Positional Dependence of Microstrip Line Properties on Artificial Substrates

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Abstract

Integration of artificial electromagnetic materials into devices can be a difficult task due to manufacturing limitations. Recently, simplified versions of these materials have been proposed that are far easier to manufacture. However, non-ideal effects are caused by the physical modification used to simplify these materials. In this paper, microstrip lines placed onto artificial material substrates composed of metallic cube and sphere particles are simulated and characterized. Positional dependence of effective line properties was observed.

1. Introduction

Integration of artificial electromagnetic materials into planar devices has proven to be a challenging task. Ideally, such materials would be composed of large arrays of sub-wavelength scatterers, often metallic, dispersed in a background material. Treating arrays of particles as truly effective materials – independent of the type of excitation field or the placement of other nearby obstacles, among other things – is applicable when there are many particles in the array so that homogenization methods can be applied. For small numbers of particles, homogenization no longer strictly applies and effective material properties can no longer be accurately ascribed [1]. Due to this limitation, it is sometimes impractical to create substrates containing a sufficient number of particles so they can be thought of as truly effective materials.

To partially circumvent this problem Substrate Integrated Artificial Dielectric (SIAD) structures have been recently proposed [2-4]. Rather than attempting to manufacture large 3-D arrays of particles, these structures are composed of at most one vertical layer of grounded particles. These types of structures greatly simplify the geometry and are much easier to manufacture than traditional artificial dielectrics such as large arrays of vertically stacked particles as illustrated in Fig. 1. Effective material properties were also proposed for these SIADs and appeared to enhance the dielectric or magnetic properties of the substrate.

Unfortunately, it may be unreasonable to homogenize these structures and treat them as effective materials. First, the particles are only periodic laterally throughout the substrate and not vertically. This disrupts the expected polarization of the particles. Secondly, the unit cell size of the particles is not small with respect to the dimensions of the structure to be placed onto the substrate and could result in material parameters that vary with position of a signal line. However, even if these structures cannot be treated as ideal effective materials they still may be worthwhile considering their ease of manufacturing. If their non-ideal behavior can be characterized and taken into account during the design process functional devices can still benefit from such substrates.

In this paper, we report the behavior of microstrip lines near artificial electromagnetic substrates composed of lattices of canonically shaped particles. Both cube and sphere media substrates are investigated, using computer simulation, and the effective properties of microstrip lines placed onto such substrates are computed.

2. Geometry and Parameter Study

Two different types of well known artificial materials were considered in this study: sphere and cube media [5, 6]. Both materials are simple cubic lattices of metallic particles that can be treated as effective electromagnetic materials. In the quasistatic limit, these materials are traditionally described by the volume fraction of the space that the particle occupies within the unit cell. In the present study, the cube media had a volume fraction of 0.5 and the sphere media had a volume fraction of 0.3. The quasistatic effective material properties of such materials are ε_r=2.4, μ_r=0.49 and ε_r=2.0, μ_r=0.7, respectively [7, 8].

Two potential sensitivities concerning the implementation of such artificial materials were of interest in this study. First, we wished to ascertain how the relative position of a microstrip line in reference to the unit cell of an artificial material substrate, as illustrated in Fig. 1 (a-d), affected the effective properties of a microstrip line. Second, we wished to understand how the number of unit cells between the substrate and signal line (i.e., the vertical direction) affected the effective line parameters. A substrate 0.5 unit cells thick is shown in Fig. 1(a,b) and a substrate 2 unit cells thick is shown in Fig. 1(c,d).

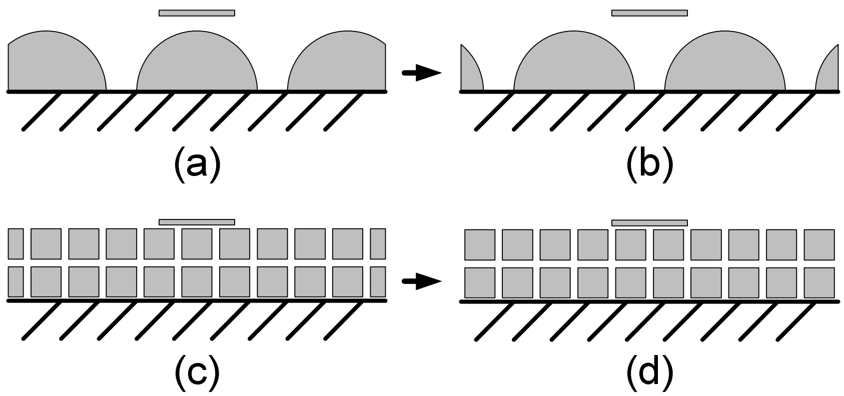

Figure 1 Cross section of microstrip line (a) directly above the unit cell, (b) shifted one half cell, (c) directly above a two unit cell thick substrate, and (d) shifted one half cell over a two unit cell thick substrate.

