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Design Issues of Flexible Antenna -A Review

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ABSTRACT

Recent years has been observed increasing attention from both academic and scientific communities in the field of flexible technology. Flexible antennas have found their importance, when conventional antenna performance is very low because of its peripheral environment. This survey reviews the development of flexible antennas, their design, substrate material used and addresses various bending conditions tested on the antenna finds many applications in military, satellite, medical and defense fields. The antenna should get adjustable to any kind of surfaces. The careful study had been done using current researches going on in the field of flexible antenna technology. Such antennas have merits of compactness, light weight, low profile, cheap and easy to fabricate. Even though there are more survey papers on flexible antenna is available, they are restricted only to particular issues only. So, in this review, a comprehensive survey has been provided which deals with all the issues and challenges of flexible antenna. Thus this review will find out the perfect solution of designing and bending issues of flexible antenna. All the designs presented are of the recent development in flexible technology.

Key words: Antenna, wearable, return loss, bending, Flexible.

1. INTRODUCTION

In the current scenario, it was evidenced a great value of interest in the field of flexible antennas from both academic as well as industrial world [1]. In other words, this field attains the top spot of research activities provided by many research agencies from national as well as international level [2]. They have the advantages of less weight, low-cost production, easy to fabricate, and the frequent availability of cheaper flexible substrates (i.e.: foam, cotton, felt, rubber) make flexible technology a desired member for the future world of electronics [3]. In addition to this, a speedy advancement in the flexible and wearable wireless devices provided a roadmap for the bankability of the above mentioned systems [4]. It is also known that the efficiency of the flexible systems mainly dependent on the properties and characteristics of the flexible antenna that have good bending support. There are more survey papers published for the past decade [5,6,7]. None of the papers have provided a complete survey on the design issues of flexible antenna. Motivated by this, this work provides a comprehensive survey on various issues and challenges (substrate material selection, antenna design, bending effects etc..) of flexible antenna.

Figure1. shows the scope of flexible antenna that shows various applications and advantages to be provided by the flexible devices. These applications include:

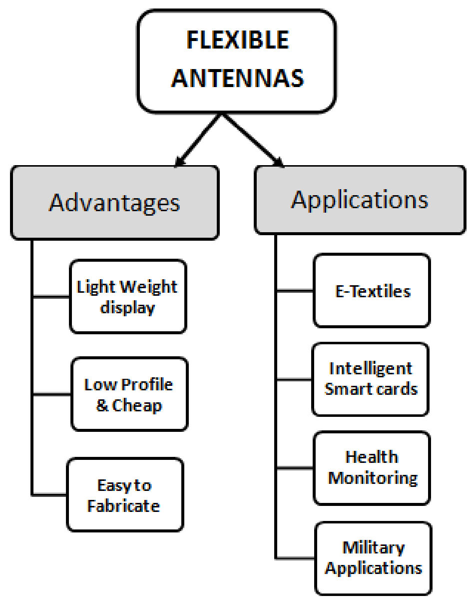


Figure 1: Scope of Flexible antenna

- Smart textiles – Electronic textiles are nothing but clothes that have been designed with modern technologies that provides increased value to the wearer. These type of fabrics are used in Health monitoring of vital signs such as pulse rate, heart rate, body temperature, training data acquisition in sports, Tracking the location and condition of soldiers in battlefield etc.,

- Military application – Soldier's bulletproof vest; if the soldier is shot, the wearable material can check the bullet's effectiveness and send a message through radio waves back to base and also monitors the pilot or truck driver's fatigue.

- Flexible electronics on foil **-** Flexible storage for wearables, implants, sensors, smart cards and bendable electronics such as organic LEDs, Photo-voltaic cells etc., [8].

- Intelligent smart cards**-** The smart card is any miniaturized card that was embedded with integrated circuits. These cards are designed with plastic material generally polyvinyl chloride, but sometimes polyethylene-terephthalate-based polyesters or polycarbonate. These find applications in schools, healthcare and multiple-use systems.

The advantages of flexible antennas are their compactness, less weight, very low profile, cheap and ease of fabrication. [9]. Their flexibility depends on the use of the substrate material. since these materials are inexpensive and able to withstand mechanical strains, the flexible antennas are increasingly improving in the electronics technology.

