JOURNAL OF NANO- AND ELECTRONIC PHYSICS
Vol. 14 No 4, 04029(5pp) (2022)
ЖУРНАЛ НАНО- ТА ЕЛЕКТРОННОЇ ФІЗИКИ
Том 14 № 4, 04029(5cc) (2022)

Bandwidth Enhancement and Circular Polarization Microstrip Antenna Using *L* Slot and Rectangular Parasitic Stacked

Syah Alam[1], Indra Surjati[1,*], Lydia Sari[1], Yuli Kurnia Ningsih[1], Dian Widi Astuti[2], Teguh Firmansyah[2], Zahriladha Zakaria[3], Noor Azwan Shairi[4]

[1] *Department of Electrical Engineering, Universitas Trisakti, West Jakarta, Indonesia*
[2] *Department of Telecommunication Engineering, Universitas Mercubuana, West Jakarta, Indonesia*
[3] *Department of Electrical Engineering, Universitas Sultan Ageng Tirtayasa, Banten, Indonesia*
[4] *Faculty of Electronics and Computer Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia*

(Received 09 June 2022; revised manuscript received 26 August 2022; published online 30 August 2022)

This study proposes a microstrip antenna with *L* slot that is optimized using parasitic patches. The addition of parasitic elements aims at enhancing the bandwidth of the proposed antenna. Parasitic elements were added using two types of FR-4 substrate, which were stacked. The radiating element was placed in the bottom layer, while the parasitic element was in the top. To produce optimal bandwidth, three models were proposed with different forms of parasitic elements. The best results were shown by model 1 with an impedance bandwidth of 1.3 GHz (2.17-3.47 GHz) or with impedance bandwidth of 52 %. In addition, the proposed antenna design also produced circular polarization with an axial ratio of ≤ 3 dB and a maximum gain of 6.76 dB. The proposed antenna design can be recommended and suitable for use as a receiving antenna in a wireless communication system.

Keywords: Microstrip, Stacked, Bandwidth, Parasitic elements, Wireless.

DOI: 10.21272/jnep.14(4).04029 PACS numbers: 41.20.Jb, 84.40.Ba

1. INTRODUCTION

Currently, wireless communication systems have become one of the most superior technologies needed by society. One of the supporting components of a wireless communication system is an antenna. Antenna function is to radiate and receive electromagnetic waves from radio transmitters and radio receivers [1]. Wireless communication systems transmit various frequencies according to rules set by the FCC (Federal Communications Commission) [2]. Some examples of frequency allocation are: DCS applies to the frequency band 1710-1885 MHz, PCS to the frequency band 1907.5-1912.5 MHz, UMTS to the frequency band 1920-2170 MHz, WLAN 2.4 GHz to the frequency band 2400-2483.5 MHz, and LTE at 2.3 GHz [3]. To its advantage, a microstrip antenna has a compact design and can function at different frequencies [4]. However, a microstrip antenna has several disadvantages such as a narrow bandwidth and low gain [5]. Generally, the bandwidth efficiency of a microstrip antenna is around 5 % and the gain is around 4 dB [6, 7]. Several methods have been developed to solve their shortcomings. To increase the bandwidth of a microstrip antenna, various techniques have been applied, including the addition of parasitic elements [8, 9], coplanar waveguide feed lines [10, 11], and slots to the radiating element [12, 13]. A previous study conducted by [14] succeeded in increasing the bandwidth of a microstrip antenna up to 30 % by adding four slots to the radiating element at a frequency of 5.2 GHz, while the use of CPW proposed in the study [15] succeeded in increasing the bandwidth up to 22.11 % at a frequency of 11 GHz. The addition of parasitic elements conducted in [16] could increase the bandwidth of a microstrip antenna up to 6.52 % at a frequency of 8.5 GHz. However, from several previous studies presented, the proposed optimization technique has not succeeded in increasing bandwidth significantly. Furthermore, another limitation is the polarization of the antenna which is still linear. This study proposes a new design of an optimized microstrip antenna that has *L* slot and stacked parasitic elements. The addition of parasitic elements aims at increasing the bandwidth of the proposed antenna. To optimize the antenna, the design is developed into three types of models by changing and modifying the shape of parasitic elements. This study aims at producing a new microstrip antenna design that has a wide bandwidth compared to the previous studies.

