JOURNAL OF NANO- AND ELECTRONIC PHYSICS
Vol. 16 No 4, 04020(5pp) (2024)

ЖУРНАЛ НАНО- ТА ЕЛЕКТРОННОЇ ФІЗИКИ
Том 16 № 4, 04020(5cc) (2024)

REGULAR ARTICLE

The Design of Low-Profile, High Gain Meta-Surface Based Microstrip Antenna for 5G Wireless Communication Systems

Vanitha Rani Rentapalli*, Bappadittya Roy†

VIT AP University, Amaravathi, Andhra Pradesh, India

(Received 27 April 2024; revised manuscript received 15 August 2024; published online 27 August 2024)

This article introduces a compact, inconspicuous antenna designed for 5G wireless communications, utilizing a broad-spectrum meta surface. The suggested antenna employs an FR4 epoxy substrate with a dielectric constant of 4.4 and a thickness of 1.6. It is engineered to resonate at a frequency of 34 GHz for the meta surface radiator. Employing HFSS, the proposed radiator is replicated to assess the antenna's functionality with appropriate operational characteristics. The meta surface antenna exhibits a bandwidth spanning 28 GHz to 41 GHz, featuring a maximum reflection coefficient of 50 dB, utilizing a low-profile antenna with dimensions of $2.27\lambda_0 \times 2.27\lambda_0 \times 0.186\lambda_0$, the final outcomes were both designed and measured. The measurements reveal that the recommended antenna achieves a 10 dB impedance bandwidth, accompanied by a gain of 9 to 10 dBi and an optimal axial ratio. The performance of this unobtrusive, high-gain microstrip antenna is primarily contingent on its radiating parameters. The meta surface plays a crucial role in regulating radiating properties, creating stringent operating conditions for the proposed antenna. In line with cutting-edge technology, communication systems demand additional resources and circular polarized radiation for the comprehensive operation of 5G antennas. The meta surface can be configured to optimize gain and reshape the radiation pattern, enhancing both bandwidth and gain.

Keywords: 5G, Low profile, MTS, MSA, Wideband.

DOI: 10.21272/jnep.16(4).04020 PACS numbers: 73.61.Jc, 71.20.Mq, 88.40.jj, 88.40.hj

1. INTRODUCTION

Wireless sensor communication has experienced widespread adoption globally, driven by the increasing number of wireless users and the expansion of services [1]. 5G stands out as an anticipated, groundbreaking antenna system crafted to deliver elevated data rates, broad bandwidth, and enhanced coverage, all while prioritizing security [2]. As wireless technologies continue to advance, there is a heightened focus on exploring and developing radiators to keep pace with the latest technological trends [3]. The meta surface-based 5G antenna is instrumental in enhancing performance and communication capabilities [4]. The Meta Surface (MTS) technique intricately analyses wireless network information by extracting essential data from the communication system [5]. Additionally, to achieve heightened data rates and superior connectivity in 5G communications, sophisticated networks come into play. The choice of a low-profile design for the microstrip antenna is pivotal in the selection of 5G technology. Simultaneously, the MTS-based Microstrip Antenna (MSA) is tailored for a 5G application-specific representation of operating parameters. The MTS-based antenna not only exhibits high directivity and improved performance but also boasts enhanced antenna gain. This positions the MTS as a fifth layer, signifying its integral role in the evolution and optimization of wireless communication systems [7] above, the patch advances its impedance bandwidth [8]. The proposition of antennas for 5G communications unveils the connection between design constraints, intertwined with the radiation assets of MTS-MSA [7]. In this manuscript, an intricately structured multilayered multiband meta surface, presenting a low-profile 5G radiator, is showcased in harmonious operation with meticulously crafted designs [9]. The formulation of MTS antennas for 5G communications is expounded upon in Section I, while Section II delves into the conception of a meta surface-based MSA using 5G communications. Section III outlines the inference of antenna function and explores its harmonious relationship among the antenna elements. Section IV discloses the results and discussions tied to various radiator structures. Design challenges are asserted in Section V, and finally, Section VI concludes the findings.

