

# **The Design and Development of Metamaterial-Based Antennas for Medical Applications**

**Gajjela Raghunatha Reddy**

Research Scholar, BESTIU, Gorantla, AP  
Lecturer in ECE, Govt. Polytechnic, Vempalli  
2022wpece008@bestiu.edu.in

**Dr. SK Masthan Basha**

Research Supervisor, BESTIU, Gorantla, AP  
Professor, Dept. of ECE, VMTW, Hyderabad, TG.  
masthanbasha.s@gmail.com

## **Abstract**

Metamaterials with smaller antennas and broader bandwidths that enhance signal penetration into biological tissues are among the new concepts being researched. Medical imaging, wearable electronics, and implanted devices are rapidly expanding fields in contemporary healthcare technology, and this analysis delves into its antenna applications. With an eye on enhancing diagnostic methods, treatment strategies, and wireless health monitoring systems, this article provides a comprehensive overview of the design and development of antennas based on metamaterials for medical purposes. New applications of metamaterials, such as biocompatibility, signal performance enhancements, and miniaturisation of antennas, are the subject of this paper. Due to their significance in medical contexts, three critical design features—impedance matching, radiation efficiency, and specific absorption rate—deserve further analysis. The proposed module has been validated using HFSS environment. Adaptive antenna design, multi-functional systems, and improved integration with biological surroundings are just a few of the research topics we suggest as potential solutions to the ever-changing demands of medical technology.

## **Keywords**

Specific absorption rate (SAR), antenna miniaturisation, increased bandwidth

## **1. Introduction**

A device that can transform electrical energy into electromagnetic waves and back again is what we call an antenna. Both the architecture and the materials used to manufacture these antennas are different from meta materials. When used, they boost the efficiency of compact antenna systems. Antennas with a split-ring resonator (SRR), high-impedance surface, cloak, super directive, electromagnetic bandgap, multiple bands, or tunable material are among the many options available. Among the several fields that gain from their development are medical imaging, radar, satellite, and wireless communication. A variety of antennas are available; among them are dielectric resonant, monopole, yagiuda, helical, horn, microstrip patch, loop, parabolic, and many more. There is a wide range of standards for antennas. What an antenna needs depends on the situation.

Reduced size, higher efficiency, enhanced radiation pattern, and superior overall performance are just a few of the numerous advantages of meta material antennas. Metamaterial antennas are a promising new direction in antenna technology that provide fresh approaches to meeting the expanding demands of contemporary sensor and communication applications. Forecasts indicate that the influence of contemporary research and production techniques will continue to expand across a number of

sectors. Among the many fields that make use of these antennas are healthcare, television, radio, networking, wireless communication, radar systems, and the Internet of Things (IoT).

## 2. Literature Review

Tharehalli, with Puneeth Kumar 2019 study by Rajanna et al. provides the author demonstrates an enhanced design for a CP antenna that regulates zero-index metamaterial (ZIM) with the aim of improving performance. Antenna unit cells are symmetrical square rings with two divisions. The focussing effect of the ZIM on the patch antenna allows for a gain improvement of around 5-6 dB. The 9x9 periodic array unit cell serves as a measuring face lens for focussing. Adding to the evidence of circular polarisation, the ZIM gives two orthogonal polarisations with the necessary phase difference. These unit cells are built using a periodic array of 9x9 cells. One of the primary functions of this array is to increase the antenna's gain by concentrating the outgoing waves. Second, it may be used to convert microstrip patch antenna-generated linearly polarised (LP) waves into circularly polarised ones. Modifying the unit cell ring's split gaps is required for this. The impedance bandwidth, as shown by the prototype, is between 7.04 and 7.68 GHz. From 7.11 to 7.56 GHz, the axial ratio bandwidth for CP varies, reaching a maximum of 12.31 dBic at 7.45 GHz. With modest degrees of cross-polarization, the gain stays at 11.5 dBic over the whole CP bandwidth. Among the many potential uses for the high-gain, CP antenna's circular polarisation characteristics are radar systems and satellite communications. Concurrently achieving circular polarisation and boosting gain using ZIM makes this method state-of-the-art in space technology (Puneeth 2019) (Figure 1).

