Çukurova Üniversitesi Mühendislik Fakültesi Dergisi
Çukurova University Journal of the Faculty of Engineering
ISSN: 2757-9255 CİLT/VOLUME: 40 SAYI/ISSUE: 2 HAZİRAN/JUNE 2025

Radiation Pattern Reconfigurable Antenna with Single RF-Switch for 38 GHz and 55 GHz mm-wave Applications

Duygu Nazan GENÇOĞLAN [1,a]

[1] *Adana Alparslan Türkeş Science and Technology University, Faculty of Engineering, Department of Electrical-Electronics Engineering, Adana, Türkiye*

[a] ***ORCID**: 0000-0001-5014-9514*

Article Info
Received : 21.02.2025
Accepted : 08.05.2025
DOI: 10.21605/cukurovaumfd.1644169
Corresponding Author
Duygu Nazan GENÇOĞLAN
dngencoglan@atu.edu.tr
Keywords
Antenna
mm-wave
Multi-band
Radiation pattern reconfigurable
***How to cite:** GENÇOĞLAN, D.N., (2025). Radiation Pattern Reconfigurable Antenna with Single RF-Switch for 38 GHz and 55 GHz mm-wave Applications. Cukurova University, Journal of the Faculty of Engineering, 40(2), 313-323.*

ABSTRACT

This study proposes a radiation pattern reconfigurable antenna operating at 38 GHz and 55 GHz for 5G, 6G, and radar applications. The antenna employs a single BAR64-02V RF switch to achieve pattern and frequency reconfigurability, enabling efficient beam steering without complex feed systems. At 38 GHz, significant beam shifts occur in Phi = 90° (180° to 50°) and Theta = 90° (–50° to –131°), while at 55 GHz, a notable shift from –120° to –108° is observed at Phi = 0°. The ON-state supports triple-band functionality, and the OFF-state provides a dual-band response. High radiation efficiencies of 93% and 90.6% are achieved at 38 GHz and 55 GHz, respectively. Simulated VSWR and S_{11} results confirm impedance matching. The design demonstrates potential for mm-Wave applications, offering beamforming, interference control, and enhanced signal quality in next-generation wireless and radar systems.

38 GHz ve 55 GHz mm-dalga Uygulamaları için Tek RF Anahtarlı Radyasyon Deseni Yeniden Yapılandırılabilir Anten

Makale Bilgileri
Geliş : 21.02.2025
Kabul : 08.05.2025
DOI: 10.21605/cukurovaumfd.1644169
Sorumlu Yazar
Duygu Nazan GENÇOĞLAN
dngencoglan@atu.edu.tr
Anahtar Kelimeler
Anten
mm-dalga
Çok bantlı
Işıma örüntüsü yeniden yapılandırabilir
***Atıf şekli:** GENÇOĞLAN, D.N., (2025). 38 GHz ve 55 GHz mm-dalga Uygulamaları için Tek RF Anahtarlı Radyasyon Deseni Yeniden Yapılandırılabilir Anten. Çukurova Üniversitesi, Mühendislik Fakültesi Dergisi, 40(2), 313-323.*

ÖZ

Bu çalışmada, 5G, 6G ve radar uygulamaları için 38 GHz ve 55 GHz frekanslarında çalışan ışıma örüntüsü yeniden yapılandırılabilir bir anten önerilmektedir. Anten, ışıma örüntüsü ve frekans yeniden yapılandırılabilirliğini sağlamak için tek bir BAR64-02V RF anahtarı kullanmakta olup, karmaşık besleme sistemlerine ihtiyaç duymadan etkin hüzme yönlendirmesi sunmaktadır. 38 GHz frekansında, Phi = 90° (180°'den 50°'ye) ve Theta = 90° (–50°'den –131°'ye) açılarında belirgin hüzme kaymaları gözlemlenmiştir. 55 GHz'de ise Phi = 0° yönünde –120°'den –108°'e bir kayma meydana gelmiştir. ON durumunda anten üç bantlı, OFF durumunda ise çift bantlı çalışma sergilemektedir. 38 GHz'de %93, 55 GHz'de %90,6 radyasyon verimi elde edilmiştir. Simülasyon sonuçları, VSWR ve S_{11} parametrelerinin tüm durumlarda empedans uyumu sağladığını göstermektedir. Tasarım, mm-Dalga uygulamaları için bir aday olup, hüzme şekillendirme, girişim azaltma ve sinyal kalitesini artırma gibi avantajlar sunarak yeni nesil kablosuz ve radar sistemleri için önemli bir potansiyel göstermektedir.

1. INTRODUCTION

The ability of radiation pattern reconfigurable antennas to adjust to different operational settings and requirements has drawn a lot of interest in recent years. In complicated situations like urban settings or mobile applications where multipath fading is common, these antennas' ability to dynamically alter their radiation patterns is essential for improving communication performance [1-3]. Several methods, such as mechanical modifications, electronic switching, and the application of cutting-edge materials like liquid crystals and metamaterials, can accomplish the reconfigurability [4-6]. By focusing the radiation pattern's main lobe toward the intended communication direction and blocking unwanted signals from other directions, radiation pattern reconfigurable antennas can reduce interference and enhance signal quality, which is one of their main benefits [7-9]. To sustain high data rates and dependable connections in crowded metropolitan locations, for example, antennas built for 5G applications frequently include reconfigurable features to improve beam steering and shaping [10,11]. These antennas' capacity to alternate between several radiation patterns enables them to adjust to shifting environmental conditions and maximize performance [12,13]. Recent developments in the sector have resulted in the creation of a variety of reconfigurable antenna types, such as those that enable pattern reconfiguration by using varactor diodes, PIN diodes, and MEMS switches [14-16]. For instance, by modifying the current distribution, which directly influences the radiation characteristics, antennas using MEMS technology may transition between various radiation patterns [14,17]. In order to maximize the design and functionality of reconfigurable antennas and enable more intelligent adaptation to environmental changes, the integration of machine learning techniques has also been investigated [18,19].

