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REGULAR ARTICLE

The Metasurface Based Antennas for 5G and Millimeter Wave Communication Systems

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An antenna is a radiating part of a wireless communication system especially intended for the arrival of future 5G and beyond technology. Based on next generation technological advancements, 5G was developed and investigated in the direction of 2020. In order to give better services and a better user experience, researchers, scientists, and engineers are searching for high-developed broad bandwidth coupled with increased performance following the development of 5G. The advancement of 5G wireless technology offers incredibly quick internet, great bandwidth, low latency, high dependability, and enhanced gain. This work introduces a lot of potential for obtaining more gain and bandwidth compared to without metasurface antennas. The metasurface characteristics are making it easier to radiate electromagnetic energy across longer distances. The authors of this review study described the development of 5G antennas and how metasurface techniques are used in the designing of antennas for 5G applications. Antenna design technologies and its methodologies are changing as per the 5G millimeter designs in connection with signal attenuation and deformation. The substrate which is suitable is suitable for the design of an antenna is FR4 and Rogers, its specific performance and signal alignment making it suitable for wireless 5G millimeter and tera hertz communications. The simulation results have been shown as per obtaining of high bandwidth, high gain, along with better antenna efficiency with a good, impedance matching, and radiation patterns using Ansys HFSS.

Keywords: WBAN, WLAN, WiMAX, Bakhram substrate, IEEE 802.15.6, SAR, Body-centric application.

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1. INTRODUCTION

Over the past decades, wireless and mobile communications have been developed with prominent technologies delivers more intriguing and creative services to the user [1]. Since the development of wireless mobile communication in 1980, a new generation has been established nearly every ten years. [2]. The initial generation used FDMA transmission techniques and analog modulation, whereas the subsequent generations of wireless networks included 2G, 3G, and 4th generation LTE [3]. The primary significant element over generation technologies is high data rate led by massive development of wireless devices. The existing technology gives services like video streaming, cloud services, IOT and device to device communications based on mobile broadband communication requirements [4]. Additionally, 5G networks controlling radio communication techniques services including GPS, AM/FM radio, cellular, Wi-Fi, and satellite communications to meet user needs [5]. However, in order to enable the effective operation of 5G communication infrastructure and its applications, the millimeter wave spectrum receives greater attention. The commercial of 5G is ongoing in the world major countries, the rapid improvements of high data rate and ultra high-speed communications requirements has led to introduce and development of sixth generation wireless technology [6]. The world's population is anticipated to be served by 6G wireless communication, which is anticipated to debut around 2030. This innovative technology emphasizes internet devices to improve wireless mobile broadband [7]. Communication systems are working toward the millimeter and terahertz high frequency bands to play the crucial function of 6G in order to meet the demands of 5G and beyond. The major uses for the Tera hertz band are the internet of nano thing, defense, military and the ultra-high speed on-chip communications [8]. The modern antennas are designed for 5G applications to attain more bandwidth and gain to accommodate higher data rates as the required parameter for 5G antenna design [9]. As per the technology upgradation from 5G to 6G, advanced data handling systems like Metasurface (MTS) based antennas are required. These kinds of antennas are designed based on left-handed materials to obtain better performance, with less transmission loss. But the atmospheric loss and pathloss create poor service performance, these can be reduced by the terahertz antenna designs with graphene substrates. Another parameter that causes demand for communication system design is spectrum efficiency. In order to enhance the spectrum efficiency an antenna with a suitable beam forming or beam steering with a switchable concept is used for 5G millimeter wave kinds of applications [10].

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In this review article the metasurface-based antenna design and its significant behavior were highlighted based on 5G and beyond communication techniques like millimeter waves. The important aspects of 5G design were outlined in section 1, whereas in section 2, the metasurface antenna design and its importance were described with a suitable proposed antenna geometric design principle. The 5G millimeter proposed design methodologies and its significant performance were enlightened in section 3. As per metasurface antenna design, its simulation measurements are detailed in section 4 as results and discussion. Finally, the conclusion for this paper was discussed in section 5 with the desired performance metrics.

