NANOCOMPOSITE MATERIALS ENHANCE FLEXIBLE AND RECONFIGURABLE ANTENNA CHARACTERISTICS

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Abstract
Reconfigurable and flexible antennas using nanocomposite materials have proved competent over the last few years due to their incredible attributes like flexibility, light weight, efficiency and economical. These portable wireless communication systems are feasible to the multiple communication strategies capable to deal with changing environment with the proper usage of available bandwidth. Flexibility and device performance can be enhanced by using different types of nanocomposite elements in conducting materials and substrates. To achieve efficient utilization of power and bandwidth availability; pattern and frequency reconfigurable methods can be employed. With respect to the operating frequency band, geometrical shape and structure of the antenna,different methods of pattern and frequency reconfigurable techniques are analyzed and their performance are compared with each other.

Keywords:
Nano composite materials, reconfigurable, flexible antennas, bandwidth availability.

1. Introduction

The Flexible antennas using nanocomposite material have attained noticeable research interest, owing to their applications like wearable and implantable devices, sensors etc.[1].The wearable and implantable electronic devices with sensors find numerous applications in human health monitoring, RFID, real time tracking and IoT techniques[2], [3]. Some of the most important features of flexible antenna include smaller size, light weight and improved performance. For the applications that entail traits like conformality, flexibility and bendability, pliant organic substrates akin polyimide, polyester, silicone are being used since they offer good chemical stability. By using these organic surfactants bid a good advantage of being gauzy, low traffic.

The modern wireless communication suffers from interference between users or electronic jamming, beam control is the good solution for this type of problem [4], which is used in MIMO systems for obtaining a good communication link. A pattern reconfigurable antenna (PRA) consists of several states that are controlled by predetermined states of switches that can solve problems of electronic jamming and interference between users. To enhance the bandwidth availability of communication systems, we can use some reconfigurability techniques in antenna system design such as frequency reconfigurability, by covering diverse frequency bands[5]. The frequency reconfigurable antennas alter its bandwidth and operating frequency, automatically or manually. Discrete switching methods are available apropos of the application, antenna framework and frequency band.

2. Flexible Nanocomposite Materialsfor Antenna Design

The fruition of the antenna in varying complex physical abode can be greatly improved by considering the pliable reconfigurable antennas. A pliable antenna can be turned up, twisted, bunched, curled or cloaked with less abrasion and almost the same performance or characteristics as that of the original one without any deformation [6]. Also, the antenna characteristics are less affected by the weather conditions like rain, ice and snow [7]. These flexible antennas have good Electromagnetic (EM) radiation protection against the antenna characteristics. In the case of wearable antenna, either flexible or non-fabric materials are used

2.1 Conductive Nano Composite Materials

Polyaniline (PANI) and Polypyrene (PPY) conductive polymers are used in electronic radiationstructures, because of the flexibility, low cost and reconfigurability [8]–[10]. PANI has goodchemical stability when compared to PPY. But PANI has relatively low conductivity. Its conductivity can be increased by totting up allotropes of carbon well- linked with Polymer matrix [11]–[14]

The screen-printing method is employed in the synthesis of a conducting Polymer patch antenna with PANI films that can act as radiating elements at 10 GHz center frequency[15]. Colloidal Quantum dots, conjugated small molecules and conjugated polymers are some of the processable semiconductors that can be introduced on the top of flexible substrate which can revamp electrical properties of nanoporous stuff. The installation and fabrication cost of the flexible substrate can be decreased by the liquid phase decomposition techniques like ink jet printing and spin coating. A conductive nanocomposite material can be classified into core type zero-dimension nanostructure materials (0DNSM) or artificial atoms, core shell artificial atoms, quantum dot based on concoction and structure [16]. In [17] a highly efficient, compact, flexible UWB antenna (3-10 GHz) made from patterned conductive polymer (PEDOT) appended to a pellucid gooey substrate. The facet of this antenna is abridged to 0.25λ with a radiation efficiency of 85 % [17].

