JOURNAL OF NANO- AND ELECTRONIC PHYSICS
Vol. **16** No 1, 01001(5pp) (2024)

ЖУРНАЛ НАНО- ТА ЕЛЕКТРОННОЇ ФІЗИКИ
Том **16** № 1, 01001(5cc) (2024)

REGULAR ARTICLE

High-Gain Microstrip Patch Antenna with a Circular Slot for WiGig Applications in the V - Band

A.S.A. Gaid*✉, A.N.S. Ali†

Dept. of Communication & Computer Engineering, Faculty of Engineering and Information Technology, Taiz University, Taiz, Yemen

(Received 20 December 2023; revised manuscript received 16 February 2024; published online 28 February 2024)

This paper presents a simple, low-profile rectangular microstrip patch antenna operating in the V-band for WiGig applications. The initial design involves a rectangular microstrip patch antenna modified by inserting a small circular slot into the radiating patch to adjust the resonance at 60 GHz and enhance its reflection coefficient performance. To support the proposed structure, a fully grounded Rogers RT/Duroid-5880 dielectric substrate, having a dielectric constant of 2.2, a loss tangent of 0.0009, and a thickness of 0.12 mm, is employed. The final design measuring 4 × 7.4 × 0.12 mm^3 attains a stable gain above 10.33 dBi over the operational band with a maximum realized gain of 10.61 dBi and a minimum S_{11} value of – 60 dB at the center frequency. Likewise, the proposed antenna achieves a minimum VSWR of 1.026. In addition, the antenna realizes an impedance bandwidth of 2.22 GHz extending from 58.809 GHz to 61.029 GHz and a radiation efficiency above 89%. The CST is utilized for antenna design, simulations, and optimizations, while HFSS validates the simulation results. The simulation outcomes from both software simulators indicate a good level of agreement.

Keywords: V-Band, Compact antenna, High gain antenna, Circular slots, WiGig applications.

DOI: 10.21272/jnep.16(1).01001 PACS number: 84.40.Ba

1. INTRODUCTION

Wireless communication technologies have evolved at an incredibly rapid pace, particularly in the field of mobile communications. The rapid growth driven by increasing data volumes and the wide range of interconnected devices has drawn attention to the need for faster and more effective communication networks [1, 2].

In response to this need, 5G technology has emerged, addressing the demands for improved performance, shorter download times, and better video quality. High-fidelity video streaming, real-time communication, fast downloading, diminished latency, and applications like autonomous vehicles, telemedicine, and augmented reality are all made possible by 5G. To achieve these promises, 5G systems must shift to a broader frequency spectrum that matches the significant data transmission requirements across networks to carry out their mission effectively [3-6].

The millimeter wave spectrum contains this necessary breadth. However, due to path and rainfall losses, atmospheric and gaseous absorption, especially within the V-band (57 GHz to 64 GHz) used for Wireless Gigabit transmission over short distances (WiGig), millimeter waves experience significant challenges. To overcome these challenges, the need for antennas to compensate for the losses through high gain and effective signal steering arises [7, 8].

The ideal option for millimeter communications is microstrip technology because of its compact size, low profile, and compatibility with printed circuit boards. Despite these advantages, microstrip antennas have many drawbacks too, such as narrow bandwidth, poor gain, and limited directivity capabilities [9-12].

To overcome the said restrictions, researchers have come up with several approaches. They have investigated a combination of patch shapes and various techniques, such as circular rings with partial ground [13], elliptical rings [14], and rectangular shapes incorporated with different configurations of slots and slits [8], [15-18]. Further, the researchers examined the application of *E*-shaped radiators with circular slots [19] and utilized optimization tools like genetic algorithms (GA) [20], as well as innovative methods like metamaterials [21], frequency selective surfaces (FSS), and electromagnetic band gaps (EBG) [22] for improving the antenna's performance in terms of gain and bandwidth. Despite considerable efforts, the reported designs still have many shortcomings, including bulk physical size, limited bandwidth, poor gain, or complicated antenna geometry.