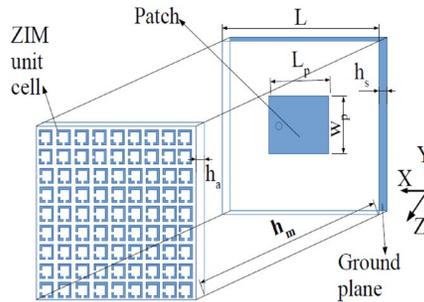


Figure 1. Proposed high-gain antenna with ZIM unit cells

Yang Zhengwei and colleagues The author proposes a new design for an antipodal tapered slot antenna (ATSA) that uses a gradient refractive index (GRIN) lens to increase the gain and bandwidth. A six-layer metamaterial GRIN lens, when positioned in front of the antenna, achieves significant improvements. The average gain peaks at 20.55 dBi, or 4.81 dB more, at 9.5 GHz. Simulations and testing have validated the antenna's outstanding performance, making it a perfect fit for applications like ground-penetrating radar and microwave imaging systems. An impressive impedance bandwidth of 175.7% and a -3 dB gain bandwidth of 65.8% allow this antenna to span an impressive range of 0.84 GHz to 13 GHz. Additionally, the antenna operates from 5.86 GHz to 11.6 GHz. All things considered, this design is exemplary of what may be achieved in the future with antennas that need a wide bandwidth and a lot of gain for various applications (Zhengwei 2019) (Figure 2).

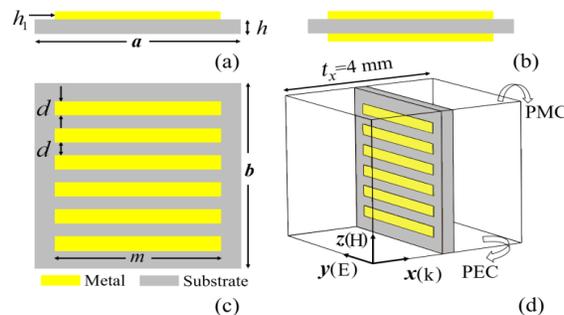


Figure 2. Side view of (a) single-layer unit cell and (b) double-layer unit cell

Researchers Muhammad Alibakhshikenari et al. (2020), This study presents a novel theoretical paradigm that is applicable to antenna arrays, particularly ones that are modelled after metamaterial materials. After being verified using full-wave electromagnetic software, the model's predictions for one-layer structures, particularly slotted circular patch radiators with metallic vias, agree well with the actual data (Figure 3). While compared to traditional electromagnetic solvers that use the method-of-moments (MoM), this model's use of singular integral formulations to compute the surface impedance matrices of the antenna components enables effective electrodynamic analysis at much reduced processing costs. Multilayer structures, prevalent in intricate antenna designs, may be included into this model to enhance its future use. When everything is considered, this approach has great potential for future effective and efficient antenna array analysis. When compared to a commercially available 3-D full-wave electromagnetic solution, the innovative method significantly decreased computation times without sacrificing accuracy. The results proved that, for a certain range of frequencies, surface impedance is a reliable indicator (Mohammad 2021)

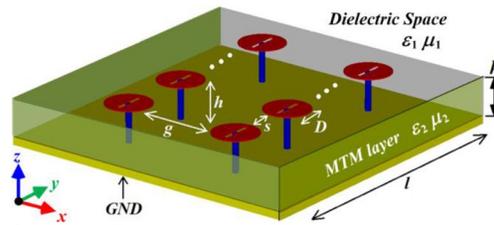


Figure 3. Antenna array realized with MTM-inspired circular patch radiators.