2. METASURFACE BASED COMMUNICATION TECHNIQUES

The most important transmission techniques are 5G, millimeter and tera hertz to attain the present technology and its requirements these approaches play a vital part. Due to the quick communication system development, the expansion of data rate became the primary necessity of 5G. architecture. As per the current technology insets the antenna design with millimeter wave reaching the specifications of 5G. A single patch antenna has poor gain and restricted bandwidth, so the patch antennas are merged with MTS to improve the band width and coverage. The circular or rectangular patch antennas with a multistructured MTS are the pertinent designs to improve the performance of 5G antenna. The communication systems' bandwidth, data rate, and capacity are all increased through the employment of multiband antenna technology. However, the substantial air absorption and path loss of the terahertz antenna need the design of an antenna to mitigate these issues. The terahertz antennas are employed for 6G wireless for all kinds of applications, including military and space. The MTS-based microstrip antenna has affordable features to design for millimeter wave applications. The main significant role of MTS based millimeter wave antenna is to provide higher bandwidth and gain, including a perfect radiation efficiency, to depict the affordable frequency response of the radiator to use at the extreme 5G frequency band (20 to 100 GHz) as given in Fig. 1. The left-handed material-based MTS helps to get the required features of an antenna to operate at millimeter wave as given in Fig. 2.

3. PROPOSED ANTENNA DESIGN

The proposed antenna was designed with 20 mm length and 20 mm width of the substrate, having a patch length and width of 12 mm to 14 mm along with all the symbols and designed geometric parameters in Figs. 3, 4 was given in [11, 12].

The authors designed an MTS antenna to cover the extreme portion of the 5G spectrum from 20 to 45 GHz. Based on that, the frequency f and λ, along with ε and ε_r, were chosen to design the 5G antenna at a particular rate. The structural design of the MTS1 and MTS2, along with its side view and patch design, as depicted in the above figs. Which indicates the perfect measurements for the geometric representation of the structured sub-wavelength MTS radiator. The length and width of the patch are taken from the length of the substrate, and the U-slot is grown on the substrate. When an electrical signal enters into the feed through port with the perfect impedance match. After attaining a perfect match, the signal would be radiated into the space through the radiator. The μ and ε variation with f and λ decides the orientation of electric and magnetic fields in a particular direction with the operating frequency produced by the radiator.

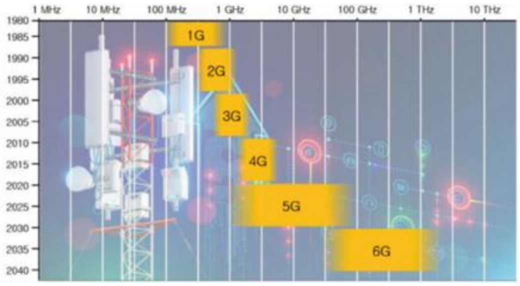

Fig. 1 – 5G evolution

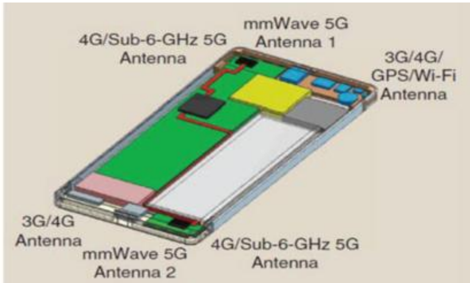

Fig. 2 – Mobile broadband at 5G

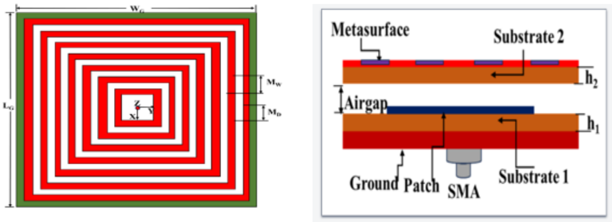

Fig. 3 – MTS1 and its side view

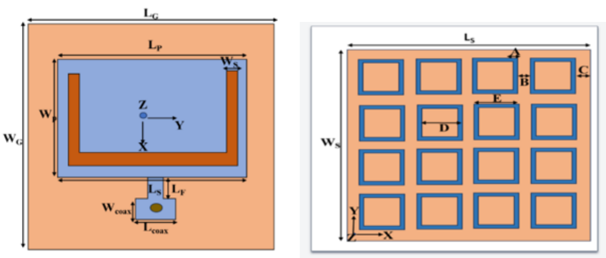

Fig. 4 – The patch along with its MTS2

In this article the authors compared the two designs having the same substrate length and width and also having the same U-slot as the patch along with a coaxial feed. The mesh is a kind of MTS1 and 4 × 4 square slot MTS2. The MTS is a 2D subwavelength artificial left-handed material. It controls the antenna parameters and tries to adapt it to a particular value. The geometric adaptation is possible with MTS, and its controlling capability generates a lossless signal along with a proper aligned, formatted, resonating frequency of the radiator.