2. ANTENNA DESIGN

The proposed antenna design uses FR 4 epoxy with a dielectric constant (ε_r) of 4.3, thickness (h) of 1.6 mm, and a dielectric loss (tanα) of 0.0265.

Fig. 1 presents the design of a microstrip antenna with the addition of *L* slot in the patch. Subsequently, Fig. 2, Fig. 3, and Fig. 4 show the antenna development by modifying the parasitic element. Model 1 can be seen in Fig. 2 with parasitic elements with a rectangular shape.

On the other hand, Fig. 3 shows the modification of the antenna's parasitic element with a rectangular ring as model 2, while the modification of the parasitic element with a circular shape is shown in Fig. 4 as model 3. Meanwhile, the dimension of the proposed antenna can be observed and shown in Table 1. It should be noted that the distance of each parasitic element (g) is 1 mm.

* indra@trisakti.ac.id

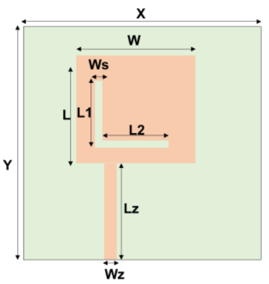

Fig. 1 – Design of a microstrip antenna with L slot

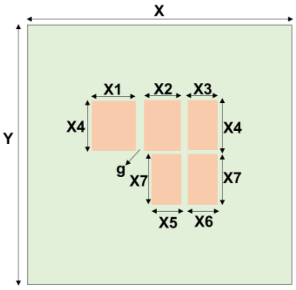

Fig. 2 – Development of parasitic element model 1

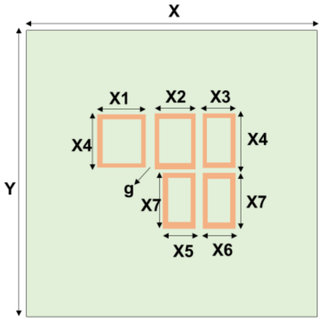

Fig. 3 – Development of parasitic element model 2

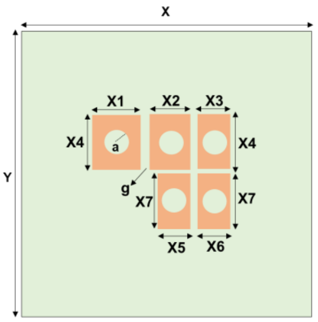

Fig. 4 – Development of parasitic element model 3

In this study, parasitic elements were added to the top layer, while the radiating element was placed in the bottom layer. The same type of substrates was used for the top and bottom layers, and it was stacked without the gap. Then, the SMA connector was connected to the radiating element, and the ground plane was placed in the bottom layer through the microstrip line. The arrangement and configuration of each layer of the proposed antenna can be seen in Fig. 5.

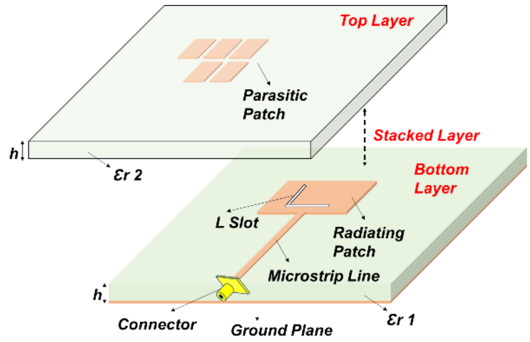

Fig. 5 – Structure of the proposed antenna

Table 1 – Dimensions of the proposed antenna

Parameter	Dimension	Parameter	Dimension
X	80 mm	X_1	10 mm
Y	40 mm	X_2	9 mm
W	40 mm	X_3	7 mm
L	30 mm	X_4	12 mm
Wz	3.1 mm	X_5	7 mm
Lz	32 mm	X_6	7 mm
$L1$	26 mm	X_7	11.6 mm
$L2$	25 mm	q	2.9 mm
Ws	3 mm	R_s	1 mm
X	80 mm	X_1	10 mm

