Dual Layer Minkowski Radiating Shape for Reflectarray Antenna Design

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1. Introduction

The reflectarray combine the best features of both reflector and an array in that better performance especially in antenna gain which can be achieved without using complex and lossy corporate transmission line feed network. A reflectarray have many advantages that can be categorized into two points of view which are from electromagnetically and mechanically. From an electromagnetically perspective, they are high gain antennas, low side lobes, capable of beam steering, and from a mechanically perspective, they have lightweight structures, easy to fabricate and manufacture and also robust [1]. In contrast, the narrow band of the radiating elements and the non-constant path delay between reflectarray elements are the two major factors that causing a reflectarray antenna has narrow bandwidth [2].

The original reflectarray designed on single layer substrate was based on microstrip patches [3]. The problem using microstrip patches is that the microstrip patch is an inherently narrow band radiating element and several concepts has been attempted to overcome this setback for reflectarrays based on various configurations [4]. It has been shown that the DRA has a larger impedance bandwidth and higher radiating efficiency that microstrip patch antenna [5] and thus is a possible alternative. On the other hand, one of the setbacks of a single layer reflectarray is that the range of reflection phase curve doesn’t reached 360°. It has to have wider phase range as phase compensation in patch variation should be at least 360° [6] and better gradient (°/µm) especially around its resonance region as well as phase linearity. The choice of a double layer variable size element structure offers a smooth reflection phase curves over a range of up to 500° [7], the range unattainable with a single patch layer. Fig. 1 show the illuminating feed of the reflectarray.

In this work, a double layer microstrip element in the form of the first iteration of fractals, this is minkowski geometries and square patch are proposed to improve the bandwidth of a microstrip reflectarray. By adjusting the shape of the original square patch into a minkowski shape, a much wider reflection phase range compared to the conventional double layer reflectarray elements is achieved. These new double layer minkowski reflectarray elements are designed within X-band frequency range from 8.4 to 12.6 GHz in CST Microwave Studio. It has been specified to operate at frequency of 11 GHz.

2. Double Layer Unit Cell Reflectarray Design

The modification of common square patches into minkowski shape as radiating elements in reflectarray is introduced in this design. The choice of this geometry is to increase the reflection phase dynamic range exceeding 400 degree. Moreover, a multilayer periodic structure composed of two stacked arrays of minkowski patches on a grounded dielectric substrate is implemented to increase the phase dynamic range. In this paper, 3 designs configuration for a dual layer unit cell is presented two stacked arrays composed of 2 minkowski patches, two stacked arrays composed of 2 square patches and two stacked arrays composed of minkowski and square patches. The purpose of doing this is to compare their reflection phase curve and proving that the minkowski shape can enhance the phase range.

Fig. 2 shows the unit cell layout of all 3 proposed configuration of dual layer microstrip reflectarray. The two patch layers used 0.035 mm thick copper printed on a substrate with thickness, t = 1.524 mm; tangential loss, $tan\ \delta$ = 0.0018; and relative permittivity, ε_r = 3.54. As seen in Fig. 3, the dimension of each unit cell configuration is 11.43 x 10.16 mm because it is based on the existing or standard waveguide dimension; a = 22.86 mm and b = 10.16 mm. Such dimension is used to facilitate the comparison between simulation and measurement purposes, especially in the design stage because there is no requirement to construct another waveguide to be attached with the design unit cell.

3. Dual layer Unit Cell Simulation Modelling

An infinite periodic planar array was modeled, all 3 configuration of dual layer microstrip reflectarray antenna enclosed within the appropriate Perfect Magnetic Conductor (PMC) and Perfect Electric Conductor (PEC) boundary conditions as shown in Fig. 4 and the reflection phase for microstrip patch antenna of various lengths was observed. An incident wave polarized along z-axis is launched into this appropriately bounded waveguide. This setting is to make sure a unit cell of reflectarray will receive incidence energy from an illuminating feed just like a plane wave. Based on these simulations setting, parameter sweep has been conducted on the unit cell reflectarray and it has been specified to have a resonance frequency of 11 GHz. The geometry of resonant element patch is swept with a patch variation, ±20% from their dominant size which is n = 0.

