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A Review of Textile and Cloth Fabric Wearable Antennas

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ABSTRACT
The recent advancements in technology in the wireless technology has led to rise of wearable antennas made of different fabrics. It is an unconventional antenna, meant to be a part of clothing and body. The radiating element is made of copper or any other conductor while the substrate used for wearable antenna application are textile or cloth based material. This literature review tends to reveal the various considerations for designing of wearable antenna from different textile materials and illustrates the effect of wearable antenna on human body and vice versa. These antennas have wide range of applications in the area of tracking, navigation, telemedicine, public safety and defence.

General Terms
Dielectric constant, microstrip, permittivity, portable antenna array, SAR (Specific Absorption Rate),textile materials

Keywords
Body-induced gain, detuning, dielectric heating, electro-textiles, high-contrast materials, telemedicine, wearable antenna

1. INTRODUCTION
A wearable antenna is an antenna that is specifically designed to function while being worn on body Wearable fabric/textile antenna is one of the dominant research topics for body centric communication. Till now many types of wearable antennas have been proposed , which are microstrip antennas integrated on textile such as cotton, foam, nylon, polyester, insulated wire , conducting paint, LCP(Liquid Crystal Polymer) etc .

A simple microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate and a ground plane on its other side. It is suitable for body-worn applications because it mainly radiates perpendicularly to the planar structure and the ground plane efficiently shields the body tissues. It is most suitable for integration into clothing because of its various advantages such as low volume, low profile planar configuration, low cost, light weight and almost maintenance free installation but it has a limitation of narrow bandwidth. The antennas in which substrate was textile material, both antenna and ground plane were made of copper tape, the phenomenon of peeling off exists when it is subjected to mechanical load[3]. To improve fixing and to prevent intermediate air gap the electro-textile patches were glued onto the substrate and additionally stitched. But because of stitching methods, the continuity of conductive materials was damaged, probably leading to the malfunctioning of the antenna[4]. In order to obtain superior integrity and impact resistance, the patch and ground plane were fully woven with the textile substrate using 3D fabric weaving methods. Using this technique peeling off phenomena could be avoided to a great extent[5]. For wearable antenna omni-directional radiation pattern is desired so that it is suitable for mobile devices and smart and comfortable clothing. The omni-directional pattern should have minimal or no side lobes, which harms the human body.Apart from measurements like: return loss, radiation pattern, gain and efficiency (which are measured for conventional antenna) other factors should also be taken into careful consideration to guarantee the performance of antenna in body-worn context. Textile antenna design also requires the knowledge on electromagnetic properties such as permittivity and loss tangent of the textile material. Conductive textiles (Zelt, Flectron and pure Copper) are used as radiating element while non-conductive textiles(silk, fleet and fleece) are used as substrate[6].

Fig 1 : Wearable antenna on human body

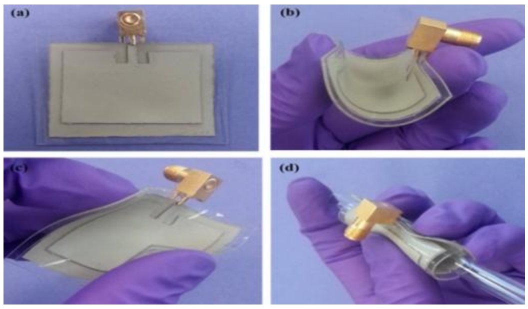

Fig 2: Conformal wearable antenna

2. INTERACTION BETWEEN WEARABLE ANTENNA AND HUMAN BODY
Wearable antennas are in close proximity with the human body. The close proximity of human body with a high dielectric constant and loss are known to have detrimental effect on antenna input impedance and efficiency. The body affects characteristic impedance of transmission lines causing mismatch, changes in electrical length, and significantly increases losses, thus potentially deteriorating its operation. The body and wearable antenna interaction can be studied under two categories:

2.1 Effects of antenna on human body

The non-ionising radiation (sound waves, visible light and microwave) does not have enough energy to ionize atoms or molecules but the energy is sufficient enough to move atoms or make them vibrate. Therefore, the non-ionising radiation can have enough energy to move human cells and increase the temperature of these cells. This temperature rise can cause dangerous affects to human tissues, the most common of which is dielectric heating. It is a thermal effect caused by microwave radiation that happens when a dielectric material is heated by rotations of polar molecules induced by the electromagnetic field. The parameter that is used to measure the rate at which energy is absorbed by human tissues is Specific Absorption Rate (SAR).