3. RESULTS AND DISCUSSION

3.1 Simulation Results

The proposed antenna design was analyzed by simulating the process using electromagnetic simulation software. The simulation results of model 1, model 2, and model 3 can be observed in Fig. 6, Fig. 7, and Fig. 8, respectively.

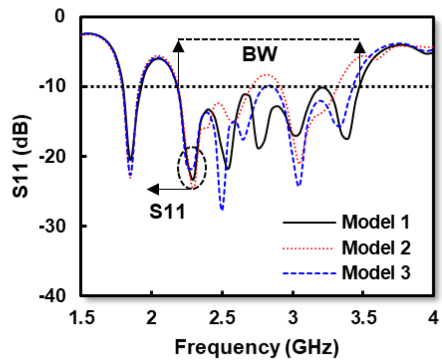

Fig. 6 – Simulation results of S_{11} parameters

Fig. 6 shows the simulation results of S_{11} for the proposed antenna. The model 1 simulation results suggest that the parameter $S_{11} \leq -10$ dB was in the frequency range of 2.17-3.47 GHz with an operating frequency of 2.55 GHz. Further, it was shown that the addition of rectangular ring parasitic elements in model 2 gave S_{11} of – 14.61 dB in the frequency range 2.18-2.71 GHz. Furthermore, model 3 that utilized circular parasitic elements obtained S_{11} of 15.99 dB in the frequency range 2.17-3.43 GHz. These results indicate that model 1 provides more optimal bandwidth compared to model 2 and model 3.

The results also indicate that the bandwidth obtained from model 1 was wider than from model 2 and model 3. Moreover, Fig. 7 shows the simulation results of the Axial Ratio (AR) of each model. It can be seen that model 1 produced an axial ratio of 1.47 dB at 2.75 GHz, while model 2 produced an axial ratio of 1.28 dB at 3.55 GHz, and model 3 produced an axial ratio of 1.77 dB at 2.4 GHz. The best axial ratio ≤ 3 dB was obtained by model 1.

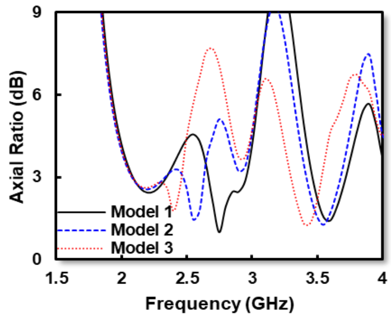

Fig. 7 – Simulation results of the axial ratio

It was found that the optimal gain of the proposed antenna was obtained by model 1 with 6.76 dB at 2.5 GHz, as shown in Fig. 8. On the other hand, model 2 produced 6.51 dB and model 3 produced 6.71 dB at 2.5 GHz. The overall comparison of the simulation results for each of the development model can be seen in Table 2. The best simulation results were obtained by model 1, which implemented rectangular parasitic elements, as presented in Table 2.