This work aims to develop a compact, high-gain antenna with reasonable bandwidth appropriate for 60 GHz (V-band) applications. The suggested design represents a compact antenna offering a moderate bandwidth of 2.22 GHz, an enhanced and steady gain above 10.33 dBi with a maximum of 10.61 dBi at the center frequency, and greater than 89% radiation efficiency for V-band applications. The overall size of the structure is 4 × 7.4 × 0.12 mm^3 and is placed on a Rogers RT/Duroid 5880 having a dielectric constant of 2.2 and a loss tangent of 0.0009. The proposed antenna operates in the license-free frequencies (inside the

---

[*] Correspondence e-mail: quddoos.gaid@taiz.edu.ye
[†] alaanabeelsaif@gmail.com

Cite this article as: A.S.A. Gaid et al., *J. Nano- Electron. Phys.* 16 No 1, 01001 (2024) https://doi.org/10.21272/jnep.16(1).01001

V-band) and is appropriate for WiGig applications.

The remainder of the article is organized as follows. The antenna's design and analysis are presented in Section 2. Section 3 investigates the effects of some parameters on reflection coefficient performance. Along with the verification, Section 4 shows simulation results for antenna characteristics. Finally, Section 5 concludes the work and outlines some future research possibilities.

2. ANTENNA DESIGN

Fig. 1 shows the optimized antenna proposed in this work. The design is a simple, compact, low-profile antenna fed through a microstrip transmission line with a length, $L_f = 0.97$ mm, and a width, $W_f = 0.35$ mm, matched with the 50 Ω input impedance of the radiating patch. The radiating element, composed of copper, has a length, $L_p = 1.5$ mm and a width, $W_p = 6$ mm, and was supported by a $4 \times 7.4 \times 0.12$ mm^3 Rogers RT-5880 substrate with a dielectric constant of 2.2, a loss tangent of 0.0009, and a complete ground plane of a thin copper sheet (with a thickness of 0.045 mm) with similar size to the substrate.

The initial design is a plain rectangular patch fed by a microstrip line. Yet, the obtainable reflection coefficient (S_{11}) performance against the operating frequencies, as shown in Fig. 2, is unsatisfactory, with a value near -15 dB, indicating a poor matching between the feed line and the radiating element. Besides, the impedance bandwidth achievable is also small (59 GHz to 60.8 GHz). Hence, further optimization is necessary to improve the impedance bandwidth and enhance matching between the microstrip transmission line and the radiating patch. To optimize the reflection coefficient performance, a circular slot with a radius of 0.3 mm is then inserted into the middle of the radiating patch, between the left and right edges, and near the feeding point. The other dimensions of the antenna remains unchanged.

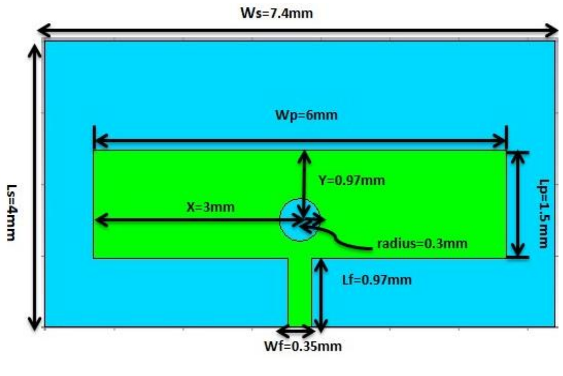


Fig. 1 – The geometry of the proposed optimized design

Fig. 2 compares the reflection coefficient performances of the initial design and the optimized antenna, showing a significant improvement in the S_{11}, from – 15 dB to about – 60 dB. Meanwhile, the impedance bandwidth also increases to about 2.22 GHz, which is reasonable.

