JOURNAL OF NANO- AND ELECTRONIC PHYSICS
Vol. **16** No 3, 03008(7pp) (2024)

ЖУРНАЛ НАНО- ТА ЕЛЕКТРОННОЇ ФІЗИКИ
Том **16** № 3, 03008(7cc) (2024)

OPEN ACCESS

REGULAR ARTICLE

Miniaturized *T* and Inverted *T* Slotted Ultra Wide Band Antenna with Defected Ground (DG) System for 5G Communication

M. Jeyabharathi[1], D. Kumutha[2,*], P. Geetha[3], R. Delshi Howsalya Devi[4], Raja Manikandan[5], T. Sripriya[2]

[1] *Department of ECE, KSR College of Engineering, Namakkal, TN, India*
[2] *Department of ECE, Jeppiaar Institute of Technology, Kunnam, Sriperumbudur, TN, India*
[3] *Department of ECE, Karpaga Vinayaga College of Engineering and Technology, Chengalpattu, TN, India*
[4] *Department of AI&DS, Karpaga Vinayaga College of Engineering and Technology, Chengalpattu, TN, India*
[5] *Department of ECE, K.Ramakrishnan College of Technology, Trichy, TN, India*

(Received 14 April 2024; revised manuscript received 19 June 2024; published online 28 June 2024)

A *T*- and Inverted *T* slotted antenna is proposed with a very compact size of (3,00 × 1,72 × 0,08) mm³. The radiator is built over FR-4 substrate. The system operates from 15 to 35 GHz attaining a very high bandwidth of 20GHz. The impedance match is observed to be high which reflects the resonances at 18.88; 21.1; 24.7; 28.0; 30.8 and 34.1 GHz with minimum reflection as – 19.6 db to a maximum of – 48db. Antenna parameters such as Gain above 3dbi as a minimum and to the maximum of 10dbi is observed throughout the operating frequency. VSWR is maintained below 2 with efficiency varying within 60%. Defected Ground Structures is implemented to obtain improved gain through the operating band. The resonance points cover the bands suggested by the International Telecommunication Union for the implementation of the 5G spectrum such as n 257 and n258 bands (26.50-29.50) GHz, whereas (15-35) GHz comes under ku, k, and Q bands. Usage of these bands improves the data rate and reduces signal distortion. Through the entire performance, the antenna becomes a good candidate for 5G applications.

Keywords: Ultra Wide Band Antenna, Fifth Generation (5G), Voltage Standing Wave Ratio (VSWR), T and Inverted T slotted antenna, Defected Ground (DG).

DOI: 10.21272/jnep.16(3).03008 PACS numbers: 73.61.Jc, 71.20.Mq, 88.40.jj, 88.40hj

1. INTRODUCTION

With advancements in wireless communications, the requirement for multifunctional gadgets has skyrocketed. The demand can be met using antennas that can be reconfigured [1]. Flexible configuration is possible in several areas, including frequency, polarisation, including radiation pattern reconfiguration. This shift is achieved by dispersing currents in antennas, which alters the electromagnetism fields generated by the antenna structure's efficient aperture. Concerning the configurable antennas characteristics, adaptable type antennas could be allocated to several subdivisions, including frequency reconfigurable adaptable antennas, pattern adaptable antennas, polarisation adjustable antennas, frequency-polarization hybrid reconfigurable antennas, as well as Reconfigurable frequency-pattern hybrid antennas, with the use of frequency adjustable antennas has been growing more prevalent in the literature [2]. There are various some methods to generate the antenna reconfigurable. The inclusion of an electrical components such as PIN diodes, RF MEMS, and varactors represents one of the main approaches. Additional techniques comprise of photoconductive (optical) modification, physical structural modification, along with the utilisation of materials such as liquid crystal and ferrites [3]. Utilizing these various strategies, multiple reconfigurable antennas may be discovered in the literature. [4] employed pin diodes to bridge the 5.35 as well as 5.85 GHz wireless local area network bands. [5] authors utilised three diodes called PIN to illuminate the WiMAX along with the Wi-Fi portions of the radio frequency band.

In [6] authors developed a microstrip tunable antenna containing radio frequency PIN diodes placed as switch control for the radio frequency bands 2.4 GHz and 5.6 GHz. It describes a circle-shaped patched micro strip input configurable adaptive antenna for Wireless communication (WLAN) via wireless networks. The authors of [6] created a reconfigurable UWB antenna along the combination of the RF-MEMS to enable when needed WLAN rejection. Thus, it showed an antenna that is sensitive to its surrounding environment by adding infrared sensors. [7] demonstrated a miniaturized adaptable antenna during wireless multi-radio communication that employed PIN diodes to provide reconfigurability. It demonstrated a wireless temperature-detecting antenna that can be reconfigured. The authors of [8] described an antenna capable of operating between 2.4 and 2.67 GHz that might flip its polarisation from horizontal to vertical circular polarisations and in the reverse direction. It describes a frequency configurable adaptable antenna with MIMO capability that co-

* Correspondence e-mail: kumutha.d@jeppiaarinstitute.org

vers LTE bands. The antenna depicted in [8] operates between 2.2 – 3.4 GHz as well as it is reconfigurable by utilizing the radio frequency (RF) MEMS switches.

