URSI AP-RASC 2019, New Delhi, India, 09 - 15 March 2019

Design of a fan beam 1×4 array antenna using V-shaped patch element for its use in X-band communication

Pranjal Borah*[(1)], Satyajib Bhattacharyya[(2)]
(1) Department of Electronics and Communication Technology, Gauhati University, Assam, India
(2) Department of Electronics and Communication Engineering, Tezpur University, Assam, India

Abstract

An array antenna is designed and fabricated using four V-shaped patch element for its application in X-band communication. Initially, a two element array is designed by using two V-shaped patch elements where the inset feed dimensions are studied and optimized experimentally. This is followed by the design of a 1×4 element array for obtaining a fan beam pattern. Prototypes with different element spacing are fabricated, measurements carried out and results compared. Co- and cross-polar radiation patterns are measured for both the principal planes.

1. Introduction

Microstrip patches, because of its advantages like low profile, light weight, low cost, economy of space, flexibility etc., are used for designing antennas ranging from compact to large arrays depending on requisite applications in modern day wireless communication systems. Some applications like radar systems, airborne collision avoidance systems, imaging systems etc. need antennas with fan beam patterns which has a narrower beamwidth in one plane and a wider beamwidth in the other [1-3]. One way of achieving a fan beam pattern is by employing truncated parabola reflector which are, however, heavy in weight and has aperture blockage issues. These issues can be addressed by designing low profile array antennas with lens system etc. [4-7] where the superposition of the radiation patterns lead to an overall fan beam pattern. In this paper a 1×4 element array is designed using a newly reported V-shaped patch [8] for obtaining a fan beam pattern. The fan beam pattern is achieved by arranging the elements such that the overall radiation decreases the beamwidth in one of the principal planes. Microstrip inset line feeding technique [9-12] is opted for exciting the V-shaped patch elements which is optimized experimentally for the newly designed geometry.

2. Two element array design

The two element array is designed by exciting two parallel V-patches by a single source fed in the middle of the feed line in untransposed configuration as shown in figure 1. A double mitered section is introduced at the right angle bends of the microstrip feed line for a better matching [13]. The design parameters of the antenna are given in table 1. The fabricated array is shown in figure 2. The blue lines in figure 1 refer to the outline of the V-shaped patch before inset feeding.

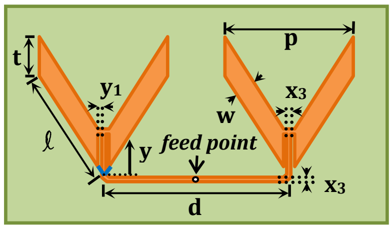

Figure 1. Schematic diagram of the two element array with microstrip inset line feed

Table 1. Design parameters of the V-shaped patch antenna

Parameters	Value (mm)
p	20
ℓ	8
t	20
w	4
$\mathbf{x_3}$	1
y	6, 7, 8, 9
$\mathbf{y_1}$	0.5
d	30

Figure 2. Fabricated two element array comprising of two V-shaped patch elements

Return loss performances are measured and compared for various prototypes of the two element array to find the optimum feeding arrangement. Variation in the feeding arrangement mainly includes the change in inset depth (**y**) and element feed point separation (**d**) of the two element array.

2.1 Return loss measurements

The Return loss measurements are carried out first for different inset depths, **y** = 6, 7, 8, 9 mm for a given element feed point separation **d** = 30 mm. The measured return loss plots are shown in figure 3 and the peak return loss values and the corresponding resonant frequencies are summarized in table 2. For an inset depth of **y** = 9 mm, the two element array configuration shows a better return loss value of -21.39 dB at 9.24 GHz for **d** = 30 mm.

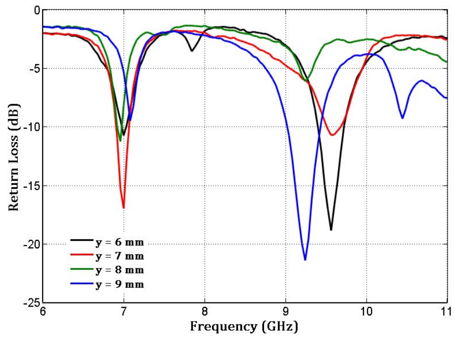

Figure 3. Measured return loss plots for different inset depth (**y**) with **d** = 30 mm

Table 2. Resonant frequencies and corresponding return loss values for different values of **y**

Inset depth, **y**(mm)	Lower resonant frequency f_l (GHz)	S_{11} at f_l (dB)	Upper resonant frequency f_2 (GHz)	S_{11} at f_2 (dB)
6	7.00	-10.76	9.56	-18.85
7	7.00	-16.97	9.56	-10.73
8	6.96	-11.27	9.24	-6.14
9	-----	-----	**9.24**	**-21.39**

Furthermore, the inter element feed separation between the two radiating elements is varied in steps of 5 mm from 25 mm to 50 mm for obtaining a better matching of the array structure keeping inset depth fixed at **y** = 9 mm. The measured return loss plots for different element feed point separation (**d**) are shown in figure 4. The measured resonant frequencies and the corresponding return loss values are given in table 3.