3. PARAMETRIC ANALYSIS

Fig. 3 and Fig. 4 present the reflection coefficient performance for different values of the parameters X and Y. The results indicate that the optimal performance is obtainable when the center of the circular slot coincides with the point (X, Y) = (3 mm, 0.97 mm), where X denotes the location of the slot's center with respect to the patch's left edge, and Y defines the position of the slot's center regarding the patch's front edge. Accordingly, varying the value of these parameters below and beyond the optimal values yields a significant deterioration of the S_{11} performance besides the bandwidth narrowing and resonance shifting below the intended 60 GHz frequency.

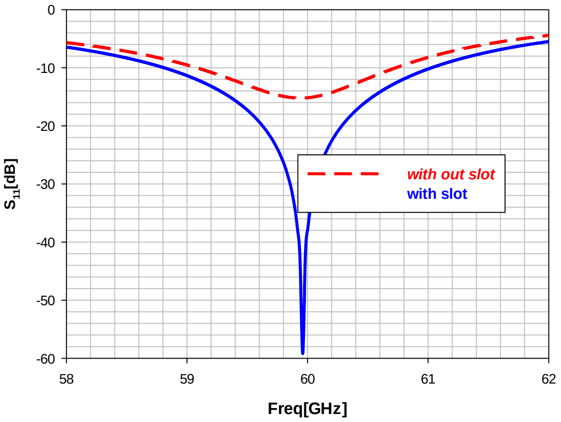


Fig. 2 – The reflection coefficient performance of the two design steps

Further, the slot's radius enormously influences the reflection coefficient performance of the proposed antenna, as shown in Fig. 5. The results reveal that the optimal value for the circular slot radius is 0.3 mm. At this value, the reflection coefficient performance is the soundest. On the other hand, modifying the radius value results in a corrupted performance, as we can observe.

4. SIMULATION RESULTS: VALIDATION AND DISCUSSION

This section describes and discusses the various performance metrics of the optimized design, including antenna reflection coefficient, VSWR, 2D radiation characteristics, surface current distribution, antenna gain, and radiation efficiency. In addition, the accuracy of the CST simulations is confirmed by simulating the optimized design again using HFSS and comparing the results with those obtained from CST.

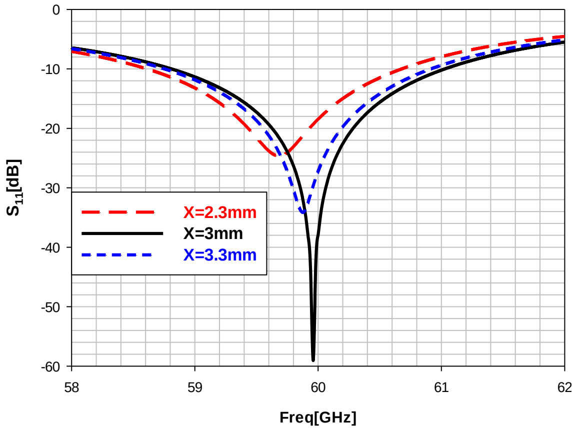


Fig. 3 – Effects of the slot's center position (X) with respect to the patch's right edge on the reflection coefficient performance

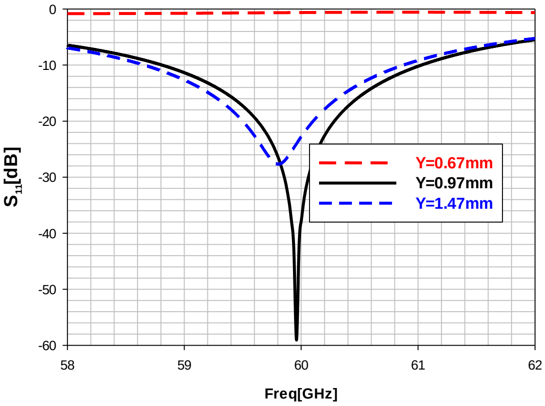


Fig. 4 – Effects of the slot's center position (Y) with respect to the patch's front edge on the reflection coefficient performance

