Buddha Journal of Engineering Sciences and Technology (BJEST)

Volume 1 | Issue 1 | August 2025Website: www.journal.bit.ac.in Email: bjt@bit.ac.in

RECENT ADVANCEMENT IN ANTENNA DESIGN: A REVIEW

Arun Kumar Mishra

Assistant Professor, Department of Electronics & Communication Engineering, Buddha Institute of Technology, Gorakhpur, Uttar Pradesh, India

akmishra298@bit.ac.in

Abstract

Developments in antenna technology are necessary to fulfill the increasing demands of modern wireless communication system, which requires higher data rates, greater bandwidth, high reliability, multiband operation etc. The growth of IoT devices requires antennas that can support large number of connected devices. Modern antenna designs are focused on reducing the size of antenna, improving the performance so that could be integrated into increasingly compact devices. Miniaturization,multiband and wideband antennas, smart antennas and beam forming, reconfigurable antennas, are the main area of antenna advancement. Development of adaptive antenna is very crucial to enhance signal quality, increase coverage and capacity. Adoptive antenna can focus signals on specific users, reject interference and reduce multipath effects by dynamitic ally adjusting antenna radiation patterns.

Keywords: Antenna miniaturization, metamaterials, beam forming, adoptive antenna, IoT,

1. INTRODUCTION

Recent antenna research focuses on enhancing performance through novel designs, materials, and techniques. Key areas include smart antennas for 5G, miniaturization using metamaterials [1], and advanced manufacturing for complex structures. This paper provides a review of latest advancements in antenna design techniques focusing on parameters such as size reduction, bandwidth, gain and efficiency. Different innovative techniques like useof metamaterials, fractal geometries, beam forming and reconfigurable antennas are discussed.Due to the development of smaller IoT devices, there are great demand of small size antennas which can be easily used in integrated circuits and on printed circuit boards. Miniaturization and integration techniques are very important to reduce space and power consumption particularly in battery operated devices.Metamaterial based antennas uses artificial materials to provide improved performance, miniaturization and beamforming. Use of metamaterials can reduce physical size of antenna with acceptable performance.Many IoT applications requires multiband communication so design of antennas with capability of operating in multiple frequency band is needed. To improve data rate and signal quality to support 6G and future wireless systems advancement in MIMO technology is necessary. Designing of MIMO antenna for mobile devices presents challenges in antenna coupling and field correlation. Reconfigurable antennas are developed which have capability to change frequency, radiation pattern, polarization etc on demand. Using antenna beamforming techniques radio signals are focused in a specific direction by using an array of antenna instead of broadcasting signals in all directions. So strong radio signal reaches to the intended receiver with improved signal quality,higher data rate and spectral efficiency.Presently wearable antennas are being popular dueto their lightweight, compactness and ability to support multifunctional wireless communication systems. These antennas are being developed for various applications such as healthcare monitoring healthcare monitoring and personal communication.

2.ANTENNA MINIATURIZATION

The aim of antenna miniaturization techniques is to reduce the physical size of antenna without reducing their performance. Several methods have been developed for this like using high permittivity materials, metamaterials, slots and perturbations in antenna, and making fractal geometries.For a given a given frequency, antenna size can be reduced significantly using materials with high dielectric constant because wavelength is effectively reduced within the material. The reduction in antenna size can be achieved by effectively increasing current path length using slots or different types of geometric perturbations in antenna structure. Within a smaller physical space antenna with increased perimeter and surface area can be created using fractal geometries. Antenna patch can be shorted to the ground plane to reduce size and to improve impedance matching.Slot cutting in the original patch is the most common technique to achieve antenna miniaturization. Several designs have been investigated in which the size of MPA is reduced by adding slots in the original design. It was seen that this technique reduced the overall patch area but the bandwidth was also reduced. By introducing different feeding techniques [2] the impedance bandwidth, antenna gain and radiation characteristics were also improved. Several antenna designs [12–22] have been published where microstrip patch size was reduced either by changing the dimensions of the original design or cutting slots in MPA. Generally, this method reduces the bandwidth, efficiency and polarization. Butby arranging these slots asymmetrically over the radiating patch or by merging two techniques such as defected ground structure and slots, improved antenna designs have been obtained [3].