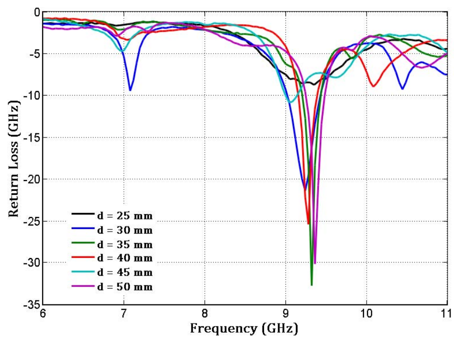

Figure 4. Measured return loss plots for different inter element feed separation (**d**) with **y** = 9 mm

Table 3. Resonant frequencies and corresponding return loss values for different values of **d** (with **y** = 9 mm)

Separation, **d** (mm)	Resonant frequency (GHz)	S_{11} (dB)
25	**----**	**----**
30	9.24	-21.39
35	**9.32**	**-33.49**
40	9.28	-25.61
45	9.06	-10.72
50	9.36	-29.97

It can be seen that the best return loss performance of the two element array is obtained with an inter element feed separation **d** = 35 mm with inset depth **y** = 9 mm. It shows a peak return loss value of -33.49 dB at 9.32 GHz.

2.2 Radiation pattern measurements

Free space radiation pattern measurements of the two element array, with inter element feed separation **d** = 30, 35, 40, 45 and 50 mm at their respective resonant frequencies are carried out using a PC automated turn table where both the receiver and the transmitter are interfaced for accurate data acquisition. Figure 5(a & b) shows the measured patterns for **d** = 35 mm.

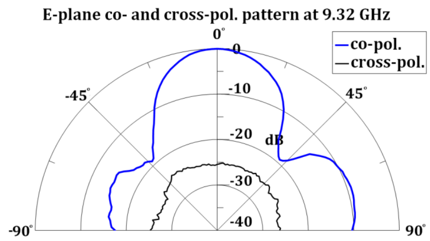

Figure 5(a). E-plane pattern for **d** = 35mm

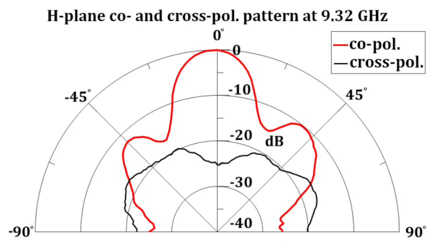

Figure 5(b). H-plane pattern for **d** = 35mm

3. Four element array design

The two element array is followed by design and fabrication of 1×4 element array. The four V-shaped patch elements are arranged in an untransposed configuration as shown in figure 6. The array is fed at the center of the four elements via a coaxial probe which connects the radiating elements with the microstrip feed line. The four element array designed can be considered as a travelling wave type array which is terminated on either side by a radiating element. The dimensions of the array elements and width of feed lines are identical to those used in the two element array.

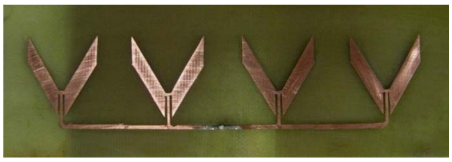

Figure 6. Fabricated four element array using four V-shaped patch antenna

3.1 Return loss measurements

Return loss measurements are carried out for five different configurations of the four element array by varying the separation between the terminating elements (**d_2**) in the range from 30 mm to 50 mm in steps of 5 mm. The centre element separation is kept constant at **d_1** = 30 mm. Figure 7 shows the measured return loss plots of the 1×4 element array for different configurations and their resonant frequencies along with their respective return loss values are given in table 4.

