International Journal of Engineering Trends and Technology
ISSN: 2231 – 5381 / https://doi.org/10.14445/22315381/IJETT-V70I7P231

Volume 70 Issue 7, 301-309, July 2022

Original Article

Investigation and Analysis of High Gain Printed Curved Shape Director-Driven Bowtie Quasi-Yagi Antenna

Pravin Dalvadi[1], Amrut Patel[2]

[1]*Ganpat University & EC Department, Government Polytechnic Gandhinagar, Gujarat, India*
[2]*Department of E. C. Engineering, U.V. Patel College of Engineering, Ganpat University, Mehsana, Gujarat, India*

[1]pravindalvadi3187@gmail.com

Received: 20 May 2022 Revised: 12 July 2022 Accepted: 17 July 2022 Published: 25 July 2022

Abstract - *This paper proposes a printed curved shape director-driven bowtie quasi-Yagi antenna for high gain applications. The proposed antenna consists of a bowtie-shaped driven element, curved shape reflector, and directors. A simple microstrip feed line is designed to feed the bowtie-driven element, which provides impedance matching between the coaxial input source and the driven element. The proposed antenna is fabricated on the low-cost Glass Epoxy FR4 substrate of thickness 1.6mm, a dielectric constant of 4.4, and a loss tangent of 0.02. The overall dimension of the proposed antenna is 75mm × 66mm × 1.6mm (0.6λ × 0.528λ × 0.0128 λ). Here, the simulated results have been compared with the measured results, and it has been found that both results are well-matched to each other. The proposed antenna obtained the bandwidth of 400 MHz (2.25-2.65 GHz) for S_{11} < -10 dB, the gain of about 6.25-7.1dBi, and VSWR < 2 for the entire frequency band. Additionally, it has front-to-back (F/B) ratio > 11 dB and cross-polarization level of < -26dB at 2.4 GHz. This antenna is suitable for industrial scientific and medical(ISM) band in the frequency range of 2.40 - 2.50 GHz, point-to-point communication in various fields, WLAN, RFID, and portable direction finding applications, where high gain with moderate bandwidth is the primary requirement.*

Keywords – *Quasi-Yagi antenna, Bowtie, Curved shaped director, Gain, and Bandwidth.*

1. Introduction

The demand for high gain, compact size, broadband, and low profile antenna, especially in mobile communication, phased array, portable direction finding systems, radio communication, RFID tags, etc., is increasing rapidly. The printed quasi-Yagi antenna has received huge interest in research because it fulfils all the abovementioned requirements. It consists of three elements, i.e., reflector, driven, and one or more directors. Initially, the Yagi-Uda antenna was designed with a simple cylindrical wire/rod. It was most popular for the home TV antenna in the early days but was bulkier and heavier [1]. Generally, a printed Yagi-Uda antenna gain is about 5-6 dBi with limited bandwidth. To achieve high gain, broad bandwidth, and compactness, the Yagi-Uda antenna can be designed by changing its original structure w.r.t different feed structures (Microstrip-to-coplanar stripline (MS-to-CPS [2-5,7-8], Coplanar Waveguide feed (CPW) [9-10], Microstrip to Slotline transitions [6], and balun structures [2,9-22]) and element shapes (dipole, bowtie [5, 7-8], periodic log antenna [12], curved shape[10, 19], folded dipole [13], meander shaped [21,22], double dipole [23]) using printed technology. These new structures formed due to different feed structures and elements shapes are not exactly the Yagi-Uda antennas but can be called printed quasi-Yagi antennas. These antennas can be used in RADARs, satellites, Amateur Radio, RFID applications, ISM bands, and many more[1,2].

