

Comparative Analysis on Antenna Balun and Feeding Techniques of Step Constant Tapered Slot Antenna

Mousumi Aktar^{1*}, Md. Masud Rana¹, Nayan Sarker², Md. Sanwar Hossain² 

¹Department of Electrical & Electronic Engineering, Rajshahi University of Engineering & Technology, Rajshahi, Bangladesh

²Department of Electrical & Electronic Engineering, Bangladesh University of Business & Technology, Mirpur, Bangladesh

Email: *mousumi_05ruet@yahoo.com, md.masud.rana.ruet@gmail.com, nayan_ece09@yahoo.com, sanwareee@gmail.com

How to cite this paper: Aktar, M., Rana, Md.M., Sarker, N. and Hossain, Md.S. (2020) Comparative Analysis on Antenna Balun and Feeding Techniques of Step Constant Tapered Slot Antenna. *Journal of Sensor Technology*, **10**, 31-45.

<https://doi.org/10.4236/jst.2020.103003>

Received: June 21, 2020

Accepted: July 27, 2020

Published: July 30, 2020

Copyright © 2020 by author(s) and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

This paper represents the performance analysis of the different shapes of antenna balun and feeding techniques for step constant tapered slot antenna. This work also addresses the benefits of antenna balun (circular and rectangular) along with two types of feeding techniques (Microstrip line L-shape and Microstrip line I-shape). The performance of the antenna for each technique is thoroughly investigated using Computer Simulation Technology (CST) Microwave Studio software simulation under the resonant frequency of 5.9 GHz. Results demonstrate that the proposed model is an effective tool for improving antenna performance. Moreover, an extensive comparison has been carried out between the two different shapes, with and without antenna balun and between two feeding techniques focusing on return losses, gain, directivity, and voltage standing wave ratio (VSWR).

Keywords

Antenna Balun, L-Shape Microstrip Feeding, I-Shape Microstrip Feeding, Return Loss, Gain, Radiation Pattern, Directivity, CST Microwave Studio

1. Introduction

Recently, different types of antenna have been manifested in the applications of ultra-wideband wireless communication [1]-[8]. Among the various types of antenna, tapered slot antenna (TSA) is one of the most important, which exhibits a wide operational bandwidth, improves gain, and identical radiation pattern. A typical Tapered Slot Antenna (TSA) consists of a tapered slot cut in a thin film of a metal plate with an electrically thin substrate on one side of the film [9] [10]

[11] [12]. Numerous research work has been conducted for improving the performance of the TSA antenna and utilizing this antenna in wireless communications, remote sensing, biosensing, ground-penetrating radar (GPR) system, etc. [13]-[20]. Due to the technological revolution, wireless communication is increasing at an exponential rate and the efficiency of the wireless system depends on these antennas that can efficiently radiate and accept UWB signals [21] [22] [23] [24] [25]. Tapered Slot Antenna was first introduced in 1979, and the basic three types of TSA antennas are linearly tapered slot antenna (LTSA), constant width slot antenna (CWSA), and Vivaldi antenna (VA) [26] [27] [28] [29] [30]. Tapered Slot Antennas are a traveling-wave antenna, whose voltage or current distribution can be represented by one or more traveling waves. TSAs contain high directivity and narrow beam width because of the traveling wave properties [31] [32] [33]. Additionally, it has almost symmetric E-plane and H-plane radiation patterns over a wide frequency band as long as antenna parameters like shape, total length, dielectric thickness, and dielectric constant are selected appropriately. TSAs have a lot of benefits over conventional antenna such as broadband operation, low sidelobes, planar footprints, and simple in fabrication [10] [31] [33]. It also shows a good match at both sides *i.e.* input side (transition from the feed line to slot line) and the radiation side (transition from the antenna to free space) of the antenna, then a TSA has a large bandwidth. At high operating frequencies (greater than 10 GHz), tapered slot antennas are also suitable, where a long electrical length corresponds to a considerably short geometrical length. Despite the above benefits, TSA has some limitations such as only linear polarization can be obtained with conventional geometries [10] [11] [12]. This paper will describe the effect of with and without antenna balun and two different feeding techniques for the step constant tapered slot antennas (STSAs) and will find the optimum results.

Over the last century, medical imaging technology has undergone a revolutionary transformation by producing valuable pictures that show the inside of the human body. Imaging technology is widely used by medical practitioners in clinics to diagnose or guide the treatment of different kinds of diseases. However, researchers continue to look for more accurate, safe, reliable, portable, and cost-effective imaging systems. In recent years, microwaves radiation has attracted particular research interest in this direction, as they offer new possibilities and prospects in imaging and spectroscopy of the biological tissues. Therefore, the development of antennas in that frequency range for such applications is expected to have a huge impact on the upliftment of human healthcare. Among numerous biomedical application fields, human brain imaging is the one that attracts a wide research interest from the engineering and medical perspectives. Detecting the presence and location of a tumor inside the human brain is one of the most important uses of brain imaging. The possibility of microwave imaging technology for brain cancer detection is increased recently as they offer a safe, rapid, low-cost, non-invasive, and highly accurate system solution that involves nonionizing radiation [10].

A high directive step-constant tapered slot antenna (STSA) is suitable for microwave imaging as an early cancer detection method. This imaging system has advantages such as low cost, being non-invasive and easy-use, giving high image resolution, and thus with potential for early cancer detection. This antenna will use for an imaging system in future work.

