Indian Journal of Science and Technology, *Vol 9(46), DOI: 10.17485/ijst/2016/v9i46/107146, December 2016*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Performances Evaluation of Reflectarray Antenna using Different Unit Cell Structures at 12GHz

Christelle Uwizeye[1], Mohd Fairus Mohd Yusoff[1*], Igbafe Orikumhi[2], Zaharah Johari[1] and Mazlina Esa[1]

[1]Electrical Engineering, Universiti Teknologi Malaysia, Johor Bahru - 81310, Skudai Malaysia
[2]Wireless Communication Center Universiti Teknologi Malaysia, Johor Bahru - 81310, Skudai Malaysia

Abstract

Objectives: To compare the performance of different unit cell shapes in the reflectarray antenna design and to provide a reference guide for researchers which reduce the time spent in the study of unit cell performance. **Methods/Statistical Analysis**: This paper employs related literature review and design. The design aspect being with the study of different unit cell elements, the optimized unit cell sizes are then used to build a reflectarray antenna. The antenna analysis was carried out via simulations on CST studio 2015. **Findings**: It is observed from exiting literature that although several unit cell have been studied in the design of reflectarry, no comparison has been made from the different unit cells performance. The simulated results show that reflectarray antenna can achieve high gain and high performance with the benefit of low cost, low weight, low transmission losses due to the low profile of the feeding mechanism and their small size. In addition, the study shows that circular patch unit cell elements perform better than the rectangular, triangular and cross shape studied in this paper. **Applications/Improvements**: This paper shows the performance of four different unit cell shapes at 12HGz, the optimized unit cell are then used to achieve high gain reflector ray antenna.

Keywords: Ku Band , Parabolic Antenna , Phased Array , Reflectarray Antenna

1. Introduction

High gain can be achieved in antennas with a big antenna aperture such as the parabolic antenna, or a large array of small size antenna such as the phased array antenna. Theoretically, a larger aperture antenna can provide higher directivity, larger amplitude higher uniform field phase and on the aperture[1]. However, large aperture makes the antenna bulkier and requires supporting structure which makes them less compatible with modern communication systems. On the other hand, an array of a small antenna increases directivity and achieves high gains but the implementation of phased array antenna is usually affected by complex feeding networks and high transmission losses. Reflectarray antenna is being considered as the possible alternative. Reflectarray antenna exploits the advantages of both the parabolic antenna and the phased array antenna while mitigating their disadvantages[2, 3].

Reflectarray antenna is made up of two main parts; the printed element array and a feeding source antenna which is usually a horn antenna which illuminates the element array. The elements vary in sizes where each specific size provides the phase shift with compensate for the path length difference between the feeding source and the element. The different sizes in the reflectarray antenna enable collimated beams to be created in the far-field region with uniform phase region[4,5]. The use of horn antenna at the focal point of the reflectarray antenna eliminates the complexities in the feeding network and the transmission losses in phase array antennas while the arrays reduce the sizes and bulkiness of the parabolic antennas[6].

**Author for correspondence*

In addition, several benefits can be obtained from reflectarray antenna such as; low profile, low-cost, high gain and planar design which allows them to be easily integrated into other structures[7]. They also by integrating Micro-Electro Mechanical Systems (MEMS)8 with the design, beam-scanning capabilities can be achieved.

Although reflectarray antenna provides numerous advantages, the design of each unit cell elements[9, 10] for specific application requirements remains a major challenge. In this paper, the uses of four different unit cell shapes are investigated at 12 GHz. The reflected phases of each unit cell are initially studied by means of simulation. Then, the complete reflectarray antenna performances are evaluated based on the antenna radiation patterns and gain.

2. Unit-Cell Design

In this section, the unit cell shapes (rectangular, circular, triangular and cross shapes) under investigation are discussed. The infinite-array approach[11] has been adopted for unit-cell phase shift design that accounts for the mutual coupling effect from the surrounding elements. Table 1 shows the material specification and parameters.
All design simulations are carried out using CST

Microwave Studio software. Figure 1 shows the geometry of the different unit cell shapes. In this simulation, each unit cell phase shift is tuned using different parameters which are noted as the length (L) for rectangular, radius (d_1) for circular, width (W_1) for triangular and width (W_3) for cross shapes. The other parameters were kept constants.

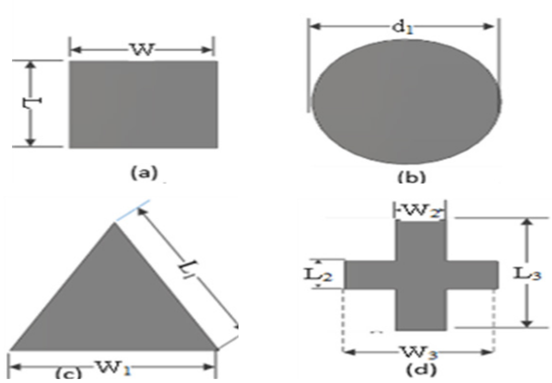

Figure 1. Phase shift tuning parameters for various Unit cell shapes (a) Rectangular (b) Circular (c) Triangular (d) Cross.

