Accuracy of homogenization models for finite high-impedance surfaces located in the proximity of a horizontal dipole

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Abstract

The accuracy of different homogenization models is analyzed in the case of a dipole antenna located very close to a finite high-impedance surface (HIS). In the different models, the periodic structure is replaced by a homogeneous boundary condition with different degrees of accuracy. It is shown that the expressions for the input impedance of HIS, that are used to compute the reflection phase diagram for normal incidence, do not provide the sufficient accuracy needed for this type of near-field problems. The accuracy of the homogenization model can be gradually improved by taking into account the spatially dispersive terms due to the grounded substrate and to the frequency-selective surface (FSS) grid. Further, it is shown that by accurately modeling the spatial dispersion in such HIS structures, one is able to reproduce correctly the presence of TE surface waves that play important role in the operation of a HIS-based antenna. Indeed, the bandwidth of the HIS-based antenna over which it presents a good return loss and broadside patterns can be extended by using the these surface waves propagating on the HIS favorably.

1. Introduction

The possibility to make a conformal horizontal dipole radiate efficiently with the use of a high-impedance ground plane was introduced by Sievenpiper et al. in [1]. From 1999 onwards, a large number of papers have been devoted to optimizing and modeling of antenna systems based on high-impedance surfaces(see, *e.g.*, [2]-[5]).

Many papers related to this subject employ simple homogenization models based on normal incidence approximations of the input impedance or reflection phase coefficient to explain the radiating mechanism or for defining qualitative design rules for the antenna system [2]-[3].Other homogenization models employing more accurate expressions of the HIS impedance [4] have been also presented, but all of them start from the initial hypothesis of infinite extent screen (see, *e.g.*, [5]). However, the size of the meta-surface plays a crucial role in defining the radiating properties of the system because of the surface waves propagating in a finite HIS that cause of additional resonances in the return loss profile [6], [7]. In this presentation the effect of TE surface waves excited by a dipole antenna in presence of a finite HIS is discussed, and we show that surface waves can be used to substantially enhance the bandwidth of the antenna. The emphasis of this paper is to study the accuracy of different homogenization models in describing this phenomenon.

2. TE surface wave resonances on HIS based antennas

A dipole antenna placed above a grounded patch array radiates efficiently in the vicinity of the HIS resonance. This radiation mechanism would be the only useful one if the high-impedance surface were infinite. However, in a realistic configuration, the finite size of the structure determines additional resonances in the s_{11} profile due to the propagation of, for instance, TE surface waves. Similarly to a classical resonant cavity [8], we can qualitatively determine the TE surface wave resonances of the

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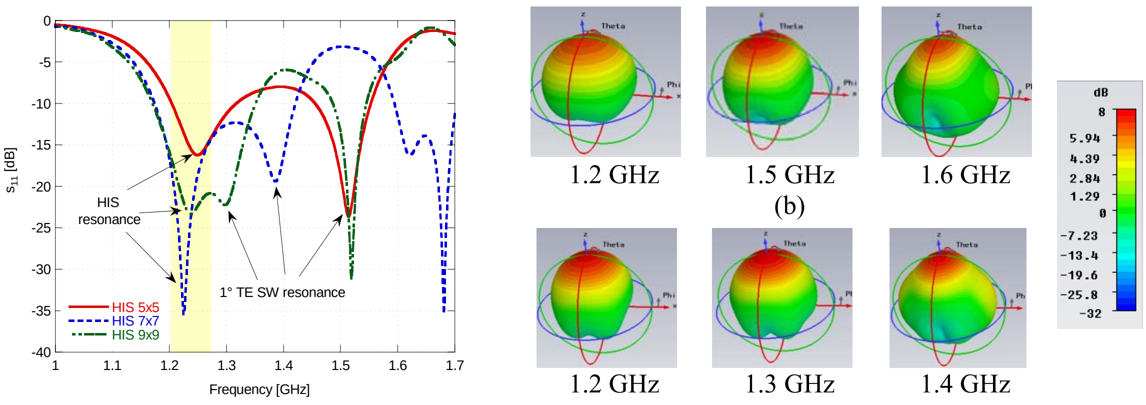

(a) (c)

Fig.1- (a) S_{11} of the dipole antenna on top of the same HIS with a different number of unit cells. Radiation patterns at different frequencies of the 5×5 (b) and for the 7×7 (c) structure

HIS from the dispersion diagram at the intersection between the TE mode curve and the vertical line representing the quantity $2\pi/l_{HIS}$ (l_{HIS} is the length of the HIS cavity). As an example, let us consider the antenna structure proposed in [9]. The s_{11} of the designed antenna (5 by 5 unit cells) is reported in Fig.1a together with the curves obtained for other dimensions of the HIS structure. For the 5×5 cells structure, the first TE surface wave resonance occurs at 1.56 GHz while larger sizes cause the first resonance to shift towards lower frequencies as predicted by the cavity representation. In Fig.1b and Fig.1c the radiation patterns of the 5×5 and the 7×7 radiating structure are shown at three different frequencies in the analyzed band. The 5×5 HIS antenna is characterized by rotationally symmetric radiation patterns in the range 1.2 GHz – 1.5 GHz. As soon as the electrical dimensions of the HIS become close to λ_{TE} (the TE surface wave wavelength), grating lobes appear in the *x*-direction of the radiation pattern. For the 7×7 structure, the degradation of the pattern starts at 1.4 GHz since the position of the first TE surface wave resonance is shifted.

