EM Properties of Synthetic Media

Yiannis C. Vardaxoglou[1], Chinwe C. Njoku[1] and William G. Whittow[1]

[1] School of Electronic, Electrical & Systems Engineering, Loughborough University, Loughborough, LE11 3TU. UK

j.c.vardaxoglou@lboro.ac.uk

Abstract—**EM properties, dielectric constant and radiation, of spherical and cuboidal particle inclusions forming volumetric media will be shown. Examples of a dielectric resonator and patch antenna will be discussed in the full paper.**

Index Terms—dielectric substrate; EM media; synthesis

I. INTRODUCTION

This paper will outline how novel substrates can be synthesized by suitably arranging metallic and non-metallic inclusions. Micro-sized cuboids each composed of these inclusions, Fig. 1, will then tessellate together and form larger structures on the mm scale. The metallic nanoparticles within these cuboids will be in contact with their adjacent neighbors forming a continuous and highly conducting section. Its dielectric counterpart will be formed from the polymer matrix filled with a small number of metallic particles. In the same fabrication process, the local dielectric properties can be changed by varying the ratio of metallic to non-metallic inclusions within each micro-sized cuboid. Therefore, a grid can be composed where each cuboid can be metallic or dielectric and the properties of the dielectric can be controlled. Connected metallic cuboids will form the conducting sections.
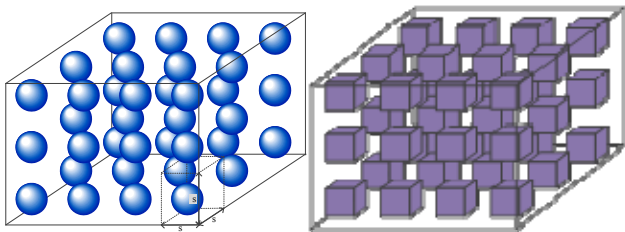
II. HYPOTHESIS

Figure 1. Micro-sized spheres and cuboids (periodically spaced) representing a volumetric synthetic medium.

EM advantages arise from having the flexibility to fabricate novel bespoke substrates with suitable properties (ε_r, μ_r and losses) as well as heterogeneous dielectrics with smooth transition gradients. These include; increased bandwidth, gain, efficiency, size reduction, multi-resonance behavior and suppression of surface waves. Integrating the radiating element, the dielectric and potentially ancillary RF components into one process will facilitate fabrication advantages (time, cost and environmental savings) compared to the current fabrication technique of printing the entire layer and then etching away

everything except the pattern required. Potential physical advantages derive from using nanoparticles that inherently have a high surface area to volume ratio and can exhibit increased scratch resistance, strength, flexibility, reduced weight and material consumption.

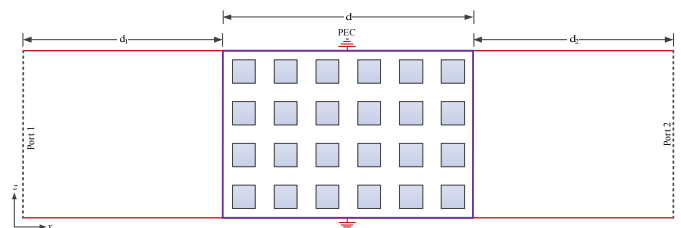## III. METHODOLOGY FOR OBTAINING EFFECTIVE CONSTITUTIVE PARAMETERS

Fig.2 A medium of thickness d in an Empire XCcel® plane wave setup

Numerical simulations of these structures in Empire XCcel® FDTD package is used to examine their properties according to the process shown in Fig.3. The simulation process works by applying an EM plane wave to the heterogeneous medium and then extracting the scattering (S-) parameters, typically, S_11 and S_21. Next, an inversion algorithm is applied to these S-parameters to obtain the EM properties. Before the heterogeneous structures were simulated, the first stage was to determine that the choice of the extraction method used in obtaining the effective permittivity and permeability (ε_{eff} and μ_{eff}) of the medium from the simulation results was correct and appropriately implemented. The reasoning behind the effective-medium theory as discussed in [1–3] was used here because the heterogeneous media could be homogenized on a macroscopic scale as the wavelengths at our frequencies of interest were much larger than the lattice constants/periodicity and the size of the inclusions.