In 2019, Fatih Yaman and Hasan Onder Yılmaz wrote the work. The impedance matching was made possible by the transmitter antenna's wide bandwidth and 6.5 dB gain, which were attributes of the double-negative index metamaterial construction with complementary split-ring resonators (CSRRs). The receiver antenna integrates a patch antenna with near-zero epsilon metamaterial to produce a gain of 11.3 dB. Consistent with the model data, the results demonstrate a considerable improvement in the transmitter's bandwidth, along with gains, directivity, and size reduction of both antennas. Both inside and outdoors, the inexpensive Doppler radar gear demonstrated effective velocity detection by means of frequency variations. The author investigates the potential of creating and evaluating metamaterial-based antennas for a 5.8 GHz Doppler radar system with the aim of detecting human motions inside or behind barriers using Doppler frequency changes. Integrating range measurement capabilities and creating software with new features should be the focus of future research in order to further show their worth for advanced radar applications (Figure 4). The findings indicate that metamaterial antennas could enhance radar functionality (Hasan et al, 2019).

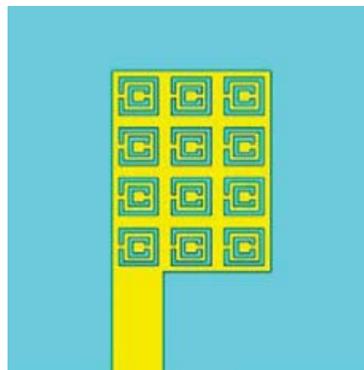


Figure 4. Simulated and realized transmitter (Tx) antenna

To improve the gain of CMPLPDA antennas, the author of a 2019 research by GuohuaZhai et al. introduced a novel non-resonant metamaterial (MTM) structure. Using the MTM considerably improved the antenna's gain and gain flatness throughout a broad bandwidth of 26 to 40 GHz, according to the study, which investigated many configurations. The MTM's broadband performance and low loss make it ideal for integration onto antenna

substrates. Printed on both sides of the substrate are metallic semi-ring patches that make it up. Three prototypes were able to demonstrate that the MTM effectively increased gain and gain flatness, with measured performance that was very close to matching the models. With any luck, this strategy will help antennas perform better in wireless communication applications. Results from both tests and simulations show that Case 4a (Figure 5), the MTM-equipped antenna, outperformed the original design by 1.6 dB generally and by 4 dB at 27 GHz in particular. Little loss was found in the MTM unit cell, as indicated by a reasonably steady effective refractive index greater than 1 (Na et al, 2018).

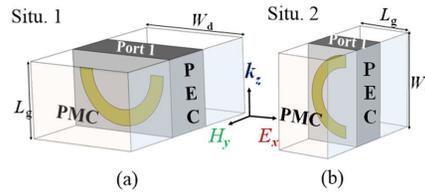


Figure 5. Two simplified situations for the wave propagating in the z-direction and the E-field parallel to the semi-ring patch (a) Situ. 1 and (b) Situ. 2

An isotropic and inhomogeneous lens that matches the free space impedance greatly improves the performance of a small high-gain horn antenna operating in the X-band (8-12 GHz), especially at a 10 GHz centre frequency. The author introduces a new planar wavefront transformation lens made of gradient-index metamaterials to improve the efficiency of horn-based antennas (Na Zhang et.al., 2018). Due to these improvements, the lens antenna may find applications in fields such as wireless communications and electromagnetic imaging. This study proves that when building antennas, a gradient-index metamaterial lens is the way to go. An increase of 6.5 dBi over the initial H-plane horn antenna is achieved by the lens integration, leading to a gain of 17.7 dBi. By reducing the half power beam width (HPBW) in the H-plane by 6.2 degrees, we can improve directivity, reduce the side lobe level to 15.3 dB, and achieve an aperture efficiency of 94%, which is higher than traditional designs (Figure 6). Lens antennas outperform their original horn counterparts by at least 5.7 dBi across the board without adjusting the aperture size, and they boost gain by an extra 1.7 dBi when compared to perfect horn antennas (Zhao 2018).

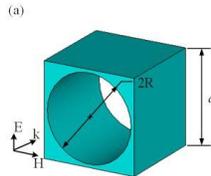


Figure 6. Illustration of the unit cell, where  $R$  denotes the radius of the air hole and  $a$  is the sidelength of the unit cells.

