

CIRCULAR PATCH MICROSTRIP ANTENNA FOR THE ULTRA-WIDE BAND APPLICATIONS

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Abstract

In this study, a design method was put for improving the antenna's wide band width. In many facets of contemporary technology and communication systems, microstrip antennas are very essential in different application. They enable wireless signal transmission and reception, facilitating smooth connection between devices and networks. They provide effective and connected IoT networks by facilitating wireless data transmission between sensors, actuators, and control systems. They are perfect for various applications because of their tiny size, low profile, and lightweight qualities. It works in the defected ground structure configuration for reducing backward radiations. This study simulates and presents a circular Microstrip Patch Antenna. The excess slots and the flawed ground structure are used for optimizing the design. The antenna is designed using Industrial Scientific and Medical (ISM) band structural prohibitions. The ISM band are globally assigned for industrial, scientific and medical applications. The quantity of signal reflected from an impedance mismatch and discontinuity known as return loss. Directivity is a measure how well an antenna focus radiation in the particular direction. These two parameters are very essential and required for measuring the performance of designed antenna. A circular patch antenna is designed with 12*12*1.6 mm in size. At 4.7 GHz, a return loss of -43 dB was attained. The improved bandwidth of 460 MHz with 3.6 dB directivity is provided by the slot structure and inserted pattern. The designed antenna having electrical field (E-field) and magnetic field (H-field) respectively 70632 V/m and 258 A/m. The Ultra-Wide Band of the antenna is used for many applications like RTAS (Real Time Location System), Healthcare or Medical application, Security, IoT applications and Defense application. The design antenna can be used in wide band applications. The results obtained demonstrate that it can be employed in any real time applications. UWB is used in healthcare for a variety of functions. In order to monitor vital signs, transmit medical data, and provide remote patient monitoring.

Keywords: Bandwidth, Circular, Microstrip Patch Antenna, Ultra-Wide Band

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Introduction

The ever-changing demands of our globalized society make wide band antennas and wireless communication systems becomes admirable. The used of wide band antenna is very desirable due to its increasing data demand, spectrum efficiency, 5G beyond, IOT connectivity, flexibility and improved signal quality.

The coming year is enhancing the requirement of the modern wireless technique. The satellite wireless communication increasing the requirement of the wide band antenna. It offers a combination of performance, compact size, and ease of integration in wide-band applications such broadband communication systems (WiMAX, LTE, etc.), satellite communication, radar systems, and some wireless sensor networks (Xia *et al.*, 2019). They can be easily fabricated and are versatile enough to meet a wide range of contemporary wireless communication requirements. Microstrip patch antenna is used for its small size, ease of integration, low profile and light weighted material (Xu, 2017a; 2017b). The limitation of the Microstrip patches antenna provides very low gain, large ohmic type losses and narrow bandwidth. Miniaturization techniques are used for reducing the size of the antenna at a particular frequency, while not affecting the efficiency, bandwidth, and radiation pattern structure. During the past year researcher used different techniques for enhance band width of antenna like increment in the thickness, by using low dielectric constant material and use of the multilayer system (Kara, 1996; Hasan and Suman, 2012; Jayasinghe and Uduwawala, 2013). The insertion of the stubs and slots in patch increases the distribution of the current in the radiating surface. Miniaturization in the design is done by various techniques (Li *et al.*, 2017). Enhancement techniques in bandwidth is achieved by using two rectangular slots. Insertion of the cross shaped slot in the design reduces the backward radiation (Gupta *et al.*, 2019). Truncated corner 'U' provides the greatest impedance matching. The decrement in the ground width lowers the resonance frequencies. It is also used for tuning at the lower band (Luo *et al.*, 2019). The slots are also used for reducing the antenna size and improving the bandwidth. The substrate material is also required for increasing the bandwidth if we used the decreased permittivity material it provides high band width on the cost of increasing resonance frequency. Enhancement in the bandwidth is achieved by inserting parasitic patch and inserting

the slots in the ground plane (Rahaman and Hossain, 2018). The defected ground plane is used for increasing the radiation from front to back ratio. The level or the decreasing parameter of the value is decreased by some amount and helpful for the implanted antenna (Rahaman and Hossain, 2019). Some complex geometrical pattern and complex patch is used for increasing the bandwidth but it also increases the complexity towards the work (Xinwei *et al.*, 2013). The application of microstrip antenna is increases for its easy integration, less fabrication and availability (Alhuwaidi and Rashid, 2021). Patch antenna can also be used for analyzing the tumor location in the human body (Gour and Rathi, 2022) and for the telemetry operations.

