

Dual-band Microstrip Antenna for 5G mm Wave Systems

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Abstract

In recent years, the fast development of fifth generation (5G) wireless communication technology has led to an increasing need for small-sized, high gain and multi-band antennas that can operate efficiently in the millimeter wave spectrum. In this paper, we have designed a miniaturized dual band microstrip patch antenna integrated with a metamaterial structure for 5G millimeter wave communications. We have developed the metamaterial patch antenna through the systematic development of a conventional microstrip patch antenna to slot-loaded antenna, two patches and finally metamaterial patch antenna. The proposed metamaterial layer design consists of concentric split ring resonators along with a hexagon shape element, where the outer ring radius is 1.3mm and inner ring radius is 1.0mm with 0.1mm gap. We have maintained the optimized distance of 1.2mm between the radiating patch and the metamaterial layer. Simulations show that the proposed antenna performs very well at 28.00 GHz and 40.95 GHz, which are significant frequencies in 5G millimeter wave bands. The antenna provides return losses of -25.66 dB and -20.20 dB, impedance bandwidth of 1.53 GHz and 3.10 GHz and realized gain of 9.0 dBi and 11.3 dBi for the lower and upper operation bands, respectively. Comparison shows that the use of the metamaterial layer increases impedance matching performance, the lower-band bandwidth and gain especially at the higher frequency band. Therefore, it can be concluded that the antenna design is a suitable choice for the development of compact 5G millimeter wave communication systems.

Keywords: 5G Communications, Dual-band Antenna, Ka-band, Metamaterial, Microstrip Patch Antenna, Millimeter-wave Antenna.

Introduction

The fast rise of 5G wireless communication demands small, high-gain, wideband millimeter-wave antennas. 28 and 40 GHz are suited for high-speed data transport because to their wide bandwidths. The frequencies create high free space loss, lower coverage and stringent impedance and radiation efficiency limits. Microstrip patch antennas are popular for their small size, flat structure, simple fabrication and RF front end compatibility. Traditional microstrip patch antennas have low strength and bandwidth. This work creates a four-stage dual-band antenna. Base the foundation on an inset-fed rectangular patch. A 40 GHz resonance frequency is achieved by adding two slots to the patch to change the surface current distribution. After two-patch assembly, inter-element spacing is optimized for radiation performance. Finally, the two-patch antenna with an air gap receives the concentric

ring element and hexagonal element-based metamaterial. You may investigate each impact independently. The completed design will operate at 28.00 and 40.95 GHz. Return losses are -25.66 and -20.20 dB, impedance bandwidths are 1.53 and 3.10 GHz and gains are 9.0 and 11.3 dBi in the simulations. 28 GHz resonates directly in the 5G mmWave range, whereas 40.95 GHz resonates in the top section. This study focuses on electromagnetic modeling and design verification; future work will include production and measurements. Small microstrip antenna for 28 GHz 5G mm-wave communication is given in article. Small 28 GHz antennas may boost gain and bandwidth (1). The standard patch antenna without metamaterial-based gain enhancement is tested (2). A past study presented a broadband architecture without dual band or metamaterial gain augmentation (3). A study describes

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conventional antenna performance, although gain and mmWave electromagnetic performance may be increased (4). An empty substrate integrated waveguide-fed aperture-coupled antenna was developed for 5G. Research provides an alternative mmWave feeding mechanism, however the structure is too intricate for compact implementation (5). Resonator loading may increase gain, although dual-band mmWave operation is not considered (6). A 5G broadband microstrip array antenna exists. Array structures improve radiation, but bulk and complexity remain (7). The radiation performance of 28 GHz antennas in 5G mobile terminal housing was investigated. Although compactness, high gain and bandwidth are difficult, the study emphasizes implementation (8). While 5G multiband operation is desirable, metamaterials are needed to enhance gain and compress performance (9). High-gain 28 GHz slotted array antennas with beam-steering capability are being studied for 5G mmWave. Beam steering increases versatility but array complexity and mass limit tiny device use (10). A 28 GHz 5G dual slot microstrip patch antenna was made. Slot modification enhances antenna properties, although metamaterial loading for gain and bandwidth is not studied (11). Negative index metamaterials increase antennas; however, no compact dual band patch antennas have been shown (12). We constructed a 28 GHz wideband double negative metamaterial loaded microstrip patch antenna. Metamaterial loading benefits antennas, although high-gain dual band microstrip patch antenna research is limited (13). A tiny broadband circularly polarized patch antenna with a truncated parasitic structure was built. Compactness and polarization were prioritized, although no metamaterial-aided dual band mmWave antenna was described (14). Metasurface antennas increased gain and bandwidth at 28 GHz. (15). Metamaterial-loaded phased patch antenna arrays for 5G base stations were constructed and studied at 28 GHz. Metamaterials boost antenna performance but need more complex array topologies (16). Although metasurfaces and optimization are more complicated, smaller antennas may be constructed (17). Design and analysis of a tiny microstrip patch antenna for high efficiency 5G applications. Miniaturization and efficiency are priorities, but metamaterial gain enhancement and dual band are

nonfunctioning (18). A low-SAR 28 GHz tiny microstrip patch antenna for 5G was explored. The technology handles compactness and human impact, although gain and dual-band operation need development (19). A compact 28/39 GHz dual-band antenna with shared aperture was proposed for 5G-IoT (20). A 39 GHz high-performance microstrip patch antenna is being considered for 5G (21). For 5G, a 28 GHz microstrip antenna was updated. This work improves 28 GHz antenna design without metamaterials or dual band operation (22). Microstrip patch antennas were studied for 5G. This work improves patch antenna design but not metamaterial gain or dual band operation (23). Multi-frequency and multi-scenario mmWave MIMO channel measurements and modeling were investigated for beyond-5G communications (24). The findings emphasize antenna integration and body effects, with small high-gain metamaterial-loaded antennas requiring more study (25). Studies of mmWave and sub-THz propagation and coverage employed transparent reflectors (26). This area has numerous concepts, but few employ 28 GHz as the operating frequency and 40 GHz resonance with high gain and a well-defined design development procedure. This work bridges this gap via slot loading, dual-patch layout and a tiny metamaterial layer. Compare designs' resonance frequency, return loss, bandwidth and gain.

Contributions of this research may be stated as follows:

- a) Design of a compact dual band microstrip patch antenna at 28.00 GHz and 40.95 GHz frequency bands for 5G mmWave communication systems.
- b) Design of a metamaterial superstrate consisting of concentric split ring resonators and hexagonal resonator for improvement in gain and impedance matching performance.
- c) Development of a systematic design approach from a traditional patch antenna to metamaterial loaded dual band antenna.
- d) Attainment of improved gain, bandwidth and impedance matching characteristics without using large antenna arrays or complicated feed network designs.
- e) Provision of a compact antenna design technique that could be applicable in future 5G and beyond-5G communication systems.

Methodology

The designed antenna is a compact dual-band microstrip antenna. The design process starts from a conventional rectangular patch, then to slot loaded patch, two patches design and finally to metamaterial loaded antenna. The patch is fabricated on a dielectric substrate with a thickness of 0.508 mm. The antenna is excited using an inset fed microstrip line. The two patches

are achieved by designing two identical elements symmetrically with an optimized center to center distance denoted as D . The metamaterial layer is created on a substrate with a thickness of 0.254 mm. The distance between the metamaterial layer and the antenna is 1.2 mm of air gap. Table 1 shows all optimized dimensions.

