Heuristic approach of Finite Grounded Frequency Selective Surface Arrays characterization in W-band

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We present the design, processing and testing of W-band finite Grounded Frequency Selective Surface (FSS). With commercial software CADs, infinite arrays can only be simulated but for FSS design there is a need for design of finite arrays. As the simulations couldn't provide direct insight into the relevant physics, we heuristically investigated designs with intermediate complexity: from infinite array towards the finite arrays, finding out the effects of finiteness and effects of array elements on the results. We fabricated the corresponding FSS arrays on quartz substrate with etching techniques, and characterized the vector S-parameters with a free space MVNA.

Introduction

Frequency Selective Surfaces (FSS) are predominantly passive electromagnetic filters formed by thin conducting elements on a dielectric substrate or periodic aperture elements in a conducting sheet [1]. Typically the analyses of FSS and other planar periodic structures are carried out under the assumption that they are infinite in extent, even though the dimensions of practical FSS structures are necessarily finite. A number of methods, e.g., mode matching, the moment method [2]-[6], the spectral-Galerkin approach [7], and certain approximate methods, are available for analyzing infinite periodic structures. All of these methods are based on a Floquet-type representation of the fields in a unit cell, whose dimensions are typically on the order of a wavelength. However, none of these techniques allow convenient extension to the more practical geometry, which comprises a large, but finite, number of array cells.

Except under the approximation that edge effects are negligible, the analysis of the finite structure cannot be simplified by invoking periodicity, and it becomes necessary to work with a large number of unknowns, often on the order of a few thousand, in order to derive an accurate solution to the finite FSS problem [8]. Matrix methods are clearly not suited for handling such problems owing to the fact that they require prohibitively large storage on the computer.

The design and development of finite antenna array is complex and costly. To reduce design costs and design risks, and to improve the performance of the arrays, simulations should meet a number of criteria: they should be fast executable, they should show boundary effects and effects of mutual coupling, and they should determine the antenna performance parameters accurately [9]. Simulations based on the generally applied infinite-array approach and simulations based on the finite-element method do not satisfy these criteria. Simulations of the first type do not describe boundary effects, while simulations of the second type are computationally too expensive. Both types of simulations do not provide direct insight into the physics relevant to the designs. Analysis of FSS is very crucial for both design and application engineers. However, Computer Aided Design (CADs) can only deal with antenna arrays with infinitely periodic boundary conditions. Hence there is a need for the development of a heuristic experimental approach to develop design skills as long as the CADs programs do not allow for finite antenna array designs. The approach provides insight into array characteristics. In this study we checked how the finite antenna array behaves with respect to the infinite array. Our contribution in this paper is to the design process which specifically focused on the finite and semi-infinite FSS arrays. On the basis of experimental results, we wanted to find characteristics that describe the (qualitative) behavior of such antenna arrays. In particular, we wanted to find characteristics which eventually will give the opportunity to check the finiteness behavior of array.

FSS Design Consideration

The simulations of the FSS unit cells of infinite array were carried out utilizing commercial CST MICROWAVE STUDIO®. The design was optimized to get the optimum unit cell dimensions to A=B=1250 µm as shown in Fig.2 (a). The boundary conditions were chosen to be E_t=0 to the perpendicular direction of the slots and H_t=0 is along the parallel plane of the slots. Open boundary and perfect electric wall (i.e. E_t=0) were chosen in the front side and the rear side of the antenna respectively.

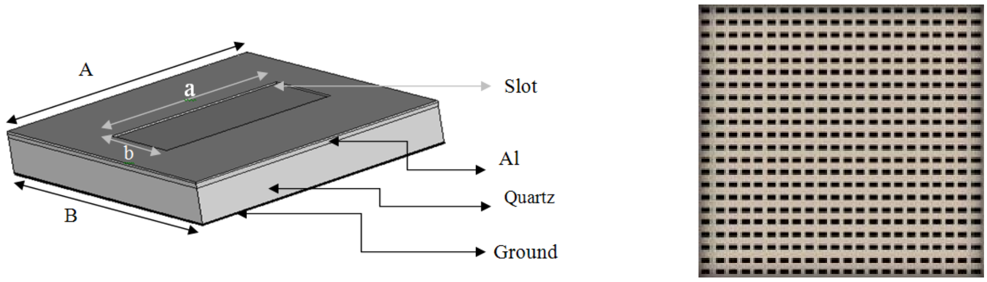

Fig.2:Infinite FSS array : (a) Unit cell configuration of Grounded FSS : (b) Infinite×Infinite Grounded FSS array