The below Table 1 representing the related previous works.

Table 1. Shows Previous Work

Ref.	Size	Substrate	Design
(Awad, N. <i>et al.</i> , 2018)	30×35×1.6	FR4	Rectangular Patch with feed line
(Pandey <i>et al.</i> , 2023)	20×15×0.5	Rogers RT 5880	Line fed Monopole antenna
(Hamza <i>et al.</i> , 2018)	20×30×1.6	FR4	Rectangular patch Antenna
(Alsharif, F. and Kurnaz, 2018)	70×60×1.6	Cotton	Rectangular Patch

As per shown in the table different research gap is found in the previous work such as:

- Rectangular patch antenna requires more size in compare to the circular one.
- Comparing line-fed antennas to some other types of antennas, their bandwidth may be restricted. This may limit their capacity to efficiently function across a large range of frequencies.
- It is difficult to further reduce the size of microstrip patch antennas without sacrificing their functionality.

The presented Microstrip Patch antenna is simulated by using the FR4 ($\epsilon_r = 4.3$, height = 1.27 mm) substrate for the ISM band as 2.4 GHz – 5GHz. The wide band antenna is designed for Radar application and IOT connectivity applications. The circular copper patch is implanted over the antenna and increasing the radiation losses and current. The radius of the circular patch is 12 mm. Different slots are added in the design for increasing the current

path and magnetic field. Mathematical analysis of the designed antenna and used parameter is presented in the next material and methods section. Different parametric sweep techniques are used for optimizing the designed antenna. Simulation results of the antenna is representing in the result and discussion section. It shows the resulting parameter of the antenna likes directivity, gain, electrical field, magnetic field and power loss.

Materials and Methods

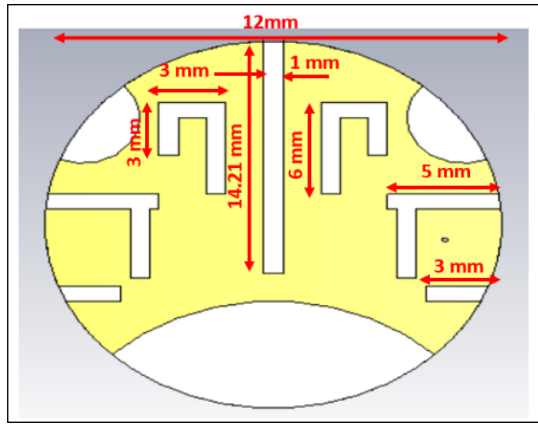
The paper presented a circular patch microstrip patch antenna for the wide band applications. Systems for biological sensing and imaging use circular microstrip patch antennas. They can be used to sense biological factors in medical monitoring devices or for non-invasive medical imaging procedures like microwave tomography. The designed antenna is design for ultra-wide band applications. It is designed for the ISM band structure due to its application of the sensing elements and medical application. The antenna's substrate is designed by using FR4 (ϵ_r : 4.3) substrate due to its easily availability and ease of fabrication. Rectangular slots in the design are added for lowering the resonance frequency of the antenna. The back radiation is removed by using the defected ground structure. Coaxial feeding is used for feeding the antenna, the feeding point can be placed anywhere for achieving impedance match. The dimension of the antenna design is achieved by using below mentioned Equations 1 and 2. The diameter of the circular patch is 24 mm and height of the patch is 0.035 mm. The resonance frequency of the antenna can be changed by the circular cut in the microstrip patch. The efficiency of the antenna is measured in terms of Radiation Pattern (it describes the angular distribution of the radiated power), Gain (concentration of the radiated power in the particular direction), Polarization (orientation of the electric field vector of radiated power), and bandwidth (range of frequency where the antenna can work effectively). Resonance frequency can be changed by changing the size and location of the cut (Diallo *et al.*, 2018). The antenna can be tuned to operate at a particular frequency or within a specified frequency band by carefully designing the circular cut. variations in the radiation pattern, such as adjustments to the beamwidth, directivity, and side lobe levels, might result from variations in the cut's size, shape, and location. For particular applications, the necessary radiation pattern features