2. Antenna Design

TSAAs can be classified into three basic taper profiles such as linear tapered slot antenna(LTSA), constant width slot antenna (CWSA), and non-linear taper slot antenna (*i.e.*, exponentially tapered slot antenna or Vivaldi) [34]. Many taper profiles exist for normal TSA [34]. Each antenna differs from one another only in the taper profile of the slot. Only the Vivaldi and linearly tapered profiles have been thoroughly studied over the past few years. But this thesis paper works on a step-constant tapered antenna. The basic architecture of the proposed step constant tapered slot antennas is shown in **Figure 1**.

The following parameters are used to design the proposed step-constant tapered slot antenna. All the antenna parameters are calculated thoroughly and listed in **Table 1**.

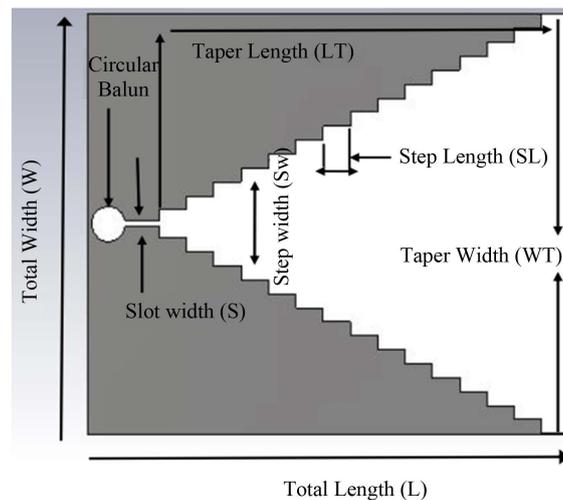


Figure 1. The geometry of step constant tapered slot antenna.

Table 1. Design parameters of step-constant TSA.

Parameters	Dimension (mm)	Parameters	Dimension (mm)
Minimum Frequency (GHz)	3.1	Taper length (LT)	60.0
Maximum Frequency (GHz)	10.6	Taper width (LT)	58.7
Step length (SL)	8.0	Slot width (S)	0.4113
Step width (SW)	3.9	Slot length	5.5
Total length (L)	70.5	Circular Balun Radius (R)	2.5
Total width (W)	58.7	Substrate Thickness (h)	1.5

3. Antenna Balun

Antenna balun plays an important role to design an antenna. The antenna balun may be different in shape. They may be circular, rectangular, square, etc. In this paper **Figure 2** shows the structure of an antenna with and without a balun. In this design, circular and rectangular shape baluns are used. Between the two shapes balun, circular shape balun provides better results. The radius of the circular balun is 2.5 mm.

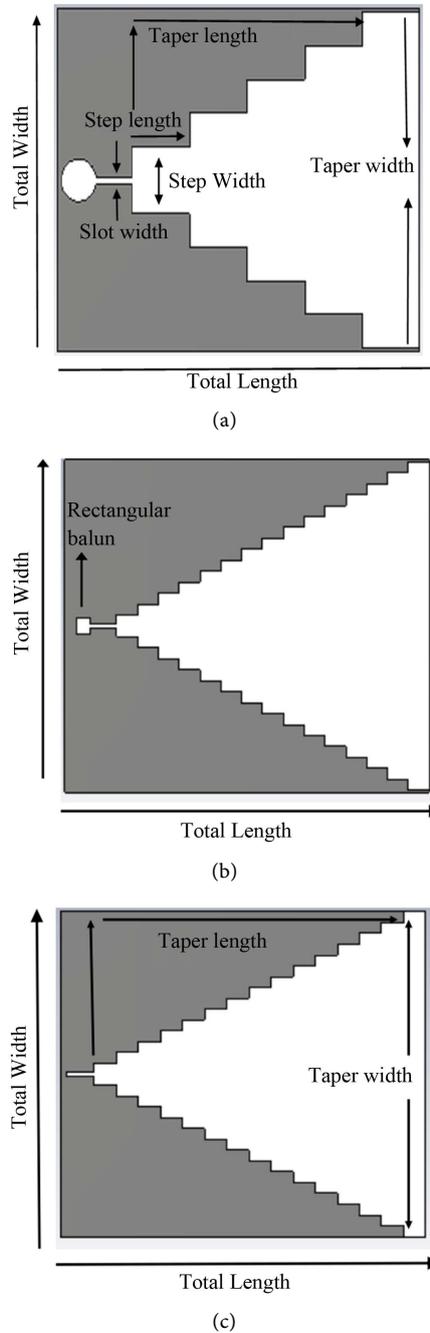


Figure 2. Structure of antenna with and without a balun. (a) With circular balun; (b) With rectangular balun; (c) Without antenna balun.

4. Feeding Techniques

A feed line is used to excite/radiate the antenna by direct or indirect contact. Step constant tapered slot type antennas can be fed by different methods. In this work, two types of feeding techniques such as Microstrip line L-shape and Microstrip line I-shape are analyzed. For fabrication Microstrip line feed is one of the simplest techniques as shown in **Figure 3**. It is easy to model. But, the downside of this technique is, in case of increasing substrate thickness the surface wave and spurious feed radiation increases that limit the bandwidth [35] [36] [37].

4.1. L-Shape Feeding Technique

In the L-shape feeding technique, the feeding microstrip-line is placed on the right side of a substrate, which is shown in **Figure 4**. In one direction, the strip is 0.4 mm wide and 7 mm long in the beginning part. Moreover, the strip is 0.4 mm wide and 10 mm long in the second part. At the beginning end of the microstrip-line, a waveguide port is connected between the microstrip-line and the substrate. The feeding position and the width of the feeding line should be optimized in such a way that, optimum simulation results can be achieved.