4. RESULTS AND DISCUSSION

The performance of proposed design was evaluated with the help of antenna radiating parameters like, S-parameter plot, gain, axial ratio and the radiation pattern. The *S*-plot variation for MTS1 design as shown in Fig. 5, indicates the operating bandwidth and the impedance match. The axial ratio at Fig. 6 indicates the rate of reflections in the antenna. The bandwidth for MTS1 is from 17 to 23 GHz at the 20 GHz resonating frequency. Whereas the MTS2 has a bandwidth from 28 to 42 GHz at the 34 GHZ resonating frequency as shown in Fig. 7. The reflection coefficient for the MTS2 design is – 50, pertained huge bandwidth 13 GHz, along with a valued gain of 10 dBi. The radiation pattern for the designed antennas was shown in Fig. 8 entitles how the antenna got radiated in a particular direction in the form of both the *E* and *H* planes. The circularly polarized patterns indicate that the axial ratio is at the 3 dB point. The peak gain at Fig. 9 indicates the variation of gain in a given bandwidth region, at 30 GHz the peak gain offered is 10 dBi. The authors used both FR4 and Roger materials for the design of proposed antenna, but as shown in Fig. 10, the reflection coefficient for substrate material is good for FR4 compared to Rogers. Hence, we have selected FR4 for our design. As shown in Fig. 11, the single-cell to multi-cell signal got compared, but as per our proposed design principles and design considerations the single-cell mesh kind of MTS1 has given perfect return loss with less impedance mismatch.

As per the design considerations and design techniques, the simulated results indicate the performance of the antenna in the 5G operating region with less transmission loss. The measured versus simulated results for MTS1 were shown on Fig. 12. Indicates the results of the fabricated antenna are almost resembling the simulated. Consequently, the measured versus simulated results for the MTS2 antenna are also closely resembling the simulated results, considering some connector losses. In this paper, how the advanced design techniques while selecting the geometric parameters measured results, all the calculations should be done as per the defined. The quality of work should be enlightened just by comparing proposed work with the existing work as shown in Table 1. In our work we have selected 5-layer design for better stability and directivity.

