

# Design of a Dual C slot Reflectarray with Enhanced Phase Range Performance

H I Malik<sup>1</sup>, M Y Ismail<sup>1</sup>, M Amin<sup>2</sup> and F Mohamed<sup>3</sup>

<sup>1</sup> Universiti Tun Hussein Onn Malaysia (UTHM)

<sup>2</sup> Institute of Space Technology (IST), Islamabad, Pakistan

<sup>3</sup> Universiti Kebangsaan Malaysia (UKM)

Email: yusofi@uthm.edu.my

**Abstract.** This paper deals with the design, fabrication and performance evaluation of a dual C slot compact reflectarray element. It has been demonstrated that the progressive phase distribution of array elements can be achieved by minor variation of C slot widths, without changing the entire patch dimensions. A comparison between measured and simulated results confirms wider phase range coverage of  $340^\circ$  and a 10% bandwidth of 70 MHz have been achieved. A good comparison between simulated and measured results has been exhibited by comparing three different slot widths of the proposed design.

## 1. Introduction

Reflectarray antennas are a moderate choice between the bulky parabolic dish reflectors and expensive phased array antennas. They have proved their significance as effective antennas in radar systems and long range communications. Reflectarrays were introduced in 1963 as a bulky waveguide structure, fed by a distant spatial source [1]. The potential of reflectarray was not gauged well at that time but with the advent of printed circuit board (PCB) technology, new design schemes have been presented combining the prime features of parabolic dish reflectors and phased array antennas. Today's reflectarray antenna consists of a planar surface with printed array of radiating elements, illuminated by a feed source. The phases of elements are controlled in such a way to form a planar wavefront at far field distance from array [2].

Different design schemes for the reflectarray unit cells have been presented in the literature to control the phase distribution of individual elements on the periodic reflectarray antenna. Recent techniques for phase distribution include stub loaded microstrip elements, elements of variable sizes and embedded slot configuration in rectangular patches [3-5]. It has also been demonstrated that different ring shaped elements such as the circular split ring, concentric split ring square and split ring with variable rotation can also be used to control the phase behavior of the reflectarray elements [6-8]. However the phase range of the split ring element is observed to be compromised. Moreover the introduction of a gap in the structure greatly decreases the gradient of the phase curve and reducing the linear phase region of the phase curve. Thus, it is leading to phase errors in a periodic array.

This work presents a novel X-band dual C slot reflectarray antenna. The proposed slot configuration offers a wider phase range coverage and bandwidth performance over the X-band frequency range. The phases of individual elements can be easily controlled by changing the width of embedded slot configuration, without any changes in the entire element size. The design was fabricated over Rogers Duroid 5880 substrate of 0.508 mm thickness. Waveguide simulator technique

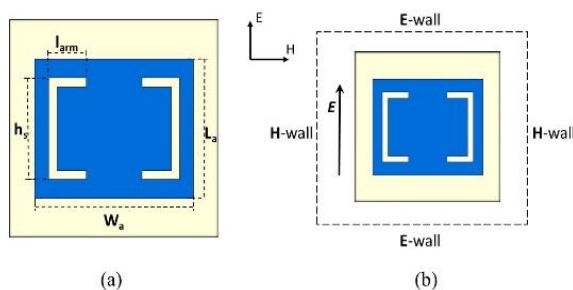


was used to measure the scattering parameters of the fabricated design. A good agreement was found between the measured and simulated results.

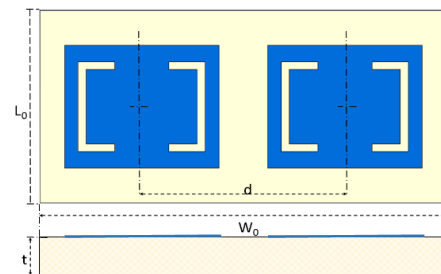
## 2. Design Considerations

The simulation designs were carried out using CST Microwave Studio. Two C slots were inserted in a conventional rectangular microstrip patch element as a mirror image of each other. The proposed element design has been presented in figure 1(a). Where  $h_s$  is the height of the slot while  $l_{arm}$  is the length of the arms of C slot. Suitable boundary conditions were applied in CST with electric and magnetic boundaries in order to realize an infinite reflectarray.

