

Design and Analysis of Compact H-Like Element Microstrip Reflectarray Antenna for X-Band Applications

ABSTRACT

This paper introduces a design and analysis method of a microstrip reflectarray antenna (MRA) with a proposed H-like shape radiating element at a frequency of 10.5 GHz. The proposed structure has been analyzed and compared with the traditional square shape one. It is found that the H-like element shape presents a good phase range to compensate for the frequency fluctuation of the differential spatial phase delay even when the single layer printed patches are applied. It is also found that this reflectarray has maximum realized gain of 29.3dB with radiation efficiency of 92.3%, half-power beamwidth (HPBW) of 5.6°, and very low side-lobe level (SLL) of about -32.4dB. This reflectarray is found to have a volume reduction of about 43.24% compared with the traditional square shape one.

Keywords: microstrip antenna, reflectarray, H-like patch, X-band

1. INTRODUCTION

The reflectarray antenna is constructed of many resonant patch elements laying on a flat surface, which is illuminated by a source feed [1]. Reflectarrays combine most advantages of parabolic reflectors and phased array elements to form a radiation beam as required in high gain antennas [2]. For satellite applications at higher microwave frequency bands, it is found difficult to manufacture parabolic reflector because of its curved shape [3]. Besides, phased arrays may support the losses and complexity of the antenna due to the power division of the transmission lines and any other electronic devices that attached to the antenna [4]. In space communication applications, reflectarray is preferred because their surface can be folded as a part of spaceship cargo before being deployed, hence, both volume and mass required in space application can be reduced greatly [5-6]. Phase compensation is vital in designing reflectarray, and it is so important for reflectarrays to behave exactly like ordinary parabolic reflector which will collect and re-radiate the particular rays to the marked position or receiver antenna. Otherwise, reflectarray will have the same behavior as a normal metal plate or ground plane where it will scatter the rays away from the receiver. Therefore, all elements on the reflectarray plane are required to be specifically designed with the appropriate phase because the incident wave will propagate and presents a different phase from one element to another. There are some methods involving phase compensation available for the reflectarray, such as using patch with variable size [6], stubs with open

circuit ended [7], microstrip patch with a slot loaded ground plane [8], microstrip patch with a slot loaded [9], and the use of electronic components [10]. Stubs produce some dispersal losses and a spurious radiation as well. In addition, more space must be kept for the open circuit ended stub on the reflectarray design. The method as suggested in [8] may produce a backward radiation, which is the reason why [9] had been proposed to reduce and overcome those backward radiations. However, method in [9] has limited phase variation because of its patch size. The integration of electronic components in one patch as proposed in [10] may contribute many losses and complexity so bad that it is very hard to analyze especially when applied to arrays at millimeter-wave frequency [11].

All the phase compensation methods that have been mentioned above were using square or rectangular patch as their array elements which are assumed as not good enough to be employed in the reflectarray design. The reflection losses and side-lobe level (SLL), realized gain, and phase difference are the major concerns in the design process [12], [13]. The use of traditional shape radiating element is vital to develop a novel configuration of the passive reflectarray unit cell, that uses a modified shape as a radiating element in the MRA design [14].

In this paper, a new structure is proposed comprises of a square patch with two half-circular slots, namely H-like element, which may give a better reflection phase range compared to the conventional square element.

2. ANTENNA STRUCTURE AND DESIGN

The pivot element for a single layer of reflectarray is proposed to be of H-like shape as shown in Figure 1.

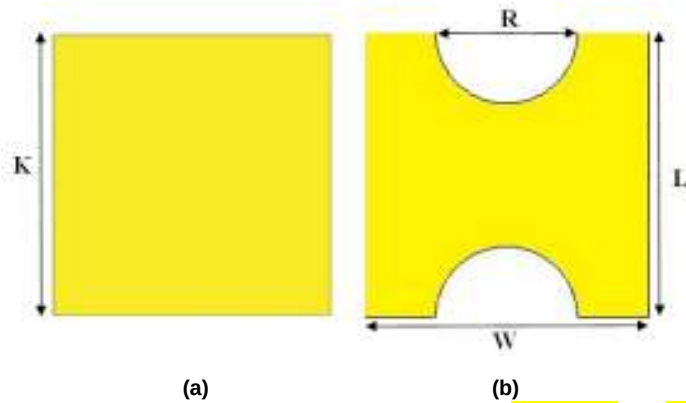


Fig.1. The dimensions of element geometry (a) Square (b) H-Like

The proposed and traditional square element geometries are tested as resonant elements at 11 GHz for a periodic reflect-array structure separately. The traditional square and proposed elements at the targeted resonant frequency of 11 GHz are printed on an FR-4 substrate material with thickness $t=1.524\text{mm}$, tangential loss $\tan\delta=0.025$, and relative permittivity $\epsilon_r=4.3$. The width dimensions of the traditional and proposed elements are $L=5.46\text{mm}$ and $K=6.06\text{mm}$ respectively. The value of R dimension is taken smaller than $L/3$ by adopting an iteration factor of $m=0.75$ in the following equation [15]:

