A COMPARATIVE ANALYSIS ON THE IMPACT OF SLOT ANTENNA ON ANTENNA PARAMETERS.

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Abstract
Reconfigurable and flexible antennas using nanocomposite materials have proved competent in recent years due to their incredible features such as flexible, light weight, low cost, portable wireless communication, and support to multiple telecommunication standards, ability to deal with changing environment, efficient use of power and spectrum. 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.
INDEX TERMS- Nanocomposite materials, reconfigurable, flexible antennas, bandwidth availability.

1. INTRODUCTION

Wireless communication is beneficial in sparsely populated areas. Wireless is essential to upsurge tele-density, which is the fastest and cheapest way to expand telecommunication networks, hence antennas have become an indispensable part of real life. Antennas are an extensive and critical segment in the information superhighway that function to be a different types like microstrip, patch, microstrip patch, helical, multiloop, Yagi-Uda and slot are a few to mention. With the advent of new digital systems at 5G and 6G new antenna designs were to be deployed toavail the vast portion of electromagnetic spectrum available over the millimeter wave frequency zone (30-300 GHz). Inspite of the various researches works being carried out on antenna design and miniaturization; it is still demanding to design antennas with optimum antenna parameters like gain, bandwidth, return loss, efficiency. The early studies have revealed that reducing the size of antenna results in reduced bandwidth[1]. Printed antennas, especially the microstrip patch antenna (MPA) were extensively reviewed and enforced as they were very small, low profile, highly reliable and low cost[2]. One of the major challenges of MPAs being lower bandwidth due to single resonance radiation [3]. Diverse bandwidth enhancing techniques are available so as to improve the bandwidth of antennas, of which this review paper will elucidate the slot antenna technique.

This review is schemed as follows. The basics of slot antenna elaborated in section2. The major slot design techniques and the effect of slot shapes on the antenna performance described in section 3. A comparison of the different slot design techniques in section 4. The conclusion and some of the modification that can be included are being discussed in section 5.

2. Slot Antenna

Slot Antenna (SA) is put into service at latency and succinct. The SA is literally an opening cut that is made on a sheet of conductor, which when energized in some manner eventually radiates electromagnetic signals. The most significant property of SA is its enhanced impedance with space, which can be explained with the help of Babinet's Principle. The SA enhanced impedance match with space offers lower attenuation to the EM wave compared to dipole antenna enabling longer distance communication with SA. This concept is useful in designing broadband antennas. When combining dipole antenna with SA the product of terminal impedance isconstant, hence it will provide a larger bandwidth over the frequency range. Fig.1. shows a complementary dipole antenna with terminalImpedance Zc, it is actually a perfect electric conductor.

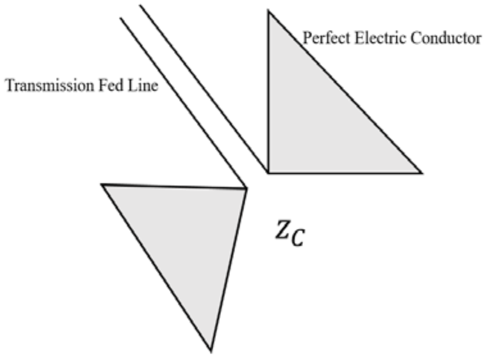

Fig.1. Complementary Dipole Antenna

SA shown in Fig.2. is an efficient radiator since the current gets spread out on the metal sheet, radiation occurs equally from both sides of the sheet. The structure gives higher mechanical stability with respect to the dipole antenna, which makes them useful in applications that require low profile, large bandwidth antennas.

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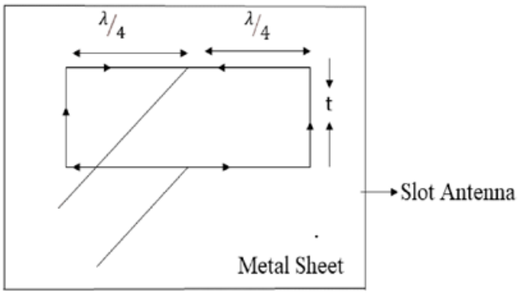

Fig.2.Slot Antenna

Communication systems mostly prefer low profile antennas because the installation space is less. SA has various advantages like simple structure, easiness of manufacture, provides directional and bidirectional radiation patterns, low cross polarization. While considering the metal sheet as the ground and the tunneling out a conduit 0.5λ long deep seated at 0.25λ the SA may be enforced at relatively longer wavelength. The non-appearance of any structures on the top of ground level, metal makes the SA widely accepted. Antenna backed by metallic cavity for unidirectional coverage. Cavity short circuited at 0.25λ will act as a short circuit.