In 1998, Yongxi Qian introduced the first quasi-Yagi antenna for X band prototype using Duroid substrate with MS-to-CPS transition feeding method. This antenna obtained gain of 6.5dBi, bandwidth of 17%, F/B ratio of l8dB, and cross-polarization level of < -15dB at 10 GHz [3]. In [4], the modified quasi-Yagi antenna with low radar cross section is proposed using Rogers RT 6010 substrate with MS-to-CPS transition feeding method. This antenna obtained the 5 - 8 GHz band for S_{11}< -10dB and the gain of about 2.5 - 4 dBi. The complicated feeding structure is the major drawback of [3-4] antenna. In [6], a quasi-Yagi antenna is designed using Rogers RT 6010 substrate using microstrip to slotline transitions balun, which achieves a bandwidth of more than 70% for S_{11} < −10 dB, a gain of 4 dBi, and an F/B ratio of 18 dB at the center frequency of 7.5 GHz. This antenna achieves broadband with low gain at the cost of design complexity and costlier substrate. In [10], the quasi-Yagi antenna is presented using the CPW feed technique, which obtained a bandwidth of 40% for S_{11} < -10 dB and gained about 2.25 - 3.2 dBi over the entire frequency. The CPW feed technique is a simple feeding structure as compared to MS-to-CPS. It provides a compact antenna structure with broad bandwidth but has limited gain. In [11], Yagi-Uda antennas are designed using a coaxial feeding method with a tapered balun. In this paper, two different designs are presented based on the shape of driven and reflector elements. Design 1 antenna achieved a bandwidth of 240 MHz (1.16 - 1.40 GHz) for VSWR ≤ 2, and the gain varies 6.3 dB over the bandwidth. Design 2 achieved a bandwidth of 200 MHz (1.20 - 140 GHz) for VSWR ≤ 2, and the gain varies 6.4 dB over the bandwidth. Comparing both antenna designs, it is found that a tapered shape Yagi-Uda antenna is more compact and has better performance concerning bandwidth, gain, and F/B ratio than a rectangular-shaped Yagi antenna. In [12], a quasi-Yagi antenna using a log-periodic antenna driver with tapered feeding is presented to enhance bandwidth. This antenna achieves 39.1% bandwidth, 6-7dB gain and F/B ratio > 20dB. In [13], a quasi-Yagi antenna using folded dipole antenna as a driven element with tapered balun is presented, which obtained 7% bandwidth for S_{11} < -10 dB and 6.1dBi gain. Tapered balun provides impedance matching by gradually tapering the bottom or both sides of the conductor, thus causing the structure complex to have a large area. In [19], quasi-Yagi antennas are designed using a simple microstrip feed line. In this paper, two quasi-Yagi antennas are designed with straight and bent arms. Both designed antennas obtained the same bandwidth (400MHz), while the quasi-Yagi with a bent arm achieved higher gain and compactness than straight arms.

This paper uses a simple microstrip feed line for this proposed antenna. It provides impedance matching between the coaxial input source and bowtie-shaped driven element. The bowtie-shaped driven element of the proposed antenna provides broadband, while the curved shape reflector and director provide high gain. The proposed antenna is simulated using HFSS 15.0 and tested using Vector Network Analyser (Anritsu VNA Master) and Anechoic Chamber.

2. Quasi-Yagi Antenna Design and Parameter Analysis

A printed curved shape director-driven bowtie quasi-Yagi antenna (BDQY; Bowtie driven curved Director Quasi-Yagi antenna) has five elements; the curved shape reflector, bowtie shaped driven, and three curved shape directors. In this antenna, the bowtie-shaped drive is designed using two triangular sheets fed at the vertex by a microstrip feed line. As the width of the bowtie arm increases, bandwidth is improved with the antenna resonating at a lower frequency [11, 25-27]. The curved shape directors are designed from rectangle sheets by taking arcs at both sides [19]. One arm of bowtie shape and microstrip feed line is printed at the top of the substrate, while other arms and curved shape reflector and directors are printed at the bottom side of the substrate. For matching input impedance, the simple feeding structure is designed by a mictrostrip line instead of a complex balun structure or any transition. The width and length of the microstrip feed line are taken as 0.024λ and 0.196λ, respectively. To increase the gain of BDQY in the desired direction with moderate bandwidth, it is designed with 5-element presented in this section. Its Geometry is shown in figure 1. It has five elements; one curved shape reflector, one bowtie-shaped driven, and three curved shape directors. Its design parameters (length, width, and space,) are chosen using parametric study to get optimum results which are mentioned as follow: Reflector: length, width (L_{ref} = 48 mm, W_{ref} = 8 mm); Driven: length, width (L_{dri} = 20.5 mm, W_{dri} = 21.5 mm); Directors: length ,width (L_{dir_1} = 30.80 mm, W_{dri_1} = 4 mm, L_{dir_2} = 28.85 mm, W_{dri_2} = 4 mm, L_{dir_3} = 28.85 mm, W_{dri_3} = 4 mm), Spacing between Reflector and driven element (S_{ref} = 24.5 mm), Spacing between driven and directors (S_{dir_1} = 15 mm, S_{dir_2} = 9 mm, S_{dir_2} = 7 mm), Feed: width, height: W_{feed} ,W = 3 mm, H=1.6 mm, substrate: length ,width, height (L_s = 75 mm, W_s = 66 mm, H = 1.6 mm).