4.2. I-Shape Feeding Technique

In this type of feeding technique, a conducting strip is directly connected to the slot line and the microstrip line is placed on the bottom side of the substrate, which is shown in **Figure 5**. The conducting strip width is thick as compared to

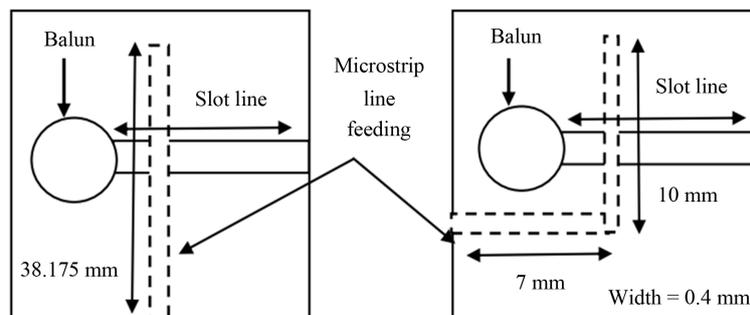


Figure 3. Structure of microstrip line feeding.

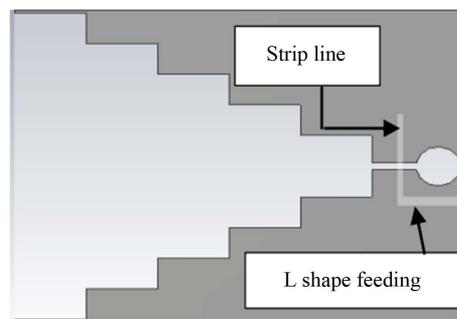


Figure 4. Microstrip line L-shape feeding.

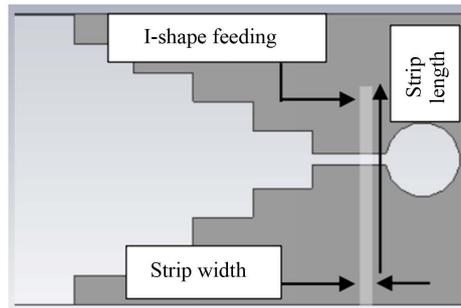


Figure 5. Microstrip line I-shape feeding.

the slot line. The strip is 0.5 mm wide 38.175 mm long. In this technique, the width of the microstrip line is always greater than the slot line. Where the width of the slot line is 0.4 mm and the microstrip line is 0.5 mm. Also, consider the feeding position here.

4.3. L-Shape with Balun Feeding Technique

Figure 6 illustrates the L-shape feeding technique. In this technique, the feeding microstrip-line has four segments. At first segment, the strip is 0.4 mm wide and 3.5 mm long horizontally. The strip is 0.2 mm wide and 3.5 mm long in the second part. In the third segment, the length and width are the same as the second segment but this is aligned in the vertical position. Finally, triangular shape balun is connected with the vertically aligned segment.

5. Simulation Results

The simulated results on with and without antenna balun and three types of feeding techniques are bringing together in the following figures.

5.1. Return Loss

Return loss is one of the key factors for designing as an antenna. Return loss calculates the effectiveness of antenna power which is radiated from the source to the antenna [35] [36] [37]. **Figure 7** represents the return loss for with and without antenna balun and L and I-shape feeding respectively. For circular shape, the balun antenna provides the minimum return loss and for the I-shape feeding technique the return loss is increasing with the increase in step size but it is not the same for the L-shape and L-shape with balun feeding techniques. Therefore, it will be effective to take the optimum result among the three feeding techniques.

After observing **Figure 7** it is clear that the return loss for circular shape balun has a better result than two others and L-shape feeding is greater than the I-shape feeding technique at the same operating frequency of 5.9 GHz. Where the value of circular shape balun is -46 dB, rectangular shape -24 dB and without balun -26.64 dB respectively and the L-shape feeding is -46.22 dB, I-shape feeding is -25.15 dB at 5.9 GHz and L-shape with balun feeding is -49 dB at 4.6 GHz.

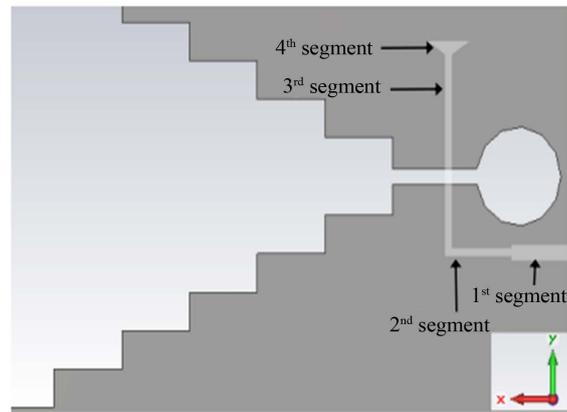


Figure 6. Microstrip line L-shape with balun feeding.

