A Review on Flexible Printed Antennas for Futuristic Applications

Srishty Saha[1]*, Sagnick Das[2], Soumaydeep Das[3], Goutam K. Das[4]
Department of Electronics & Communication Engineering
Techno India University
*srishtysaha28@gmail.com

Abstract- **Flexible antennas are one of the majorly used transceiver devices in modern day technologies. Due to its flexible nature it can be used ranging from healthcare industry to automobile industry, and many more. Study and analysis on flexible antennas have unveiled new dimensions in communication network and allied domains. Compact, lightweight, flexible materials make sure that the antenna can be used along with any existing electronics of any required shapes. Mainly the polymers, textiles and papers are being used as antenna substrates to incorporate flexibility. In recent times, flexible antennas are analysed vastly for futuristic bio-implantable antennas. Along with the flexible dielectric materials, conducting flexi materials are also investigated to replace the radiating portion of the antenna. A detailed review on flexible antennas by comparing on the basis of materials used and the applications, may find some interesting alternatives of the conventional applications. Also, this review work shall unearth the possibility of new fan outs of futuristic approaches.**

Keywords– **Antenna Review; Flexible Antenna; Polymer Substrate; Printed Antenna; Textile Substrate.**

I. Introduction

Over the last several decades, the usage of Flexible Electronic Systems (FES) have been spreading like wildfire in various industries[1] as well as organizations related to biomedical[2] and healthcare purposes[3], military and defence[4], textiles[5], GPS[6], fitness monitoring[3], entertainment world[7] and many more. They have now become the assemblage of numerous devices which are composed of organic substances as a substrate [8]. Flexible electronics (flex circuits) is a technology for assembling electronic circuits by electronic devices on flexible substrates, such as, conductive polymer [9], conductive textile [10], polyimide [11], Teflon [12], liquid crystal polymers (LCPs) [13], etc. FES technology is used for developing passive as well as active electronic devices. Flexible antennas are one of the most important

electronic devices that can be used widely as transceiver unit of a communication channel. The sphere of flexible antennas is experiencing an exponential growth due to the present-day needs for wearable gadgets, internet of things (IOT) platform [14], and wireless sensor [15] and transmitting devices[16], healthcare equipment[17] to mention a few. Flexible antennas have the ability to detect, transfer data, store energy and serve its purpose while being worn. In addition to these, flexible antennas can also accommodate the current 5G technology and ensure the accessibility of high speed, enormous capacity, and less delay in a communication channel [18]. In recent future it can be predicted that, each and every branch will prosper from 5G networks ranging from 3D imaging, military, GPS etc [19]. In recent days, state-of-the-art applications of flexible antennas has been increased worldwide due to their low-cost fabrication [16], sensing and easy configurations. Another major aspect of flexible antenna design is the choice of substrate materials. The way a particular antenna performs, depends on the material used for antenna fabrication. Depending on the adaptability to certain environment and conditions, such as, mechanical deformation, twisting, and bending, the materials can be chosen [20].

There are several techniques reported in literatures for fabrication of flexible antennas. Chemical etching (began in 1960s), usually accompanied by photolithography, is the method of fabricating metallic patterns in order to remove a selected portion corrosively [21]. The technique practiced in recent days, is the photolithography based antenna and RF circuits which depend mainly on positive resists as they show higher resolution than negative resists [21, 22]. Over the last few decades, inkjet printing has arisen as a substitute to chemical etching. This fabrication technique is most preferred for polymeric substrates like polyimide, PET and paper due to its correct and diligent prototyping fabrication method [23].

Later, another technique was introduced known as screen printing. Screen printing is a speedy, easy, cost-effective and practically applicable solution for the fabrication of flexible electronics. This technique is a woven screen-based method which has divergent thicknesses and thread densities [24,25]. Very recently, 3D printing techniques have gained popularity due to their commercially available materials of printing and the processes [26]. Polymers like thermoplastics, thermosets, are used as 3D printing materials for the applications of flexible antenna. The most common of all 3D printing technologies is Fused Deposition Modelling [27,28].