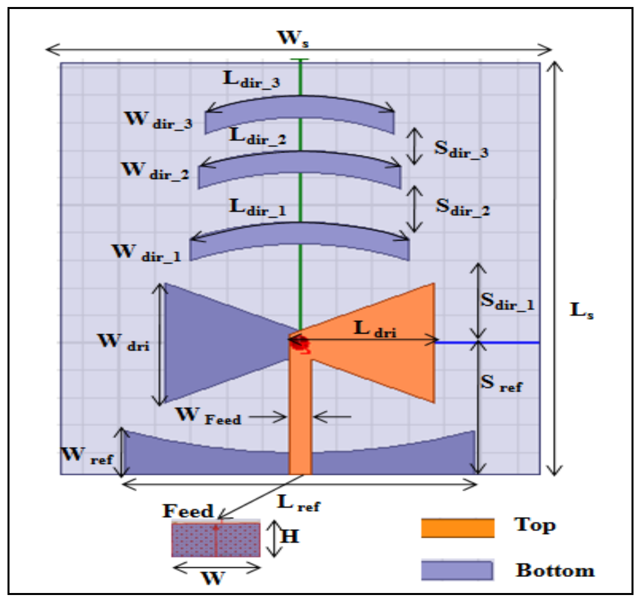


Fig. 1 Geometry of 5-element BDQY

The return loss and gain of 5-element BDQY are shown in figure 2 and figure 3, respectively. The design antenna achieved 19.3% bandwidth (2.22 - 2.7 GHz) for S_{11} < -10 dB. The gain in the H plane and E plane at 0° and 180° directions are 6.67 dBi and -4.71 dBi, respectively, and the F/B ratio > 11 dB at 2.4 GHz.

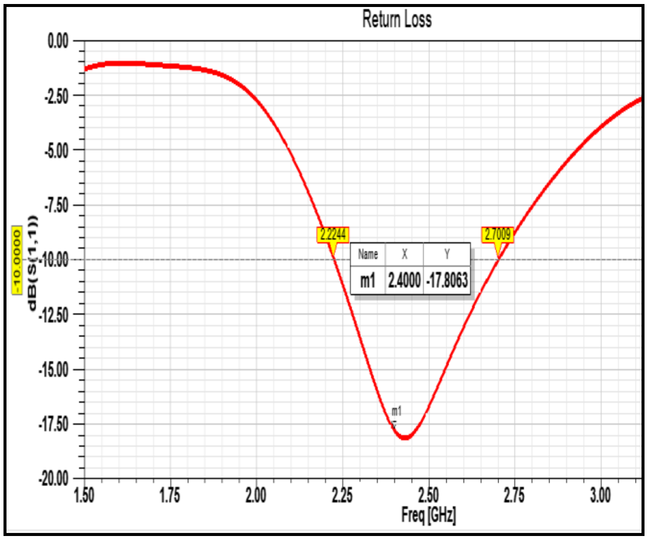


Fig. 2 Return loss of 5-element BDQY

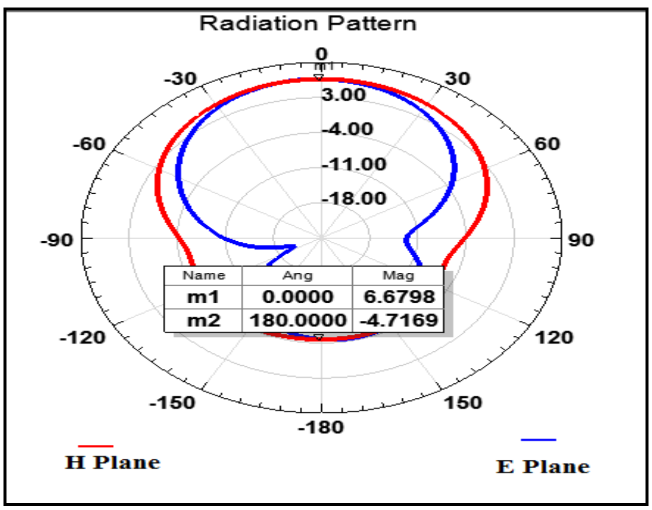


Fig. 3 Gain in H and E plane of 5-element BDQY

3. Results and Discussion

Above 5-element BDQY is fabricated, and it is the proposed antenna for this paper. Figures 4a and 4b show the photographs of the top and bottom views of the proposed antenna. It is fabricated on a low-cost glass Epoxy FR4 substrate using standard photolithography.

The proposed antenna parameters of return loss and VSWR are measured by Anritsu Vector Network Analyser (VNA) master (model: MS2037C/15/509), and the gain and gain Vs. frequency is measured in the Anechoic Chamber of Electromagnetics and Antenna research center (ELARC) lab at Birla Vishvakarma Mahavidhyalaya, Anand, Gujarat. The examination of the proposed antenna is shown in figure 5. The measurement of VSWR and return loss in VNA in the range of 1-3 GHz has been taken, and the radiation pattern and Gain Vs. Frequency has taken 9° and 200 MHz step sizes, respectively.