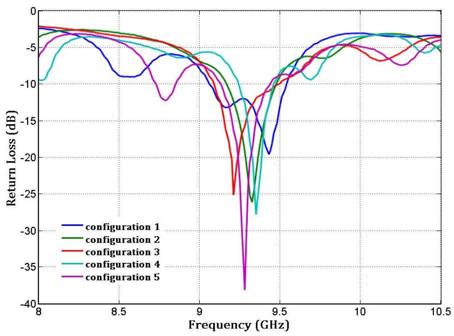

Figure 7. Measured return loss plots of the four element array with different configurations

Table 4. Measured resonant frequencies and the corresponding return loss values for different configuration of the four element array

Antenna configuration	d_1 (mm)	d_2 (mm)	Resonant frequency (GHz)	S_{11} (dB)
configuration 1	30	30	9.43	-19.62
configuration 2	30	35	9.32	-26.14
configuration 3	30	40	9.21	-25.15
configuration 4	30	45	9.35	-27.83
configuration 5	30	50	9.27	-38.08

Configuration 5 of the designed 1×4 element array shows the best matching performance with a return loss value of -38.08 dB at 9.27 GHz.

3.2 Radiation pattern measurements

Free space radiation patterns are measured for all the designed configurations of the 1×4 element array. The measured radiation pattern for configuration 2 and 5 are shown in figure 8 (a, b, c & d) respectively.

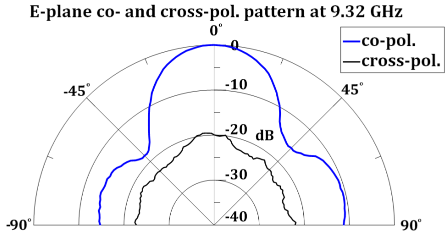

Figure 8(a). E-plane pattern for configuration 2

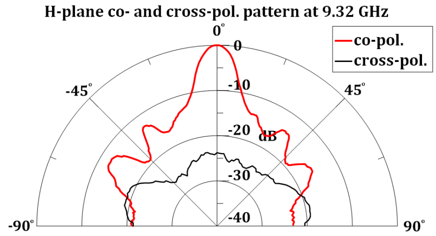

Figure 8(b). H-plane pattern for configuration 2

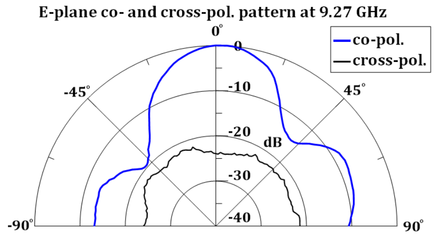

Figure 8(c). E-plane pattern for configuration 5

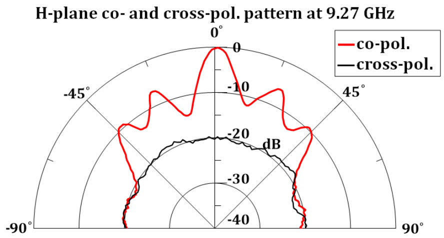

Figure 8(d). H-plane pattern for configuration 5

4. Results and discussion

Performance evaluation for two element and 1×4 element arrays designed using a newly developed V-shaped patch is carried out. Both the two element and 1×4 element configuration resonates at a higher frequency than the reported V-shaped patch (8.86 GHz) [8] which is due to the effective shortening of the V-arms with the introduction of the inset feeding. Inter element feed separations and inset depths are varied to obtain optimized array performance as theoretical formulation of the V-shaped patch is still awaited. The inset depth (**y**) is varied to a maximum value of 9 mm as further increase in step of 1 mm reached the design limitation of the V-shaped patch which will isolate the two V-arms. Although configuration 5 of the 1×4 element array shows a better matching performance, the arrangement of the elements lead to high side lobe level which deviates from the fan beam shape. On the other hand, configuration 2 of the 1×4 element array shows a better fan beam pattern with a minimum HPBW of 10.9˚ in the H-plane whereas the HPBW in the E-plane remains almost comparable as that of the single V-shaped patch with a value of 35.4˚. The measured half power beamwidths (HPBW) of the designed array configurations using V-shaped elements are given in table 5.

Table 5. HPBW values of E- and H-plane pattern

Antenna configuration (X-band)		**HPBW**	
Patch geometry	**No. of elements used**	**E-plane**	**H-plane**
V-shaped patch [8]	1	35.0˚	61.2˚
V-shaped patches	2	34.2˚	19.8˚
configuration 2✝	4	33.0˚	10.9˚
configuration 5✝	4	32.8˚	20.8˚
✝ *Table IV*			

The measured radiation patterns of all the arrays show a cross-polar level below -20 dB along the direction of the co-polar maximum. A more detailed study by varying both the inset depth and inter element feed point separation may provide clues for further improvements in performance of the 1×4 element array within the design limitations. The HPBW can also be further reduced by increasing the number of V-shaped patch elements so as to obtain a better fan beam pattern.