In this review paper, a detailed comparative study has been carried out for flexible antennas depending on various parameters. Firstly, flexible materials have been analysed and compared for efficient antenna fabrication. Antenna materials have been categorized into two parts, such as, conducting materials and dielectric substrate materials. Flexible substrates are essential for conformal antenna structures. Various polymers, textile materials, as well as, human skins are used for printed antennas. The choice of material also be determined based on the application and usage of the antennas. Apart from these, flexible antennas have also been compared for their parameters and performances, such as, antenna dimensions, bandwidth, gain, etc. flexible antennas are widely used for healthcare related industry as well as communication industry which includes devices which are kept in near proximity of human beings. Hence flexible antennas are compared on the basis of specific absorption rate (SAR) as well. In later sections, various comparison tables and analysis have been reported. Finally, some futuristic approach has been discussed based on the probable usages of flexible antennas.

II. MATERIALS FOR FLEXIBLE ANTENNAS

Flexible antennas consist of conductive layer and dielectric layer. Conductive layer prepares the radiator and ground of an antenna, whereas, the dielectric layer forms the antenna substrate. Choice of materials decides the method of fabrication for flexible antennas [29]. The selection of the conductive layer decides the performance of the antenna such as, radiation frequency [30] whereas, the dielectric layer or substrate is selected based on their dielectric properties, resistance to mechanical deformations (such as bending and twisting) and tolerance to harsh environment conditions [9].

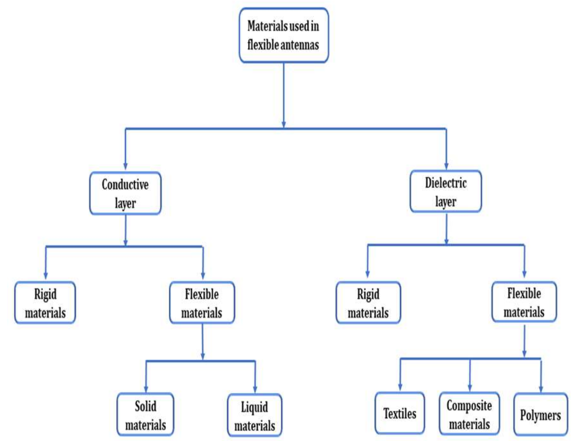

Fig. 1. Classification of materials used in flexible antennas.

A. *Conducting layer*

The understanding of conductive patterns with the best electrical conductivity is significant for ensuring high gain, bandwidth as well as efficiency in wireless applications [9].Conducting layer forms the ground plane and radiating element [29].Conductive material protects the antenna from deterioration due to mechanical deformation [9].

There are certain criteria that need to be fulfilled, in case of conductive materials:-

- They should have low resistivity or in other words, high conductivity [29].
- They should possess flexibility in order to be resistant to the deformation due to bending, stretching and crumpling [29].
- They should have the capacity to tolerate tremendous pressure [29].
- They should possess the ability to be integrated with textiles (the material can sewed to other textiles) [29].
- They should have resistance to harsh weather conditions and environmental factors such as corrosion and oxidization [29].

Keeping these properties in mind researchers have reported various materials for fabricating flexible antennas. Conducting material for an antenna can be traditional polymer based substrate or recently developed conductive ink. Conductive polymers such as polypyrrole (PPy)[30], polyaniline (PANI)[31], poly(3,4-ethylenedioxythiophene)[32] polystyrene sulfonate are considered to be more reliable for flexible antennas [10]. On the other hand,conductive ink, comprised of carbon or metal particles, is a favorable material for flexible antenna structure. Conductive inks have the merits of fabrication simplicity, compatibility with inkjet printing and screen printing process and low cost [33].