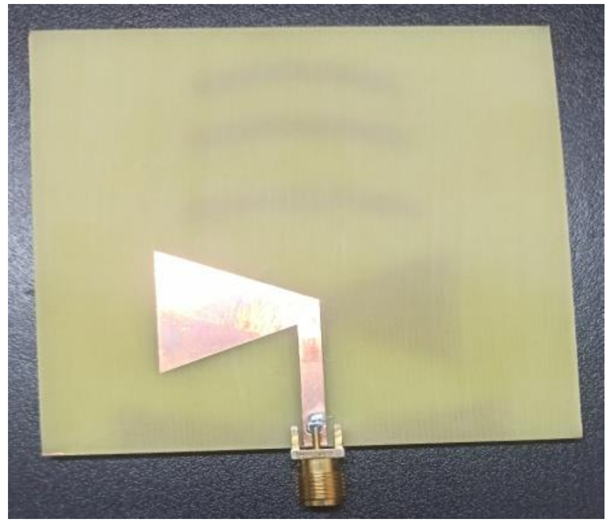


Fig. 4a) Proposed antenna – Top view

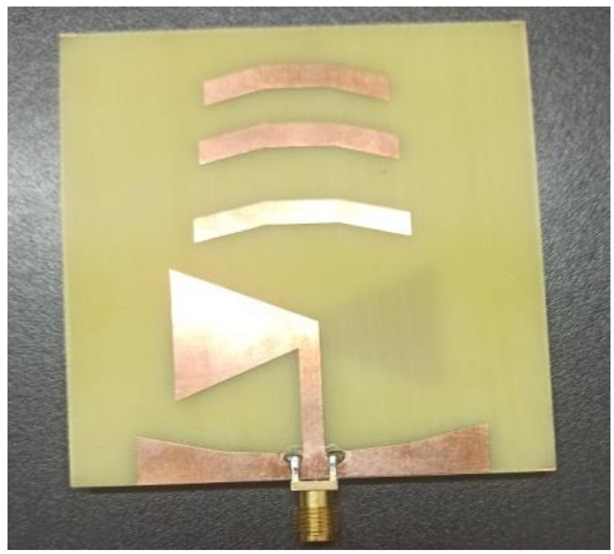
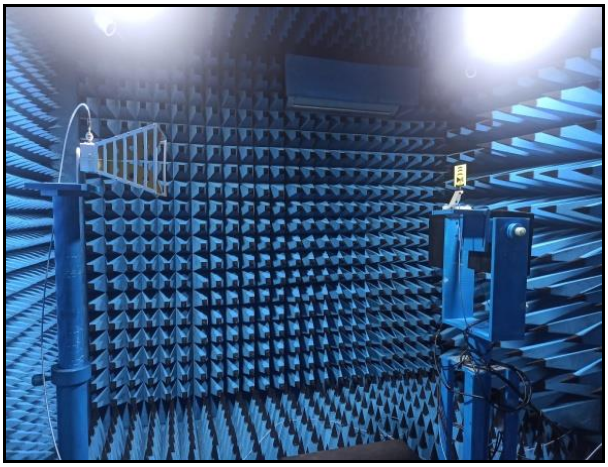
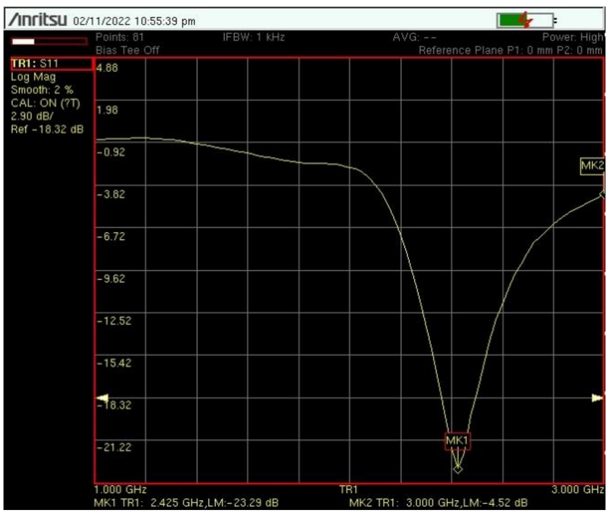


Fig. 4b) Proposed antenna – Bottom view

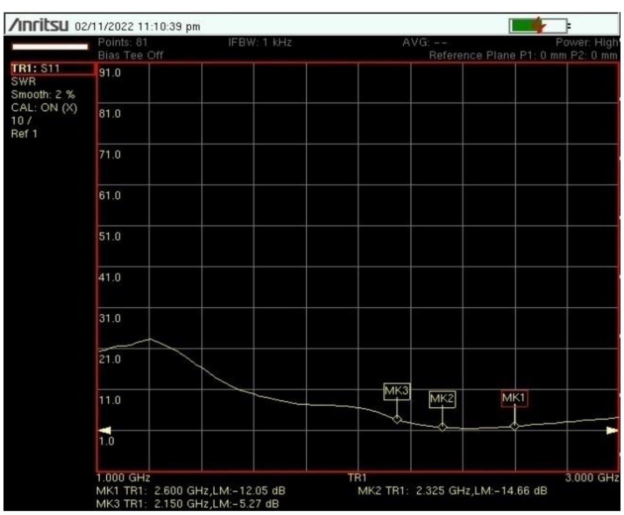

(A)



(B)



(C)



(D)

Fig. 5 (A) VSWR testing on Anritsu VNA Master, (B) Gain measurement setup in an anechoic chamber, (C) Measured return loss, (D) Measured VSWR of the proposed antenna