The flexibility and the minimum dielectric permittivity with low loss tangent losses are the opted properties of material which can be applied in the flexible micro- and mm-wave devices. The elaborate design steps involved in the flexible and wearable antennas is depicted in figure 2.

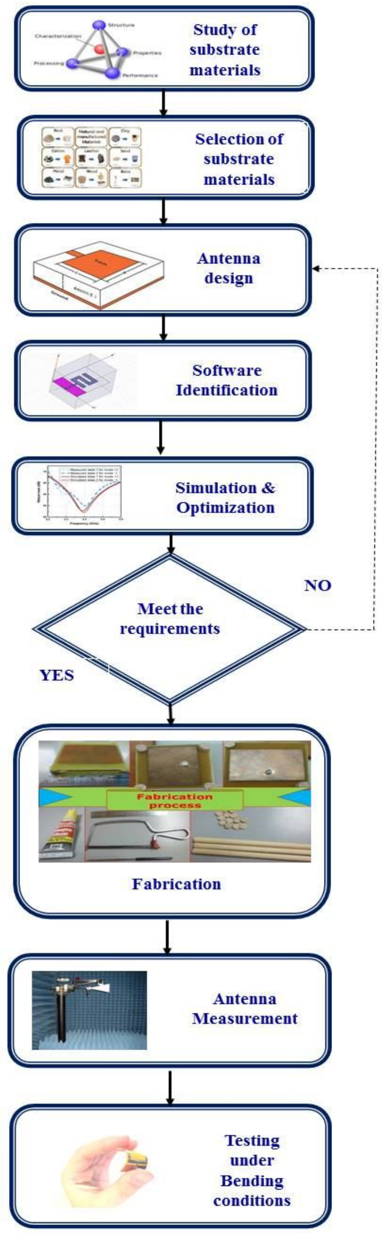
The design procedure starts with the study of the materials because for designing flexible antennas, the material will have better characteristics such as electric conductivity, loss tangent, relative permittivity. Among them, loss tangent and relative permittivity is very important. They should be a lower value. Therefore, the substrate material should be selected according to those parameters.

Then, the geometry of the antenna, radiating component, ground plane and feeding structure should be determined for designing. Then the designed structure is simulated using various software such as CST (Computer Simulation Technology), HFSS (High Frequency Structural Simulator), ADS (Advanced Design System) etc.

The antenna parameters such as gain, directivity, return loss, voltage standing wave ratio(VSWR) etc. were simulated using the software mentioned above. After better results the antenna can be fabricated and measured using VNA (Vector Network Analyzer) or by Anechoic chamber. Then for flexible antenna, it is essential to test the antenna with various bending conditions.

In order to conduct the study, all the information regarding the flexible and wearable technology and its latest trend has been gathered from the previous works that has been done. This review also focuses onto various bending conditions tested for antenna.

For selecting the antenna type and substrate material, the comparison has to be done based on the criteria needed for flexible application. Finally, the result of the comparison is discussed and concluded. It was expected that, these result can help to identify the best and suitable antenna type and substrate materials that canbe suitable for the flexibletechnology which is currently needed for designing flexible antenna. This paper will be structured as follows. Section 2 focusses on the dielectric properties of various naturally available substrate material. Section 3 focusses on the comparison of different types of antenna design with their applications. Section 4 will focus more on the various bending conditions tested on the antenna.



2: Design Procedure for Flexible antenna

2. STUDY OF SUBSTRATE MATERIALS

The first step for designing any type of antenna element comprisestwo considerations. They are choosing the correct material for the substrate and the conducting region. Choice of substrate material isprimarily needed for providing mechanical support of the antenna. This is due to high return loss, low gain and low efficiency, that can be overcome by selecting an appropriate substrate for fabrication of the antenna, without changing the resonant frequency considerably. Some of the substrate material parameters such as relative permittivity, dielectric loss has a noticeable effect on the antenna characteristics. Some of the essential properties that are to be considered while selecting a dielectric material are its homogeneity, moisture absorption and adhesion of metal- foil cladding.