The mesh cell of the design is determined prior, the simulation dual layer unit cell. Generally the default setting from the software is used in order to determine the mesh cell size of the structure. Since this parameter can give a major impact on the accuracy and speed of the simulation, the dual layer unit cell meshing size is determined by an adaptive mesh refinement in order to meet the simulation accuracy. This is important so that any further increment in mesh cell will not change the reflection phase response. Any factor or parameter which can lead to fabrication tolerance or failure in constructing the whole structure of the reflectarray should be taken seriously. Therefore, an adaptive mesh refinement should been taken into consideration before determine the reflection phase of the simulation unit cell model of a reflectarray.

4. Reflection Phase Characteristic Result and Discussion

Fig. 5 shows the comparison between all 3 proposed dual layer unit cell microstrip reflectarray of their simulated return loss characteristics. All 3 proposed structures have a patch size ratio of 0.8, meaning the patch size on the top layer was 0.8 times of the bottom layers closer to the ground plane. As can be seen from Fig. 5, all 3 proposed dual layer unit cell of reflectarray have resonant frequency band at 11 GHz with different reflection magnitudes and both have good return loss, therefore they can be considered as a good reflector as their reflection is more than 90%. Although the two stacked arrays composed of 2 square patches are shifted to right and demonstrates a double resonant in the figure, at reflection magnitude at 11 GHz is still higher than -3dB which still can be considered an acceptable reflector.

Fig. 6 shows the reflection phase variation curve for the dual layer unit cell with different radiating element shape configuration. It can be seen that the two stacked arrays composed of 2 minkowski patches demonstrated a smooth reflection phase curves over a range of up to 450°, whereas the configuration of two stacked arrays composed of 2 square patches and two stacked arrays composed of minkowski and square patches showed a reflection phase within the range of 360 to 380 degree. It is evident that the introduction of the minkowski shape as a radiating element for a reflectarray has significantly increased the range of the achievable phase. It is important to have wider reflection phase range in designing a reflectarray. This because having a reflection phase less than 360° will cause some of the position on the structure of the reflectarray does not occupy any radiating element.

5. Conclusion

A new first iteration fractals shape knows as minkowski have been introduced as a radiating element for a unit cell of dual layer reflectarray antenna. From the simulated reflection phase curve results, it can be observed that by stacking minkowski shape on two separate layers, the phase range is 460 degree compare to stacking square patch is only 380 degree. The result has proven that by using the simulated reflection phase curve obtained, a full occupied radiating elements array is achievable in constructing the whole reflectarray.

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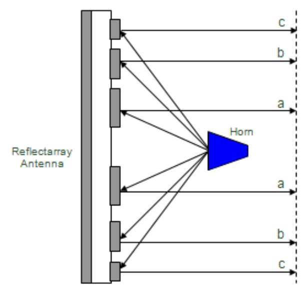

