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Reconfigurable Dual-Band Microstrip Antenna for Middle Band 5G Applications

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Abstract
A reconfigurable inset-fed Microstrip Patch Antenna (MPA) for dual-band behavior and stable-radiation direction has been demonstrated in this research. The suggested reconfigurable antenna has dimensions of 60×50 mm^2 and is printed on an FR4 substrate that is 1.5 mm thick and has a dielectric constant (ε_r) and loss tangent ($\tan\delta$) equal to 4.3 and 0.02, respectively. An inset-fed line with an impedance of 50Ω is used to feed the proposed antenna structure. The parasitic capacitance is efficiently added to the proposed structure by using the slitline approach. The proposed antenna is tested and simulated, where the result shows two resonant frequencies with S_{11} values less than -10 dB ($S_{11} \leq -10$). The first resonant frequency is found at 2.45 GHz with a value equal to -30.5 dB, while the second resonant is found at 3.54 GHz with a value equal to -32 dB. Moreover, the slits include two PIN diodes. After analyzing the antenna, two reconfigurable bands are obtained for various uses with stable radiation direction. The suggested antenna is constructed and measured, and the outputs of the simulation and the measurements show good agreement.

Keywords
Inset-Fed, Microstrip Patch Antenna, Reconfigurable Antenna, 5G Application.

I. Introduction

To accommodate the introduction of new standards, telecommunications systems must be able to integrate multiple standards into a single antenna [1]. Reconfigurable antennas are among the possible solutions that meet the necessary specifications [2]. Because MPAs are lightweight, inexpensive, and have a low profile, researchers typically use them to create reconfigurable antennas [3]. Various categories of reconfiguration techniques exist, including electrical, mechanical or physical, photoconductive or optical, and reconfiguration with smart materials that are tunable [4, 5]. Through the electrical reconfiguration approach, solid-state switching components including varactors, RF-MEMS, and PIN diodes are integrated into the antenna construction to modify the current distribution or field arrangement of the radiating element. The RF PIN diode is the most advantageous of all due to its enormous power handling capacity, quick switching speed, and cheap cost [6, 7]. In addition, slot-loaded patch antennas with different switches offer a wide reconfigurable frequency span [8, 9]. Several reconfigurable antennas have been proposed in the past [10–12]. Most of the proposed sub-6 GHz antennas are reconfigurable, using RF-PIN diodes for frequency reconfigurability to achieve single-band, dual-band, and multiple-band reconfigurability [13–15]. Most of the previous works suffer from unstable radiation direction when designing a reconfigurable frequency antenna.

In this article, a reconfigurable structure-based MPA for dual bands with stable radiation direction applications is proposed. The suggested antenna is characterized by a size of 60×50 mm^2 and fed by an inset-fed microstrip line of 50Ω impedance. Two PIN diodes are employed in the slit lines-based antenna for reconfigurable behavior. The suggested antenna structure is designed and simulated using the CST simulator. Finally, the proposed antenna structure is fabricated and measured, and good agreement is shown between the measurement and modeling results.

II. Antenna Design Methodology

The aim is to achieve dual-band operation for the reconfigurable MPA. The antenna is designed to operate at two targeted resonant frequencies; the resonant frequencies are targeted at 2.45 GHz and 3.5 GHz, respectively. These resonant frequencies are chosen based on the requirements of middle band 5G applications, as mentioned in the title of the paper. The structure of a reconfigurable MPA with two PIN diodes is shown in Fig. 1 below. The proposed structure is mounted on a 1.5 mm thick FR-4 substrate with a dielectric constant (ε_r) and loss tangent ($\tan\delta$) equal to 4.3 and 0.02, respectively. The antenna is characterized by a total size of 60×50 mm^2. An inset-fed line with an impedance of 50Ω is used to feed the proposed antenna structure. A slit-line technique is applied to enhance the antenna performance with dual-band frequency achievement. Moreover, such a technique increases the current length and parasitic effect achievement. A typical MPA with an inset-fed line is shown in Fig. 2(a). The rectangular patch is characterized by dimensions of 20×26 mm^2. Eq. (1), (2), and (3) are employed to design the conventional antenna structure [16–20].