The measured and simulated results of the proposed antenna are shown in figure 6 ((A) Return Loss, (B) VSWR, (C) Simulated Gain Vs. Frequency, (D) Cross-polarization, (E) Gain Vs. Frequency, (F) Radiation pattern). The results show a good agreement between measured and simulated results of return loss, VSWR, Gain Vs. Frequency and Radiation pattern. From the measured results, it is found that the proposed antenna obtained bandwidth of 16.3% for $S_{11} <$ -10 dB, gain of 6.25 - 7.01 dBi, F/B ratio > 11 dB, cross-polarization level of < -26 dB at 2.4 GHz. The proposed antenna also achieves VSWR < 2 for the entire bandwidth. Measured half-power beam widths (HPBW) are 106° and 64° in H and E-planes, respectively. The proposed antenna achieves flat gain over the entire bandwidth with a maximum gain of 7.01 dBi. This antenna is suitable for ISM band application, point-to-point communication, RFID, and portable direction finding, where moderate bandwidth with a moderate gain is the primary requirement.

A comparison of the performance of the proposed antenna with other reported quasi-Yagi antennas is mentioned in Table 1. Some reported configurations have complex feeding structures (MS-to-CPS, CPW, and tapered balun). Moreover, some of the configurations require a large ground plane. However, the proposed antenna achieves high gain with moderate bandwidth with a simpler microstrip feed line, smaller structure size, and low-cost FR4 substrate. In [3,10] designed antenna achieved broad bandwidth with moderate gain using costly dielectric substrate RT6010. These designed antennas are much costlier compared to the proposed antenna. Compared to [11, 15, 16], the proposed antenna achieved a wide frequency band with almost the same gain. In [12] design antenna provides a wideband with high gain using the coaxial feeding method with a tapered balun; it is a complex design and requires a large area for this structure. It is seen that the configuration in [13] has achieved high gain with a narrow band using folded dipole antenna as a driven element and 6-director with a tapered feeding structure. This structure requires a large area. In [14], the designed antenna obtained wide bandwidth using a tapered microstrip line with low gain. It is seen that the configuration in the [17] designed antenna has narrow bandwidth with almost the same gain as compared the proposed antenna. In [18], the designed antenna provides wideband with very low gain using monopole as driven element with the microstrip feed line. Compared to [19], the proposed antenna has high gain and small size with the same bandwidth. It is observed that there will always be a trade-off between parameters; bandwidth, gain, and F/B ratio while designing a quasi-Yagi antenna. If one of the parameters is improved, the antenna's performance degrades for the other two parameters.

