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# Characterization of a Linear-Structured Meta-Antenna

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***Authors' contributions***

*This work was carried out in collaboration between all authors. Author DTTT designed the study and wrote the first draft of the manuscript. Author NVH performed the modeling. Authors NKT and NDT performed the analysis and wrote the final version of the manuscript. All authors read and approved the final manuscript.*

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## ABSTRACT

We studied the relationship between the output characteristics of the meta-antenna and the structure of its surface to search for a correlation between the structure and antenna's outputs in different frequency regions. We showed that the resonance characteristics varied on the size of the unit cells but depended almost linearly on the distance between them.

*Keywords: Meta; materials; antenna; microwave; finite-elements; loss.*

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## 1. INTRODUCTION

The antenna is a common electrical device, which exhibits with many structures, shapes and sizes [1]. In general, the antenna is a bi-directional device which can transfer or receive the information in forms of micro-currents or electromagnetic waves. The working frequency region of a given antenna depends on its geometrical parameters such as size, shape, and surface structure… In the microwave region, the antenna that consists of a modified surface of the meta-materials can lead to enhancement of performance, wide band-width while reducing its size [2]. By varying the meta-structure of the surface, the resonance characteristics of antenna, such as its resonance frequency, response coefficients (loss, gain) change accordingly [3,4,5-7]. In recent years, techniques were developed towards the fabrication of highly efficient antennas of micrometer size for direct electro-optical conversion [8]. In this study the characteristics of a planar antenna consisted of small square metal pillars that were placed periodically on the surface are demonstrated. It was showed that the response loss varies nonlinearly with the size of the pillars, but its dependence on the pillar distance is almost linear.

## 2. MODELING METHODS

To simulate the operation of a meta-antenna the finite-element method which is utilized in a computational software package HFSS (High Frequency Structure Simulator) was used [9]. The fundamentals of finite-element method are given in Ref [10]. The HFSS package allows to model the antenna with a so-called "full-wave adaptive meshing technique" to find a solution for 3D models of micrometer size [11].

The modeling began with a standard structured microwave antenna as given in Fig. 1. This antenna can actually be processed as a microstrip antenna. Its characteristic settings are as follows: a glass substrate of size 20x20 mm and thickness 100 μm with two copper faces of thickness (height) 3.5 μm; the two copper faces are of size 18x15 and 18x19 mm accordingly; the supply line cross section is 100 μm with a contact point area of 2x2 mm. This antenna works at 4.1 GHz with a return loss of -10.5 dB which is a typical value of this kind of antenna.

