# Design Optimization of Reconfigurable Reflectarray Antenna Based on Phase Agility Technique

**Conference Paper** · January 2010



**2 authors:**

Muhammad Yusof Ismail
Universiti Tun Hussein Onn Malaysia


Muhammad Inam
Universiti Tun Hussein Onn Malaysia

# Design Optimization of Reconfigurable Reflectarray Antenna Based on Phase Agility Technique

M.Y. Ismail, M. Inam and J.Abdullah
Radio Communications and Antenna Design Laboratory,
Department of Communication Engineering,
Faculty of Electrical & Electronics Engineering
Universiti Tun Hussein Onn Malaysia
86400 Parit Raja, Johor, Malaysia
Tel : +607-453 8339
E-mail: yusofi@uthm.edu.my, muhammad_inamabbasi@yahoo.com

*Abstract*— **A number of slot configurations in the reflectarray patch element designed at 10 GHz are proposed to optimize the design of a reconfigurable reflectarray antenna. It has been demonstrated that the introduction of slots in the patch element can alter the resonant frequency of the reflectarray and hence can be used for frequency tuning of reflectarray antennas. Different types of slot configurations have been employed and their dimensions have been varied. This affects the electrical dimensions and modifies the surface current distributions on the patch elements and produces a change in the resonant frequency and reflection phase of a reflectarray. By varying the dimensions of different slot configurations, a phase change of up to 323.91° and a maximum reflection loss variation of 0.32 dB have been observed.**

***Keywords-Reflectarray; slots; reflection phase; reflection loss; phase range.***

## I. INTRODUCTION

Reflectarray is a high gain antenna which combines the unique features of a flat reflector and an array of microstrip patch elements printed on a thin dielectric substrate. It is illuminated using a primary feed horn placed at a particular distance from the array. It has some significant advantages over conventional parabolic and phased array antennas such as easy deployability, lower manufacturing cost, scannable beam, and it is surface mountable with lower mass and volume [1]. However the bandwidth and loss performance of the reflectarrays are limited compared to conventional parabolic reflectors [2]. The main factors that limit the bandwidth of reflectarray antenna are the narrow bandwidth of patch elements which is caused by the extended path length between the feed horn and the reflectarray, and the phase errors related to the change in patch dimensions [3]. The feed antenna bandwidth and array element spacing also limits the bandwidth of reflectarrays but these two are not serious concerns if the bandwidth requirement is less than 15% [1]. In a reflectarray antenna, the individual elements of the array are designed to scatter the incident field with a proper phase distribution to form a planar phase surface in front of the aperture [4]. The design techniques of the array element include identical patches of variable length stubs [5], square or rectangular patches of variable sizes [6], and identical planner elements of variable rotation angle [7, 8].

This paper proposes the use of slots in the reflectarray elements to scatter the incident field in a proper direction from the individual elements. The slot in the patch changes the electrical dimensions of the patch element and hence gives a variation in the resonant frequency and phase of reflection from an individual patch element. Different types of slots in the patch element are used and their dimensions have been varied in order to observe the relationship between maximum attainable linear phase range and the loss performance.

## II. ANTENNA ELEMENTS

Initially a reflectarray with rectangular patch element is designed to resonate at 10 GHz using Rogers RT/Duroid 5880 ($\varepsilon_r$=2.2 and tanδ=0.0010) as a substrate. Commercially available CST computer model has been used to design a unit cell patch element with proper boundary conditions in order to represent an infinite reflectarray and scattering parameters of modeled resonant elements have been analyzed extensively. The dimensions of the patch element (WxL) calculated to resonate at 10 GHz are 10mm x 9.4mm while the height of the substrate is 0.508mm. The port excitation is kept at a distance of λg/4 (5.08mm) from the patch element. Then different types of slot configurations are introduced in the patch element and the effect on the resonant frequency and reflection phase of the reflectarray was observed. In this work, the slots configurations of rectangular slots with variable width, circular slots have been used with variable radii along the width and

This research is fully sponsored by Fundamental Research Grant Scheme (FRGS), Ministry of Higher Education Malaysia (VOT0558).