Table 1. Material Specification and Parameters

Substrate material	Roggers RT/Duroid 5880
Relative permittivity	2.2
Loss tangent	0.0009
Thickness of substrate	0.254 mm
Conductivity layer thickness	0.035 mm
Element spacing	0.5λ

3. Reflectarray Antenna Design

The reflectarray antennas designed are comprised of an 11 by 11 elements with a total size of $13.75 \times 13.75\ \mathrm{cm}^2$ with an inter-element spacing of 0.5λ. Each unit cell element is designed with a specific size to compensate for the difference in path length between the feeding source and the element. Figure 2 shows the basic reflectarray antenna configuration.

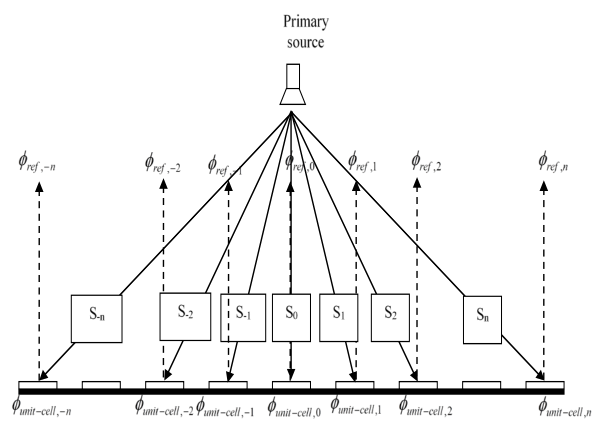

Figure 2. Reflectarray antenna configuration.

The incidence wave on each element can be computed as

$$\phi_{inc,n}(f_0) = -k_0 S_n + \phi_{primary\_source} = \frac{-2\pi S_n}{\lambda_0} + \phi_{primary\_source} \qquad (1)$$

where S_n is the path length between the primary feed to the scattered unit cell n and k_0 is propagation constant in a vacuum, $k_0 = \frac{2\pi}{\lambda_0}$.

The phase shift on each unit cell $\phi_{unit-cell}$ is first calculated based on its position on the reflectarray antennas as follows.

$$\phi_{unit-cell,n}(f_0) = -\phi_{inc,n} = -(-k_0 S_n + \phi_{primary\_source}) = -\left(\frac{-2\pi S_n}{\lambda_0} + \phi_{primary\_source}\right) \quad (2)$$

To achieve total reflection of the incidence rays (2) shows that the phase shift should be and the incidence phase should be equal in magnitude. The total reflected phase, $\phi_{ref,n}$ can then be obtained as

$$\phi_{ref,n}(f_0) = \phi_{unit-cell,n}(f_0) + \phi_{inc,n}(f_0) = 0 \quad (3)$$

In this paper, the horn antenna is placed at the reflectarray antenna focal point, such that the reflectarray size is equal to the distance between the feed and reflectarray, i.e. F/D = 1 .Figure 3.

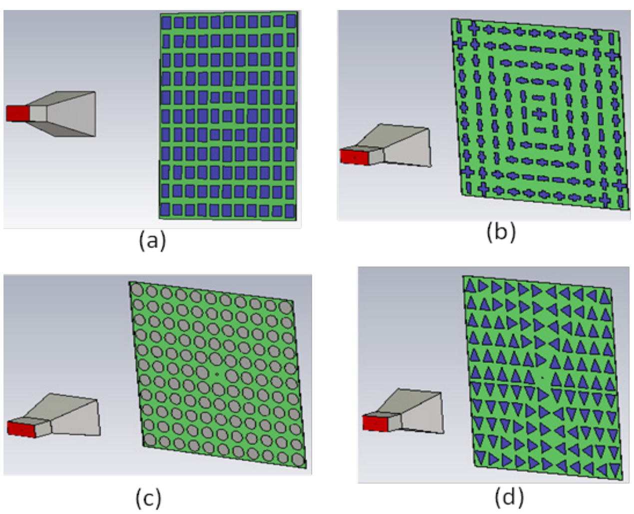

Figure 3. Reflectarray antenna structure (a) with rectangular elements (b) with cross elements (c) with circular elements (d) with triangular elements.

4. Results and Discussions

The reflected phase results for each unit cell are displayed in Figure 4. It can be observed that the reflected phase range response are obtained as 344^0, 347^0, 349^0 and 350^0 for rectangular, circular, triangular and cross shapes respectively. In addition, all shapes exhibit almost similar curves with very rapid variation near the resonance and very slow in extreme value.