Reconfigurable antennas are also essential to the development of 5G and other wireless communication technologies, especially in the millimeter-wave (mm-wave) band. By constantly changing their emission patterns, frequencies, and polarizations, these antennas improve communication effectiveness and versatility across a range of applications. 5G wireless communication is one of the most important uses for millimeter-wave reconfigurable antennas. For 5G, the FCC has allotted mm-wave channels, which provide broad bandwidths that can accommodate increased data rates and enhanced throughput [20,21]. In this spectrum, reconfigurable antennas have the ability to transition between several operating modes, which enables them to adjust to changing communication requirements and conditions. For example, in urban environments where line-of-sight conditions may vary quickly, antennas that can direct their radiation patterns to certain angles, such +45° and -45°, are very helpful [22,23]. Furthermore, the use of reconfigurable antennas with multiple-input multiple-output (MIMO) systems is essential for improving capacity and reliability in millimeter-wave communications. These antennas may be engineered to function over various frequency bands while preserving effective radiation patterns, hence alleviating problems associated with multipath fading and interference [24,25]. The capacity to modify the radiation pattern allows these antennas to concentrate energy in certain directions, enhancing signal quality and minimizing the risk of signal deterioration caused by obstructions or environmental influences [26,27].

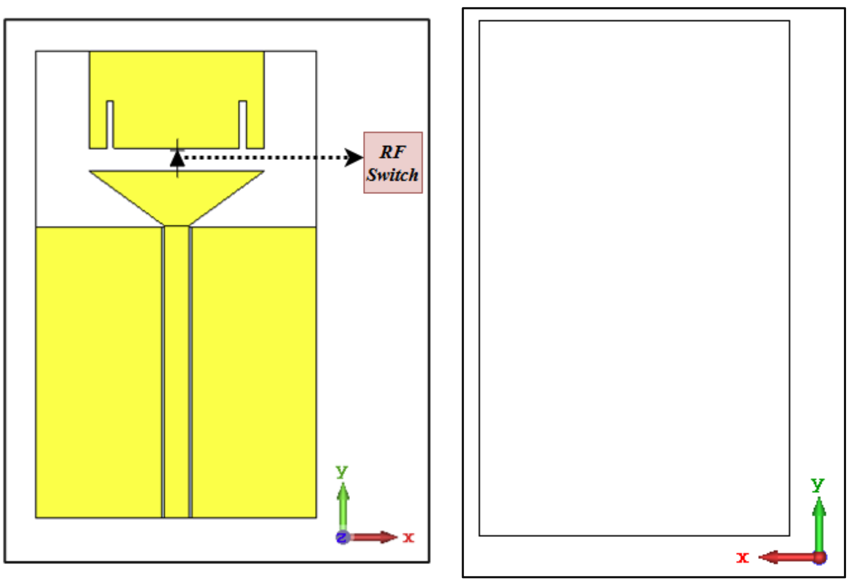
The design of these antennas often incorporates novel shapes and combinations that optimize performance while reducing size, a vital factor for mm-wave applications where space is constrained. The research conducted by Jiang et al. on a beam-switchable low-profile antenna underscores the significance of compact designs that can efficiently function at millimeter-wave frequencies while offering essential beam steering capabilities [27]. The advancement of frequency reconfigurable antennas capable of functioning across different bands, as highlighted by Parchin et al., emphasizes the adaptability necessary in contemporary wireless systems [28]. Moreover, the capacity to modify both frequency and radiation pattern is very beneficial in cognitive radio networks, where antennas need to adjust to fluctuating spectrum availability and user requirements. This flexibility is essential for maximizing resource use and guaranteeing dependable communication in changing contexts [29,30]. Current research in this domain investigates innovative methods to improve the reconfigurability and efficiency of mm-wave antennas, facilitating the development of more resilient and adaptable communication systems. In a nutshell, pattern reconfigurable antennas are set to significantly contribute to the progression of mm-wave technology, especially for 5G and future developments. Their capacity to dynamically modify radiation patterns not only improves communication efficacy but also accommodates the varied and advancing requirements of contemporary wireless applications.

This study presents an antenna structure engineered for reconfigurability in radiation pattern parameters for two specific high-frequency bands: 38 GHz and 55 GHz. These two frequencies are essential for applications necessitating directional flexibility in 5G and 6G communication systems and radar. Creating an antenna that functions consistently throughout an extensive frequency spectrum (1 GHz to 60 GHz) while preserving reconfigurable capabilities at two designated high-frequency bands presents significant challenges and is little discussed in contemporary research. The implementation of an RF switch for attaining reconfigurability in radiation patterns exemplifies a practical and compact solution in contrast to more intricate systems such as numerous feeding networks or supplementary antenna components.

The organization of this paper is structured to provide a comprehensive analysis of the proposed radiation pattern reconfigurable antenna for mm-wave applications. Section 1 introduces the importance of radiation pattern reconfigurability in next-generation wireless communication systems, particularly for 5G, 6G, and radar applications, highlighting recent advancements and research gaps. Section 2 details the antenna design, including substrate selection, structural parameters, and the integration of the RF switch for achieving pattern reconfigurability. Additionally, the RF switch's equivalent circuit and biasing network are discussed to provide insight into its operational mechanism. Section 3 presents simulation results, including reflection coefficient characteristics, VSWR, radiation efficiency, and detailed radiation pattern analysis for both 38 GHz and 55 GHz frequencies, comparing the ON and OFF states. The performance evaluation is supported by graphical representations and tabulated data for clarity. Section 4 summarizes the key findings, emphasizing the antenna's effectiveness in achieving dynamic beam steering with high radiation efficiency. Finally, Section 5 provides references to relevant literature, supporting the study's theoretical and practical contributions to the field of reconfigurable antennas.