can be obtained by modifying the circular cut's parameters (Gour *et al.*, 2022). The mentioned technique is used for optimizing the design and achieve the good result. A rectangular incision is used for reducing the size of the microstrip patch antenna (Gour *et al.*, 2023). It is possible to achieve miniaturization while keeping a satisfactory level of performance by carefully introducing the cut. Microstrip patch antenna design uses the Defected Ground Structure (DGS) technique to alter the ground plane structure below the radiating patch. It entails adding regular or irregular patterns of slots or other ground plane flaws (Rahaman and Hossain, 2019). For both signal transmission and reception, a coaxial cable must be connected to the microstrip patch antenna (Ramdani and Basari, 2019). The microstrip patch antenna can have parallel incisions deliberately placed to increase its bandwidth. Parallel cuts have the ability to increase the operating bandwidth of the antenna by altering the current distribution and effective electrical length of the patch. It is possible to obtain the needed bandwidth boost by optimizing the size, location, and number of cuts (Faisal *et al.*, 2019). An antenna's performance is greatly influenced by its radiation pattern. The antenna's electromagnetic energy is transmitted or received in various directions according to its radiation pattern. Several crucial features of antenna performance are directly impacted by the design and characteristics of the radiation pattern (Mudar *et al.*, 2010). A thorough parametric analysis is used to determine the dimensions of these cuts in the ground plane and the radiators of the suggested antennas. The radiation in the antenna is provides by using coaxial feeding techniques and the external value of the resonating frequency is 50 Ω . Different slots and curved are designed in the patch for enhanced performance of the patch antenna by its radiation pattern, directivity, gain and band width. The lower circular cut in the antenna is used for enhancing the band width of the antenna (Li *et al.*, 2017). An effective numerical method used in antenna design and analysis is called finite element analysis (FEA). It entails disassembling intricate structures like antennas into simpler, easier-to-analyze components. Researcher may model and forecast different aspects of antenna behavior by using Finite Element Analysis (FEA) in antenna design. This enables optimizations and improvements to be made prior to actual fabrication and testing. This result is used for designing more effective and customized antenna designs for certain uses. Different techniques used for optimizing the design is represented in the Table 2.

Table 2. Shows Key finding

S. No	Findings
1.	Cutting slots used for shifting the frequency and lengthen the current path.
2.	Bandwidth enhance by using parasitic patch and antenna slots in the ground plane.
3.	Current distribution effected by Coaxial feeding techniques.
4.	Shorting pin is used for reducing the electrical resistance.
5.	Circular shape structure used for antenna size reduction and frequency tuning.

The used designed or structure of the antenna is representing in the below Figure 1.

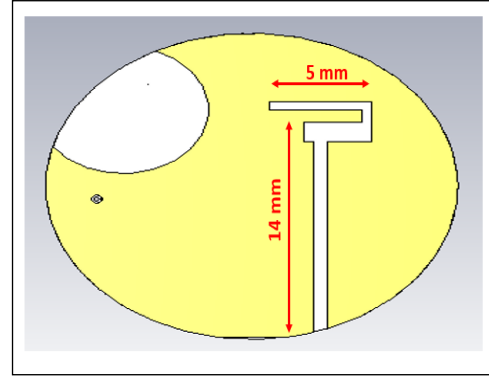
**Figure 1. Front Side of the designed Microstrip Patch Antenna**