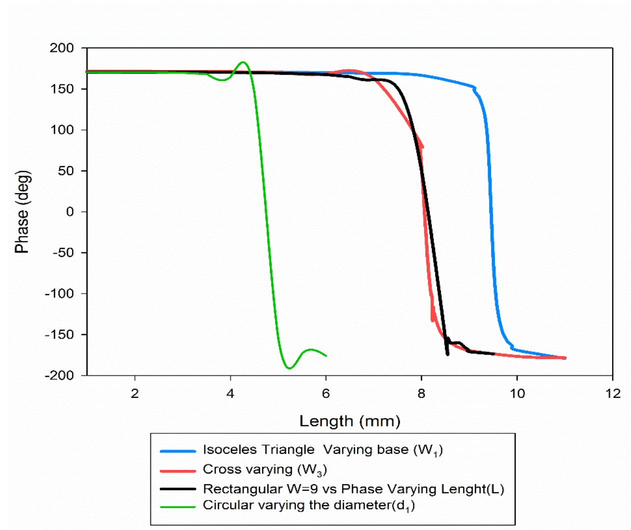

Figure 4. The reflected phase response for four different unit cells with different parameters as tunable phase shifter.

The simulated radiation patterns of the E-plane and H-plane at 12GHz are presented in Figure 5. The results show the main lobe in a broadside direction for all antennas. The circular shape also provides better radiation patterns in the E and H planes with low side lobes level below (-10dB) and smooth patterns compared to the reflectarray with other shapes. However, others shapes are affected by higher side lobes level. This can be as results of the unit cell elements phase error during the design process. Furthermore, the triangular and cross shapes show a broader beamwidth with 'shoulder' effect on the main beams.

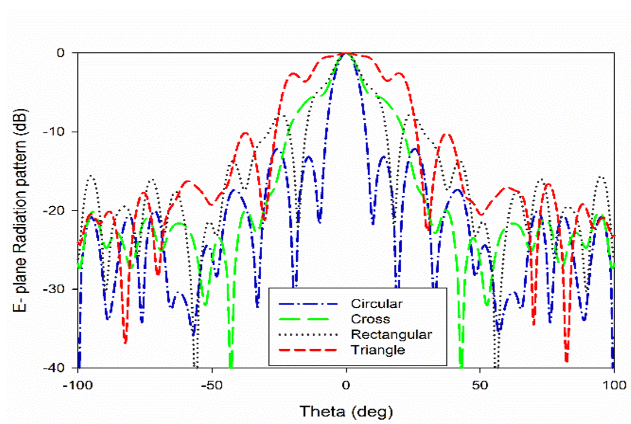

Figure 5. Radiation pattern (a) E-plane.

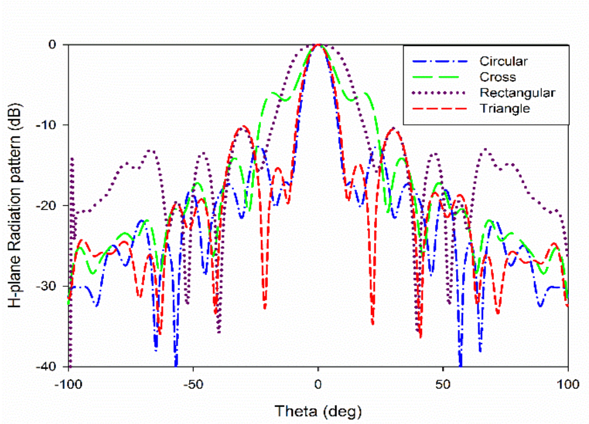

Figure 6. Radiation pattern (b) H-plane reflectarray antenna at 12GHz.

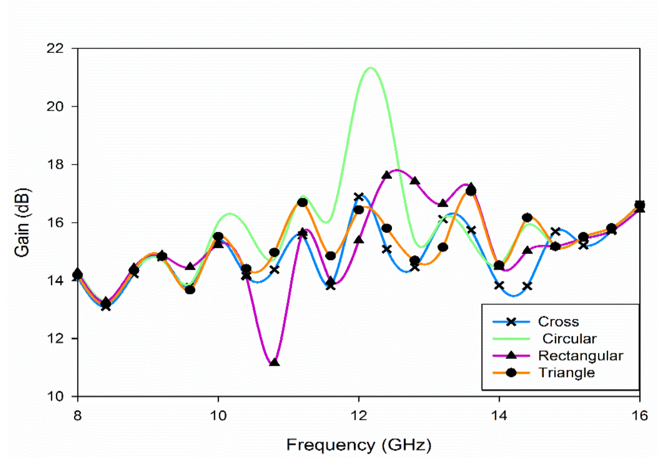

Figure 7. Gain comparison of different unit cell shapes versus frequency.

