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Research Article

A REVIEW OF THE WEARABLE TEXTILE-BASED ANTENNA USING DIFFERENT TEXTILE MATERIALS FOR WIRELESS APPLICATIONS

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ABSTRACT

Miniaturization of wireless systems empowered the use of the textile antenna for various purposes and has become one of the fastest developing technology in the world today. In general, textile antennas are microstrip antenna where the substrate is a textile material. Commercially, a variety of textile materials available these days and the properties of these textiles have an impact on the characteristics and performance of an antenna. Normally, textile materials present very low dielectric constant which is required for an efficient antenna. Nevertheless, textile fabrics are porous, anisotropic, and compressible materials whose thickness and density alters with low pressure affecting the electromagnetic properties of the material. The features of the textile materials were believed to impact the behavior of the antenna, hence this study shows minimal research highlighted on the differences of textile material properties. This review paper summarizes different types of antenna with their applications, essential antenna parameters and the textile material used for the construction of the wearable textile antenna. This literature review guides to reveal the various considerations for designing wearable antenna from different textile materials. Lastly, several open recommendations are given for further guidance for future studies.

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INTRODUCTION

Communication today makes people stay linked within a global society. Batteries and Antennas are the main components that consume a lot of space in traditional wearable systems. Nevertheless, the size of the wearable computing system is becoming smaller in size and form due to the development of electronic components in recent years. The antennas are therefore now fabricated using textile materials. Moreover, antennas integrated within clothing with the help of textile materials provide an alternative to fabricating using rigid substrates (1). Furthermore, wearable textile systems in navigation, tracking, and public safety are very effective (2). Since the applications of wearable antennas are vast, it can be seen as another significant phase in the pervasive computing movement where information is easily accessible anywhere. According to

(3), a study released by Analysis Mason, wearable device sales are projected to reach US$ 22 billion in 2020, while sales in 2014 were below US$ 3 billion as seen in Fig. 1.

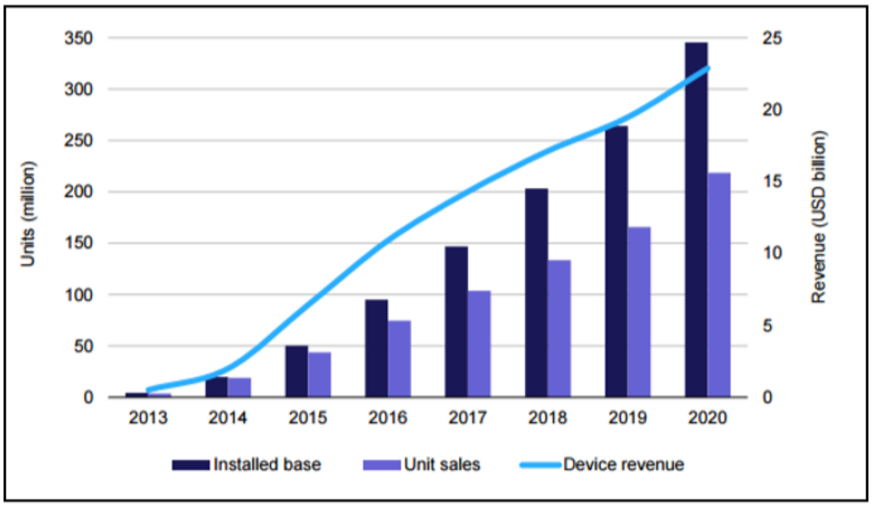

Fig. 1. Predicted sales and revenue of wearable devices 2013-2020 (3)

The wearable textile antenna is a microstrip antenna where the substrate is a textile material. Features such as durability, lighter weight, smaller size, shock resistant and vibration resistance make the wearable textile antenna very popular (4). The drawbacks of this antenna are, however, narrow bandwidth and sensitive to humidity and temperature. These drawbacks ultimately reduce antenna gain hence efficiency reduces as well. Construction of the textile wearable antenna is dependent on the materials used in the design structure as seen in Fig. 2.

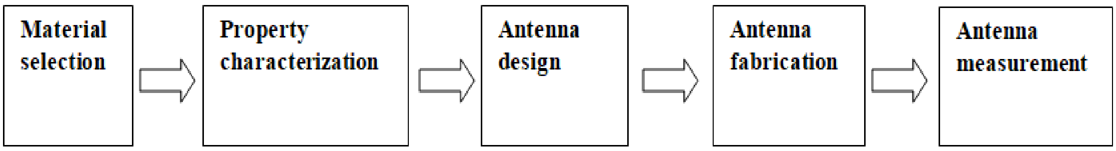

Fig. 2. A general procedure of wearable and flexible antenna

Therefore, proper selection of a textile substrate is very important to achieve a high efficiency antenna because the characteristics of the substrate have direct impacts on the antenna performance (5).

