Comparison of Resonant Elements of Microstrip Reflectarray Antenna for Ku-Band Applications

Namrata V. Langhnoja and Ved Vyas Dwivedi

Abstract— Design of unit cell of Microstrip Reflectarray Antenna (MRA) is one of important parameters. Using infinite array approach method, resonant element of MRA is observed in unit cell environment. The reflection phase curve helps to characterize different shapes of resonant elements.

Keywords— Unit-cell environment, Infinite array approach, Reflection Phase Curve, Figure of Merit, Static Phase Range

I. INTRODUCTION

The term 'flat reflector' utilizes both technologies of reflector and array hence also called as the Reflectarray. The Reflectarray antenna [1 - 4] consists of a slightly curved or flat surface as a reflector with an illuminating feed antenna. Unlike parabolic reflector antenna, an Microstrip Reflectarray Antenna (MRA) [2] having flat reflecting surface can be surface mounted conformal onto the outside structure of spacecraft, comprising lesser weight and volume. As a result Reflectarray is used to solve the problems associated with the parabolic or an usual array antennas. The feed antenna spatially illuminates the elements to form a planar phase front in the far-field region. In other words, the phase of each element is pre-designed so as to compensate for the different phases associated with the variable patch sizes, angular rotation of different patch elements and different path lengths [2].

The radiation mechanism of the reflectarray antenna giving graphical visualization as well as the study of progressive phase distribution of unit cell design has been explained in [6]. The progressive phase distribution and investigation of reflection area of Rectangular, square and triangular shape patches as well as loop structure of respective shapes was studied in [7, 8]. The better phase response was obtained by using a square and circular ring [9].

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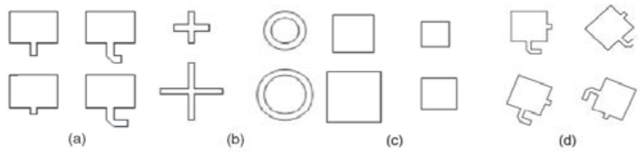


Fig 1. Various Reflectarray elements, (a) Identical patches with variable - length phase delay lines, (b) Variable - size dipoles or loops, (c) Variable - size patches, (d) Variable angular rotations.

The building block of the reflectarray antenna is unit cell. Unit cell may contains single layer or multiple layer patches. As shown in Figure 1, there are several methods for reflectarray elements to get a planar phase front. One is to use identical Microstrip patches with variable length phase delay lines attached so that they can compensate for the phase delays over the different paths from the illuminating feed.

Another is to use variable-size patches, variable length dipoles, or variable width of rings so that the resonant elements can have different scattering impedances and, thus, different phases to compensate for the different feed-path delays. With the third method, for circular polarization only, the reflectarray has all identical circularly polarized elements having different angular rotations to compensate for the feed path-length differences, reflecting surface profile, low manufacturing cost as well as small antenna mass,.

An effective approach for characterization of reflectarray element is to use an infinite-array model. Floquet's mode is used to evaluate the reflectarray element [6]. Thus overall analysis is reduced in a unit-cell environment.

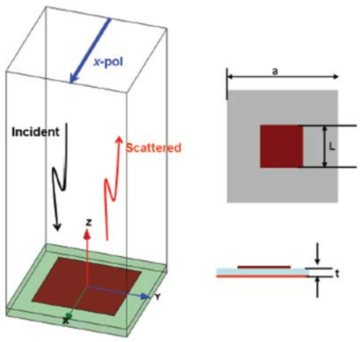


Fig 2. The infinite-array model setup of the patch element in HFSS using unit cell approach [6]

In the unit-cell once the plane wave come out from the source plane, it illuminate on the patch element. All energy is scattered back by the patch element which is backed by a ground plane, see Figure 2. There are three back scattered components due to resonant activity of patch. (1) Re-radiated component due to resonant activity of patch. (2)Specular (scattered) component due to ground plane. (3) Scattered reflected component due to non-resonant part construction of patch and any attached delay line.

To achieve phases of reflected fields, a plot of the reflection phase versus the swept parameter value is done. This result in a curve named as phase design curve or normally called as S-shaped curve.