3. Homogenization of the high-impedance surface

A high-impedance surface can be modeled by an averaged boundary condition. Since the amplitudes of evanescent modes launched by a source very close to the high-impedance surface are high, it is inappropriate to model the HIS surface with analytical expressions valid only for normal incidence [7]. The averaged surface impedance of a high-impedance surface can be represented as a parallel connection of the surface impedance of a grounded dielectric slab and the surface impedance of a capacitive grid [4]. Both of these impedances are angle dependent, *i.e.* they are spatially dispersive.

In order to highlight the dependence of the antenna behavior on the spatially dispersive terms of the input impedance, it is useful to compare the full-wave results of the actual structure with the ones obtained by using homogenized models with different degree of accuracy in the full-wave simulations. Basically, three different models can be used:

- The simplest approximation, which neglects the spatial dispersion completely. It will be referred to below as *non dispersive model*.
- An intermediate approximation, where the capacitive grid is replaced by a homogenized angle independent impedance sheet. The grounded dielectric slab is modeled in the simulation model without approximations. This model will be referred to as *partially dispersive*.
- The most accurate solution, where the FSS surface is represented by angular dependent surface impedance and the grounded dielectric slab is modeled in the simulation model without approximations. Since an impedance sheet with angular dependent impedance is inapplicable in HFSS simulator, an alternative dispersive approximation of the FSS as an anisotropic dielectric proposed by Clavijo et al. in [10] is adopted. The model will be referred to as *anisotropic dispersive*.

The dispersion diagrams of the previous models are compared in Fig.2a with the one obtained from the full-wave simulation of the actual structure by using Ansoft HFSS.

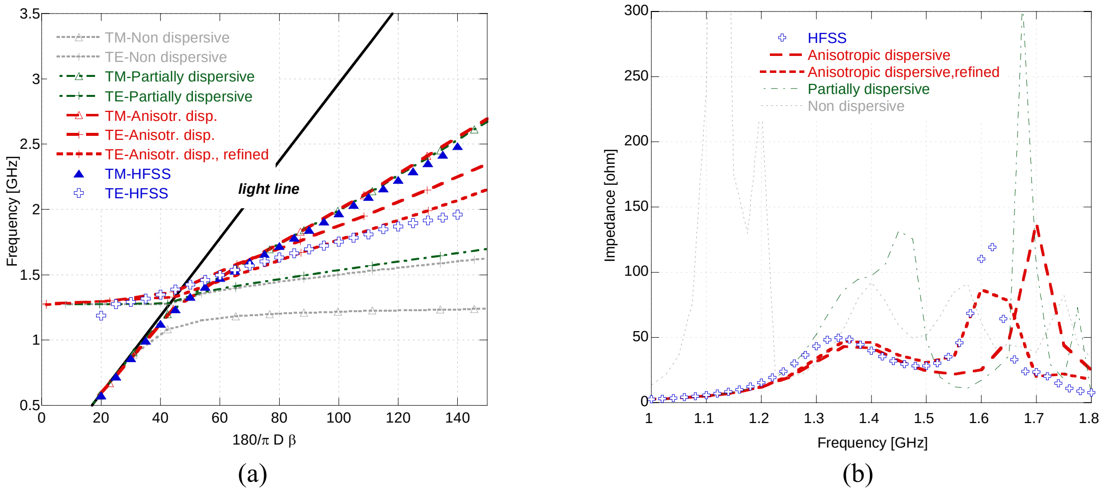

Fig.2 – (a) Dispersion diagram of the high impedance surface obtained by three different homogenized approximations and by full-wave approach. (b) Real part of the input impedance of a dipole over a 5 by 5 HIS obtained both by the aforementioned approximations and by the full-wave approach.

InFig.2b, the real part of the input impedance of a dipole antenna printed on a 5-mm thick dielectric substrate placed on top of the HIS is shown. It is apparent that the results of the two less accurate models are very different from the full wave ones due to the close vicinity of the dipole to the reactive surface. On the other hand, the *anisotropic dispersive* model turns out to have acceptable agreement with the full-wave simulations apart from a moderate frequency shift of the first TE surface wave resonance with respect to the full-wave model. The shift is towards higher frequencies since the slope of the TE surface wave propagation constant is overestimated. The small estimation error is due to the approximate calculation of the normal permeability of the FSS layer [10]. A refined model, where such a value has been empirically found in order to get the correct estimation of the TE surface wave propagation constant, guarantees a better agreement with the full-wave results.

4. Conclusion

Through a careful comparison between approximate and full-wave results of a benchmark antenna configuration, we have shown that the homogenized models which do not include spatial dispersion cannot adequately reproduce the presence of the TE surface wave resonances in HIS-based antennas.

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