2.1. Criteria for Substrate Selection

The parametersthat should be considered for selecting the substrate material in the design of an antenna are as follows,

a) dielectric constant and loss tangent of the substrate
b) Surface wave excitation
c) Copper loss
d) Anisotropy of the substrate
e) Effects of temperature, humidity and aging
f) Mechanical requirements
g) Cost

To characterize a substrate, we must know the two parameters, the relative permittivity and the loss tangent. The relative permittivity is important because it determines the impedance of the whole circuit.

The relative permittivity of a material is its absolute permittivity expressed as a ratio that is relative to the permittivity of vacuum. Relative permittivity is the factor by which the electric field between the charges is decreased relative to vacuum.

Likewise, relative permittivity is the ratio of the capacitance of a capacitor using that material as a dielectric, compared with a similar capacitor that has vacuum as its dielectric. Relative permittivity is also commonly known as dielectric constant, a term deprecated in physics and engineeringas well as in chemistry. [10]

Relative permittivity is typically denoted as $\varepsilon_r(\omega)$ is defined as

$$\varepsilon_r(\omega) = \frac{\varepsilon(\omega)}{\varepsilon_0} \quad \text{------------------} \quad (1)$$

Where $\varepsilon(\omega)$ is the complex frequency-dependent absolute permittivity of the material, and ε_0 is the vacuum permittivity in eqn.1.

Dielectric loss quantifies a dielectric material's inherent dissipation of electromagnetic energy (e.g. heat). It can be parameterized in terms of either the loss angle δ or thecorresponding loss tangent tan δ. Both refer tothe phasor in the complex plane whose real and imaginary parts are the resistive (lossy) component of an electromagnetic field and its reactive (lossless) counterpart.[11]

$$\tan\delta = \frac{\omega\varepsilon'' + \sigma}{\omega\varepsilon'} \quad \text{--------------------} \ (2)$$

Eqn.2 represents the loss tangent formula for a given material. Where ω is the angular frequency, ε'' is the imaginary component of permittivity attributed to bound charge and dipole relaxation phenomena, which gives riseto energy lossthat is indistinguishable from the loss due to the free charge conduction that is quantified by σ. ε' represents the familiar lossless permittivity given by the product of the free space permittivity and the relative real permittivity, or $\varepsilon' = \varepsilon_0\varepsilon'_r$.

The minimum relative permittivity with low loss tangent are the opted properties of any substrate material which can be applied in the flexible micro- and mm-wave devices. Recently, flexible materials have increased immense interest in antenna technology [12–14,41], however, these materials have limited on the testing under bending conditions.

In the work [15], The substrate material was chosen as Denim material which have relative permittivity of 1.40 and Loss tangent 0.07 at an operating frequency range of 2.4 GHz and 5.2 GHz. Denim is a kind of jeans cloth material which is used for textile antenna applications. The work proposed in [16] deals with substrate material Leather which have relative permittivity of 2.95 and Loss tangent 0.16 at an operating frequency of 0.9 GHz and 1.8 GHz which have an advantage of working at both high and low operating frequency applications.

The paper [17] deals with the substrate material Velcro which have relative permittivity of 1.34 and Loss tangent 0.006 at an operating frequency of 2.4 GHz and 5 GHz. Velcro is a natural material made of nylon fabric core with polyester foam. In the work [18], The silk cloth is used as a substrate material relative permittivity of 1.75 and Loss tangent of 0.012 at an operating frequency of 2.6 GHz and 3.95 GHz. The silk material has the advantage of very low relative permittivity. Cotton [19] is a good natural source material with relative permittivity value of 1.54 and Loss tangent value of 0.058 at an operating frequency of 2.4 GHz. cotton is usually used as substrate material for the flexible antenna due to its high durability and low cost.

In the work [21] three different substrate materials Polymide, Styrofoam and Nylon were discussed which have relative permittivity of 3.5,1.03,2.84 and loss tangent value of 0.0030,0.0002 and 0.0117 respectively. Of the three materials Polymide have advantage of good durability but cost is high. Styrofoam material has advantages of low cost and dielectric loss. Nylon also has an advantage of low thermal loss.