The defected ground is also used in the back side of the design so that the result can be further enhanced and the wide band width should be achieved. The defected structure provides the less EM field towards the body, so that it can be used for implantable device and can be implanted in the body. The back portion of the used antenna is representing in the Figure 2. The rectangular and circular cut in the back side provides the wider range of bandwidth with good return loss. The optimized dimension is representing in the Table 3 with the help of the below mention equation. The radius of the circle patch is examined by using the mathematical equation for any particular frequency. It is defined by following Equation 1:

$$a = \frac{f}{\{1 + \frac{2h}{\pi \epsilon_f} (\ln[\frac{\pi f}{2h} + 1.7726])\}^{\frac{1}{2}}} \quad (1)$$

Where F is given by the following Equation 2:

$$F = \frac{8.791 \times 10^9}{f_r (\epsilon_r)^{\frac{1}{2}}} \quad (2)$$

**Figure 2. Back Side of the designed Microstrip Patch Antenna****Table 3. Shows Dimension**

S. No	Parameter	Dimension (mm)
1.	Radius of the Circular Patch	12
2.	Height of Ground	0.035
3.	Height of Patch	1.27

The parametric seep techniques in the CST Microwave studio provides the optimized results of the pattern. The resonant frequency of the antenna is 4.88 GHz with -44dB return loss and 1.1 VSWR.

The optimized result of the antenna is representing in the next below section with the different parametric values. The antenna performance is analysis by the E-field, H-field and power flow of the antenna. The mentioned parameters are represented in the below section.

Result and Discussion

After simulating the designed antenna, the results of the resonance frequency and VSWR shows that it can be used for the radiating element due to its high reflection ratio. The wide band width result shows that it can be used for the wider area network. The range of the resonance region is from 4.72 - 5.1 GHz (460 MHz) at the resonance frequency of 4.88 GHz. The return loss and VSWR results are representing in the Figure 3 and Figure 4 respectively.