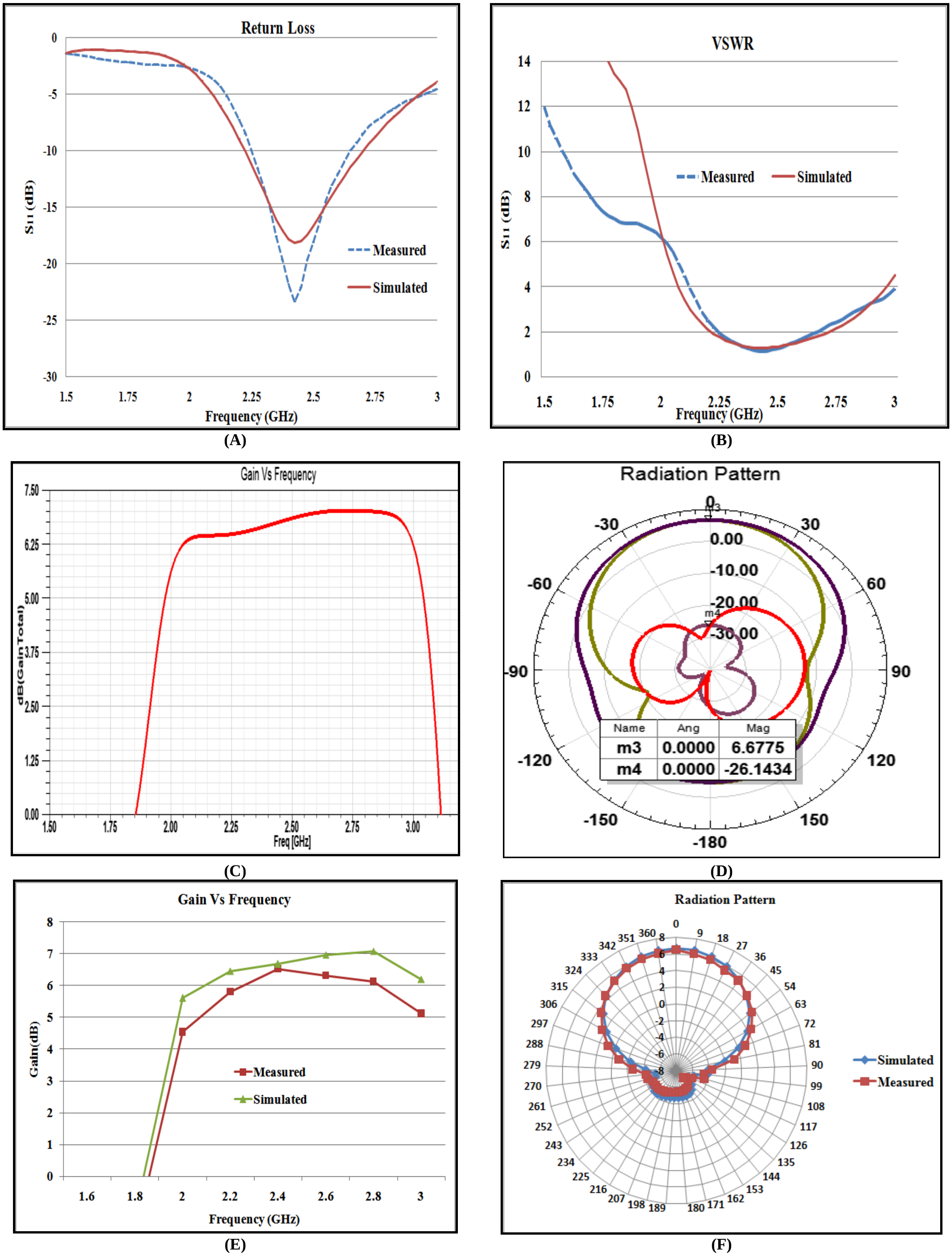
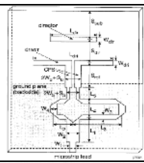
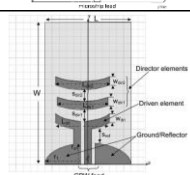
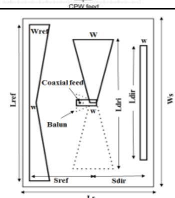
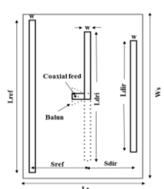
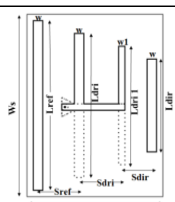
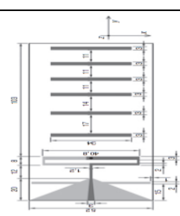
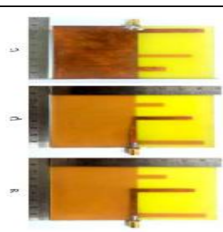
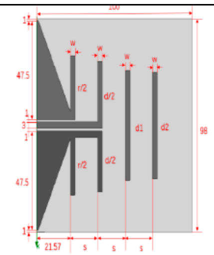
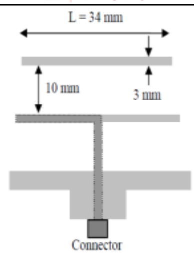
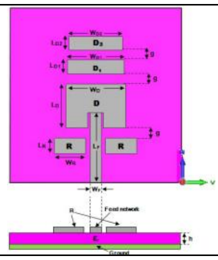
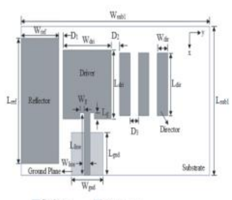
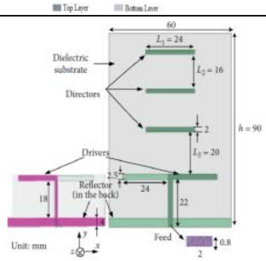
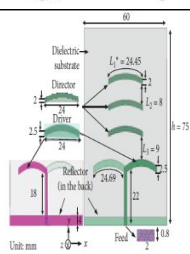


Fig. 6 Measured and simulated result of proposed antenna; (A) Return Loss, (B) VSWR, (C) Simulated Gain Vs. Frequency, (D) Cross-polarization, (E) Gain Vs. Frequency, (F) Radiation pattern

Table 1. Comparison of the proposed antenna with other reported quasi- Yagi antennas