Table 1: Dimensions of the Proposed Metamaterial-Loaded Antenna

Parameter	Dimension	Unit
Patch length (L)	4.25	mm
Patch width (W)	3.25	mm
Patch substrate length (Ls)	8	mm
Patch substrate width (Ws)	8	mm
Patch substrate thickness (h)	0.508	mm
Feed length (Lf)	2.8	mm
Feed width (wf)	0.5	mm
Inset length (Li)	0.425	mm
Inset width (Wi)	0.6	mm
Slot length (Sl)	1.5	mm
Slot width (Sw)	0.4	mm
Distance between two patches (D)	3.725	mm
Metamaterial substrate length (Lm)	16	mm
Metamaterial substrate width (Wm)	8	mm
Metamaterial substrate thickness (hm)	0.254	mm
Air gap (Ag)	1.2	mm
Outer ring radius (r)	1.3	mm
Outer ring gap (rg)	0.1	mm
Inner ring radius (ri)	1.0	mm
Inner ring gap (rig)	0.1	mm
Hexagonal element radius (Hr)	0.5	mm

Results and Discussion

Conventional Microstrip Patch Antenna

The proposed antenna was modeled and simulated using ANSYS HFSS. The electromagnetic analysis was performed using the Finite Element Method (FEM)-based Frequency Domain Solver. The reference antenna is made up of a rectangular

patch of $3.25 \times 4.25 \text{ mm}^2$ mounted on a substrate that has size $8 \times 8 \times 0.508 \text{ mm}^3$. The antenna uses a $2.8 \times 0.5 \text{ mm}^2$ microstrip feed and a $0.425 \times 0.6 \text{ mm}^2$ inset. As seen in Figure 1 below, the conventional antenna runs at a frequency of 26.67 GHz, with a return loss of -15.24 dB and an impedance bandwidth of 1.10 GHz.

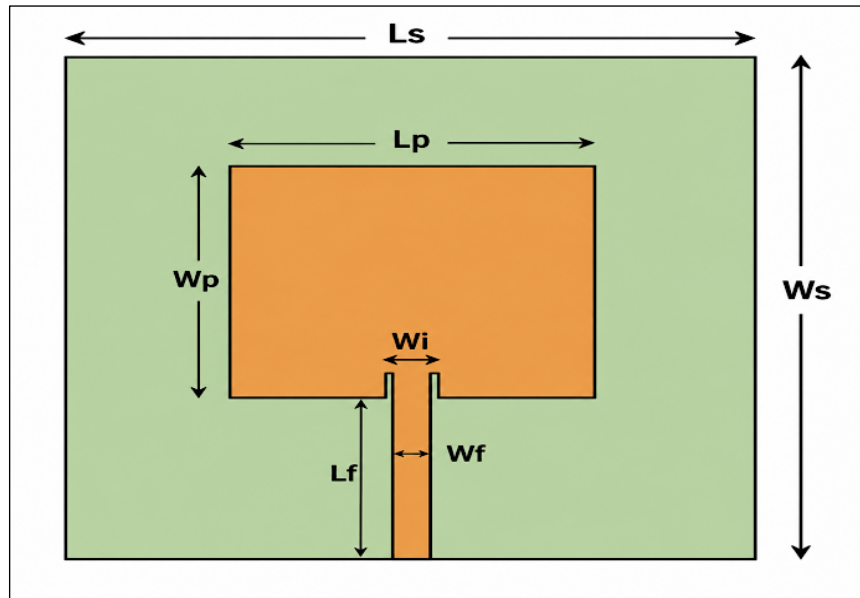


Figure 1: Conventional Microstrip Patch Antenna

Note: L_s = Substrate Length, W_s = Substrate Width, L_p = Patch Length, W_p = Patch Width, L_f = Feed Line Length, W_f = Feed Line Width, W_i = Inset Gap Width.

Figure 2 shows the simulation response of the conventional microstrip patch antenna in terms of S_{11} . A peak resonant behavior is exhibited at around 27 GHz, with a return loss of approximately

-15 dB, signifying good impedance match at the desired frequency. Additionally, there is a resonant behavior near 42 GHz with low return loss.

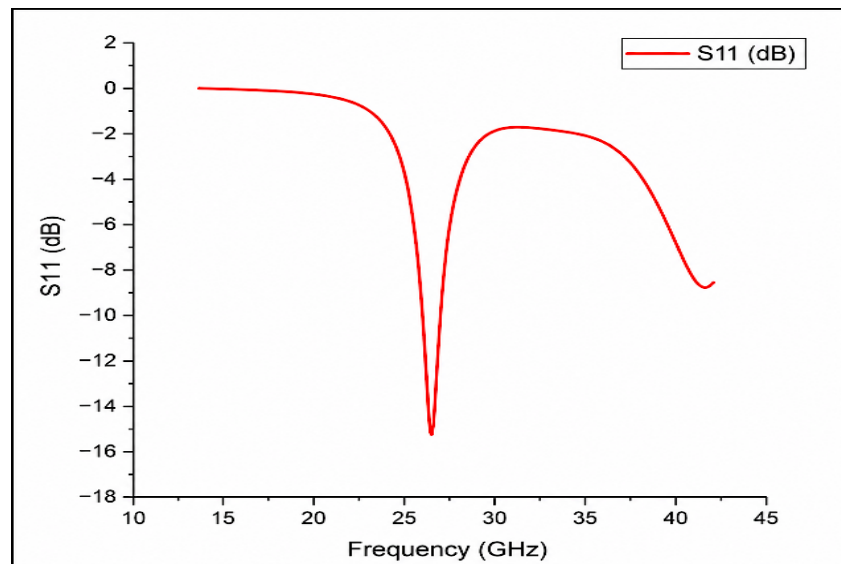


Figure 2: Simulated S_{11} Response

Note: S_{11} = Input Reflection Coefficient (Return Loss).

Slot-Loaded Configuration

Two slots of $1.5 \times 0.4 \text{ mm}^2$ each are made on the patch to improve the path of the surface current. The slot-loaded antenna resonates at 26.67 GHz and 39.90 GHz, where its return loss is -14.42 and

-19.21 dB, respectively. Its bandwidth is 1.06 and 3.03 GHz and gain is 8.0 and 6.9 dBi, respectively. The extra resonance at 40 GHz proves the feasibility of using slot-loading in a dual band antenna, as shown in Figure 3.