Figure 1: Reflectarray Geometry

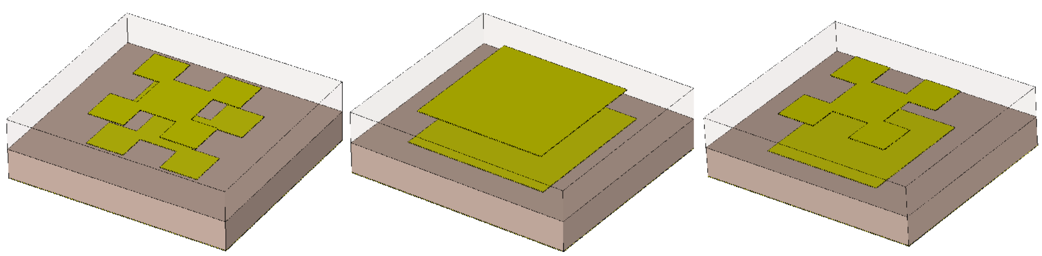

Figure 2: Dual Layer Unit Cell with Different Radiating Element Shape

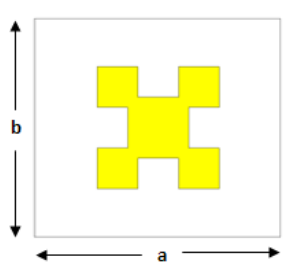

Figure 3: Unit Cell Dimension

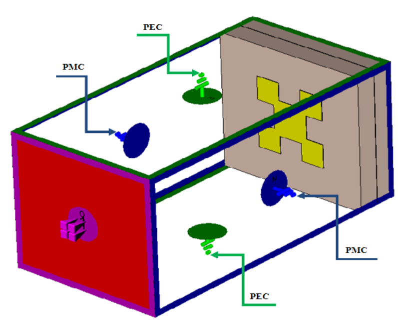

Figure 4: Boundary condition for simulation setup

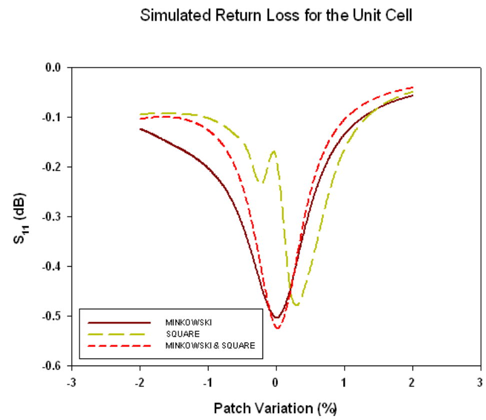

Figure 5: Simulated Return Loss

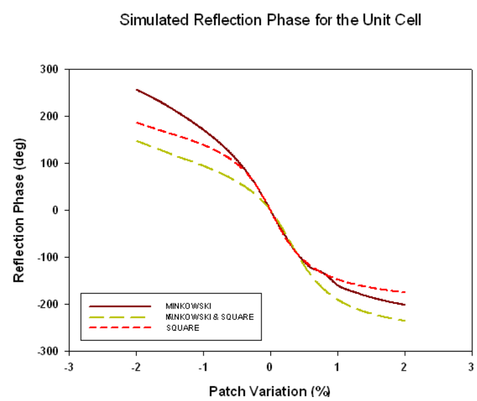

Figure 6: Simulated Reflection Phase

References

[1] D.M. Pozar, S.D. Targonski, and H.D. Syrigos, "Design of Millimeter Wave Microstrip Reflectarrays", IEEE Transaction on Antennas and Propagation, Vol. 45, No. 2, Feb. 1997.

[2] E. Carrasco, J.A. Encinar, and M. Barba, "Bandwidth Improvement in Large Reflectarrays by Using True-Time Delay", IEEE Transaction on Antennas and Propagation, Vol. 56, No. 8, Aug. 2008.

[3] A C.S. Malagisi. "Microstrip Disc Element Reflectarray", Electronics and Aerospace Systems Convention, September, 1978.

[4] J. Huang, "Bandwidth study of microstrip reflectarray and a novel phased reflectarray concept", IEEE International Antenna and Propagation Symposium Digest, pp. 582-585, 1995.

[5] R.K. Mongia, P. Bhartia, "Dielectric Resonator Antennas - A Review and General Design Relations for Resonant Frequency and Bandwidth," International. Journal of Microwaves and Millimeter-Wave Computer-Aided Engineering", Vol. 4, No. 3, pp. 230 - 247, 1994.

[6] E. Carrasco, M. Barba, and J.A. Encinar, "Reflectarray Element Based on Aperture-Coupled Patches with Slots and Lines of Variable Length", IEEE Transaction on Antennas and Propagation, Vol. 55, No. 3, March 2007.

[7]K. Y. Sze and L. Shafal, "Analysis of Phase Variation due to Varying Patch Length in a Microstrip Reflectarray", Antenna and Propagation Society International Symposium, pp. 1134-1137 Jun. 1998.