

# Investigation of Static Phasing Distribution Characteristics of Passive Reflectarray Antenna Elements

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**Abstract ?** There has been much interest recently in developing reflectarray antennas due to the combination of some of the best features between the parabolic reflector and phased array antennas. This paper presents the study of the relationship between phasing distribution characteristics and the bandwidth of different resonant reflectarray elements. The gradient characteristics of different elements of patch, dipole and ring, printed on a grounded dielectric substrate have been investigated at X-band frequency range using the commercial CST computer model. The preliminary simulated results demonstrate that ring elements contribute the highest reflection loss performance of about -1.737 dB compared to the other two elements of dipoles and patches. The attainable static linear phase range of  $177^\circ$  for ring elements is shown to offer a trade-off between the static phase range and the bandwidth of the reflectarray elements.

## INTRODUCTION

**A** microstrip reflectarray antenna consists of a flat array of microstrip patches or dipoles printed on a thin dielectric substrate [1]. Similarly as its conventional counter part, it uses a primary feed and a reflecting surface. However in microstrip antenna, the latter component is planar and forms by many micro strip antenna element. When the incident signals illuminating from a feed antenna to the array elements and scatter the incident field with the proper phase required forming a planar phase. Many types of resonant elements [2] can be used in printed reflectarray antennas depending on the required applications such as dual frequency [3] and solar panel reflectarray [4]. Examples of reflectarray antenna elements are the variable size patch elements [5], [6], spiral patch elements [7], cross dipole elements [4], [8], and ring elements [3], [9]. The focus in this paper is on the range and slope of phase characteristics of a unit cell reflectarray formed by different types of elements: patch, dipole and ring. In the reflectarray design, the obtained phase characteristics are used to work out the sizes of the individual elements in the reflectarray to compensate for the phase differences. There are two main parameters that are important in the phase compensation process, the range and the slope. The phasing range needs to be  $360^\circ$  at a given frequency of operation, in the way to provide suitable compensation. Meanwhile, the phase slope oversees the manufacturing tolerances and the operational bandwidth of the element. As the slope are slower, its offers smaller manufacturing errors and provide larger operational bandwidth. In this paper the phasing distribution characteristics was analyzed using different resonant elements. The operating frequency of operation is in the X-band frequency range (8-12 GHz).

## BACKGROUND

Reflectarray combines the feature of both a reflector and an array. As the introduction of the printable microstrip antennas, the technologies of combining the reflectarray and microstrip radiators were investigated [10]. A feed antenna illuminates the array whose individual elements are designed to scatter the incident field with the proper phase required to form a planar phase surface in front of the aperture. The bandwidth performance of a reflectarray is shown to be narrower compared to a parabolic reflector. For a printed microstrip reflectarray, its bandwidth is primarily limited by two factors that are narrow bandwidth of the microstrip patch elements on the reflectarray surface and the differential spatial phase delay [11]. The path length from the feed to all patch elements is all different. This leads to different phase delays. In order to compensate for the different path lengths, the elements must have corresponding method to overcome the problem. The reflection loss,  $S_{11}$  of a reflectarray antenna should be 0 dB at resonance in order to get a maximum reflected energy. Minimum reflection loss can be achieved when the signal energy reflection is the same as when signal energy is illuminated. The slope of the phase versus frequency is a measure of the bandwidth of reflectarray as a curve with a smaller phase slope will lead to less phase error [1] as shown Figure 2. It has been reported by Pozar that there is a trade-off between phase range and the bandwidth [1]. This is indicated by the gradient of the S-shaped phase curve. To provide a suitable compensation for all the elements in array, the phasing range needs to be close to  $360^\circ$  at a given frequency [12]. Resonance occurs at  $180^\circ$  phase difference, where the maximum reflection of the signal occurs. Figure 1(b) shows how to defined Figure of Merit (FoM) (1). It is used as an indicator

to describe phasing distribution of the static linear phase range occurs at a certain frequency range.