$$\varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[\frac{1}{\sqrt{1+12\left(\frac{h}{W}\right)}}\right] \quad (1)$$

$$W = \frac{c}{2 f_{f\sigma}\sqrt{\frac{z_r+1}{2}}} \quad (2)$$

$$L = \frac{c}{2 f_r \sqrt{\varepsilon_{\text{reff}}}} - 2\Delta L \quad (3)$$

Where ε_{eff} is the effective dielectric constant, ε_r is the relative permittivity, and C represents the speed of light. L is the actual length, and W is the feedline width of the microstrip. Furthermore, a full ground plane is applied on the other face of the substrate. A microstrip line fed with a 50 Ω inset is used to feed a conventional antenna. The width of the inset-fed line is 2.868 mm, the inset distance is 6.59 mm, and the inset gap is 1.43 mm. The slit-line technique is applied to achieve the parasitic-capacitance effect and miniaturize the antenna size by manipulating the current path. Finally, a reconfigurable design is presented, where two ideal electronic switches (PIN diodes) are inserted in the slit-lines to manipulate the antenna's frequency.

TABLE I. Reconfigurable Antenna Design Parameters (In mm)

Parameters	Value	Parameters	Value
Ws	50	Ls	60
Wp	26.08	Ld	20.03
Wf	2.87	Lf	19.5
A	13.44	B	1.43
C	4.94	D	143
E	7.74	F	1.43
H	6.59	G	1.43

Finally, the details of the geometrical antenna are presented in Table I, and the two PIN diodes are inserted in the slit lines to manipulate the antenna's frequency performance by changing the current path and parasitic effects.

Fig. 1, shows a proposed of reconfigurable antenna structure (a) front view, (b) back view, and (c) PIN-Diode equivalent circuit.

III. Results And Discussions

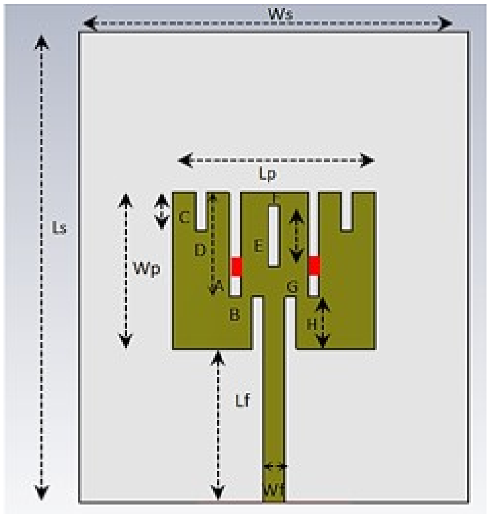
Through the use of the CST software program, the slitline-based antenna structure is investigated and analyzed. The results so obtained are compared with the conventional design. The S_{11} results are presented in Fig. 3 below. The result shows that two resonant frequencies are generated with S_{11} values less than -10 dB ($S_{11} \leq -10$). For the conventional design, at 3.5 GHz, the first resonant frequency is detected with an S_{11} value of -16 dB. On the other hand, the second resonance is located at 5.45 GHz with a value equal to -17 dB. For the slitline-based modified antenna, the first resonant frequency is found at 2.45 GHz with an S_{11} value equal to -30.5 dB. While the second resonance is found at 3.54 GHz with an S_{11} value equal to -32 dB.

The reconfigurable behavior is studied and the antenna performance is introduced. The two PIN diodes are represented by inserting a stripline in the slitlines where two states are present, ON and OFF state. Four states explain the behavior of these two switches as seen in Table II.

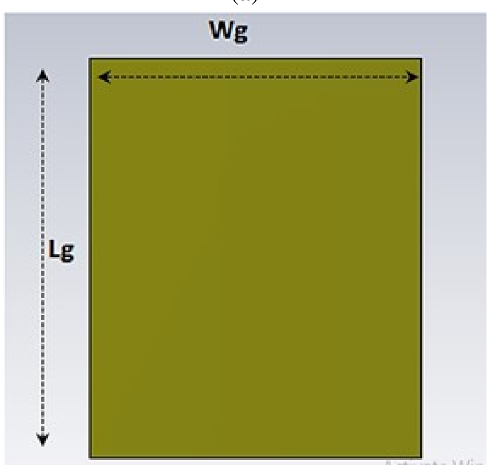
TABLE II. Different States of PIN Diodes