Researchers Mengran Zhao et al. (2021) zeroed attention on a frequency-varying metamaterial cavity antenna (FDMCA) due to its capacity to improve microwave coincident imaging. This is crucial for accurate microwave imaging. As the correlation coefficients between radiation patterns decrease, the quality of the images is improved. This is why low-correlated radiation patterns are produced. The authors of this work use the concept of Average Electric Field Variation (AEV) to make predictions about these correlation coefficients; higher AEV values indicate more accurate imaging. The FDMCA can produce a wide range of radiation patterns at different frequencies because to its slot antenna array and cavity that is based on metamaterials. As proof of concept, we evaluate the FDMCA in comparison to two alternative designs: the Disordered-Structure-Based Cavity Antenna (DSCA) and the Lumpy-Floor-Based Cavity Antenna (LFCA) (Figure 7). In addition to showing that the FDMCA may potentially significantly outperform traditional designs in terms of picture quality, the research also shows that AEV is a useful criterion for measuring imaging and correlation performance. The results of the controlled imaging trials show that FDMCA produces better pictures than both of the alternatives by generating more varied and less linked patterns. Microwave imaging applications of the FDMCA are shown by simulation and experimental confirmation of performance assessments of essential parameters including radiation efficiency, correlation coefficients, and reflection coefficients (Ramiro 2019).

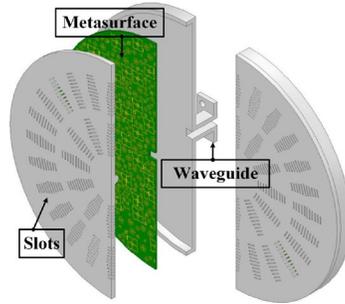


Figure 7. Schematic of the proposed FDMCA.

Because of its ability to enhance microwave coincident imaging, researchers Mengran Zhao et al. (2021) focused on a frequency-varying metamaterial cavity antenna (FDMCA). The FDMCA's metamaterial-based cavity and slot antenna array allows it to generate a broad spectrum of radiation patterns across a variety of frequencies. In order to forecast these correlation coefficients, this study used the idea of Average Electric Field Variation (AEV); larger AEV values signify more precise imaging. With two other designs, the Disordered-Structure-Based Cavity Antenna (DSCA) and the Lumpy-Floor-Based Cavity Antenna (LFCA), we consider the FDMCA as a proof-of-concept experiment. Because it generates a more diverse pattern set with a smaller number of similar patterns, FDMCA delivers better photos than the other two alternatives, according to controlled imaging research. This is an absolute must for reliable microwave imaging. The picture quality improves as the correlation coefficients between the radiation patterns decrease. As a consequence, very discordant radiation patterns are produced. The radiation efficiency, correlation coefficients, and reflection coefficients of the FDMCA have been tested both theoretically and experimentally, and the results demonstrate its usefulness in microwave imaging. The study shows that AEV is a meaningful metric for imaging and correlation capabilities, and it also suggests that the FDMCA has the potential to provide substantially superior image quality than conventional systems (Albert Nd).

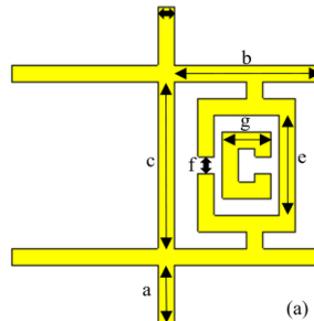


Figure 8. A proposed NRI MTM structure

Studies conducted in 2020 by Albert Sabban and coworkers, (Figure 8). A major obstacle for healthcare and wearable wireless communication systems is the poor efficiency of tiny antennas; the author tackles this problem head-on. The authors provide wearable antennas, both active and passive, that may greatly enhance performance by using a mix of metamaterials. The research, which uses 3D full-wave simulations, states that these antennas have bandwidths between 50% and 100%, a VSWR less than 2.3:1, an overall gain of around 7 dBi, and an efficiency more than 90%. Due to their properties, these antennas are ideal for usage in 5G networks, IoT devices, and medical equipment. Particularly, when compared to conventional designs, Split-Ring Resonators (SRR) antennas exhibit gains and directivity enhancements of 2.5 dB while simultaneously reducing resonance frequencies by 4-11%. The frequency of resonance might fluctuate by 3-5% according to its location on the body. The active metamaterial antennas are able to achieve a gain of  $13 \pm 3$  dB and a noise figure of  $0.5 \pm 0.3$  dB (Figure 9) in the range of 0.1 GHz to 0.8 GHz ((Dehajit 2019).



