Rectangular vs. Equilateral Triangular Lattice Comparison in a T-Slot Loaded Strongly Coupled Dipole Array

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Abstract

This work is focused on the impact of the array lattice in a strongly coupled dipole array. In order to study this, a wideband (6.2:1 BW ratio) dipole based array element was designed and used to compare lattice impact in our analysis. The element was designed using the unit cell analysis. In order to improve the bandwidth at the lower end of the frequency band the dipole was loaded with a T-slot increasing the electrical length. Based on this design a comparative analysis was conducted between rectangular and isosceles triangular lattices with respect to return loss, embedded element pattern and inter-element coupling. Emphasis was given to the analysis of the lattice comparison in the E-plane of the array as it is the most prone to variations with the array scanning.

1. Introduction

Wideband antenna arrays for wireless communication is a topic that has always attracted a lot of interest. The reason for considering antenna arrays for future commercial wireless communication systems is the expected massive increase in traffic over the next years. Furthermore, wireless base stations are envisioned to support all commercially available bands and through such a common interface leading to cost reduction since fewer base stations will be needed. Such solutions are also expected to offer advanced coverage characteristics, like dedicated user beams employing the technique of SDMA (Space Division Multiple Access). This generates the need for a wideband scanning antenna array suitable for base station applications.

Strongly coupled elements is a concept that steams from Wheeler's idea of continuous current sheet [1] and it has developed into two major wideband antenna array technologies: the capacitivly coupled dipoles, [2], and connected dipoles/slots, [3]. In our previous studies, we have investigated the inter-element coupling, [4], to enhance bandwidth performance and edge elements optimization [5], in order to compensate truncation effects at the edge elements. It has been shown that strongly coupled elements are able to provide wideband (5:1) performance while keeping a relatively low profile ($d \approx \lambda_{high\ freq}/2.5$ - $\lambda_{high\ freq}/3$, d is the distance from the ground plane to the radiating structure), thus it is an attractive approach with the possibility for communication applications. Recently, a general measure of the performance of planar arrays backed by a metallic reflector was derived: the *array figure of merit*, [6]. It provides the possibility to connect physical and electrical characteristics that result in a measure of the array's performance. In its simple form contains the distance (d) from the ground plane as the main physical characteristic which is the limiting factor of unidirectional planar arrays.

In this study, the focus is on the impact of the lattice in strongly coupled dipole arrays. Primarily, a modified unit cell element is designed and a numerical study is performed for the rectangular and triangular grid, comparing the behavior of the active reflection coefficient, the embedded element pattern and the inter-element coupling for the adjacent horizontal, vertical and diagonal element in the array.

2. Unit Cell Analysis and Design

The geometry of the unit cell design of closely spaced dipoles is depicted in Fig. 1.i-iii. The dipole has been capacitivly loaded with the small inter-element gap $2 \cdot \delta$, where δ=0.6 mm, and an additional parallel parasitic patch in the back of the dipole between the arms. The small gap in between the elements significantly increases the inter-element coupling between the adjacent dipole arms. The capacitive loading of the dipole is depicted as schematic in Fig. 1.iv. The latter is required to counteract the inductive behavior of the ground plane as is indicated in [2,4]. Furthermore the height between the dipoles and the ground plane is chosen to be $\lambda_{high\ freq}/2.5$ in order to avoid a zero in the broadside direction at the high end of the frequency band. Also, in order to increase the bandwidth towards the lower end of the frequency band we have loaded the dipole arms with a T-slot increasing the current path. The effect of the T-slot can be seen in Fig. 1.vi where the active reflection coefficient of the unit cell is depicted. We can observe that the T-slot improves by 300MHz the lower end of the frequency band for the operational limit of the return loss of 10dB. The

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dipole is fed by a balanced co-planar strip line (s=0.3mm C_l=2mm) which is tapered to a wide microstrip line (w=11mm, l=9.52mm). For the T-slot the dimensions are: w_{T1}=2mm, w_{T2}=2mm and T_l=8mm. The unit cell dimensions are chosen d=$\lambda_{high\ freq}/2$ in order to be below at the grading lobe limit for the fundamental Floquet mode. The dipole is designed in Rogers RO4003 (ε_r=3.55, tanδ=0.0027 & h=1.52 mm) printed circuit board (PCB). Finally, the dipole is loaded with a WAIM (Wide Angle Impedance Matching) layer (ε_r=2) that improves bandwidth and scanning performance. The feeding of the array element will be completed with a commercial BalUn / 4:1 impedance transformer from an unbalanced CPW (Co-Planar Waveguide) to a balanced CPS (Co-Planar Strips) line.