2. LITERATURE REVIEW

[9] presents a radio frequency (RF) MEMS-based configurable adjustable antenna was designed and analyzed for usage in emergency security bands in the United States. [9] demonstrated a tiny RF MEMS switching planar Inverted-F antenna with five wireless cellular radio frequency (RF) bands of performance functioning operation. It demonstrated a reconfigurable PIFA for WCDMA (1.82 – 2.28 GHz), USPCS (1.95 – 1.89 GHz), as well as WLAN (5.25 – 5.835 GHz) frequency bands utilizing and capable of switching PIN diode with a variable varactor. The authors reported a varactor diode that depends on the reconfigurable adaptable portable antenna with a radio frequency range of 1.8 to 2.5 GHz. [10] presents a configurable adaptable and adjustable patch type antenna with a uniformed form of E-shaped structure, whereby its operational frequency is adjusted via incorporating switches. Thus, the author Ali et al. created four types of configurable electromagnetism field antenna components for the range of 2.55 GHz and 5.68 GHz bands, which include the corner-fed triangular loop, Yagi, center-fed equilateral triangular loop, along with rectangular type spiral shaped antennas that can be reconfigured. It demonstrated a frequency-configurable patch type antenna using the Time-Domain Finite-Difference Technique.

[11] demonstrated an antenna with an annular slot having the diodes that contain PIN type used to change the impedance matching as well as to adjust the antenna's electromagnetic emission pattern. The author demonstrates dynamically operated frequency reconfigurable adaptable microstrip antennas and presents a microstrip patch antenna with liquid crystal tunable adjustment that operates in the 5 GHz bands. The reconfigurable spherical steering beam antenna using liquid metal parasitic is demonstrated in this article. The modification in ground plane height and angular location was utilized to control the frequency response of a configurable adjustable antenna reported in [12 13].

Similarly, the authors presented a micro strip-fed planar antenna that covers a total of four frequency bands: 950 MHz, 1.9 GHz, 2.5 GHz, and 3.6 GHz. In modelling, the three available switches introduced for flexible configuration are presumed to be in 0 and 1 states which is present. seen in [14], PIN semiconductor diodes are high-switching characteristics that may be set to function as a shorted circuit, an open circuit, or any other form of coefficient of reflection amongst them. [15]. The major and crucial aspect of this reconfigurable antenna is the operation of active components, such as PIN diodes. Three independent DC lines control these switches. However, because DC lines contain multiple electrical components, they disrupt the passage of current, thus inductors are put in DC lines to sever it within the radiating section of the antenna. Capacitors are placed among the DC sources and the ground plane to prevent DC from passing to the ground. [16] depicts a broadband elliptical micro strip patch antenna construction with a working bandwidth of 0.46 – 5.46 THz. However, higher data rate antenna configurations having more bandwidth are necessary to provide additional wireless communication services. A Super Wideband (SWB) antenna can accommodate more than a decade of ratio bandwidth (10:1) [17]. Several SWB antenna configurations in the THz frequency domain have been described, as illustrated in [18-19].

3. ANTENNA DESIGN

3.1 Geometry

In this paper an antenna is proposed for ultra wide band operations. This comprises a 50Ω microstrip feed line, a defective ground that is placed below the substrate. Normally a defected ground plane acts as an electrical wall in an antenna that also forms as an integral part of the feeding mechanism and radiator. This also alters the input characteristics and output radiation pattern. But here the main aim of the defective ground is to alter the current distribution and also to enhance the bandwidth. These are used to obtain omnidirectional coverage, ultra wideband operation and ripple free radiation pattern. The rectangular copper is mounted on the FR-4 substrate. The dimension of the ultrawide band monopole antenna is 1.72 mm × 3 mm × 0.08 mm. The Front and Rear view of the proposed radiator is given at Fig. 1.

3.2 Design Procedure

The proposed ultra-wide band antenna is generating through defective ground, a Rectangular shaped patch imprinted with T and Inverted-T shaped slots in it.