2. PROPOSAL OF META SURFACE BASED MICROSTRIP-PATCH ANTENNA

An MTS, a multi-faceted structured synthetic material, has found extensive application in the realms of microstrip antenna design to augment both amplification and the frequency range. The suggested antenna characteristics are detailed in Table 1, along

---

[*] Correspondence e-mail: rentapalli@gmail.com
[†] Bappadittya.roy@vitap.ac.in

Cite this article as: V.R. Rentapalli et al., *J. Nano- Electron. Phys.* 16 No 4, 04020 (2024) https://doi.org/10.21272/jnep.16(4).04020

with the meta surface radiator. layers are revealed in Fig. 1, depicts how the size of the radiator at the operating frequency limits the design of the meta surface radiator. The reference antenna and the top view of the meta surface radiator are exposed in Figs. 2 and 3, which designate how the reference antenna is linked to the meta surface antenna. The key resolve of meta surface is to regulate the radiating functions of the reference radiator with its directional properties. The future MTS created wideband CP rectangular patch radiator was intended with a periodic lattice of a 4 × 4 square ring meta surface layer on the radiator.

Table 1 – The proposed antenna parameters

Parameter	L_G	W_G	H_S	L_{S1}	W_{S1}	L_{S2}	L	W_{S2}	L_P	W_P	h_1
Value (mm)	20	20	1.6	20	20	20	1.2	20	10	12	1.6
Parameter	S	G	K	L_S	P	M	J	CF_I	CF_0	CF_S	h_2
Value (mm)	0.3	0.5	1.65	20	2.3	1.8	8.9	0.2	1.16	0.8	1.6

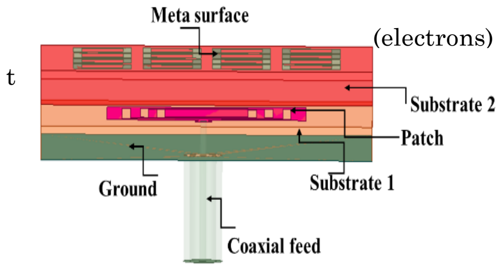

Fig. 1 – Layers of the MTS antenna

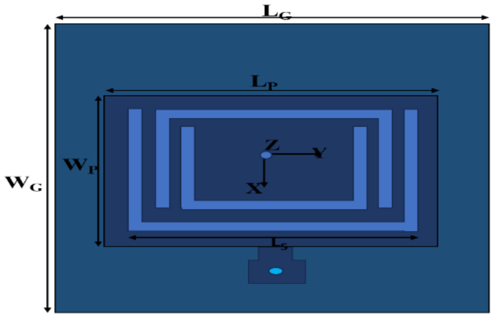

Fig.2 – Reference antenna with patch for 5G

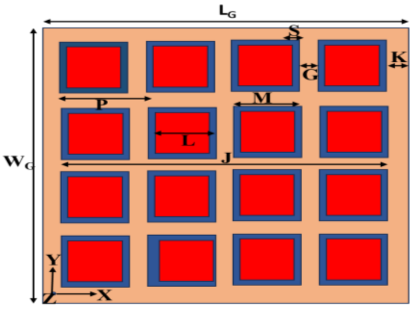

Fig. 3 – Top view of the MTS for 5G the meta surface

The direct stacking of the meta surface layer on substrate 2 with some air gap allowed a very low-profile of the microstrip radiator, making it appropriate for the compact 5G devices. The MTS design has the perfect optimization process about how the antenna is designed and what the necessary parameters are required to invent the functionality of the radiator. The wideband features of the MTS based CP patch antenna not only advance the bandwidth but also it enhances of gain, with this the performance of the antenna would be increased.

3. ANTENNA STRUCTURE PROCEDURE

The inception of the proposed emitter begins as a simulation for the rectangular patch antenna, where the emitter is energized through a 50 Ω connector via a microstrip antenna. The design methodology of the antenna involves a quintet of operational layers, commencing with a foundational ground layer measuring 20 × 20 mm. Atop this, substrate 1 is cultivated with identical dimensions. The dynamic element of the emitter is the patch, meticulously crafted on substrate 1 with measurements of 10 × 12 mm, complete with a U slot. Another substrate is superimposed onto the patch to facilitate the emergence of a meta surface with a distinct unit cell. The primary objective of this meta surface is to capture electromagnetic energy emanating from the emitter. Once harnessed, it governs and reshapes the radiation pattern of the antenna, rendering it amenable for transmission through the channel. The rectangular microstrip patch antenna inherently possesses linear polarization. By incorporating a slot adorned with a transmissive meta surface, the outcome is circular polarization. The discrete resonances of both the patch and the slot contribute to the advancement of impedance and axial ratio bandwidth for the MTS-based microstrip emitter Leveraging the dimensions of the microstrip patch and slot, geometric parameters are finely tuned to regulate the orthogonal modes, thereby augmenting circularly polarized radiation.