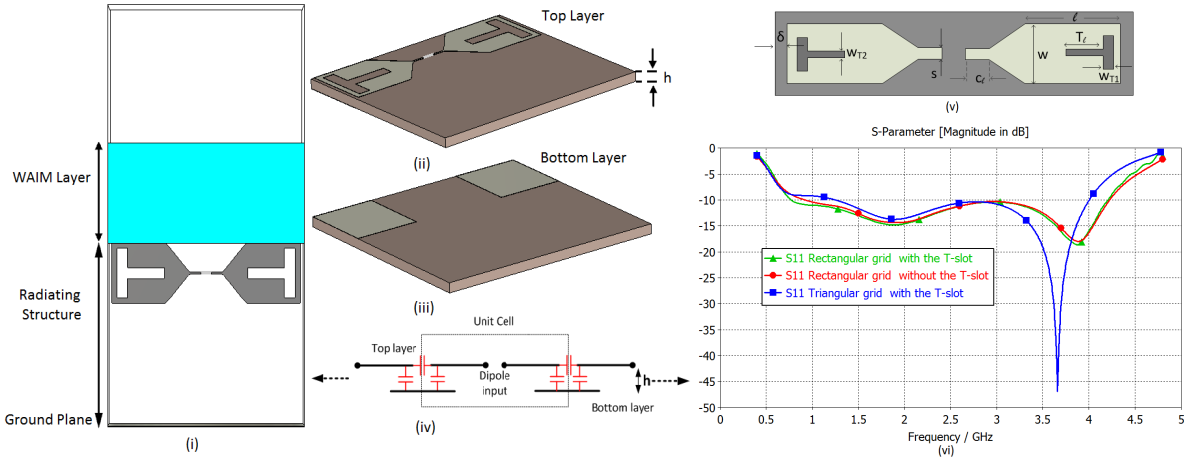

Fig. 1. (i) Array unit cell with T-slot loaded dipole and WAIM (ii) Top layer (iii) Bottom Layer (iv) Capacive dipole loading (v) Element with corresponding dimensional variables (vi) Active reflection coefficient comparison for the rectangular grid with and without the T-slot and the triangular grid.

3. Comparative Study

In this section the comparative study between the rectangular and triangular array lattice is performed. The schematic representation of the lattices can be seen in Fig. 2, where the x-direction is the E-plane and y-direction is the H-plane of the array. The comparison is with respect to reflection coefficient performance, embedded element pattern for E- and H-plane and coupling between the adjacent vertical (B), diagonal (C) and horizontal elements (D) according to Fig.2. For the inter-element coupling two (one for each grid) 7×7 arrays where studied by exciting the central element. The coupling of the elements is important as it is taken into account in the active reflection coefficient.

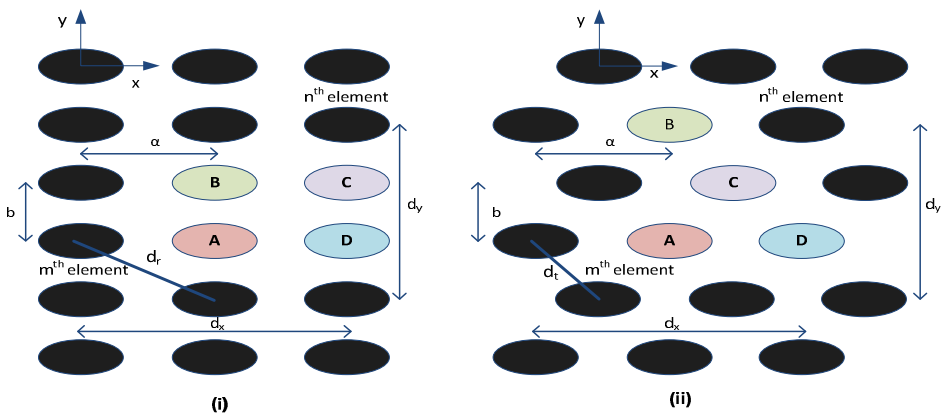

Fig. 2. (i) Rectangular grid (ii) Triangular grid.

