University of Thi-Qar Journal of Science (UTJsci)
E-ISSN: 2709-0256, P-ISSN: 1991-8690, Vol. 12, No. 1, June. 2025

Microstrip Patch Antenna Array Design and Mutual Coupling Reduction for Wi-Fi and Wi-Max Applications

Saja H. Kareem *[1a], Hassan A. Yasser [1b] and Ahmad H. Al-Shaheen [2c]

[1] *Department of Physics, College of Science, University of Thi-Qar , Thi-Qar, Iraq.*
[2] *Department of Physics, College of Science, University of Misan, Misan, Iraq.*

[b]E-mail: hassan.yasser_ph@sci.utq.edu.iq, [c]E-mail: prof.dr.ahmad@uomisan.edu.iq.

[a*]Corresponding author: saja.hamed24@gmail.com

Received:2024-07-28, Revised:2024-09-10, Accepted: 2024-09-18 , Published:2025-06-08

***Abstract*— The 5G multiple-input multiple-output (MIMO) microstrip antenna with isolation enhancement that is tiny and based on a BandPass metamaterial (BPM) is presented in this study. The expectation of higher data rates drove the development of fifth-generation (5G) mobile communication networks. The performance of a two-element microstrip antenna array with and without bandpass metamaterial is compared in this work. The antenna consists of two parts, with its radiators positioned to report the parallel direction. The array antenna's overall dimensions are small, measuring 40 × 72 × 1.6 mm^3. The proposed isolated double patch parallel antenna produces bandwidth and mutual coupling equal to 11GHz and less than -30dB at a frequency range from 1.5 to 6GHz, respectively, while the rectangular microstrip patch antenna array produces these values at 14.80 GHz and -55.94dB. When compared to the double microstrip parallel antenna, the double microstrip parallel antenna with BPM is superior in terms of mutual coupling. This increasing demand for faster data speeds in the rapidly changing field of mobile communication technologies is met by this creative antenna.**

***Keywords*— Antenna Array, HFSS, Bandpass Metamaterial, 5G.**

I. Introduction

Manufacturers are always coming up with new wireless communication systems because more and more people need and use wireless devices in areas like medicine, defense, and aeronautics. From this point of view and over the last few years, microwave circuit technologies have changed a lot [1,2]. The antenna has a bigger footprint, which makes it harder to put in small areas because it takes up more space in the communication chain. Microstrip patch antennas are valuable parts of fifth-generation (5G) wireless communications today. They are small, cheap, and simple to attach to integrated circuits, satellites, cars, planes, and even people inside and outside of them. Some problems with their performance are that they have a narrow bandwidth, low collection power, and low gain, which means they can't be used in all cases [3]. It is the antenna's return loss, gain, and bandwidth that really matter when it comes to the high frequencies of 5G wireless communication technology. The best antennas should have high gain, low return loss, and wide bandwidth [4-6]. This will solve these problems and meet user needs. The fastest 5G wireless connection can only send and receive 100 Mbps of data, but the current needs are estimated to be more than 10 Gbps. And so, the 5G wireless network is what we need to have a wireless information system that works for these purposes. This second one has a reaction time of less than a millisecond, covers 1 million components in a square kilometer, gives 10 Tbps network access in a square kilometer, 10 Gbps, and many other benefits [7-9]. Using the highest frequencies is the best way to meet all of the requirements and get good results with 5G. This is because the International Telecommunication Union (ITU) set aside frequency bands between 3.4 and 3.6 GHz, 5 to 6 GHz, 24.25 to 27.5 GHz, 37 to 40.5 GHz, and 66 to 76 GHz as special bands for 5G. The Federal Communications Commission (FCC) set aside the band between 27.5 and 28.35 GHz [8]. Out of all these frequency ranges, we picked the 2–6 GHz band for our study because it has been used in trials in several countries and is a good fit for 5G.