A monopole antenna operates on double frequency bands by utilizing different layers of cobalt nano particle ink [18]. The ink is printed with different layers of thickness on top of the substrate that tunes the center frequency of the radiating element. In this paper, the antenna radiation characteristics like center frequency and total efficiency, of reference radiating antenna is compared with an antenna having magnetic layers coated on it. A multilayer magnetic monopole radiating antenna having thickness of 90 μm works on dual band operation with frequency of 900 MHz and 1800MHz [18]. The flexible conductive nanocomposite materials with their properties are summarized in Table 1.

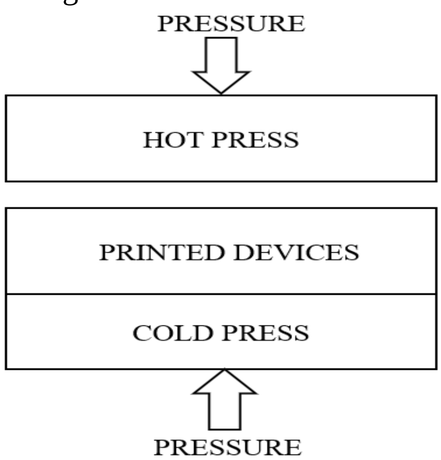
2.2 Nanocomposite Substrates

The nanocomposite materials are widely being used as substrates in antenna fabrication like polydimethylsiloxane (PDMS) that can be lodged to conductive fabric. This advancement in fabric technology has set up a handy routine for the realization of conformal, adaptable antenna that can accomplish basic antenna characteristics like toughness, moisture resistance with superior mechanical and chemical solidity [19]–[21]. Due to the flexibility of Kapton substrate, we can bend the uncrumpled antenna into different angles. Here, Kapton substrate of thickness 0.13mm is being used to provide the flexibility and the antenna is operated in UWBapplication by designing the coupling between coplanar wave-guide (CPW) and the ellipse. Due to the flexibility of this antenna, it can be easily integrated into clothes and other desired materials[22]. When the crushing depth was selected at 5.3 mm the length of the antenna got reduced (from 48mm to 35 mm) generating a flat dimension [22].

Table 1. Resemblance study of conductive nanocomposite material

Conductive Material	Thickness of Patch	Conductivity of Patch in (S/m)	Resonant Frequency	Gain	Bandwidth	Loss Tangent (tan (δ))
PANI/MWCTs [22]	75 µm	4500	Dual Band 1.9 GHz and 5.7 GHz	2.48 dBi, at 5.7 GHz	Dual Band 1.65-2.62 GHz 4.2-7.58 GHz	0.002
Polyaniline [15]	100 µm	6000	9.85 GHz	3.42 dBi	3.1%	0.001
PEDOT [17]	70 µm	9532	UWB, 3-20 GHz	1.1-4.4dB	3-20GHz	0.01
Egalan Liquid Fillet [25]	0.08mm	$2.5x10^5$	2GHz	-	1910-1990 MHz	-
Zoflex + Copper [26]	0.175 mm	$1.93x10^5$	360 MHz 1.8 GHz 2.4 GHz	6.18 dBi	2.69- 2.97 GHz	0.01
Copper Coated Taffetta[27]	0.15 mm	$3.4x10^6$	2.45 GHz	1.6 dBi	2.37-2.6 GHz	-
Meshed Fabric [28]	0.057 mm	$2x10^5$	UWB 2.2-25GHz	4.3dBi at 10 GHz	2.2- 25 GHz	-
Cobalt nanoparticle ink [18]	90 µm	-	Dual Band 900 MHz,1800MHz	2.63 dB (lower band) 3.54dB (upper band)	30 MHz (lower band) 176 MHz (upper band)	0.92 for 900 MHz 1.73 for 1800 MHz

Polyaniline sedated multiwall carbon nanotubes seemed propitious in antenna prototype. When the patch thickness was 75µm its conductivity becomes 4500 S/m. In [23] the Q-factor improvement of loop antenna (HF RFID) through thermal compression and annealing is discussed. The substrates here are polyethylene terephthalate (PET) and paper since, both these substrates are not tampered during the process of thermal mechanical treatment. When the thermal compression process [23] was carried out the printed tracks are obtained with the help of flatbed press. To begin with, the hot platen was heated at the glass transition temperature followed by placing the device on cold platen. The device is then pressurized for short span of time and the steps may be repeated. Finally, the device is presented for the succeeding procedures as shown in Fig.1



