Progress In Electromagnetics Research Letters, Vol. 69, 45–50, 2017

Butter Fly Shape Compact Microstrip Antenna for Wideband Applications

Rakesh N. Tiwari[1, *], Prabhakar Singh[2], and Binod K. Kanaujia[3]

Abstract—In this article, a novel design of butterfly-shaped compact and small size microstrip antenna is proposed. The radiating structure consists of four circular discs in coalesced form and fed with coaxial probe. The initial antenna resonates at 9.64 GHz with impedance bandwidth of 11.41%. The resonance frequency is further reduced to 8.12 GHz with bandwidth 10.10%, when a rectangular slot is incorporated in the initial patch. Finally, two parallel slots are embedded in the initial patch which improves the antenna bandwidth up to 21.50% (6.02–7.47 GHz). The gain and efficiency of this antenna are above 8.80 dBi and 90% respectively across the entire operating band. Radiation pattern is calculated at lower end (6.02 GHz), upper end (7.47 GHz) and centre frequency (6.75 GHz) of operating band. The proposed antenna is fabricated, and measured results are validated with the simulated ones.

1. INTRODUCTION

Modern communication systems are getting smaller and robust day by day. Therefore, the need of miniaturized, wideband and compact patch antennas are in high demands [1, 2]. Microstrip patch antennas are widely used in this regard as they offer compactness, low profile, light weight and capability to easily integrate with circuits. However, the microstrip patch antenna is limited by its narrow operating bandwidth. Bandwidth improvement and size reduction are major challenges for researchers because the bandwidth and size of an antenna are generally mutually conflicting properties. There are various impedance matching and feeding techniques used to achieve wide bandwidth [3–5]. Using some narrow slots or removing some portion from the resonators such as patch loaded with U-slot [6, 7], W-slot [8], V-slot [9], T-slot [10] and fractal shaped patch [11, 12] provides a compact antenna with enhanced bandwidth. An asymmetric E-shaped patch and proximity coupled patch antenna [13, 14] also provide improved bandwidth, but the overall size is compromised. Other methods for broadening the impedance bandwidth include stacked patch antenna and E-shaped patch [15, 16], L-shaped probe and shorting pins [17, 18]. However, these antennas have certain drawbacks in terms of high volumetric size and design complexity.

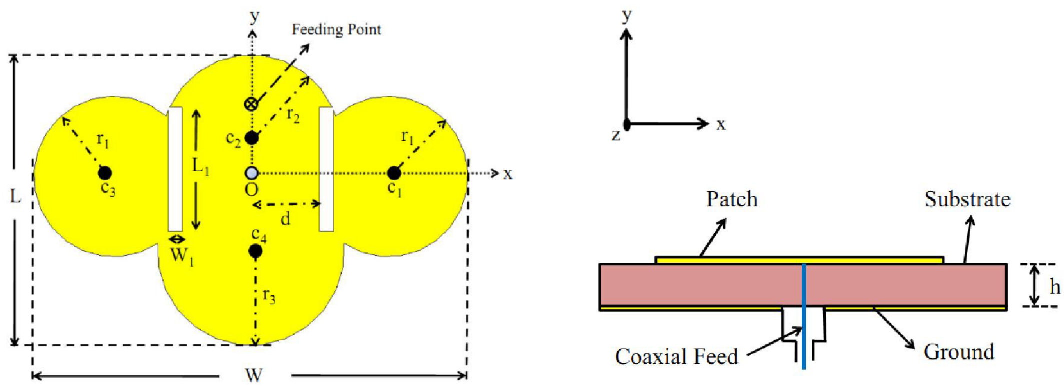
In this paper, a novel and simple butterfly-shaped wideband patch antenna is presented. Such a design, as per the authors' knowledge, has not been reported in the literature so far. The proposed antenna structure is coaxially fed and realized using four circular discs of different radii and etching the slots in the patch. This structure increases the periphery of the patch which increases the effective length of the patch. This increment in the length causes the shift of resonance frequency towards the lower side. The antenna parameters such as radiation pattern, bandwidth, gain and efficiency are calculated by CST microwave studio, and the results are compared with the measured data. The antenna structure and its fabrications are described in Sections 2 and 3. The measured results and discussions are presented in Section 4 followed by conclusion in Section 5.

Received 27 April 2017, Accepted 12 June 2017, Scheduled 5 July 2017

* Corresponding author: Rakesh Nath Tiwari (srakeshnath@gmail.com).
[1] Department of Electronics and Communication Engineering, Raffles University, Neemrana, Rajasthan, India. [2] Department of Physics, Galgotias University, Greater Noida, Uttar Pradesh, India. [3] School of Computational and Integrative Sciences, Jawaharlal Nehru University, New Delhi, India.

