Fused Deposition Modelling of Composite Meta-Atom 3D Structures

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***Abstract*—Examples of meta-atom 3D geometries are shown. These can be classed as connected and disconnected pluralities of inclusions. Using FDM technology the dielectric and magnetic properties of meta-atom artificial materials could be tailored to suit specific designs for antennas and microwave components. These structures could be manufactured using 3D printing techniques including FDM.**

***Index Terms*—artificial materials, meta-atoms, effective media, antennas, 3D printing**

I. INTRODUCTION

With the advent of 3D printing one is able to construct composite structures that have a desired shape and desired set of properties over a wide range of frequencies. These structures could be viewed as artificial materials and provide a means of altering the electromagnetic (EM) properties of naturally-occurring materials.

In order to create these artificial materials, dielectric, magnetic or metallic inclusions in a host medium are arranged in defined or random lattices to alter the EM properties of a hybrid structure. The size of the inclusions is typically less than $\lambda/10$ [1, 2]. These synthetic materials typically have an effective permittivity, ε_{eff} and effective permeability, μ_{eff}, [1-3] where a wide range of values could be obtained. Inclusions, termed here as meta-atoms, can be used to achieve the required overall bulk change in ε_{eff} and μ_{eff}. This paper shows a range of meta-atom configurations used to augment 3D structures that can be constructed using Fused Deposition Modelling (FDM). By means of an example their effect on the resonance of spherical resonator is shown here.

II. EXAMPLES OF META-ATOM COMPOSITES

A meta-atom is defined here as a meso-scale particle (or inclusion) with constitutive (dielectric/ferrite) parameters that can have a wide variation. These will then build into a specific formation or a plurality of an array in 3D to invoke the required shape. Fig. 1 shows the analogy between the model of natural materials and meta-atom based materials. The meta-atoms in our case have typically meso-scale dimensions. For microwave applications and with the currently available FDM printers this is sufficient for structures operating at low GHz. These can also be conveniently represented by equivalent circuits since they are weakly coupled and assuming they are packed closely they can be nearly homogeneous. Fig. 2 shows an exemplar of two primary meta-atom classifications of disconnected and connected pluralities. The former behaves primarily capacitive having an inductance as the frequency increases. The latter (connected meta-atoms) is predominant inductive with a soft capacitance appearing at the high frequencies.

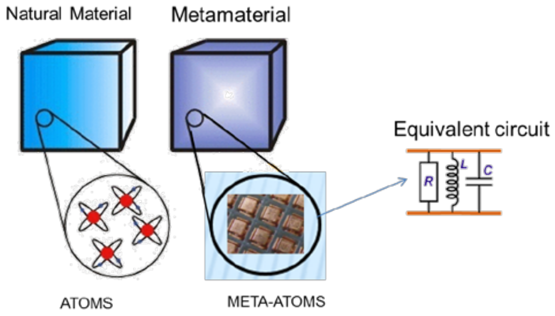

Fig. 1 Spheres with connected meta-atom composition in a pentagonal lattice.

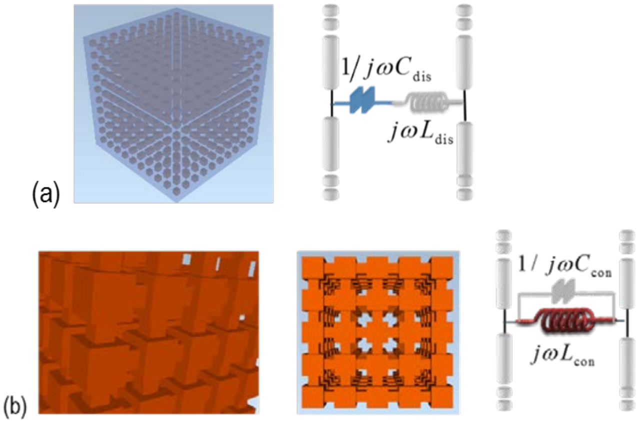

Fig.2 (a) Disconnected and (b) connected meta-atoms and their equivalent circuit

These meta-atoms could be arranged on a regular lattice in 3D by either stacking them or displacing them in their own plane. Building up the structure with layers of these the desired thickness could be obtained, see Fig 3 [4, 5].

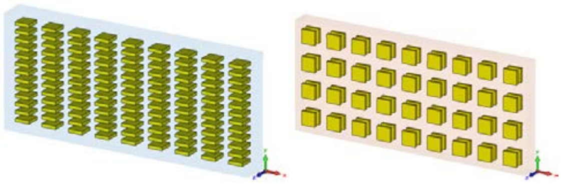

Fig.3 Stacked and lateral displacements of conducting pads

In building an equivalent model to approximate a homogeneous structure one could start building a model with a number of closely packed cuboids in a rectangular or spherical geometry. Examples of these are shown in Fig. 4. This will in effect produce a suitable ε_{eff} and μ_{eff} combination and and is facilitated by 3D manufacture.

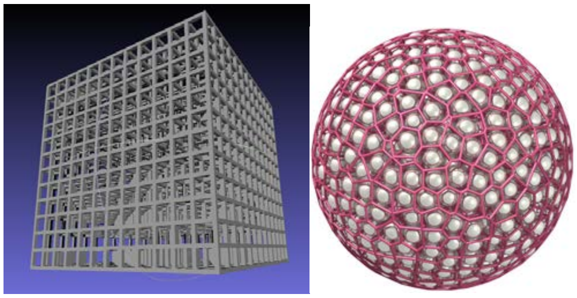

Fig.4 Connected meta-atom structures of cuboid and spherical geometries

III. PROPERTIES OF THE COMPOSITES

An equivalent meta-atom spherical body to act as a spherical resonator is shown in Fig 5.

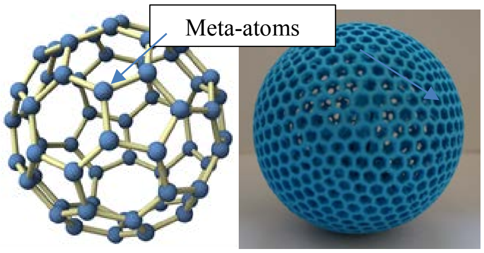

Fig.5 – Meta-atom model and FDM spherical body (outer shell) resonators

In order to see their resonant behaviour the spheres were excited with a small dipole antennas located at their centres. Their resonant frequency change for material with different ratios of permittivity and permeability, keeping their product ε' μ' constant is shown in Fig 5. Good matching was achieved for each ratio by adjusting the length of the dipole, which varied between 25.5 and 9mm. The sphere was tested for tanδε = tanδμ = 0; 0.01 and 0.03. Good similarity is observed between the behaviour of the curves above and the ones derived from the theoretical model [6].

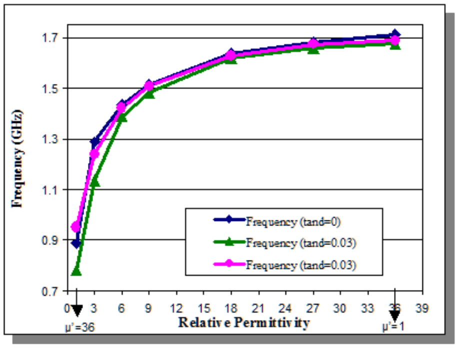

Fig. 5 – Variation of frequency with permittivity and losses for FDM spherical resonator (tanδε = tanδμ = tand)

IV. CONCLUSION

The concept of meta-atom FDM structures and their equivalent have been introduced. The advent of 3D printing models could be built for a practical implementation of these which may or may not be of canonical shape

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