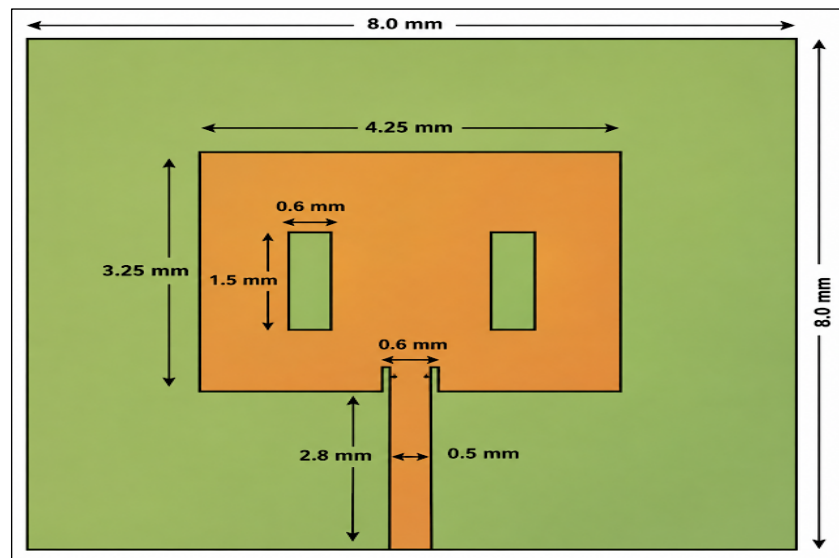


Figure 3: Slot-loaded Antenna

The graph for the simulation of S11 parameter for the slot loaded microstrip antenna is shown in Figure 4. The presence of slots provides another form of resonance and, thus, two resonant frequencies at 27 GHz and 40 GHz have been

obtained. The lower frequency resonance shows a return loss value of -15 dB, while the higher frequency resonance has a return loss value of -19 dB.

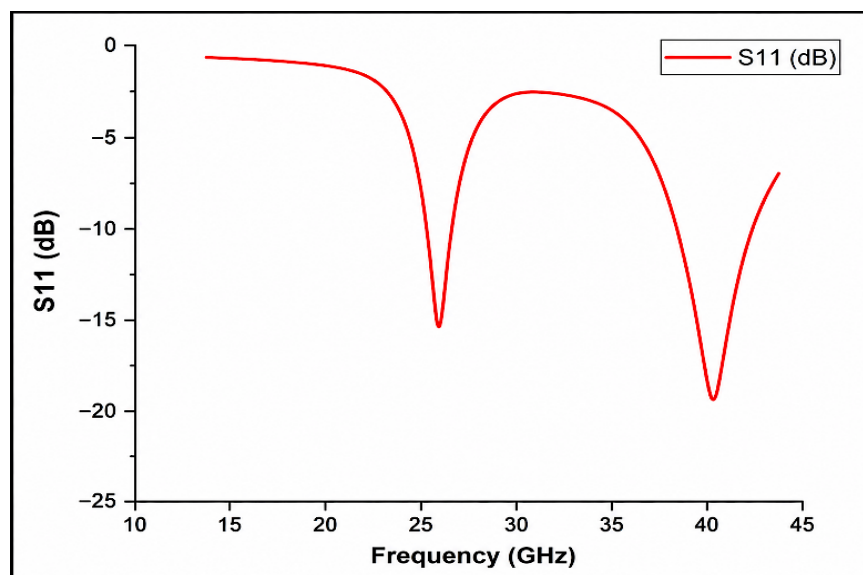


Figure 4: Slot-loaded Antenna Simulated S11 Response

Note: S11 =Input Reflection Coefficient (Return Loss).

Two-patch Configuration

A second identical patch is used for enhancing the radiation performance. Distance D is optimally determined at 3.725 mm. The two patches operate at frequencies of 26.46 and 40.04 GHz with return loss values of -15.20 and -20.21 dB, bandwidth of 1.05 and 3.10 GHz and gains of 8.1 and 9.55 dBi, respectively. Figure 5 shows the two-patch antenna design that results from the modification of the slot loaded antenna. The inclusion of the

second patch leads to electromagnetic coupling between the adjacent radiators; this coupling leads to better current and radiation performance. Proper inter-patch spacing has been used for good coupling. The simulated S11 characteristic of the two-patches antenna design is illustrated in Figure 6. The antenna shows dual-band performance where resonances are realized at the expected 28 GHz and 40 GHz frequencies. Better impedance

matching is achieved for the two-patches antenna structure than the slot-loaded one because of

better electromagnetic coupling between the patches.

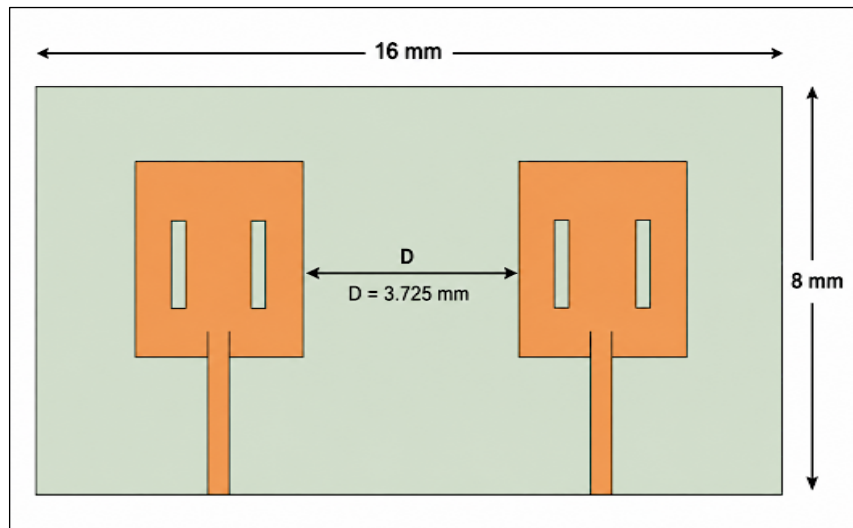


Figure 5: Two-patch Configuration

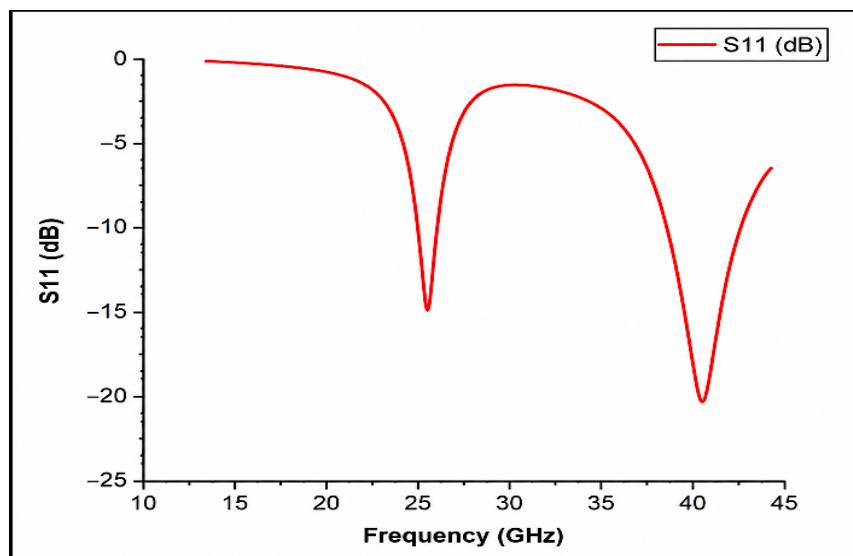


Figure 6: Two-patch Configuration Simulated S11 Response

Note: S11 =Input Reflection Coefficient (Return Loss).