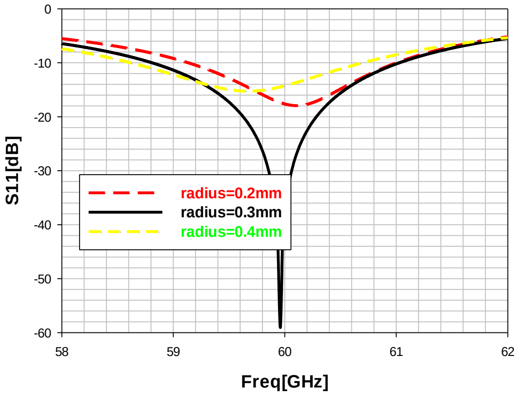


Fig. 5 – Effects of the slot's radius on the reflection coefficient performance

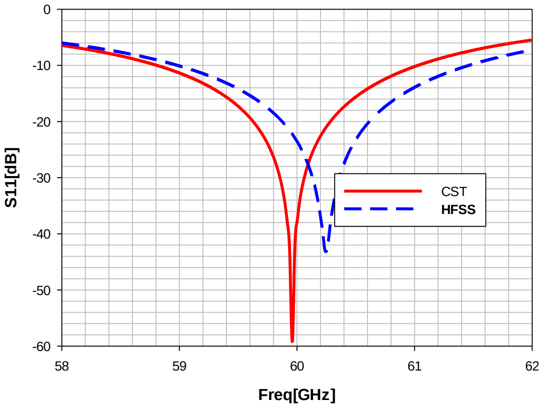


Fig. 6 – The reflection coefficient performance of the proposed design using HFSS and CST

Fig. 6 shows that results obtained from CST and HFSS are in acceptable agreement, with a little deviation in the resonance frequencies. The red line represents the reflection coefficient performance obtained from the CST software, which indicates that the impedance bandwidth achieved ranges from 58.809 GHz to 61.029 GHz, with a minimum S_{11} value of about – 60 dB at the center frequency (60 GHz). On the other hand, the black line represents the reflection coefficient performance obtained from the HFSS software, with an impedance bandwidth extending from approximately 59 GHz to 61.4 GHz and a minimum S_{11} value of – 45 dB at 60.2 GHz. Despite the slight deviation, the two curves are almost similar.

Fig. 7 displays the VSWR performance of the proposed antenna as predicted by CST and HFSS software packages. The CST-generated VSWR curve shows a value very close to the unity (1.026) at the resonance frequency of 60 GHz. Additionally, the curve obtained from the HFSS software (the black solid line) indicates a VSWR value close to the unity but with a tiny shift in the resonance to 60.2 GHz. The two curves demonstrate good similarity, indicating agreement between the results obtained from the two software packages. The impedance bandwidth obtained for VSWR ≤ 2 nicely agrees with that obtained for ≤ –10 dB and this agreement highlights the consistency and accuracy of the simulation results.

As for the radiation characteristics, Fig. 8 (a, b) presents the 2D radiation patterns at 60 GHz for $\varphi = 0°$ and $\varphi = 90°$. The figure exhibits a good consistency between the simulated patterns obtained from both simulators. The peak gain predicted by CST is 10.6 dBi, while that delivered by HFSS is 10.7 dBi.

In addition, Fig. 9 depicts the proposed antenna's gain and radiation efficiency as functions of operating frequencies. The curve with the blue dashed line shows that the realized gain varies from 10.33 dBi at the lowest frequency of the operational band to 10.61 dBi at the highest frequency of the operation band, with a value of 10.61 dBi at the 60 GHz (the center frequency). Furthermore, the antenna has a radiation efficiency of more than 89 % across the frequency band.

Moreover, Fig. 10 shows that the surface current density primarily concentrates on the feed line, the outer edges of the circular slot, and the left and right edges of the patch.