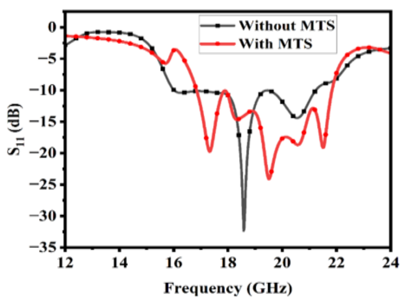

Fig. 5 – S-parameter plot for the MTS1

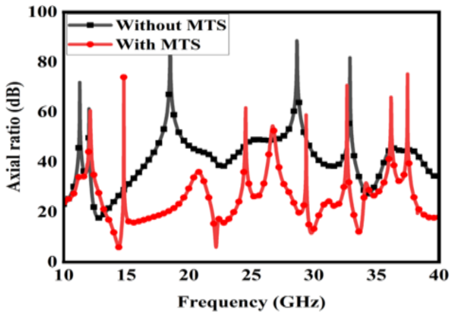

Fig. 6 – Axial ratio plot for 5G antenna

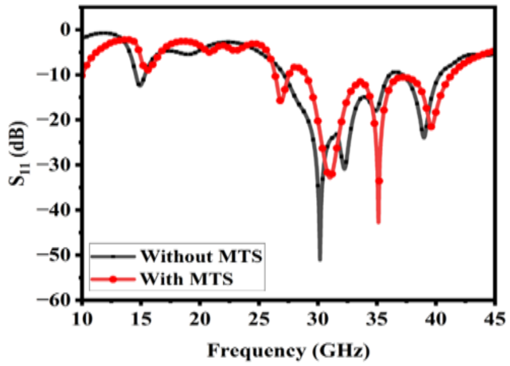

Fig. 7 – S-plot for the MTS2

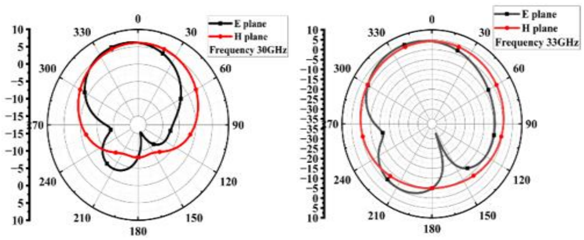

Fig. 8 – Radiation pattern for MTS1 andMTS2

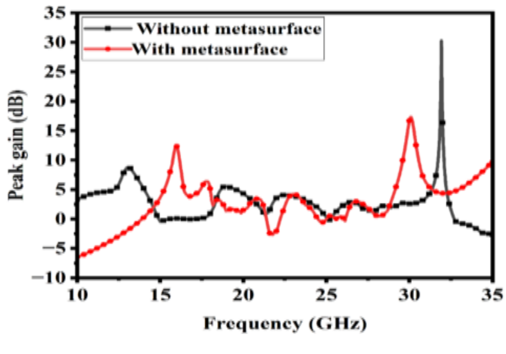

Fig. 9 – Peak gain plot for 5G antenna

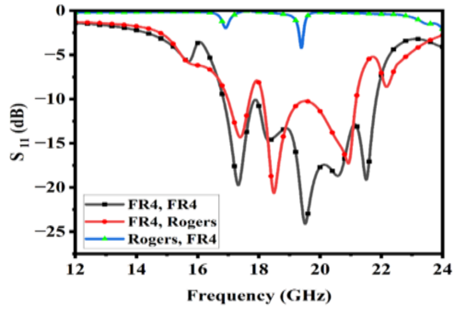

Fig. 10 – Reflection coefficient variatio for materials

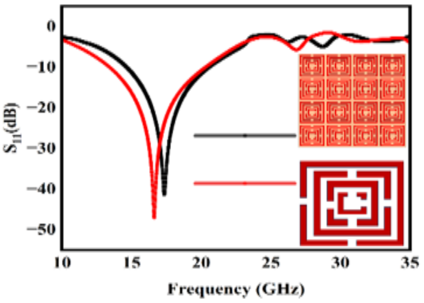

Fig. 11 – Reflection coefficient variation from single cell to multi cell

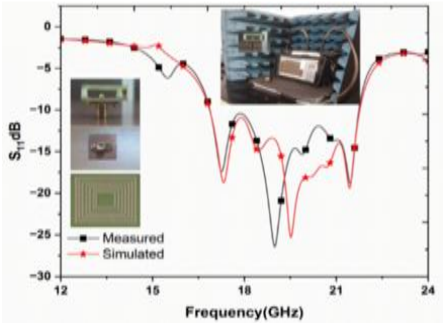

Fig. 12 – Simulated versus measured result for MTS1

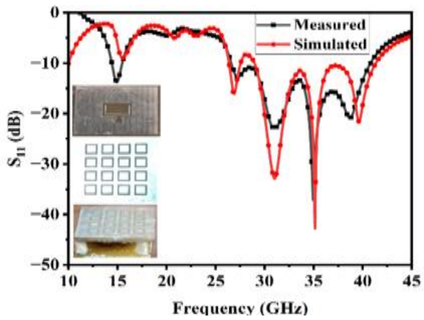

Fig. 13 – Simulated versus measured result for MTS2

5. CONCLUSION

In this paper the authors presented the review work on metasurface-based patch antennas for 5G and beyond. The frequencies selected for the operation of 5G antenna are 20 GHz for MTS1 and 34 GHz for MTS2. These frequency ranges are well suited for the generation of high bandwidth and gain as required for our proposed study. These frequency bands are well-suited for wireless video streaming and advanced communications where the high frequency operating band is the main authentication. The simulated results give clear confirmation that the proposed design could apply for a wide range of frequencies to adapt and control the 5G network with the proper operating parameters. The simulated versus measured is given the clear information about the operating bandwidth.

Table 1 – Comparative analysis with other conventional antennas

Ref. No	Substrate	Dimensions (mm^2)	Band Width (GHz)	Operating Frequency (GHz)	Peak Gain (dBi)	Reflection Co-efficient (S_{11})	Layers
[1]	RT/Duroid 5880	$0.27\ \lambda_0 \times 0.27\ \lambda_0$	2.6	3.5	2.69	– 49.1	3
[3]	RT/Duroid 5870	$0.48\ \lambda_0 \times 0.48\ \lambda_0$	1.8	5.2	3.5	–	–
[4]	FR4	$0.25 \times 0.25\ \lambda_0$	2	2.4	4.1	– 20	3
[8]	Rogers 5880	$1.12\ \lambda_0 \times 0.28\ \lambda_0$	1.4	10	5.6	– 30.11	–
Proposed	FR4	$1.64\ \lambda_0 \times 1.64\ \lambda_0$	13	34	10	– 34	5