The orientation of the E-field excitation is shown in figure. 1(b) by an E-field vector. Figure. 2 shows two patch elements that were fabricated for waveguide simulator measurements. The inter element spacing 'd' was kept half wavelength at 10 GHz to avoid the problem of grating lobes. The width of the slots was varied from 0.6 to 1 mm for three different values, to monitor the effect over scattering parameters. Table 1 summarizes the design specification of double C slot element at X-band frequencies.



**Figure 1.** Proposed element design for reflectarray element (a) A dual C slot element (b) Applied boundary conditions in CST MWS



**Figure 2.** Design of a two element sample for waveguide simulator measurement

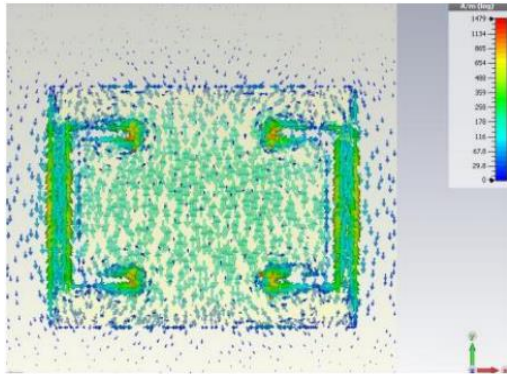
**Table 1.** Design specification for double C slot element for X-band operation

Parameter	Dimension (mm)
$L_a$	9.3
$W_a$	11.4
$l_{arm}$	2.3
$h_s$	7
$W_o$	40
$d$	15
$t$	0.508
$L_o$	23

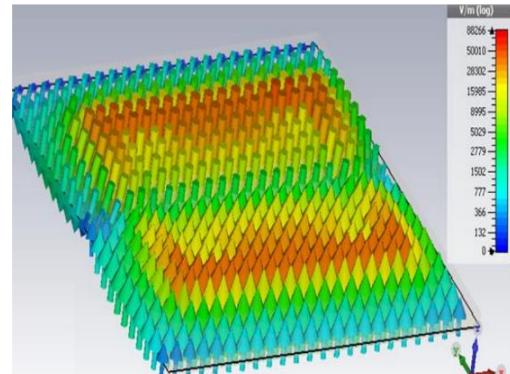
The surface current distribution of the patch element is shown in figure. 3. The surface current distribution shows a major flow of charge carriers between the upper and lower radiating edges of the patch. While travelling between the edges a lot of charge carriers follow the spacing between the slots and the non-radiating edges (mentioned by green shade in figure. 3). There is an even distribution of the charge carriers between the arms of the C slots and charge carriers follow the edges of the C slot, thus increasing the length of the arms will increase the distance travelled by the charge carriers. This

will result in decrease in resonant frequency. Moreover the width of the C slot in the patch also affects the flow of the charge carriers, increasing the width decreases the resonant frequency.

In order to examine the dominant mode inside the cavity between the patch and ground plane, E-field monitors were simulated at the resonant frequency. The results have been presented in figure. 4.