2. ANTENNA STRUCTURE

The basic geometry of the proposed antenna is shown in Fig. 1. The proposed antenna is realized in two steps. (i) Four circular discs of radii r_1, r_2 and r_3 are partially coalesced. The radii of discs along horizontal direction are taken equal (i.e., r_1) while the radii of discs along vertical direction are r_2 and r_3. (ii) Two parallel slots (dimension $L_1 \times W_1$) are symmetrically embedded in the patch with respect to feed point. This perturbation in the patch increases the electrical length of the antenna and hence reduces the resonance frequency. The dimension of vertical and horizontal length ($L \times W$) of the antenna is $21.0 \times 31.8\,\text{mm}^2$, and the thickness of the radiating copper patch is 0.1 mm.

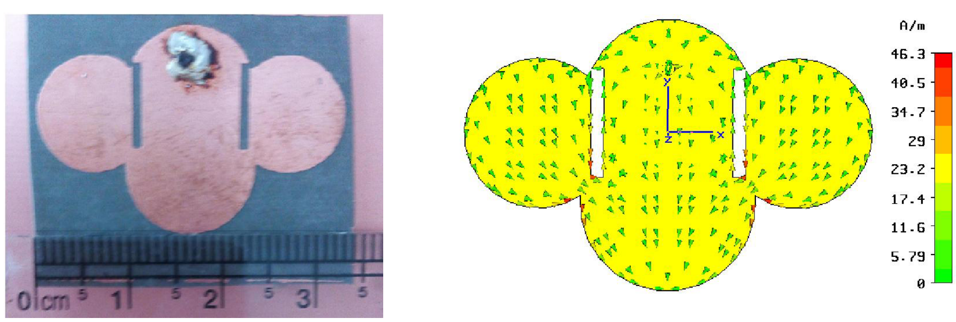


(a) (b)

Figure 1. Geometry of the proposed antenna (a) top view and (b) side view.

3. ANTENNA FABRICATION

The proposed antenna is printed on RT/duriod 5880 ($\varepsilon_r = 2.2$) of thickness $h = 3.0$ mm as shown in Fig. 2(a). The ground plane size is $27.0 \times 34.0\,\text{mm}^2$.



(a) (b)

Figure 2. (a) Prototype of the proposed antenna and (b) surface current distribution at 6.75 GHz (centre frequency).

Two slots of dimension $8.4 \times 1.0\,\text{mm}^2$ are etched symmetrically at a distance 5.0 mm along x-axis from the origin 'O'. The proposed antenna is coaxially fed at a distance 5.0 mm along y-axis from the origin. The corresponding current distribution at center frequency (6.75 GHz) is shown in Fig. 2(b). The design specification of the proposed antenna is given in Table 1.

Table 1. Design parameters of the proposed antenna.

Parameters	Size
$L \times W$	$21 \times 31.8\,\mathrm{mm}^2$
$L_1 \times W_1$	$8.4 \times 1.0\,\mathrm{mm}^2$
Substrate	RT/duriod 5880 ($\varepsilon_r = 2.2$)
r_1	5.8 mm
r_2	6.5 mm
r_3	6.8 mm
h	3.0 mm
d	5.0 mm

4. RESULTS AND DISCUSSION

Figure 3 shows the simulated results of return loss for three different antennas. The initial antenna (antenna A) resonates at 9.64 GHz with bandwidth 11.41%, while antenna B with a narrow rectangular slot resonates at 8.12 GHz. The reduction in resonant frequency is attributed to the fact that the narrow slot in the patch effectively increases the overall length of current. This increment of the current length decreases the resonance of the antenna. However, due to this the mismatching increases and reduces the bandwidth (10.10%). But it is interesting to note that when two parallel narrow slots are symmetrically incorporated in the patch, two different modes come closer and realize the wideband characteristics. The detailed characteristics of three antennas are presented in Table 2 and also compared with another antenna [19] working in this range. It is also noted that the position (d) of two parallel slots and the

Table 2. Comparison of antenna characteristics.