2. ANTENNA DESIGN

The proposed novel antenna structure is illustrated in Figure 1. It is clear from Figure 1 that the proposed antenna structure has only one RF switch namely BAR64-02V to alter and navigate the antenna performance parameter configurations. The overall dimension of the proposed antenna is 20.3×15.2×1.6 mm3. The substrate material is Arlon AD 250C with the permittivity of 2.5, the copper thickness of 0.035 mm, and the thickness of 1.512 mm, respectively [31]. The main purpose is to select substrate material such as Arlon AD 250C, which has low dielectric loss for higher frequency applications, stable dielectric constant across wider frequency range, low moisture absorption, and compatibility with printed circuit board (PCB) antenna design [31-33]. Thus, the commonly used technique, which is PCB, is preferred for the implementation of the proposed antenna design [34-36]. Initially, the triangular monopole antenna design with respect to the dimensions given in Table 1. Then, the slotted radiating part is integrated into the proposed antenna design to provide the desired antenna performance parameters along with the radiation pattern reconfigurability and operating frequency alteration.



(a) (b)

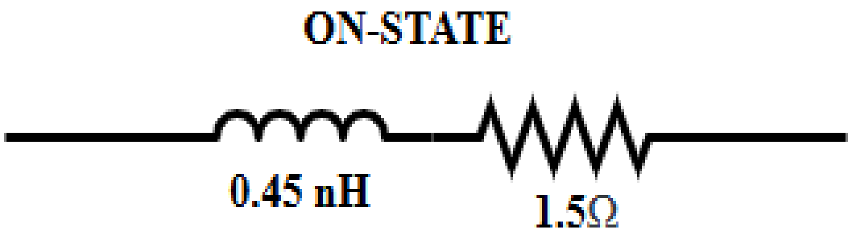
Figure 1. a) Front and b) Back views of the proposed antenna structure with one RF switch

Table 1. The proposed triangular monopole antenna dimensions

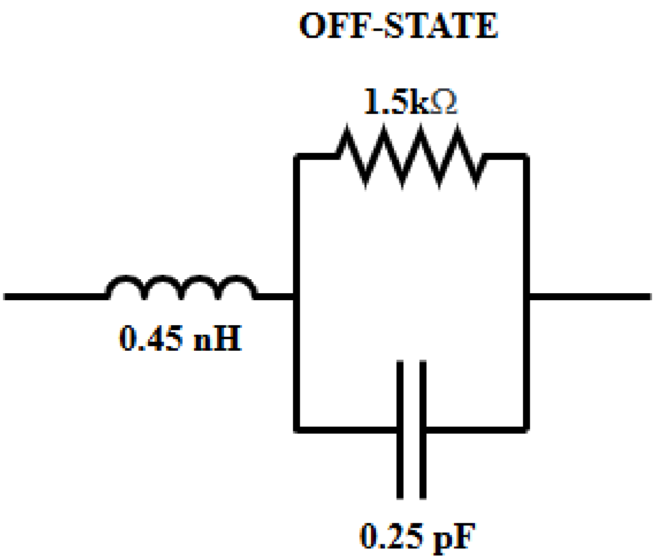
Physical dimensions	Value	Unit
Taper angle	36	Degree(°)
Substrate height	1.524	mm
Slot width	0.30	mm
Slot offset	4.26	mm
Slot length side	2.40	mm
Slot length bottom	6.08	mm
Relative permittivity	2.5	--
Guide width outer	1.27	mm
Guide width inner	1.05	mm
Ground plane width	15.20	mm
Ground plane length	12.67	mm
Feed gap	0.03	mm
Element width	7.6	mm
Element length	7.6	mm
Dielectric extension length	Element length + feed gap	mm

2.1. RF Switch Equivalent Circuit and Biasing Network

RF switch, which is BAR64-02V [37], has equivalent circuits with respect to the ON and OFF states. Figure 2a and Figure 2b are detailed the equivalent circuits and their corresponding values [38]. Figure 3 also details the bias circuitry of BAR64-02V for the further analysis and measurement procedure of the proposed antenna.



a)



b)

Figure 2. The detailed equivalent circuits of RF switch namely BAR64-02V

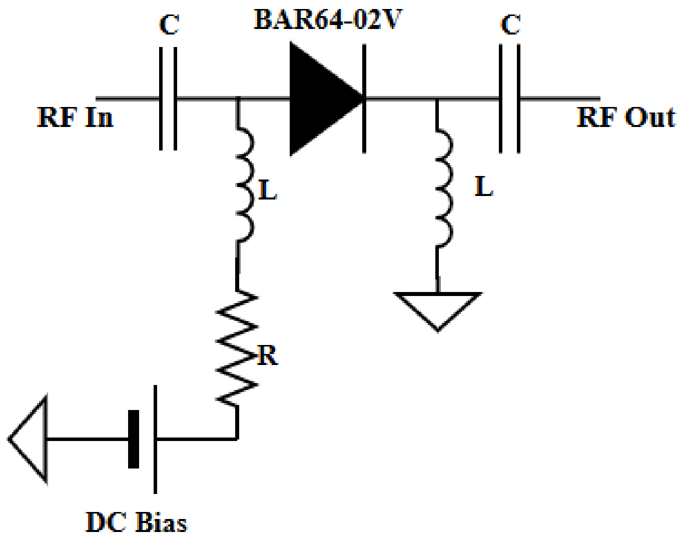


Figure 3. The bias circuitry for BAR64-02V for the measurement setup

3. RESULT AND DISCUSSIONS

The reflection coefficients of the proposed antenna are simulated with respect to the switch condition and given in Figure 4, respectively. It is clear from Figure 4 that the proposed antenna with ON state has a triple band characteristic and with OFF state has dual-band characteristic. It can be deduced from reflection coefficient analysis that the proposed antenna has common operating frequency bands, which makes the reconfigurability analysis for the radiation pattern characteristic of the proposed antenna. Table 2 details the RF performance parameters of the proposed antenna structure as well. It is also clear from Table 2 that the operating frequency ranges and corresponding bandwidths are quite promising values for the desired application areas. Figure 5 depicts the visualization of the operating frequency bands for both OFF and ON states. The horizontal bars represent the frequency ranges, with the OFF state shown in blue and the ON state in green.