B. *Dielectric Layer (Substrate)*

The dielectric layers (or the substrate) are mainly used to brace the conductive layer of the antenna [29]. Electrical properties of this layer, along with the antenna dimensions, determine the operating frequency of the antenna. The material chosen as a dielectric layer should possess high thermal conductivity, minimum dielectric loss, low coefficient of thermal expansion and low relative permittivity[34]. Different kinds of flexible substrates are adopted depending on the nature of the conductive materials used in the design [29].

Among a large variety of substrate materials, it can be preliminary categorized into three subdivisions depending on the physical properties. Those are, plastics or polymer substrates, thin glass, and metal foils. Although thin glass is bendable, its utility has been restricted by the intrinsic brittle property. Metal foils can tolerate high temperatures and allow deposition of inorganic materials on them. However, their high cost and roughness of the surface restrict their applications [35]. Plastic (or polymer) materials are best suited for flexible antenna applications. Some of them include:

- Thermoplastic semicrystalline polymers – Polyethylene terephthalate (PET)[36], polyethylene naphthalate (PEN) [37].
- Thermoplastic non-crystalline polymers – Polycarbonate (PC)[38], polyethersulphone (PES) [39].
- High glass transition temperature materials – Polyimide [40].
- Other than polymer substrate, paper substrates are used widely as well. Paper substrates are most suitable for screen printing and inkjet printing processes on the basis of conductive inks [41].
- In very recent times, textile in clothing (non-conductive fabric) can be used as a material for flexible antennas, especially when braced with metal-plated textile conductors. Different types of textiles are involved such as: cotton, silk, wool etc. Their relative permittivity is highly dependent on how they are knit or woven, materials involved and thickness. Certain materials have anisotropic features like, Cordura and Ballistic fabrics. Thus, being aware of the parameters is crucial for the chosen textile clothing prior to designing of the antenna [42].

III. STUDY ON FLEXIBLE ANTENNAS

A. *Antenna Performances*

The performance of a flexible antenna depends on several parameters like gain, bandwidth, specific absorption rate (SAR), etc. Selecting a suitable dielectric material iscrucial for antenna performance [48]. While the permittivity of the dielectric substrate defines the operating frequency, the gain is reduced for a higher value of loss tangent of the dielectric substance [49].

Here are some parameters mentioned below which decide the performance of the antenna:-

- **Gain** – Gain (or absolute gain) is defined as, “The ratio of the radiation intensity in a given direction to the radiation intensity that would be produced if the power accepted by the antenna was isotropically radiated” [50]. This ratio is expressed in decibels with respect to an isotropic radiator (dBi).
- **Bandwidth** – Bandwidth is another fundamental parameter of flexible antennas. It describes the range of frequencies over which the antenna can properly radiate or receive energy. Bandwidth is typically quoted in terms of Voltage Standing Wave Ratio (VSWR) [51]. Antenna researchers have set a maximum VSWR value as 2 for efficient radiation of the antenna. This VSWR corresponds to about 10 dB return loss characteristics. Hence the bandwidth can be calculated from the S_{11} parameter graph of a specific antenna application [52].

- **Specific Absorption rate** – Specific absorption rate (SAR) is a measure of the amount of energy is absorbed per unit mass by a human body when exposed to a radio frequency (RF) electromagnetic field. In other words, it is defined as the power absorbed per mass of tissue [53]. Its SI unit is Watts per kilogram (W/kg) [54][55].According to the Federal Communications Commission (FCC), an independent agency of the United States of America (USA), has crafted a strict regulation for maximum SAR value of a radiating device that is essentially exposed to human beings. According to the FCC norms, the maximum permissible limit of SAR is 1.6 W/Kg for a 1g unit tissue model [56].

B. *Advantages of Flexible Antennas*

There are certain advantages that make flexible antennas so popular in the industry. Some of them are:-

- They are easy to manufacture [29]. Simple chemical etching or inkjet printing can felicitate the batch production of antenna.
- They are compact [29]. Hence, these antennas can be clubbed with existing electronic devices as transducer unit. Less layout spacing makes these applications as well [66].