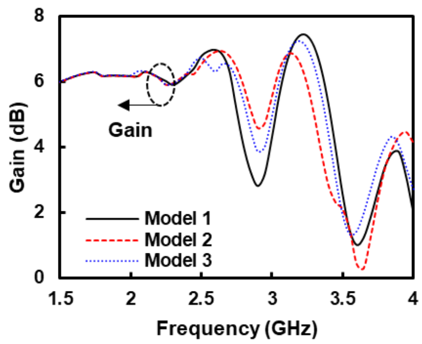

Fig. 8 – Simulation results of the gain

Table 2 – Comparison of simulation results from iterations

Model	Parameter			
	S_{11}	BW	AR	Gain
Model 1	– 21.57 dB	1.30 GHz	1.04 dB	6.76 dB
Model 2	– 14.61 dB	0.52 GHz	1.28 dB	6.51 dB
Model 3	– 15.99 dB	1.25 GHz	1.29 dB	6.71 dB

3.2 Analysis of Simulation Result

Furthermore, the simulation results of the microstrip antenna design with *L* slot without parasitic elements were compared with the designs that employed parasitic elements. A comparison of the simulation results of the proposed antennas with and without parasitic elements is presented in Fig. 9 and Fig. 10.

Fig. 9 shows the simulation results of the S_{11} parameter of the proposed antenna before and after the addition of parasitic elements. Before adding the parasitic elements, the *L* slot microstrip antenna was a dual band at 2.5 GHz (A) and 3.2 GHz (B) with a narrow bandwidth. After adding the parasitic elements, the bandwidth of the *L* slot microstrip antenna increased up to 1.3 GHz (C) with a frequency range of 2.17 MHz-3.47 GHz at an operating frequency of 2.55 GHz.

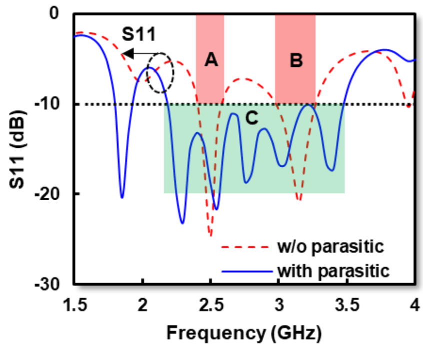

Fig. 9 – Comparison of S_{11} and bandwidth

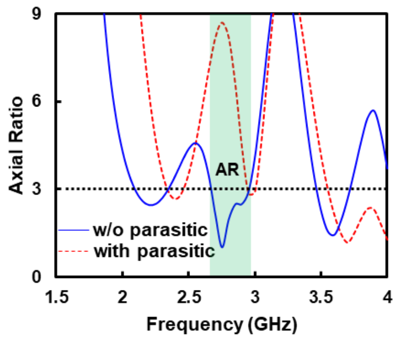

Fig. 10 – Comparison of the axial ratio

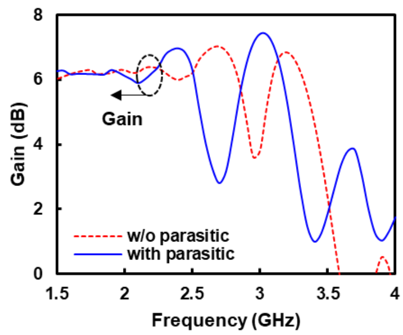

Fig. 11 – Comparison of gain

The addition of parasitic elements also affected the axial ratio and gain of the proposed antenna. Fig. 10 shows the axial ratio obtained after the addition of parasitic elements, which was better than before. Before the addition of parasitic elements, the antenna did not have a circular polarization with an axial ratio of ≥ 3 dB at 2.75 GHz. The gain of the antenna, which had been optimized with parasitic elements, also increased, as shown in Fig. 11. The optimal gain of the microstrip antenna with parasitic elements was 6.6 dB at 2.55 MHz, while the optimal gain of the antenna without parasitic elements was only 6.1 dB at 2.55 GHz.

Table 3 shows that parasitic elements can increase bandwidth from 0.2 to 1.3 GHz, or to 84.61 % compared to the designs without parasitic elements. In addition, the gain of the proposed antenna also increased to 12.1 % after the addition of parasitic elements. Furthermore, circular polarization with an axial ratio of ≤ 3 dB was also obtained after optimization with the addition of parasitic elements.