In directions right angle to slot the radiation is maximum, while it is null along the end of slot. Aiding waveguides as an array of slots, it can be channeled to get a directional radiation pattern. Trenching out inclined slots at interval of 0.5λg these slots gets energized in phase to yield directional patterns having maximum radiation broadside to the guide. For the slot to be fed in phase, the spacing of slot must be 0.5λg, thus the impedances or admittances of slots appear in parallel[4]. The slot positions in waveguide determine the current flow, impedance presented to the transmission line, energy coupled and radiation to slot[4]. The vertical beam width and gain of the antenna are determined by the vertical aperture of slots[5]. SA can be fed by microstrip line, slot line or coplanar waveguide (CPW). Feeding not provided at the center because of the high impedance. The coupling from feedline to slot is designed at 0.25λ distance to yield maximum magnetic field to be coupled to the slot. The parameters that are necessary for antenna design are the resonant frequency, dielectric constant of substrate, height of the substrate material[5]. The position of the inset feed point is crucial in the design of antenna. For achieving a good impedance match, the feed line is placed at the end of slot antenna [6], which makes slot antennas a good counterpart in designing reconfigurable structure, as other type of antennas necessitates the use of special structures to match network [6].

3. Bandwidth Enhancement using Slot Antenna

Slot cutting techniques (circular, rectangular, elliptical, square slot) are suitable for bandwidth enhancement[7,]. The introduction of T and C shaped slot in a rectangular patch provides bandwidth enhancement [8]. The introduction of curved shaped slots in the radiating patch [9] and truncating the corners of the patch[10]enabled bandwidth enhancement. Bandwidth enhancements in the lower frequency band were reported in[11]. When strips were incorporated in ground plane and patch was provided with a circular slot, it enabled impedance matching at specific band from 7.1GHz to 8.4GHz. The variation in slot shape from straight to, L and T shapes generate additional resonance that are coupled to the original resonances of the slot, which results in increased impedance bandwidth [12]. A mirror image dual L – slot antenna, placed at two adjacent corners of the ground plane is investigated and optimized which proved to provide an impedance of 87% [12]. In Fig.3. A straight monopole slot is being placed at the center of the ground plane and optimized for wide bandwidth. The monopole slot is bent into the L and inverted T shapes, this reduced size allows more useable space for electronic circuits.

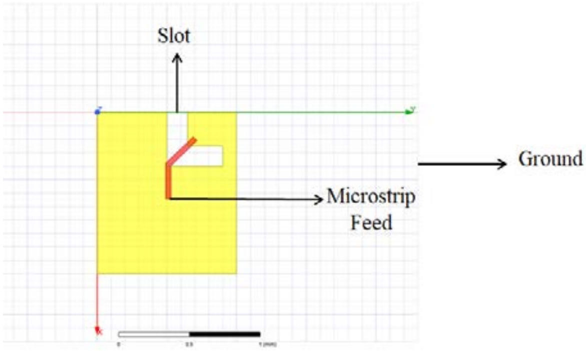

Fig.3. Microstrip Patch Antenna with L- slot[12].

A large bandwidth over frequency 2.75 GHz to 20 GHz is obtained by using modified patch and ground plane with ring and circular shaped slots on the patch[13]. This design has resulted in optimum impedance bandwidth due to the coupling between the feeding structure and the slot. To further improve the bandwidth, the ground plane is modified to be T shaped having diagonal cuts at the top corners and rectangular slot on the body.

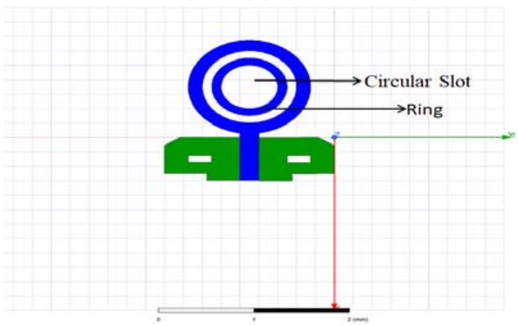

Fig.4. Circular slot on Patch with Ring[13].