States	PIN-D_1	PIN-D_2	fr (GHz)
State1	OFF	OFF	2.45, 3.54
State2	OFF	ON	2.71, 3.54
State3	ON	OFF	2.71, 3.54
State4	ON	ON	3.54

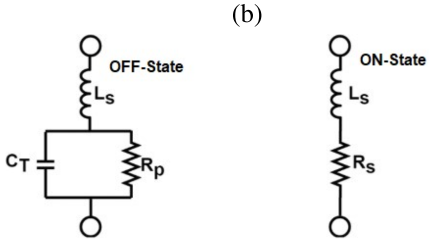
In Fig. 4, the reflection coefficient $S_{11} \leq -10$ dB for all switch states is displayed. The effect of two switch states



(a)



(b)



(c)

Fig. 1. Proposed reconfigurable antenna structure (a) front view, (b) back view, and (c) PIN-Diode equivalent circuit.

on the generating frequency band is studied. In the state where the two switches are off, the result shows two resonant frequencies are generated with S_{11} values less than -10 dB ($S_{11} \leq -10$). The first resonant frequency is found at 2.45 GHz, with an amplitude value equal to -30.5 dB. While the second resonant is found at 3.54 GHz with an amplitude equal

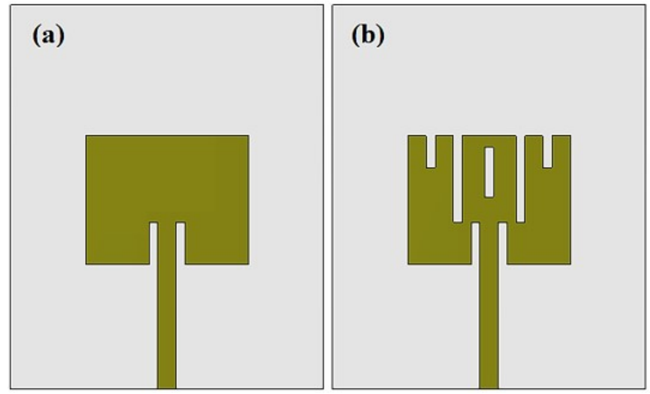


Fig. 2. shows the Microstrip antenna modifying steps; a) Conventional antenna, b) Modified antenna.

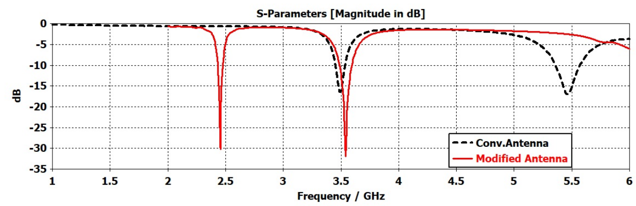


Fig. 3. Reflection coefficient S11 of the suggested antenna structure.

to -32 dB.

When Switch-1 is in the ON state and Switch-2 is in the OFF state, two resonant frequencies are found: the first resonant is found at 2.71 GHz with an S_{11} value of -12.43 dB, while the second resonant is found at 3.54 GHz with an S_{11} value of -32.34 dB.

On the other hand, when Switch-1 is in the OFF state and Switch-2 is in the ON state, two resonants are found. The first resonant is found at 2.71 GHz with an S_{11} value of -12.43 dB, while the second resonant is found at 3.54 GHz with an S_{11} value of -32.34 dB. The last case is related to both ideal diodes in the ON state. A single resonant frequency is produced at 3.54 GHz with an S_{11} value of -33.3 dB.

For all switching cases, the current behavior of the suggested antenna is found and studied at different resonant frequencies, as seen in Fig. 5. In the case where all switches are in the off state, the current in the radiating layers is found to take a long path of moving in the patch, around the slits, and that leads to a reduction in antenna size due to large fringing fields. While in other states, the current is found to take the short path and cross the switch, which leads to low size reduction. Fig. 6 and Fig. 7 show, respectively, the 3D and 2D radiation patterns of the proposed antenna. The suggested

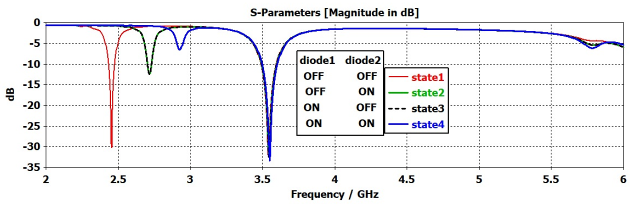


Fig. 4. S11 Simulation of the suggested reconfigurable antenna for all diode states.

antenna showed a maximum gain of 3.07 dB at 3.54 GHz.