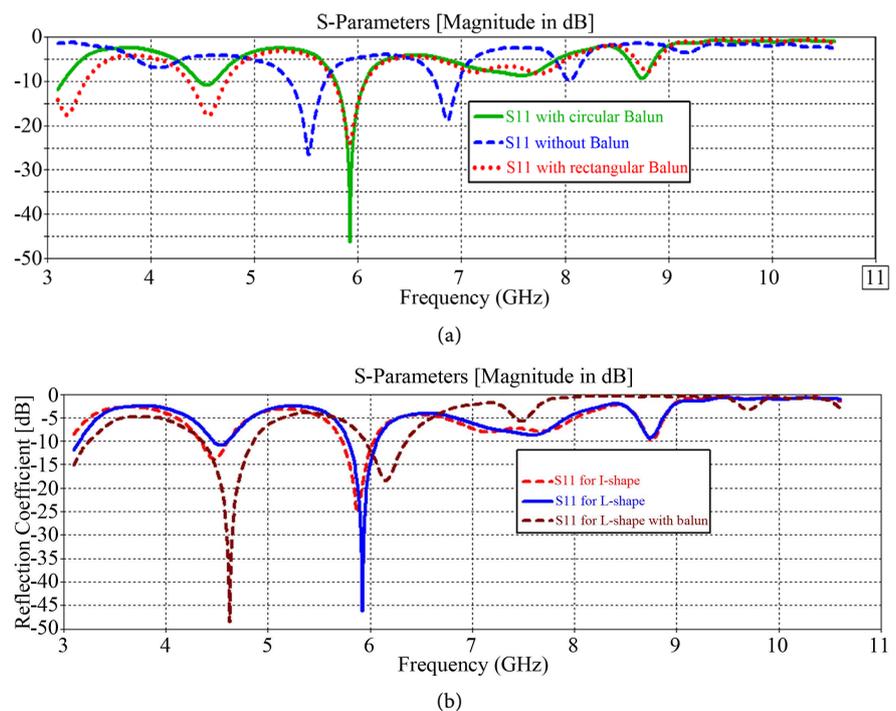


Figure 7. Return loss for (a) with and without antenna balun (b) L and I-shape feeding.

5.2. Voltage Standing Wave Ratio (VSWR)

Voltage Standing Wave Ratio is defined as the ratio of the peak amplitude of a standing wave to the minimum amplitude of a standing wave. The minimum value of VSWR is 1.0 [30]. The following figures show the VSWR for different balun and three feeding techniques.

Figure 8 displays the voltage standing wave ratio for with and without balun and all feeding techniques. The VSWR is minimum for circular balun and L-shape feeding is 1.00.

In this paper, different step size STSAs are analyzed with and without balun and with three feeding techniques and it represents optimum results for 15-step size antenna for circular shape balun and L-shape feeding.

Table 2 represents the performance of the STSA. After analyzing the performance of the antenna with and without balun, it concluded that because of using balun the antenna provides better performance than without using a balun. Between two balun circular balun gives better results. So, antenna balun decreases the return losses of antennas and enhances the directivity as well as antenna gain.

The performance parameters of the L shape feeding antenna are presented in **Table 3**. After analyzing **Table 3** it is observed that the results of the performance parameter for different step size are increasing to a specific step size (5 steps to 15 steps) and after that if we increase the step size (15 steps to 25 step) the results of the performance parameter of STSA are decreasing. The optimum results achieved for 15-step size STSA.

Table 4 displays that, the simulation results for different step size antenna for I-shape feeding, which are increasing with the increase in step size and it is approximate to 15-step size of L shape feeding technique. The best simulation result for I-shape feeding is less than the L-shape feeding technique.

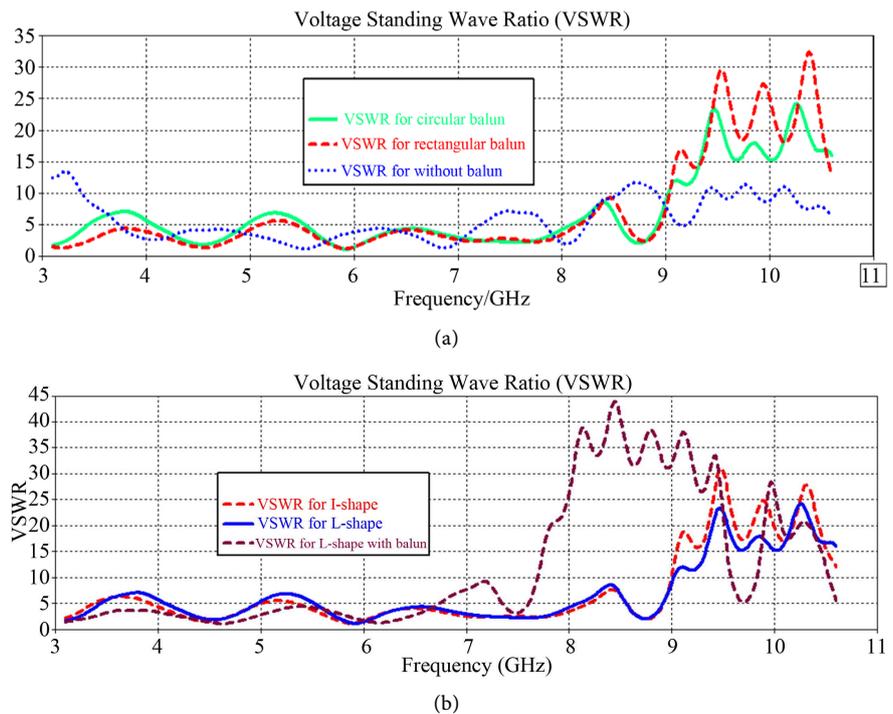


Figure 8. VSWR for (a) with and without antenna balun; (b) L and I-shape feeding.

Table 2. Performance of the STSAs for with and without a balun.