Figure of Merit = Static Linear Phase Range / Frequency Range

$$FoM = \frac{\Delta\Phi}{\Delta f} = \frac{(\Phi_1 - \Phi_2)}{(f_1 - f_2)} \quad (1)$$

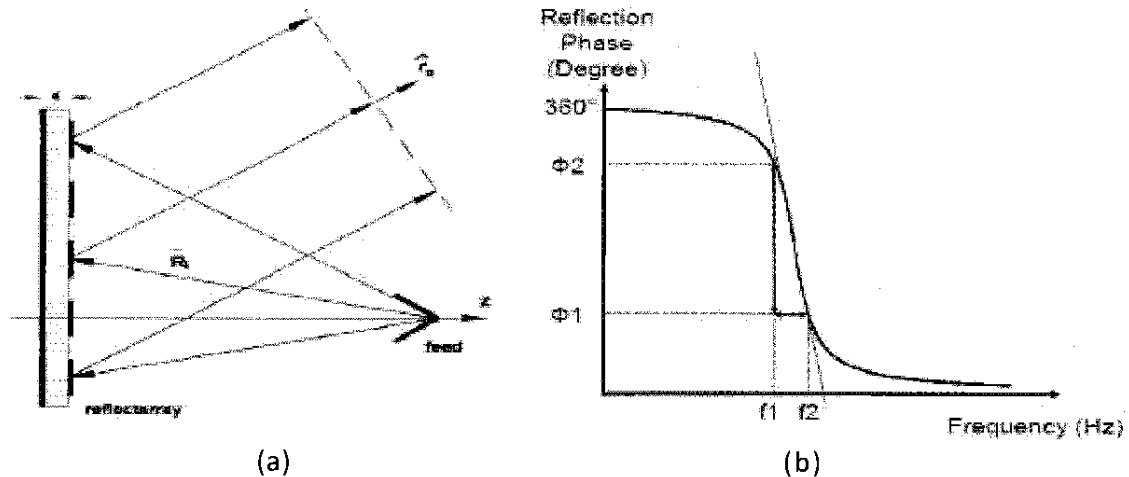


Figure 1: (a) Geometry of the microstrip reflectarray (b) Reflection Phase versus frequency

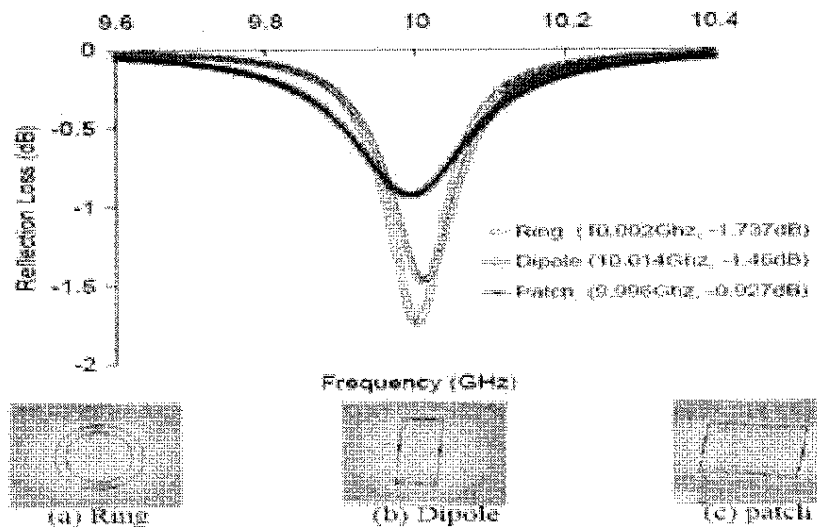
## METHODOLOGY

The considerations start with a microstrip reflectarray operating in the X-band with the center frequency of 10 GHz. The reflectarray is assumed to be formed by elements printed on a substrate of dielectric constant and thickness and arranged in a square lattice. In the built model simulator, the elements are assumed to have symmetry with respect to the X and Y axis. In order to work out the phase characteristics, only the case of a vertically polarized (in Y-axis) TEM plane wave that is normally incident on an infinite periodic array is considered. These 3 considerations based on the fact that TEM provides a good approximation to the phase range and slope. In order to identify phase distribution characteristics, different types of elements are used. By using the equivalent waveguide approach, the phase of the reflected wave at each element is determined as the phase of the scattering parameter for the waveguide one-port containing these elements. The structure was modeled using the commercial full-wave electromagnetic software CST Microwave Studio. The reflection loss performance and the phase characteristic of unit cells with different type of resonant element were generated. The parameters such as S11 and S-shaped phase curves obtained from commercially available CST computer model have been investigated. Current distributions of resonant elements of dipole, patch and ring have been studied to observe the effect on the reflection loss and static linear phase range performance.