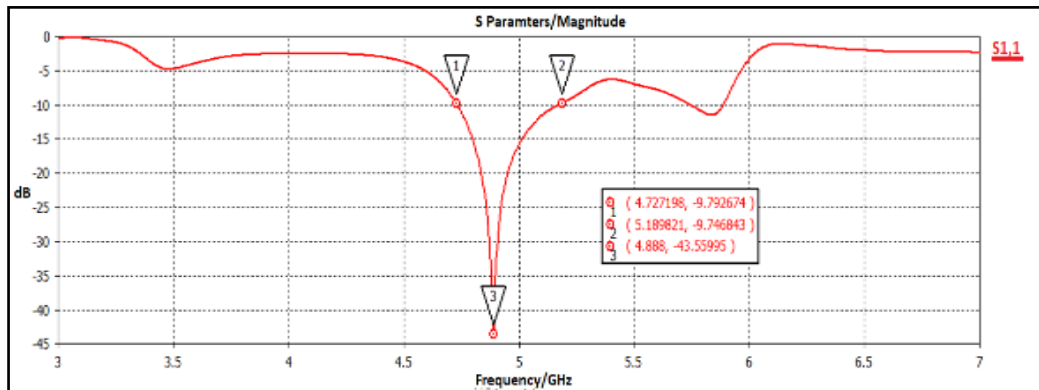


Figure 3. Return Loss (S11) of the designed antenna

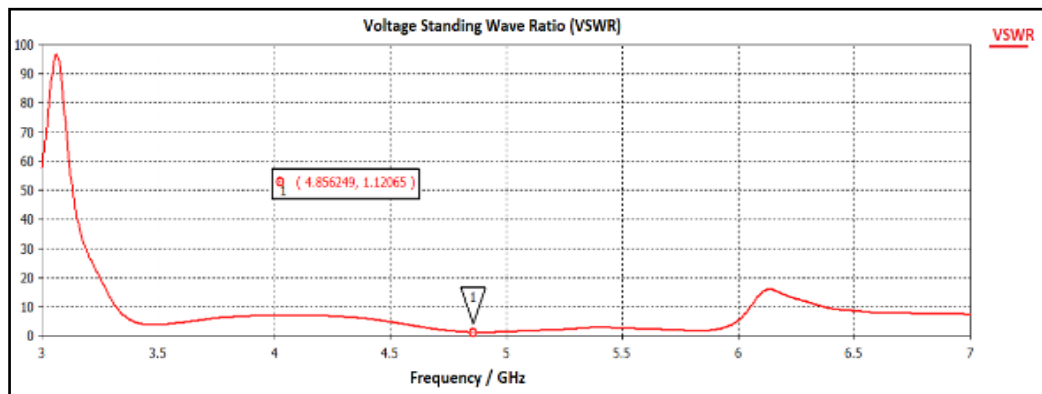


Figure 4. VSWR of the designed antenna

The return loss results shows that the antenna has the proper impedance matched with the -44 dB. So it can be easily used for perfectly match device. The achieved value of the VSWR is below the 1.5. The degree to which an antenna system is matched to the transmission line and source can be expressed using the VSWR value. A VSWR indicates a perfect match (no reflections), meaning 100% of the source's power is delivered to the load without any reflections.

Varying electrical and magnetic field shows the field structure in the below Figure 5 and Figure 6. The value of the electrical energy is 0.00678 J/m^3 and magnetic energy is 0.0105 J/m^3 .

The high electric field electron moves to conduction band and so it lose its dielectric property. The maximum field can be applied is known as dielectric strength and breakthrough process. Directivity of antenna is defined by average of the maximum radiation to average radiation intensity. The gain of the antenna is the term where gain can

be defined with respect to the reference antenna and for enhancing the performance. The farfield pattern of the antenna shows that how far the antenna can be worked by deteriorate the performance itself. The farfield results is representing in the below Figure 7.