Table1. Summary of antenna miniaturization techniques

Miniaturization technique	Features	Advantages	Disadvantages
Using high permittivity materials	Utilizing substrates with high dielectric constant	Higher size reduction	Expensive, limited Bandwidth
Using fractal geometries	Alter the current distribution and increases the electrical length	Antenna performance maintained, Multiband operation	Increases complexity in design and fabrication
Introducing a shorting pin between patch and ground plane	Effectively alters the antenna’s electrical length	Cost effective, smaller physical size	Increases complexity, Reduces bandwidth and antenna gain
By cutting slots in the patch	Common slot configurations are L,H,U, helical, fractal, folded slots	Increases bandwidth Can operate at multiple frequency band	Poor polarization, reduces antenna gain, increases complexity
Using meta-materials	Use of ENG, MNG	Compact design, smaller physical size, polarization control	Limited bandwidth, lower efficiency

3.USE OF METAMATERIALS

Metamaterials are artificially engineered materials whose properties depend on their unique structural designrather than their inherent composition. Over past few years work on EM MTM for use in antenna is very attractive area for researchers. They are fabricated with specific structural elements at a scale smaller than the

Buddha Journal of Engineering Sciences and Technology (BJEST)

Volume 1 | Issue 1 | August 2025Website: www.journal.bit.ac.in Email: bjt@bit.ac.in

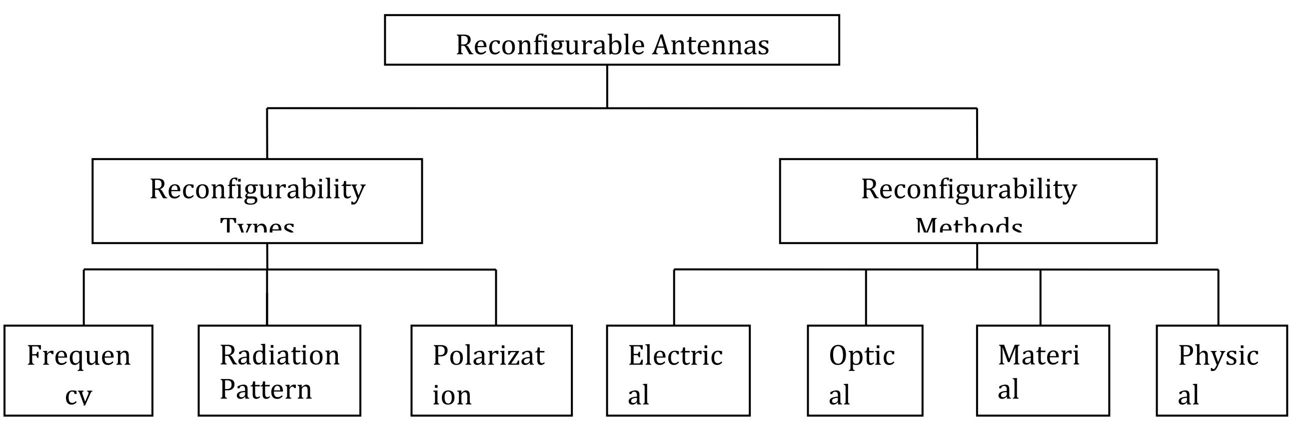
wavelength of the waves they interact with.Metamaterials can enhance antenna performance in great amount by enabling antenna miniaturization, gain improvement, bandwidth enhancement and reconfigurability. Metamaterials can be used to construct antennas with improved performance for difference applications such as wireless communication , radar and sensing.The metamaterial can be classified as single negative (SNG), double negative (DNG), double positive (DPS) and MNG (mu-negative) material. When only one parameter permittivity (ε) or permeability (μ) is negative then it is known as SNG materials, when permittivity (ε) and permeability (μ) both are negative then it is called DNG metamaterial and when both (permittivity ε and permeability μ) are positive it is known as DPS material. MNG material has positive value of permittivity and negative value of permeability ($\varepsilon > 0$, $\mu < 0$).

To increase the radiation and matching properties of small electric and magnetic dipole antennas, metamaterial coatings have been used. Use of metamaterial increases the radiated power. The newest experimental metamaterial antenna is as small as one fifth of the wavelength and is capable to radiate the 95 % of input radio signal at 350 MHz. Using Metamaterial covering, the directivity of patch antenna has been increased. The directivity offlat horn antenna with flat aperture can be improved by using zero index metamaterial. Using zero index metamaterial highly directive antennas can be constructed. In MIMO antennas metamaterials can be used to enhance the performance, isolation, bandwidth and gain. Metamaterials can be used in antennas to provide multiple functionalities such as to support multiple frequency band or supporting different polarization modes. The metamaterial will enhance the gain and minimize the return loss of a patch antenna [4].

4. RECONFIGURABLE ANTENNAS

Reconfigurable antennas have the capability to adjust their frequency, radiation pattern, and polarization according to requirement.

Figure 1: Different types and methods to design reconfigurable antennas.