To understand, whether the reflectarray element design resonates at the frequency or not, static phase range performance is used. Using the Figure of Merit (FoM), static phase range performance comparison gives an observation of reflection phase curve slopes for different resonant elements. Figure of Merit is defined as the ratio of change in reflection phase to the change in the frequency [8]. Mathematically, it is written as,

$$\mathrm{FoM} = \frac{\Delta\text{Ø}}{\Delta \mathrm{f}} \left(\frac{{}^{\circ}}{\mathrm{MHz}}\right) \tag{1}$$

The present work uses infinite array approach method for analysing the unit cell element of Microstrip Reflectarray Antenna (MRA). Here rectangular shape patch (RP), Rectangular patch with rectangular slot (RS), rectangular patch with plus shape slot (PS) and rectangular patch with star shape slot (SS) are used as a unit cell element of MRA. Comparison of Figure of merit and static phase range has been done based on the reflection phase curve obtained. The analysis work has been carried out in Ansys High Frequency Structure Simulator (HFSS) software.

II. Reflection Phase Curve

The modeling and design of unit cell is carried out carefully for best performance of reflectarray. Method of Moments (MoM), Finite Element Method (FEM) and Finite Difference Time Domain (FTDT) are the numerical methods available for reflectarray design.

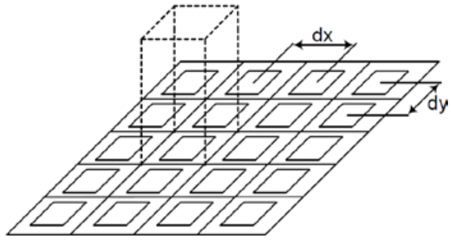
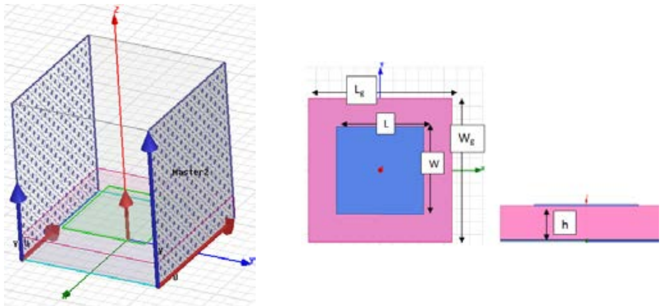


Fig 3. Unit Cell Treated As An Infinite Array.

An effective approach for characterization of reflectarray element is to use an infinite-array model. Floquet's mode is used to evaluate the reflectarray element. Thus overall analysis is reduced in a unit-cell environment. Figure 3 shows how a unit cell is treated as an infinite array. Phase difference between the Master and Slave boundaries is kept 0° as shown in Figure 4(a).



(a) (b)

Fig 4. Reflectarray Element with (a) Master and Slave Boundary (b) Unit Cell Dimensions

Here variable size microstrip patches were used in the reflectarray antenna design. The unit cell or resonant element was made up of a square metallic microstrip patch placed on to the substrate or dielectric material, backed by a ground plane, as shown in Figure 4(b). The height (h) of substrate is 1.6 mm (according to $0.003\,\lambda_0$ to 0.5) with dielectric constant $\varepsilon_r = 4$ (FR4 (epoxy resin)) and loss tangent of 0.02. The frequency of operation was 13.4 GHz. The Length (L and width (W of substrate and ground were fixed at 11.19 x 11.19 ($i.e. 0.5\,\lambda_0$ x $0.5\,\lambda_r$.

Based on the substrate specifications and dimensions, the guided wavelength (λ at 13.4 GHz was 11.06mm. Based on dielectric constant and thickness of the substrate, the element resonant length was 4.76mm. From Figure 5, it could be seen that this length corresponds to the 0° reflection phase on the S-curve, where patch length was varied from 1.7mm to 10 mm.