The SAR is defined as the rate at which RF electromagnetic energy is imparted to unit mass of biological body. It is a measure of the rate at which energy is absorbed by the human body when exposed to a RF electromagnetic field. SAR is usually averaged either over the whole body, or over a small sample volume (typically 1 g or 10 g of tissue). The value cited is then the maximum level measured in the body part studied over the stated volume or mass.SAR is calculated using the formula given as :

$$SAR=\sigma E/\rho$$

Where, σ = electrical conductivity, E = RMS electric field and ρ = sample density.

There are various rules and regulations in the world regarding the SAR limit of electromagnetic devices because of the fact that high SAR values may have severe consequences on the human body. The Federal Communication Commission (FCC) has established the SAR limit to 1.6 W/kg averaged over 1 g of actual tissue, while the Council of European Union has fixed the limit to 2 W/kg averaged over 10 g of actual tissue.

It is also explained that the limit of temperature increase in head tissues is 1 K .The increase in the temperature in the head tissue may affect the behaviour and memory of the people besides causing anatomical injuries[7].

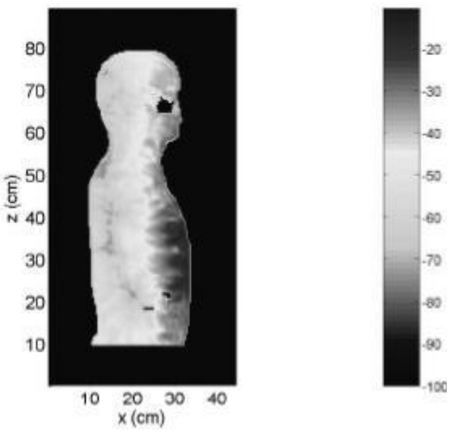

Fig 3: SAR values obtained at 2.2 GHz [8].

2.2 Effect of human body on wearable antenna

To the antenna the human body is lossy and deteriorates the communication link. Scanlons and Evans proposed two figures of merit for body-worn antennas:

2.2.1 Body-induced gain

It is the ratio of gains (in dB) between body-worn antenna and that of the antenna in free space.

2.2.2 Body-worn efficiency

It is the ratio of total radiated power when antenna is worn in the body to the total radiated power in free space isolation. It represents the overall power loss in human body.

The various body effects on wearable antenna that have been discussed are:

2.2.3 Body effect on impedance

The input impedance of the antenna will be lowered if the user is too close to the antenna [7].

2.2.4 Detuning by the body

The dielectric constant of soft tissues is of the order of 20-50.This high value of dielectric causes dielectric loading that shifts the resonant frequency of an antenna located nearby.

The efficiency of an antenna is often greatly reduced because of absorption when it is placed near the human body. The effect of human body on antenna radiation properties is two-fold: when the antenna-body separation distance is very small, absorption dominates and reduction of efficiency is the major effect. If the distance is increased, the body can be modelled as a reflector[7].

3. CONSIDERATIONS OF TEXTILE MATERIAL FOR WEARABLE ANTENNA

Textile materials are made up of fibre, which are generally made of long chain polymers and have high length to diameter ratio. They are generally considered as insulators as the electrical conductivity of these polymers is very low.

3.1 Features of textile materials

Commercially available conductive textiles used in designing of wearable antennas are termed as electro-textiles.

3.1.1 Dielectric constant of the fabrics (ε)

It is the constitutive parameter of dielectric which is expressed as:

$$\boldsymbol{\varepsilon} = \boldsymbol{\varepsilon_0}(\boldsymbol{\varepsilon' r} - \boldsymbol{j\varepsilon'' r})$$

Where, $\boldsymbol{\varepsilon_0}$ = permittivity of vacuum (8.854×10^{-12} F/m)

And εr is relative permittivity. The dielectric property depends on frequency, temperature, surface texture, moisture content purity and homogeneity of the material. It also depends on electric field orientation as the textile materials are an isotropic. The different methods used for the accurate measurement of dielectric characteristics are: Transmission line method, Cavity Perturbation Method, Resonance Method and MOM-segment method.The resonance method has been successfully used to find out the dielectric constant of fabrics substrate materials such as jeans cotton, polyester combined cotton and polyester from the measured resonant frequency of the patch radiator[26]. On lowering the dielectric constant, spatial wave increases and hence the impedance bandwidth of antenna also increases allowing high gain and acceptable efficiency [11,24,25].

3.1.2 Thickness of the dielectric fabrics

It is an important parameter that determines efficiency and bandwidth of planar microstrip antenna. Textile materials have a very narrow range of permittivity values, so thickness may present much larger variations and determine the bandwidth, input impedance and resonant frequency of the antenna. It also influences geometric size of the antenna [8].

