

# Flexible Wearable Antennas for Body Area Network

Vilas S. Ubale, O. S. Lamba

**Abstract:** In recent years, wearable antenna design has grossed research interest amongst academicians and researchers due to its versatile application in body area networks for transmitting/receiving signals in sufficiently large areas such as ICU, trauma centers in hospitals for biomedical applications at ISM (2.45 GHz) frequency range. A wearable antenna is highly flexible in nature making it popular and demanding. What makes it even more suitable for biomedical applications is its simple design methodology and ease of integration on patient's dress/clothes for antenna placement in wireless communication. This paper presents a thorough investigation of various antenna design methodologies to design a flexible wearable antenna that can be mounted on textile material for body-centric wireless communication. The traditional antenna design uses non-flexible substrate materials (such as FR-4, RT duroid, foam, etc.) having medium to high dielectric constant. This results in generation of surface wave losses which reduces antenna transmission capabilities. Flexible wearable antennas, on the contrary, use ordinary textile materials used as a substrate whose dielectric constant is very low thereby providing reduced surface wave losses. As wearable antennas are mounted on textile fabrics it is possible to use these antennas to implant them on patients' bodies (inside/outside on the clothes) for transmitting the patients' body parameters (such as body temperature, heart rate, etc.) measured using various sensors/transducers. In this paper, a thorough review of different types of substrate materials used for designing flexible wearable antennas is done.

**Keywords:** Body area network, Flexible antenna, Wearable antenna

## I. INTRODUCTION

Body area network, in wireless communication, is termed as a collection of small lightweight sensors placed on the human body to measure various physical parameters [1]. The network of such intelligent systems permits the doctors and his experts to consistently ensure the health of patients and acquire the response [2]. Very small sized microelectronics sensors installed on the patient's human body or clothes or even implanted inside the human body converts the physical parameters (such as blood pressure (BP), oxygen level, pulse rate, etc.) into electrical signals which are hardwired transmitted to the monitoring stations. These parameters are continuously monitored from remote station and provide the lifesaving drugs to the patient through medical experts or by the actuators implanted on the human body [2]. However, hardwire transmission of signals can become cumbersome, particularly, wherein various parameters are to simultaneously.

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Wireless transmission in these situations will provide added advantage. Hence, flexible wearable antenna design is becoming popular choice of research in biomedical application design. Textile materials are commonly used which are easily available is a promising material to design and develop wearable antennas for body area networks. Thin and robust fabric antennas integrated into RF circuits are capable to sense, communicate and collect data in body area network. The design of wireless body area networks mainly focuses on designing efficient antenna systems. Different types of textile antennas are manufactured and used satisfactorily to transfer signals between two points on human body. Antennas in body-area networks need to be compact in size, light in weight and, flexible allowing its integration on clothes. An antenna designed from 400MHz to few GHz frequency ranges if placed close to the human body experiences high radiation, frequency detuning and changes in impedance and efficiency [3]. Antennas for wireless communications in body area network use Inverted F antenna (IFA) [4], low-Profile microstrip antenna [5], wearable (fabric) and sleeve Antenna [6-9]. Wearable antennas normally placed near to the human body are affected by the biological tissues resulting in deterioration of antenna performance [10]. Dielectric characteristics of the human body may vary at millimeter and microwave frequencies [11]. Moreover, the dimension and size of a human body are electrically higher at millimeter frequencies associated with microwaves.

## II. CONTRIBUTIONS

The key objective of this review paper is to present various methodologies proposed for designing flexible wearable antennas, materials used for embedding wearable antenna and design challenges in implementing wearable antennas for wireless communication in body area networks. The main contributions are as follows:

- Critical literature review for identifying current research developments in flexible wearable antenna design.
- Identify gaps in research through detailed literature review and present challenges in wearable antenna design.
- Opportunities for RF engineers in developing innovative design solutions to meet needs of antenna for wireless communication in body area networks, specifically for biomedical applications.

III. WEARABLE ANTENNAS: DESIGN METHODOLOGIES AND SUBSTRATE MATERIALS

A. Conventional Wearable Antenna Designs

Conventional antenna design for wearable antenna is largely focused on monopole antenna, coplanar dipole antenna, planar inverted-F antennas (PIFAs), and Microstrip patch antennas. A printed circuit board (PCBs), commonly made of FR-4 (Fire Retardant) substrates are used for manufacturing microstrip antennas. Due to its low cost and easy for manufacturing this type of antennas are popular choice for the practical implementation of antenna system. A PIFA antenna for wearable applications implanted on a sleeve of shirt is reported in [12]. PIFA's normally are quarter-wave ( $\lambda/4$ ) monopole antennas, whose folded structure is parallel with the ground plane, as shown in Fig 1.