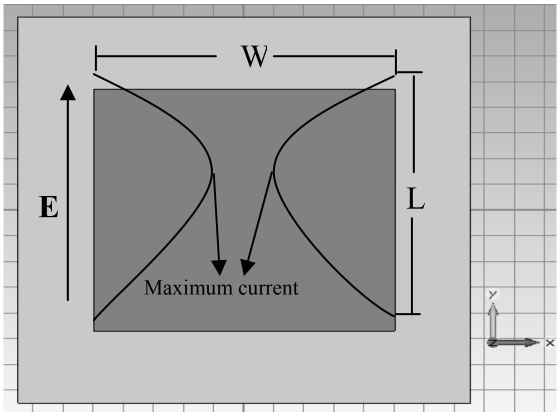


Figure 1. A reflectarray unit cell surface currents

circular slots with variable radii along the length of the patch element. The direction of port excitation and surface currents on a patch without slot are shown in Figure 1.

*A. Rectangular slots with variable width*

As shown in Figure 1 the reflectarray patch element modeled in commercially computer model of CST is excited in the Y-direction therefore the maximum current generated in the middle of the patch surface. By introducing a slot in the patch, the current distribution on the surface of the patch element is shown to be modified. Figure 2 shows the rectangular slot configuration in the patch element. The width of the slot $W_0$ is varied from 0.1W to 0.6W while the length of the slot is kept constant at 0.125L. Figure 3 shows reflection phase plots generated from rectangular slots. As depicted in Figure 3, it is clearly shown that the resonant frequency decreased from 9.972 GHz to 8.108GHz. Moreover the lengthened surface current distributions results in the reflection loss to be increased from 0.344dB to 0.667 dB by increasing the slot width. The reflection loss for different widths of rectangular slots in the patch element is shown in Figure 4.

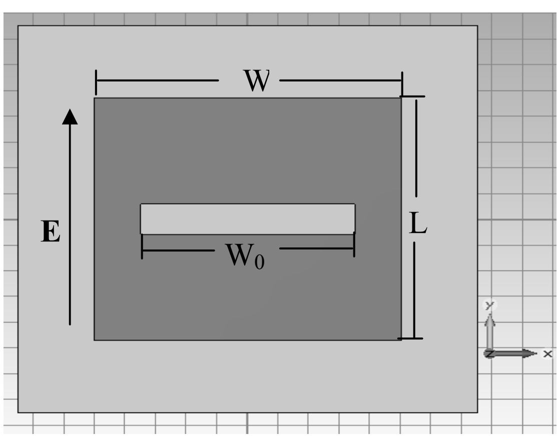


Figure 2. Rectangular slot in the patch element

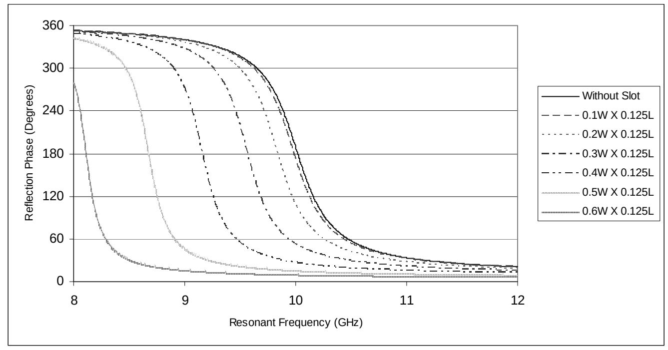


Figure 3. Reflection phase curves for variable width slots

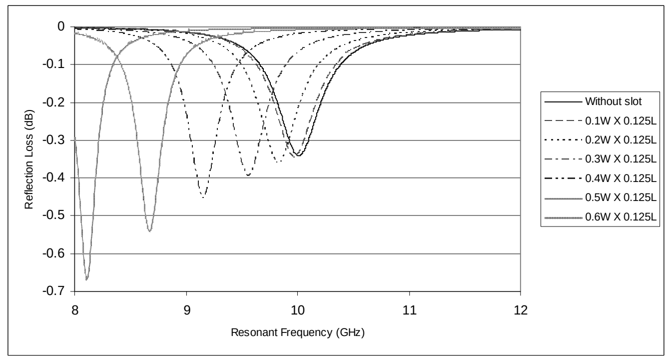


Figure 4. Reflection loss curves for variable width slots

*B. Circular Slots with variable radius along patch width*

Circular slots along the width of the patch with variable radius are applied to observe the effect on the scattering parameters of the reflectarray. The configuration of the patch element with one of the circular slot pairs is shown in Figure 5. From Figure 1 and Figure 5, it can be observed that the current distribution on the patch surface is not going to be affected by the introduction of circular slots along the width of patch element. Therefore the reflection loss of the reflectarray as depicted in Figure 6 is not affected by this configuration but the resonant frequency and reflection phase is clearly shown to vary from 10.11GHz to 11.8GHz. The radii (R) of the circles are varied from 0.5mm to 3.0mm and a significant variation in the resonant frequency was observed. This effect is shown in Figure 6 and Figure 7.