In the annealing technique as the wavelength of the conductive particle are comparable to the screen printing inks the light get converted to thermal energy by bouncing of light rays in between the particle.In [1], use of a magneto-dielectric substrate having high value of permittivity (ε_r) and permeability (μ_r) where by finding its usage in broadband and miniaturized applications (10 MHz to1 GHz). These substrates having excellent valueε_r and μ_r are fabricated by combining $NiZnCO$ ferrite and poly vinyl alcohol (PVA) by a process called extrusion technology. Nanodispersed RT Duroid 5880 [24] form a nanocomposite material which is used for the reduction of radiating patch and substrate dimension by a large amount. The facet of the aspired antenna is minute compared to conventional patch antenna that possess good antenna radiation characteristics like bandwidth, radiation pattern and power density

An ultra-thin liquid crystal polymer (LCP) [29] is betide to motif ultra-wideband notched wearable antenna (UWA) of bandwidth 7 GHz at center frequency 6.5 GHz. This design discards the frequencies allotted to wireless local area network (WLAN) at 5.25 GHz. The substrate assigned here is ultra-thin liquid crystal polymers of ply 0.05mm by a relative permittivity of 2.9 which is fed to a CPW

The LCP is coated with a copper film of stratum 0.018 mm. when LCP is used as a substrate it can be easily integrated to the RF module package by virtue of properties like light weight, low cost and low loss factor. The curved and tapered slots are used as ground. The overall design provides a gain of -10 dB atop the UWB frequency realm. The impedance matching parameter is obtained by the ratio of ellipse semi major axis to semi minor axis.

The high permittivity low loss, flexible substrates are obtained from the fabrication of polymer ceramic nanocomposites [30]. Particle filling density, ranges from 10% to 30% are prepared for PDMSceramic filler composite substrates. For low frequency application from 400 MHz to 4400 MHz, bequeath sterling microwave behavior such as permittivity (ranges from 8 to 9). Alike nanocomposite stuff is also used for microwave requisites in the range of 17 GHz that exhibits solid dielectric permittivity.

The Fe_3O_4-PDMS nanocomposite substrates exhibits a wide variety of magneto-dielectric properties suitable in the reconfigurable antenna design[31]. The resultant microwave material possesses a good microwave properties like permittivity, permeability and loss tangents for the electromagnetic spectrum from 1 GHz to 8 GHz. A low value of (less than 0.02) magnetic and dielectric loss tangents are achieved by exciting the biasing field between 0.2 T and 0.4 T. Different types of flexible nanocomposite substrates and their properties are summarized in Table 2.

3.Recon figurability

3.1. Pattern Recon figur ability

Pattern reconfigurability is a real time operation and it is obtained by electrically controlled devices like PIN diodes or varactors [6]. The multifunctionality features displayed in a single package like better performance, reduced polarization mismatch, noise problem reduction, reduced electronic jamming and energy saving refers to the reconfigurability feature. Hence, reconfigurable antennas are inevitable part of intelligent antenna system design. In [6] the electrical size reduction is achieved by use of NFRP (Near Field Resonant Parasitic) element. Good impedance matching and high radiation efficiency (96%) are the key features of an electrically small antenna (ESA).

Quasi-Yagi antenna performance obtained by blending a pair of bent NFRP elements atop the substrate (RogersDuroid5880) [6].The bending angle of the NFRP elements is α=70.86^0aligned with reference to the y axis and both pair of NFRP elements are mirror symmetry in connection with the x axis.Biting the two driven dipole elements atop the surfactant. These dipole elements consist of six metal strips and it is connected by four PIN diodes. A highly directional radiation pattern in both forward and backward direction is obtained by the switching action of two pair of PIN diodes [6].