Semi -Infinite arrays

Instead of modeling a rectangular uniform slot array as being infinite in length and width direction, the array is modeled as being infinite in one direction and finite in the other direction. In that case, only a single row of element in the finite direction needs to be considered. In Fig.3 (a) and 3(b) semi-infinite (half-infinite-by-infinite) array designs are shown. The semi-infinite array solution is based on the assumption of infinite array plus addition of a few edge elements. The main objectives in the development of our analysis approach are: Given that the infinite-array approach is most frequently used, to show in what way and to what extent our approach improves the infinite-array approach.

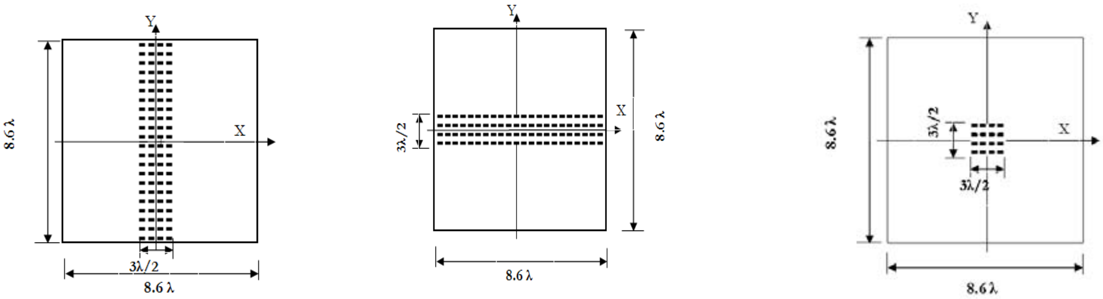

Fig.3: A 8.6λ ×8.6λ Unit cell with Finite FSS array.: (a) *finite ×Infinite array* with 88 (e.g. 4×22) slots (b) *Infinite ×Finite array configuration with 88* ((e.g. 22×4) slots *(c) finite ×finite array with 16* (e.g. 4×4) slots. (White arrea in the array indicates metal and black dots are slots).

Finite array

In this case the modeling is with rectangular uniform array as being finite both in length and width direction as shown in Fig.3(c). In this case, double rows of elements in the finite direction needs to be considered. The similar unit cell of infinite FSS is used in this case. The currents in this case will be the currents on both edge elements and the assumption that the currents on the infinite array equal the infinite-array solution.

Fabrication

The FSS arrays were fabricated on a grounded quartz substrate. The basic Unit cell of the arrays is shown in Fig. 2(a). The slots (width: 400µm, length: 786µm) are etched in Aluminum on the quartz substrate (relative permittivity: 3.78, loss tangent: 0.0001, thickness: 800µm). Slot length (786µm) is chosen so that the resonant frequency is approximately at 85.5GHz. An anti-reflective chrome coating was applied on the mask before process. The maximum defect size allowed on the mask(s) before the device is adversely affected is 5µm.The maximum number of allowable defect per square inch was 2. The minimum feature size (i.e. critical dimension) we measured and controlled in the fabrication process was 5.0µm. All the antennas considered here were processed on the same wafer to avoid the relative processing error between antennas.