Ref.	Antenna Geometry	Frequency band (GHz)	BW %	Gain dBi	Substrate, dielectric constant,	Size (mm) Ls × Ws	Feeding technique, Driven element shape, Applications, and remarks
*	Proposed Antenna	2.25-2.65	16.3	6.25-7.1	FR-4, 4.4	75 × 66	Microstrip feed line, bowtie, simple design structure, ISM band, point-to-point communication
3		9.5–11.6	17	6.5	Duroid, 10.2	15 × 18	MS-to-CPS, Dipole, X band Prototype complex feeding structure
10		8-12	40	2.25 - 3.2	RT6010, 10.2	12 × 20	CPW feed, curved shape structure, X-band prototype
11		1.16-1.40	18.6	6.4	Fr4, 4.4	85 × 102	Tapered balun, Tapered shape with coaxial feeding method, portable direction finding, RFID, spectrum monitoring systems
		1.20-1.40	15.5	6.3	Fr4, 4.4	85 ×112	Tapered balun Dipole with coaxial feeding method, spectrum monitoring systems, portable direction finding
12		1.15-1.75	39.1	6-7	Fr4, 4.4	84 × 111	Tapered balun, LPDA with coaxial feeding method, RFID, spectrum monitoring systems, portable direction finding
13		2.31-2.5	7.7	7.5	FR-4, 4.4	52 × 143	Tapered balun, Folded dipole with 6 directors, WiFi applications
14		1.7-2.1	47.6	4.1	FR-4, 4.4	76 × 86	Microstrip line, monopole, ISM Band, LTE Band 3 and 4
		1.5-2.53	53.5	4.65			Tapered balun, Monopole, ISM Band, LTE Band 3 and 4 , IEEE 802.15.4

15		2.82- 3.07	8.4	8.17	Fr4, 4.4	100 × 98	Tapered balun / single side printed, Dipole, CubeSat communications
		1.30 -1.40	7.4	5.28			
		2.34 -2.52	7.6	6.12			
16		2.8- 3	6.8	6.5	εr = 2.17	----	Microstrip line, dipole
17		5.70-5.81	1.89	6.89	Fr4, 4.4	65 × 80	Microstrip feed line, patch, WiFi applications
18		3.25-3.75	14.32	3.25	TMM-4 ,4.5	50 × 90	Microstrip fed line, monopole, broadband application
19		2.3-2.7	16	6.03	Fr4, 4.4	90 × 60	Microstrip feed line, Dipole, WLAN, ISM band for 2.4- 2.48 GHz, rail transit communication,
		2.3-2.7	16	6.13	Fr4, 4.4	75 × 60	Microstrip feed line, Dipole with a bent arm, WLAN, ISM band for 2.4- 2.48 GHz, rail transit communication,

4. Conclusion

The BDQY has been designed and fabricated on a low-cost substrate using a simple microstrip feeding method. The proposed antenna has a good agreement between measured and simulated results for the entire bandwidth. From this study, it is found that the proposed antenna obtained 16.3% bandwidth for S_{11} < -10 dB with gain of 6.25-7.1 dBi, F/B ratio of 11dB and cross-polarization level of < -26 dB. The proposed antenna achieved high gain with moderate bandwidth, which will be helpful to antenna design engineers to design applications on 2.4 GHz, where high gain with moderate bandwidth is the primary requirement.

Acknowledgment

The author would like to thank Dr. J M Rathod–Professor I/C- Electromagnetics and Antenna research centre (ELARC), Birla Vishvakarma Mahavidhyalaya, Anand, Gujarat, who permitted to test the antenna in their LAB.

References

[1] Constantine A. Balanis "Antenna Theory Analysis and Design," *Third Edition Wiley-Interscience*, 2005.

[2] G. Kumar and K.P. Ray, "Broadband Microstrip Antennas," *rtech House*, 2003.

[3] Y. Qian, W.R. Deal, N. Kaneda, and T. Itoh, "Microstrip-fed Quasi-Yagi antenna with broadband characteristics," *Electronics Letters*, vol. 34, no. 23, pp. 2194-2196, 1998.

[4] Jie Lv, Shu-Xi Gong,Fu-Wei Wang, Jie Luo, and Yong-Xia Zhang, "RCS Reduction of Quasi-Yagi Antenna," *Progress In Electromagnetics Research C*, Vol. 53, 89–97, 2014.

[5] Hao Wang, Yan Chen, Fangshu Liu, and Xiaowei Shi "Wideband and compact Quasi-Yagi antenna with bowtie-shaped drivers," *Electronics Letters*, 2013.

[6] P. T. Nguyen, A. Abbosh and S. Crozier, "Wideband and compact Quasi-Yagi antenna integrated with balun of microstrip to slotline transitions," *Electronics Letters*, Vol. 49 No. 2, 2013.

[7] Tinghui Zhao, Yang Xiong, Xian Yu, Haihua Chen, Ming He, Lu Ji, Xu Zhang, Xinjie Zhao, Hongwei Yue and Fangjing Hu, "A Broadband Planar Quasi-Yagi Antenna with a Modified Bow-Tie Driver for Multi-Band 3G/4G Applications," *Progress In Electromagnetics Research C* ,· 2017.

[8] Tianming Yang, Deqiang Yang, Dongdong Geng, "Compact planar quasi-Yagi antenna with band-notched characteristic for WLAN and DSRC for ultra-wideband applications," *IET Microwaves, Antennas & Propagation*, Vol. 12 Iss. 7, pp. 1239-1245, 2018. ISSN 1751-8725.

[9] H. K. Kan, R. B. Waterhouse, A. M. Abbosh and M. E. Bialkowski, "Simple broadband planar CPW-fed Quasi-Yagi antenna," *IEEE Antennas and Wireless Propagation Letters*, Vol. 6, 2007.