There needs to be high bandwidth and good directivity in 5G antennas so that users can get what they want, like the high data rates of current technology. They also need to have a lot of gains so microwaves don't damage them. Living things can stop the flow of electromagnetic information on millimeter waves and the bad things that happen when very high frequencies are used [10-13]. For 5G wireless technology to work, antennas need to be cheap, easy to place on all electronic systems and devices, work well, and be able to be used on both flat and curved surfaces. When mounted on rigid surfaces, they also need to be mechanically sound. In order for scientists to work on this topic, a microstrip patch antenna is now an important part of all 5G wireless communication systems. Because of this, this type of antenna is very important to this study paper. The needs and standards for the wireless communication network have grown a lot along with this

https://doi.org/10.32792/utq/utjsci/v12i1.1288

progress. New wireless standards have been made to deal with these issues, and the next wave of standards is made almost every ten years [14-17]. The main point of this piece is to make a patch array antenna that works with 5G mobile phones by using bandpass metamaterial to stop the antenna elements from interacting with each other. The suggested antenna should have a large bandwidth, a basic shape, a unique beam pattern, and a high gain. Notably, a wide bandwidth will improve range and capacity, while a small size will lower costs and make installation easier. The separated microstrip array antenna methods that have been suggested lower mutual coupling and raise antenna gain.

II. ANTENNA DESIGN

The goal is to make an antenna with a higher gain and a more focused radiation pattern that is just right for next-generation mobile transmission on cell phones. Millimeter-wave frequencies are set aside for future 5G systems, so antennas that work in this range need to be small. Fig. 1 shows in great detail the antenna's size and shape. The antenna is put together on a piece of FR4 that has a width of 1.6 mm, a permittivity of 4.4, and a loss tangent of 0.025. The antenna's ground plane is 36 × 14.5 mm^2.

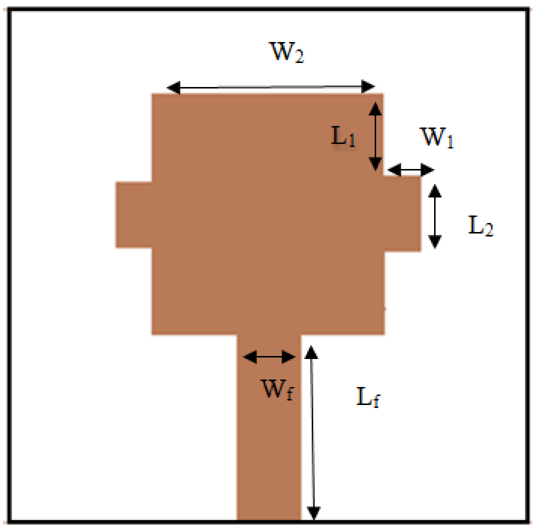
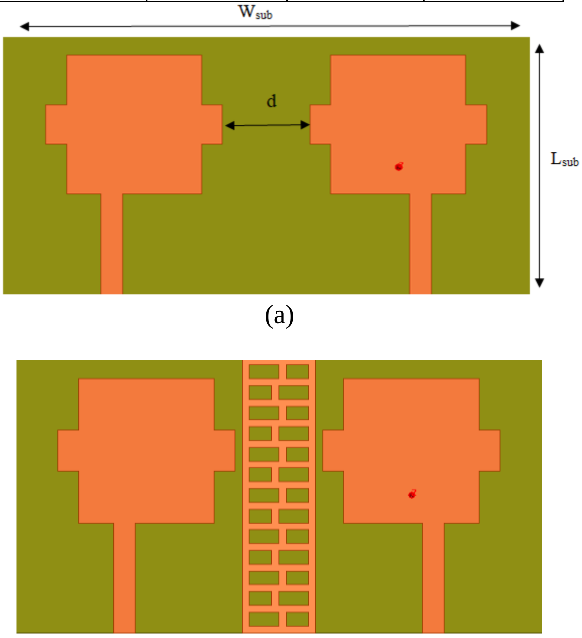


Fig.1: The geometry of the proposed RMPA single-element antenna.