The realized half power beam width (HPBW) of the circular shape reflectarray in the E-plane and H-plane are observed to be 8.7^0 and 9.1^0 while the side lobe level is -12.2 and -12.6 dB respectively. The HPBW of the cross unit cell shaped reflectarray is observed to be 10.8^0 and $12.7\ ^0$ with side lobe level of -11.1 dB and -6.0 dB in the E-plane and H-plane respectively. $11.4\ ^0$ in the E-plane and $22.4\ ^0$ in the H-plane HPBW is observed for the rectangular shape element reflectarray antenna. Side lobe level of -8.3 dB and 10.7 dB are also observed in the E-plane and H-plane respectively. Finally, the HPBW of the triangular element shaped reflectarray is observed to be 27.2^0 and $10.\ 2\ ^0$ with side lobe level is -2.6 dB and -10.1 dB in the E-plane in the H-plane respectively.

The observed gain at 12GHz from the reflectarray antennas are presented in Figure 6. It can be seen that the circular shape provides much higher gain (21.2dB) compared to the other shape elements. A gain of 17dB, 16.1dB and 15.7dB is achieved for cross, triangular and rectangular shaped reflectarray elements respectively. This indicates that the reflectarray performances do not solely depend on the reflected phase range of the unit cell only. This can be observed in circular and rectangular shaped reflectarray elements which give much better performances although they have less range compared to the cross and triangular shapes.

5. Conclusion

This paper investigates the performance of four reflectarray antennas with cross, rectangular, triangular and circular shaped unit cells. The four designs are compared based on their antenna radiation pattern, unit cell reflected phase response and gains. It is observed that, all the antennas show broadside radiation patterns and achieved a gain higher than 15dB at 12GHz. The achieved gains make them suitable for Ku-band systems. In addition, the results of the four reflectarray antennas are compiled in this paper as for quick reference to researches as it aims to reduce the time taken for designing such reflectarray antenna at 12 GHz with the four unit cell shapes provided in this paper.

6. Acknowledgment

The authors acknowledge the financial support from Ministry of Higher Education (MOHE) under project QJ130000.2523.09H83. Also thanks to the Research Management Centre (RMC) of Universiti Teknologi Malaysia (UTM) for providing an excellent research environment in order to complete this work.

7. References

1. Woodward PM, Lawson JD. The theoretical precision with which an arbitrary radiation-pattern may be obtained from a source of finite size. Electrical Engineers-Part III: Radio and Communication Engineering. Journal of the Institution of Electrical Engineering. Sep 1948; 95(37):363–70.
2. Hum SV, McFeetors G, Okoniewski M. Integrated MEMS reflectarray elements. In Antennas and Propagation. EuCAP First European Conference. 6 Nov 2006; p. 1–6.
3. Hamzavi-Zarghani Z, Atlasbaf Z. A New Broadband Single-Layer Dual-Band Reflectarray Antenna in X-and Ku-Bands. Antennas and Wireless Propagation Letters. IEEE. 2015; 14:602–5.
4. Shaker J, Chaharmir MR, Ethier J. Reflectarray Antennas: Analysis, Design, Fabrication, and Measurement. Artech House; Nov 2013:p.256.
5. Huang J, Encinar JA. Reflectarray Antennas. IEEE Press; 2008.
6. Cheng YJ, Guo YX, Liu ZG. W-Band large-scale high-gain planar integrated antenna array. IEEE Transactions on Antennas and Propagation. Jun 2014; 62(6):3370–3.
7. Huang J. Capabilities of printed reflectarray antennas. IEEE International Symposium on In Phased Array Systems and Technology. Oct 1996. p. 131–14.
8. Malfajani RS, Atlasbaf Z. Design and Implementation of a Dual-Band Single Layer Reflectarray in X and K Bands. IEEE Transactions on Antennas and Propagation. Aug 2014; 62(8):4425–31.
9. Qu SW, Chen QY, Xia MY, Zhang XY. Single-layer dual-band reflectarray with single linear polarization. IEEE Transactions on Antennas and Propagation. Jan 2014; 62(1):199–205.
10. Li L, Chen Q, Yuan Q, Sawaya K, Maruyama T, Furuno T, Uebayashi S. Novel broadband planar reflectarray with parasitic dipoles for wireless communication applications. Antennas and Wireless Propagation Letters. IEEE. 2009; 8:881–5.
11. Pozar DM, Targonski SD, Syrigos HD. Design of millimeter wave microstrip reflectarrays. IEEE Transactions on Antennas and Propagation. Feb 1997; 45(2):287–96.