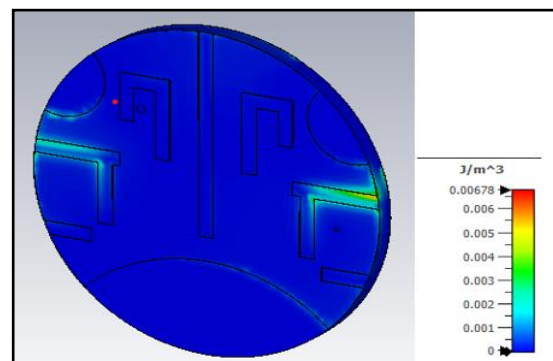


Figure 5. Electrical Energy of Antenna

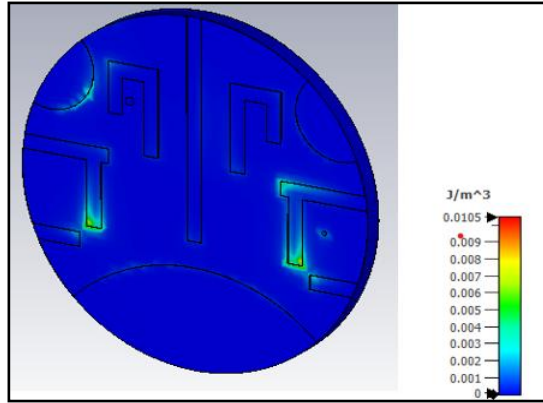


Figure 6. Magnetic Energy of Antenna

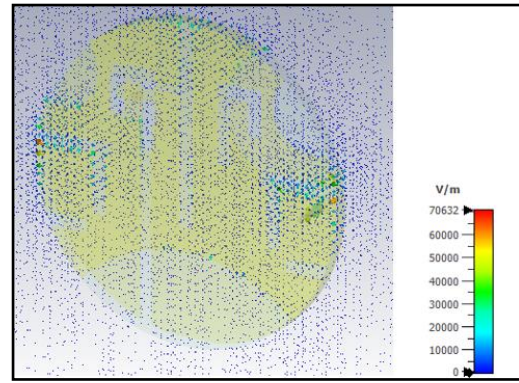


Figure 8. E-Field of the antenna

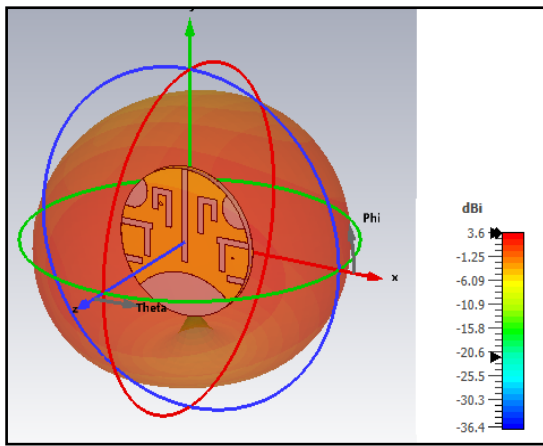


Figure 7. Directivity of the proposed design

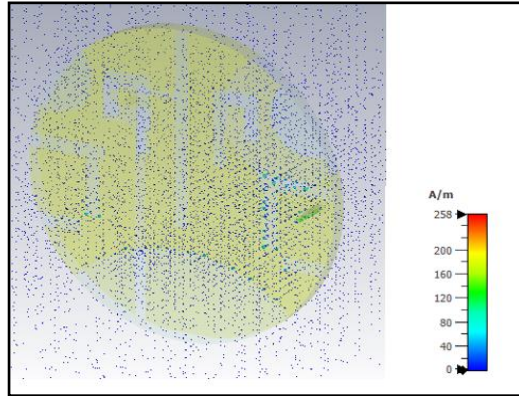


Figure 9. H-Field of the antenna

The measured directivity of antenna is 3.6 dB, represents that it can be easily implanted and forwarded radiation in the desired directions.

The e-field and h-field of the antenna is shows in the Figure 8 and Figure 9. It shows the electrical and magnetic movement of the field of the antenna in the particular E and H direction.

The power flow of the signal shows the power generation towards the antenna and represents in the field of the pattern defined. The generated power flow of the design at resonant frequency of 4.7 GHz is representing in the below Figure 10.

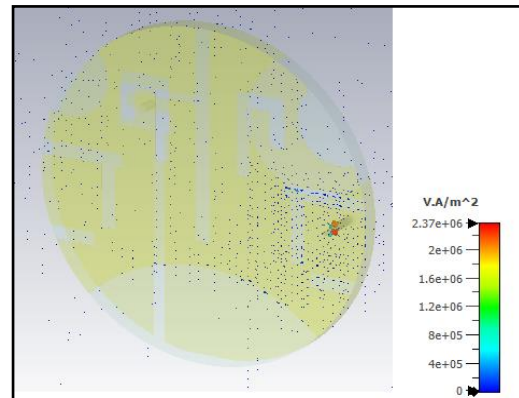


Figure 10. Power Flow of the Antenna

Table 4. Shows Comparative Analysis

S. No	Ref	Return Loss (dB)	Resonant Freq. (GHz)	Substrate	Bandwidth (MHz)
1.	(Rahaman and Hossain 2019)	-46.64	2.45	Teflon	390
2.	(Malak and Shubair 2016)	-13.3	2.4	Alumina	150
3.	(Farhad <i>et al.</i> , 2019)	-63	2.45	FR4	60
4.	(Nasim <i>et al.</i> , 2015)	-38.42	2.45	-	127.9
5.	(Yousaf <i>et al.</i> , 2019)	-29.2	2.45	Rogers	70
6.	(Nikolayev <i>et al.</i> , 2019)	-27	0.4	Kapton	434
7.	(Malik <i>et al.</i> , 2020)	-	2.67	Rogers	166
8.	Proposed	-43.5	4.85	FR4	460