The rest of the paper is organized as follows. Section 2 presents the basic theory of textile fabric characteristics and the fabrics used for wearable antennas. Section 3 focuses on the materials mostly used and discussions on the results obtained. Finally, the main conclusion of this work is set out in Section 4.

REVIEW AND SURVEY

For a wearable textile antenna, characteristics such as dielectric constant ($_r$), thickness and loss tangent (tan( )) of textile fabrics are indispensable factors that must be considered for the efficient design purpose. These three characteristics of textile materials known to influence the performance of the antenna. This section focuses on the dielectric constant, loss tangent and thickness of textile fabrics for which in total ten previous works on similar topics are studied as a part of the survey.

TEXTILE CHARACTERISTICS

Textiles typically have a very low dielectric constant (r) value between 1 and 2 since they are very porous materials and the presence of air is close to one relative permittivity. Low dielectric constant limits surface wave losses associated with the propagation of guided waves within substrates. The lowering of the dielectric constant therefore increases the spatial waves and therefore increases the bandwidth of the antenna impedance. Apart from that, lowering the permittivity of the substrate increases antenna resonance frequency, enabling antenna performance with acceptable efficiency and high gain. Another important feature of textiles is "thickness". The thickness of the dielectric material is vital for wearable antennas design. For fixed relative permittivity, the thickness of the substrate can be increased to maximize the bandwidth of the planar antenna. Therefore, it can achieve higher gains. And the selection of the thickness of the dielectric material is to be taken into consideration. Loss tangent (tan ( )) has a significant impact on an antenna's output and gain. When the tangent loss increases, antenna gain decreases and bandwidth increases for microstrip antenna. In general for microstrip antennas, an increase in loss tangent degrades the performance of that antenna(6).

TEXTILE MATERIALS USED IN WEARABLE ANTENNA

In paper (4), four narrowband rectangular microstrip antennas were designed where different cotton materials of same thickness 1.60 mm with different dielectric constant values were used: Wash cotton (r=1.45), Curtain cotton (r=1.47), Poly cotton (r= 1.50) and Jeans cotton (r= 1.59). A similar work has been done in (7) but wash cotton (r = 1.51), curtain cotton (r = 1.47), polyester (r = 1.44) Jeans cotton (r= 1.67), floor spread (r= 1.46) and poly-cotton (r = 1.56) were used as a substrate .The substrate thickness is 3.0 mm for wash cotton, curtain cotton, floor spread, and polycount but the thickness for polyester jeans cotton was 2.85 mm and 2.84 respectively. The loss tangent was 0.02 (wash cotton, curtain cotton, floor spread polycot), 0.01 (polyester) and 0.003 (jeans). Related to the type of antenna in paper (4,7) but material such as leather (r =1.8 and thickness 1.36 mm) as a substrate to operate at 2.44GHz on a small ground plane for wireless body communication is proposed by Ifrat Ahmed and Musfiqur Rahman in (8). A similar study has been done in paper (9) where a microstrip antenna is designed by using polyester fabric with a dielectric constant value of 1.44, loss tangent 0.01 and thickness of 2.85 mm for 2.4 GHz.

However, despite narrowband microstrip antennas have several advantages, they typically present low fractional bandwidths and it is noticed by the authors in (10-13).Therefore, to overcome this drawback, another concept of the microstrip antenna is the "Wideband antenna". These antennas usually have larger bandwidths. Authors (10) had done an experiment where a UWB (ultra-wideband) antenna is designed using Flannel fabric, Jeans fabric and Cotton fabric as a substrate and the dielectric constant values are 1.7, 1.67 and 1.6 respectively. The thicknesses of the designed antennas were 1 mm and the loss tangent value was 0.025. Ameni Mersani and Lotfi Osman (11) introduced a dual-band antenna with a rectangular patch to operate at 2.45 GHz - 5.8 GHz for wireless applications using textile materials such as polyester (r = 1.748) and jeans cotton (r =1.67) are used as a substrate. The thickness of polyester was 0.28 mm and jeans cotton 2.84 mm. Furthermore, the loss tangent of polyester and jeans cotton was 0.0044 and 0.033 respectively. V.K. Singh and Naresh Bangari (12) presented a triple band wearable textile antenna using Jeans fabric with dielectric constant ($_r$) value 1.7, thickness 1 mm and loss tangent value of 0.025 as the substrate. Felt fabric is another popular textile material available commercially since it has low dielectric value. Hence, a dual-band textile antenna design is carried out in paper (13) using FELT fabric with a dielectric constant value of 1.44 and thickness 4.8 mm to operate at 2.4 GHz and 5.6 GHz as substrate.