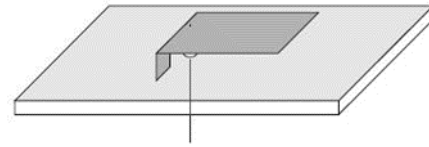


Fig1: Planar inverted-F antenna (PIFA) mounted on sleeve of a shirt for wearable application [12]

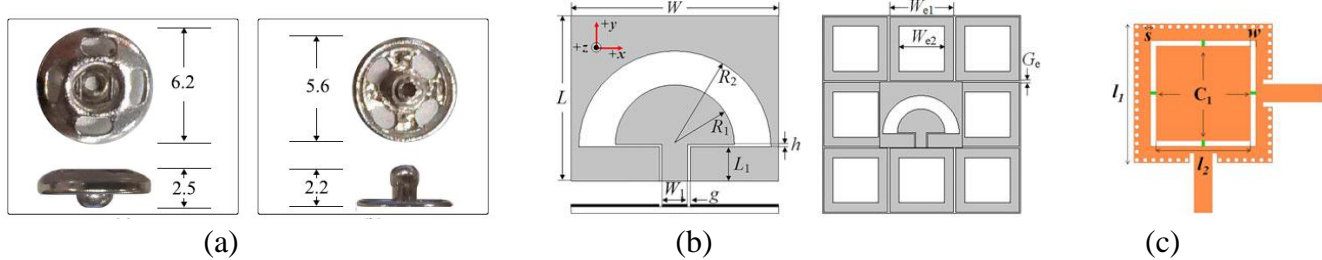
B. Textile Antenna Designs

The ordinary textile material is used as substrate for the manufacturing these types of antenna. Due to flexible nature of the textile material such type of antenna can be used for wearable applications. Circular polarization is required in applications scenarios where the antenna wearer is mobile. A textile antenna with circular polarization characteristics is firstly reported in [13]. A circular polarised antenna radiates energy in all planes [14]. A circularly polarized antenna can receive signals even if its orientation changes.

TABLE I: EXISTING WEARABLE ANTENNA DESIGN AND ITS ANALYSIS

Sr. No.	Ref No.	Year of publication	Research focus and outcomes
1	[15]	2018	<p><b>Focus:</b> A Z-shape flexible wearable microstrip patch antenna placed on thyroid gland for detection of cancer cells is designed over textile. For antenna design, textile silk material is used as substrate as silk has very low SAR (Specific Absorption Rate).</p> <p><b>Outcomes:</b> When this Z-Shaped Microstrip patch antenna placed on thyroid gland of human tissue its performance varied (gain and electrical conductivity changes were observed). The human tissue properties were analyzed for cancer affected/not affected area and it is found that the gain and electrical conductivity of antenna changes in cancer affected area as cancer cell consists of more water content as compared to normal cells. While inserting the antenna on endocrine it's conjointly determined that the operating frequency of Z-shape patch antenna changes with silk substrate wearable antenna. This type of antenna is very useful for detecting thyroid cancer by placing such antenna on human body.</p>
2	[16]	2018	<p><b>Focus:</b> A compact multi-in multi-out (MIMO) wearable antenna of size <math>38.1 \times 38.1 \text{ mm}^2</math> is fabricated on textile material of 2 mm thickness. A four-element high impedance surface (HIS) is used to get 2dBi improvement in gain.</p> <p><b>Outcomes:</b> This antenna is easy to integrate on textiles because it has only one conducting layer. A small size high impedance surface (HIS) with circular shape structure is used to make the antenna small, compact and low profile antenna. These types of antennas are widely used for wearable applications. The antenna is intended to work for ISM band i.e. 2.4GHz to 2.49 GHz. This frequency is used in wireless communication for local area network applications. The port-to-port isolation of less than 15dB is achieved to avoid the mutual coupling of the MIMO antenna.</p>
3	[17]	2018	<p><b>Focus:</b> A textile compact single-layer MIMO antenna having dimensions <math>38.1 \times 38.1 \times 2 \text{ mm}^3</math> is presented.</p> <p><b>Outcomes:</b> A textile substrate is used for fabricating the antenna so that it can be used for wearable applications. Different characteristics of the antenna is thoroughly analyzed to evaluate its performance. A small ground plane acts as the main radiator in this MIMO antenna. This radiator is formed due to two strips along with two orthogonal edges which are in capacitive nature. Linear polarization with '8' shaped radiation pattern is achieved. Isolation of above 12db is achieved due to quasi-orthogonal radiations which are generated by the 2 antennas.</p>