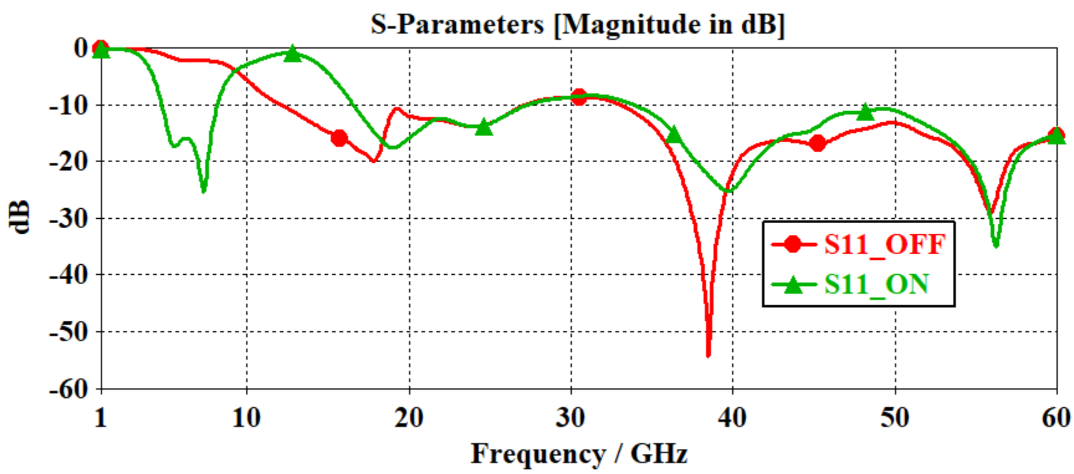


Figure 4. The simulated reflection coefficients of the proposed antenna along with ON and OFF states

Table 2. RF performance parameters of the proposed antenna along with ON and OFF states

States	Operating frequency band	Bandwidth
OFF	12.13-27.22 GHz	15.09 GHz
	33.12-60 GHz	26.88 GHz
ON	4.74 – 8.16 GHz	3.42 GHz
	16.6-27.4 GHz	10.8 GHz
	33.86-60 GHz	26.14 GHz

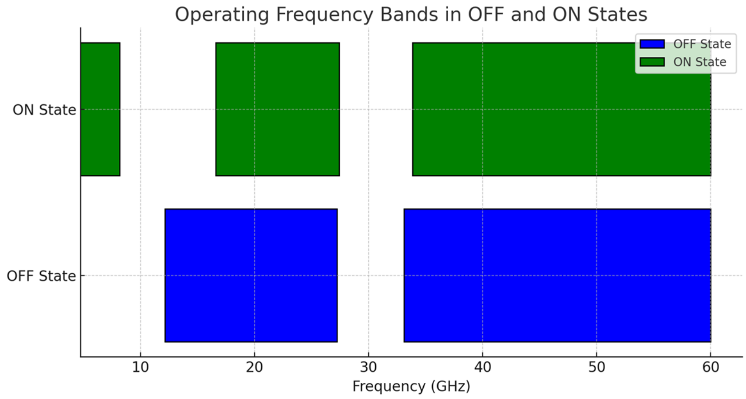


Figure 5. The visualization of proposed reconfigurable antenna frequency bands in OFF and ON states.

The other proposed antenna performance parameters are depicted in Figures 6 and 7, respectively. The simulated VSWR parameters with ON and OFF states also comply with the reflection coefficient parameters. On the other hand, simulated radiation efficiencies are quite acceptable values for the desired frequency range.

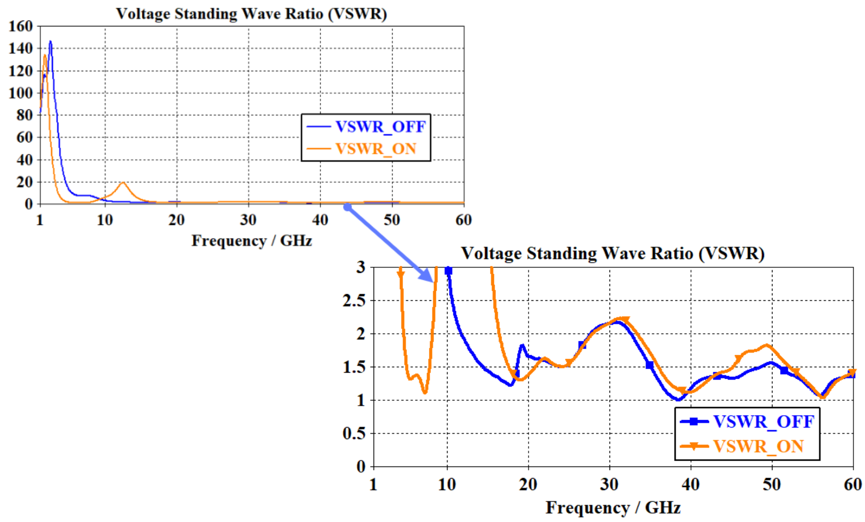


Figure 6. The simulated VSWR characteristic of the proposed antenna along with changing switch conditions