In situations where several communication systems working in different frequency bands are present frequency reconfigurable antennas are very useful. In this situation instead of using multiple antennas a single reconfigurable antenna can be used. Frequency reconfiguration is generally achieved by modifying physical or electrical dimension of antennas using RF-switches, tunable materials or impedance loading. Radio Frequency Micro Electromechanical System (RF-MEMS) switches are most widely used components to configure the frequency, pattern, and polarization. A number of researchers have implemented this technique to achieve the reconfigurability of the antennas. For example, in [5], the authors designed a reconfigurable patch antenna in the form of a hexagon. Radiating length of the antenna may be changedby using of RF-MEMS switches. Due to this, the antenna's frequency was changed from8.56GHz to8.90GHz.Thus,antennamaybe design to operate at various frequencies by turning on or of RF-MEMSswitches. In order to cover the complete long-term evolution (LTE) spectrum, with an emphasis on the 600MHz frequency band, the authors in [6] suggested the designing of an adjustable antenna array. In this suggested design four multiband antennas are mounted on the frame and MEMS adjustable capacitors are used to reduce the resonance frequency up to the required value. By adjusting the capacitive gapand amount of reconfiguration by adding more switches resonant frequency, bandwidth and radiation patterncan be controlled.

Another method to achieve the reconfigurability is the use of PIN diode because these switches are easily available and inexpensive. Therefore, various authors have used this technique in the antennas. For example, a RA with minimal complexity that can use fewer switches to guide its beam into 9 distinct directions (θ ={−42°, 0°, 42°} in the φ={25°, 0°, 155°} planes, and θ=±25° in the φ=90° plane) was shown. The 3.4GHz–3.8GHz RA[7] was made up using four switchable parasitic dipoles situated at various heights above a ground plane. These dipoles acted as a director for elements at a lower layer and a reflector for those at an upper layer. The central dipole element was excited using a coaxial probe. A p-i-n diode was used as a switch in each parasitic dipole which activate these components to work in the required mode of operation.[8]

In another study, a reconfigurable microstrip antenna with polarization switching is initially built and then enhanced to provide polarization reconfigurability in three switchable frequency bands by using extra patch connection/disconnection and corner connection/disconnection methods. To provide three switchable operating bands with center frequencies of 5.1GHz, 5.45GHz, and 6.3GHz five p-i-n diodes are used. This proposed structure is able to reconfigure to operate in LHCP, RHCP, or LP due to the corner connection/disconnection of additional patches and use of p-i-n diodes. In every working band, the proto typed antenna provides a respectable AR≤3dB and reflection coefficient. [9].A varactor diode is another type of switch which can be used to provide reconfigurability in the antennas. In one research work [10], a dual-frequency reconfigurable MIMO PIFA has been developed for use in handheld devices to work in LTE bands. Using varactor diodes the antenna elements adjust their operating frequency between the 1.65GHz–2.2GHz and 0.8GHz-0.98 GHz bands. The isolation offered by this suggested MIMO antenna is more than 20dB for all frequencies that are feasible. It is composed of two symmetrical PIFAs which has center-to-center spacing of 43mm (0.1906λ0). In another approach [11], for cognitive radio applications, a RA with an 11.5:1 bandwidth was developed. This new antenna comprises two separate lines that span the frequency range of 430MHz to 5GHz. The first route had a direct connection to an (Ultra Wide Band (UWB) antenna that operates in the frequency range of 1GHz–5 GHz. The second route had a DC-controlled varactor-based matching network to work in frequency range 430MHz–1GHz range. Two discrete switches were used to provide switching capability between reconfigurable area (430MHz–1GHz) and wideband (1–5GHz). The 60mm by 100mm designed antenna was small and has a straight forward construction. The use of this innovative antenna in cognitive radio systems was very promising. For Internet of Vehicles (IoV), a unique, low-cost, high-performance, segmented reconfigurable patch antenna [12] was suggested. The radiating patch's form was controlled by frequency reconfiguration.For this three p-i-n diodes are integrated into two slots. Pattern reconfiguration is used to control the size of two parasitic components which are placed in close proximity to the patch through the application of the Yagi–Uda principle. This study was the first in the literature to demonstrate 12 different operational modes using just fve p-i-n diodes. These modes included endfire and broadside radiation across four frequencies (4.1GHz–5.7GHz) in the H-plane and four operating modes in the E-plane.

In another work frequency and polarization reconfigurability of a microstrip circular patch antenna was obtained using liquid metal. This antenna has a C-shaped slot in the middle of the patch, and it can be reconfigured to operate in four different states by employing liquid metal and two putty containers. In the absence of liquid metal in the containers LP was detected at 5.83GHz. Two liquid metal droplets deposited in the containers provide CP at 6GHz. RHCP was obtainedwhen the rightmost container was filled and LHCP was obtained when the leftmost container was filled. When every container was filled then LP was detected at 6.15 GHz. In case of LP, the antenna gain was 2.68dB for all full containers and 3dB for empty ones. For full containers the corresponding AR was 19.65dB and for empty containers it was 23.74dB. When LHCP was turned on, the gain was 2.44dB and the AR was 0.54dB at 6GHz.When the RHCP was turned on, the gain was 2.37dB and the AR was 1.5dB at 6GHz[13].