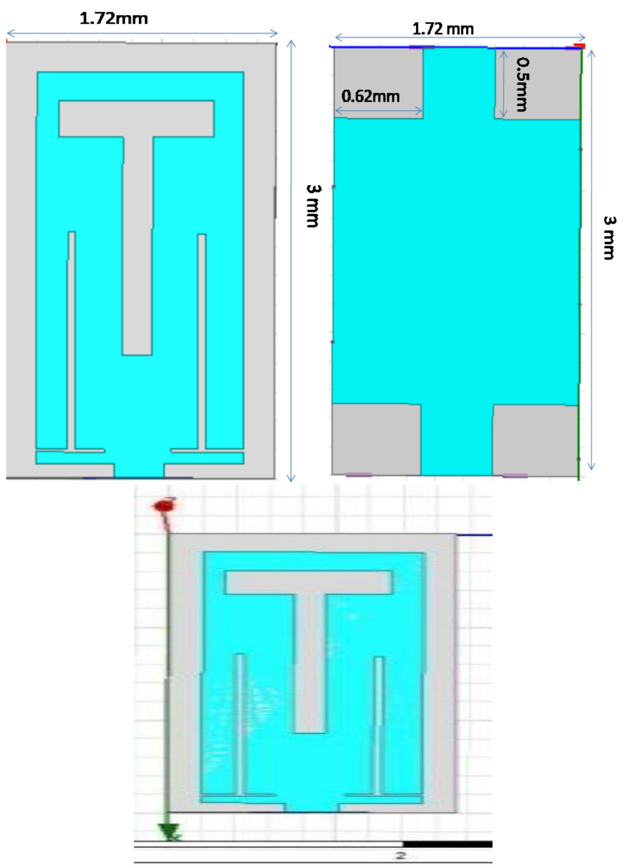

Fig. 1 – Front and rear view of proposed radiator

For clear understanding purpose, the developing stages of the antenna are shown in Fig. 1. The design can be understood by two development stages.

Evolution of Defected Ground Structure.

- **Step 1:** First, an antenna with microstrip feed is introduced with rectangular patch and Full ground. Further optimization where made so as to attain a good operating band.
- **Step 2:** Optimizations in patch such as T and Inverted T slots where made whose results are discussed in parametric study. The dimensions of slots in patch are given in Fig. 2.
- **Step 3:** Implementation of Full Ground that is Defected Ground Structure brought a very demanding change in the reflection coefficient. On the rectangular full ground, small rectangular slots on all corners were imprinted whose dimensions are given in Fig. 3.

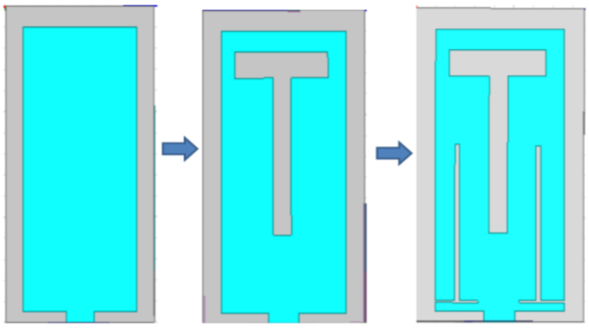

Fig. 2 – Evolution of patch

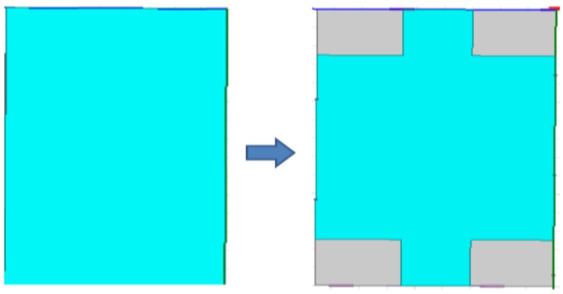

Fig. 3 – Evolution of DG structure

4. PARAMETRIC STUDY

The proposed antenna is based on the defected ground structure and hence the parameters that effect the operating band characteristics of the antenna such as the position of DGS slots and T slots are parametrically analyzed.

4.1 Effect of Introducing Inverted *T* Slots:

Initially, when the antenna as designed it operated at 17 GHz, further observing the reflection coefficient and impedance matching it was decided to implement slots over the patch, as the literature study stated implantation of slots would make the radiator operate at multiband operations. As the study stated, many slots were implemented where inverted T-Shaped Slots on either sides of the feed on the patch made the radiator operate at multi band operations. It was observed a multiple minute notches arrived disturbing the attainment of ultra wide band operation. With Slot implantation, the radiator operated at 15.2 GHz, 17.5 GHz, 22.5 GHz, 25.5 GHz, 32 GHz, 35 GHz, 32.5 GHz below – 10 dB reaching a maximum of 37.5 dB reflection. The result is attached in Figs. 4, 5.

