Physics-Based Approach to Efficient Electromagnetic Modeling of Multiscale Antennas with Metasurfaces

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Abstract

This paper presents a novel 'physics-based' technique for numerically modeling of multi-scale problems, e.g., antennas with metasurfaces operating at mm wavelengths. The metasurface is replaced by an Equivalent Dielectric (ED) medium, whose use in the numerical simulation significantly reduces the computational resources required to model the problem. Furthermore, the proposed method is accurate and does not need sophisticated new code development but can be used in the existing commercially available software instead.

1 Introduction

Analytical techniques, though elegant, often have their limitations when we employ them to model electromagnetic problems that are of practical interest, and are not merely canonical geometries that are amenable to analysis by using conventional and well established analytical or asymptotic techniques, such as the Wiener-Hopf method [1] or the Geometrical Theory of Diffraction (GTD) [2] .And yet, often relying solely on numerical techniques is not a viable option either, from a practical point of view, because for certain type of geometries with multi-scale features can place a heavy burden on the CPU time and memory, with the simulation sometimes taking hours if not days depending upon the size and complexity of the problem. An example of such a problem is a metasurface screen placed above an antenna to enhance its performance, for instance, as shown in Fig.1 below.

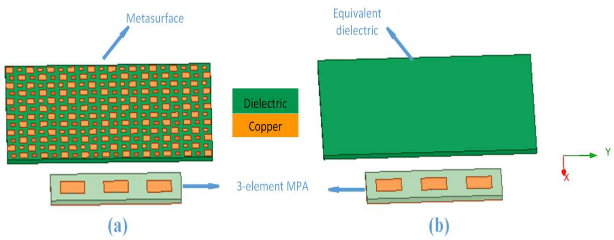
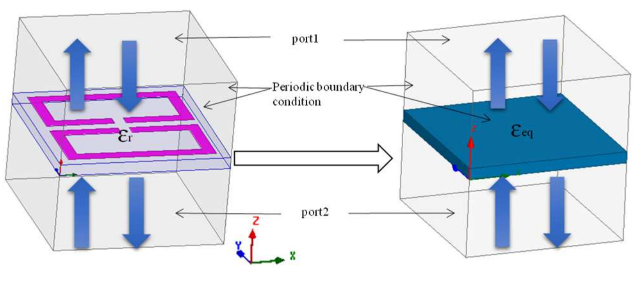


Figure 1. Three-element MPA with different superstrates: (a) Metasurface; and (b) Equivalent Dielectric(ED).

When the unit cells of the metasurface is comprised of elements that have fine features, the simulation time for this combination of the antenna and the metasurface can become quite high, especially in the millimeter wave frequency range (~30 GHz), or above, which is of interest in 5G applications, among others. Although, attempts have been made to reduce the simulation time by using equivalent circuits for the metasurface screen, such an approach is not as accurate as one would desire, because of the complications that arise when one attempts to include the effects of the higher-order modes, especially when the screen has anisotropic properties, because it is not X-Y symmetric, where X-Y is the plane of the surface (see Fig.1).

An alternative, proposed herein, is to replace the metasurface with an equivalent dielectric medium, which is homogeneous, though it can be locally varying and anisotropic. The principle of the proposed method has been described in [3], [4] and is sketched in Fig.2. Below we briefly discuss the theoretical basis upon which this physics-based tactic is based, and demonstrate that its use can result in considerable time saving, with no sacrifice in accuracy of the results for the return loss and radiation pattern that are of typical interest when we numerically simulate problems of this type.



(a) (b)

Figure 2. (a) Original unit cell of MTS; (b) Equivalent Dielectric slab

The example geometry of the test problem is shown in Fig. 1(a). A metasurface is placed at a height of 0.5mm from the 3-element microstrip patch array (MPA), which operates in the mm-wave band. The thickness of the metasurface is 0.6mm. To compare the computational resources, the metasurface is replaced by an equivalent dielectric (ED) as shown in Fig. 1(b). Our objective is to compare the computational times, RAM requirements and accuracy of our proposed method when measured against the reference solution of the original problem, namely (antenna+metasurface).

