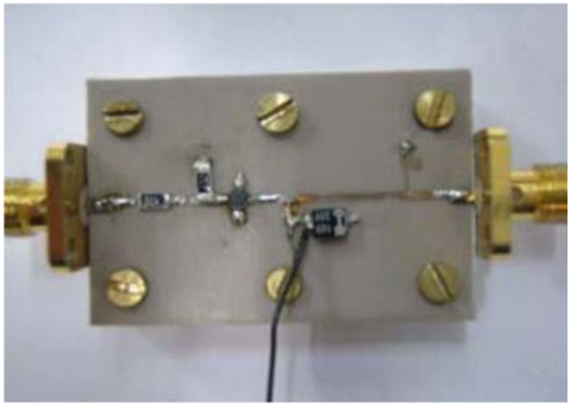


Figure-2. UWB pulse generation circuit.

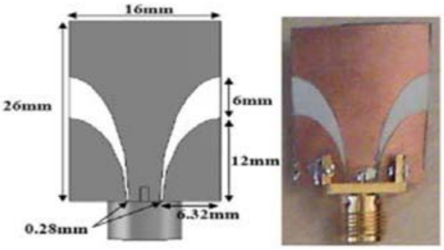


Figure- 3. Compact UWB antenna.

Many researchers have developed various dual band and multi band antennas [28] - [30] such as M-shaped patch antenna and Dual band Fork-shaped patch antennas (Figure-4 and 5) for different wearable applications.

Figure-4. M-shaped patch antenna.

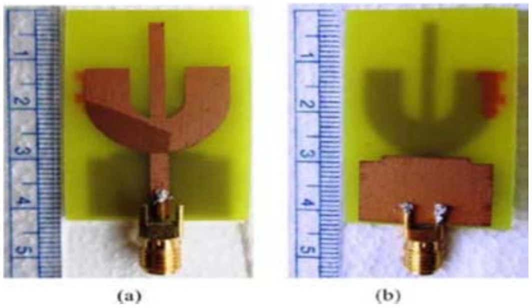


Figure-5. Dual band fork-shaped patch antenna.

Mohsen Koohestani [31] had designed Coplanar-fed UWB monopole antenna with a dome-topped, bowl-shaped radiating element and a 50 Ω coplanar feed line excitation as shown in figure-6. Md. Shad Mahmud *et al* [32] developed compact, logotype textile antenna structure for two sets of resonance frequencies 1.2985 GHz to 1.986 GHz and the second band from 3.678 GHz to 21.167 GHz. Hypalon coated Dacron fabric textile material has been used as substrate of permittivity $\varepsilon_r = 3$, thickness of 1.6 mm and woven copper thread as the conductive part of the antenna patch.

There has been a remarkable increase in the interest of researchers to create notch filters [33-34] for preventing various interference effects in UWB antennas. Shilpa Jangid and Mithilesh Kumar have proposed a Novel UWB Band Notched Rectangular Patch antenna with Square slot [33] with FR-4 substrate having $\varepsilon_r = 4.4$, thickness of 1.6 mm and a compact structure with a total size of 15×14.5 mm^2 as shown in figure-7. The design of an UWB band-notched wearable antenna (figure-8) was briefed that uses an ultra-thin LCP substrate with a thickness of 0.05 mm and a copper layer of only 0.018 mm on the LCP [35]. The return loss and radiation pattern of this antenna shows negligible variations when bent at different angles (15°, 30°, 45°, and 60°) as shown in figure-9 or placed in adverse conditions.

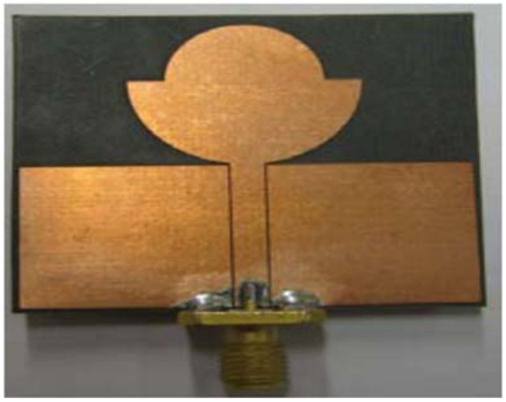


Figure-6. Coplanar-fed UWB monopole antenna.