Types of antenna	Total antenna size (mm^3)	Center frequency (GHz)	Bandwidth (GHz)	Peak gain (dBi)
Antenna A	$27 \times 34 \times 3$	9.64	9.09–10.19	8.50
Antenna B	$27 \times 34 \times 3$	8.12	7.71–8.53	8.20
Antenna C	$27 \times 34 \times 3$	6.75	6.02–7.47	8.80
2nd Antenna [19]	$42 \times 50 \times 1.6$	7.00 (second band)	4.0–10.0	3.30

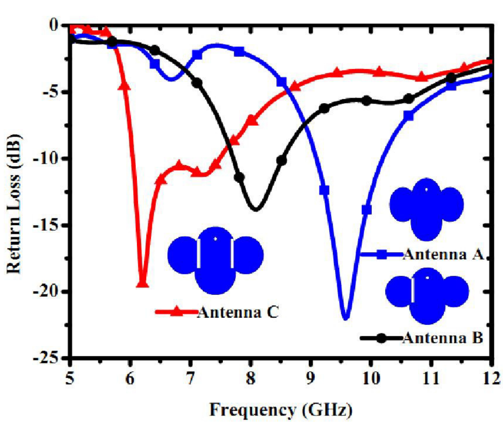


Figure 3. Simulated return loss for three antennas.

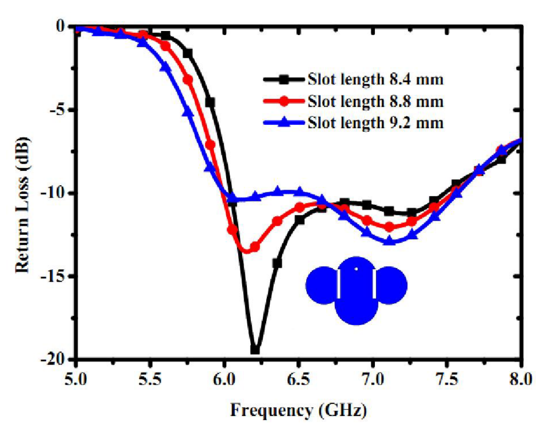


Figure 4. Variation of return loss for different slot length L_1.

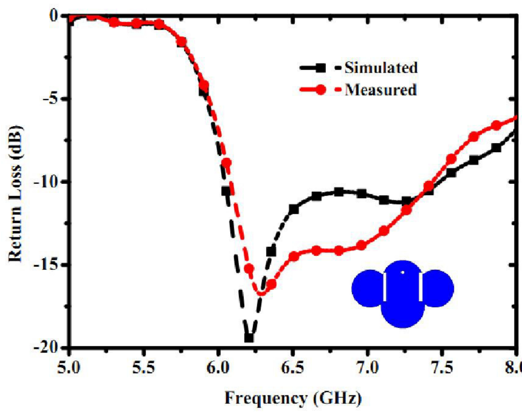


Figure 5. Measured return loss.

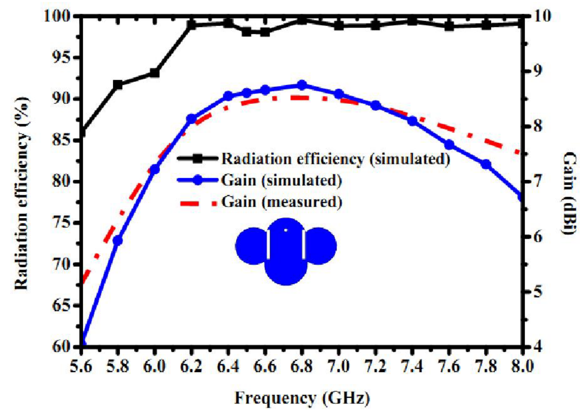


Figure 6. Variation of radiation efficiency and gain of the proposed antenna.