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REFERENCES

1. Z. Wang, Y. Dong, Z. Peng, *IEEE Trans. Antennas Propag.* **70** No 9, 7646 (2022) https://doi.org/10.1109/TAP.2022.3169067.
2. K.K. Jayanthi, D. Jayabharathi, *Distributed Computing and Optimization Techniques* **903**, 807 (2022) https://doi.org/10.1007/978-981-19-2281-7_74.
3. S. Tariq, Y.I. Naqvi, N. Hussain, *IEEE Access* **9**, 51805 (2021) https://doi.org/10.1109/ACCESS.2021.3069185.
4. N. Hussain, N. Kim, A. Abbas, *IEEE Access* **8**, 130293 (2020) https://doi.org/10.1109/ACCESS.2020.3009380.
5. N. Hussain, T.-J. Kim, M.-J. Jeong, *IEEE Access* **8**, 22127 (2020) https://doi.org/10.1109/ACCESS.2020.2969964.
6. D.A. Sehrai, M. Asif, W.A. Shah, *IEEE Access* **9**, 125348 (2021) https://doi.org/10.1109/ACCESS.2021.3110905.
7. Z. Wang, S. Liu, Y. Dong, *IEEE Trans. Antennas Propag.* **69** No 9, 5437 (2021) https://doi.org/10.1109/TAP.2021.3061013.
8. B. Feng, X. He, J.-C. Cheng, *IEEE Access* **8**, 21589 (2020) https://doi.org/10.1109/ACCESS.2020.2968964.
9. K.S. Sultan, H.H. Abdullah, E.A. Abdallah, *IEEE Access* **8**, 37250 (2020) https://doi.org/10.1109/ACCESS.2020.2975271.
10. T.-N.H. Thi, D.-N.T. Viet, H.-H. Tran, *International Conference on Advanced Technologies for Communications (ATC)* (2023) https://doi.org/10.1109/ATC58710.2023.10318850.
11. V.R. Rentapalli, B. Roy, *Res. Eng.* **24**, 103146 (2024) https://doi.org/10.1016/j.rineng.2024.103146.

12. V.R. Rentapalli, B. Roy, *Opt. Quant. Electron.* **56**, 1231 (2024) https://doi.org/10.1007/s11082-024-06767-z.
13. N.-S. Nie, X.-S. Yang, Z.N. Chen, *IEEE Trans. Antennas Propag.* **68** No 2, 665 (2020) https://doi.org/10.1109/TAP.2019.2940367.
14. G. Federico, A. Hubrechsen, *IEEE Access* **10**, 102308 (2022) https://doi.org/10.1109/ACCESS.2022.3208597.
15. T.Z. Fadhil, N.A. Murad, *IEEE Access* **10**, 1162 (2022) https://doi.org/10.1109/ACCESS.2021.3137324.

Антени на основі метаповерхні для систем зв'язку 5G та міліметрових хвиль

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Антена – це випромінювальна частина системи бездротового зв'язку, спеціально призначена для появи майбутніх технологій 5G та наступних. Ґрунтуючись на технологічних досягненнях наступного покоління, 5G було розроблено та досліджено до 2020 року. Щоб забезпечити кращі послуги та кращий користувацький досвід, дослідники, вчені та інженери шукають високорозвинену широку пропускну здатність у поєднанні зі збільшеною продуктивністю після розвитку 5G. Розвиток бездротової технології 5G пропонує неймовірно швидкий Інтернет, велику пропускну здатність, низьку затримку, високу надійність та покращений коефіцієнт посилення. Ця робота відкриває великий потенціал для отримання більшого посилення та пропускної здатності порівняно з антенами без метаповерхневих антен. Характеристики метаповерхневих антен полегшують випромінювання електромагнітної енергії на більші відстані. Автори цього оглядового дослідження описали розробку антен 5G та те, як методи метаповерхневих антен використовуються при проектуванні антен для застосувань 5G. Технології проектування антен та їх методології змінюються відповідно до міліметрових конструкцій 5G у зв'язку з ослабленням та деформацією сигналу. Підкладка, яка підходить для проектування антени, – це FR4 та Rogers, її специфічні характеристики та вирівнювання сигналу роблять її придатною для бездротового зв'язку 5G міліметрового та терагерцового діапазонів. Результати моделювання показали отримання високої пропускної здатності, високого коефіцієнта посилення, а також кращої ефективності антени з гарним узгодженням імпедансу та діаграмами спрямованості за допомогою Ansys HFSS.

Ключові слова: WBAN, WLAN, WiMAX, Підкладка Бахрама, IEEE 802.15.6, SAR.