Finally, Table 1 tabulates a comprehensive comparison of the suggested antenna in this research work with some recently published designs. The performance metrics considered in the evaluation include antenna size, S_{11}, impedance bandwidth, and gain. Based on the outcomes, the proposed antenna exceeds all the antennas presented in [8], [13], [15], and [16] in terms of gain, antenna size (measured in mm^3), and reflection coefficient (S_{11}). Moreover, the proposed antenna has a reasonable impedance bandwidth, slightly surpassing that of the antennas in references [15] and [16], although it is a little less than that outlined in [8] and [13].

5. CONCLUSION

This paper introduces a simple and compact rectangular microstrip patch antenna with a circular slot in the radiating patch for WiGig applications in the V-band (60 GHz band). The proposed design realizes a high and stable gain of more than 10.33 dBi across the operational band, achieves a moderate impedance bandwidth of 2.22 GHz (58.809 GHz to 61.029 GHz), and steady radiation efficiency of almost 89% across the frequency band. The radiating patch is well matched to its feed line, as indicated by the low reflection coefficient (– 60 dB) and low VSWR (1.026). CST is employed for the antenna design, simulations, and optimizations, with the simulation results validated using HFSS. The outcomes obtained from both simulators show a good agreement, exhibiting the accuracy and effectiveness of the proposed antenna design. Future work involves the optimization of antenna bandwidth to cover the 60 GHz band from 57 GH to 64 GHz.

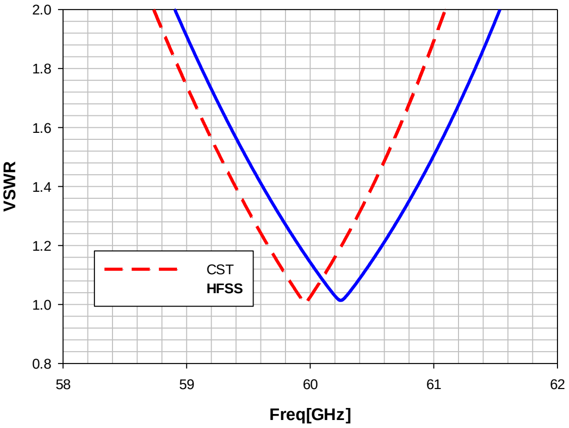
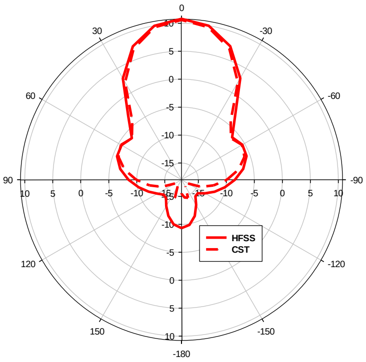
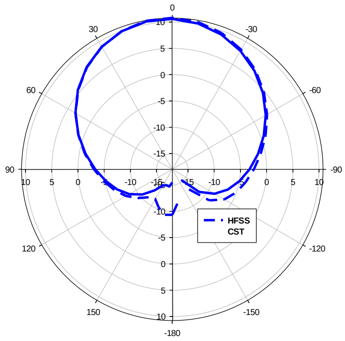


Fig. 7 – The VSWR performance of the proposed design using HFSS and CST



(a) $\varphi = 0°$



(b) $\varphi = 90°$

Fig. 8 – The 2D radiation patterns of the proposed design at 60 GHz using HFSS and CST: $\varphi = 0°$ (a) and $\varphi = 90°$ (b)