5. CONCLUSIONS

In this paper different techniques which are used in latest design of antenna to meet the requirements of modern wireless communication systems have been discussed. Latest advancements in antenna technology are mainly focused on antenna miniaturization, multiband operation, use of metamaterials, use of liquid metals and reconfigurable antenna capabilities. For integration of antennas into smaller devices, antennas are becoming smaller and more compact. So antenna miniaturization plays a crucial role in the designing of antenna. Antenna miniaturization can be achieved by usingmetamaterials, slots and perturbations in antenna, and making fractal geometries.Metamaterials offer unique electromagnetic properties which allow the manufacturing of antennas with unconventional shapes with improved performance characteristics. Multiband antennas are being designed to support various wireless communication standards and protocols. Multiband and wideband characteristics of antenna can be enhanced using fractal geometries in antenna design.In this paper, different types of switching mechanisms are presented to achieve the various types of reconfigurability.RF-MEMS switches and PIN diodes are the most widely used methods to provide antenna reconfigurability.

References

1. Rakesh N. Tiwari, Prabhakar Singh, and Binod Kumar Kanaujia, “A Modified Microstrip Line Fed Compact UWB Antenna for WiMAX/ISM/WLAN and Wireless Communications”, International Journal of Electronics and Communications 2019.
2. Kakoyiannis, C.G., Constantinou, P., “A compact microstrip antenna with tapered peripheral slits for CubeSat RF payloads at 436 MHz: miniaturization techniques, design, and numerical results”, IEEE Int. Workshop on Satellite and Space Communications (IWSSC08), October 2008, pp. 255–259.
3. Marques R, Martin F, Sorolla M. Metamaterials with negative parameters: Theory, design and microwave applications. In: Wiley Series in Microwave and Optical Engineering. Wiley-Blackwell; 2008.
4. Wojciech Jan Krzysztofik and Thanh Nghia Cao: “Metamaterials in Application to Improve Antenna Parameters.
5. T. Garg, “Hexagonal Shaped Reconfigurable Microstrip Patch Antenna, “International Journal of Engineering Science 6, no. 3 (2016): 2944–2947.
6. C. D. Paola, S. C. D. Barrio, S. Zhang, A. S. Morris, and G. F. Pedersen, “MEMS Tunable Frame Antennas Enabling Carrier Aggregation at 600 MHz,” IEEE Access 8 (2020): 98705–98715.
7. J. A. Byford, K. Y. Park, P. Chahal, and E. J. Rothwell, “Frequency Reconfigurable Patch Antenna Array,”Electronics Letters 51,no.21(2015):1628–1630, https://doi.org/ 10.1049/el.2015.1771
8. I. Zhou, G. A. Ram´ırez, L. Montero, S. Blanch, J. Romeu, and L. Jofre, “Tree-Dimensional Beamsteering Low-Complexity Reconfigurable Multilevel Antenna,” IEEE Antennas and Wireless Propagation Letters 19, no. 6 (2020): 1017–1021,
9. R. K. Singh, A. Basu, and S. K. Koul, “Reconfigurable Microstrip Patch Antenna With Polarization Switching in Tree Switch able Frequency Bands,” IEEE Access 8 (2020): 119376–119386.
10. G. Shruthi and C. Y. Kumar, “Dual-Band Frequency Reconfigurable MIMO PIFA for LTE Applications in Mobile Hand-Held Devices,” IET Microwaves, Antennas & Propagation 14, no. 5 (2020): 419–427, https://doi.org/ 10.1049/iet-map.2019.0878.
11. A.Kantemur,J.Tak,P.Siyari, A. H.Abdelrahman,M.Krunz, and H. Xin, “A Novel Compact Reconfigurable Broadband Antenna for Cognitive Radio Applications,” IEEE Transactions on Antennas and Propagation 68, no. 9 (2020): 6538–6547.
12. S. Gaya, A. Hamza, O. Sokunbi, S. I. M. Sheikh, and H. Attia, “Electronically Switchable Frequency and Pattern Reconfigurable Segmented Patch Antenna for Internet of Vehicles,” IEEE Internet of Things Journal 11, no. 10 (2024): 17840–17851,

13. A. Arbelaez, I. Goode, J. Gomez-Cruz, C. Escobedo, and C. E. Saavedra, "Liquid Metal Reconfigurable Patch Antenna for Linear, RH, and LH Circular Polarization With Frequency Tuning," Canadian Journal of Electrical and Computer Engineering 43, no. 4 (2020): 218–223, https://doi.org/ 10.1109/CJECE.2019.2904898.