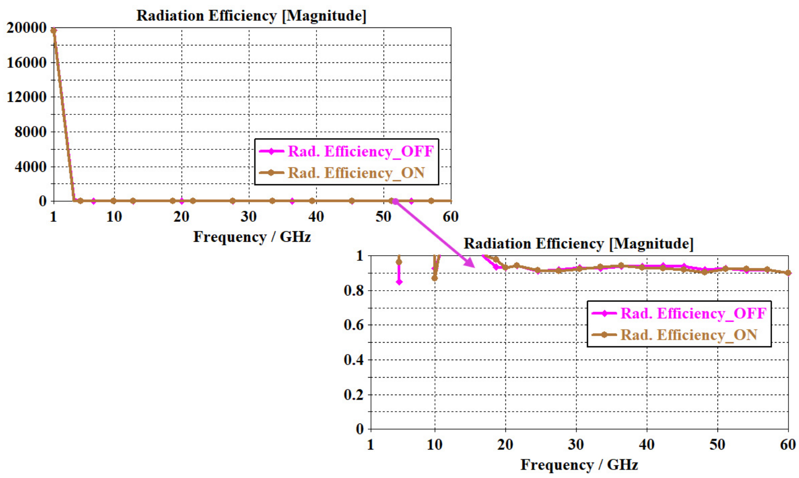


Figure 7. The simulated radiation efficiency characteristic of the proposed antenna along with changing switch conditions

The radiation pattern characteristics of the proposed antenna along with two states are presented at the frequency of 38 GHz in Figure 8. It is clear from Figure 8a that the main lobe directions are 180° and 169° for OFF and ON states, respectively. Table 3 is detailed by the additional information of the radiation pattern characteristic namely main lobe direction, main lobe magnitude, and angular width (3 dB). It can be deduced from Figure 8 and Table 3 that the main lobe direction shift in each state suggests that the antenna successfully achieves radiation pattern reconfigurability. The changes in beamwidth and magnitude might indicate a trade-off between directivity and gain when switching states. The substantial beam direction shift confirms that the antenna can significantly steer beams based on the switch state. The observed behavior is ideal for beamforming applications in 5G mm-Wave (38 GHz) networks, where dynamic radiation pattern control is essential. The proposed antenna provides radiation efficiencies of 92.8% (OFF state) and 93% (ON state), which is acceptable values.

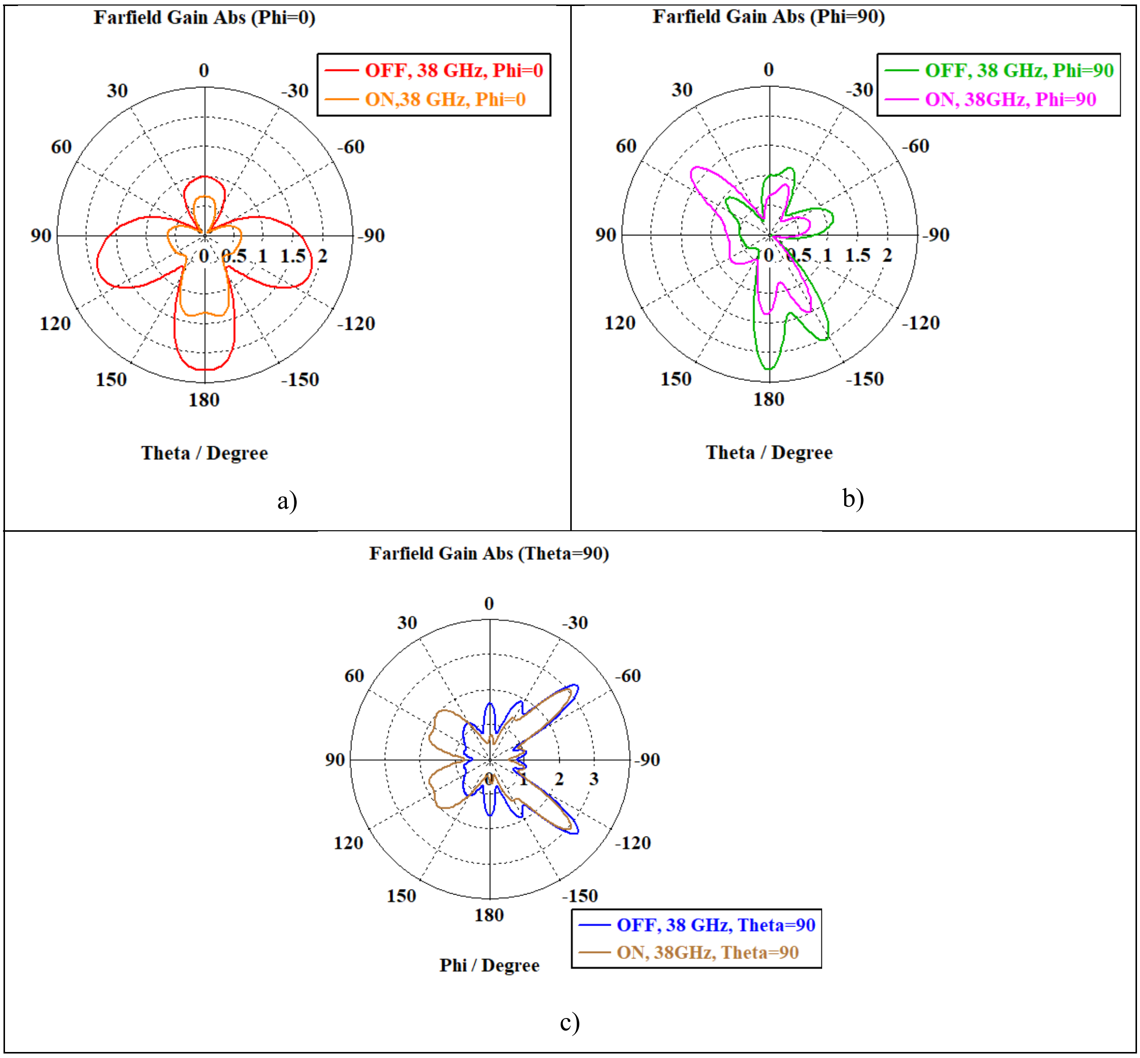


Figure 8. The radiation pattern characteristics of the proposed antenna along with two states at the frequency of 38 GHz

