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COMPARISON AND ANALYSIS OF UNIT-CELL ENVIRONMENT BEHAVIOR OF REFLECTARRAY ANTENNA

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ABSTRACT

The reflectarray combines much of the simplicity of the reflector antenna with the performance of the array antenna. This paper presents an analysis and design of unit cell of reflectarray antenna using a square patch and square loop radiating elements and the steps taken in the design of a reflectarray unit cell operates in X -Band (8-12 GHz) at the center frequency of 10 GHz. The result of an analysis is generated from the Computer CST Microwave Studio using the approach of Floquet. This model takes into account a mutual coupling between elements, and is an efficient way to accurately characterize reflectarray elements.

Keywords: reflectarray, reflector, unit-cell, reflection phase, floquet mode.

INTRODUCTION

Microstrip reflectarrays are flat reflector antennas consisting of a planar array of microstrip patches illuminated by a feed. Reflectarrays are an innovative and attractive alternative to conventional reflector antennas. They show several advantages when compared with parabolic reflector antennas or conventional arrays. In fact, reflectarrays can be conformal to a slightly curved surface, their efficiency can be very good because there are no power dividers and their main beam can be pointed at a large fixed angle from the broadside direction (J. Huang and J. Encinar, 2007). With all the above capabilities, there is one distinct disadvantage associated with the reflectarray antenna. This is its inherent characteristic of narrow bandwidth, this later limited by two factors. One is the narrow bandwidth of the microstrip patch elements on the reflectarray surface and the other is the differential spatial phase delay (D. M. Pozar, 2003). Different types of reflectarray elements have been proposed in recent years to improve the element bandwidth in printed reflectarrays.

The reflectarray concept is based on the scattering characteristics of microstrip patches. Each radiating element is designed to reflect the incident field with a suitable phase shift necessary to produce a phase coherent beam in a specified direction. A critical feature of the microstrip reflectarray design is the choice of the shape of the elements. Several design techniques have been proposed so far; microstrip patches with different resonant lengths (Erdinç Erçil, *et al*, 2015), (D. Pozar *et al*, 1997), patches of the same size loaded with stubs of variable length or identical patches with different angular rotation (J. Huang, 1991), (Xian-Jiang Zhong *et al*, 2014) and the usage of electronic components (Tahir, F. A *et al*, 2010). The phasing method using variable size patches is a preferable choice in many designs due to its simplicity. The use of microstrip reflectarrays is largely diffused in many application fields, such as remote sensing and satellite communications. With the new emerging technologies, advanced features are required in terms of broadband, dual-polarization, and beam-scanning operations (M. Ramli *et al*, 2016), (Min Zhou *et al*, 2013). Some potential applications of reflectarrays in space have been researched, such as contoured beam antennas for Direct Broadcast Satellites and very large inflatable antennas (Jose A. Encinar *et al,* 2011).

In this paper, we present a comparison of two structures of a unit cell of reflectarray antenna: square patch and square loop radiating elements, all results of the reflection characteristics and phase range are reported.

DESIGN PROCEDURE

In order to investigate the scattering characteristics of the unit cell studied we use commercially available computer models of CST Microwave Studio, based on the method of finite integration technique, and using the approach of Floquet. (Infinite periodic approach), it's used to approximate the mutual coupling between cells (J. Montgomery, 1987). It considers that each cell is taken from an infinite periodic network. Each cell is studied separately and boundary conditions are applied to the cell to get the behavior of the latter when it is surrounded by a uniform and infinite environment, and the excitation of a cell is achieved by a plane wave as shown in Figure-1.

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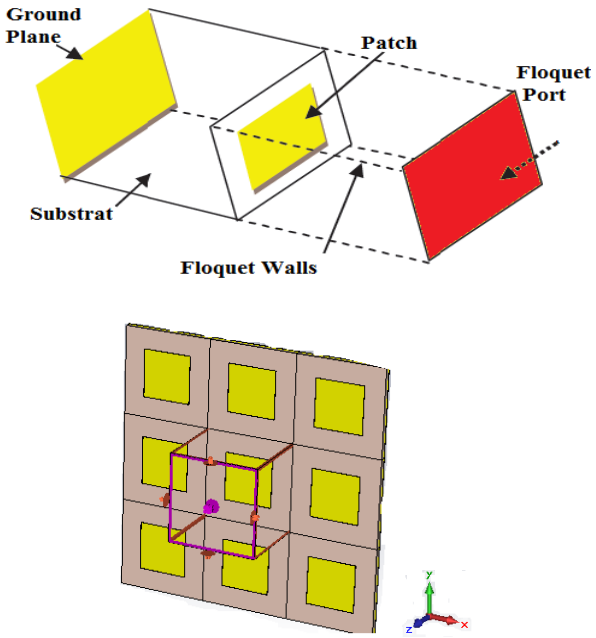


Figure-1. Infinite periodic array modeled with unit cell in CST-MWS (Floquet approach).

x and y boundaries are chosen to be of type unit cell. The boundaries perpendicular to the unit cell are left open. The incident plane wave is realised using Floquet modes. The incident angle (spherical angle) of the plane wave is explicitly defined by two parameters θ and φ. The solver enables as many Floquet modes to be defined for each port. In this simulation only two modes are chosen.