Figure 7 below represents the symmetry analysis of the two-patch antenna using the S11 and S22 values. The similarity of the above two graphs clearly shows the symmetry of the geometry and electrical properties of the antenna design. The Figure 8 below represents the S11 and S21 characteristics of the two-patch antenna. This

gives us an idea about the impedance matching and mutual coupling efficiency of the antenna. The S21 graph above clearly shows the isolation level of the antenna elements. Low mutual coupling is always desired to maintain constant radiation characteristics.

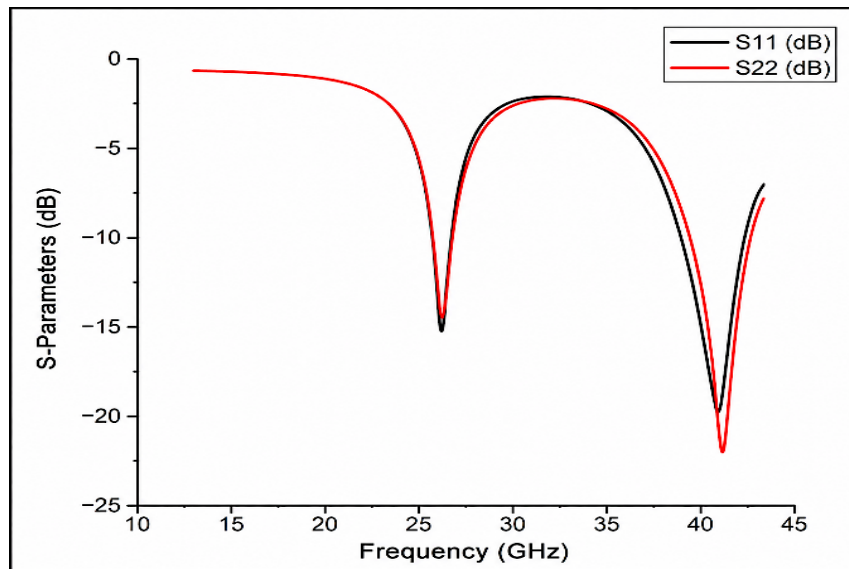


Figure 7: S11/S22 Symmetry Verification

Note: S11 = Input Reflection Coefficient (Return Loss), S22 = Reflection Coefficient.

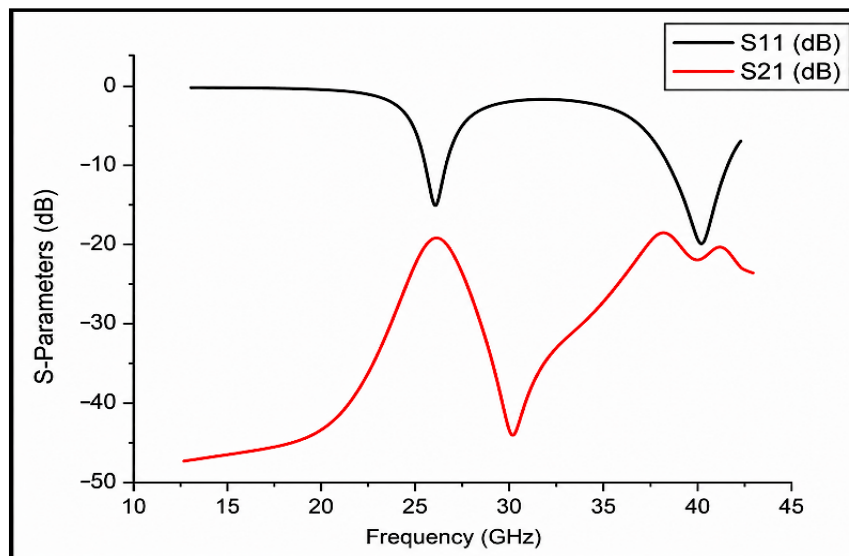


Figure 8: S11/S21 Isolation Response of The Two-Patch Antenna

Note: S11 = Input Reflection Coefficient (Return Loss), S21 = Transmission Coefficient.

Metamaterial-loaded Configuration

The final design will be achieved by placing the metamaterial layer on top of the two-patch antenna. The dimensions of the metamaterial substrate are $16 \times 8 \times 0.254 \text{ mm}^3$, whereas the dimensions of the patch layer are calculated using the data in Table 1. Figure 9 shows the finalized configuration of the metamaterial-loaded antenna design with an optimized air-gap distance between the radiating patch and the metamaterial. This is

due to the position of the metamaterial relative to the antenna, which enhances the interaction for improved radiation characteristics. The optimized air-gap distance of 1.2 mm enhances the interaction between the radiating patch and the resonant metamaterials. Figure 10 shows the simulation of the reflection coefficient (S11) of the designed metamaterial-loaded antenna. There are two well-separated resonances at 28.00 GHz and 40.95 GHz with corresponding return losses of -25.66 dB and -20.20 dB, respectively.

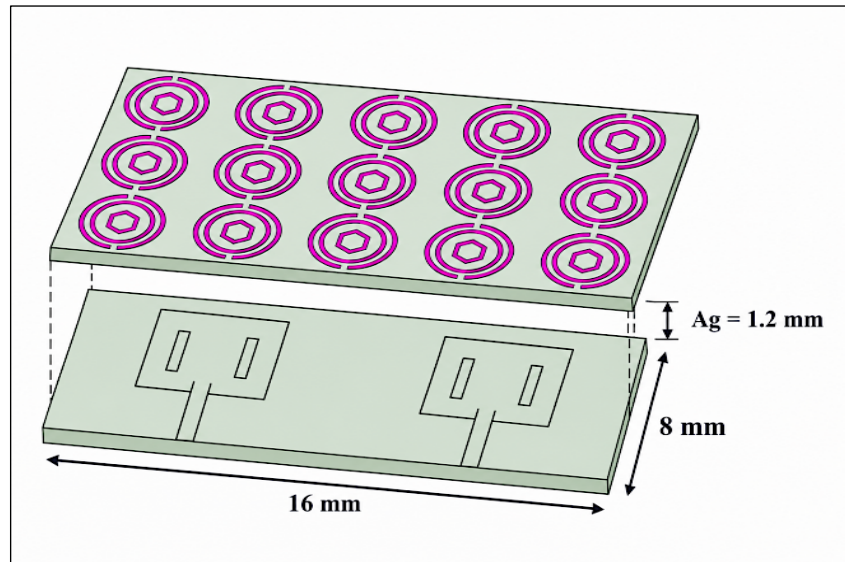


Figure 9: Metamaterial-loaded Antenna with The Optimized Air Gap

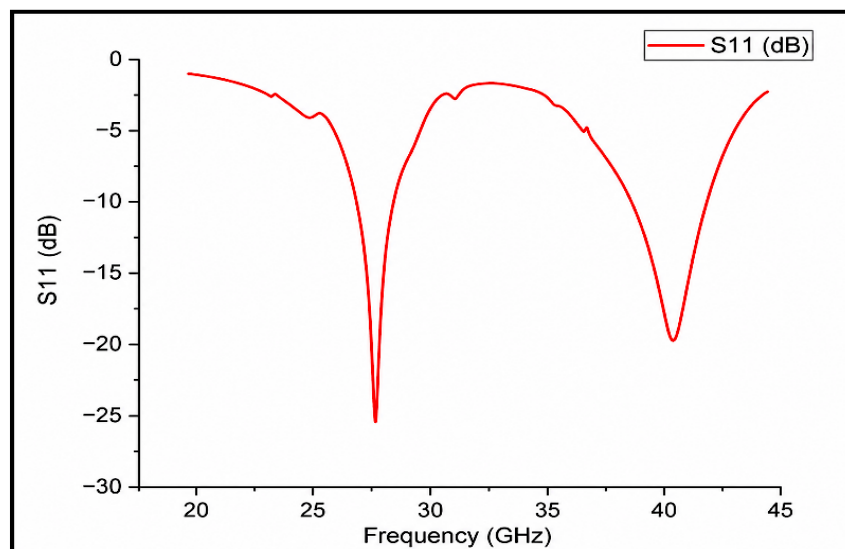


Figure 10: Metamaterial-loaded Antenna of Simulated S11 Response

Note: S11 =Input Reflection Coefficient (Return Loss).