Thus, the results of the designed antenna shows that it could used for wide-band application and enhancing the performance of the wide area network. The resonating frequency of antenna is 4.7 GHz with the bandwidth of 460 MHz. The tripping of the signal is enhanced by inserting and adding the slots in the design. The addition of the slots in the design is used for lowering return loss for the desired frequency. The DFG is used for the lower tripping the return loss and decrease the back radiation of the antenna. The achieved directivity of the antenna is 3.5 dB for the resonance frequency of 4.7 GHz. Wide band range and lowering the tripping range shows that it can be used for wide area network application and enhancing capacity. The addition of slots in ground back structure reduces the backward radiation of the antenna. The back circle shaped design is used for tripping the return losses in the design. The result can be further optimized by using different material substrate for the different parametric design. The presented work is compared by the previously done work in the Table 4. Comparison shows that it can be used as antenna in ultra-wide band applications.

Conclusions

A circular microstrip patch antenna for the ultra-wide band application is presented in this paper. The miniaturization in the antenna is achieved by using different slots in front and back design. The back designing is used for reducing the backward radiation in the antenna. By include a few slots and introducing parametric variation, the broad band antenna is made possible. The return loss of the present antenna is 4.7 GHz at -43 dB. The bandwidth of the antenna is 460 MHz, which falls inside the ISM band structure. The wide band can be used for the scientific, medical and industrial applications. The E-filed and H-filed results shows that it can be used for the electromagnetic wave applications. The antenna has an E-field and H-field of 70632 V/m and 258 A/m, respectively. The

antenna has a directivity of 3.1 dB, allowing for further improvement of the antenna's direction for extensive area coverage.

References

- Alhuwaidi, S. and Rashid, T. (2021). A Novel Compact Wearable Microstrip Patch Antenna for Medical Applications. International Conference on Communications, Signal Processing, and their Applications (ICCCSPA). <https://doi.org/10.1109/ICCCSPA49915.2021.9385726>
- Diallo, K., NGom, A., Diallo, A., Ribero, J.M., Dioum, I., and Ouya, S. (2018). Efficient dual-band pifa antenna for the internet of things (IOT). IEEE Conference on Antenna Measurements & Applications (CAMA). <https://doi.org/10.1109/CAMA.2018.8530584>
- Faisal, F., Amin, Y., Cho, Y., and Yoo, H. (2019). Compact and Flexible Novel Wideband Flower-Shaped CPW-Fed Antennas for High Data Wireless Applications. IEEE Transactions on Antennas and Propagation, 67(6):4,184-4,188. <https://doi.org/10.1109/TAP.2019.2911195>
- Farhad, M.M., Akbar, M.A., Chakraborty, S., and Gani, M.M (2019). Performance Analysis of a Microstrip Patch Antenna for Biomedical Applications. 2019 International Conference on Electrical, Computer and Communication Engineering (ECCE).
- Gour, S. and Rathi, A. (2022). Analyzing Performance of Microstrip Patch Antenna for Detecting the Tumor in the Human Body. Telecommunications and Radio Engineering, 81 (10):37-51. <https://doi.org/10.1615/TelecomRadEng.2022043399>
- Gour, S., Rathi, A., Sharma, A., and Yadav, A.K.S. (2022). Design And Analysis of An On-Body Microstrip Patch Antenna for Biomedical Application. Advances in Communication, Devices and Networking.
- Gour, S., Sharma, R., Sharma, A., Rathi, A. (2023). Wheel Shaped Defected Ground Structure Microstrip Patch Antenna with High Gain and Bandwidth for Breast Tumor Detection. Proceedings of the International Conference on Intelligent Computing, Communication and Information Security, 21-29. https://doi.org/10.1007/978-981-99-1373-2_2
- Hasan, M.R. and Suman, A.A.I. (2012). Substrate height and dielectric constant dependent performance analysis of circular microstrip patch array antennas for broadband wireless access. American Academic and Scholarly Research Journal, 4(6):43-49.
- Jayasinghe, J.M.J.W. and Uduwawala, D.N. (2013). Optimization of the performance of patch antennas using genetic algorithms. Journal of the National Science Foundation of Sri Lanka, 41(2):113-120. <https://doi.org/10.4038/jnsfr.v41i2.5705>