In Fig. 8, the modified antenna structure is manufactured by employing the CNC-Machine type of LPKF Proto Mat S100. Furthermore, the Vector Network Analyzer type of Anritsu-MS4642A is used to test and measure the proposed antenna structure. A strip connector is used instead of a pin-diode in the case of the ON-state. The measurement result is found and compared with those from the simulation, and excellent agreement is observed with insignificant differences, as seen in Fig. 9.In Table III the proposed antenna structure is compared with other related works in the literature in terms of size, operating frequency, and reconfigurable type. Compared with the other research works, it is observed that the proposed antenna shows good performance related to structure size.

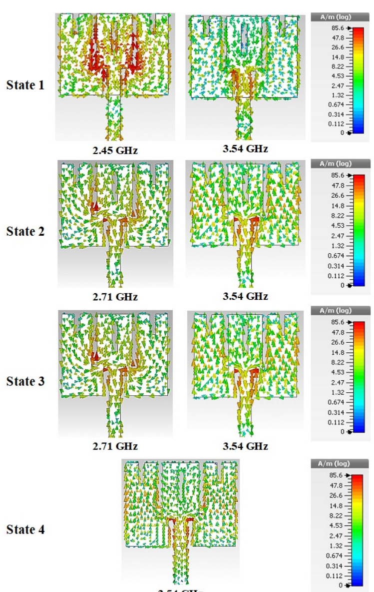


Fig. 5. Current distribution of the reconfigurable antenna at different cases and different resonant frequencies.

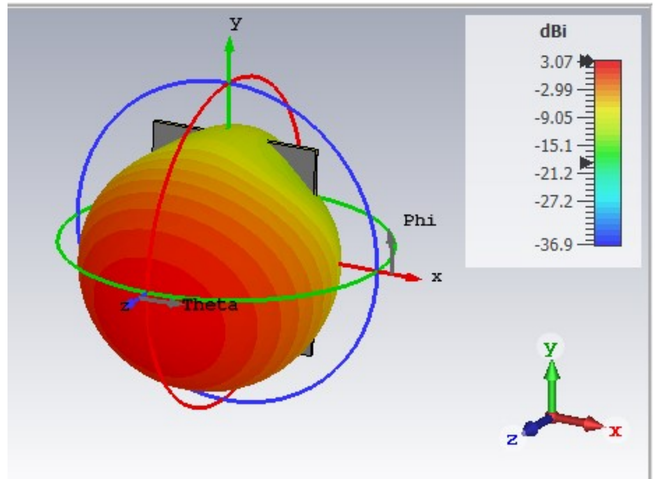


Fig. 6. The recommended antenna's 3D radiation pattern at 3.54 GHz.

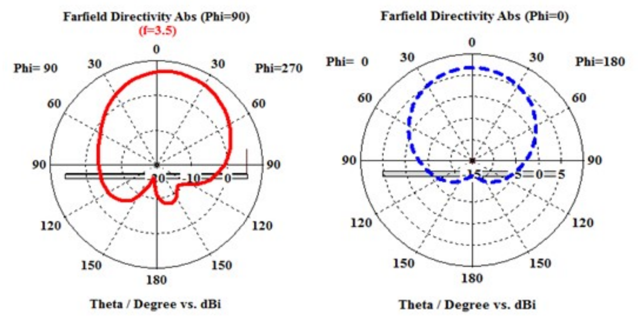


Fig. 7. Antenna's 2D radiation pattern.

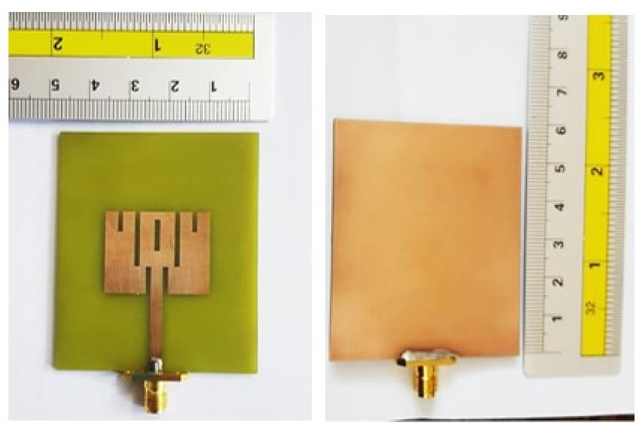


Fig. 8. Manufactured Antenna Structure Prototype.