**Figure 3.** Surface current distribution of a dual C slot element configuration

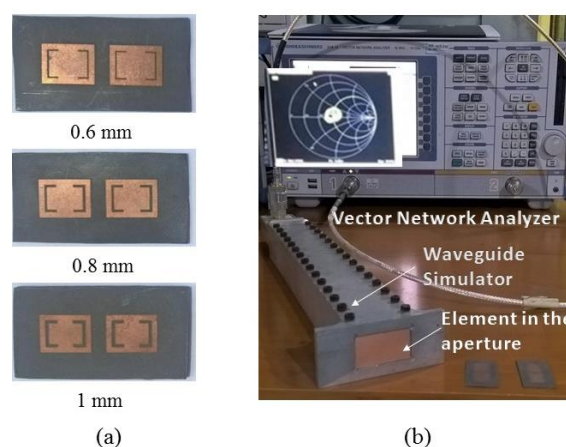


**Figure 4.** Field Configuration (mode) for the proposed design inside the cavity

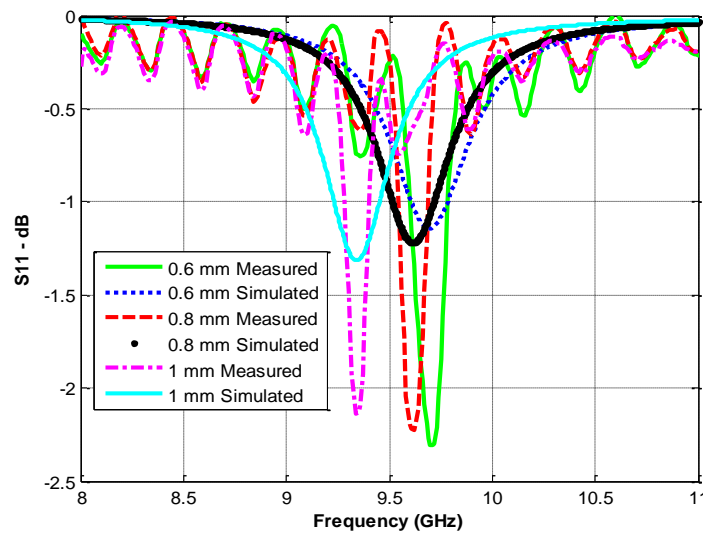
The orientation of the E-field lines shows a similar trend as presented for TM<sub>01</sub> mode in [9]. At TM<sub>01</sub> mode shows a maximum electric field intensity of 88.2 mV/m inside the cavity. This shows that the insertion of C slots does not affect the dominant mode of operation of patch element.

### 3. Measurement and Considerations

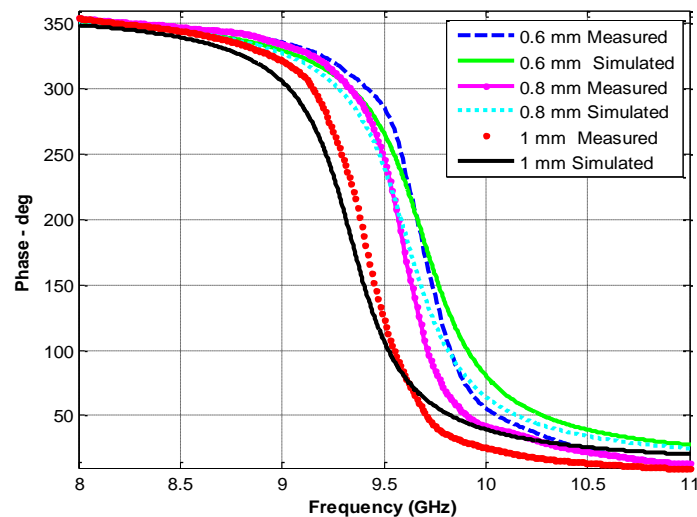
Samples with two unit elements were fabricated over a Rogers Duroid 5880 substrate, with a thickness of 0.508 mm using photolithic etching process. Elements with three different width of C slots were fabricated to validate the proposed design. An X-band waveguide simulator was used in order to realize the effect of an infinite periodic reflectarray. The waveguide simulator technique applies perfect electric and magnetic boundaries for unit reflectarray element to determine its reflection phase and loss before embedding the element into the array [10]. Fabrication tolerances were incorporated in the simulated results after a thorough examination of fabricated samples under a microscope. Figure 5(a) shows the fabricated samples with three different slot sizes. Three samples for each slot width were fabricated and tested in order to ensure repeatability of results. Figure 5(b) shows the measurement setup for the arrangement of the waveguide simulator attached to a vector network analyser via coaxial cable.



**Figure 5.** (a) Fabricated samples of dual C slot element with variable slot widths (b) Measurement set up for scattering parameter measurements, waveguide simulator attached to a vector network analyzer