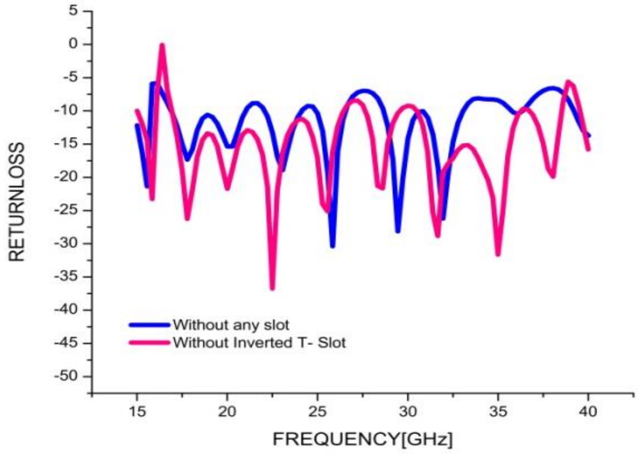

Fig. 4 – Reflection of with and without slots

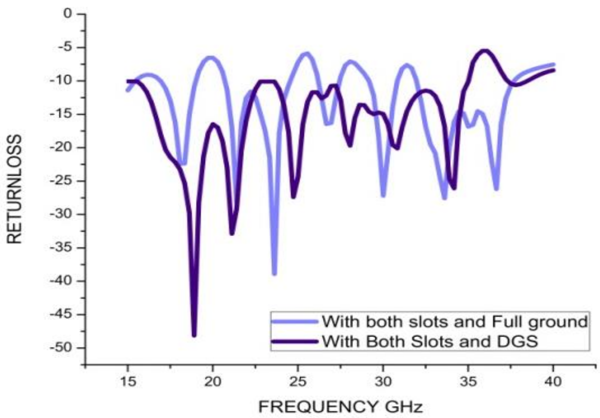

Fig. 5 – Reflection of with and without slots

With Inverted T-Slot being Imprinted, additionally T-shaped slot was made above the portion of Feed. For which the radiator operated at all the slots being Introduced the radiator operated at 17.5 GHz, 22 GHz, 24 GHz, 26 GHz, 30 GHz, 34 GHz, 37 GHz below – 10 dB with maximum reflection at – 40db. Through all the implementations of slots, the radiator remained as multi-band antenna with good reflection. As a Final Step, Rectangular slots over the ground were made developing it as a Defected Ground System. Which Transformed the Multi band antenna as an Ultra wide band antenna with 6 resonances at 18.88 GHz, 21.1 GHz, 24.7 GHz, 28 GHz, 30.8 GHz, 34.1 GHz. The entire band from 15 GHz to 35 GHz operates under – 10 dB satisfying good impedance match and reflection. The results are depicted in Fig. 5.

5. RESULTS AND DISCUSSION

The simulation studies are performed using HFSS EM solver, with the operating frequency from 15 GHz to 35 GHz and the analysis has been carried out on single patch antenna. Figs. 6 to 9 shows the distribution of surface current through the patch. The distribution of surface current is simulated and verified at 18.88 GHz, 21.1 GHz, 24.7 GHz, 28 GHz, 30.1 GHz, 34.1 GHz which the specific operating points. The electrical field is maintained with a medium distribution throughout the antenna and provides good stability, and radiates maximum energy which is received at the port. Maximum current distribution is available at the center of the proposed patch and near the feed of the proposed antenna with high magnitude at the edges. The antenna design is simulated for the frequency ranging from 15 GHz to 35 GHz and for the process of calculating the bandwidth, the first step is to find out the S11 of both the antennas.