Results

As mentioned before, many cases have been measured. It is both unnecessary and formidable to show all results here. The MVNA measurement results show Good agreement with the theories as shown in Fig.4. The measured reflection coefficients decreases as the antenna arrays are decreases and after a certain value the reflection again increases. The bandwidth of Infinite FSS array is the W-band. The reflection amplitudes of semi infinite arrays are the balancing weight reflection from the effective antenna/ metal area. The finite × infinite array shows higher attenuation than infinite x finite antenna of same number of element. As the antenna size reduces from infinite towards finite, the resonant frequency shifting and attenuation increases then again decreases in the case of finite × finite array. Fig.5 (a) shows the attenuation of different arrays. We see the resonance frequency of 22×22 array is same that of 22×4 array and that of 4×22 array is same of 4×4 array. However we investigated that the infinite × finite array shows 1˚ downward resonant frequency shifting in compare to infinite × infinite array. Our investigation concludes that the resonant frequency of the finite array is determined by the number of slots in the tangential electric field (i.e. E_t) direction.

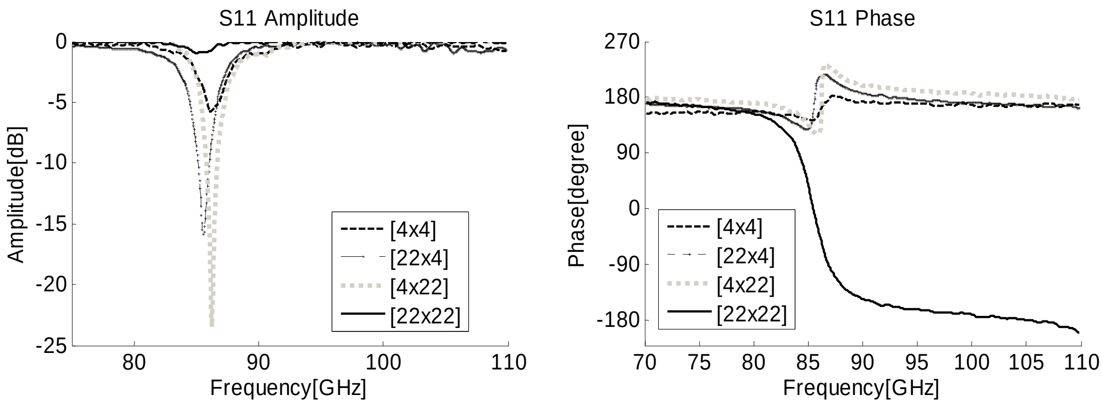

Fig.5: S parameters of different size FSS arrays (a) S11 Amplitudes (b) S11 Phases

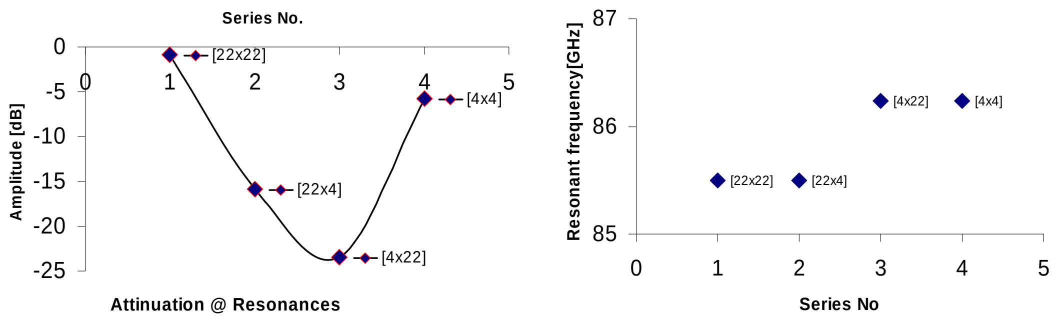

Fig.6: Effect of finite array size variation (a) Attenuations at resonant frequencies (b) resonance shifting

Conclusions

This study aimed at getting inside into the effects of finite array and finite beam size on the reflection characteristics of frequency selective surfaces. As the basic element we chose here grounded FSS. The experimental results clearly indicate the differences between infinite, semi-infinite and finite arrays. We have presented a clear view on the order of magnitudes change in amplitude and phase changes when the dimensions of the array changes from infinite towards finite. The reflection amplitudes and phases are the weighted balance between metal reflection and slot FSS reflection which also shows the interference effect.

Acknowledgments

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