Fig. 12 shows that the addition of parasitic elements has an impact on the current distribution when the antenna works at a frequency of 2.55 GHz. Parasitic elements and the *L* slot antenna have a resonance, as indicated by the red marker which is about 40 dB (V/m). To show its novelty, the results of this study were compared with several previous studies, as shown in Table 4.

Table 4 shows that the proposed antenna has significantly increased the bandwidth up to 53 %. This result is much better than some of the previous studies that proposed increasing bandwidth in microstrip antennas.

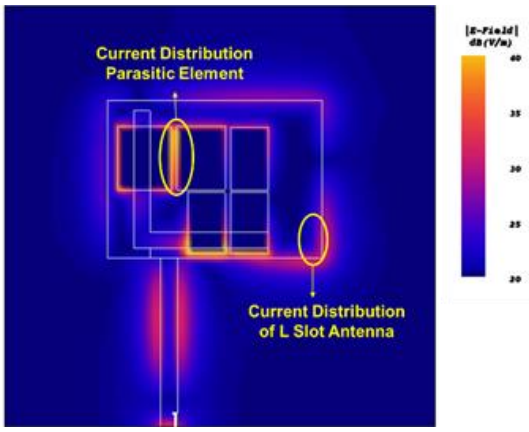

Fig. 12 – Current distribution of the proposed antenna

Table 4 – Comparison of simulation results from iterations

Ref.	Parameter			
	Gain	BW	AR	Frequency
[14]	NA	30 %	NA	5.2 GHz
[15]	7.50 dB	22.11 %	NA	11 GHz
[16]	5.62 dB	6.52 %	NA	8.5 GHz
[17]	6.64 dB	21 %	NA	3.6 GHz
This paper	6.76 dB	53 %	1.04 dB	2.55 GHz

4. CONCLUSIONS

This study describes and investigates new designs of microstrip antennas with *L* slot and stack parasitic elements. It was found that the addition of rectangular parasitic elements increased bandwidth of the proposed antenna to 84.61 % compared to the previous design. Moreover, the bandwidth obtained from the proposed antenna was 1.3 GHz or with a fractional bandwidth of around 52 %. In addition, the gain of the proposed antenna was 6.76 dB, while the axial ratio was 1.004 dB at 2.55 GHz. The results indicate that the addition of parasitic elements has succeeded in increasing the bandwidth and generating circular polarization of the proposed antenna.

ACKNOWLEDGEMENTS

The authors express their gratitude to the Research Institute of Universitas Trisakti and Universiti Teknikal Malaysia Melaka (UTeM) which supported and funded this research activity through the scheme of foreign joint research grant for fiscal year 2022.