When you change the antenna's key parameters, which are shown in Table 1, you can get different frequency bands. The patch and transmission line are on top, the base is in the middle, and the ground plane is at the bottom. This is how a patch antenna is developed and made. It gets power from a microstrip line. Five hundred ohms is what the second one is set to. Fig. 1 shows the shape of a single patch antenna that has been suggested. The structure of a two-element MIMO antenna with a linear orientation and dimensions of 40 × 72 × 1.6 mm^3 is shown in Fig. 2 (a). Table 2 shows the antenna's most important parameters, and Fig. 2(b) displays the layout of a two-element MIMO antenna patches with bandpass metamaterial BPM added between them.

Table 1: Dimension of the single antenna element (all in mm)

Parameter	dimension	Parameter	dimension
W_1	2.8	L_1	7.5
W_2	18.4	L_2	6
W_f	3	L_f	16



(b)

Fig.2: Layouts for the 1 × 2 MIMO RMP antenna array (a) without bandpass metamaterial structures and (b) with bandpass metamaterial structures.

This problem with coupling can be fixed by making the antenna's mutual impedance (both real and imaginary parts) equal to zero at antenna resonance. This solves the coupling problem at all frequencies when the distance between the elements is very small, which leads to a strong coupling. This state can be reached by making the antenna more isolated. The band stop filtering system structure has been put in place between the surface microstrip patches to make the antenna separation better. By adding the BPM to the planned MIMO antenna, we hope to get good band rejection properties. We put bandpass metamaterial BPM filtering structures between the spots on the surface to look into how well they stop mutual coupling.

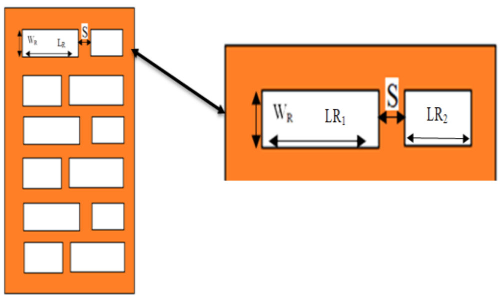


Fig.3: The layout of the designed BandPass Metamaterial structures.

Table 2. Dimensions of the Designed Antenna.

parameter	Value(mm)	Parameter	Value(mm)
W_{sub}	72	L_{R2}	3
L_{sub}	40	W_R	2
h	1.6	s	1
d	12	L_{R1}	4

III. RESUITS AND DISCUSSION

Impedance matching between an antenna and its source is crucial for maximizing power transfer and minimizing reflection. The Voltage Standing Wave Ratio (VSWR) indicates the quality of the match; a low VSWR (close to 1) means better matching. Ideal power transfer occurs when the antenna and source have the same impedance.

We made the antenna based on the transmission line model results. Now we'll look at the HFSS antenna modeling results. The reflection coefficient for one-element S_{11} is shown in Fig. 4. Its values are -17.13, -24.46, -24.80, -15.84, -12.43, and -26.87 dB for resonance frequencies of 2.98, 4.80, 7.57, 8.74, 10.14, and 12.38 GHz. As the frequency goes up, the range of the transmission line model gets bigger. This is especially true for millimeter-wave frequencies. The frequency range is 10.55 GHz (2.50–13.05 GHz). As you can see in Fig. 5 and Fig. 6 the values of the 2D gain plot are 2.64 and 4.29 dB at phi 0^o and 90^o, and the VSWR is 1.00. Printed antennas that are all in one piece don't work well enough most of the time. With some properties, like high gain or a shaped main lobe, you can only get them by putting together a system of several transmitting sources. This is called an antenna array. It is possible to get highly directed radiation by combining several main antennas. However, this relies on the number and type of elements, how they are powered, and how they are properly set up in the array.