Table 3. The radiation characteristics for both states at 38 GHz

States (at 38 GHz)	Phi=0°		Phi=90°		Theta=90°	
	OFF	ON	OFF	ON	OFF	ON
Main lobe direction	180°	169°	180°	50°	-50°	-131°
Angular width (3 dB)	48.2°	61°	53.1°	37.1°	22.7°	22.4°
Main lobe magnitude	2.28	1.38	2.28	1.7	3.26	3.02

The radiation pattern characteristics of the proposed antenna along with two states are presented at the frequency of 55 GHz in Figure 9. It is clear from Figure 9a that the main lobe directions are -120º and -180º for OFF and ON states, respectively. Table 4 is detailed by the additional information of the radiation pattern characteristic namely main lobe direction, main lobe magnitude, and angular width (3 dB). It can be deduced from Figure 9 and Table 4 that the main lobe direction shift in each state suggests that the antenna successfully achieves radiation pattern reconfigurability. Especially, the most significant beam shift occurs in Phi = 0° (-120° to -108°), meaning the antenna can redirect signals effectively in this plane. Minimal beam shift in Phi = 90° and Theta = 90° suggests stability in those orientations. Phi = 90° has the narrowest beam, making it ideal for directional applications. Theta = 90° and Phi = 0° broaden when ON, indicating wider coverage potential. The observed behavior is ideal for beamforming applications, especially at Phi=0º due to the 12º shift for 5G mm-Wave (55 GHz) networks, 6G and V band applications. The substantial beam direction shift confirms that the antenna can significantly steer beams based on the switch state. The proposed antenna provides radiation efficiencies of 90.6% (OFF state) and 90.4% (ON state) at the frequency of 55 GHz.

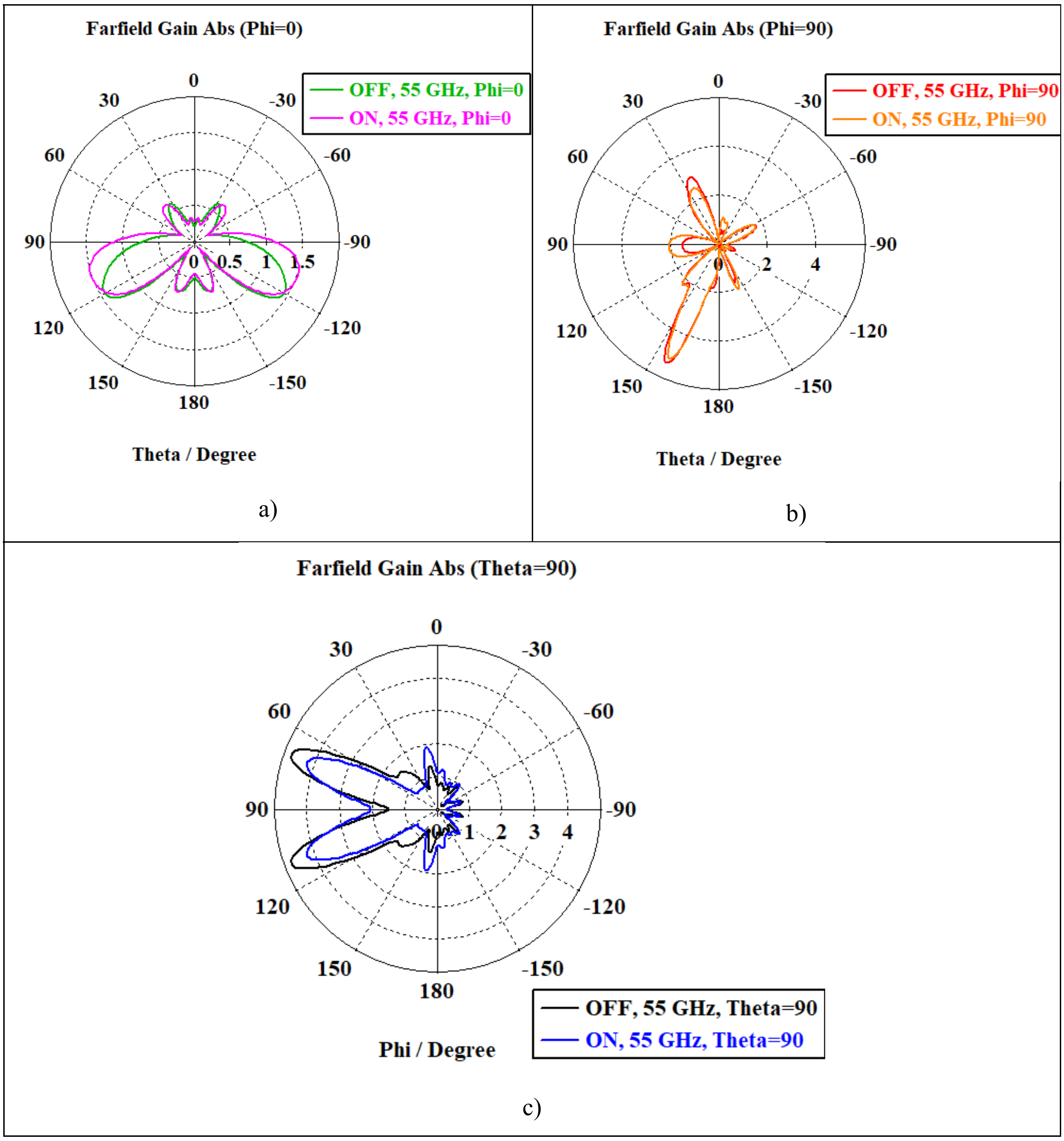


Figure 9. The radiation pattern characteristics of the proposed antenna along with two states at the frequency of 55 GHz