3.1.3 Surface resistivity of fabric

The electrical behaviour of planar fabrics is characterised by the surface resistivity. It is the ratio of DC voltage drop per unit length to the surface current per unit width. It is property of the material and does not depend on the configuration of electrodes used for measurement.

3.1.4 Conductivity of fabric

It has unit Seimens per meter (S/m) and it is inversely proportional to surface resistivity and thickness. The choice of conductive fabric for the patch and ground planes is one of the important criteria to assure good performance of the antenna.

3.1.5 Moisture content of the fabrics

The fibres are continuously exchanging water molecules with air and always establish equilibrium with the temperature and humidity of air in contact with it. When water is absorbed by textile fibres, it changes the electromagnetic properties and increases its dielectric constant and loss[9,10].Climatic changes as well as proximity of antenna to skin will cause the fabric to absorb moisture from skin and hence affecting the antenna performance.

3.1.6 Mechanical deformations of the dielectric and conducting fabrics

The bending and elongation of dielectric fabrics, when it adapts to the surface topology, influences its permittivity and thickness, which further affects the bandwidth as well as the resonant frequency of the antenna. Woven and nonwoven fabrics are more stable fabrics than knitted fabrics, as they allow higher geometrical accuracies.

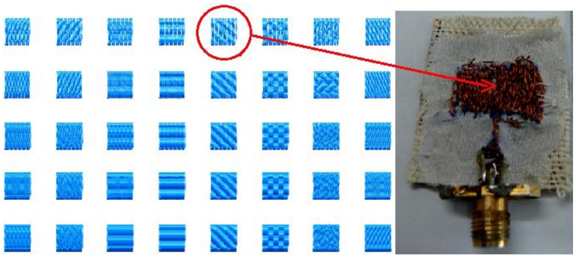

Fig 4: Various stitching styles and used stitching style

3.2 Factors affecting measurement of dielectric properties of fabric

The dielectric properties of materials are also affected by their mechanical and thermal properties. The dielectric loss is a time dependent phenomenon and it also depends on temperature [13,16]. None of the standard methods can be applied directly to measure the dielectric properties of fibre. A textile product is usually a 3-plane system and therefore it was suggested to refer in a capacitance of 'fibre-moisture-air' system[13-16].

The various factors that affect the measurement of dielectric properties are broadly classified as :

3.2.1 External factors

These are the factors under which measurement is done, e.g. frequency and temperature. The dielectric property of fibre having high moisture content is more influenced by frequency. At the frequency corresponding to realization time of dipole, the energy will be dissipated and permittivity will drop. Due to presence of a range of relaxation time in fibres, there is gradual change in permittivity with frequency. The real part of permittivity(ε') increases with the increase in temperature and imaginary part of it(ε") shows frequency dependence with respect to temperature.

3.2.2 Internal factors

These are the factors which are decided by test specimen itself and include moisture content and packaging density. Since with molecules polar in nature, there is increase in dielectric constant due to release of polar groups as well as release of ions in fibre molecules. Since textile materials are not homogeneous so the measured dielectric values show gross effects of heterogeneous mixture of fibre and air.

Table 1. Different textile materials with dielectric constant [26]

Textile Material	Dielectric Constant
Wash Cotton	1.51
Curtain Cotton	1.57
Polyester	1.44
Polycot	1.56
Jeans Cotton	1.67
Bed Sheet/Floor Spread	1.46

4. APPLICATIONS OF WEARABLE ANTENNA

The major applications of wearable antenna at present are:

4.1 Telemedicine

Wearable antenna is one of the best solutions for telemedicine purpose. It is a technique to provide live, interactive audio-visual clinical health care at a distance .It helps to eliminate distance barriers and can improve access to medical services that would often not be consistently available in distant rural communities. The present era of telemedicine is supported by the high speed and quality offered by the Internet or 3G mobile telephony that is easily accessible to people[22].

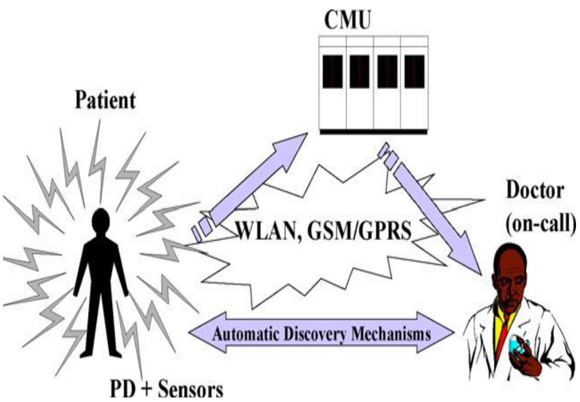

Fig 5: Use of wearable antenna for telemedicine.