TABLE I
Comparing properties of dielectric materials used for flexible antennas.

Ref	Material	Dielectric Constants	Dielectric Loss	Antenna Type	Operating Freq.	Area of Usage
[36]	Polyethylene Terephthalate	3.4	0.01	monopole antennas	60 GHz	Millimeter wave application
[37]	Polyethylene Naphthalate	2.9	0.025	monopole with omnidirectional	60 GHz	RF, HF and millimeter-wave Applications
[39]	Polyether-sulphone	3.2	0.022	slotted monopole	20-40 GHz	Millimeter wave application
[43]	Polydimethylsiloxane	42.92	1.562	dual-ring slot antenna	2.45 GHz	Bio-implantable Application
[44]	Jeans	1.67	0.025	Ultra Wide Band antenna	5 GHz	Wearable Application
[45]	Polyester	1.44	0.01	Patch antenna	2.4 GHz	Wearable Application
[46]	Curtain	1.47	0.04	Patch antenna	12.125 GHz	Ku Band application
[46]	Fleece	1.04	0.02	Patch antenna	12.932 GHz	Ku Band application
[47]	Leather	1.8	0.01	Patch antenna	2.45 GHz	Military applications
[47]	Silk	1.2	0.02	Patch antenna	2.40-2.50 GHz	Wearable application

- They have low profile and come with low cost [29]. Hence, flexible antennas are used vastly for various industries, such as, healthcare, defence, communication, etc.

C. *Applications of flexible antennas*

Due to the advantages mentioned in the previous section, flexible antennas are being used massively in various fields, ranging from military and defencetohealthcare industries. A few of them include:-

- **Military and defence** – Flexible antennas are used in a wide range of military applications like communication satellites and for "find and track" missions. While the recent uses of antennas bring up challenges with respect to isolation, frequency variation, directionality and testing for the design, dielectric materials have shown a viable way to deal with the shortcomings in military and defence [4].

TABLE II
Comparing flexible antenna parameters presented in various literatures.

Ref.	Types of Antenna	Dimension (mm^2)	Operating Freq. (GHz)	Bandwidth	Antenna Gain
[57]	Dual-Band Antenna	15 x 14	2.5/4.5	600 MHz–1 GHz to 2.25 GHz–2.95 GHz	5 dB
[57, 58]	Poly-Imide Based Single Band Antenna	26.5 x 25	2.4	305 MHz	-0.6 dB
[57,58]	Poly-Imide-Based Dual Band Antenna	35 x 25	2.5/5.2	290 MHz-280 MHz	-0.4 dB
[57, 59]	Textile Antenna	180 x 150	2.2/3	100 MHz- 110 MHz	
[57, 60]	Paper-Based Antenna	46 x 35	2.4	600 MHz	1.2dB
[61]	Microstrip-based Koch fractal	39 × 39 × 0.508	2.45	2.36 GHz-2.55 GHz	2.06 dB
[62]	Microstrip patch.	60 × 60 × 0.110	4.5	4.43–4.76 GHz	5.18 dB
[63]	Elliptical quasi-dipole antenna	46 × 45	2	1-5 GHz	2.3dB
[64]	Multilayer microstrip fractal patch antenna	22 × 31 × 0.125	N/A	4.79–5.04 GHz	4.5 dB
[65]	CPW-fed Hybrid Shaped patch	0.4 × 38 × 70	3.5, 6.7, & 12	3.06–13.58 GHz, 15.9–20.5 GHz, & 20.9–22 GHz	1.69 dB