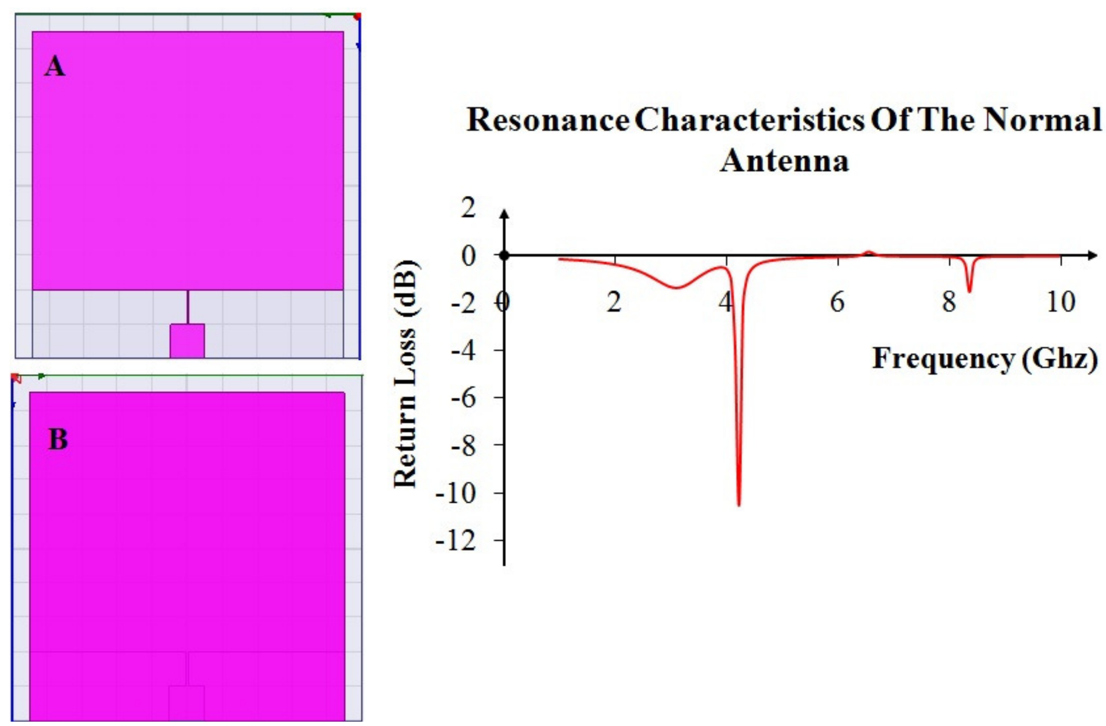


**Fig. 1. Structure and resonance characteristics of a sample microwave antenna. (A) The "active" upper and (B) the "ground" lower face**

On the basis of this standard sample, the upper face was split into the uniform square cells of the same size. The size was varied to determine the maximal number of disjoint cells that could be put onto the given area of surface. All cells were considered as the copper pillars with height of 3.5 μm. As the size of the pillars varied the corresponded losses were observed and the best case was selected for the investigation of dependence of responses on the inter-pillar distance. By the same manner, after the best distance was revealed, the maximal number of pillars that provided a best response was to determine. By this systematic approach the optimized surface structure for a planar meta-antenna was obtained. Unfortunately, the HFSS software cannot simulate the response of any antenna in the presence of secondary radiation field. The presence of this field may not induce a significant issue for the antennas working in the radio frequency regions, but the interferences in the higher frequency regions such as in the THz and infra-red or visible regions may be expected, as the plasmonic effect of absorption may arise if the pillar size become small enough [12].

## 3. RESULTS AND DISCUSSION

From the standard antenna shown in Fig. 1 the upper face was modified to consist of only one square unit cell whose size varied from $s$ = 1, 2, 3, to 10mm. The return loss diagrams are showed in Fig. 2 (with 1dB offsets between the lines for clarity). Because this antenna works as a standard microstrip antenna, the following formula for its frequency can be applied [13]:

$$f_r = \frac{c}{2L\sqrt{\varepsilon_r}} \qquad (1)$$

where $f_r$ is the frequency, $L$ the cell size, $c$ the velocity of light in vacuum and $\varepsilon_r$ the relative dielectric constant of glass substrate ($\varepsilon_r$ = 5).

As estimated from (1) some resonance frequencies appeared above 15 GHz for the cells with size $L$ < 5 mm, and they could not be showed in Fig. 2. From the size $L \geq 5$ mm we can clearly observe the high resonance frequency at around 12 GHz which is very close to the theoretical value of 13.4 GHz determined from Eq. (1). Both theory and simulation results showed that the resonance frequency decreased when the size of the cells increased. Fig. 2 also shows that at $L$ = 1 mm the basic resonance frequency peaked out at 6.1 GHz with -6.3 dB return loss. This is a best result that was obtained so the size $L$ was set fixed at 1 mm for the further optimization steps.

Next, the change in the cell distance was considered whereas the number of cells $n$ was fixed at 9. Eight antennas with the cell distances at 0.5, 1, 1.5, 2, 2.5, 3, 3.5, and 4mm respectively were modeled. The results are showed in Fig. 3 (offsets of 1dB were set between the lines for clarity).