Industrial, Scientific and Medical frequency band (ISM) is a range of operating frequency which is heavily used for industrial purposes. This is a range of radio and microwave frequencies clustered around 2.4 GHz, allocated and approved for RF-using industrial, science and medical instruments. The ISM frequency range is used for medical devices such as MRI machines, research facilities, and radio telescopes. In paper (14), the authors have proposed a wearable antenna that is designed using leather ($_r$=1.8), silk ($_r$=1.2)and nylon ($_r$= 3.5) as a substrate with a thickness value of 0.5 mm to operate at ISM band (2.45 GHz).

Another popular band of frequency is called Ku- band (K-under) range of frequencies usually from 12 GHz to 18 GHz. This band is used for VSAT, VMES, Broadcasting, TV, Satellite applications, and Mobile, etc. Amarveer Singh et al. (15) proposed textile microstrip antennas with different textile materials as a substrate for KU band applications (12GHz -14GHz) and the material characteristics are shown in Table 1:

Table 1: Textile fabrics characteristics (15)

Characteristics	Fleece	Felt	Curtain Cotton	Denim Cotton	Polyester	Silk
Dielectric Constant ($_r$)	1.04	1.35	1.47	1.6	1.62	2.7
Thickness (mm)	0.3 mm	0.4 mm	0.1 mm	0.7 mm	0.14 mm	0.09 mm
Loss Tangent ( )	0.02	0.02	0.04	0.02	0.02	0.02

DISCUSSION

Different types of textile materials such as wash cotton, curtain cotton, poly-cotton, jeans cotton, polyester, poly –curtain, leather, flannel fabric, felt fabric, nylon, silk, and fleece are used in (4,7-15). All the material used has a range of dielectric constant from 1.04 to 2.7 with a thickness of 0.09 mm to 2.84mmand loss tangent of 0.0033 to 0.2.

The material most widely used in all of these studies is jeans cotton, which was used in six studies in (4,7,10-12,15). Jeans cotton material, which is versatile and comfortable, is also ideal for wearable applications. In addition, jeans cotton have a fairly low dielectric constant compared to other commercially available materials and are widely manufactured throughout the world (16). Table 2 shows the overall characteristics and results obtained in these six papers :

Table 2: Summary of jeans fabric properties and achieved gain

Paper	Dielectric Constant	Thickness (mm)	Loss Tangent	Frequency (GHz)	Achieved Gain (dB)
(4)	1.59	1.60	-	2.0	2.29
(7)	1.67	2.84 mm	0.0033	2.45	5.91
(10)	1.67	1.0	0.025	3.0	3.27
(11)	1.67	2.84	0.0033	2.45 and 5.8	0.622 and 2.61
(12)	1.70	1.0	0.025	2.1366, 4.7563 and 11.495	3.353, 4.237 and 5.193
(15)	1.60	0.7	0.020	12.64 and 13.515	8.25 and 6.14

The material second most commonly used in these studies is polyester, which is used in (7,9, 11,15). The physical properties of polyester, such as strength, absorbency, and dimensional stability, making it a common option for wearable antenna construction. In general, the strength of the polyester fibers is higher, and it is found to be extremely robust. Next is the absorbency of which polyester has the least absorbent material. Finally, the fiber does not shrink due to the dimensional stability of the polyester(17). Table 3 shows the overall characteristics and results obtained in these four papers :

Table 3: Summary of polyester fabric properties and achieved gain

Paper	Dielectric Constant	Thickness (mm)	Loss Tangent	Frequency (GHz)	Achieved Gain (dB)
(7)	1.44	2.85	0.1	2.45	7.14
(9)	1.44	2.85	0.01	2.4	6
(11)	1.784	0.28	0.0044	2.45 and 5.8	0.591 and 2.36
(15)	1.62	0.14	0.002	13.295	2.167