The active reflection coefficient $\Gamma(\psi_x,\psi_y)$ of the unit cell takes into account all coupling phenomena that occur in the array. For a given planar lattice under fundamental Floquet excitation is given as in [7]:

$$\Gamma(\psi_x,\psi_y)=\sum_{n=-\infty}^{\infty} S_{mn}\exp\left[-j\left(\frac{d_x(m,n)\psi_x}{a}+\frac{d_y(m,n)\psi_x}{b}\right)\right] \tag{1}$$

where all scattering parameters S_{mn} contribute to the final active reflection coefficient. The spatial parameters of the active reflection coefficient are with respect to the Fig. 2. In detail, ψ_x and ψ_y are the phase differences between the adjacent elements, in our case $\alpha = b$ and $d_x(m,n)$, $d_y(m,n)$ are the relative distances along the x and y direction between the mth and nth element as depicted in Fig. 2. Based on the $\Gamma(\psi_x,\psi_y)$ analysis we expect lower vertical coupling in the triangular lattice. It is clear that in the triangular grid the diagonal distance is smaller whereas the vertical distance is significantly larger when compared to the rectangular grid. The vertical distance is the same in both cases. This results in an improved scanning volume as the spatial sampling of all elements is the same in triangular lattices. Thus triangular lattices offer better element packing resulting in denser arrays. All simulations for the present analysis have been carried out in CST Microwave Studio [8].

Primarily it is important to study the return loss performance with respect to scan angle. It is expected that as the array is scanned away from broadside the return loss will vary and the operational bandwidth will be shrinked. In Fig. 3 the VSWR performance for the comparison between the rectangular and equilateral triangular lattice is depicted. Since, in dipole arrays the E-plane is more sensitive to variations with scanning the focus is directed towards the E-plane scan performance. In Fig 3.i-ii the E-plane scanning performance can be seen. We observe that equilateral triangular grids have smother variations compered to rectangular and in 60° better performance can be achieved. The comparison in D- and H-plane when the array is scanned towards 45° depicted in Fig. iii and in each case yields in no significant variation.

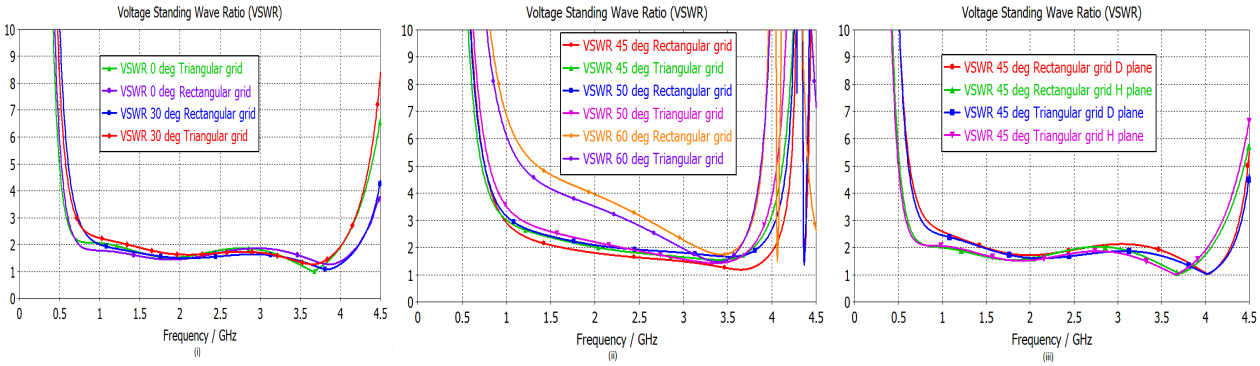

Fig. 3. VSWR performance for rectangular and triangular grid at E-, H- and D-planes.

In Fig. 4 the normalized gain embedded element pattern is depicted for E- and H-plane in rectangular and triangular grid. In the visible area at the E-plane the triangular grid performs better as is has an almost flat behavior whereas in the rectangular grid decays faster. On the other hand with the triangular lattice we have a significantly smaller visible area. No significant variations are observed for the H-plane.