The reflection coefficient and gain plots of the 3-element MPA, either covered by a metasurface superstrate or with the ED, are presented in Figs. 3 and 4, respectively. It is evident that the ED method yields results that are very similar to those of the original metasurface. In addition, the proposed method offers the flexibility of changing the thickness of the ED to further reduce the burden on the computational resources.

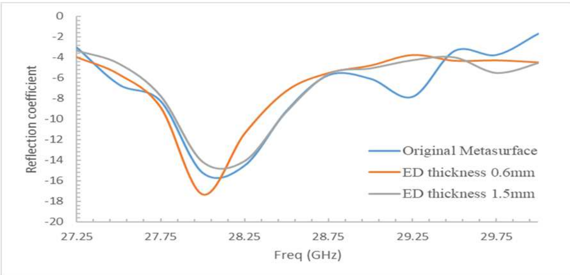
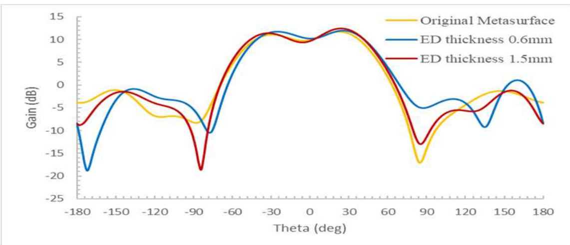
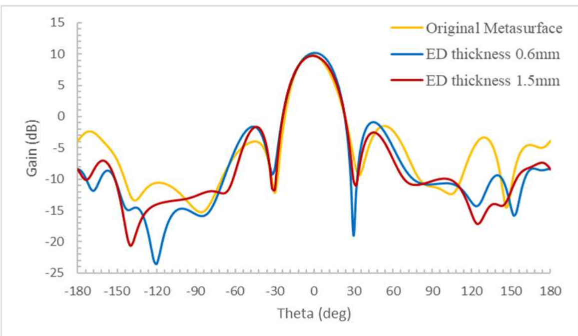


Figure 3. Simulated reflection coefficient plot of the 3-element MPA with different superstrates



(a)



(b)

Figure 4. 2D Simulated gain plot of the 3-element MPA with different superstrates at 28 GHz frequency: (a) $\phi\phi=0°$ cut; and (b) $\phi\phi=90°$ cut.

A comparison of the computational resources needed to model the antenna, with either the metasurface or the ED slab as a superstrate, is presented in Table 1. We observe that a significant reduction in the CPU time and RAM utilization is achieved by using the ED method. (Note: The CPU time is the simulation time when only a single core of the processor is used to run the simulation).We also observe that the CPU time of the simulation is reduced by a factor of 50 when the ED approach is used; additionally, the RAM requirement is also reduced by a factor of 18. It is worthwhile to mention that a commercially available software was used to run both the simulations and it was not necessary to develop a new software module to realize the timesaving when the ED approach was used. As an aside, we note that the simulation of the 3-element MPA with metasurface (original geometry) failed to converge even though it required substantially large amount of resources to run when using the same commercial solver in which the ED approach was used.

Table 1. Computational resources comparison

Freq. Sweep (GHz)	Geometry	Max RAM(GB)	Convergence achieved	CPU Time
27-30	3-element MPA	1.56	Yes	00:30:43
27-30	3-element MPA +Metasurface	231	Not Converged	345:56:31
27-30	3-element MPA +ED of 0.6mm thickness	57.6	Yes	49:55:15
27-30	3-element MPA +ED of 1.25mm thickness	22	Yes	14:59:01
27-30	3-element MPA +ED of 1.5mm thickness	11.9	Yes	06:46:04

2 Conclusion

In this paper, a physics-based approach has been proposed to efficiently simulate a class of multiscale problems, e.g., antennas with metasurfaces operating in the mm-wave regime. The proposed method reduces the burden on the computational resources significantly, without compromising the accuracy of the results for the S-parameters or radiation pattern characteristics. Furthermore, the proposed scheme does not require the development of a new computational code, but can use existing commercially available software without modification.

3 References

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