- **Biomedicine and health** – Nowadays, the need for flexible antennas has increased in biomedical applications. The antennas are a major component in monitoring regulation of organ functions, in implementing vivo monitoring of major signs, intracranial sensors, drug delivery systems etc [38][63].
- **Automobile industry** – Flexible antennas are becoming more and more popular in the automobile industry [64]. They play a pivotal role in establishing and sustaining an efficient cordless connectivity in and among the networks within. They are not only employed to provide a safe driving environment but also to improve the run-time efficiency [64].
- **Textile industry** – Embedding flexible antennas into clothing makes the attire transform into smart interface for the communication between the user and the network. The antennas should be lightweight, resistant to washing and of low cost for manufacturing and advertising [11]. Conductive textile materials are needed for the conductive layer (ground plane) and non-conductive textile materials are required for the dielectric layer [67].
- **Telecommunication** – As the world is heading towards 5th generation (5G) wireless mobile communication, flexible antennas are responsible for enhancing its possibility. 5G is providing enormous data bandwidth, humongous capacity of networking, and a fabulous signal coverage to enable high range of good quality individualistic service to the users[66]. Flexible antennas are crucial for radio wave communication. They are

a stepping stone for 5G network as it requires outstanding flexibility and intelligence in terms of spectrum sharing, millimetre wave communication, integrated access of Internet of Things (IoT), huge multiple input and multiple output system (MIMO), transferring of big data etc[68].

IV. CONCLUSION

In this review paper flexible antennas are being compared based on the antenna materials and antenna performances. Also the flexible antennas have been analysed by categorising the flexible materials as conducting materials and dielectric materials. Also extensive study reveals that the flexible antennas can be used for several applications, such as automobile, healthcare industry, military and defence, and many more. Researchers are attempting early detection of disease and continuous monitoring of massively ailed patient by using flexible implantable antennas. The only drawback of this technology is that, the flexible antennas are new and vastly untested over various applications in longer time. However, flexible antenna is the need of the future and it enlightening the new dimensions in the relevant research fields.

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IV. BIOGRAPHIES

Ms. SrishtySaha is a student of Techno India University. She is 19 years old. She is a resident of Kolkata and completed her schooling from Auxilium Convent School, dumdum. Currently, she is pursuing B. Tech. In Electronics and Communication Engineering from Techno India University. She plans to perform further research on Antennas in future.

Mr. Sagnick Das is a student of Techno India University. He is from Chakdaha, West Bengal, and completed schooling from Satish Chandra Memorial School,Chakdaha He has completed his diploma from Acharya Institude, Bangalore in Electronics and Communication. Currently He is pursuing B. Tech in Electronics and Communication. His future plans include further research on Antenna.

Dr. Soumyadeep Das was born in Kolkata, India. He receieved the B.Tech degree in Electronics & Communication Engineering from West Bengal University of Technology (WBUT)), India and the M.E. degree in Microwave engineering specialization from Birla Institute of Technology (BIT), Mesra, India in 2013 and 2015 respectively. He has been awarded Ph.D degree from the department of Electronics & Telecommunication Engineering, Indian Institute of Engineering Science and technology, Shibpur, India in 2022. He was awarded with the Visvesvaraya PhD fellowship, under the Ministry of Electronics & Information technology (MeitY), Govt. of India. His main research includes design & analysis of the implantable antennas, and their performance enhancements using periodic structures. Apart from his research works, he takes interest in short film making and reading good story books. He is currently associated with Techno India University, West Bengal as an assistant professor in the department of Electronics & Communication Engineering.

Dr. Goutam Kr Das completed his B.E. degree in Electronics & Tele-communication Engineering from BE College, Shibpur, West Bengal, India in 2000. He received his M. E. degree in Electronics & Tele-communication Engineering from Bengal Engineering and Science University, India in 2008 and obtained the Ph.D. degree in engineering (Electronics & Tele. Comm.) from Indian Institute of Engineering Science and Technology (IIEST), Shibpur, Howrah, India in 2021. Dr. Das has 22 years teaching experience now he is an Assistant Professor in the department of Electronics and Communication Engineering, Techno India University, West Bengal, Kolkata, India. His current research interest is in bio medical antenna design, signal processing, Computational intelligence and IoT in smart cities.