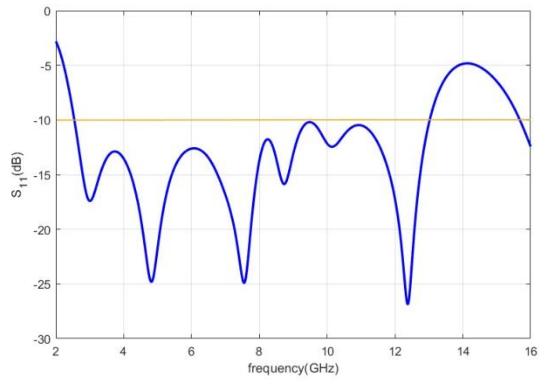


Fig .4: Simulation results of the reflection coefficients for the proposed single-element antenna.

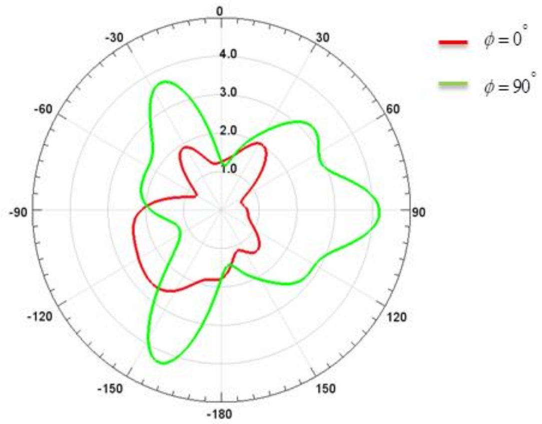


Fig. 5. Simulated far-field radiation pattern of one-element patch antenna.

There are many things that affect the choice of the best configuration (feed), such as the antenna gain, insertion loss, beam angle, array, side lobe level, ability to control the feed, and polarization. The serial transmission line feed type was chosen because it has a larger capacity, lower insertion loss, and lower polarization. Microstrip patch antennas work better when there are more of them in a group. We recommended a 1x2 grid of two antenna elements to get the study results we needed. This would make the antenna work very well. Fig. 2. The reflection coefficient S_{11} shows that there is a break in the plane between the broadcast source and the antenna. This coefficient, which is generally given in decibels, is the ratio of the wave that hits the antenna to the wave that is reflected. The amount of matching (or, more accurately, mismatching) is measured by the standing wave ratio (VSWR). When the chains are exactly matched, this ratio goes to 1; when the chains are not matched, it goes to infinity. Some ways to match that can be used to improve energy flow are single-stub matching, double-stub matching, and quarter-wave matching. It has two elements and doesn't have BPM S_{11}. Fig. 7 and 8 show the shapes for the reflection coefficient and VSWR. The values are -55.94, -55.94, -41.93, and -29.61 dB for resonance frequencies of 3.65 GHz, 5.79 GHz, 9.02 GHz, and 9.61 GHz. The frequency range is 14.80 GHz (1.20–16.00 GHz), and the VSWR is 1.00.

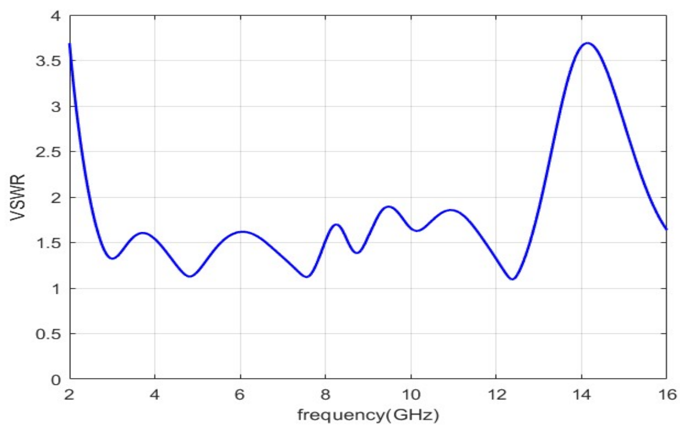


Fig.6. VSWR of proposed antenna of a one-element patch antenna.