Figure 6 and Figure 7 shows the reflection loss and reflection phase curves of the variable radius slots along the width of the patch element. It can be observed from the above figures that the resonant frequency of the reflectarray changes from 10.112GHz to 11.8GHz as the radius of the circular slot is increased from 0.5mm to 3.0mm but there is no significant effect on the reflection loss. The reason behind these results is that the introduction of circular slots along the width of the patch element does not affect the surface current distributions but the dimensions of the patch are reduced which causes an increase in the resonant frequency.

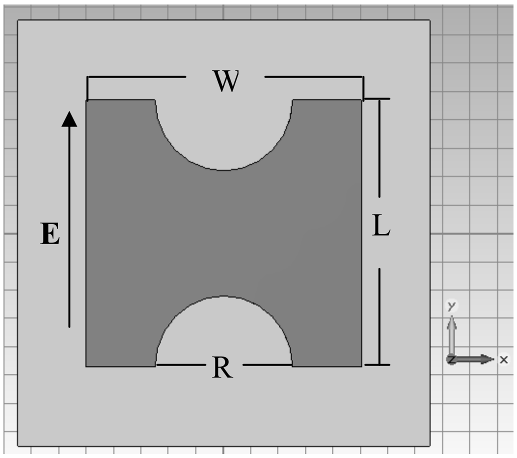


Figure 5. Circular Slots along width of patch element

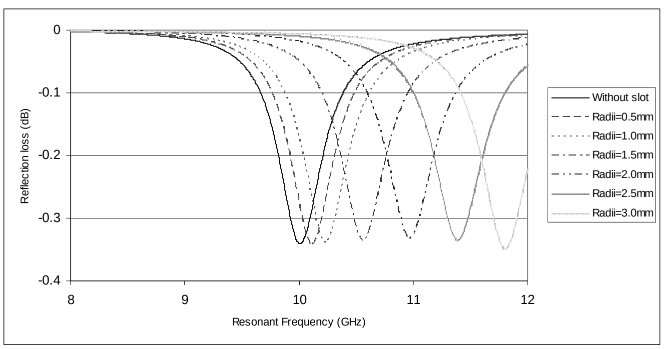


Figure 6. Reflection loss curves for variable Radii slots along width of patch

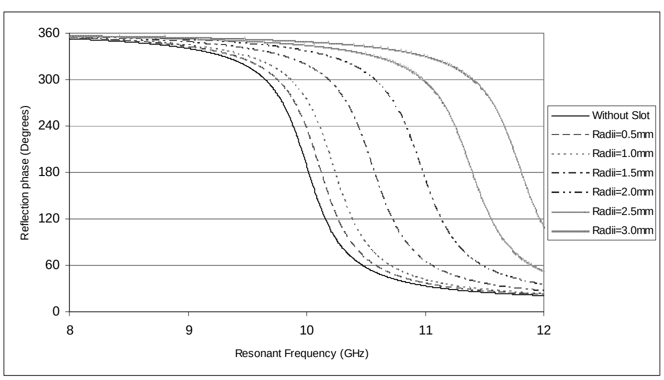


Figure 7. Reflection phase curves for variable Radii slots along width of patch

*C. Circular Slots with variable radius along patch length*

Circular slots along the length of the patch with variable radius are applied to observe the effect on resonant frequency and reflection loss of the reflectarray. The configuration of the patch element with one of the circular slot pairs is shown in Figure 8. The radii (R) of the circles are varied from 0.5mm to 2.5mm and a significant variation in the resonant frequency and reflection loss was observed..