Table 4. The radiation characteristics for both states at 55 GHz

States (at 55 GHz)	Phi=0°		Phi=90°		Theta=90°	
	OFF	ON	OFF	ON	OFF	ON
Main lobe direction	-120°	-108°	156°	157°	69°	70°
Angular width (3 dB)	45.4°	50.7°	16.6°	17.5°	24.6°	27.9°
Main lobe magnitude	1.42	1.51	5.34	5.11	4.76	4.22

4. CONCLUSION

This study presents the design and analysis of a novel radiation pattern reconfigurable antenna that operates efficiently at two key mm-wave frequencies, 38 GHz and 55 GHz. The proposed antenna incorporates a single RF switch (BAR64-02V) to dynamically alter its radiation pattern, making it an optimal choice for next-generation wireless communication systems, including 5G, 6G, and radar applications. The integration of reconfigurability enables the antenna to adapt to varying communication requirements, providing enhanced beam steering and interference reduction. Through detailed simulations, it is observed that the proposed antenna exhibits significant beam direction shifts and variations in angular width and gain, confirming its effectiveness in achieving reconfigurable radiation patterns. At 38 GHz, the main lobe direction shifts from 180° (OFF) to 169° (ON) in Phi = 0°, and at 55 GHz, the shift is observed from -120° to -108°, highlighting its capability for effective beam steering. Additionally, the antenna maintains high radiation efficiency across both frequencies, with values exceeding 90%, ensuring reliable performance in practical implementations. The frequency reconfigurability of the proposed antenna extends across a broad spectrum, from 1 GHz to 60 GHz, with distinct reconfigurable bands in both ON and OFF states. This flexibility allows the antenna to support various applications requiring dynamic frequency adaptation, such as cognitive radio networks and multi-band communication systems. The compact and efficient design of the antenna, with a low-loss Arlon AD 250C substrate, ensures stable performance at high frequencies while maintaining a simple structure. The practical realization of radiation pattern reconfigurability using a single RF switch, as opposed to complex multi-feed networks, demonstrates a cost-effective and scalable solution for mm-wave applications. The proposed radiation pattern reconfigurable antenna demonstrates significant potential for use in beamforming applications, 5G/6G wireless networks, V-band satellite communication, and advanced radar systems. Future work may focus on hardware validation, prototyping, and integration with MIMO systems to further explore its capabilities in real-world scenarios.

5. REFERENCES

1. Padmanathan, S., Al-Hadi, A., Soh, P. & Al-Bawri, S. (2021). Dual band radiation pattern reconfigurable antenna for two-port 5G mobile terminals. *2021 IEEE Asia-Pacific Conference on Applied Electromagnetics (APACE),* 1-4
2. Liu, L., Li, W., Li, Y., Zhang, Z. & Feng, Z. (2014). A planar reconfigurable antenna with bidirectional end-fire and broadside radiation patterns. *Microwave and Optical Technology Letters, 56*(8), 1942-1946.
3. Huang, H. & Bu, H. (2021). Electrically small radiation pattern reconfigurable antenna with expanded bandwidth and high front-to-back ratio. *Progress in Electromagnetics Research M, 103,* 103-113.
4. Shi, H., Li, J., Zhu, S., Zhang, A. & Xu, Z. (2018). Radiation pattern reconfigurable waveguide slot array antenna using liquid crystal. *International Journal of Antennas and Propagation, 2018,* 1-9.
5. Dakhli, S., Floc'H, J., Mahdjoubi, K., Rmili, H. & Choubani, F. (2014). A reconfigurable radiation pattern metamaterial-inspired antenna. *2014 Loughborough Antennas and Propagation Conference, LAPC, 1-4.*
6. Hao, J., Ren, J., Du, X., Mikkelsen, J., Shen, M. & Yin, Y. (2021). Pattern-reconfigurable yagi–uda antenna based on liquid metal. *IEEE Antennas and Wireless Propagation Letters, 20*(4), 587-591.
7. Liu, N. & Wang, A. (2010). A novel tree-shaped antenna with reconfigurable radiation pattern. *ICMMT,* 359-361.
8. Patriotis, M., Ayoub, F., Tawk, Y., Costantine, J. & Christodoulou, C. (2021). A four-element antenna array system with 15 reconfigurable radiation patterns. *IEEE Access, 9,* 108579-108585.
9. Gao, F. (2024). A radiation-pattern reconfigurable antenna array for vehicular communications. *Sensors, 24*(13), 4136.

10. Isa, S., Jusoh, M., Sabapathy, T., Nebhen, J., Kamarudin, M., Osman, M. & Soh, P. (2022). Reconfigurable pattern patch antenna for mid-band 5G: a review. *Computers Materials & Continua, 70*(2), 2699-2725.

11. Aboualalaa, M. (2023). A pattern reconfigurable antenna using eight-dipole configuration for energy harvesting applications. *Sensors, 23*(20), 8451.

12. Ghassemiparvin, B. & Ghalichechian, N. (2019). Reconfigurable antennas: quantifying payoffs for pattern, frequency, and polarisation reconfiguration. *IET Microwaves Antennas & Propagation, 14*(3), 149-153.

13. Mahlaoui, Z., Antonino-Daviu, E. & Ferrando-Bataller, M. (2021). Radiation pattern reconfigurable antenna for IoT devices. *International Journal of Antennas and Propagation, 2021,* 1-13.