IV. CONCLUSIONS

This paper introduced a reconfigurable microstrip patch based on slitlines. By adjusting the current path, the slit-line technique was utilized in the antenna to produce the parasitic-

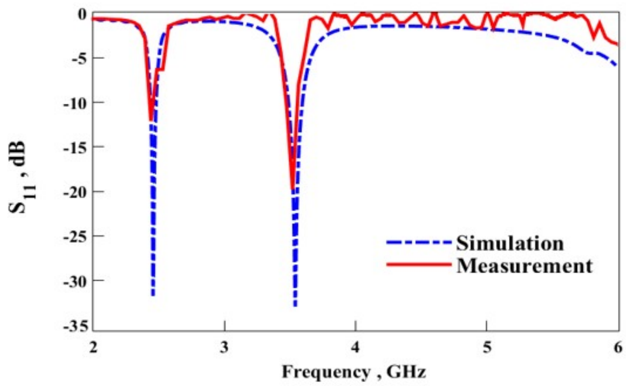


Fig. 9. Measurement results compared with those from the simulation.

TABLE III. COMPARATIVE OF THE PROPOSED STRUCTURE WITH OTHER RELATED WORKS.

Ref.	Size (mm^2)	f_δ in GHz	Reconf. Type
[21]	82 × 82	4.8, 6.9 and 7.7	Freq. Reconf.
[22]	60 × 60	5.194, 6.4 and 5.182	Freq. Reconf.
[23]	58 × 66	2.47, 3.8 and 5.36	Freq. Reconf.
[24]	50 × 50	3.4	Freq. Reconf.
This work	60 × 50	2.45, 2.71 and 3.54	Freq. Reconf.

capacitance effect and reduce the size of the antenna. In addition, two PIN diodes that are placed in the slitlines and have four states (visible-ON, OFF, and both) are used to control the antenna's frequency and explain the behavior of the two switches. Multi-operating frequencies are observed at 2.45 GHz, 2.71 GHz, and 3.54 GHz with a stable broadside radiation and a maximum gain of 3.07 dB. The software program Computer Simulation Technology (CST) was used for the reconfigurable antenna's design and analysis. Ultimately, there was a strong agreement between the modeling and measurement data.

CONFLICT OF INTEREST

The authors have no conflict of relevant interest to this article.

REFERENCES

[1] N. O. Parchin, H. J. Basherlou, Y. Al-Yasir, R. Abd-Alhameed, A. Abdulkhaleq, and J. Noras, "Recent developments of reconfigurable antennas for current and future wireless communication systems," *Electronics*, vol. 8, no. 2, p. 128, 2019.

[2] H. C. Mohanta, A. Z. Kouzani, and S. K. Mandal, "Reconfigurable antennas and their applications," *Universal Journal of Electrical and Electronic Engineering*, vol. 6, no. 4, pp. 239–258, 2019.

[3] I. Nazir, I. E. Rana, N. U. A. Mir, and K. Afreen, "Design and analysis of a frequency reconfigurable microstrip patch antenna switching between four frequency bands," *Progress In Electromagnetics Research C*, vol. 68, pp. 179–191, 2016.

[4] J. Costantine, Y. Tawk, S. E. Barbin, and C. G. Christodoulou, "Reconfigurable antennas: Design and applications," *Proceedings of the IEEE*, vol. 103, no. 3, pp. 424–437, 2015.

[5] Y. Rahayu, Y. B. Pradana, and Y. Yamada, "Dual-band frequency reconfigurable 5g microstrip antenna," *SINERGI*, vol. 27, no. 1, p. 81, 2023.

[6] M. F. Ismail, M. K. A. Rahim, and H. A. Majid, "Wideband to narrowband frequency reconfiguration using pin diode," *Microwave and Optical Technology Letters*, vol. 54, no. 6, pp. 1407–1412, 2012.