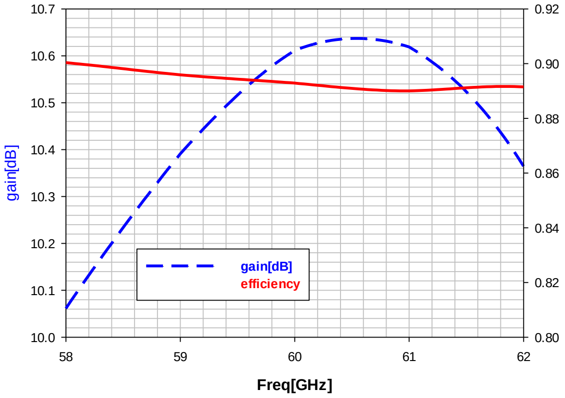


Fig. 9 – The antenna gain and radiation efficiency vs operating frequencies (CST)

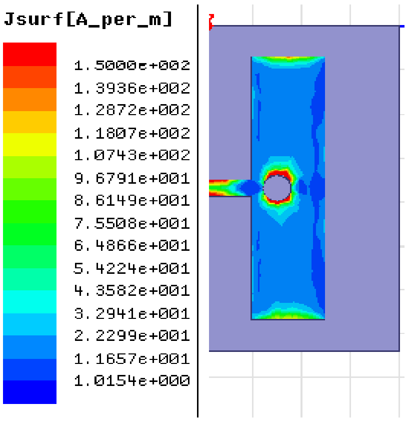


Fig. 10 – The surface current distribution at 60 GHz (HFSS)

Table 1 – Comparison of the proposed antenna with some other published works

Ref.	**[8]**	**[13]**	**[15]**	**[16]**	**This Work**
Ant. Size mm^3	3.18 × 4.84 × 0.308	9 × 11 × 0.25	5 × 20.5 × 1.59	4 × 5.8 × 0.16	4 × 7.4 × 0.12
F_{req} GHz	60.09	60	60	59.95	60
S_{11} dB	– 39.27	– 33	– 16	– 36.41	– 60
Gain dBi	8.4	4.8	5.90	9.2	≥ 10.33
B_W GHz	3	≈ 3.14	≤ 0.5	2.15	2.22

REFERENCES

1. P. Pirinen, *1st International Conference on 5G for Ubiquitous Connectivity (5GU)*, art. No 258061, 17 (Akaslompolo: IEEE: 2014).
2. R.N. Mitra, D.P. Agrawal, *ICT Express* **1** No 3, 132 (2015).
3. J. Navarro-Ortiz, P. Romero-Diaz, S. Sendra, P. Ameigeiras, J. Ramos-Munoz, J.M. Lopez-Soler, *IEEE Commun. Surveys & Tutorials* **22** No 2, 905 (2020).
4. S. Hakak, T.R. Gadekallu, P.K.R. Maddikunta, S.P. Ramu, M. Parimala, C.D. Alwis, M. Liyanage, *Vehicular Communications* **39**, 100551(2023).
5. K. Hameed, I.S. Bajwa, N. Sarwar, W. Anwar, Z. Mushtaq, T. Rashid, *Journal of Healthcare Engineering* **2021**, 1 (2021)
6. Y. Siriwardhana, P. Porambage, M. Liyanage, M. Ylianttila, *IEEE Commun. Surveys & Tutorials* **23** No 2, 1160 (2021).
7. N. Abdelatif, H.M. Zamel, A. Attiya, A. Awamry, *Progress In Electromagnetics Research C* **99**, 133 (2020).
8. Z.N.M. Alhaj, A. Saif, A.S.A. Gaid, 2nd *International Conference on Emerging Smart Technologies and Applications (eSmarTA)*, art. No. 9935397 1 (Ibb, Yemen: IEEE: 2022).
9. A.S.A. Gaid, A.A. Sallam, A.M.H. Aoun, A.A.A. Saeed, O.Y.A. Saeed, *IRICT 2020* **72**, 728 (2020).
10. A.M.H. Aoun, A.A.A. Saeed, A.S.A. Gaid, O.Y.A. Saeed, M.N.G. Mohammed, B. Hawash, *International Conference of Technology, Science and Administration (ICTSA)*, art.