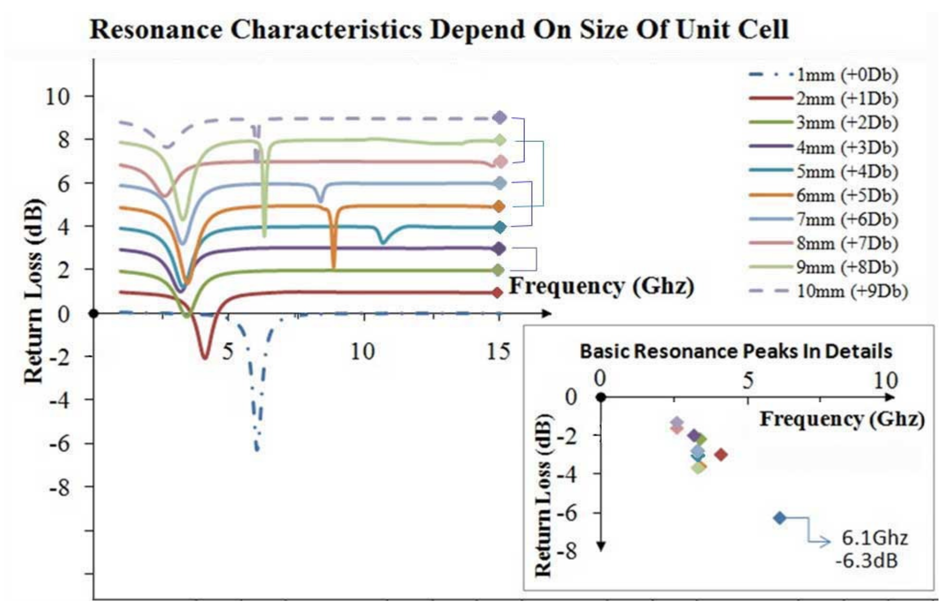


**Fig. 2. Dependence of resonance characteristics on cell size**

These results clearly demonstrate a strong dependence of resonance frequency on the cell distance. While the return loss at high frequency strongly increased, the ones at basic frequency decreased to smaller values, which fluctuated around –5dB. Especially, at the distance *d* = 4 mm, the return loss of the high frequency resonance at 6.6 GHz reach –22.8 dB. This result is very impressive for a standard structured microwave antenna. The return loss for the high frequency resonance of the distance of *d* = 0.5 mm (a small gap less than 0.1mm was considered between the cells) was good too (–13.4 dB at 13.5 GHz). The distance of *d* = 1.5 mm gave a worst return loss of –9.3dB.

Fig. 4 shows that when the distance between the pillars increased, the losses and frequencies (for both basic and high resonances) decreased. But while the frequencies appeared to scale linearly on distance, the losses did not follow the linear response, especially for the resonances in high frequency region.

Although the distance of *d* = *4* mm gave a best return loss in high frequency region, the utilization of this distance in the further simulation steps was not practically possible because of the fixed sample surface of 18x19mm. This limited area does not allow the large number of pillar cells. The purpose of choosing a fixed 18x19mm area is to maintain the antenna within the microwave region and simulation result applicable in the later step of fabrication. So we selected the pillar distance of *d* = 0.5 mm (which gave a good return loss of –13.4 dB, allow 0.1 mm gap between cells) for the next step. This *d* value also gave a more appropriate result in a low frequency region (3 ÷ 5 GHz, see Fig. 3) where the case *d* = *4* mm did not appear as a good choice.

To observe the dependence of resonance characteristics on the number of cells with size and distance determined in the previous sections, 7 antennas with different numbers of cell pillars as shown in Fig. 5 were simulated (allow 1dB offsets between the lines).

