Reflection properties of mushroom-type surfaces with loaded vias

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Abstract

In this paper we study the reflection phase characteristics of mushroom-type surfaces with impedance loadings (as lumped loads) at the junction of vias and metallic elements (patches and ground plane). The analysis is carried out using the nonlocal homogenization model for the mushroom structure with a generalized additional boundary condition for loaded vias. It is observed that the reflection characteristics obtained with the homogenization model strongly depend on the type of the load (inductive or capacitive), and are in a good agreement with the full-wave simulation results.

1. Introduction

Since the introduction of mushroom electromagnetic bandgap (EBG) structure [1], hundreds of papers have been published exploring the theoretical challenges and practical realizations of such type of high-impedance surfaces (HIS) due to their widespread applications in antenna technology and metamaterials. Recently, efficient homogenization models have been developed which capture the physics of the plane-wave interaction and surface-wave and leaky-wave propagation on these structures [2, 3]. More recently, a generalized additional boundary condition (GABC) has been derived in a quasi-static approximation for the wire media by including arbitrary wire junctions with impedance loadings [4, 5]. The present paper focuses on the reflection phase characteristics of mushroom-type surfaces with vias connected to the metallic elements through lumped loads. The analysis is carried out using the nonlocal homogenization model with the GABC derived in [5] at the junction with impedance loadings.

2. Mushroom structure with loaded vias

The geometry of the mushroom structure with loaded vias is shown in Fig. 1 with the TM-polarized plane-wave incidence. The patch array is at the plane $z = 0$ and the vias are connected to the patches and the ground plane through lumped loads at the planes $z = 0$ and $z = -h$, respectively. The homogenization model for the analysis of reflection properties of the mushroom structure is based on the spatially-dispersive model for the wire media ([2] and references therein). The spatial dispersion effects in the vias are taken into account by considering that the field in the vias region is a superposition of three plane wave modes of the bulk wire media. Moreover, the nonlocal response of the wire medium is taken into account through the generalized additional boundary conditions at the connection of lumped loads

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to metallic elements (patches and ground plane) [5]:

$$\left[\frac{dI(z)}{dz} + \left(j\omega C Z_{\text{Load1}} + \frac{C}{C_{\text{patch}}}\right) I(z)\right]_{z=0} = 0 \tag{1}$$

$$\left[\frac{dI(z)}{dz} - \left(j\omega C Z_{\text{Load2}}\right) I(z)\right]_{z=-h} = 0, \tag{2}$$

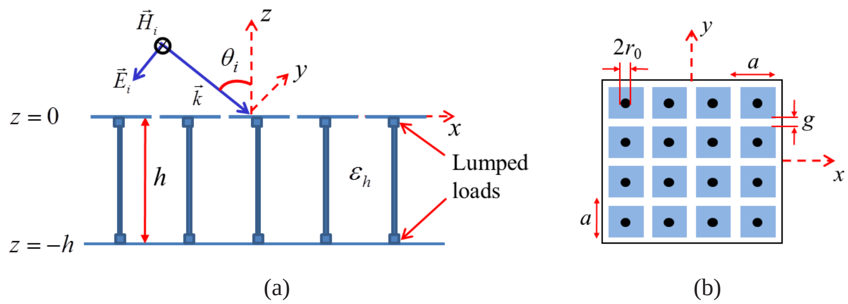

Fig. 1: Geometry of the mushroom structure with loaded vias illuminated by an obliquely incident TM-polarized plane wave: (a) Cross-section view and (b) top view.

where C is the capacitance per unit length of the wire medium, C_{patch} is the capacitance of the patch in a regular array of patches defined in [4], and $Z_{\text{Load1,2}}$ are the impedances of lumped loads. Since the insertion of loads in the wire introduces non-uniformity in the current and charge distributions, the correction terms described in terms of the parasitic capacitance C_{par} and parasitic inductance L_{par} should be taken into account in the above equations for load impedances [5],

$$Z_{\text{Load,eff1,2}} = j\omega L_{\text{par}} + \frac{1}{j\omega C_{\text{par}} + (1/Z_{\text{Load1,2}})}. \tag{3}$$

The reflection coefficient can now be obtained by matching the tangential components of the electric and magnetic fields at the air-patch interface by using the two-sided impedance boundary conditions, classical boundary condition at the ground plane, and the above GABC's Eqs. 1 and 2 at the connection of loaded vias to metallic elements. It should be noted that the homogenization model is valid for long wavelengths, i.e. provided the spacing between the wires is much smaller than the wavelength.