The E-plane and H-plane radiation patterns of the antenna designed at 28 GHz are depicted in Figure 11A. The antenna features the stable radiation pattern in the form of a beam directed along the broadside direction. This behavior is expected from the high gain 5G communication system. Figure 11B demonstrates the radiation patterns of the antenna designed at 40.95 GHz. As seen, the directional radiation characteristic of the antenna is preserved, but the antenna has extra side lobes because of its large electrical size and coupling

between different elements. At 28 GHz, both planes exhibit a clear directional radiation characteristic, with the main radiation concentrated around the broadside direction and relatively lower radiation toward the opposite directions. At 40.95 GHz, the antenna also maintains directional radiation in both principal planes, although additional lobes are observed because of the higher operating frequency and electromagnetic coupling within the structure.

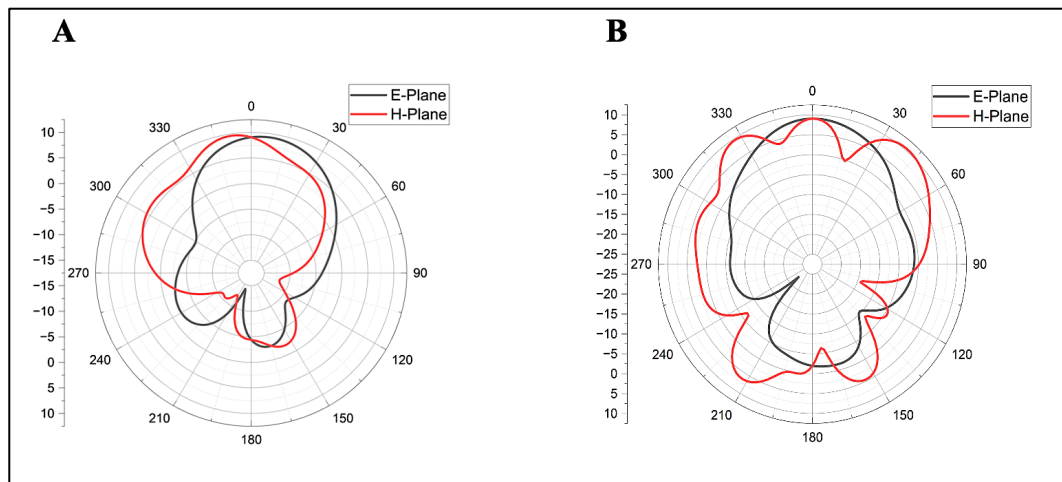


Figure 11: Simulated E-plane and H-plane Radiation Patterns. (A) 28 GHz, (B) 40.95 GHz

Figure 12A demonstrates the 3-D gain characteristics of the antenna operating at 28 GHz. Maximum realized gain is about 9.0 dBi for a directed beam of radiating energy. This means that all the radiating energy is directed to the desired direction with effective power usage. Figure 12B displays the gain characteristic of the antenna working at 40.95 GHz. A higher gain value of about

11.3 dBi is obtained because of the improved electromagnetic coupling due to the use of the metamaterial layer. Overall, the radiation patterns confirm that the proposed antenna provides stable directional radiation at both operating frequencies, supporting its suitability for 5G mmWave applications.

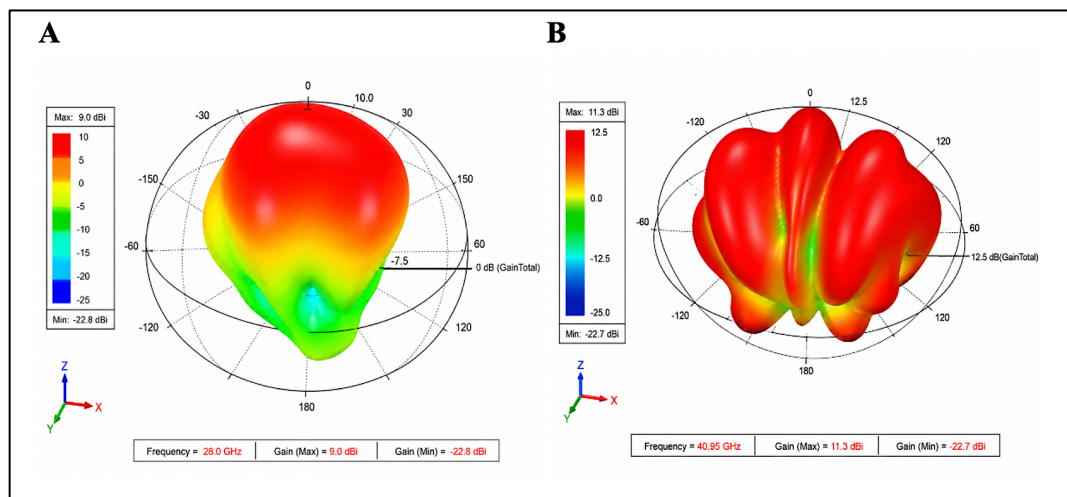


Figure 12: Simulated 3-D Gain Patterns. (A) 28 GHz, (B) 40.95 GHz

Metamaterial Unit Cell Configuration

Unit cell of metamaterial is made up of two concentric split ring structures along with the hexagonal structure present at the center. The external split ring has a radius of 1.3 mm and a 0.1 mm split; the internal ring has a radius of 1.0 mm with a 0.1 mm split; the hexagonal structure has a radius of 0.5 mm as seen in Figure 13. This specific geometrical structure offers resonance in inductive capacitive loadings within the required frequency range. Unit cell substrate size is $8 \times 16 \times$

0.254 mm^3 and the patch substrate is $8 \times 16 \times 0.508 \text{ mm}^3$. In the case of the ring elements, the gaps create the capacitor effect while the currents flow through the metallic rings create the inductor effect. This leads to an inductance and capacitance effect which forms the resonance electromagnetic effect. The interaction of the near fields of the radiator and the resonant elements in the metamaterial, when it is placed near the patch, results in alteration in the properties of current flow and coupling.