Figure 9. Antenna with SRR and Metallic strips

Civil aviation Traffic Alert and Collision Avoidance System (TCAS) implementation of a quad-feed end-fire microstrip antenna in 2019 is the subject of this article. Aerodynamically curved antennas, built on conformal metamaterial lenses, reduce side lobes, increase gain, and dampen surface waves to optimise the radiation pattern for 360-degree surveillance coverage. It turns out that the simulated and experimental outcomes are very congruent. Every performance metric that was tested shows that the suggested antenna outperforms the typical monopole TCAS antennas. It is affordable, compact, lightweight (550 grammes), and compliant with current avionics regulations. We used CST Microwave Studio to create and test the antenna and random, and it passed all of our tests and manufacturing requirements (Figure 10).

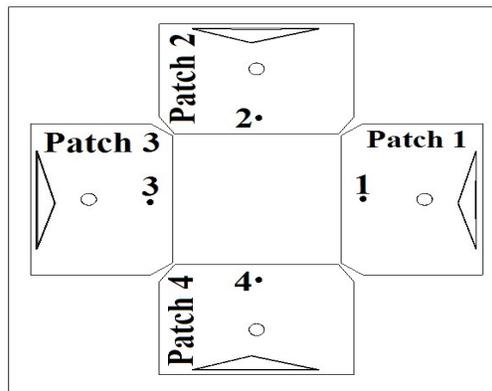


Figure 10. Schematic view of proposed antenna model

### 3. Impact of Metamaterial-Based Antennas for Medical Applications on the parameters of antenna

The ability to communicate across different systems and medical equipment is enhanced with a larger gain, which allows for stronger signals. When compared to an isotropic radiator, the gain of an antenna is its ability to concentrate radio frequency radiation in a particular direction. The universally accepted unit of measurement is the decibel (dB). Reliable and accurate data transfer is crucial for applications like remote monitoring. The output-to-input power ratio is one indicator of an antenna's efficiency. This metric assesses the efficiency with which an antenna converts the energy it receives into usable form. Compatibility with portable health monitoring is ideal. Broadband refers to the frequency range that an antenna can consistently work with. Applications that rely on cross-protocol communication should give this their full attention. If antennas could handle more medical applications with higher bandwidth, diagnostic capabilities may be improved.

Due to improved efficiency, which reduces power losses, medical equipment may run for an extended period of time on a single charge. This is best shown in the imaging industry, where various types of data need distinct frequencies. The directivity of an antenna is the degree to which its radiation pattern is directed in a particular direction; it is measured in decibels compared to its isotropic counterpart. Enhanced directivity is essential for applications such as focused drug delivery and precise imaging. It allows for the targeted transmission of data while lowering interference and enhancing accuracy. What we call "returned power" is the amount of energy that ends up in the antenna instead of being sent. The results demonstrate the efficacy of impedance matching. Signal integrity in medical imaging and communications systems relies on enhancing performance and energy transmission while decreasing return loss. A radiated wave's polarisation may be used to ascertain the electric field's direction. Its form

could be elliptical, cylindrical, or linear. Accurate data transmission in medical applications relies on antenna polarisation alignment with signals. Signal loss will be reduced and overall communication will be improved. The use of metamaterials in antenna design significantly improves these performance indicators, allowing medical devices to communicate reliably and efficiently even in challenging environments. Antennas' large bandwidth allows for a multitude of frequencies and protocols, which might be useful for many medical technologies. The ability to tailor antenna performance for specific uses is driving innovation in healthcare. Medical equipment may be made smaller and more efficient with the use of metamaterials, which allow for the creation of smaller and lighter antennas. This improves the efficacy of tracking, diagnostics, and therapies. Their antennas, which are based on metamaterials, have medical applications that improve patient care and work optimally.