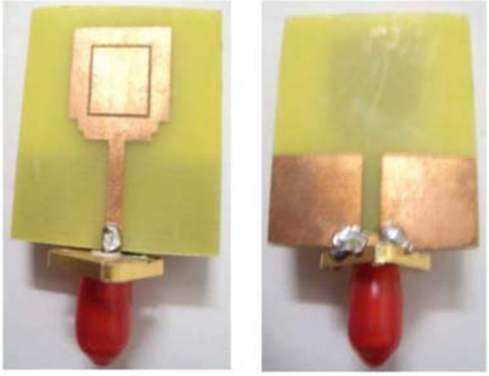


Figure-7. Band notched rectangular patch antenna.

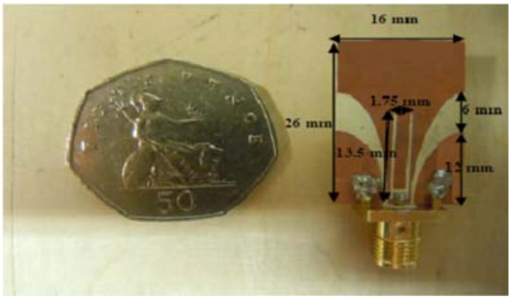


Figure-8. UWB band-notched wearable antenna

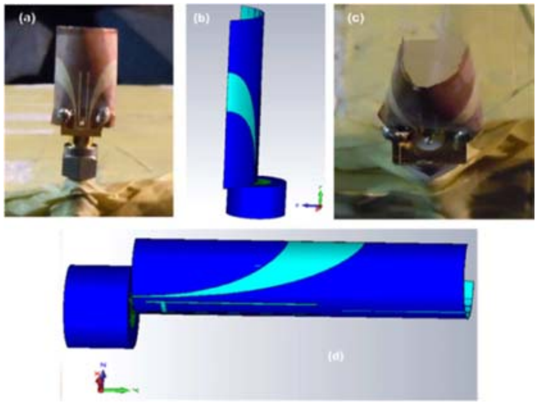


Figure-9. Antenna bent at different angles.
(a) 0º (b) 15º (c) 45º (d) 60º

A reconfigurable antenna for wearable application [36] is elucidated in which the direction of the radiation pattern has been reconfigured. The radiating element of this antenna has been created by stitching the conductive thread instead of copper metallization ,with LCP as ground plane and the substrate being jeans fabric with ε_r=1.7. Multiple bands, multi polarized and multiple sector structures have also been presented in the literature [37]-[39].

Recently, the performance of the antenna has been improved by using fractal geometries based on space filling and self-similarity attributes. The space filling has been implemented with different feeding methodologies like microstrip lines and Co-Planar Waveguide (CPW) transmission-line feed method [40-44].

One of the most important parameter in the design of a wearable antenna is the selection of substrate for the fabrication of antennas. The impact of substrate materials in the design of UWB modern antennas has been presented by Gerard Rushingabigwi *et al* [45]. The performance of microstrip monopole antenna has been analysed with different substrate materials for a bandwidth of 3.3 - 5.8 GHz and with a return loss of below -10 dB. Among all the substrate materials, RO3003C proved to be superior and more competitive as shown in Table-1 in terms of optimal fractional bandwidth, maximum radiation gain and impedance matching. The Rogers 3003C substrate has comparatively less return loss than other substrates as shown in Figure-10.

Table-1. Antenna bandwidth and gain with different substrates

Substrate	Relative permittivity (ε_r)	Fractional bandwidth at 3.8 GHz	Radiation gain (dB)
Rogers (RO3003)	3	63.2%	4.31
Rogers (RO3003C)	3.8	67%	4.23
FR4 (Epoxy)	4.4	63.17%	3.83