14. Deng, Z., Gan, J., Wei, H., Gong, H. & Guo, X. (2016). Ka-band radiation pattern reconfigurable antenna based on microstrip MEMS switches. *Progress in Electromagnetics Research Letters, 59,* 93-99.

15. Wu, C. & Ma, T. (2014). Pattern-reconfigurable self-oscillating active integrated antenna with frequency agility. *IEEE Transactions on Antennas and Propagation, 62*(12), 5992-5999.

16. Idris, I., Hamid, M., Kamardin, K. & Rahim, M. (2017). A multi to wideband frequency reconfigurable antenna. *International Journal of RF and Microwave Computer-Aided Engineering, 28*(4), e21216.

17. Deng, Z., Gan, J., Wei, H., Gong, H. & Guo, X. (2016). Ka-band radiation pattern reconfigurable antenna based on microstrip mems switches. *Progress in Electromagnetics Research Letters, 59,* 93-99.

18. Montaser, A. (2023). Machine learning based design of pattern reconfigurable antenna. *IEEE Access*, *11,* 33121-33133.

19. Mohan, R. & Padmasine, K. (2022). A review on materials and reconfigurable antenna techniques for wireless communications: 5G and IoT applications. *Progress in Electromagnetics Research B, 97,* 91-114.

20. Alekhya, B., Murugan, N.A., Madhav, B.T.P. & Reddy, N.K.R. (2021). Millimeter-wave reconfigurable antenna for 5G Wireless Communications. *Progress in Electromagnetics Research Letters, 101,* 107-115.

21. Tang, S., Chiu, C. & Murch, R. (2020). Investigation of a reconfigurable pixel antenna for millimeter wave bands. *2020 IEEE International Symposium on Antennas and Propagation and North American Radio Science Meeting*.

22. Gerami, H.H. & Kazemi, R. (2024). Development of a compact metasurface antenna with reconfigurable pattern through mode combination technique for 5G mm-wave applications. *IET Microwaves, Antennas & Propagation, 18*(12), 885-897.

23. Trzebiatowski, K., Rzymowski, M., Kulas, L. & Nyka, K. (2020). Simple 60 GHz switched beam antenna for 5G millimeter-wave applications. *IEEE Antennas and Wireless Propagation Letters, 20*(1), 38-42.

24. Alsaab, N., Alhassoon, K., Alsaleem, F., Alsunaydih, F.N., Madbouly, S.O., Khaleel, S.A. & Shaban, M. (2025). High-performance series-fed array multiple-input multiple-output antenna for millimeter-wave 5G networks. *Sensors, 25*(4), 1036.

25. Mshwat, W.A., Kosha, J., Salisu, A., Ullah, A., Ali, N.T., Issa, E. & Abd-Alhameed, R. (2024). Compact reconfigurable MIMO antenna for 5G and Wi-Fi applications. *IEEE Access*.

26. Akinola, S. & Reddy, L. (2023). The enhancing energy efficiency in hyperthermia treatment: a frequency-reconfigurable l-shape antenna design and analysis. *Technology Audit and Production Reserves*, 1(1(75)), 43-50.

27. Jiang, Z., Su, T., & Hou, J. (2018). A beam-switchable low-profile antenna based on substrate integrated waveguide. *International Journal of RF and Microwave Computer-Aided Engineering, 28*(9), 1-8.

28. Parchin, N.O., Al-Yasir, Y.I.A., Abdulkhaleq, A.M., Elfergani, I., Rayit, A., Noras, J.M. & Abd-Alhameed, R.A. (2018). Frequency reconfigurable antenna array for mm-wave 5G mobile handsets. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering. *Springer,* 438-445.

29. Tang, S., Chiu, C. & Murch, R. (2020). Investigation of a reconfigurable pixel antenna for millimeter wave bands. *2020 IEEE International Symposium on Antennas and Propagation and North American Radio Science Meeting*.

30. Jilani, S.F., Rahimian, A., Alfadhl, Y. & Alomainy, A. (2018). Low-profile flexible frequency-reconfigurable millimetre-wave antenna for 5G applications. *Flexible and Printed Electronics, 3*(3), 035003.

31. Available Online: https://www.rogerscorp.com/advanced-electronics-solutions/ad-series-laminates/ad250c-laminates. Access date: 20.02.2025.
32. Available Online: https://www.andwinpcb.com/arlon-diclad-527/. Access date: 20.02.2025.
33. Available Online: https://www.matweb.com/search/datasheet.aspx?matguid=edefd245b2de46ceb5f3d8f1f63740f7&ckck=1. Access date: 20.02.2025.
34. Akgöl, O. (2018). PCB dairesel yama anten tabanlı etanol ve metanol algılayıcı tasarımı. *Çukurova Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi, 33*(2), 287-296.
35. Ünal, E. ve Doğan, C. (2020). Metamalzeme yapılarıyla fraktal anten parametrelerinin iyileştirilmesi. *Çukurova Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi, 35*(1), 67-78.
36. Biçer, M.B. ve Akdağlı, A. (2016). Ultra geniş bant uygulamaları için yeni bir yığın monopole mikroşerit anten. *Çukurova Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi, 31*(ÖS2), 21-26.
37. Datasheet for Infineon BAR50-02V, Silicon PIN Diode, Infineon Technologies AG. Available Online: https://www.infineon.com/dgdl/Infineon-BAR64-02V-DS-v01_01-EN.pdf?fileId=5546d462689a790c01690f0247ae38fc.
38. Varshney, A., Neebha, T.M., Sharma, V., Jency, J. G., & Andrushia, A. D. (2023). Dodecagon-shaped frequency reconfigurable antenna practically loaded with 3-delta structures for ISM band and wireless applications. *IETE Journal of Research, 69*(11), 7747-7759.