Antenna Balun with 15 Step size	Reflection coefficient (dB)	VSWR	Directivity (dBi)	Gain (dB)
Without Balun	-26.64	1.09	9.58	8.51
Rectangular Balun	-24.19	1.13	10.3	10.1
Circular Balun	-46.22	1.00	10.52	10.21

Table 3. Performance of the STSAs for L-shape feeding.

Antenna Step size	Reflection coefficient (dB)	VSWR	Directivity (dBi)	Gain (dB)
5 step	-25.92	1.10	8.38	8.1
10 step	-28.66	1.07	8.71	8.47
15 step	-46.22	1.00	10.52	10.21
20 step	-35.82	1.03	10.55	10.2
25 step	-33.34	1.04	10.43	10.03

Table 4. Performance of the STSAs for I-shape feeding.

Antenna Step size	Reflection coefficient (dB)	VSWR	Directivity (dBi)	Gain (dB)
5 step	-24.00	1.13	8.11	7.82
10 step	-26.71	1.09	8.32	8.1
15 step	-25.15	1.11	10.05	9.83
20 step	-25.37	1.11	10.41	10.0
25 step	-31.50	1.04	10.55	10.20

5.3. Gain and Directivity

The ratio of the radiation intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna radiated isotropically is defined as gain (IEEE 1993, p. 547). The directivity of the proposed model is shown in [Figure 9](#).

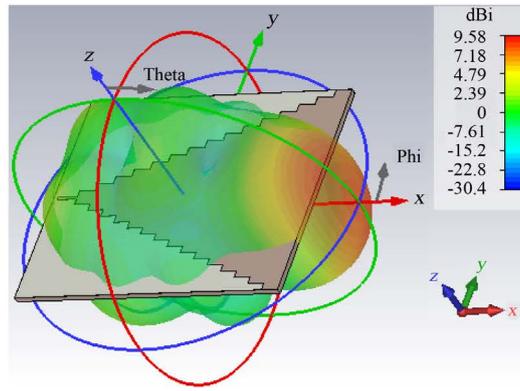
5.4. Radiation Pattern

The radiation pattern is usually a graphical representation of the radiation properties including power flux density, radiation intensity, field strength, and polarization as a function of angle [35] [36] [37]. The radiation pattern for the different types of antenna patterns is illustrated in [Figure 10](#).

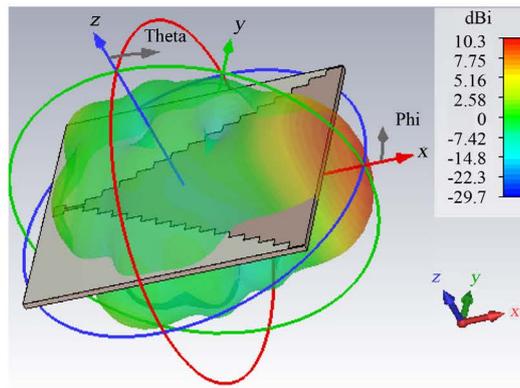
For L-shape, feeding technique the gain is 10.21 dB, Sidelobe level of -8.9 dB, and Angular width of 35.5 deg. is observed in the radiation pattern. At the same time, for I-shape feeding the gain of 9.83 dB, Sidelobe level of -9.1 dB, and Angular width of 37.1 deg. is observed in the radiation pattern.

After analyzing the above figures and comparison [Table 5](#), it is established that the use of antenna balun is necessary for better performance of antenna which provides best return loss, gain, directivity, and VSWR than without balun. Comparing with and without balun, we conclude that the antenna with circular balun has better radiation performance among others.

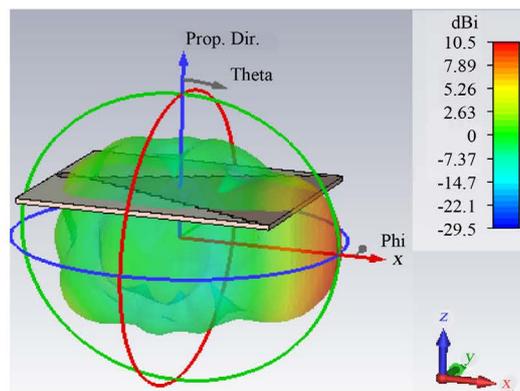
After analyzing [Table 6](#), it is established that the L-shape feeding techniques provide the best return loss, gain, directivity, and VSWR than others. Comparing the feeding techniques, we conclude that the L-shape feeding has better radiation performance.



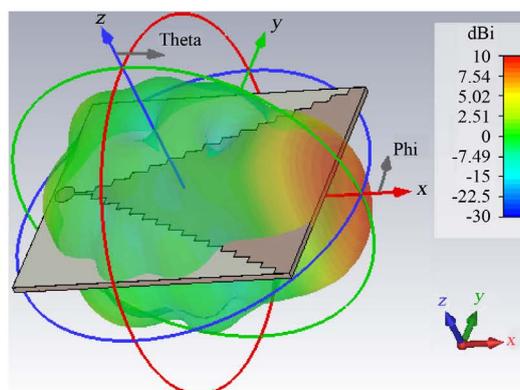
(a)



(b)



(c)



(d)

