CHAPTER 32

Wearable Antennas-An Overview

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Abstract: The most popular antenna for portable devices in current communication technologies is the wearable antenna due to its compactness and flexibility; demand was rapidly growing and can communicate through signals with the human body and the wearable devices. The advantages of wearable antennas are flexible, hidden, low profile, and no harm to humans. The key benefit of this antenna is that it is placed on the human body or included in clothing, effortlessly transmits, and receives signals through clothes or on-body. These antennas play a vital role in the number of applications, *viz*. navigation (118MHz to 137MHz), medicine (750MHz to 2.6GHz), military (225MHz to 400MHz), RFID (433MHz to 5.4GHz), physical training, tracking, and health monitoring, *etc*. This paper discussed the important aspects of wearable antennas, which include materials used, substrate, and fabrication techniques. Next, discussed a clear overview of wearable antennas existing and design aspects, their advantages, and drawbacks.

Keywords: Fabrication Technique, Flexible Antennas, ISM Band, Substrate Integrated Waveguide, Textile Antennas, Wearable Antennas.

1. INTRODUCTION

It has been seen that during the last decade of years, portable devices play a proximity role in human life those are mobiles and tablets. The technology is rapidly changing year by year and the size of the device, visibility decreases. In forthcoming days, sensors are used to control human activities; further devices are used to monitor the different requirements of the human including medical

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other and stuffs outside. In real-world communications, all these advancements are possible only because of wearable devices and antennas [1].

Generally, Wearable devices are carried by the person within the body or on-body and are capable of communicating among them *via* cellular connectivity. The devices used in these types of communications would include other components such as like sensors, antennas, and batteries. One of the most important components in the wearable device is antennas and they contribute overall efficiency of a wearable wireless link [2 - 4]. The wearable antennas must be light in weight, conformal design, low cost, easy system integrable, *etc*. and the design ought to be specified which is not deteriorated even if they are bent [5].

In our life, Wearables play a significant role and are found to be used in many portable devices used for Security and Entertainment like fitness bands, wristwatches, reality glasses, and cover a lot of medical applications and rescue operations [6]. In the field of health monitoring, wearable devices are used to monitor the patient's health conditions who are in the critical stage like, the sugar level of the patient, glucose level of the patient, Blood pressure, inner intestinal system, body temperature, *etc*. of the patient minute to minute. Wearables are also used in rescue operations as well as entertainment. The Table **1** describes the field involved in wearable antennas with their applications.

Table 1. Applications of Wearable devices in different fields [7].

Field	Applications
Health Monitoring	Glucose Level Monitoring / Oximetry/ Endoscopy / GPS tractor / Wearable Doppler unit
Entertainment	Smartwatches / LED dress / Music Jackets / Intelligent
Rescue and security	Helmet / Tractors / E-shoes / Fitness-bands / Life jackets/ Raincoat

In day-to-day life, Wearable antennas are integrated into humans wearing gadgets like shoes, jackets, helmets, lenses, cooling glasses, raincoats, *etc*., and numerous aspects to be considered while designing wearable antennas as they need to be flexible, hidden, unobtrusive, low profile and should not be considerable degradation in proximity to the human body [8].

This paper discusses the overview of wearable antennas and mainly about on-body as well as textile-based antennas. Section II describes important aspects involved in wearable antennas and section III involved the discussion about the design of substrate integrated waveguides. Section IV is about the existing different wearable antennas and ended with concluding remarks.

2. IMPORTANT ASPECTS IN WEARABLE ANTENNAS

This section discusses important aspects of wearable antennas and includes a discussion about materials, the substrate as well as fabrication techniques.

2.1. Materials

The different kinds of dielectric, conductive materials are used to implement Wearable antennas, and these can be carefully chosen to prevent mechanical bending, mechanical wrapping at different weather conditions for the protection of EM radiation [9]. Table **2** reports the flexible conductive materials with their Thickness and conductivity.

Table 2. Thickness and conductivity of Flexible conductive materials.