The monopole reconfigurable antenna discussed in [32] has a driver element placed at the epicenter with two directors track down the fringes of the driver. This arrangement ensures a compact size. The three arms of driven element being folded structures aid to step up radiation resistance. The PIN diode switches stationed beneath the directors establish a gain of 8.5 dB and 7 dB front to back ratio.

Table. 2. Types of Flexible Nanocomposite Substrate and their properties

Dielectric material	Dielectric constant (ε_r)	Dielectric loss (tan (δ))	Substrate Thickness	Frequency Band	Resonance Frequency	Gain	Efficiency (%)
PDMS [21]	2.7	0.07	-	3.7- 10.3 GHz	-	4.53 dBi	27
Kapton [22]	3.48	0.002	0.13 mm	Dual Band 1.65- 2.62 GHz 4.2- 7.58 GHz	Dual Band 1.9 GHz 5.7 GHz	2.48dBi at 5.8 GHz	-
PET [23]	3.5	0.022	-	-	13.56 MHz	-	-
NiZnCo ferrite + PVA [1]	9	0.008	0.1mm	10 MHz- 1 GHz	260 MHz	-	-
Liquid Crystal Polymer (LCP) [29]	2.9	0.0049	0.05 mm	5.15- 5.35 GHz	5.25 GHz	6dBi	94

The compact antenna having conical and boresight pattern are obtained by a pair of antenna structure, each antenna consists of two layers i.e., PIFA (Planar inverted- F antenna) and monopole layer [33], the PIN diodes act as a switching function between each layer. It is applied in MIMO terminals designed at 2.65GHz.In [34] the wide-angle scanning is achieved through pattern reconfigurability in the planar phased array having a windmill shaped loop element, each element houses four port windmill shaped structure which could be excited port wise simultaneously which shows the capability of guiding the main beam at four quadrants [34]. A Yagi- Uda structure is modified to form four orthogonal beam patterns in the planar beam switchable antenna [35]. This structure consists of double-crossed elements that are active with the same number of parasitic

Elements at each direction as in Fig. 2. The effective electrical span of these parasitic elements determines the design of the reflector and the director element

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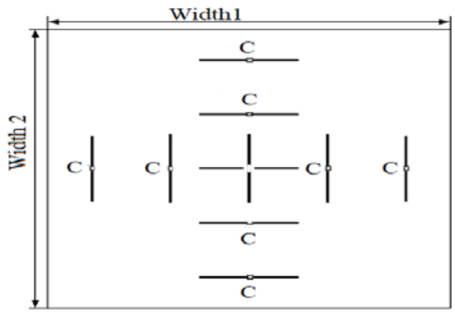

Fig. 2. Yagi-Uda antenna with parasitic elements

Eight quasi-end-fire radiation patterns is formed by a cylindrical dielectric resonator antenna with switchable beam [4]. A quasi-end -fire radiation pattern with high gain is obtained by the antenna when the higher order $HEM_{21(1+\delta)}$[4] vogue of cylindrical dielectric oscillator, resonated at 5.8 GHz. Eight beam directions can be obtained by eight switches, whose position where carefully optimized. The PIN Diodes are suitably turned ON in the proposed antenna so as to rotate the beam to the opposite direction. A remarkable gain of 7.27 dBi and high efficiency of 86.1% with low cross polarization level [4].

MIMO systems make use of reconfigurable orthogonally oriented field strength pattern [36] of soaring seclusion and scant correlation coefficient formed by amalgamation of loop and dipole structure. This antenna is designed with the annular recurved dipole geometry and artificial switches [36].