## RESULTS AND DISCUSSIONS

This section reports on simulated results for the phase characteristic of different type of resonant reflectarray element as obtained with CST Microwave Studio. The

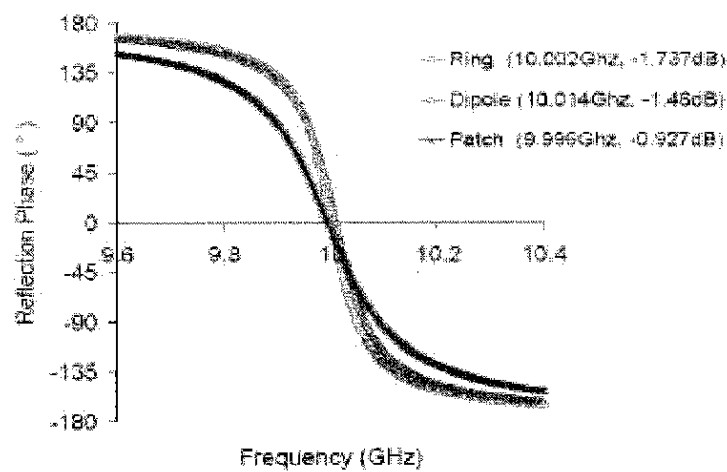
relationship between the static linear phase range and the bandwidth is investigated in order to find the best element which suits the criteria for greater phase range and low loss performance of reflectarray elements. Resonant patch elements of dipole, patch and ring have been analyzed using the commercially available CST computer model. The simulated results shown in Figure 3 show that ring element has higher loss compared to dipole element and rectangular patch element, -1.737 dB, -1.46 dB and -0.927 dB respectively. This is significantly due to the surface area of ring element as shown in surface color contour distribution in Figure 3(a) which has smaller area compared to dipole element and rectangular patch element that allows more current distribution to be concentrated in that particular region. Because of the area of the resonant elements, ring element has a higher loss due to the reflection properties from the elements and hence less bandwidth compared to dipole element and rectangular patch element [1]. This is clearly shown by the surface current distribution generated from the CST computer model. The red color represents the areas which have the highest concentration of current distributions.



**Figure 3:** Combination of ring, dipole and rectangular patch element in S11 (dB) parameter

The static phase range generated from the CST computer models for three different types of resonant elements of ring, dipole and patch can be clearly seen in Figure 4. The ring element shows a greater static linear phase range compared to the other two elements. However the increase in the static phase range has to be traded off with the bandwidth and the reflection loss performance of the reflectarray. Although the bandwidth of the reflectarray elements is shown to be very narrow, it can be increased by suitable choosing suitable ratios of the outer and inner radius ratio [8].

Table 1 summarizes the static linear phase range and Figure of Merit for three resonant elements of dipole, ring and patch. It is clearly shown that both the linear phase range and larger Figure of Merit are contributed by ring element but however it has to be traded off between narrow bandwidth and greater linear phase range.



**Figure 4:** Comparison between S-shaped phase curves of ring, dipole and rectangular patch element

**Table 1:** Figure of Merit (FoM)

Case	Elements	Linear Phase Range (°)	Figure of Merit (FoM) (°/GHz)
1	Ring	177	1967
2	Dipole	171	1710
3	Rectangular Patch	150	1250

## CONCLUSIONS

In conclusion, the trend of the S-shaped phase curves of the reflectarray antenna has been investigated using different resonant elements. Analysis of the phase distribution of resonant elements were carried out using CST computer model demonstrate that there is a trade off between the static phase range and the reflection loss of the elements. Predicted results generated from commercially available CST computer model demonstrate that ring elements offer a greater static phase range compared to the elements of dipole and patch. The Figure of Merit has been defined in order to give an indicator of the performance between the static phase range and the reflection loss of different resonant elements of reflectarray. Waveguide simulator measurements will be performed in order to see the reliability of the predicted results obtained from the commercially available CST computer model.

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