And the third most commonly used textile material in these studies is curtain cotton in (4, 7, 15). Curtains are usually made of cotton, linen, rayon, polyester or mixtures of any combination of these fibers. The dielectric constant value of this fabric is relatively small, making it an effective textile antenna fabric. Correspondingly, in recent years, the curtain has become a very important feature of the wearable textile industry. People use curtain fabric as part of daily clothes since this fabric is smooth and has a linear density. In addition, the curtain fabric is perfect for air permeability, tensile and abrasion resistance (18). Table 4 shows the overall characteristics and results obtained in these three papers:

Table 4: Summary of curtain fabric properties and achieved gain

Paper	Dielectric Constant	Thickness (mm)	Loss Tangent	Frequency (GHz)	Achieved Gain (dB)
(4)	1.47	3.0	0.02	2.0 -2.40	2.29
(7)	1.47	3.0	0.02	2.45	2.29
(15)	1.47	0.1	0.04	12.125	1.3

Since there are different types of textile materials are available these days, the gain achieved by the remaining textile materials used in the survey is extracted and illustrated in Table 5 so that it helps the researchers to select the suitable fabric for wearable antenna based on the antenna's requirement.

Table 5: Gain achieved by other fabrics in (4, 7-15)

Textile Material	Frequency (GHz)	Achieved Gain (dB)
Felt	12. 328 and 12.916	3.5 and 7.5
Fleece	12.932	4.197
Wash cotton	2.0	2.21
Leather	2.45	4.79
Nylon	2.45	6
Silk	2.45	5
Flannel	3 - 6.5	3.27

From the findings in Table 2-4, it can be seen, the higher gain is achieved while having a low dielectric constant value. Jean, polyester and curtain cotton is mostly used in the studies since they have relatively low dielectric constant (r) value of 1.6 -1.7 (jeans), 1.4-1.8 (polyester) and curtain cotton (1.47) respectively. From paper (4,7), it can be seen that using same frequency value of 2.45 GHz, a high gain value of 7.14 dB was achieved by using polyester substrate while the gain achieved by jeans cotton was 5.91 and the gain achieved by curtain cotton was 2.29 for almost the same thickness but the dielectric constant value was lowest for polyester fabric (1.44) compared to jeans (1.67) and curtain cotton (1.47). However, by comparing (12,15), it can be seen, jeans fabric having lower loss tangent value achieved a high gain value of 3.353 dB whereas at similar frequency polyester and curtain fabric achieved a gain value of 2.167dB and 1.3 dB respectively. It is observed that, in paper (11), the thickness of the substrate helped the antenna to achieve high gain because, at 5.8 GHz, jeans with a thickness value of 2.84 mm achieved higher gain (2.61dB) compared to curtain cotton (2.36 dB) with a thickness value of 0.28 mm. Therefore, it can be concluded, textile characteristics have a big impact on the performance of the antennas. Thus, textile characteristics must be considered carefully to design a high-efficiency antenna. Hence, fabrics such as jeans cotton, polyester, and curtain cotton can be considered for wearable textile antenna fabrication since the results obtained match with the theoretical concept provided in Section 2.1 and these are among the popular choices for wearable textile antenna construction.

In short, textiles have a very low dielectric constant, between 1 and 2. Dielectric constant value has a greater effect on antenna performance as seen in Table 2-4. Thus, if the dielectric value is lower, the antenna can obtain a wider bandwidth as well as a significantly higher gain. As a result, the overall performance of the antenna increases. Another observation noticed, thicker the substrate, the higher gain can be achieved since the efficiency increases. Lastly, lower the value of loss tangent better the performance of the antenna. Overall, the selection of materials depends on the application of the antenna. This paper gives a brief idea to the future researchers about the factors which need to be considered while designing a wearable antenna.

CONCLUSION

This paper describes a review of the wearable-based textile antenna where different textile materials are used as substrates. In this study, ten previous research papers with similar topics are thoroughly studied. Textile material characteristics such as dielectric constant, thickness and loss tangent are mainly reviewed in this paper. All the papers (4, 7-15) are discussed in detail and all of the considerations regarding the materials used along with antenna gain are mentioned in this study. In the tables, characteristics of textile materials and results obtained from the previous works are reviewed. Finally, aside from the fact that the efficiency of the textile antennas can be improved with integrated solutions and given the considerable progress already made in developing wearable antennas, the authors of this paper suggest further analysis and improved characterization of ordinary and conductive textile materials to achieve substantial changes in terms of design and antenna behavior optimization. The review is done to give a brief idea for new researchers on the current design of on-body an implanted antenna based on different objectives and purposes. Wearable textile antennas are becoming more and more enhancing and challenging and carrying a great future in the development of rapidly growing wireless communication technology.

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