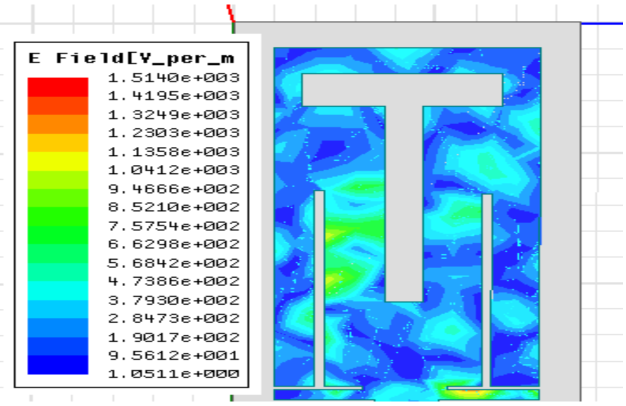

Fig. 6 – Surface Current at 18.88 GHz

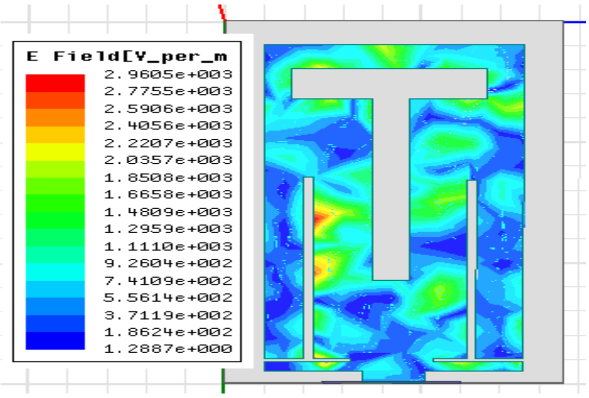

Fig. 7 – Surface Current at 21.1 GHz

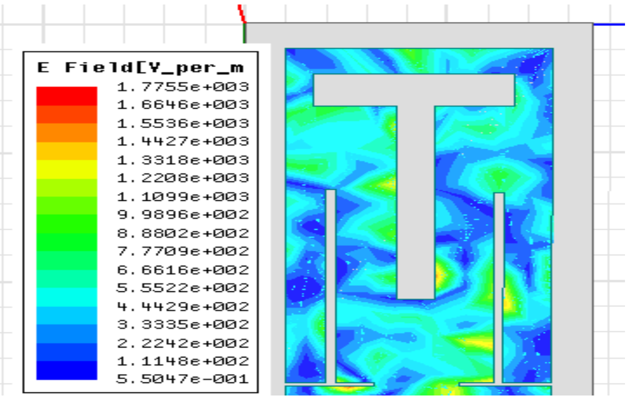

Fig. 8 – Surface Current at 24.7 GHz

Figs. 4, 5 represents the reflection coefficient vs. frequency characteristics of the single patch antenna. It is evident from the portrayed figure that the suggested patch antenna provides excellent performance and multiple resonating frequencies. Attaining perfect resonant characteristics as per observation below – 10 dB level of S_{11} parameter. However, very good reflection coefficient is

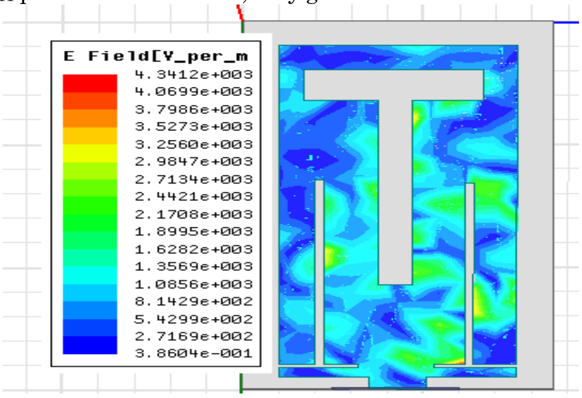

Fig. 9 – Surface Current at 28 GHz

observed at minimum resonance with a minimum attained value of − 19.6 dB at the resonant frequency of 28 GHz which is the nc7 band. As per Figs. 6, 7, 8, and 9 the antenna provides hexa operating points considering $S_{11} \le -10$ dB with significant bandwidths at each operating bands of 18.88 GHz, 21.1 GHz, 24.7 GHz, 28 GHz, 30.1 GHz and 34.1 GHz with the reflection coefficients of – 48 dB, – 32.9 dB, – 27.3 dB, – 19.6 dB, – 20.1 dB and – 26 dB respectively .The best value of reflection coefficient is recorded as – 48 dB at the frequency of 18.8 GHz in the operating frequency.