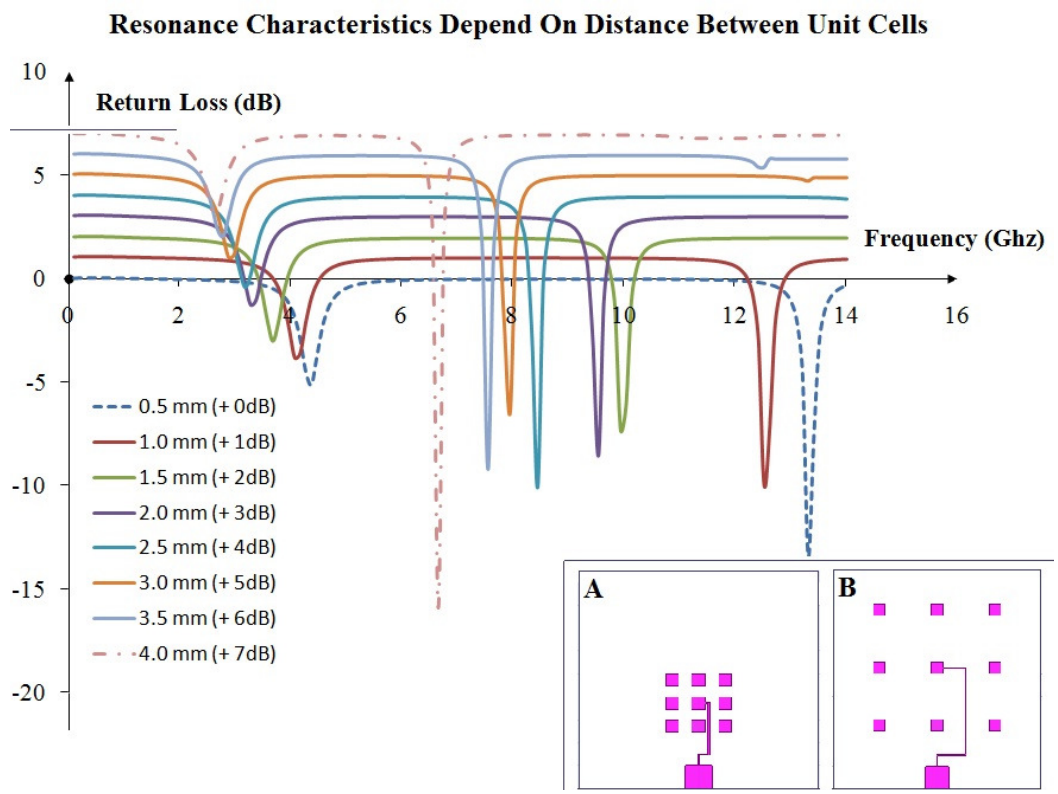


**Fig. 3. Dependence of resonance characteristics on cell distance: (A) Higher face of the meta-antenna with the cell distance *d* = 0.5 mm; (B) Higher face of the meta-antenna with the cell distance *d* = 4 mm**