$$R = m \times (L / 3) , \quad 0 < m < 1 \quad (1)$$

The rate of the unit cell reflectarray is based on a standard waveguide dimension due to the simplicity of measuring the reflection coefficient [16]. Figure 2 shows the geometry of rectangular waveguide (X-band) that has been used as a model in term of its dimension to design a unit cell for reflectarray, and a boundary condition in the simulation setup for infinite array approach. Since the waveguide standard dimensions are $a=22.86\text{mm}$, $b=10.16\text{mm}$ and $p=120\text{mm}$, a suitable periodicity of the unit cell reflectarray is chosen as $L_1=10\text{mm}$ and $W_1=10\text{mm}$, with a copper thickness of 0.035mm . In the simulation, there is only one unit cell being excited using TEM-mode, and actually illuminated by a linearly polarized plane wave with a normal incidence angle. The resonant behavior of periodic arrays of squares is determined by the element size, periodicity, and the electrical properties of the substrate materials [17]. In the absence of mutual coupling, the squares resonate giving 180° reflection phase with respect to the incident wave when $\lambda_{\text{eff}}=nK$, where λ_{eff} is the effective wavelength, n is a constant > 1 ($n = 2, 3, 4, 5$ and so on), and K is the square element dimension [18].

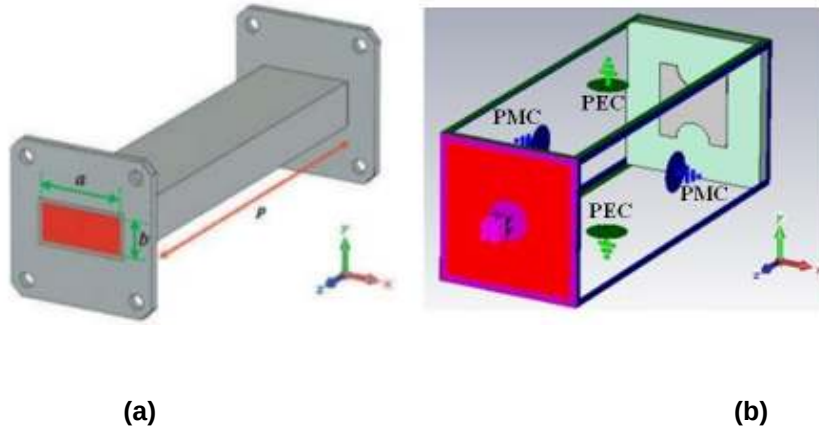


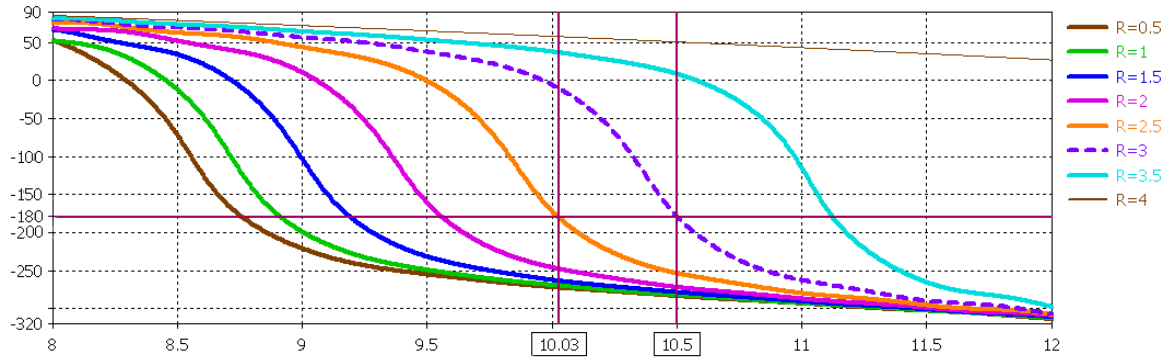
Fig.2. (a) Illustration of the standard X-band waveguide . (b) Microstrip reflectarray unit cell in the TEM-mode waveguide.