#### **4. Conclusion**

The purpose of this literature study is to examine several metamaterial antenna design objectives, all of which aim to enhance performance by tackling distinct problem statements. Several important factors need to be considered while constructing high-gain antennas. These include fractal dimensions, antenna shape and size, feed methods, substrate materials, and split-ring and complementary split-ring resonator properties. Contrarily, small, hidden antennas revolve on metamaterial architectures, loading methods, material qualities, and fractal dimensions. Engineers primarily study the shape, dielectric properties, feed mechanism efficiency, and metamaterial unit cell design of wide bandwidth antennas. Through careful adjustment of its fractal order, patch geometry, metamaterial characteristics, substrate materials, feed structures, and overall dimensions, an ideal antenna will reduce return loss (S11) to less than -15 dB. The potential for metamaterial technology to enhance antenna performance is shown by each of these objectives. potential of metamaterial technology to advance antenna performance across various metrics.

#### **References**

- Albert Sabban and Israel, "Small New Wearable Metamaterials Antennas for IOT, Medical and 5G Applications" UTC from IEEE Xplore.
- Debajit De, Student Member, IEEE, and Prasanna Kumar Sahu, Senior Member, IEEE, "Design of an End-Fire Microstrip Antenna for Aircraft Collision Avoidance System" DOI 10.1109/LAWP.2019.2907477, IEEE Antennas and Wireless Propagation Letters.
- GuohuaZhai, Xi Wang, RenshengXie, Jin Shi, Jianjun Gao, Bo Shi, and Jun Ding "GuohuaZhai, Xi Wang, RenshengXie, Jin Shi, Jianjun Gao, Bo Shi, and Jun Ding", DOI 10.1109/TAP.2019.2924111, IEEE Transactions on Antennas and Propagation.
- Hasan O" nderYilmaz and FatihYaman "Meta-material Antenna Designs for a 5.8 GHz Doppler Radar" DOI 10.1109/TIM.2019.2914131, IEEE Transactions on Instrumentation and Measurement JOURNAL.
- Mohammad Alibakhshikenari , Member, IEEE, Bal S. Virdee , Senior Member, IEEE, Sonia Aïssa , Fellow, IEEE, Chan H. See , Senior Member, IEEE, Ayman A. Althwayb ,Raed A. Abd-Alhameed , Senior Member, IEEE, Isabelle Huynen , Senior Member, IEEE,Francisco Falcone , Senior Member, IEEE, and Ernesto Limiti , Senior Member, IEEE, "Singular Integral Formulations for Electrodynamical Analysis of Metamaterial-Inspired Antenna Array", IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, VOL. 20, NO. 2, FEBRUARY 2021.
- Na Zhang, Wei Xiang Jiang, Member, IEEE, Hui Feng Ma, Wen Xuan Tang and Tie Jun Cui, Fellow, IEEE " Compact High-Performance Lens Antenna Based on Impedance-Matching Gradient-Index Metamaterials" DOI 10.1109/TAP.2018.2880115, IEEE Transactions on Antennas and Propagation.
- Puneeth Kumar TharehalliRajanna , Student Member, IEEE, KarthikRudramuni, Student Member, IEEE, and Krishnamoorthy Kandasamy , Member, IEEE "A High-Gain Circularly Polarized Antenna Using Zero-Index Metamaterial"IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, VOL. 18, NO. 6, JUNE 2019.
- Ramiro Adrian Valdez &NantakanWongkasem "Manipulation of Microstrip Antenna Directivity and Radiation Pattern using Negative Index Metamaterials"978-1-7281-0692-2/19/\$31.00 ©2019 IEEE.
- Zhao Mengran, Student Member, IEEE, Shitao Zhu , Huilin Huang, Di Hu,Xiaoming Chen , Senior Member, IEEE, Juan Chen , and Anxue Zhang " Frequency-Diverse Metamaterial Cavity Antenna for Microwave Coincidence Imaging"IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, VOL. 20, NO. 6, JUNE 2021.

Zhengwei Yang, LinyanGuo, Changli Yao, Qisheng Zhang, ZiyuXu, MinjieGuo, and Ziye Wang “Ultra-wideband Antipodal Tapered Slot Antenna with Gradient Refractive Index Metamaterial Lens” DOI 10.1109/LAWP.2019.2950676, IEEE ANTENNA AND WIRELESS PROPAGATION LETTERS.