No. 9406550, 1 (Taiz, Yemen: IEEE: 2021).

11. A.S.A. Gaid, A.A. Sallam, M.H.M. Qasem, M.S.G. Abbas, A.M.H. Aoun, *IRICT 2020* **72**, 647 (2020).
12. A.S.A. Gaid, M.H.M. Qasem, A.A. Sallam, E.Q.M. Shayea, *IRICT 2020* **72**, 717 (2020).
13. S.A. Alassawi, W.A.E. Ali, M.R.M. Rizk, *J. Nano- Electron. Phys.* **13** No 3, 03029 (2021).
14. S.A. Alassawi, W.A.E. Ali, N. Ismail, M.R.M. Rizk, *Microsystem. Technologies* **29**, 431 (2023).
15. B.V. Naik, D. Nath, *IEEE 10th Region 10 Humanitarian Technology Conference (R10-HTC)*, art. No. 9929963, 26 (Hyderabad: IEEE: 2022).
16. S. Didi, I. Halkhams, M. Fattah, Y. Balboul, S. Mazer, M. El Bekkali, *J. Nano- Electron. Phys.* **15** No 2, 02015 (2023).
17. M.M. Khan, K. Islam, M.N.A. Shovon, M. Baz, M. Masud, *Int. J. Anten. Propag.* **2021**, 1 (2021).
18. S.A.M. Alwazzan, A.A. Khamees, M. Al-Rubaye, *J. Commun.* **17** No 4 280 (2022).
19. T. Jang, C.S. Park, *IEEE Access* **10**, 79939 (2022).
20. H. El-Hakim, H.A. Mohamed, *Journal of Infrared, Millimeter, and Terahertz Waves* **44**, 752 (2023).
21. M. Alibakhshikenari, B.S. Virdee, A.A. Althuwayb, S. Aïssa, C.H. See, R.A. Abd-Alhameed, F. Falcone, E. Limiti., *Journal of Infrared, Millimeter, and Terahertz Waves* **42**, 17 (2021).
22. M. Shafeay, S. Kurnaz, H.M. Marhoon, *Des. Eng* No 8, 9867 (2021).

Мікрополоскова патч-антена з високим коефіцієнтом посилення з круглим слотом для додатків WiGig у V-діапазоні

A.S.A. Gaid, A.N.S. Ali

Dept. of Communication & Computer Engineering, Faculty of Engineering and Information Technology, Taiz University, Taiz, Yemen

У даній статті представлено просту, низькопрофільну прямокутну мікросмужкову антену, яка працює у V-діапазоні для програм WiGig. Початкова конструкція включає в себе прямокутну мікросмужкову антену, модифіковану шляхом вставлення невеликого круглого отвору в випромінювальну ділянку для регулювання резонансу на 60 ГГц і підвищення її коефіцієнта відбиття. Для підтримки запропонованої структури використовується повністю заземлена діелектрична підкладка Rogers RT/Duroid-5880, що має діелектричну проникність 2,2, тангенс втрати 0,0009 і товщину 0,12 мм. Остаточна конструкція розміром $4 \times 7.4 \times 0.12$ мм^3 досягає стабільного посилення понад 10,33 дБ і в робочому діапазоні з максимальним реалізованим посиленням 10,61 дБі та мінімальним значенням S11 – 60 дБ на центральній частоті. Так само запропонована антена досягає мінімального КСВ 1,026. Крім того, антена реалізує імпеданс смуги пропускання 2,22 ГГц, що розширюється від 58,809 ГГц до 61,029 ГГц, і ефективність випромінювання вище 89%. CST використовується для проектування антени, моделювання та оптимізації, тоді як HFSS перевіряє результати моделювання. Результати моделювання обох програмних симуляторів вказують на хороший рівень узгодженості.

Ключові слова: V-діапазон, Компактна антена, Антена з високим коефіцієнтом підсилення, Кругові слоти, WiGig програма.