In [13]the diagonal cut at the top corners and the rectangular slots increase bandwidth of antenna. In Fig.4.the design has rectangular slots, shaped slots and corner cut slots introduced in the antenna to achieve highest bandwidth of Ultra-Wide Band (UWB) antenna. The triangle slot in the ground plane of the antenna increases radiating edges which results in improved bandwidth. In [14]a Z like slot is introduced which effectively excites the additional current paths that were induced by microstrip feedline and slot edges. The bandwidth enhancement was obtained by dividing the side apertures of the Z slot to two or three fingers. This antenna was fabricated from FR4 Epoxy.The bandwidth of the proposed antenna finds applications in Bluetooth, WLAN, WiMAX and Hiper-LAN systems.

The placing of slots closed to each other results in strong coupling between the neighboring slots. The total number of resonance and resonant frequency of the slot antenna increases when the number of finger slots is increased. Thus with proper design these resonance can be proceeded and integrated into wide operating band. The bandwidth of the slot antenna can also be improved by manipulating the field distribution along resonant slot structures using feedline [15]that has resulted in dual resonance behaviors, which increases the bandwidth by more than 200% relative to a narrow slot. In[15]a bandwidth enhancement of a microstrip -fed wide slot antenna is explained. The bandwidth can be doubled by creating a fictious short circuit along the slot. The design shows two antennas placed in close proximity to each other tuned to a resonance of 850 MHz which creates significant coupling resulting in an increase of total bandwidth of 21 MHz.

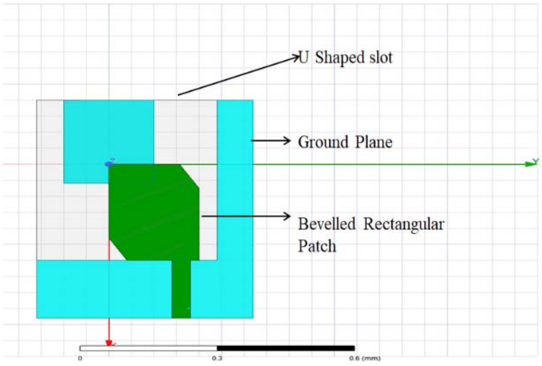

Fig.5. U Shaped slot and rectangular patch [16]

The compact open slot antenna for bandwidth enhancement [16]presents multiple resonances that are generated using asymmetrical patch with U shaped open slot etched on the ground plane on the opposite sides providing wide impedance bandwidth of 122% for frequency from 2.95 GHz to 12.1 GHz, maintaining the UWB performance. To improve the impedance matching two bevels are cut on the rectangular edges. The U-shaped slot comprises two vertical slots and one horizontal slot. The patch is optimized to achieve a miniaturized design; U shaped open slot, Fig.5.That is etched on ground plane to enhance the bandwidth. The bandwidth enhancement in [17] elaborates a printed slot antenna that is microstrip line fed with a pair of parasitic patches, having a voltage standing wave ratio (VSWR) less than 2 and enhanced impedance bandwidth of about 136 % ranging from 2.1 GHz to 11.1 GHz. The proposed antenna is fed by a microstrip line printed on other side of substrate; pair of semi-circular parasitic patches is also embedded.A wide slot in[18] is with an aspect- ratio significantly smaller than that of usual narrow slots. With a simply rotated slot with an angle of 45 degree for bandwidth enhancement is proposed and investigated. In Fig.6. A square slot with square ground plane is shown.

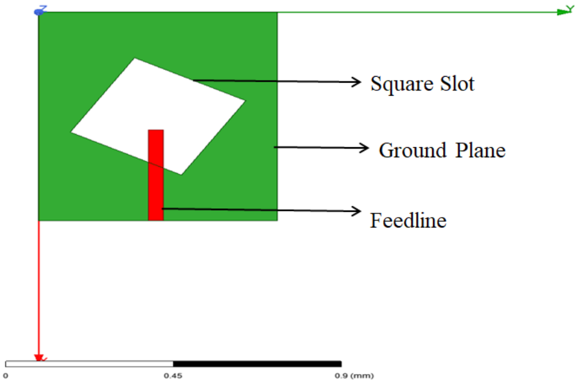

Fig.6. Square slot with Square ground plane[18].

Assigning the roper rotation angle with respect to the center of square wide slota second resonant mode is obtained having similar slot radiation patterns and same polarization planes ensures desirable bandwidth as large as 2.2GHz and antenna gain of about 4.6 to 5.2 dBi **.**A substrate integrated waveguide (SIW) array antenna presented in [19]is having non alternating longitudinal slots to realize the impedance bandwidth enhancement. The impedance bandwidth of the slot array antenna is expanded 2.3 times much more than conversional slots, a stable radiation pattern bandwidth of 2.3% is obtained having a gain of 17 dBi with center frequency at 94 GHz.The bandwidth enhancement technique discussed in[20]deals with a via-hole placed above the slot, this generates an additional resonance at a higher frequency by shortening the effective length of the slot. The position of via-hole is varied to get second resonance frequency of antenna. The fabricated slot antennas with via-hole located above the slot create a 60% wider bandwidth.