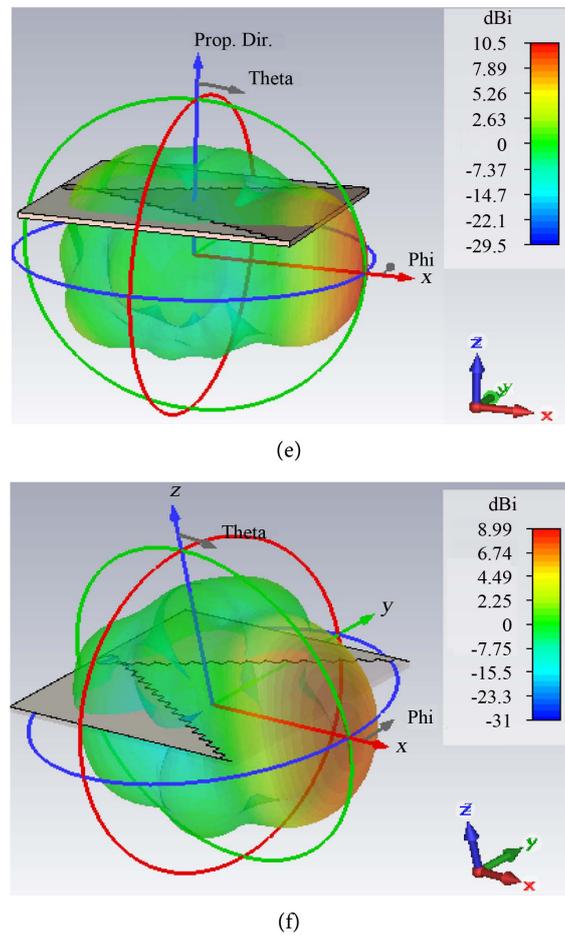


Figure 9. Directivity of the proposed antenna. (a) Without a balun; (b) With a rectangular balun; (c) With a circular balun; (d) I-shape feeding; (e) L-shape feeding; (f) L-shape with balun feeding.

Table 5. Comparison among without and with a balun.

Performance Parameter	Without Balun	With Rectangular Balun	With Circular Balun
Return Loss (dB)	-26.64	-24.19	-46.22
VSWR	1.09	1.13	1.00
Directivity (dBi)	9.58	10.3	10.52
Gain (dB)	8.51	10.1	10.21

Table 6. Comparison between two feeding techniques.

Performance Parameter	L-shape feeding	I-shape feeding	L-shape feeding with balun
Return Loss (dB)	-46.22	-25.15	-48.45
VSWR	1.00	1.11	1.00
Directivity (dBi)	10.52	10.05	8.99
Gain (dB)	10.21	9.83	8.75

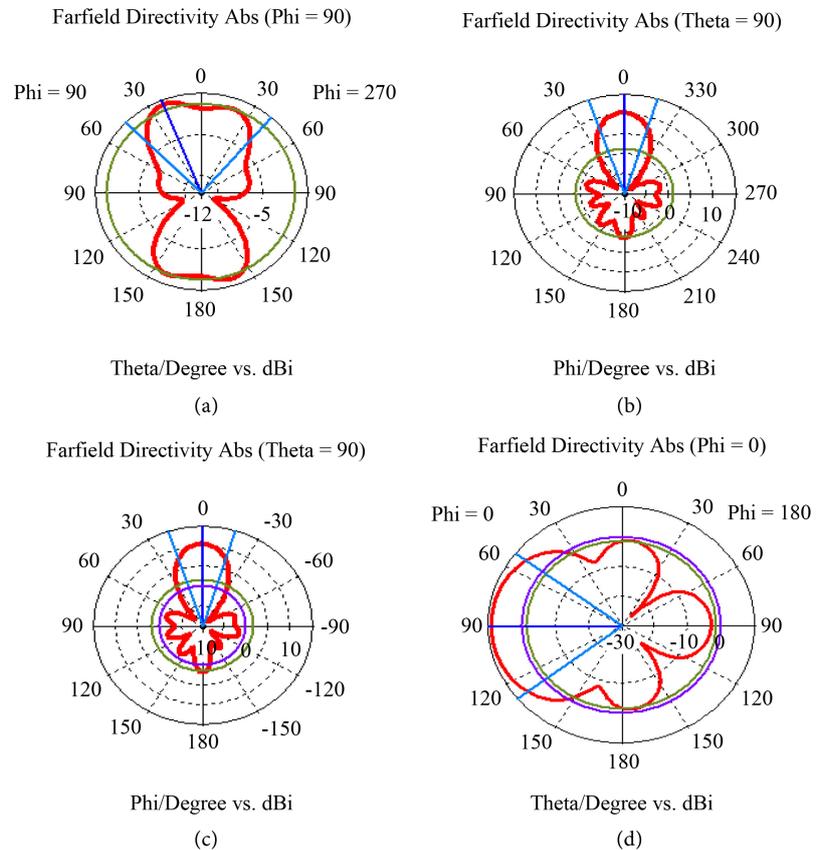


Figure 10. The radiation pattern of the proposed antenna with and without balun and different feeding techniques. (a) Without balun; (b) With rectangular balun; (c) With circular balun and L-shape & I-shape feeding; (d) L-shape with balun feeding.