Table 2. Different wireless technologies for telemedicine[22]

Type	Sub-type	Frequency band	Data transfer rate
GSM	GSM-900	900MHz	9.6-43.3 Kbps
	GSM-1800	1800MHz	9.6-43.3 Kbps
	GSM-1900	1900MHz	9.6-43.3 Kbps
GPRS	GPRS	900/1800/1900MHz	171.2 Kbps
Wireless LAN	IEEE 802.11a	5GHz	20Mbps
	IEEE 802.11b	2.4GHz	11Mbps
	Hiperlan1	5GHz	20Mbps
	Hiperlan2	5GHz	54Mbps
	Bluetooth	2.4GHz	723.2Mbps
Satelite	ICO	C,S band	2.4Kbps
	Globalstar	L,S,C band	7.2Kbps
	Indium	L,Ka band	2.4Kbps
	Cyberstar	Ku,Ka band	400Kbps-30Mbps
	Celestri	Ka band 40-50 GHz	155Mbps

4.2 Portable radio and radar application or defence purpose

Miniaturised wide band antenna unit is required for radars and sensors providing high resolution and real time hazard monitoring. The antenna should have dimensions comparable to wavelength($\lambda/2$ or $\lambda/4$) in order to be an efficient radiator. However, the wavelength is relatively large i.e. 10m at 30MHz for VHF-UHF frequency bands. Therefore most antennas used at these frequencies are electrically small antenna but with relatively large physical dimensions, hence lack portability. A trade-off has to be made among efficiency, size and bandwidth to design electrically small antenna. Two methods have been used for this purpose.

4.2.1 Single radiator design

The guided wavelength within high-contrast materials is smaller so the lowest operating frequency of the antenna can be reduced as the dimension of substrate is changed. But miniaturization using high-contrast material is not that efficient due to higher dielectric loss and cost. However, recently commercial available and affordable ceramic materials with light weight, low loss and relatively less thickness may solve these concerns.

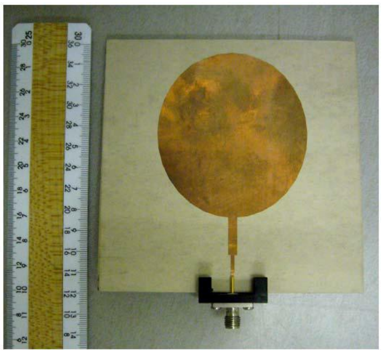

Fig 6: Wearable antenna having elliptical patch on front side and partial notched ground plane on other side [19]

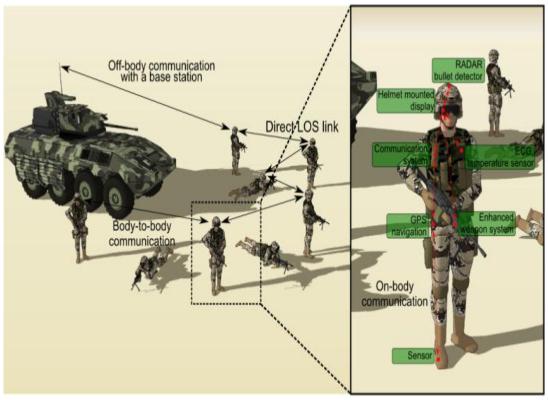

Fig 7:Use of wearable antenna for defence.

4.2.2 Portable array antenna design

A wideband array antenna prototype for wearable antenna system with eight elements and spacing of 25cm has been designed and studied. Despite the shielding effects of ground plane of individual patch antenna reduces the influence of human body on antenna pattern, still the central frequency is observed to change by over 1% and the efficiency will decrease by over 10% due to presence of human body [23].

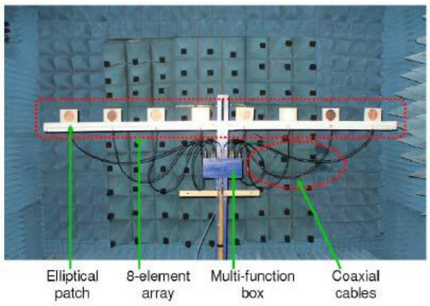

Fig 8:A wideband array antenna prototype for wearable antenna system[23].

5. CONCLUSION

From the review, it is concluded that for designing of an efficient wearable antenna we need to make trade-off among different antenna parameters such as: efficiency, size and bandwidth. The designed model should satisfy the standard SAR limits (1.6W/kg over 1g of actual tissue). Proper analysis of textile material should be done for optimising the gain and bandwidth of the antenna.

Wearable antennas have many applications and there is a wide scope of research in this field, especially for portable antenna array design.

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