4. RESULTS AND DISCUSSION

The efficacy of the suggested emitter is substantiated through comparisons with various reference antennas, elucidating the enhancements and restructuring of radiative characteristics toward a resonant frequency. The S11 parameter delineates the extent of power reflected from the receiver circuit to the transmitter. Remarkably, the performance of S parameters exhibits impeccable stability, manifesting a reflection coefficient of – 50 dB, as depicted in Figure 4.

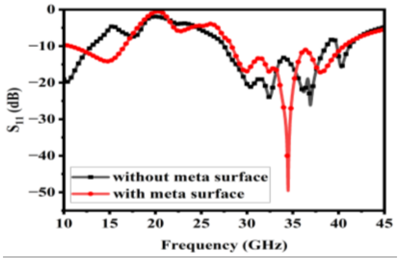

Fig. 4 – S-plot for the meta surface for 5G

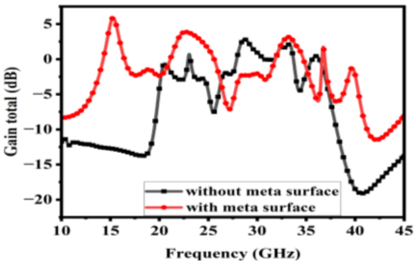

Fig. 5 – Gain plot for the MTS for 5G

A comparative analysis between the proposed antenna, both with and without the meta surface, was undertaken, revealing their respective merits, operational coefficients were computed, and the radiative parameters were fine-tuned through HFSS analysis, resulting in a meticulously balanced and flawless gain, as depicted in Figure 5. The proposed antenna structure underwent optimization with a precisely maintained air gap, ensuring seamless traversing through a broader bandwidth and achieving an equilibrium in the gain of the antenna system. The anticipated gain ranges from 9 to 11 dBi, contingent upon the operational bandwidth values spanning from 28 to 41 GHz. Figure 6 illustrates the antenna's axial ratio, elucidating the accuracy with which the radiator can convey and receive Circular Polarization (CP) waves. Signal variations were adeptly utilized in crafting the axial ratio design. The paramount constraint of the MTS radiator is delineated through the peak gain, showcased in Figure 7. This metric quantifies the power emitted in a specific direction, with the esteemed gain fluctuating from 8 to 10 dBi within the bandwidth of 28 to 41 GHz.

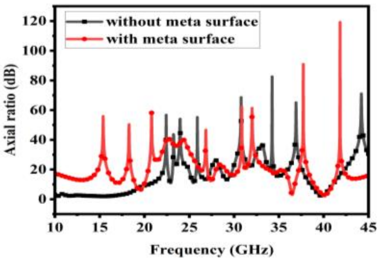

Fig. 6 – Axial plot for the MTS antenna

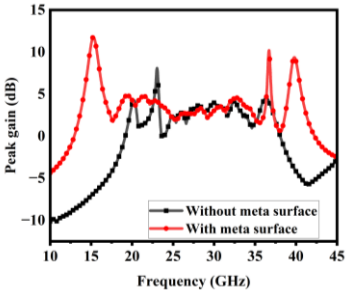

Fig. 7 – Peak gain for the MTS antenna

The incorporation of peak gain articulates the genuine operating modes of the MTS antenna while transmitting through the valued gain. The synergy between patch and ground currents is contingent upon the intricacies of the feed design. The additional structures integral to the radiator underscores the essential aspects governing current distribution across the antenna's surface, elucidated in Figure 8. The current distribution intricately influences radiation effects at the resonant frequency, aligning with the pivotal elements of the MTS radiator, detailed in Figure 9. Figures 10 and 11 provide a visual representation of the proposed antenna's radiative structure. The discussions on radiation proposals and polarization, expounded upon in the subsequent sections, significantly influence the precision and outcomes of the radiation pattern of the MTS radiator.