2.1 Proposed Element Design and Behavior

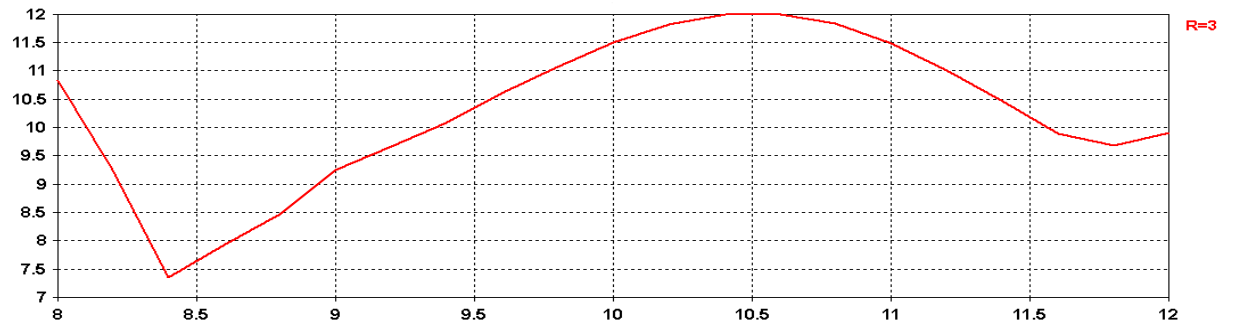
To investigate the new element behavior, the initial dimension of the square element is taken as $L=6\text{mm}$ (which constitutes $\lambda/5$). By using the utilizing parameter sweep software, which takes L range variation as $\pm 20\%$ of the chosen value, the resonant value is found 6.5 mm at 10.5GHz . The circular slot radius R is initially taken as $R=3\text{mm}$ (which constitutes $\lambda/10$), and is tested by using parameter sweep software to yield R range (1 to 4).

The resonant frequency of the proposed element is found to be varying with the value of the circular slot radius R as shown in Figure 3. The maximum directivity of the proposed element at $R=3\text{mm}$ is found to occur at 10.5 GHz as shown in Figure 4. From the above, it's clear

123 that, choosing the 10.5 GHz as the resonant frequency instead of 10 GHz is more
 124 reasonable. Figure 5 depicts the simulated reflection phase responses for different patch
 125 sizes. The proposed patch has an improved reflection coefficient (-0.345dB or 92.3%
 126 reflection) compared with that of the square patch (-0.17dB or 96% reflection) as appeared
 127 in [12]. The results shows that the proposed element has a higher reflection losses
 128 compared to the traditional square element, but still have more than 90% reflection at
 129 resonant frequency (10.5GHz), which satisfies the reflector design consideration [19].
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 136 **Fig. 3. The simulation phase result for the proposed element with various circular slot**
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 146 **Fig.4. The simulation directivity result for the proposed element at R=3 mm.**
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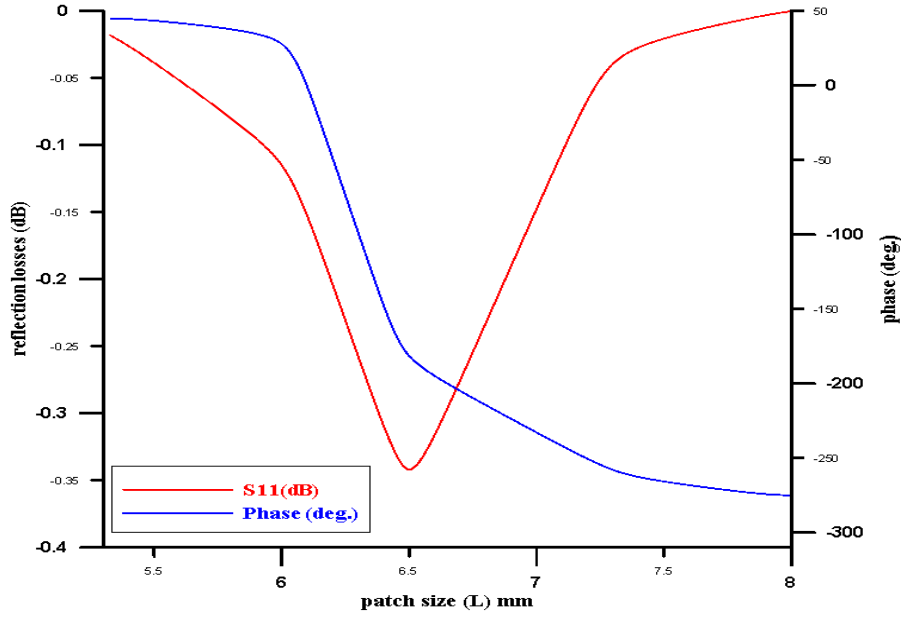


Fig.5. Reflection coefficient and phase responses at $f = 10.5$ GHz.