[10] H. K. Kan, A. M. Abbosh R. B. Waterhouse and M. E. Bialkowski, "Compact broadband coplanar waveguide-fed curved Quasi-Yagi antenna," *IET Microwaves, Antennas & Propagation*, Vol. 1, No. 3, 572–574, Jun. 2007.

[11] H. Kumar and G. Kumar, "Compact planar Yagi-Uda antenna with improved characteristics," *2017, 11th European Conference on Antennas and Propagation* (EUCAP), 2008–2012, Paris, 2017.

[12] Hemant Kumar and Girish Kumar, "A Broadband Planar Modified Quasi-Yagi Using Log-PeriodicAntenna," *Progress In Electromagnetics Research Letters*, Vol. 73, pp.23–30, 2018.

[13] M. Farran, S. Boscolo, A. Locatelli, A.-D. Capobianco, M. Midrio, V. Ferrari and D. Modotto, "Compact quasi-Yagi antenna with folded dipole fed by tapered integrated balun," *Electronics Letters*,12th May 2016, Vol. 52 No. 10 pp. 789–790, 2016.

[14] Amar D. Chaudhari, Kamla Prasan Ray, "Printed broadband Quasi-Yagi antenna with monopole elements," *IET Microwaves, Antennas & Propagation*, 2020. ISSN 1751-8725.

[15] Sining Liu, Raad Raad, Panagiotis Ioannis Theoharis and Faisel Em Tubbal,"A Printed Yagi Antenna for CubeSat with Multi-Frequency Tilt Operation," *MDPI, Electronics* , vol. 9, pp.986, 020.

[16] J.M. Floc'h, F. Queudet, E. Fourn "Design of printed dipole with reflector" *IEEE Xplore*, 2007.

[17] Nuraiza bt. Ismail, M.T Ali, N.N.S.N. Dzulkefli, R. Abdullah, S. Omar, "Design and analysis of microstrip Yagi antenna for WiFi application," *2012 IEEE Asia-Pacific Conference on Applied Electromagnetics* (APACE 2012), December 11 - 13, Melaka, Malaysia, 2012.

[18] Moumita Sarkar, Tarakeswar Shaw, Rhitam Datta, Pujayita Saha, and Debasis Mitra, "Design of a Compact Planar Quasi-Yagi Antenna with Enhanced Gain and Bandwidth Using Metamaterial," *Progress In Electromagnetics Research Letters*, Vol. 62, pp.125–131, 2016

[19] Wen-Ying Zhou, Zhong-Lei Mei, and Mai Lu, "A Compact Quasi-Yagi Antenna with High Gain by Employing the Bent Arms and Split-Ring Resonators," Hindawi, *International Journal of Antennas and Propagation*, 2021.

[20] G. Zheng, A.A. Kishk, A.W. Glisson and A.B. Yakovlev, "Simplified feed for modified printed Yagi antenna," *Electronics Letters 15th* Vol. 40 No. 8, 2004.

[21] Huang, H. C., J. C. Lu, and P. Hsu, "A planar Yagi-Uda antenna with a meandered driven dipole and a concave parabolic reflector," *2010 Asia-Pacific Microwave Conference*, pp. 995–998, 2010.

[22] Huang, H. C., J. C. Lu, and P. Hsu, "On the size reduction of planar Yagi-Uda antenna using parabolic reflector," *2015 Asia-Pacific Microwave Conference (APMC)*, Nanjing, pp. 1–3, 2015.

[23] Ta, S. X., H. Choo, and I. Park, "Wideband double-dipole Yagi-Uda antenna fed by a microstrip slot coplanar stripline transition," *Progress In Electromagnetics Research* B, Vol. 44, pp.71–87, 2012.

[24] Pravin Dalvadi, Dr. Amrut Patel, "A Comprehensive Review of Different Feeding Techniques for Quasi Yagi Antenna," International *Journal of Emerging Trends in Engineering Research*, Vol. 9. No. 3, 2021.

[25] Pravin Dalvadi, Dr. Amrut Patel, "Comparative analysis of Dipole and Bowtie Antenna on 2.4 GHz," *Lecture Notes in Networks and Systems (LNNS) Series of Springer*, pp. 21-35, 2022.

[26] Pravin Dalvadi, Dr. Amrut Patel, Devendra Patel, G. D. Makwana, "Design of Wideband Bowtie Antenna using Tapered Balun for Industrial, Scientific and Medical Band Application," *International Journal of Information Technology and Electrical Engineering*, Vol.10, no. 3, 2021.

[27] D. A. Abd El-Aziz, T. G. Abouelnaga, E. A. Abdallah, M. El-Said, Yaser S. E. Abdo, "Analysis and Design of UHF Bow-Tie RFID Tag Antenna Input Impedance" *Open Journal of Antennas and Propagation*, vol.4, pp.85-107.