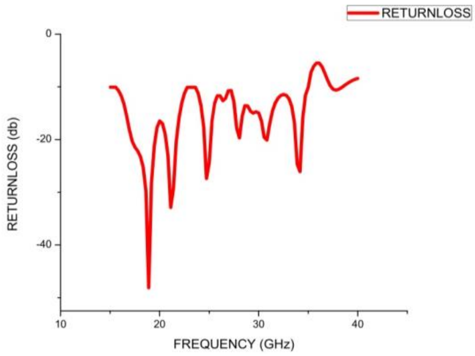

Fig. 10 – Reflection coefficient

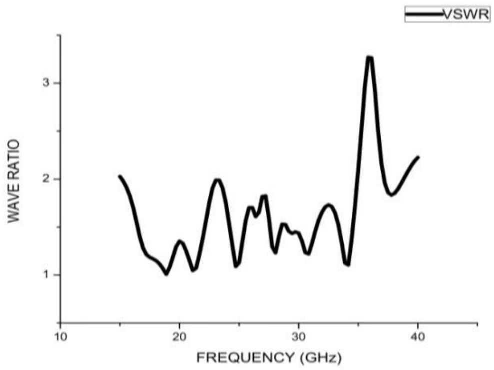

Fig. 11 – Wave Ratio of proposed radiator

The reflection coefficient and wave ratio values are shown in Figs. 10, 11. The minimum The acceptable VSWR confirms that well impedance matching the designed structures and ensure low mismatch losses associated with the suggested designed antenna models such that these antenna models can be used practically. Figs. 12 to 17 provides the radiation pattern of antenna at operating bands of 18.88 GHz, 21.1 GHz, 24.7 GHz, 28 GHz, 30.1 GHz and 34.1 GHz. The gain is plotted with the theta ranging from 0 degrees to 180 degrees with the phi value of 0 degrees. At 18.8 GHz - 9.57 dBi, 21.1 GHz - 18.9 dB, 24.7 GHz - 11.68 dBi, 28 GHz - 19.93 dBi, 30.1 GHz - 12.08dBi, 24.1 GHz - 10.10 dBi is observed as gain where the maximum gain is 19.97 dBi at 28 GHz which belongs to nc7 band. The achieved values imply that the radiation pattern is best suitable for 5G communication.