**Figure 6.** Comparison of simulated and measured reflection loss measurements for 0.6, 0.8 and 1 mm slot width samples



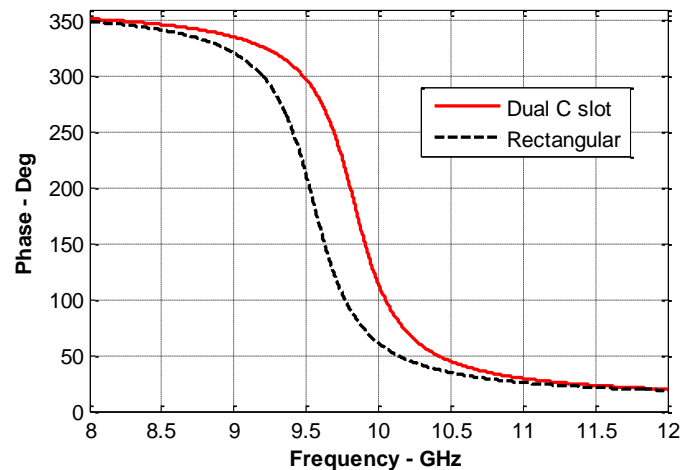
**Figure 7.** Comparison of simulated and measured reflection phase measurements for 0.6, 0.8 and 1 mm slot width samples

A comparison between scattering parameter measurements and simulated results is presented in figure. 6. The ripples present in the measured results might be due to limitation of the measurement set up. The results demonstrate that with the increase in the slot width from 0.6 to 1 mm the resonant frequency decreases from 9.7 to 9.34 GHz. It can be seen that the loss for the simulated designs is below -1.4 dB while for measured results the loss is -2.3 dB. The increase in loss might be due to losses of the measurement set up such as the insertion loss of connectors and the coaxial cable. The measured results show a 10% bandwidth of 50, 70 and 73 MHz for 0.6, 0.8 and 1 mm slot width elements respectively. Figure. 7 shows the reflection phase measurements of fabricated elements. It can be seen that the measured curves show a steep trend when compared to simulated phase results. This may be due to the increased loss of the measured results than simulated results. In order to analyse the phase curves of measured samples a Figure of Merit (FOM) has been defined in equation 1 [11].

$$FOM = \frac{\Delta\phi}{\Delta f} \quad (1)$$

where  $\Delta\phi$  is the reflection phase in degrees, and  $\Delta f$  is the frequency range covered. The FOM is calculated in  $^{\circ}/\text{MHz}$ . In order to verify the wide phase range of the proposed design, a comparison was also done with the reflection phase of a conventional rectangular patch element with similar substrate properties. Figure 8 shows the reflection phase curves for dual C slot element and rectangular patch element. FOM was calculated for both the designs to compare the static phase region.

Table 2 summarizes the performance analysis of the proposed design configuration. It has been shown that the bandwidth of dual C slot element decreases with increase in slot width. The 10% bandwidth reduces from 73 MHz to 50 MHz as the slot width is increased from 0.6 to 1 mm respectively.



**Figure 8.** Comparison between reflection phase curves between conventional rectangular patch element and dual C slot embedded elements

**Table 2.** Performance comparison between rectangular patch and dual C slot element

Slot Width	Bandwidth (MHz)		FOM deg/MHz
	10%	20 %	
Rectangular patch	78	120	0.52
0.6 mm	73	105	0.82
0.8 mm	70	96	0.70
1 mm	50	87	0.55

Moreover, it can be seen from Table I that FOM decreases from 0.82 to 0.55 deg/MHz with slot width increase from 0.6 to 1 mm respectively. The FOM for a rectangular patch is 0.52 with a 20 % bandwidth of 120 MHz, however dual C slots of 0.6 mm provides an FOM of 0.82 with a 20 % bandwidth of 105 MHz. The decrease in the bandwidth is due to slight increase in the loss of the element. Thus a dual C slot configuration offers a better phase gradient as compared to conventional rectangular patch.

#### 4. Conclusion

A novel rectangular microstrip reflectarray element embedded with dual C slots has been presented for X-band frequency applications. It has been demonstrated that a small variation in the width of C slots results in a significant change in the resonant frequency of the element. The results show that by

changing the slot width from 0.6 mm to 1 mm the resonant frequency varies from 9.7 to 9.34 GHz. Moreover the proposed design with a slot width of 0.6 mm is shown to offer wider phase range coverage of  $340^\circ$  along with efficient bandwidth performance. The proposed design scheme offers a 20% bandwidth improvement from 87 to 105 MHz with the decrease in slot width from 0.6 to 1 mm. A Figure of Merit (FOM) has been defined in order to analyse the gradient of phase curves. Comparison of phase gradient with a conventional microstrip patch shows wider phase coverage for dual C slot embedded configuration.

### Acknowledgement

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