Because of numerous factors which impact on the design of reflectarray, it is very important to select the type and geometry of reflective element as well as the substrate properties was chosen. The geometry of unit cell is shown in Figure-2, it's square patch, and square loop resonating in X-band frequency range, printed on Arlon AD 320 substrate of εr=3.2, tgδ=0.0038, h=1.016mm, and backed by conducting ground plane, thickness used is tm=0.035mm.

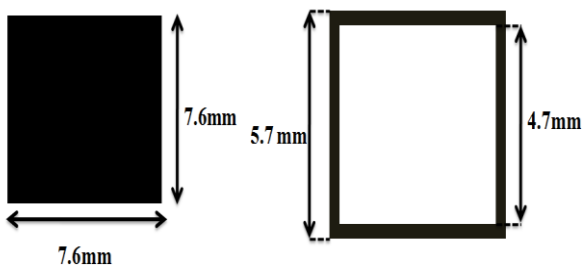


Figure-2. Unit -cell geometry; (a) square patch, (b) square loop.

SIMULATION RESULTS

Figure-3 shows simulated reflection loss of different resonating elements at the resonance frequency 10 GHz. It can be observed from Figure 3 that the square loop element has higher loss compared to square patch element,-2.15 dB, and -1.11 dB respectively. This is due to the surface area of square loop element which has a smaller area compared to square patch element, 10.4 mm^2, 57.76 mm^2, respectively, that allows more current distribution to be concentrated in that particular region. Because of the area of the resonant elements, square loop element has a higher loss due to the reflection properties of the elements and hence less bandwidth compared to square patches element.

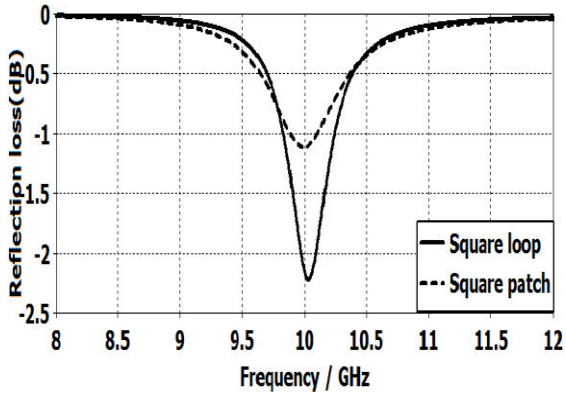
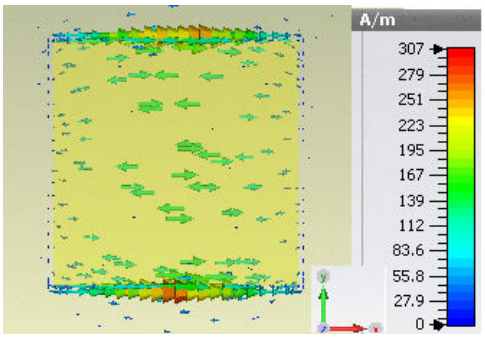
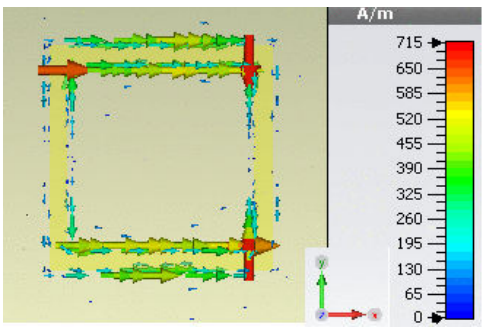


Figure-3. Combination of patch element and square loop element in S11 (dB) parameter.

Figure-4 below shows the surface current distribution generated from the CST computer model of the resonant elements, the red color represents the areas which have the highest concentration of current distributions.



(a)



(b)

Figure-4. Surface current density on reflectarray resonant elements; (a) square patch, (b) square loop

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The reflection phase is considered as an important parameter as the reflection loss curve in the analysis of the reflectarray design. Figure-5 below shows static phase range of resonant elements of square patch and square loop. Figure of Merit can be used as an indicator to describe phasing distribution of the static linear phase range. The FoM is given by:

Figure of Merit= Static Linear Phase Range /Frequency Range.

$$FoM = \frac{\Delta\phi}{\Delta f} = \frac{\phi 1 - \phi 2}{f1 - f2} \quad (1)$$

$\Delta\phi$ is the change in the reflection phase in degrees and Δf is the change in the reflectarray antenna resonant frequency in MHz, thus FoM is calculated here in °/MHz.