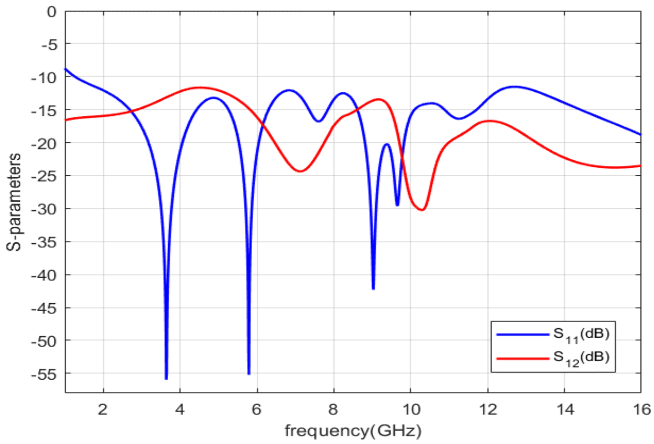


Fig.7: Simulated S11 and S12 of the two-element microstrip Patch array antenna without BPM structures.

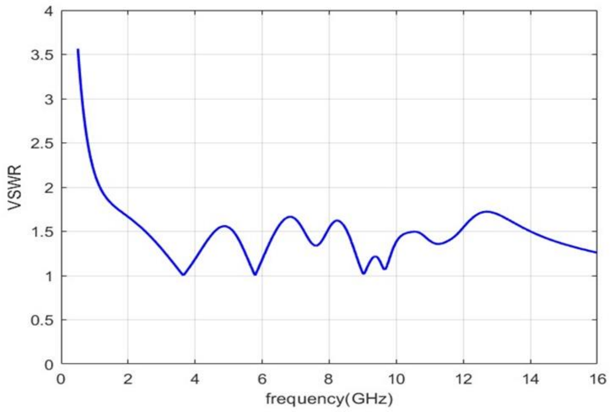


Fig.8. VSWR of proposed antenna array of the double microstrip parallel antenna without BPM structures .

The 2D gain figure in Fig. 9 shows that the value is 4.49 and 6.28 dB at phi 0 and 90, respectively, at 3.65 GHz. A radiation pattern is any graph that shows how the radiation behaves at each antenna based on how they change (β, φ), or, in other words, based on the polar plane. To see the curves of the reflection coefficient and VSWR for a two-element system with BPM between patches, look at Fig. 10 and 11.

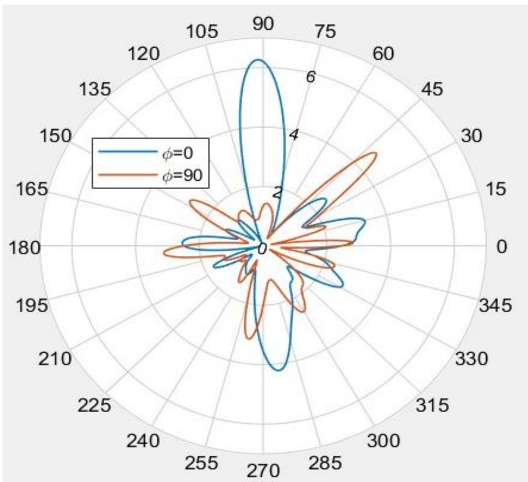


Fig.9. The radiation pattern of the double microstrip parallel antenna without BPM structures.

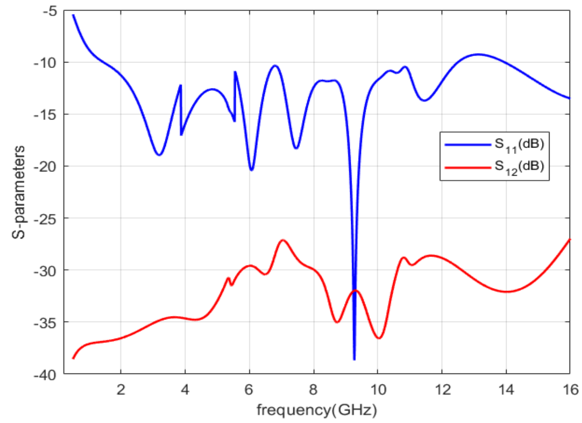


Fig.10: Simulated S_{11} and S_{12} of the double microstrip parallel antenna with BPM structures.