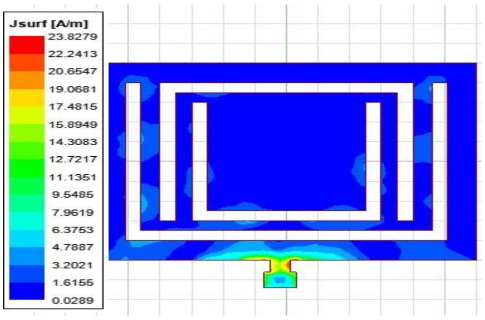

Fig. 8 – Current distribution for the patch of the MTS

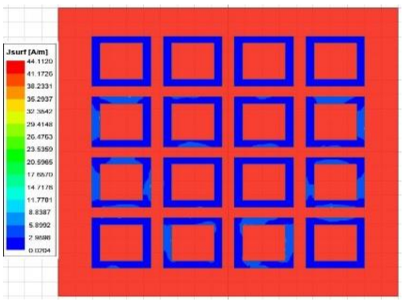

Fig. 9 – Current distribution for the MTS antenna

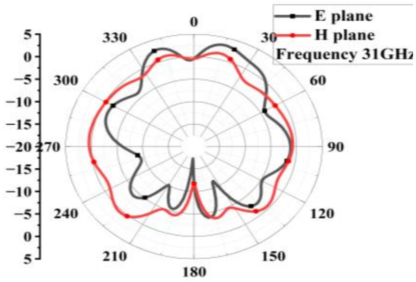

Fig. 10 – Radiation pattern of MTS at 31 GHz

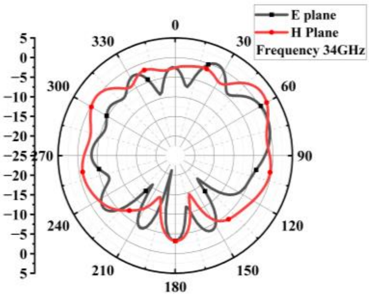

Fig. 11 – Radiation pattern of MTS at 34 GHz

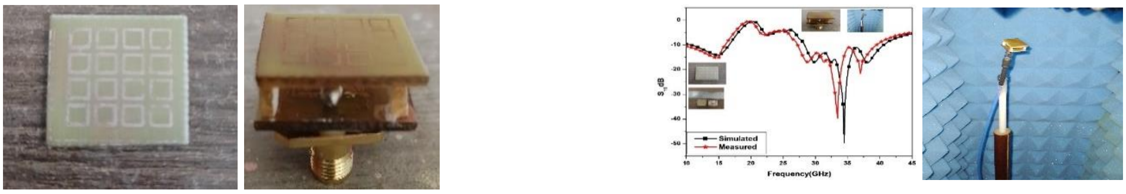

Fig. 12 – Fabrication set up for MTS 5G antenna

Table 2 – The proposed antenna performance comparison with the other works

Ref	Antenna type	Antenna size (λ_0)	Frequency (GHz)	S_{11} (dB)	ARBW	Gain (dBi)	Layers
10	Fabry parrot	2.5 × 2.5 × 1.48	25	30	3.9	4	3
11	Stacked patch	0.81 × 0.81 × 0.09	27	25	7	3	3
12	Stacked patch	2.67 × 2.45 × 0.05	20	26	5	2	2
13	Cross dipole	1.19 × 0.66 × 0.27	24	27	6	6	3
Proposed	Meta surface	2.27 × 2.27 × 0.186	34	50	10	11	5

Figure 12 delineates the fabrication steps, incorporating MTS, showcasing a meticulous setup that governs the precise performance of the antenna. The performance of CPMTS, contrasted with measured outcomes, is presented in Table 2. From this, it can be deduced that the proposed radiator exhibits more favourable features compared to the other referenced radiators. This emphasizes the uniqueness and distinct advantages of the proposed antenna.

5. DESIGN CHALLENGES

In line with contemporary technological advancements, the methodologies for proposing radiators are subject to constant evolution. Concurrently, the requisites for data rate, latency, and other pivotal project constraints of 5G are undergoing dynamic transformations. The central objective of MTS 5G design is to integrate cellular and satellite technology into the MTS radiator. A crucial phase involves evaluating antenna parameters in alignment with the defined objectives of the 5G network. Of paramount significance in the proposal process is the nuanced understanding of how the essence of the antenna undergoes transformation due to progressive technological approaches, such as MTS.

6. CONCLUSION

This article presents a sophisticated five-layered MTS-based low-profile wideband emitter tailored for 5G applications. The MTS antenna adeptly orchestrates radiated waves in diverse directions, proposing variations and reconstruction of the radiating signal to enhance overall system performance. The MTS holds the potential for advancing and diversifying radiation structures in MTS radiators. A low-profile wideband emitter harnesses the exceptional capabilities of MTS unit cells. The addition of a U slot and the MTS contributes to the patch's bandwidth augmentation from 28 to 41 GHz. Furthermore, the stability in the radiation pattern of gain, integral to 5G technology, is seamlessly attained within the operational bandwidth of the antenna. With the recommended antenna configuration, the emitter achieves a remarkable impedance bandwidth of 54 %, ensuring that S11 is less than – 10 dB. Additionally, a 3 dB AR bandwidth of 20 %, broadside gain ranging from 9 to 11 dBi, and a radiation efficiency exceeding 90 % are realized. This proposed high-gain, wideband emitter, with its low-profile structure, has been meticulously designed, simulated, and measured as an MTS-based wideband antenna for 5G wireless communications.