- Kara, M. (1996). The resonant frequency of rectangular microstrip antenna elements with various substrate thicknesses. *Microwave and Optical Technology Letters*, 11(2):55-59. [https://doi.org/10.1002/\(SICI\)1098-2760\(19960205\)11:2<55::AID-MOP1>3.0.CO;2-N](https://doi.org/10.1002/(SICI)1098-2760(19960205)11:2<55::AID-MOP1>3.0.CO;2-N)
- Li, R., Guo, Y.X., Zhang, B., and Du, G. (2017). A Miniaturized Circularly Polarized Implantable Annular-Ring Antenna. *IEEE Antennas and Wireless Propagation Letters*, 2,566-2,569 <https://doi.org/10.1109/LAWP.2017.2734246>
- Malak, Y.E. and Novel, R.M. (2016). Novel Design of Compact Low-Profile Multi-Band Microstrip Antennas for Medical Applications. 2015 Loughborough Antennas & Propagation Conference (LAPC). <https://doi.org/10.1109/LAPC.2015.7366015>
- Mudar, A.A., Suzette, M.A., Nader, B., and Hagness, N.C. (2010). Dual-Band Miniaturized Patch Antennas for Microwave Breast Imaging. *IEEE Antennas and Wireless Propagation Letters*, 268-271. <https://doi.org/10.1109/LAWP.2010.2045871>
- Nasim, A.I., Tajwar, A.I., Arafat, U., Islam, A.J. and Hoque, R. (2015). Design and Performance measurement of an in-body implantable miniaturized slot dipole rectangular patch antenna for biomedical applications. *International Conference on Advances in Electrical Engineering (ICAEE)*, 59-63. <https://doi.org/10.1109/ICAEE.2015.7506796>
- Rahaman, M.A. and Hossain, Q.D. (2018). Design of a Miniature Microstrip Wide Band Antenna for On-body Biomedical Telemetry. *International Conference on Smart Systems and Inventive Technology (ICSSIT)*, 141-144. <https://doi.org/10.1109/ICSSIT.2018.8748503>
- Rahaman, M.A. and Hossain, Q.D. (2019). Design and Overall Performance Analysis of an Open-End Slot Feed Miniature Microstrip Antenna for On-body Biomedical Applications. *International Conference on Robotics, Electrical and Signal Processing Techniques (ICREST)*, 200-204. <https://doi.org/10.1109/ICREST.2019.8644334>
- Ramdani, S., Pratama, I., and Basari, I.P. (2019). Single Coaxial Feed Microstrip GPS Antenna Aimed at Wearable Device Application. *IEEE Conference on Antenna Measurements & Applications (CAMA)*, 247-250. <https://doi.org/10.1109/CAMA47423.2019.8959786>
- Xinwei, C., Fengxian, Z., Liyun, Y., and Wenmei, Z. (2013). A compact filtering antenna with flat gain response within the passband. *IEEE Antennas and Wireless Propagation Letters*, 12:857-860. <https://doi.org/10.1109/LAWP.2013.2271972>
- Xu, J., Tao, L., Zhang, R., Hao, Y., Huang, S., and Bi, K. (2017). Broadband complementary ring-resonator based terahertz antenna. *Optics Express*, 25(15):17,099-17,104. <https://doi.org/10.1364/OE.25.017099>
- Xu, J., Zhao, M., Zhang, R., Lei, M., Gao, X., Huang, S., Bi, K., (2017). A wideband F-shaped microstrip antenna. *IEEE Antennas and Wireless Propagation Letters*, 16:829-832. <https://doi.org/10.1109/LAWP.2016.2606118>
- Yousaf, M., Bashir, Z., Yasar, A., and Akram, A. (2019). A Miniaturized Wideband Implantable Antenna for Telemetry Applications. *International Conference on Electrical, Communication, and Computer Engineering (ICECCE)*. <https://doi.org/10.1109/ICECCE47252.2019.8940777>