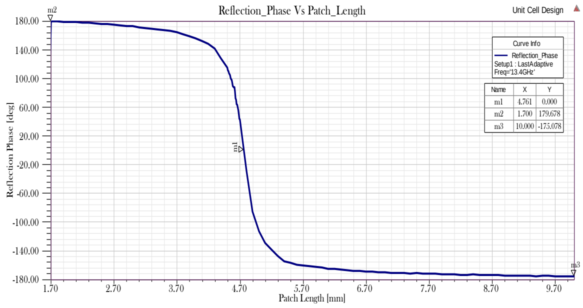
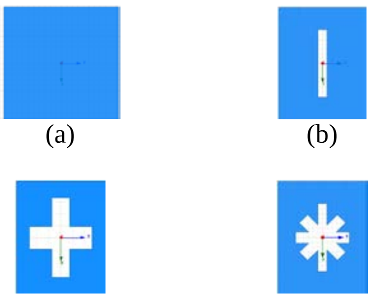


Fig 5. Reflection Phase Versus Patch Length (S - Curve)

III. Comparison of Different Shapes of Microstrip Patch Element

The research work consists of reflectivity and miniaturization performance of 4 different shapes of reflectarray resonant elements. Figure 6 shows the shapes of patch elements containing Rectangular Patch (RP), Rectangular Patch with slot (RS), Rectangular Patch with plus shape slot (PS) and Rectangular Patch with Star shape slot (SS).

According to the dimensions L x W of the resonant patches, the slots are made with the dimensions of 0.6L x 0.1W. Only the plus shape slots consist of 0.8L x 0.2W. The calculation of reflection area and volume necessitates the calculation of miniaturization of reflectarray antenna on the length, width and height of each individual resonant element.



(a) (b)

(c) (d)

Fig 6. Different Types of Configurations In Unit Cell of Reflectarray (a) Rectangular Patch (RP) (b) Rectangular Slot (RS) (c) Plus Shape Slot (PS) (d) Star Shape Slot (SS)

Reflection area and volume measurement for each resonant element has been calculated and given below in Table I. As depicted in Table I, patch element with the largest reflecting area of 17.31 mm^2 has been shown to exhibit no miniaturization. Introduction of slots into the Patch element according to its dimension gives reduction in the reflecting area and volume. This in turn increases the percentage of miniaturization of a reflectarray antenna. The patch with plus slot have very less reflection area as well as volume. The ratio of the patch with the plus slot were kept larger compared to the other shapes available due to the resonance of patch element at same frequency.

Table I: Reflection Phase Area and Volume of Different Reflectarray Resonant Elements

Resonant Element	Reflection Area $(mm)^2$	Reflection Volume $(mm)^3$.	Miniaturization (%)
RP	17.31	1.2117	--
RS	16.56	1.16	6
PS	11.98	0.838	32
SS	13.39	0.94	24

The reflection phase performance of different reflectarray resonant elements including patch with rectangular slot, patch, patch with plus shaped slot, patch with star shaped slot and star shape patch have been analyzed using Floquet's Port. Figure 7 shows the reflection phase curves for all the resonant elements. The results demonstrate that plus shape patch slot, which has lowest reflection area and volume gives smoother slope of reflection as compared to patch element.

Table II: Static Phase Range comparison and FoM Values for Different Reflectarray Element Shapes

Resonant Element	Figure of Merit FoM (°/MHz)	Static phase Range (°)
RP	0.136	102.19
RS	0.126	95.02
PS	0.140	140.2
SS	0.135	116.17

Table II summarizes the static phase range and Figure of Merit of the resonant elements under study. It has been observed that Rectangular patch element has FoM value of 0.146 °/MHz offers static phase range of 102.19° while rectangular patch with plus slot shaped patch with maximum FoM value of 0.140°/MHz is shown to give maximum static phase range of 140.2°.

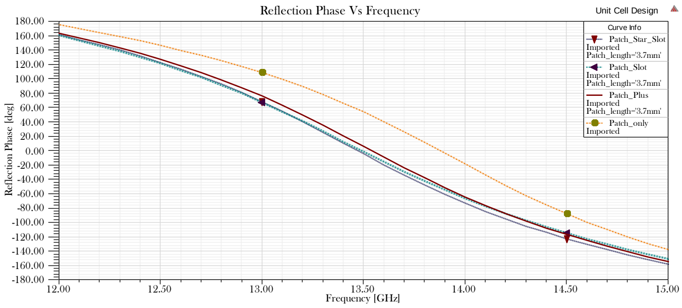


Fig 7. Reflection Phase curves of RP, RS, PS and SS.

I. CONCLUSIONS

FoM value increases with increase in the surface current density. This is due to the reflection phase curve gets smoother and greater value of static phase range over same frequency range.

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