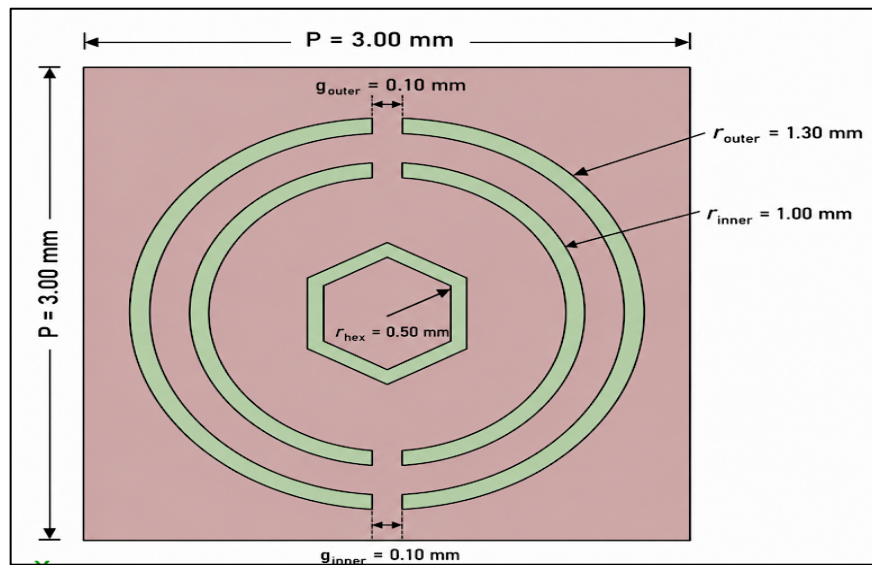


Figure 13: Metamaterial Unit Cell

Unit-cell Characterization

Figure 14 shows the effective electromagnetic response of the metamaterial unit cell in a simulation. The response shows that there is resonance at the desired frequency range, implying good interaction with electromagnetic waves in the structure. These properties validate the use of the unit cell in applications involving metamaterial antennas. The distinct resonances clearly show that the electromagnetic resonance

created by the split ring resonators is very strong. Once the unit cell is defined, the metamaterial layer is incorporated into the two-patch antenna. An air-gap separation of 1.2 mm is chosen for its use in the final antenna as the electromagnetic coupling and gain of the antenna highly depend on the gap between these two layers. Further refinement of the optimized result could have been done through an air-gap sweep, but the current design employs the 1.2-mm optimized design.

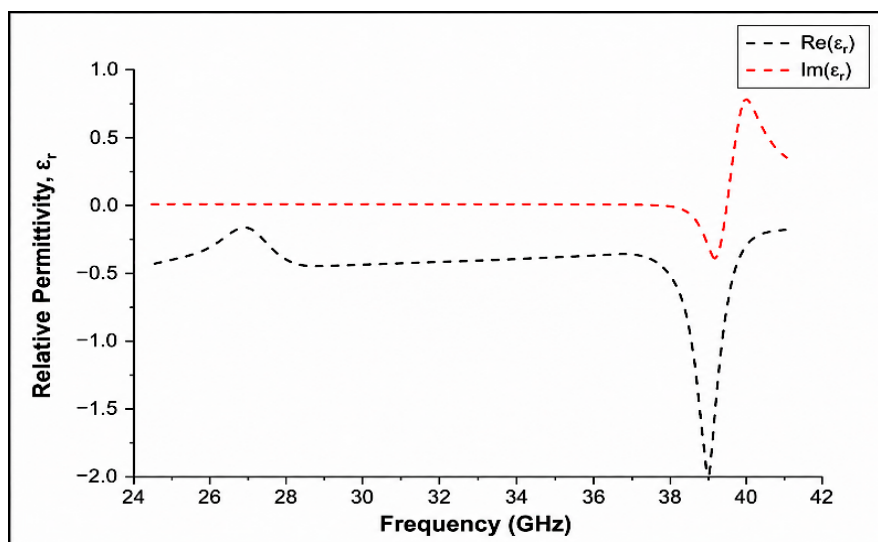


Figure 14: Metamaterial Unit Cell Simulated Effective-Parameter Response

Note: ϵ_r = Relative Permittivity (Dimensionless Quantity), $\text{Re}(\epsilon_r)$ and $\text{Im}(\epsilon_r)$ = the Real and Imaginary Parts of the Effective Relative Permittivity.

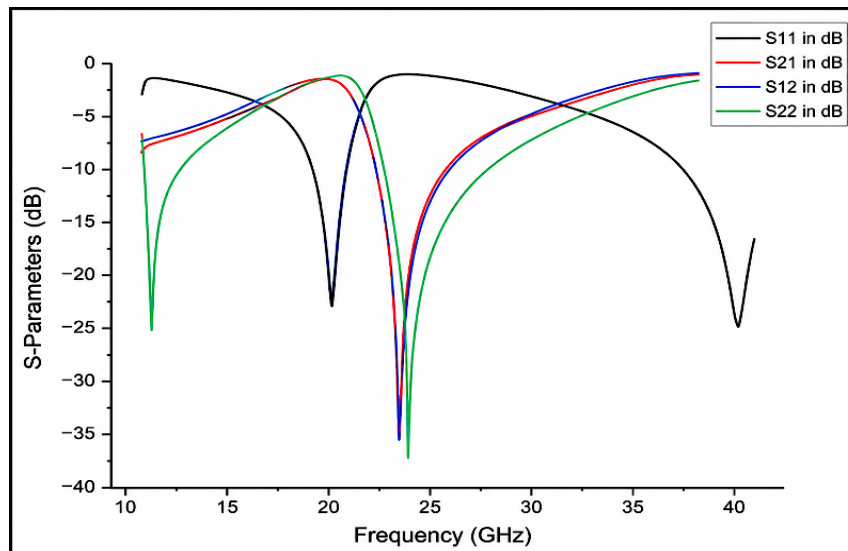


Figure 15: Metamaterial Unit Cell Simulated S-parameters

Note: S11 = Input Reflection Coefficient (Return Loss), S12 = Reverse Transmission Coefficient, S21 = Forward Transmission Coefficient, S22 = Reflection Coefficient.

The characteristics of the simulated S-parameters of the unit cell of the proposed metamaterial have been shown in Figure 15 within the desired operating frequency band. The reflection parameters (S11 and S22) display the resonant dips around the desired mmWave frequencies, thus proving the effective impedance matching of the unit cell. The transmission parameters (S21 and S12) represent the propagation characteristics within the structure and display identical values due to the reciprocity property of the metamaterial design. Performance of the proposed antenna is compared with respect to its four design steps according to resonance, return loss, impedance

bandwidth and gain. The results obtained reveal that there is a clear transition from single-band to dual-band to better matching and gain after incorporating metamaterials.

Performance Evolution

The traditional patch only responds to 26.67 GHz frequencies. The slot-loading technique provides the second resonance frequency at 40 GHz. Two-patch configuration enhances the performance of the upper band gain. Using the metamaterial technology, the lower band resonance is altered to 28.00 GHz and it provides improved lower band matching and gain as given in Table 2.