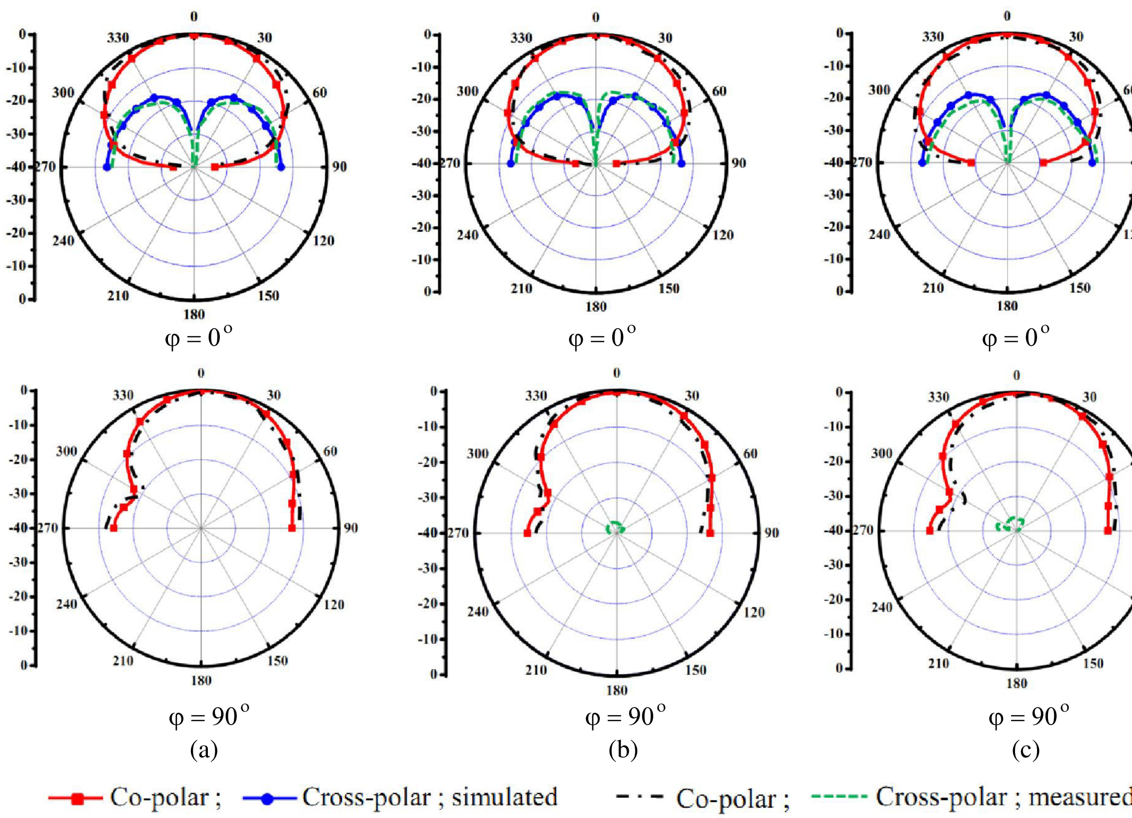


Figure 7. Radiation pattern of the proposed antenna at (a) $f = 6.02\,\text{GHz}$, (b) $f = 6.75\,\text{GHz}$, and (c) $f = 7.47\,\text{GHz}$.

width of the slot (W_1) for antenna C are optimized for the best result. Variation in d or W_1 gives unacceptable results, and hence it is not reported in the paper.

Figure 4 depicts the variation of return loss for different slot lengths (L_1). From the figure it is clear that when two slots are used in the radiating patch, the bandwidth varies directly with L_1. The maximum frequency band (5.98–7.56 GHz) is observed at $L_1 = 9.2\,\text{mm}$. It is also noted that beyond $L_1 = 9.2\,\text{mm}$, the antenna exhibits a single band which resonates at 7.25 GHz. Fig. 5 shows a comparison of simulated and measured return losses of the butterfly-shaped antenna. The simulated bandwidth for given $L_1 \times W_1$ ($8.4 \times 1.0\,\mathrm{mm}^2$) is compared with measured bandwidth. The calculated bandwidth (20.97%, 6.06–7.48 GHz) is in good agreement with the measured result (19.82%, 6.09–7.43 GHz).

Figure 6 shows the calculated radiation efficiency of the proposed antenna which is found above 93% for the entire operating band. Also, the simulated and measured gains are compared in the figure, and they are above 7.22 dBi throughout the band of operation. The maximum realised gain for antenna C is 8.80 dBi. The radiation patterns of the proposed antenna are plotted at the two extreme edges (6.02 GHz and 7.47 GHz) and at center frequency (6.75 GHz) of the usable band (Fig. 7). The calculated radiation patterns at $\varphi = 0°$ and $\varphi = 90°$ are plotted and compared with the measured results. The cross polarisation components are very low at the broad side angle for $\varphi = 0°$ and $\varphi = 90°$.

The simulated cross polarisation is below −40 dB at the broadside angle. Therefore, it is not observed at 6.02 GHz, 6.75 GHz and 7.47 GHz for $\varphi = 90°$. However, some measured cross polarisation components (except for 6.02 GHz) are observed at $\varphi = 90°$ for 6.75 GHz and 7.47 GHz (Figs. 7(b) and (c)). The proposed antenna exhibits a linearly polarized, broadside and almost identical radiation characteristic for the entire band of operation.

5. CONCLUSION

In this paper, a novel, compact and small size patch antenna is investigated. The present study infers that the resonant frequencies and bandwidth are controlled by using thin rectangular slots in the reference antenna. The effective size of the antenna is significantly reduced with maximum bandwidth of 21.50%. The cross polarization of the antenna is very low. The radiation pattern is stable for the entire frequency band, and relative power is maximum at broadside angle. The antenna performance can be further improved by optimizing the radii of four coalesced disks. The antenna operates in C-band and can be suitably used for various microwave devices operating in this range, primarily for satellite communications.