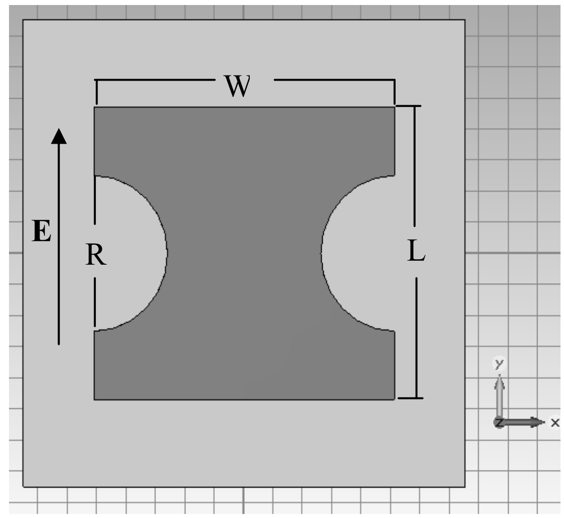


Figure 8. Circular Slots along length of patch element

This effect is shown in Figure 9 and Figure 10. From the results shown in Figure 9 and Figure 10, it can be observed that the resonant frequency of the reflectarray is decreased form 9.9GHz to 8.152 GHz and reflection loss is increased from 0.347dB to 0.642 dB as the radius of the slots are increased from 0.5mm to 2.5mm. These results are caused by the fact that the introduction of circular slots along the length of the patch affects the surface current distribution and the electrical dimensions of the patch. The variation in the current distribution causes a variation in the reflection loss while the increase in the electrical dimensions of the patch causes a decrease in the resonant frequency

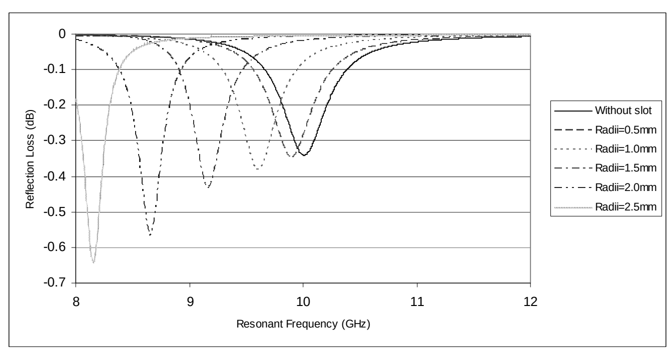


Figure 9. Reflection loss curves for variable Radii slots along length of patch

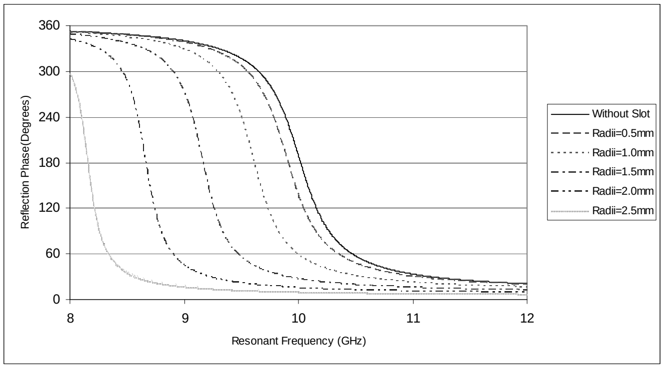


Figure 10. Reflection phase curves for variable Radii slots along length of patch

## III. DYNAMIC PHASE RANGE

In order to define a figure of merit, dynamic phase range for the four main slot configurations is observed. Dynamic phase range is defined as the difference between the phases of two reflection phase curves at the mean resonant frequency.