The work presented here demonstrates that the V-shaped patch can be a suitable element choice in design of arrays for fan shaped patterns. Moreover, the V-shaped patch may find applications in stealth technology owing to its inherent low RCS compared to the nearest triangular geometry.

5. Acknowledgements

The authors acknowledge the valuable suggestions of Prof. N. S. Bhattacharyya, Dept. of Physics, Tezpur University and the fellow members of the microwave research group of Tezpur University during the course of carrying out the work. The authors are thankful to Mr. Faiz Hussain of Tezpur, for his help in the prototyping process.

6. References

1. R. M. Thompson, “Doppler-weather signal processing for a rapid RF- and PRF-agile airport surveillance radar,” *Proc. 19th Digital Avionics Syst. Conference*, **2**, 2000, pp. 1–8, doi**:** 10.1109/DASC.2000.884929.

2. H. Lee, Y. Kim, V. Volkov, R. Kozhin, D. Vavriv and T. Kim, “35 GHz compact radar using fan beam antenna array for obstacle detection,” *Electronic Letters*, **43**, 25, 2007, pp. 1461–1462, doi**:** 10.1049/el:20072774.

3. S. G. Hay, J. W. Archer, G. P. Timms and S. L. Smith, “A beam-scanning dual-polarized fan-beam antenna suitable for millimeter wavelengths,” *IEEE Trans Antennas Propagation*, **53,** 8, 2005, pp. 2516–2524, doi**:** 10.1109/TAP.2005.852298.

4. K. Mohammadpour-Aghdam, R. Faraji-Dana, G. A. E. Vandenbosch and W. De. Raedt, “Fan and Pencil beam aperture coupled patch antenna array with low Side Lobe Level,” *Int. 4th European Conference on Antennas and Propagation*, Spain, 2010, pp. 1–4.

5. H. Nakano, M. Iwatsuki, M. Sakurai and J. Yamauchi, “A cavity-backed rectangular aperture antenna with application to a tilted fan beam array antenna,” *IEEE Trans Antennas and Propagation*, **51**, **4,** 2003, pp. 712–718, doi**:** 10.1109/TAP.2003.811085.

6. H. Nakano, Y. Shinma, H. Mimaki, J. Yamauchi and K. Hirose, “Fan beam formation using spiral array antennas,” *Antennas and Propagation Society International Symposium*, **3**, 1996, pp. 1628–31

7. M. Miyakawa, T. Takahashi, N. Iwata, N. Ishii and M. Bertero, “Fan Beam-Type CP-MCT with Microstrip Dipole Array Receiving Antenna,” *36th European Microwave Conference*, 2006, pp. 1244–1247, doi**:** 10.1109/EUMC.2006.281203.

8. P. Borah, A. K. Bordoloi, N. S. Bhattacharyya and S. Bhattacharyya, “Bridged 'V'-shaped patch antenna for dual-band communication,” *Electronic Letters*, **48**, 8, 2012, pp. 419-20, doi**:** 10.1049/el.2012.0221.

9. S. T. Frang, K. L. Wong and T. W. Chiou, “Bandwidth enhancement of inset microstrip-line-fed equilateral-triangular microstrip antenna,” *Electronic Letters*, **34**, 23, 1988, pp. 2184–86, doi: 10.1049/el:19981578.

10. G. B. Hsieh and K. L. Wong, “Inset-microstrip-line-fed dual-frequency circular microstrip antenna and its application to a two-element dual-frequency microstrip array,” *Proc. IEE Microwave Antennas Propagation*, **146**, 5, 1999, pp. 359-361, doi**:** 10.1049/ip-map:19990667.

11. W. S. Chen, K. L. Wong and C. K. Wu, “Inset microstripline-fed circularly polarized microstrip antennas,” *IEEE Trans Antennas and Propagation*, **48**, 2000, pp. 1253–1254, doi**:** 10.1109/APS.1999.789130.

12. L. I. Basilio, M. A. Khayat, J. T. Williams and S. A. Long, “The dependence of the input impedance on feed position of probe and microstrip line-fed patch antennas,” *IEEE Trans. Antennas and Propagation*, **49**, 1, 2001, pp. 45–47, doi**:** 10.1109/8.910528.