3. CHOICE OF ANTENNA TYPE FOR DIFFERENT APPLICATIONS

There are several antenna types available in the existing technology. For example, Yagi Uda, Loop and Microstrip Patch antenna. Each of them has their own advantages and disadvantages. Among them, Microstrip patch antenna [40] is recently used in the design of flexible antenna. In addition to the microstrip patch, fractal antenna, Bow-tie etc also be used in the design which is discussed below.

The work in [22] shows the design of Pythagorean Tree Fractal antenna with FR-4 as substrate material at UWB frequencies (6.9 GHz). The return loss is -46dB which is very low value needed for the flexible antenna, but the VSWR value is high i.e. 2. Normally, the VSWR value should be maintained less than 2. The work in [23] shows the Microstrip patch antenna with epoxy substrate material at ISM band frequencies. The feeding technique used is coaxial probe wire feed line. The return loss and VSWR values are acceptable values. The work in [24] shows the design of bow-tie antenna with polymide substrate applicable in WBAN. The work in [25] shows the design of Printed Monopole antenna integrated with Artificial Magnetic conductor(AMC) having kapton polymide as substrate. It shows difference in return loss values with and without AMC. The VSWR value given as less than 2 which is essential for any antenna to design. The paper [26] denotes the design of Patch antenna with Electro- magnetic band gap(EBG) ground plane with cotton material as substrate. Cotton is very cheap with very low dielectric constant and loss tangent values which is advantageous for the design of antenna to be flexible. The results show improvement in the return loss with and without Electro- magnetic band gap (EBG) ground plane. The antenna is normally used in ISM band applications. The work in [27] shows the design of Stacked Textile antenna with foam substrate with center feed with improvement in return loss value andis used in multiband applications. The paper [28] shows the Microstrip antenna with 2 substrate materials: rubber and FR-4. their results were compared and it shows similar values of return loss and VSWR . The work in [29] shows the design of Flanged Micro strip patch antenna with Teflon substrate having microstrip feed line. The return loss was improved with -42.6dB with low VSWR. The antenna has various applications like Radio Astronomy, Radio location /Airborne Doppler navigation etc., The paper[42] deals with the design of hybrid cylindrical dielectric resonator antenna that operates at quad band frequencies. The substrate material used is FR4.

4. STUDY OF BENDING CONDITIONS IN ANTENNA DESIGN

For designing flexible antenna, it is important for the antenna material to be adjustable for any type of stretching, bending and deforming. This may leads to changes in resonance frequency and field pattern with respect to the flat position in which their nominal design is performed. Thus it is important for flexible antenna experts to be able to estimate these performance parameters as a dependent of the bending radius.

This section elaborates the previous work done for flexible and wearable communications and it will focus more on the various bending conditions tested on the antenna. Wearable and Flexible communication have possible benefits for any surrounding environment where information is desired, and the use of a hands-free interface is considered essential.

Mai A. R.Osman et al[30] designed a UWB antenna using flannel fabric withcopper conducting sheet and Shield it conducting fabric. Flannel fabric is a type of 100% cotton material with smooth, firm, and feathery surface that makes the fabric materialperfectly suitable for wearable applications. The measured relative permittivity offlannelfabric covering the frequency range from 300MHzup to 20 GHz is approximately 1.7 while the loss tangent isabout 0. 025.Thefabricated antenna was tested undervarious bendingconditions The return loss was also obtained less than -10 dB. Gain also improved with the frequency ranging from 2 to 15 GHz.

Yung-Yu Chen et al [31] designed and fabricated a monopole antenna operate at dual band frequency using polyimide film as a substrate material. The results show that antenna parameters such as reflection co-efficient i.e. return loss and the bandwidth are predominantly same during 90’ and 45’ bending. But, the bending an antenna with slight changes in the value of radius will definitely alter the polarization of that antenna, which leads to radiation loss. Thus the antenna's peak gain is minimized by more than 40 percent as the bending radius rises. However, the gain for the antenna bent under less than 90-degree is still higher than 1dB.

V K Lamba et al [32] designed a patch antenna with carbon nano tube-polymer ink. The designed antenna had been fabricated with cotton and song ket fabric material which have relative permittivity of 1.5 and 1.6 respectively. The thickness of the substrate material had been varied in order to study the effects on the performance of the antenna in a range of 1.5mm to 2.2mm. Measured and simulation results shows that bandwidth depends on the thickness and the type of substrate material used. It also shows that the slight changes in the value of return loss under different bending conditions.