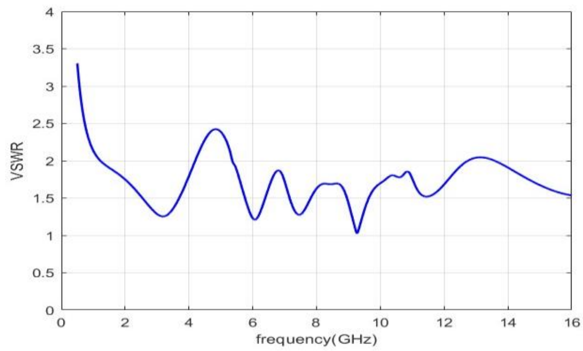


Fig.11. VSWR of proposed antenna array of the two-element microstrip patch array antenna with BPM structures.

These were made with S_{11} = -18.24, -17.08, -15.29, -20.20, -18.35, -40.35 and -13.71dB, and the resonance frequency was 3.18 GHz, 9.34 GHz, and 14.94 GHz. The frequency range is 3.18 GHz, with a VSWR of 1.26 and bandwidths of 2.81 GHz, 6.65 GHz, and 2.9 GHz. As you can see in Fig.12, the 2D gain plot has a value of 7.56 dB at phi 0 and 9.87 dB at phi 90, both at 3.18 GHz. At the ideal frequency, the mutual coupling between the antennas is seen to drop from -26.95 dB.

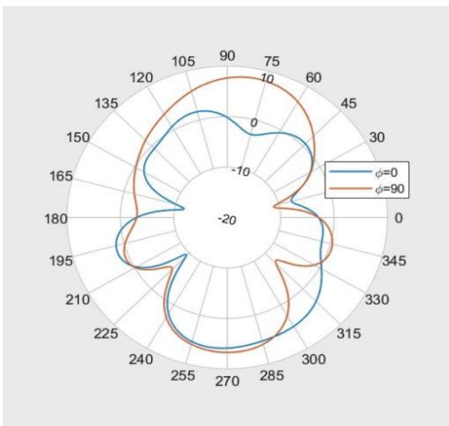


Fig.12. The radiation pattern of the two-element microstrip patch Array antenna with BPM structures.

IV. MUTUAL COUPLING COMPARISON

This picture (Fig. 13) shows the difference in the mutual coupling between two MIMO antenna patches with and without BPM added between them. The isolated microstrip antenna array that was mentioned has resonance frequencies of 3.18 GHz, 9.34 GHz, and 14.94 GHz, in that order. The range of frequencies that are responsive is 2.82 GHz, 6.65 GHz, and 2.90 GHz, in that order. An RMPA array without BPM has a bandwidth of 14.80 GHz, but the isolated microstrip antenna array that is being proposed has a lower bandwidth. So, the first proposed microstrip antenna array (the RMPA array without BPM) has a wider bandwidth than the second suggested isolated microstrip antenna array. The isolated microstrip antenna array that was recommended has a lower mutual coupling of -26.24 dB at the resonant frequency of 3.18 GHz compared to RMPA. In addition, the suggested separation microstrip antenna array is no longer crossing over at 3.18 GHz, which is the resonant frequency.