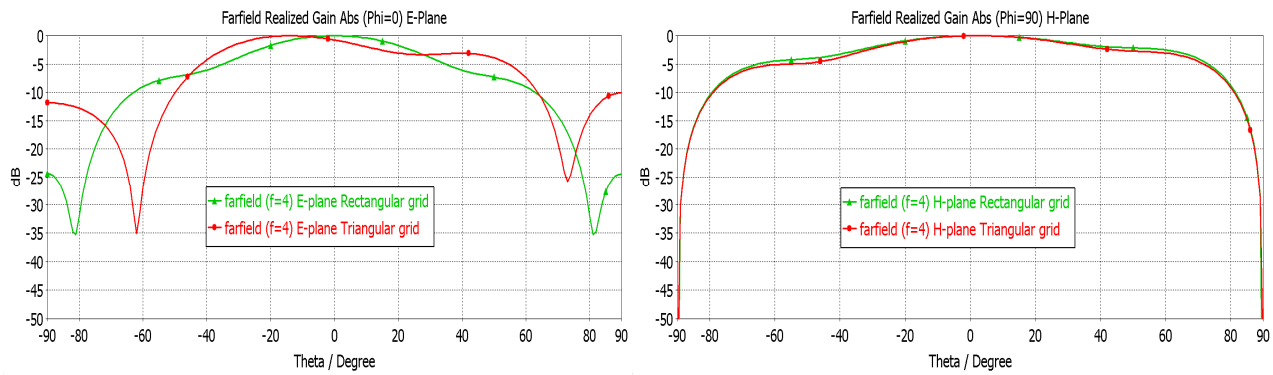

Fig. 4. Embedded element pattern comparison for rectangular and triangular grid for E- and H-plane for f=4GHz.

Finally, a comparison of coupling coefficients between adjacent elements for the two grids is depicted in Fig. 5. This analysis is based on two (one for each grid) 7×7 arrays by exciting the central element and studying the coupling coefficients for the two grids. As expected, the A to D coupling, S_{AD}, behaves similarly with frequency with a variation in the high end of the frequency band. The coupling coefficient for the diagonal behavior for the triangular lattice S_{AC} is more stable for most of the frequency band and with similar amplitude levels as the rectangular grid. The triangular vertical coupling coefficient S_{AB} has significant decreased amplitude for most of the band as expected whereas

approaches the rectangular grid levels at the high end band. The deeps for vertical and diagonal coupling coefficients at the upper band need to further be investigated.

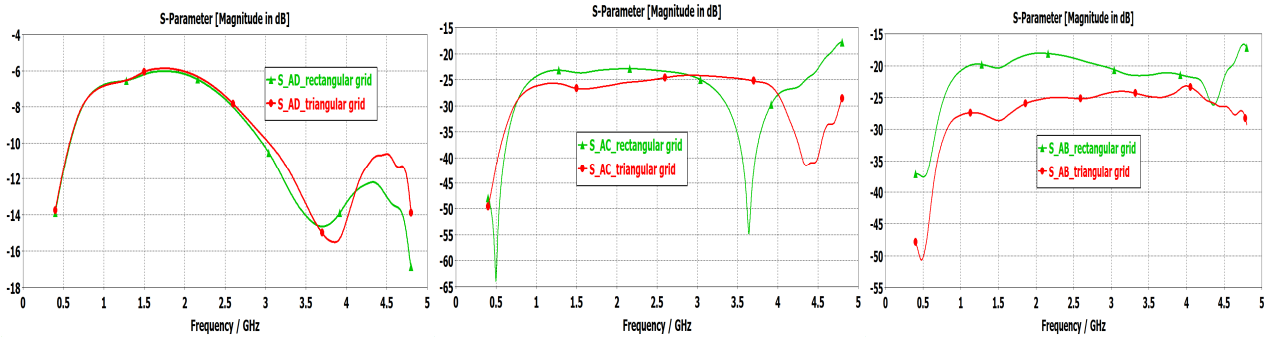

Fig. 5. Coupling coefficients between A, B, C, D for rectangular and triangular grid for the S_{AD}, S_{AC} and S_{AB}, see Fig. 2.

4. Conclusion

The impact of the array lattice of a strongly coupled dipole element is studied in this work. Initially a T-slot loaded dipole was designed with improved return loss performance in the lower end of the band. This element was then used in a rectangular and an equilateral triangular grid. The performance of the two grids was studied and compared in terms of VSWR, embedded element pattern and coupling between adjacent elements in two 7×7 arrays. The study showed a small improved scanning performance at the E-plane of the array where the operational bandwidth for the 10dB return loss limit was improved by 10% at 60°. Further improvement is expected if the element is optimized for the triangular during the design procedure.

5. Acknowledgments

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