I. Rexiline Sheeba et al [33] proposed a flexible software antenna for ISM (Industrial, Scientific and Medicine) band. Pure Cotton is used as substrate material with relative permittivity of 1.6. The designed antenna operates at around 2.45 GHz with a return loss of greater than −25 db. Then the antenna was tested under various bending condition. Its radiation characteristics, return loss, gain, polarization have been tested which are the issues when it is used as a wearable antenna for medical purpose. Investigations were done for PVC pipes with various diameter which is similar to the human body organs like arm or in the leg, ankle, knee, thigh and their resonant frequencies were noted.

Freek Boeykens et al [34] discussed about the various prototypes of Textile patch antennas. The patch of the electro-textile Flectron that is stretchable material is used for prototype 1, whereas non stretchable copper foil is used for prototype 2. Prototypes 3, 4, and 5 are fabricated on cotton substrates and have copper foil as patch material. Then, there was an expression for the substrate permittivity as a function of the bending radius, which separates the effect of bending from all other external effects.

N. N. A. N. A. Rahman et al [35] described the bending effects on four different paper-based antennas i.e. conventional, with EBG circular and rectangular and fractal antenna. The design was simulated using CST MICROWAVE Studio at 10.15 GHz using photo paper as the substrate material. From the results, it was informed that bending under any conditions will affect the resonant frequency of the antenna element to change.

Rashayati Yahya et al [36] presented an antenna with bendable design using jeans substrate for microwave imaging applications. The slot technique used was Koch shape having coplanar waveguide (CPW) feeding structure was fabricated for broad bandwidth. This antenna was tested under all possible conditions such as normal, bending as well as on-arm bending effect. The design was simulated using CST software and fabricated. It was observed that the return loss of the antenna under the on-arm bending deteriorated slightly so that the measured bandwidth became smaller. The gain of the antenna also continuously swings between 2.5 dBi and 5.6 dBi and then between 1.5dBi and 2.8 dBi with partially-omnidirectional pattern within the range of frequency band for normal and bending condition, respectively.

Saadat Hanif Dar et al [20] proposed a patch antenna using rubber substrate. The design performance of the antenna on human body was also investigated. simulations were done using CST software. It was observed that bandwidth and return loss were improved by adding the content of substrate material. The efficiency and gain of the radiating element was decreased, but this was considered reasonable since natural rubber is quite loss in nature.

Liu Jianying, Dai Fang et al [37] proposed an ISM band antenna using polyimide substrate for WBAN applications. The bending effects of the proposed antenna was analyzed. The various parameters were simulated under different bending conditions. It was observed that the increase in bending degree will affect the input matching.

Hamid Reza Sanjari et al [38] proposed a elaborate study on the various bending behavior of patch antenna including analytical modeling, simulations and measurements. The simulations were performed in two modes; patches with fixed and widened dimensions. The results showed that antenna parameters including the bending direction, thickness of the substrate andmechanical properties of radiatingelement canchange the patch antenna's behavior under various bending conditions.

M. I. Ahmed et al [39] investigated the radio frequency characteristics of three different textile materials using two different methods: Goch, Jeans and Leather. the microstrip ring resonator method and DAK (Dielectric Assessment Kit) method were used. Bluetooth antennas were designed and fabricated using these substrates. The results were compared for both the methods. The bending effect of these antennas on its impedance characteristics due to human body movements was also investigated. The results showed that the antenna fixed on the Leather substrate performs much better than the antennas that are fixed on Goch or Jeans substrates.

Sherif R. Zahran et al [7] proposed an antenna with liquid crystalline polymer material as substrate. It was operated at Ultra Wide Band frequency ranges from 4 to 10.6 GHz. The antenna has an omnidirectional radiation pattern both in flat and bent positions.

5. DISCUSSIONS

A summary of the properties of various substrate materials that has been used by various researchers for antenna design are outlined in Table 1.