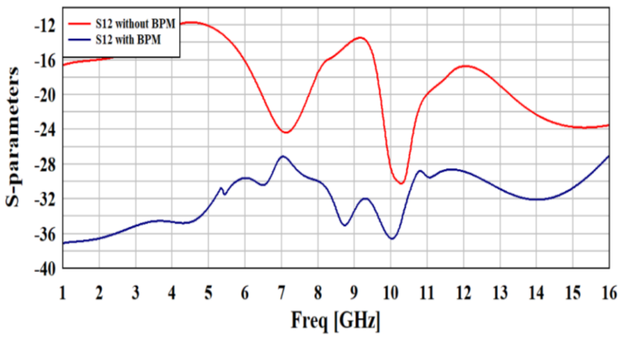


Fig.13: Comparison of the mutual coupling S_{12} of two MIMO antenna patches with and without inserting BPM between patches.

The comparison between the proposed antenna and other antennas is listed in Table 2. It can be seen that the proposed antenna has advantages over the existing antennas in terms of the small size of separation structure, low edge-to-edge distance, and low mutual coupling value. The antenna is suitable for beam scanning and other applications requiring high directivity.

Table 2: Comparative Analysis with Existing Design.

Ref. No	Substrate Material	Antenna Size(in mm^3)	Frequency Range	S_{21} (in dB)
18	FR-4	36x44x1.6	5.8 GHz	−24.5 dB
19	FR-4	50x50x1.6	2.45, 5.8 GHz	-25, -29 dB
20	FR-4	44x37x1.6	5.4 GH	-23dB

IV. CONCLUSION

This paper shows a planar array of 1x2 antenna elements that can be used for 5G. This is done to make the standard rectangular patch microstrip antenna work better by increasing its band width and gain. When the reconfigurable patch and ground plane are used to widen the band, the band width gets wider than with the standard RPMS. To improve the 1x2 array's directivity and gain and to get rid of the effect of mutual coupling between closely spaced elements, BPM is shown. The results clearly show that the S_{12} is different when comparing cases with and without BPM between the two elements, which leads to a smaller overall design. It can be used for many different types of wireless tasks, including ISM band, 5G, Wi-Fi, WiMax, and UWB.

CONFLICT OF INTEREST

Authors declare that they have no conflict of interest.

REFERENCES

[1] K. Shafique, B. A. Khawaja, F. Sabir, S. Qazi and M. Mustaqim," Internet of Things (IoT) for Next-Generation Smart Systems A Review of Current Challenges, Future Trends and Prospects for Emerging 5G-IoT Scenarios," *IEEE Access*, vol. 8, pp. 23022–23040, 2020.

[2] A. K. allappil, M.K.A. Rahim, B. A. Khawaja and M.N. Iqbal, "Compact Metamaterial Based 4×4 Butler Matrix with Improved Bandwidth for 5G Applications," *IEEE Access*, vol. 8, pp. 13573–13583, 2020.

[3] L. Xu and Y. J. Zhou, " Low Profile High-Gain Antenna for Broadband Indoor Distributed Antenna System,". *Appl. Comput. Electromagn. Soc. J. (ACES)*, vol. 35, pp. 791–796, 2020.

[4] G. Deng, L. Hu, H. Mo, J. Xu, Z. Yin, H. Lu, M. Hu, J. Li, and J. Yang, " A tunable terahertz metamaterial wideband absorber with liquid crystal,". *Opt. Mater. Express*, vol.11, pp.4026–4035,2021.

[5] A. K. Vallappil, M. K. A Rahim, B. A. Khawaja, M. N. Iqbal , N. A. Murad, M. M. Gajibo and L.O. Nur, "Nugroho, B.S. Complementary split-ring resonator and strip-gap based metamaterial fractal antenna with miniature size and enhanced bandwidth for 5G applications," *J. Electromagn. Waves Appl*, PP.1–17, 2021.

[6] S. Hamdan, H. A. Mohamed and E. K. I. Hamad, " Design of High Isolation Two-port MIMO Two-element Array Antenna Using Square Split-Ring Resonators for 5G Applications", *international journal of microwave and optical technology*, vol. 17, No. 4, 2022.