Materials for Conductor	Thickness (mm)	Conductivity
Egain Liquid fillet [9]	0.08	250K
Ployleurethene nanoparticle composite sheet [10]	0.0065	1.1M
Zoflex plus copper [11]	0.175	193K
Copper coated taffeta [12]	0.15	3.4M
Sliver flakes plus fluorine rubber [13]	NA	85K
PANI/ CCo composite [14]	0.075	7.3K

2.2. Substrates

The dielectric substrate plays a very dominant role in the design of wearable antennas. The standard substrates like Rogers, Teflon, RT-Duriod, and silicon have been not preferred in the case of textile antennas due to bending, stretching, and rotating capabilities [15 - 18]. This needs to invent flexible conductive materials and some of the materials which having loss tangent, dielectric constant as revealed in Table **3** .

Table 3. Flexible materials (Dielectric constant and loss tangent).

Conductive Material	Dielectric Constant (εr)	Loss Tangent (Tan δ)
Polydimethylsiloxane [13]	3.2	0.01
Polydimethylsiloxane -ceramic composite [14]	6.25	0.02
Ethylene Vinyl Acetate [15]	2.8	0.002

2.3. Fabrication Techniques

Fabrication methods play a very important role in the design of wearable antennas concerning the accuracy, and speed of antenna while choosing the design of an antenna. The most common wearable fabrication techniques are Screen Printing [19], Inkjet Printing [20,21], Wet etching [22,23], Embroidery methods [24].

3. SUNSTRATE INTEGRATED WAVEGUIDE

SIW is one of the families of substrate integrated circuits (SICs). SIW is like a transmission line and is invented to overcome the drawbacks that occurred in existing transmission lines like microstrip and coplanar waveguide [25]. SIW is purely invented for higher frequencies that are millimeter and centimeter wavelength frequency applications and most preferred for millimeter-wave applications. Laminated waveguides, post-wall waveguides are the other names and general structures being illustrated in Fig. (**1**). The outline is familiar; derived from a rectangular waveguide, integrated with two rows of cyclic vias or holes placed in between the two ground planes through a substrate. The planar structure is used for developing SIW based wearable devices, called System on Substrate (SoS) [26 - 28].

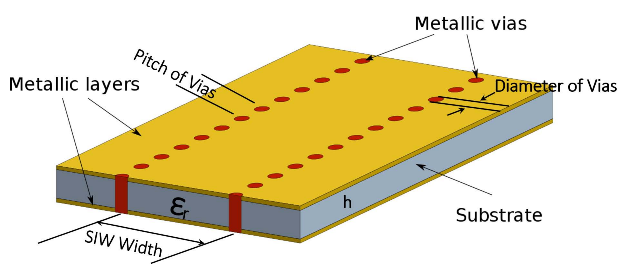
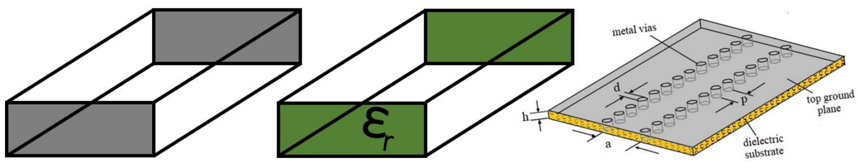


Fig. (1). Schematic representation of SIW.

3.1. Design of SIW

The Width of SIW is derived from the rectangular waveguide that is also called an air-filled waveguide, the schematic is shown in Fig. (**2a**), and generalized formulae for cutoff frequency are represented in Equation **1**. The dominant mode of the rectangular waveguide is TE_{10} and simplified formulae for the width of the rectangular waveguide as mentioned in Equation **2** [29 - 31].



(a) (b) (c)

Fig. (2). (a) Air-Filled Waveguide **(b)** Dielectric Filled Waveguide **(c)** SIW.

$$f_c = \frac{C}{2\pi}\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2} \quad \textbf{(1)}$$

$$a = \frac{c}{2 * f_c} \quad \textbf{(2)}$$

The rectangular waveguide packed with a dielectric material is called a dielectric-filled rectangular waveguide (DFW) and its schematic representation is shown in Fig. (**2b**), the width is mentioned in Equation **2** [32].

$$a_R = \frac{c}{2 * f_c * \sqrt{\varepsilon_r}} \quad \textbf{(3)}$$

DFW is filled with two rows of holes is called SIW and their representation is shown in Fig. (**2c**). The standard equation is used to find the width of the SIW is represented in Equation **3** [32].