To study these sensitivities, a model containing a microstrip line on top of an artificial substrate was developed. The model geometry contained a microstrip line (3 mm wide, 0.025 mm thick) above a ground plane. An artificial material slab (2 mm thick) was used as a substrate for the microstrip line. The artificial material slab was composed of empty cube shaped objects containing either a metallic cube or sphere and the unit cell size was varied from 4 mm down to 0.666 mm.

3. Modeling and Material Parameter Extraction Method

CST Microwave Studio was used to numerically compute the scattering parameters for the structures described earlier [9]. All materials were assumed to be lossless in the simulations. To converge the model, the lateral dimension of the artificial substrate was increased in width sequentially by adding more unit cells in the lateral direction until no change in the S parameters was seen. A total width of 60 mm (20 microstrip line widths) was found necessary.

To extract the effective properties of the microstrip line from these simulations, a transmission line equivalent problem was formed by treating the section of microstrip line over the artificial material substrate as a transmission line with unknown material parameters. The Nicolson, Ross, and Weir method was then used to solve for the unknown material parameters [10, 11].

When microstrip structure junctions between sections of heterogeneous lines exist, as shown in Fig. 2, it is a challenge to properly develop analytical models for these junctions. Generally only approximate analytical models exist and attempting to apply them when extracting effective line parameters often yields unsatisfactory results. Rather than attempting to analytically model them in this present material parameter extraction process, we instead chose to limit their effects on the extracted material parameters by making the length of the line in simulation very long.

To choose the length of line that is necessary to mitigate these junction effects, a parameter study of the extracted effective material parameters of the line was conducted versus the line length. As seen in the plot in Fig. 2 and for the model used in this work, as the length of the line increases the extracted material parameters converge to a constant value. We found that a total line length of 100 mm was necessary. In the simulation, an artificial material substrate was used with a unit cell size of 1 mm. This translates into a line length of 100 unit cells of particles.

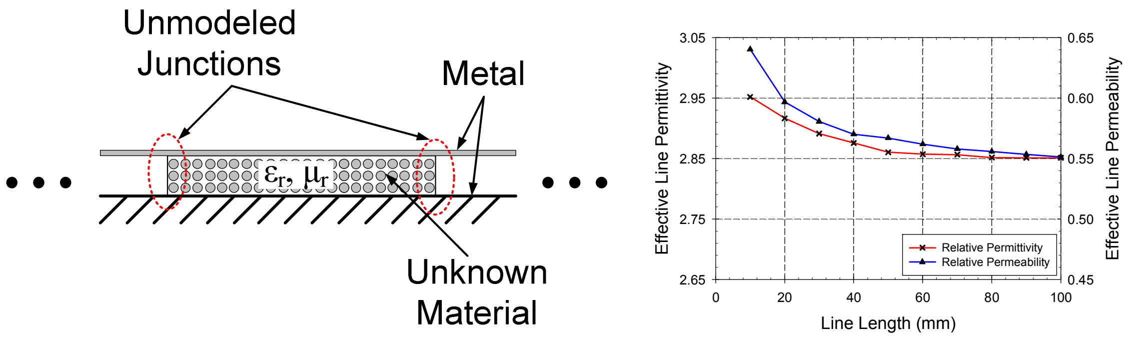

Figure 2 (Left) Section of microstrip line over an artificial electromagnetic medium with unknown material properties and (right) extracted line material properties versus line length.

4. Numerical Results

The first geometry studied was a microstrip line over an artificial substrate composed of a one half cell thick sphere media, as illustrated in Fig. 1(a). The effective line parameters versus offset of the artificial substrate were computed. The artificial media was offset in discrete steps from being directly underneath the microstrip line, as in Fig. 1(a), up to one half unit cell displacement, as in Fig. 1(b). The results of that study are shown in Fig. 3. Significant variation in effective permittivity of the line is seen with little change in permeability.

The second geometry studied was a microstrip line over an artificial substrate composed of a one cell thick sphere media. Following the same procedure used in the one half cell thick study, the effective material properties of the line were calculated vs. offset of the substrate and are shown in Fig. 3. A significant but smaller change in permittivity is again seen with little change in effective permeability.