[7] Y. Yu, J. Xiong, H. Li, and S. He, "An electrically small frequency reconfigurable antenna with a wide tuning range," *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 103–106, 2011.

[8] R. Baruah and N. S. Bhattacharyya, "A frequency reconfigurable meandered slot cut rectangular patch antenna using pin diodes," *Progress in Electromagnetics Research C*, vol. 77, pp. 81–89, 2017.

[9] B. Saikia, P. Dutta, and K. Borah, "A compact dual asymmetric l-slot frequency reconfigurable microstrip patch antenna," *Progress in Electromagnetics Research C*, vol. 113, pp. 59–68, 2021.

[10] H. H. Al-Moameri, G. Hassan, and B. Jaber, "Simulation physical and chemical blowing agents for polyurethane foam production," in *IOP Conference Series: Materials Science and Engineering*, vol. 518, p. 062001, 2019.

[11] D. E. Hadri, A. Zakriti, and A. Zugari, "Reconfigurable antenna for wi-fi and 5g applications," *Procedia Manufacturing*, vol. 46, pp. 793–799, 2020.

[12] A. Muduli, M. K. Kanneboina, K. V. Mudumunthala, and S. Valluri, "A reconfigurable wearable antenna for mid band 5g applications," in *Journal of Physics: Conference Series*, vol. 1921, p. 012051, 2021.

[13] M. Aneesh, M. G. Siddiqui, J. Ansari, and A. Singh, "Kamakshi. inset feed toppled h-shaped microstrip patch antenna for pcs/wimax application," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 1, no. 2, pp. 365–370, 2016.

[14] T. Ali and R. C. Biradar, "A compact hexagonal slot dual band frequency reconfigurable antenna for wlan applications," *Microwave and Optical Technology Letters*, vol. 59, pp. 958–964, Feb 2017.

[15] S. Ullah, I. Elfergani, I. Ahmad, I. Din, W. R. Khan, T. Ahmad, U. Habib, C. Zebiri, and J. Rodriguez, "A compact frequency and radiation reconfigurable antenna for 5g and multistandard sub-6 ghz wireless applications," *Wireless Communications and Mobile Computing*, vol. 2022, pp. 1–12, 2022.

[16] C. A. Balanis, *Antenna theory: analysis and Design*. John Wiley & Sons, 2016.

[17] A. K. Hadi, M. F. Mosleh, A. R. Azeez, and R. A. Abd-Alhameed, "Meander-line slots based miniaturized inset-fed patch-sensor antenna for water characterization technique," in *2023 IEEE 13th International Conference on System Engineering and Technology (ICSET)*, pp. 200–204, 2023.

[18] R. H. Thaher and Z. S. Jamil, "Design of dual band microstrip antenna for wi-fi and wimax applications," *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 16, no. 6, p. 2864, 2018.

[19] Z. A. A. Hassain, A. A. AL-Behadili, and A. R. Azeez, "First order parallel coupled bpf with wideband rejection based on srr and csrr," *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 17, no. 6, p. 2704, 2019.

[20] A. R. Azeez, S. K. Ahmed, A. M. Zalzala, Z. A. A. Hassain, and T. A. Elwi, "Design of high gain uwb vivaldi antenna with dual band-notches characteristics," *International Journal on Engineering Applications (IREA)*, vol. 11, no. 2, p. 128, 2023.

[21] M. Shrivastava, R. Agrawal, and P. Tapashetti, "Design and development of reconfigurable antenna using memsm*," in *2018 International Conference on Advanced Computation and Telecommunication (ICACAT)*, pp. 1–5, IEEE, 2018.

[22] A. Kajla and D. Somwanshi, "Reconfigurable microstrip patch array antenna: Design and performance analysis," in *International Conference on Artificial Intelligence: Advances and Applications 2019*, pp. 287–293, Springer Singapore, 2020.

[23] A. A. Palsokar and S. L. Lahudkar, "Frequency and pattern reconfigurable rectangular patch antenna using single pin diode," *AEU - International Journal of Electronics and Communications*, vol. 125, p. 153370, 2020.

[24] J. Navarajan, M. R. E. Jebarani, and V. G. Krishnan, "Frequency reconfigurable microstrip patch antenna for multiband applications with shunt-series mems switch," *International Journal on Recent and Innovation Trends in Computing and Communication*, vol. 10, no. 12, pp. 125–132, 2022.