REFERENCES

1. Shackelford, A. K., K.-F. Lee, and K. M. Luk, "Design of small-size wide-bandwidth microstrip-patch antennas," *IEEE Antennas and Propag. Magazine*, Vol. 45, No. 1, 75–83, 2003.
2. Xiong, J., Z. Ying, and S. He, "A broadband low profile patch antenna of compact size with three resonators," *IEEE Trans. Antennas Propag. Magazine*, Vol. 57, No. 6, 1838–1843, 2009.
3. Pandey, G. P., B. K. Kanaujia, A. K. Gautam, and S. K. Gupta, "Ultra-wideband L-strip proximity coupled slot loaded circular microstrip antenna for modern communication systems," *Wireless Personal Communication*, Vol. 70, No. 1, 139–151, 2013.
4. Deshmukh, A. A. and K. P. Ray, "Broadband proximity-fed square-ring microstrip antennas," *IEEE Antennas Propag. Magazine*, Vol. 56, No. 2, 89–107, 2014.
5. Chen, H.-D., "Broadband designs of coplanar capacitively-fed shorted patch antennas," *IET Microwave Antennas Propagation*, Vol. 2, No. 6, 574–579, 2008.
6. Wi, S.-H., Y.-S. Lee, and J.-G. Yook, "Wideband microstrip patch antenna with U-shaped parasitic elements," *IEEE Trans. Antennas Propag.*, Vol. 55, No. 4, 1196–1199, 2007.
7. Khodaei, G. F., J. Nourinia, and C. Ghobadi, "A practical miniaturized U-slot patch antenna with enhanced bandwidth," *Progress In Electromagnetics Research B*, Vol. 3, 47–62, 2008.
8. Neyestanak, A. A. L., F. H. Kashni, and K. Barkeshli, "W-shaped enhanced-bandwidth patch antenna for wireless communications," *Wireless Personal Communication*, Vol. 43, No. 4, 1257–1265, 2007.
9. Ansari, J. A., P. Singh, S. K. Dubey, R. U. Khan, and B. R. Vishvakarma, "Analysis of stacked V-slot loaded patch antenna for wideband application," *Microwave Optical Technology Letter*, Vol. 51, No. 2, 324–330, 2009.
10. Xie, J.-J., Y.-Z. Yin, S.-L. Pan, and L. Sun, "A novel circular slot antenna with two pairs of t-shaped slots for WLAN/WIMAX applications," *Progress In Electromagnetics Research Letters*, Vol. 32, 49–57, 2012.

11. Krishna, D. D., M. Gopikrihna, C. K. Aanandan, P. Mohanan, and K. Vasudevan, "Compact wideband koch fractal printed slot antenna," *IET Microwave Antennas Propag.*, Vol. 3, No. 5, 782–789, 2009.
12. Sung, Y. J., "Bandwidth enhancement of a wide slot using fractal-shaped sierpinski," *IEEE Trans. Antennas Propag.*, Vol. 59, No. 8, 3076–3079, 2011.
13. Malekpoor, H. and S. Jam, "Miniaturised asymmetric E-shaped microstrip patch antenna with folded-patch feed," *IET Microwave Antennas Propag.*, Vol. 7, No. 2, 85–91, 2013.
14. Sun, D. and L. You, "A broadband impedance matching method for proximity-coupled microstrip antenna," *IEEE Trans. Antennas Propag.*, Vol. 58, No. 4, 1392–1397, 2010.
15. Matin, M. A., B. S. Sharif, and C. C. Tsimenidis, "Probe fed stacked patch antenna for wideband applications," *IEEE Trans. Antennas Propag.*, Vol. 55, No. 8, 2385–2388, 2007.
16. Ang, B. K. and B. K. Chung, "A wideband E-shaped microstrip patch antenna for 5–6 GHz wireless communications," *Progress In Electromagnetics Research*, Vol. 75, 397–407, 2007.
17. Islam, M. T., "Design analysis of high gain wideband L-probe fed microstrip patch antenna," *Progress In Electromagnetics Research*, Vol. 95, 397–407, 2009.
18. Ansari, J. A., P. Singh, and N. P. Yadav, "Analysis of shorting pin loaded half disk patch antenna for wideband operation," *Progress In Electromagnetic Research C*, Vol. 6, 179–192, 2009.
19. Zarrabi, F. B., R. Ahmadian, M. Rahimi, and Z. Mansouri, "Dual band antenna designing with composite right/left handed," *Microwave Optical Technology Letter*, Vol. 57, No. 4, 774–779, 2015.