The effective-medium theory involves the averaging of the electric and magnetic fields over the unit cell containing one inclusion in the heterogeneous medium. Well-known inversion/extraction techniques exist such as the Resonant Inverse Scattering method [4], and other variants of the effective medium theory. This method uses the S-parameters and the thickness of the material to obtain the effective EM properties of the medium subjected to a plane wave or when the sample is placed in a waveguide.
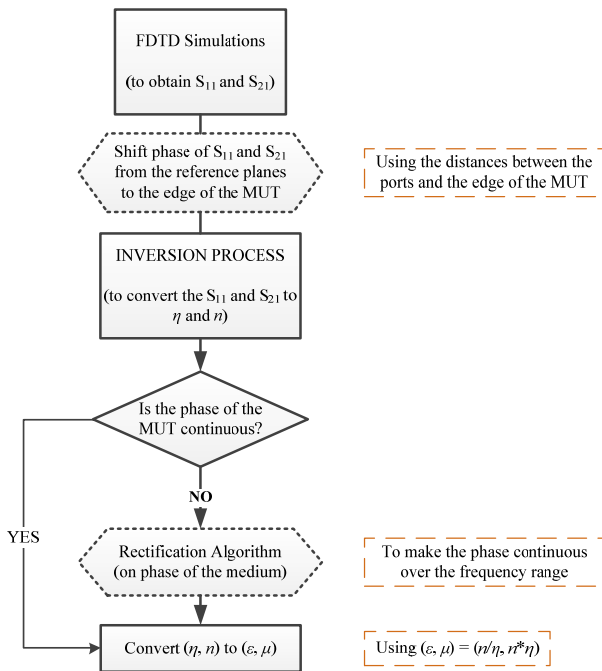
Fig.3 Flow chart for extraction of effective permittivity and permeability of Material Under Test (MUT).

The next step after deciding on the extraction technique to be used was to make sure that it was robust enough to be applied to heterogeneous and homogenous materials. Therefore, dielectric slabs of known EM properties (ε "and" μ) and finite thicknesses were simulated using Empire XCcel®. In order to achieve infinite dimensions in the simulated structures, perfect electric and magnetic conductors (PEC and PMC) were used as boundary conditions.

IV. INDICATIVE RESULTS

The host material is central to the effective dielectric constant as shown in the example of Fig. 4. The volume fraction ratio is also important and higher volume ratios lead to higher ε_{eff}.
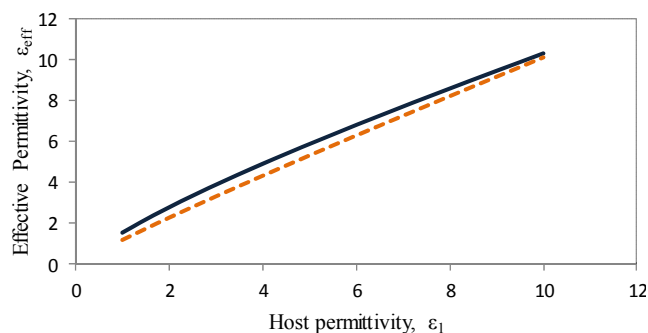

Figure 4: Variation of ε_eff with ε_1 for a heterogeneous medium of 100 μm metallic cubes with 180 (━) and 250 μm (— — —) spacing using the inversion process.
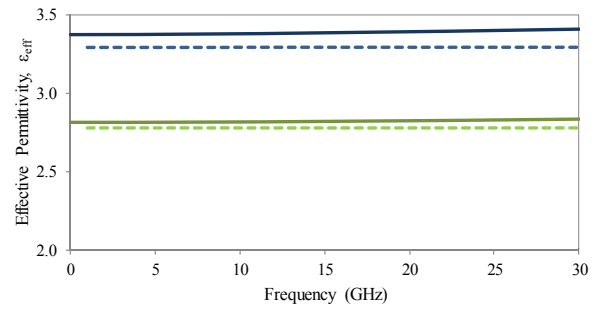

Fig.5 Effective permittivity for ε=11.9, 100um dielectric cubes in a homogenous medium, ε=2.25, for 180um spacing (blue) and 250um spacing (green) from equations (dashed) and simulations (continuous)

Dielectric inclusions produce moderate increases to ε_{eff}, but larger ε_{eff} values can be achieved with metallic inclusions, as shown in Fig.5.
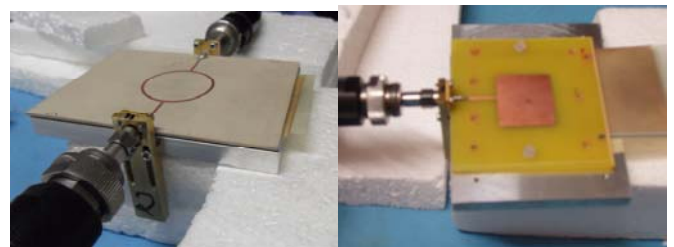

Fig.6. Dielectric resonator and patch antenna with synthetic media

The full paper will also discuss results ascertaining the validity of our hypothesis using a set of ring resonators and patch antennas [1] apparatus, Fig. 6.

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