Table 2: Performance Evolution of The Four Antenna Configurations

Configuration	Resonant Frequency (GHz)	Return Loss (dB)	Bandwidth (GHz)	Gain (dBi)
Conventional patch	26.67	-15.24	1.10	8.0
Slot-loaded patch	26.67 / 39.90	-14.42 / -19.21	1.06 / 3.03	8.0 / 6.9
Two-patch configuration	26.46 / 40.04	-15.20 / -20.21	1.05 / 3.10	8.1 / 9.55
Metamaterial-loaded antenna	28.00 / 40.95	-25.66 / -20.20	1.53 / 3.10	9.0 / 11.3

Performance evolution of the proposed antenna for the four stages of design is provided in Table 2. The conventional patch operates at 26.67 GHz, has a return loss of -15.24 dB and a bandwidth of 1.10 GHz with gain of 8 dBi. Adding slots enables the antenna to operate in the dual-band regime, achieving resonance frequencies of 26.67 and 39.90 GHz with enhanced gain of 8.0 and 6.9 dBi, respectively. In the case of using the two-patch scheme, the operating frequencies are moved to 26.46 and 40.04 GHz, while good return losses and

bandwidth are achieved with the values of -15.20 and -20.21 dB, as well as 1.05 and 3.10 GHz, respectively. Eventually, the proposed antenna with metamaterial loading operates in the dual-band regime with improved resonance frequencies, return losses, bandwidth and gain of 28.00 and 40.95 GHz, -25.66 and -20.20 dB, 1.53 and 3.10 GHz, 9.0 and 11.3 dBi, respectively.

Return Loss, Symmetry and Isolation

In the end, two clear resonances can be seen in the final S11 plot at 28.00 GHz and 40.95 GHz. Return

losses of -25.66 dB and -20.20 dB confirm a good impedance matching at both operational frequencies. The S_{11} and S_{22} plots for the symmetric two-patch design are quite similar to each other, which implies symmetry between the two antenna elements as depicted in Figure 4. At the same time, the S_{21} plot is much lower than the input plots over the operational frequency range, which suggests an effective inter-element isolation.

Radiation and Gain Performance

The simulated 3D gain pattern at 28 GHz yields a maximum gain of 9.0 dBi, while the maximum gain for the simulation at 40.95 GHz is 11.3 dBi as seen

from Figure 7. The radiation patterns of Fig. 6 demonstrate the directional nature of the antenna in the principal planes. This high gain in the upper band is especially helpful in mmWave band where there are high path loss and directional radiation is preferred. When compared to the two-patch antenna design, the new design offers an improvement in the lower-band return loss from -15.20 to -25.66 dB and increase in lower-band bandwidth from 1.05 to 1.53 GHz. In the upper band, there is an increase in gain from 9.55 to 11.3 dBi. It can be inferred that the metamaterial layer is helpful in impedance matching and radiation.

Table 3: Comparison of the Proposed Antenna with Selected Reported 5G Millimeter-Wave antennas

Operating frequency (GHz)	Bands	Bandwidth (GHz)	Gain (dBi)	Metamaterial / metasurface	Application	References
28 / 39	2	NR	4.74	No	5G / WBAN	(1)
28 / 39	2	17 / 12.71%	9.4 / 11.25	No	5G / IoT	(2)
~28	1	NR	Gain enhanced	Yes	5G mmWave	(3)
28	1	NR	Gain enhanced	Yes	5G NR	(4)
28 / 39	2	26.5–29.5 / 37–40	26.28 / 27.4 dBic	Yes	5G mmWave	(5)
28.00 / 40.95	2	1.53 / 3.10	9.0 / 11.3	Yes	5G mmWave	Proposed

Note: NR = Not Reported, WBAN = Wireless Body Area Network.

From Table 3, it can be noted that the design of the suggested antenna includes dual band working along with high gain and metamaterial layer. In comparison to the single band design, the suggested design works at 28.00 and 40.95 GHz frequencies. The gain of 11.3-dBi in the upper band of the proposed design is greater than those of many compact dual band patch designs shown in the table. Due to differences in the substrates used, geometries and other aspects, the comparison is indicative in nature.

The results agree with the latest research conducted on dual-band 5G mm-wave antennas working at the 28 GHz and 39 GHz frequency bands (20, 21). The proposed antenna provides better impedance match and higher gain in comparison with conventional microstrip patch antennas (18, 19, 22, 23), owing to the use of a metamaterial layer. The latest investigations have proven that the properties of antennas can be improved due to a change in the effective electromagnetic parameters of the radiating structure using a metamaterial layer (12, 15, 16, 26). The gains of 9.0 dBi and 11.3 dBi for frequencies of 28.00 GHz and 40.95 GHz are obtained in the presented design,

which is competitive or higher compared to some of the latest designed dual-band antennas for 5G communication (20, 21, 26). While some types of array antenna and SIW antenna exhibit improved bandwidths and gains (5, 20), most of these designs tend to have a larger size and complicated feeding structure. However, the designed antenna presents an optimum balance between its compactness, dual band, increased gain and simplicity. Hence, the proposed metamaterial assisted antenna provides a practical solution for the coming 5G millimeter-wave communication.

Conclusion

Design and analysis of a novel and compact dual band metamaterial loaded microstrip patch antenna for mmWave 5G communication systems have been accomplished via electromagnetic full wave simulation. The design of the proposed antenna evolved via a systematic evolutionary design process comprising conventional inset fed microstrip patch antenna, a slot loaded design, a dual patch design and ultimately the design of a metamaterial loaded antenna.

The last antenna has two operational frequencies of 28.00 GHz and 40.95 GHz, which are significant frequency bands for the existing and upcoming 5G mmWave communications. In this case, the antenna realizes return loss values of -25.66 dB and -20.20 dB, bandwidths of 1.53 GHz and 3.10 GHz and realized gain values of 9.0 dBi and 11.3 dBi at the low and high frequencies, respectively. Indeed, the slot-loading technique was useful in achieving the second resonant frequency, whereas the double patch helped to improve radiation performance. Additionally, the utilization of the metamaterial layer was very useful in enhancing impedance and gain performance, especially at the high operational frequency.

From the achieved results, it can be stated that the presented antenna design represents an appropriate combination of small size, dual-band operation and high gain characteristics, thus being a good choice for 5G millimeter-wave wireless equipment, small-size communication modules and future high-data rate wireless communication systems. At the same time, the present research shows the possibilities to improve the performance characteristics of microstrip antennas using metamaterials in the mmWave range.

However, there are some limitations to the present research. First, the presented antenna performance has been estimated only using computer modeling without fabrication and testing of a physical model. Second, more complex analysis of radiation and total efficiencies, as well as the parametric optimization of the geometry of the metamaterial structure and its air gap, were out of the scope of this work. Third, the electromagnetic properties of the metamaterial unit cell, such as relative permittivity (ϵ_r), relative permeability (μ_r) and refractive index, have not been determined quantitatively.

Future research will be carried out for fabricating the antennas and experiments will be conducted in order to perform an efficient analysis of the proposed design, carrying out a parametric study of the structure of the metamaterial along with that of the air gap and deriving the effective material parameters of the unit cell from the S-parameters.

Abbreviations

mm wave: Millimeter-Wave, MIMO: Multi Input Multi Output, MM: Metamaterial, UC: Unit Cell, RF: Resonant Frequency, RL: Return Loss.

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Author contributions

All authors contribute equally to the research, design the study, analyzed data and approved the final manuscript.

Conflict of Interest

The authors declare that they have no conflict of interest.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Declaration of Artificial Intelligence (AI) Assistance

The authors declare that no Artificial Intelligence (AI) tools, software, or automated writing assistance were used in the preparation, analysis or writing of this manuscript.