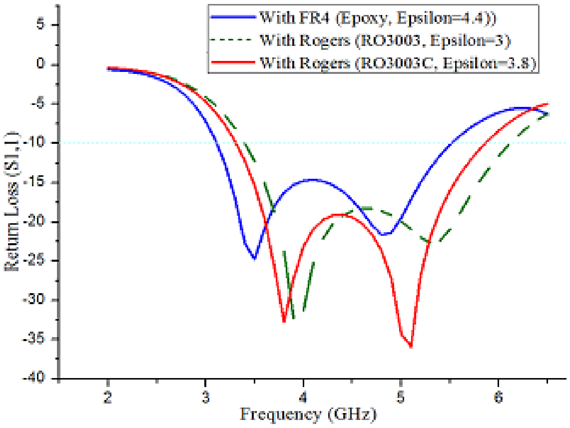


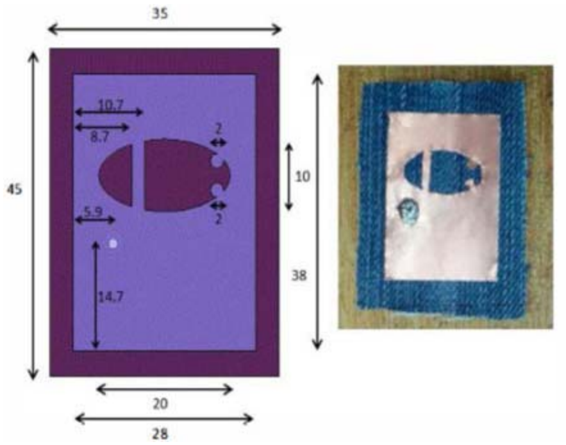
Figure-10. Return loss with different substrates [45].

Reshma Lakshmanan *et al* have presented UWB coplanar waveguide patch antenna [46] using natural rubber as the substrate due to its flexibility, versatility and light weight. It is used as a body worn antenna for WBAN. The cost of antenna has been significantly reduced with rubber as substrate due to its high relative permittivity of 9.39.The comparison of performance metrics with different substrates is presented in Table-2.

Table-2. Comparison of performance metrics with different substrates.

Substrate	Permittivity	Peak gain (dB)	Radiation efficiency (%)	Radiation pattern
FR4	4.4	1.7	97	Omni directional
Rubber	9.39	8	93	

J. C. Wang *et al* [47] has reviewed wearable textile antennas with five different patch structures such as On-body Textile antenna, Dual Band Diamond Textile Wearable antenna, Polygon Shaped Slotted Dual band antenna, Small Planar UWB Wearable antenna and Compact UWB Wearable antennas. The Planar On-body textile antenna[48] has been fabricated using jean as the substrate with ε_r of l.68, a loss tangent of 0.01, thickness of 1 mm and copper tape as the radiating element that yields flexible conformal antenna as shown in Figure-11. The slots in this antenna are designed to attain adequate bandwidth, high gain and minimum antenna parameter variations when in close proximity to the human body. This antenna has been designed with a high gain of 12.8 dB with phantom and 13.2 dB without body phantom.



(a) (b)

Figure-11. Planar on-body textile antenna (a) Antenna design (b) Fabricated prototype.

The diamond shaped dipole antenna for wearable applications [49] has been presented with an improved bandwidth and efficiency over the standard dipole as shown in the Figure-12. The antenna has been designed with a dielectric constant of 1.7, copper foil tape with high conductivity of 5.88x 10^7 and a thickness of 0.035 mm as the conducting element. The performance of this antenna has been investigated using Computer Simulation Technology (CST) software under three conditions: free space (no body phantom), 3 mm from the backside of the phantom and in the same position but with the 3 mm gap filled with a layer of washed clothes. The results at 2.45 GHz and 5.8 GHz have been presented in Figure-13.

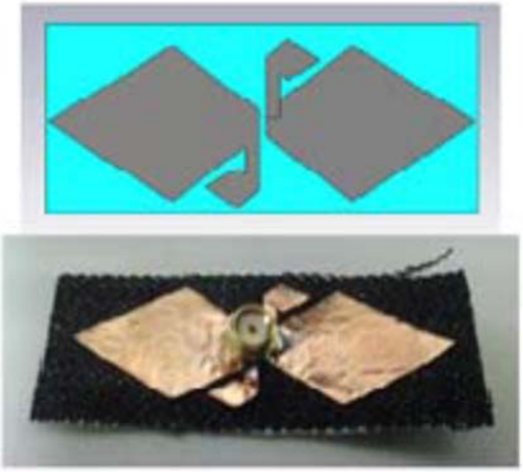


Figure-12. Diamond-shaped dipole dual antenna.