REFERENCES

1. Constantine A. Balanis, *Antenna Theory: Analysis and Design* (John Wiley & Sons: 2016).
2. Bennett Z. Kobb, *Wireless Spectrum Finder: Telecommunications, Government and Scientific Radio Frequency Allocations in the US 30 MHz-300 GHz* (McGraw-Hill, Inc.: 2001).
3. Mingfu Li, Liang-Wei Chen, *Comput. Commun.* **99**, 119 (2017).
4. M. Aboualalaa, A.B. Abdel-Rahman, A. Allam, H. Elsadek, R.K. Pokharel, *IEEE Anten. Wirel. Propag. Lett.* **16**, 1622 (2017).
5. Siti Sarah Hardianti, Eki Ahmad Zaki Hamidi, Nanang Ismail, Achmad Munir, *2019 IEEE 5th International Conference on Wireless and Telematics (ICWT)*, 1 (IEEE: 2019).
6. Lal Chand Godara, *Handbook of Antennas in Wireless Communications* (CRC Press: 2018).
7. Madhukant Patel, Piyush Kuchhal, Kanhaiya Lal, Virendra Singh, Hemangi Patel, *Intelligent Communication, Control and Devices* (Springer: Singapore: 2018).
8. Kai Da Xu, Han Xu, Yanhui Liu, Jianxing Li, Qing Huo Liu, *IEEE Access* **6**, 11624 (2018).
9. Syah Alam, Lydia Sari, Indra Surjati, Yuli Kurnia Ningsih, Aida Safitri, Elfi Syukriati, *2019 16th International Conference on Quality in Research (QIR): International Symposium on Electrical and Computer Engineering*, 1 (IEEE: 2019).
10. Indra Surjati, Yuli Kurnia Ningsih, Syah Alam, *2017 4th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI)*, 1 (IEEE: 2017).
11. Junfang Wang, Hang Wong, Zhuoqiao Ji, Yongle Wu, *IEEE Anten. Wirel. Propag. Lett.* **18** No 3, 517 (2019).
12. Jyotibhusan Padhi, Madhulita Mohapatra, Muktikanta Dash, *2018 9th International Conference on Computing, Communication and Networking Technologies (ICCCNT)*, 1 (IEEE: 2018).
13. Prasetiyono Hari Mukti, Helmut Schreiber, Helmut Paulitsch, Andreas Gruber, Wolfgang Bösch, *2017 XXXIInd General Assembly and Scientific Symposium of the International Union of Radio Science (URSI GASS)*, 1 (IEEE: 2017).
14. Maryam Razmhosseini, Roshanak Zabihi, Rodney G. Vaughan, *2019 IEEE 90th Vehicular Technology Conference (VTC2019-Fall)*, 1 (IEEE: 2019).
15. Hsiu-Ping Liao, Shih-Yuan Chen, *2019 IEEE Asia-Pacific Microwave Conference (APMC)*, 1449 (IEEE: 2019).
16. Mekala Harinath Reddy, R.M. Joany, M. Jayasaichandra Reddy, M. Sugadev, E. Logashanmugam, *2017 IEEE International Conference on Smart Technologies and Management for Computing, Communication, Controls, Energy and Materials (ICSTM)*, 295 (IEEE: 2017).
17. Javed Iqbal, Usman Illahi, Mohamad Ismail Sulaiman, Muhammad Mansoor Alam, Mazliham Mohd Su'ud, Mohd Najib Mohd Yasin, Mohd Haizal Jamaluddin, *IEEE Access* **7**, 94365 (2019).

Мікросмужкова антена з розширенням смуги пропускання та круговою поляризацією з використанням *L*-слоту та стопкою прямокутних паразитних елементів

Syah Alam[1], Indra Surjati[1], Lydia Sari[1], Yuli Kurnia Ningsih[1], Dian Widi Astuti[2], Teguh Firmansyah[2], Zahriladha Zakaria[3], Noor Azwan Shairi[4]

[1] *Department of Electrical Engineering, Universitas Trisakti, West Jakarta, Indonesia*
[2] *Department of Telecommunication Engineering, Universitas Mercubuana, West Jakarta, Indonesia*
[3] *Department of Electrical Engineering, Universitas Sultan Ageng Tirtayasa, Banten, Indonesia*
[4] *Faculty of Electronics and Computer Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia*

У роботі запропоновано мікросмужкову антену з *L*-слотом, оптимізовану за допомогою паразитних елементів. Додавання паразитних елементів спрямоване на розширення смуги пропускання запропонованої антени. Паразитні елементи додавалися з використанням двох типів підкладки FR-4, які були складені в стопку. Випромінювальний елемент розташовувався в нижньому шарі, а паразитний – у верхньому. Для отримання оптимальної пропускної здатності було запропоновано три моделі з різними формами паразитних елементів. Найкращі результати показала модель 1 з імпедансною смугою пропускання 1,3 ГГц (2,17-3,47 ГГц) або 52 %. Крім того, запропонована конструкція антени також створювала кругову поляризацію з осьовим співвідношенням ≤ 3 дБ і максимальним підсиленням 6,76 дБ. Запропонована конструкція антени може бути рекомендована і придатна для використання як приймальна антена в системі бездротового зв'язку.

Ключові слова: Мікросмужковий, Складені в стопку, Пропускна здатність, Паразитні елементи, Бездротовий зв'язок.