$$a_{siw} = a_R + \frac{d^2}{0.95 * s} \quad \textbf{(4)}$$

Where 'd' is a diameter of holes and 's' is spacing between holes. The diameter (d) to a width (a_R) is not included in Equation **4**. Sometimes, give an error value and the more appropriate equation is:

$$a_{siw} = a_R + 1.08 * \frac{d^2}{s} - 0.1 * \frac{d^2}{a_{SIW}} \quad \textbf{(5)}$$

The condition used to maintain the loss-free radiation is [33],

$$d \leq \frac{\lambda_g}{5} \text{ and } s \leq 2d \tag{6}$$

The Planar technology is used in the substrate integrated waveguide fabrication process. So, SIW can be extended to implement like a SIW antenna, SIW active component, and SIW passive component.

4. WEARABLE BASED ANTENNAS

The wearable antenna was implemented on eyeglasses for 4G applications [34], which contain shapes like a wire and ground plane act as a glass frame with a thickness of 0.85mm, PCB fabrication technique is used in this model. The patch-based wearable antenna was introduced for mobile phones [35], which is implemented with FR-4 material and ferrite material used to act as an antenna, which was more expensive.

The monopole-based wearable antenna [36] was introduced for 802.11ac an application that contains wire mesh sheets, PCB etching was used, facing complexity while fabricating. The textile-based wearable antenna [37] is implemented for ISM band applications. The shape of the antennas used in this design is the circular patch which is migrating soft surfaces and the material used as an implement of an antenna is a textile material. The truncated patch antenna [38] is implemented for on-body applications which are operated between 2 GHz to 10.6GHz frequency bands. The full ground reflector plane was used as mitigation techniques and fabricated manually used as felt substrate.

A Quarter Mode Substrate Integrated Waveguide-based slot antenna is proposed with microstrip line feed using wool felt substrate, a relative permittivity of ε_r= 1.2 and a loss tangent of tan δ = 0.02 is shown in Fig. (**3**). The shorting vias are used near the feed line to implement dual-band operation are suitable for the 3.5-GHz WiMAX band and the 5.8-GHz industrial, scientific, and medical (ISM) band [39].

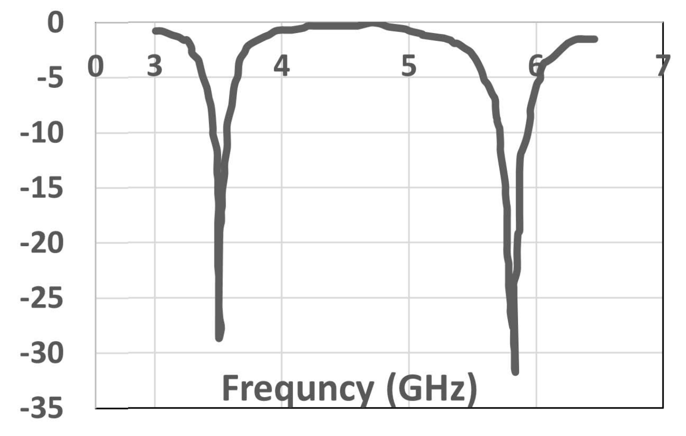


Fig. (3). Quarter mode substrate integrated waveguide-based slot antenna [39].

The unilateral patch-based antenna [40] was implanted for mobile phone applications which is feed by CPW and used radiating patch as asymmetric, and flexibility is the major drawback of the antenna. The textile-based antenna [41] is used for wearable application with a fractal-based monopole patch antenna and introduced EBG structure for SAR reductions.

The polyester cotton-based fabric used in the design of the patch and implemented for scientific, industrial, a medical band (ISM) [42] with an operating frequency of 2.4 GHz. Polyurethane material is used as a paste and printed on the cotton, but it damages the substrate for reduced sizes. In inkjet printing, post-heating is the major issue, to avoid that deposition and sintering have been introduced [43].