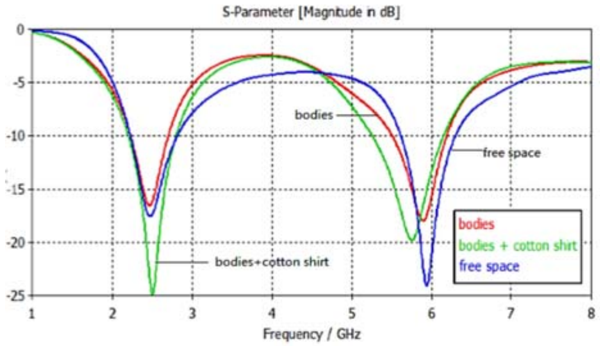


Figure-13. Return loss of textile antenna in free space with bodies, and with bodies and cotton clothes [49].

A polygon shaped patch antenna with a ring shaped slot has been presented by E. F. Sundarsingh [50] that reduced the patch area and increased the electrical length. The fabricated dual-band antenna (Figure-14) has been designed with a jean fabric as substrate of thickness 1mm, loss tangent of 0.025 and is located in between the ground plane and patch. The results with directivity of 8.1dBi at the higher and 7.4 dBi at lower resonant frequencies have been presented.

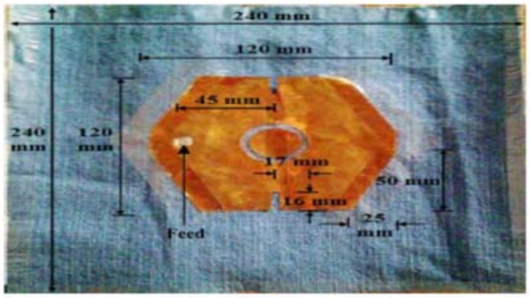


Figure-14. Fabricated polygon shaped slotted dual band antenna.

The fabrication of Small Planar UWB Wearable antenna [51] has a substrate made of jean with the dielectric constant of 1.76, a loss tangent of 0.078 and a metal radiator (adhesive copper tape) has been discussed as shown in Figure-15.

(a) (b)

Figure-15. Small planar UWB wearable antenna (a) front view (b) back view.

The Compact UWB Wearable Antenna has been designed [52] to improve the impedance and bandwidth by combining slot and truncation techniques with a flexible jean substrate and metallic radiator is shown in Figure-16.

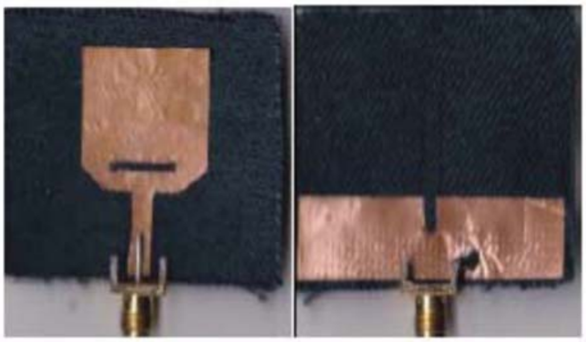

(a) (b)

Figure-16. Compact UWB wearable antenna (a) front view (b) back view.

The return loss of below -10dB has been obtained for the Compact UWB Wearable antenna in the presence of the human body. The bandwidth has been improved up to 86.48% by taking the upper frequency limit as 10.6 GHz and lower frequency as 4.2 GHz. The maximum gain of 2.74 dB at 3.0 GHz, 4.17 dB at 7.0 GHz and 4.07 dB at 9.0 GHz have been achieved. This study substantiates that the patch antenna is a good candidate for wearable applications due to its low profile and easy fabrication.

4. CONCLUSIONS

The UWB antennas for wearable application development have been depicted. It is indispensable to be thorough with the history of the antenna art for any antenna designer to build novel designs rather than renovate the antennas of previous generations. The main mission of this review is to assist the researchers in the field of UWB Wearable Antennas for Wireless on-Body Area Networks to be aware of the available techniques, challenges and adopt the same in various application environments.

Using textile materials as substrate, helps to reduce the surface wave losses and enhance the overall bandwidth. Several health risks are possible due to extended exposure of electromagnetic radiations with a wearable textile antenna on the human body. Minimization of Specific Absorption Rate is therefore a challenge for wearable antennas. The antenna performance and robustness under deformations (bending, crumpling, wrinkling, wetting) have to be investigated and incorporated into the design of wearable antennas to meet conformal requirement.

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