Ethics Approval

This study does not involve human participants, animals, or any biological materials. Therefore, ethical approval was not required for conducting this research work.

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References

- Güneşer MT, Şeker C. Compact microstrip antenna design for 5G communication in millimeter wave at 28 GHz. *Erzincan University Journal of Science and Technology*. 2019;12(2):679-86. doi:10.18185/erzifbed.477293
- Darsono M, Wijaya AR. Design and simulation of a rectangular patch microstrip antenna for the frequency of 28 GHz in 5G technology. *Journal of Physics Conference Series* 2020;1469(1):012107. doi:10.1088/1742-6596/1469/1/012107
- Fante KA, Gameda MT. Broadband microstrip patch antenna at 28 GHz for 5G wireless applications. *International Journal of Electrical and Computer Engineering*. 2020;11(3):2238-44. doi:10.11591/ijece.v11i3.pp2238-2244
- Rana MS, Smieeee MM. Design and analysis of microstrip patch antenna for 5G wireless communication systems. *Bulletin of Electrical Engineering and Informatics*. 2022;11(6):3329-37. doi:10.11591/eei.v11i6.3955
- Ullah Khan Z, Fizzah Jilani S, Belenguer A, Loh TH, Alomainy A. Empty substrate integrated waveguide-fed MMW aperture-coupled patch antenna for 5G applications. *12th European Conference on Antennas and Propagation (EuCAP 2018)*. 2018;850. doi:10.1049/cp.2018.1209
- Vempalle R, Dhal PK, Vali SH, Krishna SR, Suryavalli U, Prakash SV. Enhanced multi-mode control of Z-source virtual synchronous generator for photovoltaic systems using fuzzy logic controller. *International Journal of Applied Power Engineering (IJAPE)*. 2025;14(3):701-11. doi:10.11591/ijape.v14i3.pp701-711
- Andrews JG, Buzzi S, Choi W, *et al.* What will 5G be?. *IEEE Journal on selected areas in communications*. 2014;32(6):1065-82. doi:10.1109/JSAC.2014.2328098
- Xu B, Ying Z, Scialacqua L, *et al.* Radiation performance analysis of 28 GHz antennas integrated in 5G mobile terminal housing. *IEEE Access*. 2018;6:48088-101. doi:10.1109/ACCESS.2018.2867719
- Ikram M, Nguyen-Trong N, Abbosh AM. Common-aperture sub-6 GHz and millimeter-wave 5G antenna system. *IEEE Access*. 2020;8:199415-23. doi:10.1109/ACCESS.2020.3034887
- Khalaf TA, Yetkin GÖ. 28 GHz High gain Slotted Array Antenna with Beam Steering Capability for 5G mm Wave Applications. *Defence Science Journal*. 2025;75(2):215-23. doi:10.14429/dsj.20405
- Fadhila EN, Setyowati E, Putri DIH. Design and Analysis of Microstrip Antenna Using Double Slot Patch At 28 GHz Frequency for 5G Technology. *Inform: Jurnal Ilmiah BidangTeknologi Informasi dan Komunikasi*. 2025;10(1):89-96. doi:10.25139/inform.v10i1.9285
- Aziz RS, Koziel S, Pietrenko-Dabrowska A. Millimeter wave negative refractive index metamaterial antenna array. *Scientific Reports*. 2024;14(1):16037. doi:10.1038/s41598-024-67234-z
- Smith DR, Padilla WJ, Vier DC, Nemat-Nasser SC, Schultz S. Composite medium with simultaneously negative permeability and permittivity. *Physical review letters*. 2000;84(18):4184. doi:10.1103/PhysRevLett.84.4184
- Vempalle R, Dhal PK. Loss minimization by reconfiguration along with distributed generator placement at radial distribution system with hybrid optimization techniques. *Technology and Economics of Smart Grids and Sustainable Energy*. 2020;5(18). doi:10.1007/s40866-020-00088-2
- Bilal A, Dat PT, Antoniadis MA, *et al.* Metasurface antenna for gain and bandwidth enhancement in 28 GHz radio-over-fiber system. *Institute of Electrical and Electronics Engineers Inc*. 2024;1-4. doi:10.1109/MWP62612.2024.10736219
- Raju K, Kavitha A. Linear phased metamaterial incorporated patch antenna array at 28 GHz for 5G base stations. *Proceedings of the Bulgarian Academy of Sciences*. 2024;77(2):246-55. doi:10.7546/CRABS.2024.02.10
- Babu KV, Sree GN, Das S, Ali W, Altameem T, El-Shafai W. Machine learning-based printed lens antenna with graded-index metasurface for mmWave 5G NR N261 mobile communication applications. *International Journal of Communication Systems*. 2025;38(12):e70176. doi:10.1002/dac.70176
- Janarthanan S, Bennet MA. Advanced Miniaturized microstrip patch antenna design for High-Efficiency 5G applications. *Measurement Science Review*. 2024;24(6):239-43. doi:10.2478/msr-2024-0032
- Al-Tayyar HA, Mohammed Ali YE. Compact 28GHz Microstrip Patch Antenna Design with Reduced SAR for 5G Applications. *Mathematical Modelling of Engineering Problems*. 2023;10(5):1866-72. doi:10.18280/mmep.100540
- Zidour A, Ayad M, Alibakhshikenari M, See CH, Abbasi NA, Limiti E, Saber T. A compact shared-aperture dual-band 28/39 GHz endfire antenna phased array for 5G-enabled IoT systems. *AEU-International Journal of Electronics and Communications*. 2026;211:156320. doi:10.1016/j.aeue.2026.156320
- Ali WA, Ghareeb YH, Shokair M, Zayed MM. High-Performance 39 ghzMmWave microstrip patch antenna for Next-Gen 5G networks. *Menoufia Journal of Electronic Engineering Research*. 2025;34(2):78-92. doi:10.21608/mjeer.2025.363196.1117
- Zakariyya SO, Sadiq BO, Alao RA, Adesina JA, Obi E. Design of an improved microstrip antenna operating at a frequency band of 28GHz. *FETiCON 2024*. 2024. doi:10.48550/arXiv.2412.20400
- Djouimaa A, Bencherif K. Design of a compact circular microstrip patch antenna for 5G applications. *Engineering, Technology and Applied Science Research*. 2024;14(4):16020-4. doi:10.48084/etasr.7961
- Huang J, Wang CX, Chang H, Sun J, Gao X. Multi-frequency multi-scenario millimeter wave MIMO channel measurements and modeling for B5G wireless communication systems. *IEEE Journal on Selected Areas in Communications*. 2020;38(9):2010-25. doi:10.48550/arXiv.2007.13973

25. Vähä-Savo L, Cziezerski C, Heino M, Haneda K, Icheln C, Hazmi A, Tian R. Empirical evaluation of a 28 GHz antenna array on a 5G mobile phone using a body phantom. *IEEE Transactions on Antennas and Propagation*. 2021;69(11):7476-85. doi:10.1109/TAP.2021.3076535
26. Talari S, Sekhar PC. A high gain dual band hexagonal metamaterial inspired antenna for 5G applications. *Engineering, Technology and Applied Science Research*. 2024;14(6):18029-35. doi:10.48084/etasr.8575

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