REFERENCES

1. A. Lalbakhsh, M.U. Afzal, T. Hayat, K. Esselle, K. Mandal, *Sci. Rep.* **11** No 1, 9421 (2021).
2. Priyanka Das, Gaurav Varshney, *Opt. Quant. Electron.* **54**, 161 (2022).
3. S. Li, F. Xa, X. Wan, T.J. Cui, *IEEE Trans. Antennas Propag.* **69** No 5, 2958 (2021).
4. S. Tariq, S.I. Naqvi, N. Hussain, Y. Amin, *IEEE Access* **9**, 51805 (2021).
5. Qi Zheng, Chenjiang Guo, Jun Ding, *IEEE Trans. Antennas Propag.* **70** No 9, 8584 (2022).
6. X. Tong, Z.H. Jiang, C.Yu, F. Wu, *IEEE Antennas Propag. Lett.* **20** No 10, 2038 (2021).
7. W. Wan, M. Xue, L. Cao, T. Ye, Q. Wang, *IEEE Antennas Wireless Propag. Lett.* **19** No 7, 1251 (2020).
8. Yonghui Qiu, Zibin Weng, Ding Hou, *IEEE Antennas Wireless Propag. Lett.* **22** No 4, 933 (2023).
9. Yao Kan, Rui Yang, Aofang Zhang, Zhenya Lei, Yongchang Jiao, Jianfeng Li, *IEEE Trans. Antennas Propag.* **70** No 5, 3894 (2022).
10. Prajwalitha Saikia, Keshav Singh, Omid Taghizadeh, Wan-Jen Huang, Sudip Biswas, *IEEE Trans. Cognitive Commun. Network.* **10** No 1, 164 (2024).
11. Hiromi Matsuno, Takuya Ohto, Takahiro Hayashi, et al., *IEEE Access* **11**, 95757 (2023).
12. Chunhua Xue, Qun Lou Zhi Ning Chen, *IEEE Trans. Antennas Wave Propag.* **68** No 3, 1468 (2020).

Конструкція низькопрофільної мікросмужкової антени на основі метаповерхні з високим коефіцієнтом посилення для систем бездротового зв'язку 5G

Vanitha Rani Rentapalli, Bappadittya Roy

VIT AP University, Amaravathi, Andhra Pradesh, India

У цій статті представлено компактну, непомітну антену, розроблену для бездротового зв'язку 5G, яка використовує метаповерхню широкого спектру. Запропонована антена використовує епоксидну підкладку FR4 з діелектричною проникністю 4,4 і товщиною 1,6. Він створений для резонансу на частоті 34 ГГц для метаповерхневого радіатора. Використовуючи HFSS, запропонований випромінювач копіюється для оцінки функціональності антени з відповідними робочими характеристиками. Метаповерхнева антена має смугу пропускання від 28 ГГц до 41 ГГц, максимальний коефіцієнт відбиття 50 дБ, використовує низькопрофільну антену з розмірами $2,27\lambda_0 \times 2,27\lambda_0 \times 0,186\lambda_0$, кінцеві результати були розроблені. і виміряно. Вимірювання показують, що рекомендована антена забезпечує імпеданс смуги пропускання 10 дБ, що супроводжується посиленням від 9 до 10 дБі та оптимальним осьовим співвідношенням. Ефективність цієї непомітної мікросмужкової антени з високим коефіцієнтом посилення в першу чергу залежить від параметрів її випромінювання. Метаповерхня відіграє вирішальну роль у регулюванні випромінювальних властивостей, створюючи жорсткі робочі умови для запропонованої антени. Згідно з передовими технологіями, системи зв'язку вимагають додаткових ресурсів і випромінювання з круговою поляризацією для комплексної роботи антен 5G. Метаповерхня може бути налаштована для оптимізації підсилення та зміни діаграми спрямованості, покращуючи як пропускну здатність, так і посилення.

Ключові слова: 5G, Низькопрофільний, MTS, MSA, Широкосмуговий.