3. Results and discussion

Let us consider the case of the mushroom structure with the vias connected to the ground plane through lumped loads and a true short circuit (SC) at the via-to-patch connection. The dimensions of the structure (with the notations as shown in Fig. 1) are as follows: $\theta_i = 60°$, $\varepsilon_h = 10.2$, $a = 2$ mm, $g = 0.2$ mm, $r_0 = 0.05$ mm, and $h = 1$ mm. Fig. 2 (a) demonstrates the reflection phase characteristics for different loads (at the ground plane) as a function of frequency. The load is connected to the ground plane through a gap of 0.1 mm. By comparing the analytical results with the full-wave results using HFSS [6], it is estimated (by curve fitting) that the gap is characterized by the parasitic capacitance $C_{\text{par}} \approx 0.02$ pF and parasitic inductance $L_{\text{par}} \approx 0.06$ nH. It can be seen that the homogenization results are in a good agreement with the HFSS full-wave results. It is observed that for an increase in the inductive load, the resonance corresponding to the HIS shifts to the lower frequencies with a decrease in the plasma resonance. The case of the mushroom structure with the lumped loads at the via-to-patch connection and a true SC at the via-to-ground connection, results in the same reflection phase behaviour as seen in Fig. 2 (a). However, the results of the reflection phase behaviour for the loads at both the via-to-patch

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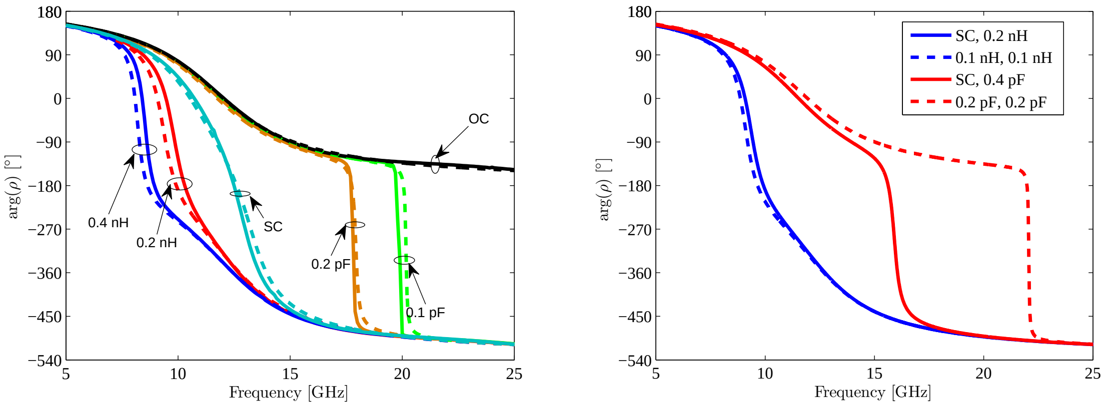
and via-to-ground plane connection differ in comparison with the equivalent load at the via-to-ground connection, as shown in Fig. 2 (b). The difference in the results is due to the presence of parasitic capacitance and parasitic inductance for lumped loads, which vanishes for the case of a true SC load.



(a) (b)

Fig. 2: Phase of the reflection coefficient as a function of frequency for the mushroom structure with loaded vias: (a) Loads at the via-to-ground connection. The dotted lines represent the analytical results and the solid lines correspond to the simulations results obtained using HFSS, and (b) loads at the via-to-patch and via-to-ground connection. The solid lines represent the analytical results for the loads at the ground plane and the dotted lines correspond to the loads at both the patch and the ground plane.

4. Conclusion

The reflection phase characteristics of the mushroom structure have been studied using the nonlocal homogenization model with generalized ABC's at the insertion of impedance loadings and are compared with the full-wave results. It is observed that the reflection phase depends strongly on the value and type (inductive or capacitive) of the load impedance. The proposed configuration based on lumped loads may enable to design more compact mushroom structures, and the described theory can be instrumental to model structures with either a tunable frequency response or nonlinear lumped elements.

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[6] HFSS: High Frequency Structure Stimulator based on Finite Element Method, Ansoft Corporation, http://www.ansoft.com.