In the third and fourth studies the previous procedure was repeated for a microstrip line over two and three cell thick artificial substrates composed of sphere media. The results of those studies are shown in Figs. 3. A significant change in the permittivity is seen for a two cell thick substrate but as the substrate is increased to three cells as seen in Fig. 3 the positional dependence of the effective permittivity substantially decreases. The effective permeability shows little change.

In studies 5-8, the procedure was repeated but instead of using sphere media, cube media was implemented. The effective line parameters for one half, one, two, and three cell cube media are shown in Fig. 4. Great variation in both the permittivity and permeability are initially seen in the half cell study, but as the number of unit cells thick increases, that variability significantly decreases. For the three cell cube media, very little variation in either permittivity or permeability is seen.

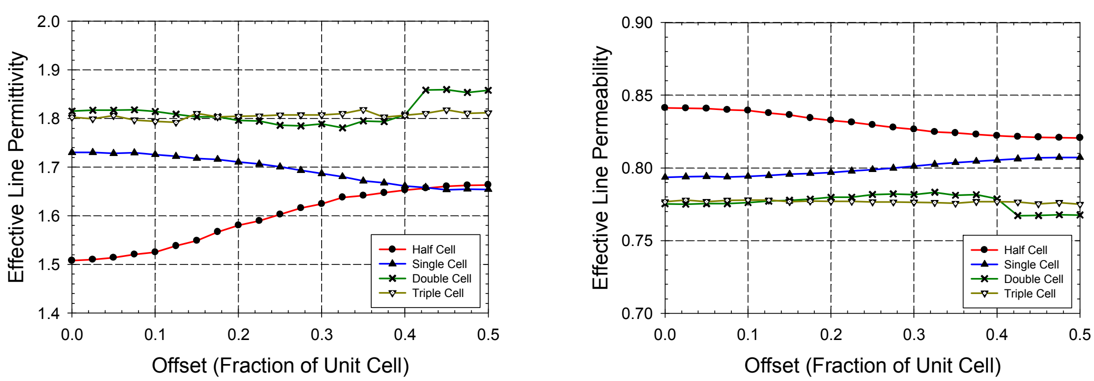

Figure 3 Effective line parameters versus offset of microstrip line over a sphere medias slab 0.5, 1, 2, and 3 unit cells thick.

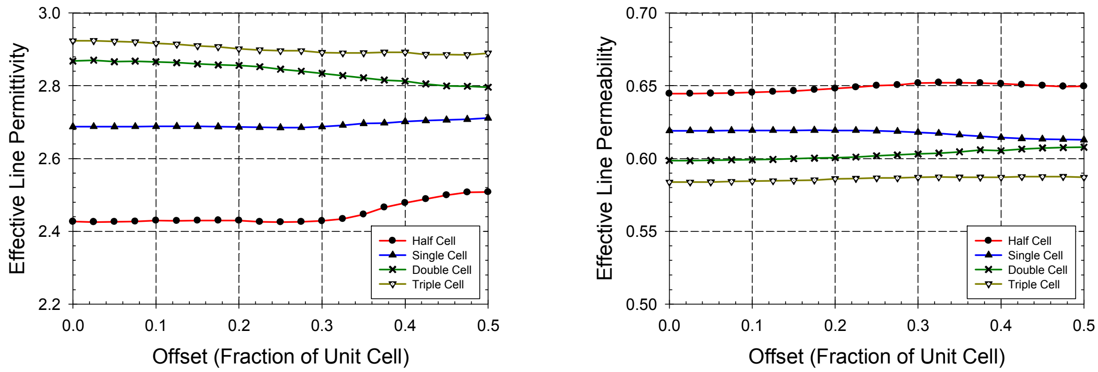

Figure 4 Effective line parameters versus offset of microstrip line over a cube media slab 0.5, 1, 2, and 3 unit cells thick.

5. Discussion

Two trends can be seen from Figs. 3 and 4. First, as the number of unit cells between the microstrip line and the ground plane increase the average dielectric constant increases substantially. For small numbers of unit cells this is expected because the particles in the media may not be polarized as those in an infinite space. Once there are several unit cells the particles begin to polarize as expected. Second, as the number unit cells between the line and ground plane increase, the positional dependence of the effective line properties decreases. This is also expected because the microstructure of the artificial dielectric is becoming very small with respect to the structure placed on top of it.

Lastly, from this work we conclude that very simplified versions of artificial material substrates should not be treated as effective materials. When microstrip lines are placed on such substrates these lines exhibit a significant amount of positional variation that needs to be taken into account during design. This could be accomplished through sufficiently detailed simulations and design adjustments.

6. Acknowledgements

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7. References

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