The mixing of two substrates was used to design an antenna for wearable tracking applications [44] and both the substrates being printed by applying the interface layer with Dimatix printer [45], avoided ink smear onto the fabric material. Inkjet printing technology [46] has been used to reduce the cost of the equipment, eliminate the process of printing layer. A conductive layer with silver nanoparticles (AgNP) is printed using an instant chemically curing process, which avoids the need for post-processing [47]. Mandal *et al.* [48], a wearable antenna was fabricated using the printing method and is designed for operating ISM band applications, PET substrate material is used in this design, and the cost of the material is low. Compare to the inkjet printing method, the cost is low and effective using surface morphological measurements. Moreover, a 3D surface propeller has been used for measuring surface roughness.

The Substrate integrated waveguide-based wearable antennas were introduced, and two antennas are designed using the same substrate [49], wearers garment material is used as substrate. Another antenna was designed with the leather substrate for multiband band applications [50]. On the top of the substrate, a copper sheet was placed to enable the operations like WiMAX, Wi-Fi. The different methods used for fabricating textile antennas are presented in [51].

The woolen substrate is added with pure copper fabric for wide-band operation [52], these wearable antennas have more radiation efficiency like 84% and fractional bandwidth is 46%. A meta-material impressed SIW based antenna has been projected on woolen felt substrate using conductive fabric [53]. This antenna was placed on the body and measured the radiation efficiency is approximately 75% with a reduction of size is 80% as compared with other structures and performance of the antennas was satisfactory, back radiation was low towards the human body.

The miniaturized dipole antenna is introduced for 2.4GHz operating a frequency application, which is designed by using paper-based substrate material [54]. The mixing of nanowire/ nano-paper high-h sliver material has reduced the size by 50% compared with ordinary low nano-paper antennas. The EBG structures are used to reduce the size of an antenna and designed a complementary split-ring resonator (CSRR) antenna to miniaturization [55] and gain of the antennas was slightly decreased.

The wearable antenna is introduced for mobile phone applications and designed by using FR-4 substrate material, ferrite sheet used as copper material [56]. The monopole-based wearable antenna is introduced for 802.11ac applications and thin wire mesh sheet used for designing, PCB etching, and the main drawback is complex fabrication [57].

The monopole-based wearable antenna is introduced for energy harvesting applications, GPS and DCS band, the adhesive sheet on zelt-fiber was used and a laser machine is used to cut the shape [58]. Agarwal *et al.* [59], the truncated patch antenna has been introduced for on-body application with an operating frequency of 2 to 10.6 GHz. The material used in this design is felt substrate and the shape was etched manually.

The antenna is with a circular disc monopole structure designed on a thin and flexible Ultralam 3850 laminate, which can support with the bandwidth of 1.74 to 100 GHz. The experimental results were suited to be used for a vast range of applications including 5G technologies [60]. The design structure is depicted in Fig. (**4a**) and results are shown in Fig. (**4b**).

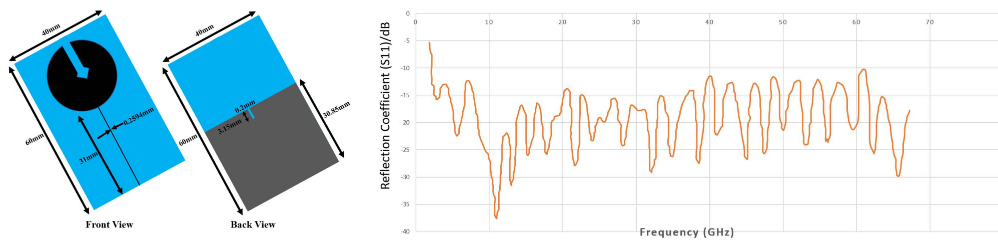


Fig. 4. (a) Disc monopole structure (front and back views), **(b)** Simulated results [60].

CONCLUSION

In the recent past, Wearable antennas attracted huge attention due to their tremendous features like being cost-effective, flexible, lightweight, used for portable communications. These antennas are generally preferred to implement on different parts of a human body, which is very attractive to implement by using flexible materials as well as low profile structure. This paper provided an overview of wearable antenna-based textile antennas as well as wearable antennas for on-body applications. The materials preferred for designing wearable antennas and their merits and demerits are exposed. The different types of wearable antennas are discussed and observed that gain, efficiency, *etc*. were less as demanded. The design of the Substrate integrated waveguide is also discussed in this review to extend this work to implement in SIW based structures.

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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