Table 1: Properties of Various substrate materials

Substrate Material	Relative Permittivity (ε_r)	Loss Tangent (tan δ)	Frequency (GHz)	Remarks
Denim [15]	1.40	0.07	2.4 & 5.2	Jeans cloth material used for textile antenna applications
Leather [16]	2.95	0.16	0.9 & 1.8	Used for Ultra High Frequency applications.
Velcro [17]	1.34	0.006	2.4& 5	Made of 100% nylon fabric with polyester foam core.
Silk [18]	1.75	0.012	2.6-3.95	Used for its low relative permittivity
Cotton[19]	1.54	0.058	2.4	Most commonly used flexible substrate material due to its durability and low cost.
Polystyrene foam	1.02	0.00009	2.4	Low cost and durability
Felt	1.36	0.016	2.4	Low cost and high durability.
Rubber[37]	3	0.0001	2.4	High degree of shock resistance. Durability High impact resistance.
FR-4	4.3	0.018	-	Suitable for DC and low frequency applications. Low cost
Woven fabric[21]	2.5	0.0015		Low cost
Polymide[21]	3.5	0.0030	0.001-5	Cost expensive Good durability
Styrofoam[21]	1.03	0.0002	3	Low cost Low dielectric loss
Nylon[21]	2.84	0.0117	3	Type of polymer material. Low thermal loss

From table 1, it was clear that substrate materials used for flexible antennas typically have a low relative permittivity as well as low loss tangent. Among them, FR-4, cotton, Rubber, Styrofoam, Felt, Polystyrene and Denim material have advantages of low cost but the relative permittivity and loss tangent values are high for FR-4 and Rubber. So, according to their values of relative permittivity and loss tangent, the substrate material should be properly chosen. Figure.3 shows the graph for relative permittivity for various substrate materials. From the figure, it was easily understood that the foam materials have very less relative permittivity values.

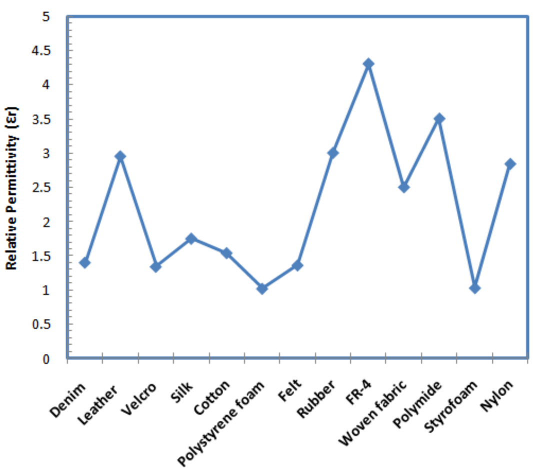


Figure 3: Relative Permittivity of different substrate materials

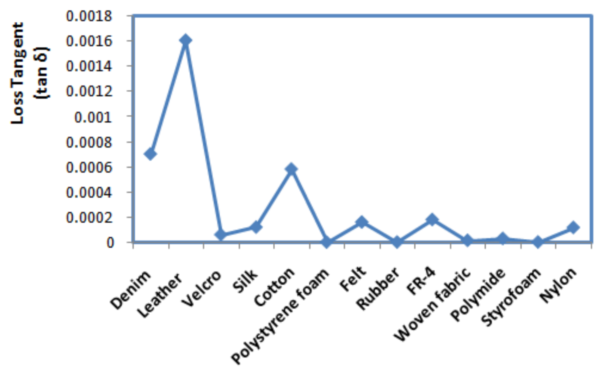


Figure 4: Loss tangent of different substrate materials

Figure 4 shows the loss tangent values for various substrate materials. Of these the Polystyrene foam, Rubber and woven fabric have lesser loss tangent values. We have to consider lesser loss tangent value while choosing the substrate materials.

Table2 shows the types of antenna, substrate material used, feeding technique, return loss, Voltage Standing Wave Ratio (VSWR) and their applications.