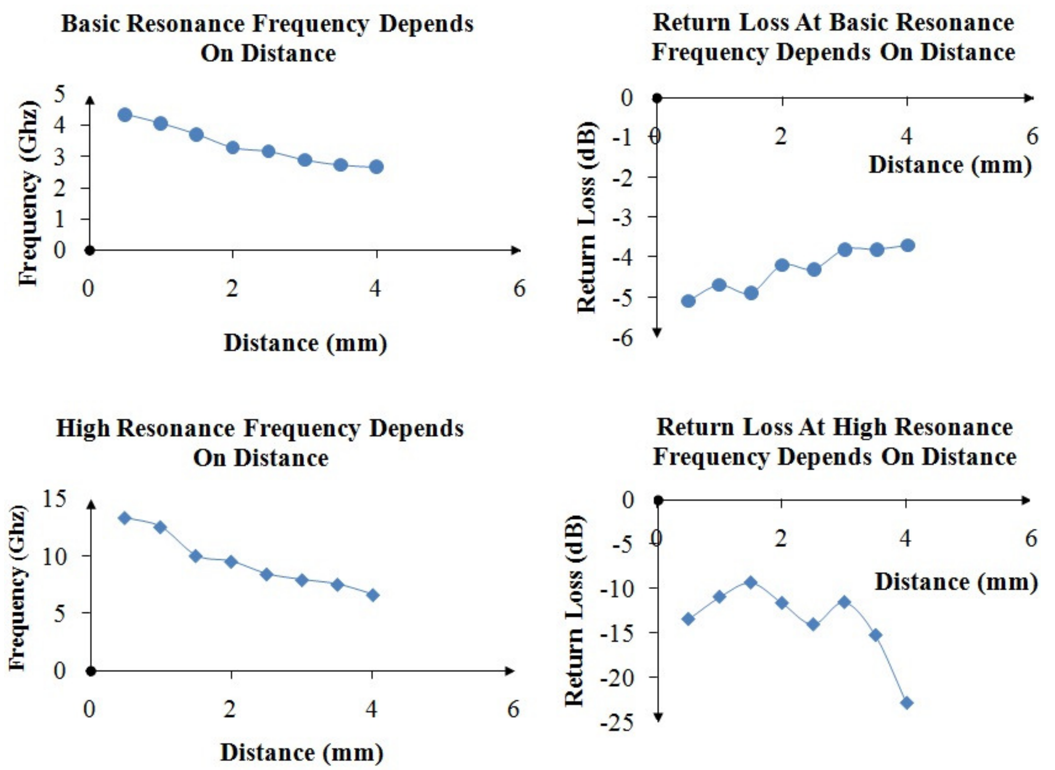


**Fig. 4. Dependences of high and basic resonances on cell distance *d***

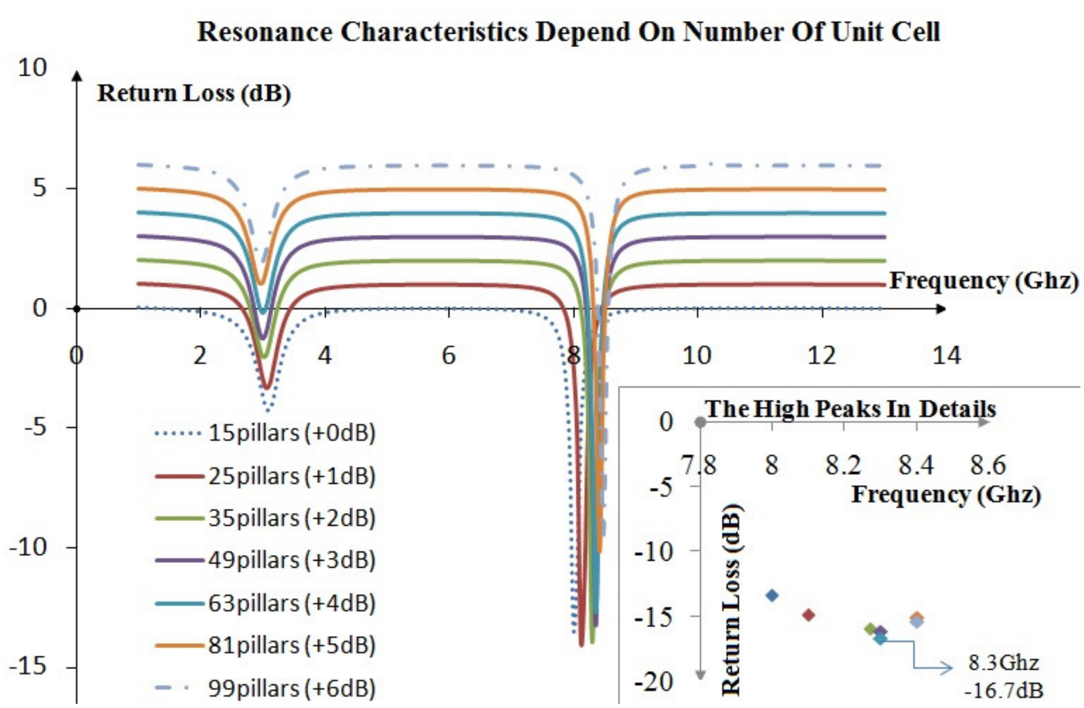


**Fig. 5. Dependences of resonance characteristics on cell number *n* of fixed size *s* = 1mm, height *h* = 3 μm and square-center distance *d* = 0.5 mm**

As seen, the changes were not significant for both resonance regions with the ones in the high frequency region more noticeable. The return loss reached a highest value when 63 cells were arranged (which was -16.7dB at 8.3GHz). This result is somehow surprising because one usually expect an increase of losses when the number of unit cells increased. Thus, for this structure of the meta-antenna, it is not preferable to increase the number $n$ of cells more than 63. A large number of cells will not induce a significant outcome.

The worsening of return loss may be associated with the possible secondary effects of re-absorption and high order scatterings of wave among the cells when the number of cells increased above a certain number (within a limited surface area), in this case, above $n$ = 63. To investigate such effects, the further study will be needed in the future.

## 4. CONCLUSION

For a meta-antenna that was derived from a standard structured microwave antenna, it has been showed that there were two resonance regions, one that appeared around 2.5 GHz and another around 8 GHz. Although the interference between these two modes was not considered in this stage, the obtained results clearly demonstrated that with the varying of cell size and distance between them, the frequency responses scaled almost linearly while the losses only peaked out at certain settings, particularly, at the size $s$ = 1mm and distance $d$ = 4 mm. Another interesting result was that the increase in the cell number $n$ did not have a significant effect on the responses. The corresponded loss appeared to be maximal for $n$ = 63, the further increase of $n$ decreased the outcome. The optimal set of values that offered a largest return loss at -22.8 dB was obtained for an antenna consisted of $n$ = 9 square pillar cells of size $s$ = 1mm and a center-to-center distance $d$ = 4 mm.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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