3.2. Frequency Reconfigurability

Antenna reconfiguration enables to merge different diverging modules at distinct frequencies into a single entity there by reducing the space [37]. The attributes of frequency reconfigurability allow suitable variations in resonant frequency, operational bandwidth innately or manually. Discrete switching routines deployed in the reconfigurability are micro or nanoelectromechanical systems [38], [39], metal- semiconductor field effect transistor (FET) and pseudomorphic high electron mobility transistor [40], [41], PIN diodes [42], [43], varactors [44], [45] or tunable materials. A few features of reconfigurable antennas like metasurface planar slot antenna and metallic reflector are obtained by congruously modifying the placement of metasurface and planar slot antenna [46]. A geometric structure involving a double helical chain [47] at the substrate top with a gain of 16.5 dBi variegated across few microns to meters when unfurled, helps in improving the frequency reconfigurability of antenna. This geometric structure helps to design a reconfigurable antenna with different modes and frequency. The operating center frequency of radiating element veered whence 0.36 GHz to 2.50GHz by swapping the antenna from the normal mode to axial mode. A microwave range frequency reconfigurable antenna is procured from graphene. The graphene blended with copper is worthy in motif of reconfigurable antennas [37]. The proper selection of the bias voltage being applied to the graphene the surface impedance is tuned to utmost ranges displayed as ON and OFF states of the switches. By swapping the slot facet in E shaped patch slot antenna [48] the frequency reconfigurability can be improved to yield a wide bandwidth of 1.2 GHz with center frequency at 2.6GHz, as in Fig.3[48].

A U-shaped microstrip patch antenna acts as radiating elements, with pooling four slots and PIN diodes fused for frequency reconfiguration mechanism [49], resulting in a band of frequencies from 2.63GHz to 3.7GHz that leads to four different sub bands suitable for cognitive radio communication systems. A reconfigurability in both frequency and polarization is obtained by a stub -loaded micro strip patch antenna; which consists of twelve varactors with two independent voltages [50]. The resulting antenna works with 2.4 GHz to 3.6 GHz band with a fractional bandwidth of around 40 %.

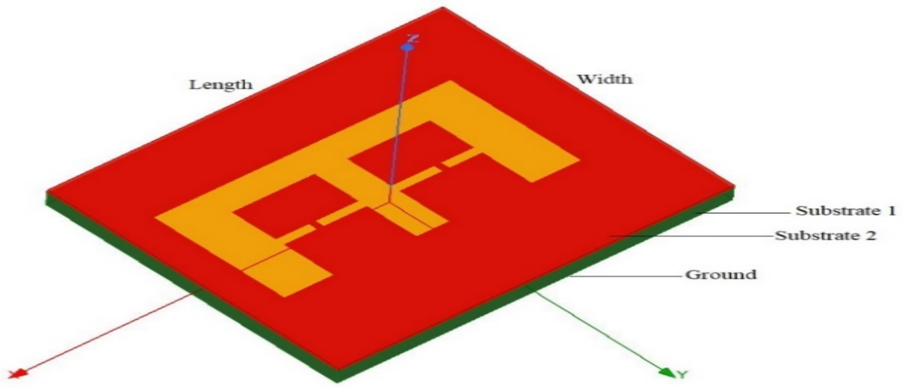

Fig. 3.E-shaped patch

The frequency reconfiguration characteristics in [51] is obtained optically. A compact optically steered reconfigurable for cognitive radio communications. This radiating antenna system contains two fragments, for spectrum sensing and communication. In [51] the spectrum discern function is effectuated by a U- shaped monopole UWB antenna with quadruple photoconductive switches so as to hand on at various frequency bands [51].

An optically pumped reconfigurable antenna is prototyped in cognitive radio system [52]. The antenna system subdues two modules; first slice is reconfigurable tapered antenna and UWB antenna. The narrow band reconfigurability property of antenna is improved by coalescing laser diodes within the antenna structures which are controlled by photoconductive silicon switches. The switches usher the light through optical fiber cables which succour the integration of reconfigurable antenna with cognitive radio communication system [52]. Several flexible, compact and nanocomposite based antennas are detailed in [53-62].

4.Summary

Reconfigurable and flexible antennas are habile in revamping frequency, radiation pattern by remoulding of geometry and behavior of antennas for efficient use of power and spectrum. By the pattern and frequency reconfigurable techniques, antennas can be designed for various applications like wearable antennas, remote aerospace applications, high frequency battle field communication and medical devices. This review begins with agglomerating the benefits of flexible and reconfigurable antennas which is followed by explaining the materials used to realize these structures. The frequency and pattern reconfigurability techniques are based on considerations such as light weight, flexible, low cost, ability to deal with trading domain and streamlined ply of power and spectrum.

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