Table 2:. Types of antenna with various parameters

Type of Antenna	Substrate material used	Feed-line used	Return Loss (S_{11})	VSWR	Applications
Pythagorean Tree Fractal antenna [22]	FR-4	Microstrip feed line	-46dB	2	Ultra Wide Band (UWB) applications
Microstrip patch[23]	Epoxy	Coaxial Probe feed line	-30.59dB	1.04	Industrial, Scientific and Medical (ISM)Applications
Bow-Tie Antenna [24]	Polymide	Center feed	-24.82	<2	Wireless Body Area Network(WBAN)Applications
Printed Monopole antenna integrated with Artificial Magnetic conductor(AMC)[25]	Kapton Polymide	Coplanar waveguide(CPW) feed line	-21.7 dB (without AMC)	<2	ISM, Bluetooth applications
			-11.68dB (With AMC)		
Patch antenna with Electro-magnetic band gap(EBG) ground plane[26]	Cotton	Center feed	-21.38dB (without EBG)	1.186	ISM Applications
			-30dB(with EBG)	1.0655	
Stacked Textile antenna [27]	Foam substrate	Center feed	-21.33dB	<2	Multiband Applications
UWB antenna [28]	Rubber & FR-4	CPW feed	-31dB(Rubber) -30.6dB(FR-4)	<2	UWB and WBAN Applications
Flanged Microstrip patch antenna [29]	Teflon	Microstrip feed line	-42.6dB	1.0148	Radio Astronomy, Radio location /Airborne Doppler navigation

Different antenna types were designed with different flexible substrate materials and tested under different bending conditions. Table 3 shows the comparative review of various research papers having many antenna types designed with flexible substrates and tested under various bending conditions. the return loss was also tabulated. Return loss is defined as the parameter that indicates how amount of power that was lost to the load and does not return as a reflection. Return loss is defined as an important parameter used to indicate how effective that the matching between transmission line and antenna takes place. Ideal value of return loss is chosen around -13dB.

Table 3: Comparison of various antenna types with different bending conditions

Type of Antenna	Substrate material used	Frequency range	Return loss,S_{11}(in dB)			
			Flat mode		Bending mode	
Dual band Monopole antenna [31]	Polymide	2.5GHz	Measured	-25	45’	-26
					90’	-20
Softwear antenna [33]	cotton	Around 5.59GHz	Simulated	-31.44	Diameter=11cm	-12.4
					Diameter=5cm	-36.9
			Measured	-31.6	Diameter=3cm	-29

Paper based EBG &Textile antenna [35]	HP Photo paper	10.15 GHz	Rectangular EBG	-40dB	Radius =30mm	-21
			Circular ring	-35		-25
Wideband Jean antenna [36]	Jean material	3.6-3.95GHz	Simulated	-24	Radius =40mm	-21
			Measured	-22	On arm bending	-13
Yagi – Uda antenna[37]	Polymide	2.45GHz	Simulated	-34	Radius 20mm	-22
					30mm	-27
			Measured	-30.5	40mm	-31
					50mm	-32
atch antenna [39]	Goch	2.5GHz	Simulated	-15.6	Radius 70mm	-18
			Measured	-15	150mm	-15
	Jeans		Simulated	-18.9	70mm	-21
			Measured	-30	150mm	-23
	Leather		Simulated	-19.8	70mm	-20
			Measured	-20	150mm	-16
UWB antenna[7]	Not specified	7.5GHz	Simulated	-35	Radius 40mm	-24
			Measured	-35		

From this discussions, the choosing of antenna type normally depends on the selection of the substrate material as well as where it is applied. Usually The PVC (Polyvinyl Chloride) cylinder has been used for bending support, because the antenna cannot have bent independently on air with any specific radius. From the table 3, the antenna nevertheless of any type with fabric material have a better return loss for bending test that is equally matching with flat conditions.

5. CONCLUSION

6.

This work has provided a comprehensive study of various design issues of flexible antenna. From this review, it was concluded that there are several additional aspects to be taken into account when designing a flexible antenna, in comparison to a conventional antenna design. It showed that there exists a spectrum of potential materials that could be used in designing flexible antennas. Testing with various bending and on body measurements have to be done in order to obtain an antenna design that meets the wearable antenna specification. Flexible antennas are now accepted and used in the application of telecommunication through Radio Detection and Ranging and in Defense, telemedicine, Global Positioning System and satellite communication. Recent techniques for the designing and characterization of antenna and their effects on various bending performance were reviewed. These antennas are robust, promising, and hold a great future with therapidly increasing wireless communication technology. Thus the review has been paved the way for the future researchers to design a flexible antenna which will be perfect in all aspects.

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