4. Miniaturization in Slot Antenna

The miniaturization of antenna is important and it has great preference in the application of the antenna. The design of the small slot antenna can be done only at the tradeoff of size, bandwidth and gain. It is a truth that antenna miniaturization have effect on radiation patter, return loss. The proper design of the antenna with combination of loop, slit and strip can yield a better miniaturization. The antenna miniaturization achieved in the reference [21]is with the help of wire loop and is called a miniature composite wire loop antenna (MCWLA). The device that operates at UHF band benefits as a result of antenna miniaturization, since the wavelength at these bands is relatively low. The slot antenna having infinite ground plane ought to generate omnidirectional radiation pattern in E plane while small size slot antenna with finite ground planes produce a null radiations alon the ground plane direction. In [21]introduces a small size, low profile, horizontally polarized antenna with omnidirectional radiation pattern with no external matching network. The antenna with small magnetic loop on metallic ground is fabricated on 0.5mm thick RT Duroid 5880. The antenna is fabricated as three layers on separate substrate as top layer, middle layer, bottom layer where each layer is placed on top of other layer.

A new class of wire antennas called meander antennas [22] introduced in is made by continuously folding wire. The efficiency of meander geometry is excellent in comparison to lumped loading and the use of dielectric materials. Meander antennas find its application in large antenna arrays having long elements like log periodic arrays and Yagi-Uda antennas. The reduction in size of the resonant length is 20 % to 40% with a negligible cross polarization**.** Theminiaturizationof antenna in [23]is achieved by a method of bisection. This miniaturized slot antenna is suitable for terrestrial communication operating from 3GHz to 8GHz. The half cutting method or bisection method provides the required miniaturization offering a 75 % size reduction. The antenna is designed and made from a 0.5mm thin Taconic TLX9 substrate with dielectric constant 2.5 and loss tangent 0.0015. The electromagnetic coupling between the feedline and the annular slot antenna determines resonance characteristics of the antenna, which can be enhanced by adding stubs at the microstrip feedline ends. The bandwidth of the antenna decreases with decreases in thickness of microwave laminate.

A high level of miniaturization[24] is achieved with slits [25]loaded on either side of radiating slots . The substrate used here is RT Duroid 6010 LM with dielectric loss tangent of 0.0023 permittivity of 10.2. The slot antenna being loaded with six slits on both ends of slots.

In [26]the loading wires placed on both ends of the slots penetrate into the substrate which enhances coupling between slot and loading elements through substrates. The miniaturization is because the capacitive reactance of slot below resonance with the inductance of loading wires. The length of wire is important to provide the required inductance. The return loss is improved with decrease in wire length. A high index metamaterial is being used for miniaturization of slot antenna in[27]. The miniaturization of slot antennais performed with high refractive index (HRI) Material Medium composed of Complementary Split Ring Resonator (CSRR) as shown in Fig. 7.

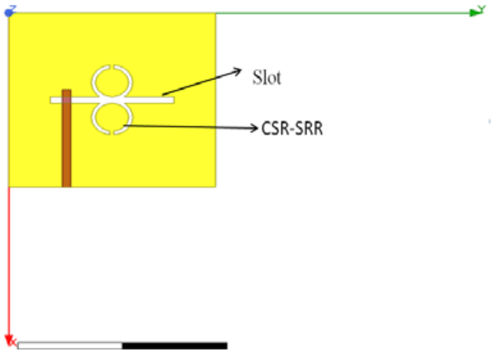

Fig.7. Slot antenna with loading[27].

The addition of two unit cells of CSIR-SRR on either sides of slot antenna modifies the impedance properties of the antenna due to the addition of extra reactance components on to the slit this in return modifies the impedance along the length of the slot. This slot antenna resonates at 2.5 GHz. The large wavelength is squeezed on to a small space by HRI Metamaterial medium.