6. Conclusion

This paper has examined the performance of step constant tapered slot antenna with and without balun along with three types of feeding techniques and comparisons are made among them in terms of S11 parameter, VSWR, directivity, gain, and sidelobe level. The optimal quantity and perfect matching of the antenna have been found by varying the key parameters such as width and position of the feeding considering the fifteen steps constant antenna. Additionally, an extensive simulation has been done considering the effect of return loss, radiation pattern, VSWR. Numerical results tell that the selection of balun and feeding techniques is an effective tool because it affects the antenna parameter and the proposed antenna works well at the 5.9 GHz operating frequency.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Jiang, Y., Yuan, R., Gao, X., Wang, J., Li, S. and Lin, Y. (2016) An Ultra-Wideband

- Pattern Reconfigurable Antenna Based on Graphene Coating. *Chinese Physics B*, **25**, Article ID: 118402. <https://doi.org/10.1088/1674-1056/25/11/118402>
- [2] Sabban, A. (2015) New Wideband Meta Materials Printed Antennas for Medical Applications. *International Journal of Advance in Medical Science*, **3**, 1-10. <https://doi.org/10.12783/ams.2015.0301.02>
- [3] Sabban, A. (2016) Wideband RF Technologies and Antenna in Microwave Frequencies. Wiley Sons, New York. <https://doi.org/10.1002/9781119048640>
- [4] Alomainy, A., Sani, A., *et al.* (2009) Transient Characteristics of Wearable Antennas and Radio Propagation Channels for Ultrawideband Body-Centric Wireless Communication. *IEEE Transactions on Antennas and Propagation*, **57**, 875-884. <https://doi.org/10.1109/TAP.2009.2014588>
- [5] Sarker, N., Islam, M.A. and Mondal, M.R. (2018) Two Novel Multiband Centimetre-Wave Patch Antennas for a Novel OFDM Based RFID System. *Journal of Communications*, **13**, 303-316. <https://doi.org/10.12720/jcm.13.6.303-316>
- [6] Kumar, A., Kaur, J. and Singh, R.K. (2013) Performance Analysis of Different Feeding Techniques. *International Journal of Emerging Technology and Advanced Engineering*, **3**, 884-890.
- [7] Sarker, N. and Mondal, M.R. (2018) Design and Analysis of Double E-Shaped Array Antennas for an Outdoor RFID System. *International Conference on Electrical and Computer Engineering*, Dhaka, 20-22 December 2018, 453-456. <https://doi.org/10.1109/ICECE.2018.8636764>
- [8] Arora, A., Khemchandani, A., Rawat, Y., Singhai, S. and Chaitanya, G. (2015) Comparative Study of Different Feeding Techniques for Rectangular Microstrip Patch Antenna. *International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering*, **3**, 32-35.
- [9] Aktar, M., Rana, Md.M., Hossain, Md.S. and Hossain, Md.B. (2019) Design and Implementation of Step-Constant Tapered Slot Antennas for UWB Application. *Journal of Sensor Technology*, **9**, 91-100. <https://doi.org/10.4236/jst.2019.94008>
- [10] Unadkat, V. and Dwivedi, V.V. (2013) Design of Corrugated Linearly Tapered Slot Antenna for Wireless Apps. LAP Lambert Academic Publishing, Mauritius, 104.
- [11] Yin, X., Su, Z., Hong, W. and Cui, T.J. (2005) An Ultra-Wideband Tapered Slot Antenna. *IEEE Antennas and Propagation Society International Symposium*, Washington DC, 2A, 516-519.
- [12] Klemm, M. and Troester, G. (2006) Textile UWB Antenna for Wireless Body Area Networks. *IEEE Transactions on Antennas and Propagation*, **54**, 3192-3197. <https://doi.org/10.1109/TAP.2006.883978>
- [13] Gopikrishna, M., Krishna, D.D., Aanandan, C.K., Mohanan, P. and Vasudevan, K. (2009) Design of a Microstrip Fed Step Slot Antenna for UWB Communication. *Microwave and Optical Technology Letters*, **51**, 1126-1129. <https://doi.org/10.1002/mop.24262>
- [14] Aktar, M., Islam, M. and Islam, M.S. (2012) Design and Performance Analysis of 10 GHz Horn Antenna. *ARPJ Journal of Science and Technology*, **2**, 427-432.
- [15] Asif, S.M., Iftikhar, A., Braaten, B.D. and Khan, M.S. (2016) Design of an Ultra-Wideband Antenna Using Flexible Graphene-Based Conductor Sheets. *IEEE International Symposium on Antennas and Propagation*, Fajardo, 26 June-1 July 2016, 1863-1864. <https://doi.org/10.1109/APS.2016.7696638>
- [16] Hossain, Md.B., Hossain, Md.S., Moznuzzaman, Md., Hossain, Md.A., Tariquzzaman, Md., Hasan, Md.T. and Rana, Md.M. (2019) Numerical Analysis and Design of Photonic Crystal Fiber-Based Surface Plasmon Resonance Biosensor. *Journal of Sensor*