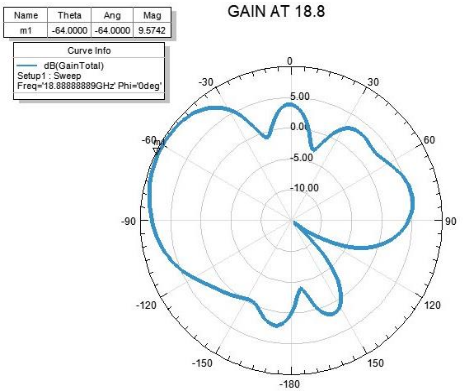

Fig. 12 – Gain at 18.8 GHz

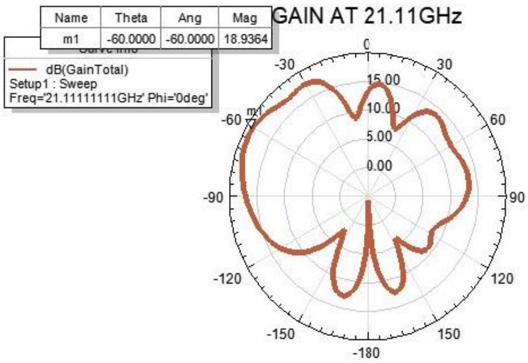

Fig. 13 – Gain at 21.11 GHz

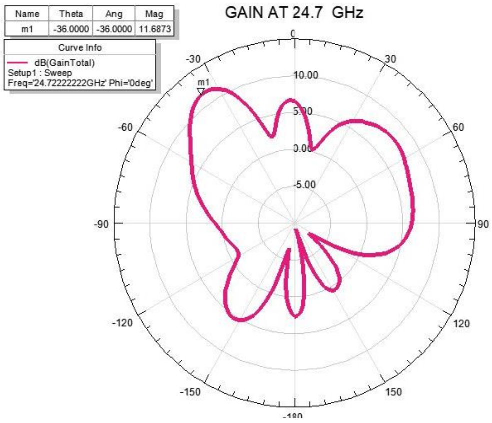

Fig. 14 – Gain at 24.7 GHz

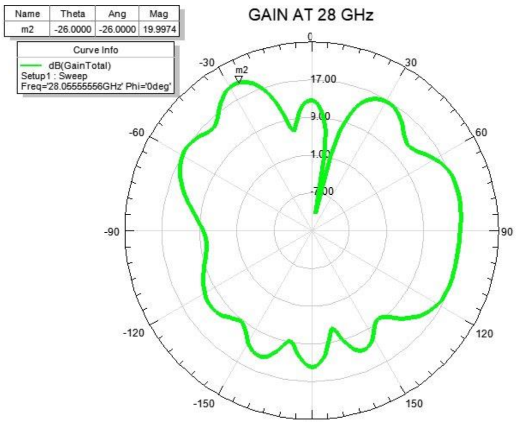

Fig. 15 – Gain at 28 GHz

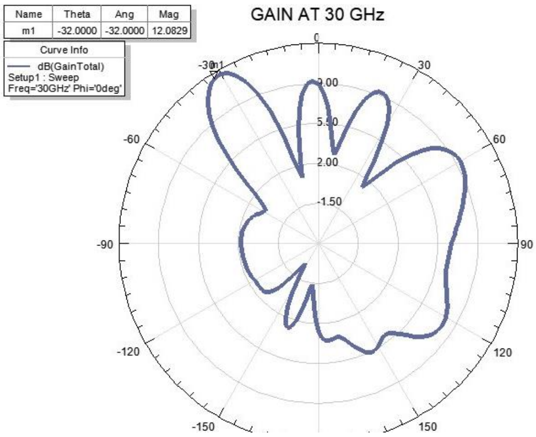

Fig. 16 – Gain at 30.1 GHz

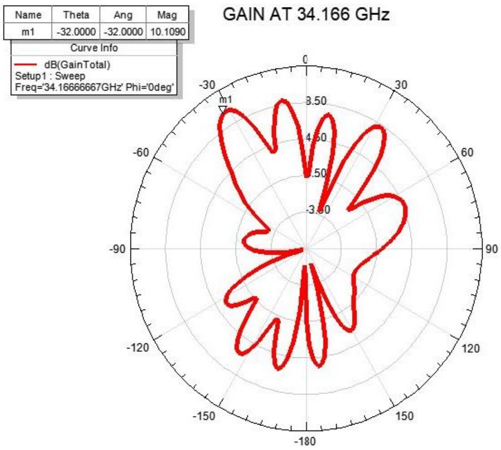

Fig. 17 – Gain at 34.166 GHz

Fig. 18 provides the details about total gain with the primary sweep of frequency at theta and phi at zero degrees. The gain of the antenna reaches the maximum gain of 19.97 dB, and for most of the frequency range, the gain is greater than or equal to 1.5 dB. Fig. 19 depicts the efficiency throughout the operating band. It is observed that the efficiency is maintained above 60% at all resonance points.

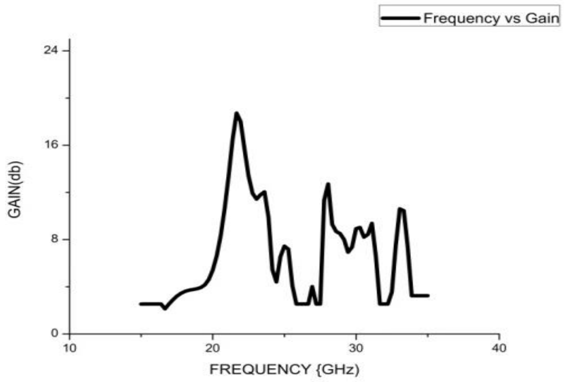

Fig. 18 – Frequency vs Gain Sweep

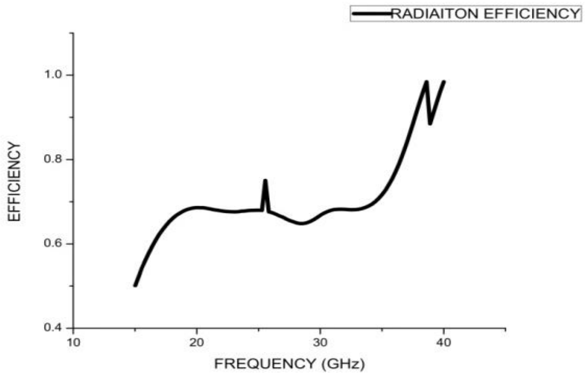

Fig. 19 – Efficiency vs Gain Sweep

Table 1 – Results produced by the proposed Radiator

Resonant Points (GHz)	Ref. Co-efficient (dB)	VSWR	Gain (dB)	Efficiency (%)
18.88	-48	1.11	9.57	67
21.1	-32.9	1.04	18.9	68
24.7	-27.3	1.08	11.68	67
28	-19.6	1.23	19.97	64
30.1	-20.1	1.21	12.08	66
34.1	-26	1.10	10.10	69

6. CONCLUSION

A T and Inverted T-Shaped Miniatured Rectangular antenna has been proposed which produces hexadic operating points which are 18.88 GHz, 21.1 GHz, 24.7 GHz, 28 GHz, 30.8 GHz, 34.1 GHz attaining a massive bandwidth of 20 GHz under G milli-meter wave spectrum. The results have been discussed in Table 1 in detail. The proposed system holds a unique feature of its dimensions $3 \times 1.72 \times 0.08$ mm^3. With high gain and radiation efficiency above 60% through the entire band this radiator attains the candidature under 5G spectrum.