In [28]a noval approach for miniaturization of slot antenna introduces, a concept of virtual enforcement of the required boundary condition at slot antenna ends helps to achieve the required miniaturization. This concept is basedon equivalent circuit model for antenna and its feed structure. A finite voltage when introduced to the ends of slots a magnetic current distribution on slot antennais established in this procedure the dimension of the miniaturized slot antenna are chosen arbitrarily based on the application with less impact on impedance matching. In [29]a dual band microstrip patch antenna using metamaterial artificial substrate in the frequency range from 1GHz to 4 GHz is put forth. Metamaterial based substrate is designed using square split ring resonator (SSRR) and wire strip. The substrate used is FR4 Epoxy having dielectric constant of 4.4. Patch and conductive elements made from copper of thickness 0.03 mm. The reduction in patch size is about 84% .Fig.8. The antenna introduced here is agood counterpart in mobile communication and WiMAX application.

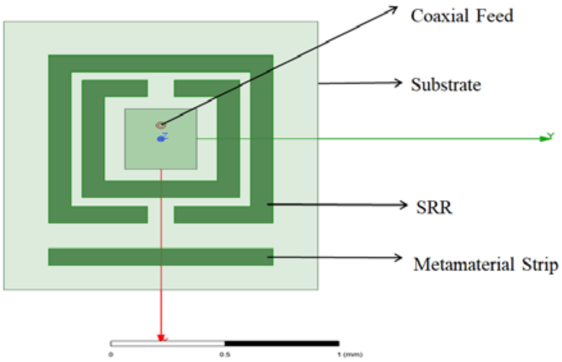

Fig.8. SRR metamaterial inserted antenna[29].

The antenna reported in [34] presents a ring monopole, rectangular complementary split ring resonator (RCSRR) as radiating part where two L and one T shaped slots behave as the ground plane. Miniaturization is established by metamaterial RCRR. The antenna exhibits resonance in all the frequencies 2.4 GHz, 5.6GHz and 8.8GHz with wide applications in WLAN, WiMAX, C Bands, and X Bands. Miniaturization is achieved through metamaterial and multiband operation achieved through the slots. The use of metamaterial RCSRR is to provide miniaturization and multiband operation. RCSRR is formed by two complementary metallic rings. A summary of the slot antenna miniaturization techniques with the type of loading is included in Table.1.

4. Slot design techniques employed in SA.

The size and height of the slot has great impact on the bandwidth. By increasing the height of the slot the bandwidth is increased [35]. The slots etched out in the antenna can be of differenttypes like circular, rectangular, trapezoidal, L shaped, U shaped and E shaped. Each of these slots improves antenna parameters in different ways. A band notched facet worked out through enforcing stepped impedance resonator (SIR) [30] and an arc shaped parasitic element (ASPE) [30]. The antenna is engraved on substrate fed by coplanar waveguide (CPW). Circular slot ingrained to the substrate with quadruple switches restrictively picked procure reconfigurability, to ensue quadrupletantenna namely Ultra-wide Band (UWB), Multiband dual band notched UWB, UWB with single notched antennas with sift and reconfigurable attributes. A summary of the slot feeding techniques included in Table.2.

Table.1. Summary of Slot Antenna miniaturization technique.

Reference	Type of Loading	Maximum miniaturization (%)	Gain
[27]	Radiating slots, slits, metallic strips	63.52	-2.05 dBi
[28]	HRI Metamaterial	40.8	-1.1 dB
[29]	Slits	31.6	-0.6dB
[30]	Wire loading	28.83	2.3dB
[31]	Inductive or Capacitive Loading	-	-3dBi

Table. 2. Summary of SA Design Techniques

Reference	Type of slot	Bandwidth (GHz)	Feeding and Polarization	Gain (dBi)
[30]–[36]	Circular Slot	2.00-14.00	Coplanar Waveguide Feeding (CPW)/Microstrip Feed Line	2.48 dBi, at 5.7 GHz
[37]	Rectangular slot with inverted L shaped strip and triangular shaped element.	3.00-11.20	CPW	3.00 dBi
[38]	Combination of rectangular and circular slot	1.73 GHz	Microstrip Feed	1.1-4.4dB
[39]	Rectangular slot with U Shaped strip	270 MHz,1854 MHz	Microstrip Feed	0.85 -3.00 dB
[40]	Rectangular Slot, Circular Slot, E Slot	0.78-1.09 GHz	Coaxial Feeding	-

Circular patch fed by CPW[31],[32] at frequency 2.9 GHz to 13.73 GHz bring forth antenna to meet wideimpedance bandwidth. Erratic cross path with diffusing arms dogged with circular slots[33]furnish good impedance match by cleaving cross path into two sections with gap, that induces capacitive loading referred to as perturbation technique[33]suitable for WLAN. Dual band slot antenna rigged up with circular patch furnish radar application [34]by virtue of niching ground plane catalogued and shelved beneath the substrate in L shape that augments good directivity crucial in radar application. In millimeter wave communication system[35]ground made of copper, patch encompass rectangular slot. Adjunction of bonus slots within patch of antenna swap antenna behavior inflating return loss and impedance matching with an impedance bandwidth of 500 MHz.