- Technology*, **9**, 27-34. <https://doi.org/10.4236/jst.2019.92003>
- [17] Sabban, A. (2018) New Wideband Compact Wearable Slot Antennas for Medical and Sport Sensors. *Journal of Sensor Technology*, **8**, 18-34.
- [18] Zitouni, M., Pan, Q., Brulin, D. and Campo, E. (2019) Design of a Smart Sole with Advanced Fall Detection Algorithm. *Journal of Sensor Technology*, **9**, 71-90. <https://doi.org/10.4236/jst.2019.94007>
- [19] de Avila, U.E.R., Braga, I.C., de França Campos, F.R. and Nafital, A.C. (2019) Attention Detection System Based on the Variability of Heart Rate. *Journal of Sensor Technology*, **9**, 54-70. <https://doi.org/10.4236/jst.2019.94006>
- [20] Hossain, M.S., Rahman, M., Sarker, M.T., Haque, M.E. and Jahid, A. (2019) A Smart IoT Based System for Monitoring and Controlling the Sub-Station Equipment. *Internet of Things*, **7**, 1-16. <https://doi.org/10.1016/j.iot.2019.100085>
- [21] Al-Amin, Md.R., Chowdhury, S.S. and Islam, K.Z. (2015) Design and Simulation of an Edge-Coupled Band Pass Filter at X Band. *International Conference on Materials, Electronics & Information Engineering (ICMEIE)*, Rajshahi, 5-6 June 2015, 1-5.
- [22] Hossain, M.S., Jahid, A., Islam, K.Z., Alsharif, M.H. and Rahman, M.F. (2020) Multi-Objective Optimum Design of Hybrid Renewable Energy System for Sustainable Energy Supply to a Green Cellular Networks. *Sustainability*, **12**, 3536. <https://doi.org/10.3390/su12093536>
- [23] Hossain, M.S. and Rahman, M.F. (2020) Hybrid Solar PV/Biomass Powered Energy Efficient Remote Cellular Base Stations. *International Journal of Renewable Energy Research*, **10**, 329-342.
- [24] Jahid, A., Islam, K.Z., Hossain, M.S., Monju, M.K.H. and Rahman, M.F. (2019) Performance Evaluation of Cloud Radio Access Network with Hybrid Supplies. *IEEE International Conference on Sustainable Technologies for Industry 4.0 (STI)*, Dhaka, 24-25 December 2019, 1-5. <https://doi.org/10.1109/STI47673.2019.9068074>
- [25] Hossain, M.S., Jahid, A., Islam, K.Z. and Rahman, M.F. (2020) Solar PV and Biomass Resources-Based Sustainable Energy Supply for Off-Grid Cellular Base Stations. *IEEE Access*, **8**, 53817-53840. <https://doi.org/10.1109/ACCESS.2020.2978121>
- [26] Sabban, A. (2012) Wideband Tunable Printed Antennas for Medical Applications. *IEEE Antenna and Propagation Symposium*, Chicago, 8-14 July 2012, 84-91. <https://doi.org/10.1109/APS.2012.6349023>
- [27] Sabban, A. (2013) New Wideband Printed Antennas for Medical Applications. *IEEE Transactions on Antennas and Propagation*, **61**, 84-91. <https://doi.org/10.1109/TAP.2012.2214993>
- [28] Charoensiri, Y., Thaiwiro, W. and Akkaraekthalin, P. (2017) Design of Ultra-Wideband Tapered Slot Antenna by Using Binomial Impedance Transformer. *Frequenz*, **71**, 251-260. <https://doi.org/10.1515/freq-2016-0131>
- [29] Inum, R., Rana, M.M. and Shushama, K.N. (2017) Development of Graphene-Based Tapered Slot Antennas for Ultra-Wideband Applications. *Progress in Electromagnetics Research C*, **79**, 241-255. <https://doi.org/10.2528/PIERC17072611>
- [30] Wu, J., Zhao, Z., Liu, J., Nie, Z.P. and Liu, Q.H. (2012) A Compact Linear Tapered Slot Antenna with Integrated Balun for UWB Applications. *Progress in Electromagnetics Research C*, **29**, 163-176. <https://doi.org/10.2528/PIERC12031204>
- [31] Izdebski, P.M., Rajagoplan, H. and Rahmat-Sami, Y. (2009) Conformal Ingestible Capsule Antenna: A Novel Chandelier Meandered Design. *IEEE Transactions on Antennas and Propagation*, **57**, 900-909. <https://doi.org/10.1109/TAP.2009.2014598>
- [32] Vignesh, N., Kumar, G.A.S. and Brindha, R. (2014) Design and Development of a

- Tapered Slot Vivaldi Antenna for Ultra-Wide Band Application. *International Journal of Advanced Research in Computer Science and Software Engineering*, **4**, 174-178.
- [33] Lee, D.-H., Yang, H.-Y. and Cho, Y.-K. (2012) Tapered Slot Antenna with Band Notched Function for Ultra-Wideband Radios. *IEEE Antennas and Wireless Propagation Letters*, **11**, 682-685. <https://doi.org/10.1109/LAWP.2012.2204718>
- [34] Mohammed, B.J., Abbosh, A.M., Mustafa, S. and Ireland, D. (2014) Microwave System for Head Imaging. *IEEE Transactions on Instrumentation and Measurement*, **63**, 117-123. <https://doi.org/10.1109/TIM.2013.2277562>
- [35] Bisht, S., Singh, A., Chauhan, R. and Pant, G. (2014) Implementation and Applications of Various Feeding Techniques Using CST Microwave Studio. *International Journal on Recent and Innovation Trends in Computing and Communication*, **2**, 1754-1760.
- [36] Arora, A., Khemchandani, A., Rawat, Y., Singhai, S. and Chaitanya, G. (2015) Comparative Study of Different Feeding Techniques for Rectangular Microstrip Patch Antenna. *International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering*, **3**, 32-35, <https://doi.org/10.17148/IJIREEICE.2015.3509>
- [37] Chakravarthy, S.S., Sarveshwaran, N., Sriharini, S. and Shanmugapriya, M. (2016) Comparative Study on Different Feeding Techniques of Rectangular Patch Antenna. *International Conference on Wireless and Optical Communications Networks (WOCN)*, Hyderabad, 21-23 July 2016, 1-6. <https://doi.org/10.1109/WOCN.2016.7759032>