4	[18]	2018	<p><b>Focus:</b> A printed antenna for wearable and RFID applications in the UHF band is presented.</p> <p><b>Outcomes:</b> High hardness with regards to the human body coupling is obtained by limiting the electrical energy density in the border area of antenna. The projected configuration additionally provides compact implementation and high flexibility of antenna making it is simple to adjust in various industrial/commercial chips.</p>
5	[19]	2018	<p><b>Focus:</b> A compact flexible wearable antenna design on textile material operating in ISM band (2.45 GHz) is presented and verified. The presented antenna consists of an inverted E-shaped antenna having an oblong window/cut with inserted strip line.</p> <p><b>Outcomes:</b> This type of structure is simple, compact, and easy to manufacture on any standard textile material. A size reduction of about 75% less than a standard antenna is reported due to the unique antenna geometry. A less bending effect is observed in antenna performance when undergone deformation.</p>
6	[20]	2018	<p><b>Focus:</b> A very simple and best-suited antenna for wearable applications is presented. The antenna is fabricated on fabric material and has reconfigurable characteristics.</p> <p><b>Outcomes:</b> The presented antenna uses active elements like varactor diodes or PIN diodes with its necessary biasing elements to achieve frequency reconfigurable characteristics. The antenna is placed on the back-to-back commercial snap-on buttons. The antenna offers reconfigurable characteristics for fabric antennas and is also safe as it maintains stable electrical connections with flexible metalized fabric. The tuning range of such is 32.8% and 8.8% for its two operating bands i.e. 2.45GHz and 5.8 GHz ISM bands, respectively.</p>
7	[21]	2018	<p><b>Focus:</b> An electromagnetic bandgap (EBG) structure is used for antenna is design. A round shape ring slot type wearable antenna is proposed for wireless body area networks. A thorough analysis of the equivalent model of antenna and the EBG structure that minimises the size of antenna is presented.</p> <p><b>Outcome:</b> A 50Ω impedance bandwidth is achieved over the frequency range of 2.28GHz to 2.64GHz for ISM band applications. A very low measured SAR is achieved i.e. 1g as per US standards and 10g as per European standards.</p>
8	[22]	2018	<p><b>Focus:</b> A dual-band dual-polarized flexible wearable antenna is presented. The antenna consists of a substrate integrated waveguide (SIW) resonant antenna, based on a composite right-left-handed (CRLH) structure.</p> <p><b>Outcomes:</b> SMD (Surface mount device) capacitor is mounted on the top layer of SIW to provide required reactance. The antenna resonates at two frequencies i.e. at 1.78GHz with a right-hand circular polarization beam and at 5.36GHz with a left-hand circular polarization beam. Dual orthogonal feedlines are used to provide polarization-swift characteristics at both operating bands.</p>
9	[23]	2018	<p><b>Focus:</b> A flexible, wideband antenna made by using a flexible magnetodielectric polymer-based nanocomposite layer covered by Kapton substrate is presented. The presented antenna resonates at 1.8 GHz – 2.45 GHz providing services for personal wireless communication (PWC) application and at 5.15 GHz–5.825 GHz providing services for wireless local area network (WLAN) applications.</p> <p><b>Outcomes:</b> The novel nanocomposite layer is dependants on carbon-coated cobalt (CCo) and is coated with a conjugated polymer, polyaniline (PANI). When relative permeability, dielectric permittivity, and conductivity of such nanocomposite PANI/CCo is checked using electron microscopy it is found to be 5.5, 4.3, and 7500 S/m, respectively.</p>
10	[24]	2018	<p><b>Focus:</b> A highly flexible antenna design on polydimethylsiloxane (PDMS) with implanted conductive fabric for wearable applications is presented. Polydimethylsiloxane is used as a substrate with embedded conductive fabric as radiator which eliminates the issue of poor adhesion of metal to fabric.</p> <p><b>Outcomes:</b> This type of combination allowing for a comparatively simple designing of strong versatile antennas. The mechanical and electrical properties of antenna with such combination are tested by fabricating many samples of microstrip patch antenna and reconfigurable patch antennas. When the PDMS-ceramic composite material is used as substrate for designing antenna it is found that the size of proposed antenna reduced up to 50% compared to pure PDMS and metal combination.</p>



**Fig. 2** Wearable antenna design methodologies and substrates used (a) Snap-on buttons (Female and male) and their dimensions (mm) [20] (b) Wearable antenna with EBG structure [21] (c) flexible magnetodielectric polymer-based nanocomposite antenna [23]

## IV. CHALLENGES AND OPPORTUNITIES

There are many challenges in designing and implementing wearable antenna on human body such as size and shape of antenna, flexibility that is achieved, proper placement of wearable antenna on body/cloth, good radiation patterns with more area of transmission/reception, impedance matching and near field deterioration. To overcome these challenges, we should use proper textile material as a substrate, so that we can increase the flexibility of wearable antenna as well as we can minimize the SAR. By proper shape we can minimize the size of antenna keeping high gain.

## V. CONCLUSIONS

In this paper, we study the outstanding research carried on design techniques for wearable antennas, the material used for antenna substrate, its specifications and applications. Wearable antennas are designed on different substrates with different design techniques for different frequency bands. The proposed wearable antennas were designed on different types of substrate material. If we use textile material as a substrate the flexibility of wearable antenna increases.

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