REFERENCES

1. U. Pandey, P. Singh, R. Singh, N.P. Gupta, S.K. Arora, E. Nizeyimana, *Int. J. Wireless Commun. Mobile Comput.* 1 (2023).
2. P. Liu, D. Sun, P. Wang, P. Gao, *Prog. Electromag. Res. Lett.* **74**, 23 (2018).
3. B. Azarm, C. Nourinia, M. Ghobadi, N. Majidzadeh, Hatami, *Int. J. Radioeng.* **27** No 4, 983 (2018).
4. D.K. Rani, J.V.K. Ratnam, *International Journal on Recent and Innovation Trends in Computing and Communication*, **6**, 244 (2017).
5. J. Tao, Q.Y. Feng, *J. Electromag. Waves Appl.* **30** No 16, 2206 (2016).
6. M. Manohar, R.S. Kshetrimayum, A.K. Gogoi, *Int. J. Microwave Wireless Technol.* **9** No 21, 143 (2015).
7. R. Jinger, N. Agrawal, *International Conference on Advanced Computing Networking and Informatics*, 381 (2019).
8. H.S. Mewaraab, D.J. Mahendra, M.S. Jitendra, K. Deegwala, *Int. J. Electron. Commun.* **83**, 222 (2018).
9. B.T. Ahmed, P.S. Olivares, J.L.M. Campos, F.M. Vazquez, *Int. J. Electron. Commun.* **94**, 348 (2018).
10. K.G. Thomas, M. Sreenivasan, *IEEE Trans. Anten. Propag.* **58** No 1, 27 (2010).
11. G. Srivastava, L. Hoang Son, R. Kumar, M. Khari, *Int. J. Wireless Pers. Commun.* **110**, 1021 (2016).
12. S.C. Puri, S. Das, M. Gopal Tiary, *Int. J. RF Microwave Comput.-Aid. Eng.* **29** No 8, 1 (2019).
13. D.S. Kolluru, P.B. Reddy, *AIP Conf. Proc.* **2407**, 203 (2021).
14. J.H. Park, M.Q. Lee, *Int. J. Electromag. Eng. Sci.* **21**, 64 (2021).
15. M.Z. Chowdhury, M. Shahjalal, M.K. Hasan, Y.M. Jang, *Appl. Sci.* **9**, 4367 (2019).
16. A. Basit, M.I. Khattak, A. Althuwayb, J. Nebhen, *Int. J. Electromag. Eng. Sci.* **21**, 316 (2021).
17. A. Abbas, N. Hussain, M.J. Jeong, J. Park, K.S. Shin, T. Kim, N. Kim, *Sensors* **20**, 777 (2020).
18. Y. Sung, *Int. J. Electromag. Eng. Sci.* **21**, 425 (2021).
19. El Arrouch Tarik, Najiba El, *J. Nano- Electron. Phys.* **15** No 1, 01026 (2023).

Мініатюризована Т- та перевернута Т-щілинна ультраширокосмугова антена з системою DG для 5G зв'язку

M. Jeyabharathi[1], D. Kumutha[2], P. Geetha[3], R. Delshi Howsalya Devi[4], Raja Manikandan[5], T. Sripriya[2]

[1] *Department of ECE, KSR College of Engineering, Namakkal, TN, India*
[2] *Department of ECE, Jeppiaar Institute of Technology, Kunnam, Sriperumbudur, TN, India*
[3] *Department of ECE, Karpaga Vinayaga College of Engineering and Technology, Chengalpattu, TN, India*
[4] *Department of AI&DS, Karpaga Vinayaga College of Engineering and Technology, Chengalpattu, TN, India*
[5] *Department of ECE, K.Ramakrishnan College of Technology, Trichy, TN, India*

У роботі пропонується *T*- і перевернута *T*-щілинна антена з дуже компактним розміром (3,00 × 1,72 × 0,08) мм³. Радіатор побудований над підкладкою FR-4. Система працює від 15 до 35 ГГц, отримуючи дуже високу пропускну здатність 20 ГГц. Спостерігається, що імпеданс високий та відображає резонанси на рівні 18,88; 21,1; 24,7; 28,0; 30,8 та 34,1 ГГц з мінімальним відображенням як – 19,6 дБ до максимум – 48 дБ. Параметри антени, такі як посилення вище 3DBI як мінімум, і до максимуму 10DBI спостерігається у всьому частотному діапазоні. VSWR підтримується нижче 2, а ефективність змінюється в межах 60 %. Дефектні наземні структури реалізуються для отримання покращеного посилення через діючу діапазон. Резонансні бали охоплюють групи запропоновані Міжнародним телекомунікаційним союзом для впровадження спектру 5G, таких як N 257 та N258 гуртів (26,50–29,50) ГГц, тоді як (15–35) ГГц потрапляє під діапазони KU, K та Q. Використання цих смуг покращує швидкість передачі даних та зменшує спотворення сигналу та робить антену хорошим кандидатом для додатків 5G.

Ключові слова: Антена ультраширокого діапазону, П’яте покоління (5G), Співвідношення хвилі стоячої напруги (VSWR), *T*- та інвертована *T* -щілинна антена, дефектна земля (DG).