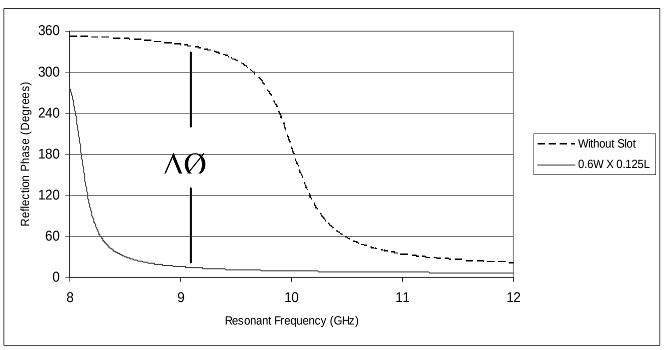


Figure 11. Maximum Phase Range for variable width slot

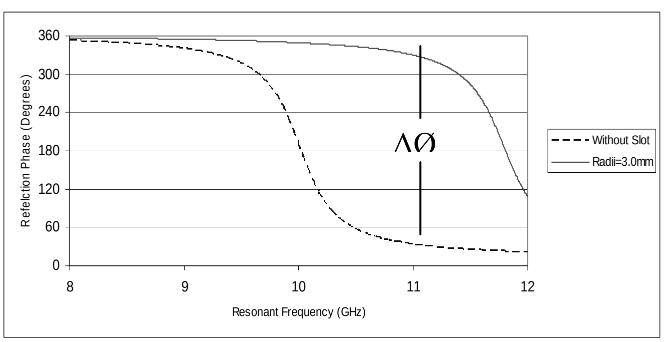


Figure 12. Maximum Phase Range for variable circular slot along width

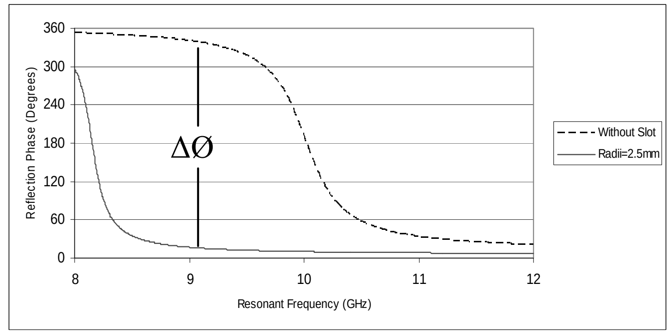


Figure 13. Maximum Phase Range for variable circular slot along length

Maximum dynamic phase range for variable width rectangular slot is measured as the difference in the phases of the phase curve obtained without slot and the one obtained by maximum width slot (0.6W) as shown in Figure 11. The phase range is measured at the mean of the resonant values of two curves i.e. at 9.062 GHz. Similarly the minimum phase range is measured by comparison of minimum slot length (0.1W) and without slot patch elements. In the same way maximum and minimum phase ranges for the circular slots along width and length are calculated and are shown in Figure12 and Figure 13 respectively.

Table 1. Phase ranges of different slot configurations

| **Configuration of Slots** | **ΔØ** | **Dynamic Phase range (ΔØ) (Degrees)** |
|---|---|---|
| **Variable width rectangular Slots** | **ΔØ min** (Without slot and 0.1W width slot) | 19.23° |
| | ΔØ max (Without slot and 0.6W width slot) | 323.91° |
| **Variable radii circular slots along width** | ΔØ min (Without slot and R=0.5mm slot) | 45.44° |
| | ΔØ max (Without slot and R=2.5mm slot) | 297.56° |
| **Variable radii circular slots along length** | ΔØ min (Without slot and R=0.5mm slot) | 55.37° |
| | ΔØ max (Without slot and R=3.0mm slot) | 322.31° |

The phase ranges for different slot configurations is listed in Table 1. From Table 1 it can be observed that the maximum phase range (ΔØ max) for variable width slots and variable circular slots along length is very close 323.91° and 322.31° while the maximum phase range for circular slots along width is very low (297.56°) as compared to other two elements . This is because circular slot along the width of the patch only affects the electrical dimensions and has no effect on the surface currents of the patch while the other two configurations effects the surface current distributions and the electrical dimensions of the patch.

## CONCLUSION

The results obtained from this work demonstrate that the slots in the patch element can be used as one of the possible methods for dynamic phase distribution control to form a planar phase surface in front of the aperture. Different types of slot in the patches have been employed to realize a reconfigurable reflectarray antennas which permit the change in the frequency of resonance and the phase distributions as well. It has been shown that a maximum phase range of 323.91° is achieved with variable rectangular slots in the patch. Further studies are required to use these types of slot configurations in the design of reconfigurable reflectarray which can be applied in active reflectarray antennas for terrestrial and space applications.

## ACKNOWLEDGEMENT

We would like to thank the staff of Radio Communications and Antenna Design (RACAD) laboratory of Universiti Tun Hussein Onn Malaysia (UTHM) for the technical support. This work is supported by Short Term Research Grant VOT 0494 of University Tun Hussein Onn Malaysia.

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