A rectangular microstrip slot antenna[36] fed by microstrip line brings forth 36 percentage reaching bandwidth. Ground plane [36] cleaved into square slot and rectangular slot. In [37] the antenna comprehends rectangular slot in ground plane engrossed by trapezoid shaped patch bandwidth at the center frequency 2400 MHz remarkably thin nanocomposite substrates aid in far Double notched bands procured by acquainting inverted L shaped strip and triangle shaped element linking to patch.

In[38]a microstrip fed substrate and ground plane whence slots addressed. Main slots merged with rectangle, circular and L shaped slots.Physical magnitude of antenna lowered by vertically folding the antenna. The slots fed employing deformed structures to acquire wideband impedance matching. A rectangular slot[39]enclosed by U shaped slot to cover IEEE 802.11a/b/g stretched linking the arms of U shaped sorted out to procure the appropriate bandwidth. A microstrip patch antenna encumbered[40] with reactive elements like slot, stub or shorting pin accords tunable or multi frequency antenna features. A multiband E shaped microstrip patch antenna[40]with E shaped slot, one rectangular slot and three circular slots on rectangular patch. Patch antenna with U shaped slot[41]analyzed with Characteristic Mode Analysis (CMA) and Coupled Mode Theory (CMT)retaining bandwidth 780 MHz to 1090 MHz with center frequency at 940 MHz.

T stub U slot frequency reconfigurable notch antenna[42]employing CPW is considered. The reconfigurability is actuated by housing PIN diodes at T stubs. The design is suitable for WLAN, Wi-Fi, LTE and Bluetooth application. The sweep of feed, T stub, span of slot are differed to bring off reconfigurability. PIN diode actuates high power drive with limited driving voltage at vile cost.Intrusion of UWB and other narrow band communication culminated in design of traits [43]. Band notched antenna tactic engraving thin slots in radiating surfaceof antenna or ground plane to attain a multiple band antenna creating notch at lower frequencies. Appending etching slot sweeps current distribution and characteristic impedance[43]across radiating surface resulting out in a midget antenna. A multiband H shaped slot antenna[44] ingrained to PC or tablet. The H shaped slot arbitrated to rectangular aperture perturbed by double strips fed by microstrip coupling. At low frequency current glides through outer fringes of H shaped slot, boosting the frequency surface current glides along edges of inserted strips.The [45-54]explains different SA using nanocomposite materials in antenna design. Nanocomposite slot antennas represent a cutting-edge advancement in antenna technology, combining the benefits of nanomaterials with the versatility of slot antenna design. By embedding conductive or dielectric nanomaterials, such as graphene, carbon nanotubes (CNTs), or metal nanoparticles like FeCoNi—into polymer or ceramic matrices, these antennas achieve enhanced electromagnetic performance, miniaturization, and mechanical flexibility. The nanocomposite structure allows for tunable electrical conductivity, improved impedance matching, and better radiation efficiency at high frequencies (e.g., in the GHz range). Slot configurations further aid in planar integration, making them ideal for compact, conformal applications such as wearable devices, IoT, and aerospace systems. Their fabrication methods, including inkjet printing and spin-coating, enable low-cost, scalable production while preserving the high-performance characteristics of the embedded nanomaterials.

4. Conclusion

The inquisitive study on slot antenna, bandwidth enhancement and its miniaturization tactics reveals that these antennas come up perpetually with superior attributes such as directivity, frequency reconfigurability, efficiency and fidelity. The slot loci in the antenna ascertain the current flow and impedance vitally influencing the antenna parameters. For realizing proper impedance match the feed position is pertinent. Bandwidth enhancement are effectuated in SA adjoining slots to encompass disparate forms like L,T,Z,U,E shapes etc. MiniaturizationSA secured by loading it with wire loop, folding wire, metamaterial, radiating slots and inductive or capacitive loading. All these methods bring about miniaturization but radiating slots, slits and metallic strips put forward 64 % miniaturization. Miniaturization of antennas with wider bandwidth can offer ultra-fast speed rate with low latency have become the demand for the upcoming communication era.

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