Table-1 summarizes the static linear phase range, bandwidth, and figure of Merit for resonant elements. It can be observed from Table-1 that both the linear phase range and larger figure of Merit (FoM) are contributed by square patch element, square patch offers minimum static phase range of 147°, whereas square loop offers maximum phase range of 179°. However, it has to be traded off between narrow bandwidth and greater linear phase range.

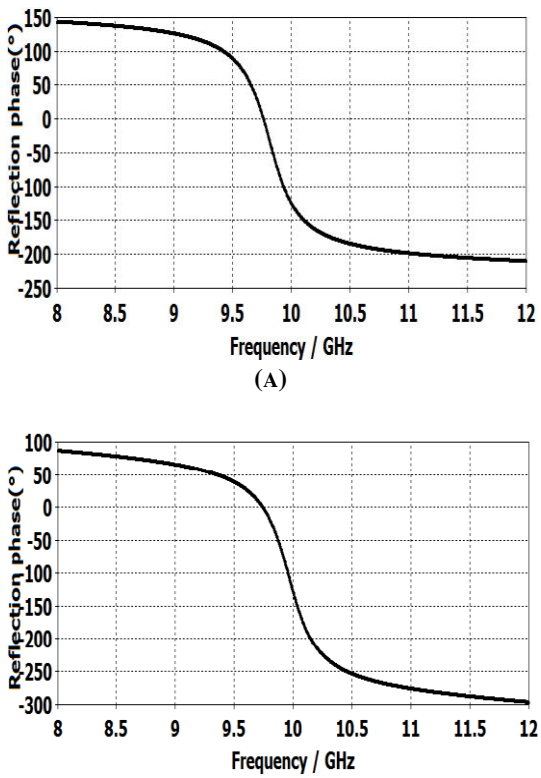

Figure-5. Reflection phase curves of, (a) square patch, (b) square loop.

Table-1. Performance comparison for different resonant elements of reflectarray.

	Resonant elements	
	Square patch	**Square loop**
Reflection loss (dB)	1.11	2.15
10% Bandwidth (MHz)	238	163
Static linear phase range (°)	147	179
Figure of Merit (FoM)(°/MHz)	0.32	0.50

The Figure-6 obtained by varying the length of radiating elements and keeping other parameters fixed. It is illustrated in Figure-6 that the resonance frequency shifts to lower values of length of patch for higher frequencies (square patch; for F=10.8 GHz lp=2mm), (square loop;for F=11.5 GHz ls=2.2mm). Increasing the frequency results in a reduced wavelength which is directly related to the patch resonance length.

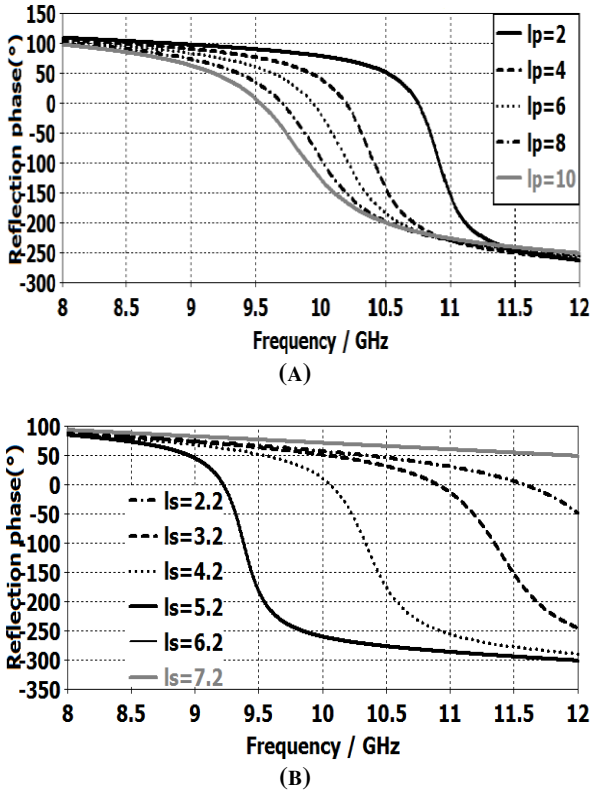

Figure-6. Phase diagrams of a variable-sized resonant element as function of frequency; (a) square patch, (b) square loop.

CONCLUSIONS

In this paper, the analysis of reflectarray unit cell, using different resonant elements and using the approach of Floquet, has been presented. The phase distribution of resonant elements was presented using CST computer model demonstrate that there is a trade -off between the static linear phase range and the reflection loss of the

elements. The square loop offer greater static linear phase and narrow bandwidth as compared to square patch element, that is due to a reduction in reflecting area of the resonant elements modifies the electrical dimensions and surface current density which can significantly affect the reflection loss and reflection phase performance.

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