[7] G. Dai, X. Xu, X. Deng, Z. Zhang, J. Liu, J. Su, J. Song, Y. Gao, W. Peng and et al," Size-Reduced Equilateral Triangular Metamaterial Patch Antenna Designed for Mobile Communications," *Appl. Comput. Electromagn. Soc. J*,vol.36, pp.1026–1030, 2021.

[8] M. K. Shereen, M. I. Khattak, and J. Nebhen, ''A review of achieving frequency reconfiguration through switching in microstrip patch antennas for future 5G applications,'' *Alexandria Eng. J*, vol. 61, no. 1, pp. 29–40 Jan. 2022.

[9] J. Khan, D. A. Sehrai, M. A. Khan, H. A. Khan, S. Ahmad, A. Ali, A. Arif, A. A. Memon, and S. Kha, ''Design and performance comparison of rotated Y-shaped antenna using different metamaterial surfaces for 5G mobile devices,'' *Comput., Mater. Continua*, vol. 60, no. 2, pp. 409–420, 2019.

[10] R. Sharma, R. Khanna, and Geetanjali, ''Compact sub-6 GHz and mmWave 5G wideband 2 × 1 MIMO

antenna with high isolation using parasitically placed double negative (DNG) isolator,'' *Wireless Pers. Com- mun*, vol. 122, no. 3, pp. 2839–2857, 2022.

[11] G. Naik, J.-M. Park, J. Ashdown, and W. Lehr, ''Next generation Wi-Fi and 5G NR-U in the 6 GHz bands: Opportunities and challenges,'' *IEEE Access*, vol. 8, pp. 153027–153056, 2020.

[12] W. M. Al-Mosawi, " Investigation of Cavities at Petrochemical, Basra South of Iraq by Using Ground Penetration Radar (GPR) Technique," *Journal of University of Thi- Qar*, vol.8, No.3, 2013.

[13] A. H. Abood, "Phased Linear Array of Circular Aperture Antennas," *J.Thi- Qar Sci*, ISSN 1991-8690, vol.4, 2009.

[14] O. Elalaouy, M. El Ghzaoui and J. Foshi, "Enhancing antenna performance: A comprehensive review of metamaterial utilization," *Materials Science and Engineering: B*, vol. 304, 2024.

[15] M. Berka, U. Özkaya, T. Islam, M. El Ghzaou, S. Varakumari, S. Das and Z. Mahdjoub, "A miniaturized folded square split ring resonator cell based dual band polarization insensitive metamaterial absorber for C- and Ku-band applications, " *Optical and Quantum Electronics*, vol. 55, 2023.

[16] I. U. Din, S. Ullah , S. I. Naqvi, R. Ullah, S. Ullah, E. M. Ali and M. Alibakhshikenari, "Improvement in the Gain of UWB Antenna for GPR Applications by Using Frequency-Selective Surface", *International Journal of Antennas and Propagation*, vol.2022, pp. 12.2022.

[17] P. Jha, A. Kumar, A. De and R. K. Jain, "Super Ultra-Wideband Planar Antenna with Parasitic Notch and Frequency Selective Surface for Gain Enhancement, " *aces journal*, vol. 37, 2022.

[18] A. Iqbal, O. A. Saraereh , A. Bouazizi 3 and A. Basir, " Metamaterial-Based Highly Isolated MIMO Antenna for Portable Wireless Applications, " *Electronics,* vol.7, 2018.

[19] Y. Alnaiemy, T. A. Elwi and L. Nagy, " Mutual Coupling Reduction in Patch Antenna Array Based on EBG Structure for MIMO Applications," *Period. Polytech. Elec. Eng. Comp. Sci*, vol. 63, pp. 332–342, 2019.

[20] A. Iqbal, A. Altaf, M. Abdullah, M. Alibakhshikenari ,E. Limiti and S. Kim," Modified U-Shaped Resonator as Decoupling Structure in MIMO Antenna," *Electronics*, vol. 9, 2020.