2.2 Progressive Phase Distribution

The whole geometry of the antenna is as shown in Figure 6. The technique used in this paper to determine the progressive phase distribution on the microstrip reflectarray surface with a centered focal point that will produce a narrow beam normal to the surface is shown in Figure 7. The required phase of each element can be deduced as [20].

$$\begin{aligned} \phi(x, \lambda) &= -\beta \{ \Delta R_{\max} - \Delta R(x) \} \\ &= -\frac{2\pi F}{\lambda} \{ \sqrt{1 + (D/F)^2} - \sqrt{1 + (x/F)^2} \} \end{aligned} \quad (2)$$

where,

ϕ - is the required phase-shift,

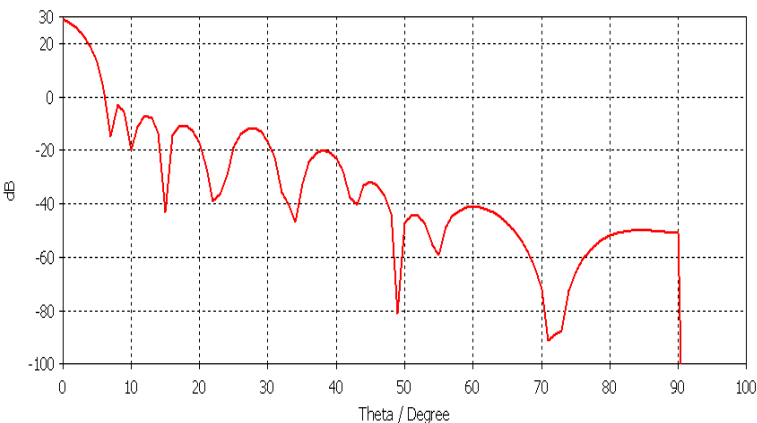
x - is the radial distance of the element location inside the reflectarray aperture,

λ - is the operating wavelength,

D and F - are the diameter and the focal length of the feed to the reflectarray center, respectively.

239 **3. RESULTS AND DISCUSSION**

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241 A typical X-band rectangular pyramidal horn antenna (R100/WR90) that has a gain around
242 15dB has been used with the proposed microstrip reflectarray. The simulation results show
243 the efficiency, realized gain, SLL, and half-power beamwidth (HPBW) are as follow, the
244 radiation efficiency of -0.345dB or 92.3% as shown previously in Figure 5, the realized gain
245 of the MRA with the (H-like) is 29.3dB. **Figure 8** shows the plot of the E-plane radiation
246 pattern of H-like radiating element at 10.5GHz. It is clear that the SLL of H-like element
247 equals to -32.4dB, and the HPBW approximately as 5.6°. Table 1 compares the result of this
248 work with that stated in [6].
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264 **Fig.8.** The Radiation pattern of H-like radiating element at 10.5 GHz.

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268 **Table 1. Summary of the simulation results compared with [12]**

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Antenna parameters	MRA with H-Like radiating elements	MRA with square radiating elements [12]
Operating frequency	10.5GHz	11GHz
Array volume (mm ³)	974.4	1716.8
Realized gain	29.3dB	27.4dB
Side-lobe level (SLL)	-32.4dB	-19dB
HPBW	5.6°	3.6°
Radiation efficiency	92.3%	95.6%
Reflection phase range	320°	250°

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4. CONCLUSION

A design and analysis procedure for microstrip reflectarray antenna with proposed H-like shape radiating elements are presented in this paper. It is found that modifying the current distribution of the physical geometry of the basic square element leads to a better phase compensation, and also gives a wider phase range for a good practical region. The MRA with H-like shape of radiating elements is found to provide higher realized gain, good radiation efficiency, and very low SLL due to its wider reflection phase range (320°) compared to the MRA with square elements (250°). The results also reveal that there is a volume reduction of about 43.24% gained by using the H-Like element.

REFERENCES

- [1] J. Shaker, M. R. Chaharmir, M. Cuhaci, and A. Ittipiboon, "Reflectarray research at the communications research centre Canada," *Antennas and Propagation Magazine, IEEE*, vol. 50, pp.31-52, 2008.
- [2] J. Huang and J. A. Encinar, "Introduction to Reflectarray Antenna," in *Reflectarray Antennas*, ed: John Wiley & Sons, Inc., pp.1-7, 2007.
- [3] H. Legay, et al., "Satellite antennas based on MEMS tune-able reflectarrays," *Proc. Antennas Propagation, EUCAP 2007*, Vol. 1- 6, pp.11-16, 2007.
- [4] T. Yuan, N. Yuan, L.-W. Li, and M.-S. Leong, "Design and analysis of phased antenna array with low side-lobe by fast algorithm," *Progress In Electromagnetics Research*, Vol. 87, pp.131-147, 2008.
- [5] H. Bui Van, P. Pirinoli, R. E. Zich, M. Mussetta, and D. Chien Ngoc, "Reflectarray antenna for X-band satellite communication," *2012 Fourth International Conference on Communications and Electronics (ICCE)*, pp.417-420, 2012.
- [6] S. Targonski and D. Pozar, "Analysis and design of a microstrip reflectarray using patches of variable size," *International Symposium in Antennas and Propagation Society, AP-S. Digest*, pp. 1820-1823, 1994.
- [7] D. Pozar and T. Metzler, "Analysis of a reflectarray antenna using microstrip patches of variable size," *Electronics Letters*, vol. 29, pp. 657-658, 1993.
- [8] M. Chaharmir, J. Shaker, M. Cubaci, and A. Sebak, "Reflectarray with slots of varying length on ground plane," *IEEE International Symposium in Antennas and Propagation Society*, p. 144, 2002.
- [9] D. Cadoret, A. Laisne, R. Gillard, L. Le Coq, and H. Legay, "Design and measurement of new reflectarray antenna using microstrip patches loaded with slot," *Electronics Letters*, vol. 41, pp. 623-624, 2005.
- [10] Y. Radi, S. Nikmehr, and A. Pourziad, "A novel bandwidth enhancement technique for X-band RF MEMS actuated reconfigurable reflectarray," *Progress In Electromagnetics Research*, vol. 111, pp. 179-196, 2011.
- [11] D. Pilz and W. Menzel, "Printed millimeter-wave reflectarrays," *Annales Des Télécommunications*, vol. 56, pp.51-60, 2001.
- [12] F. Zubir, M. K. A. Rahim, O. B. Ayop, and H. A. Majid, "Design and analysis of microstrip reflectarray antenna with minkowski shape radiating element," *Progress In Electromagnetics Research B*, vol. 24, pp.317-331, 2010.
- [13] B. Khayatyan, Y. Rahmat-Samii, and J. Huang, "Radiation characteristics of reflectarray antennas: Methodology and applications to dual configurations," *First European Conference on Antennas and Propagation EuCAP 2006*, pp.1-12, 2006.
- [14] R. Florencio, R. R. Boix, and J. A. Encinar, "Efficient analysis of multi-resonant periodic structures for the improved analysis and design of reflectarray antennas," *2012 6th European Conference on Antennas and Propagation (EUCAP)*, pp. 2654-2667, 2012.

- 325 [15] C. Mahatthanajatuphat, and P. Akkaraekthalin, "An NP generator model for H-like
326 fractal antenna," Proceeding of the 3rd ECTI-CON, Vol. 2, 749-752, 2006.
- 327 [16]. D. M. Pozar, "Bandwidth of reflectarrays," Electronics Letters, Vol.39, No.21, 2003.
- 328 [17]. E. A. Parker, and S. M. A. Hamdy, "Rings elements for frequency selective surfaces,"
329 Electronics Letters, Vol.17, No.17, 612-614, 1982.
- 330 [18] S. H. Yusop, N. Misran, M. T. Islam, and M. Y. Ismail, "Analysis of concentric split ring
331 square reflectarray element for bandwidth enhancement," *International Conference on*
332 *Space Science and Communication, IconSpace 2009.*, pp. 62-66, 2009.
- 333 [19] H. Legay, D. Bresciani, E. Girard, R. Chiniard, E. Labiole, O. Vendier, *et al.*, "Recent
334 developments on reflectarray antennas at Thales Alenia Space," *3rd European*
335 *Conference on Antennas and Propagation, EuCAP 2009*, pp. 2515-2519, 2009.
- 336 [20] F. Venneri, S. Costanzo, and G. Di Massa, "Bandwidth Behavior of Closely Spaced
337 Aperture-Coupled Reflectarrays," *International Journal of Antennas and Propagation*,
338 vol. 2012, p. 1, 2012.

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