Automated Fabrication of Three Dimensional Dielectric Composites for RF Applications

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Artificial composites or electromagnetic metamaterials have been demonstrated to promise new functionality, through otherwise physically unobtainable properties. Their electromagnetic properties arise from a particular design, arranging conductors, dielectrics, and magnetic substances in space. Recent design studies showed that the unique arrangement of dielectrics for desired specific needs such as large bandwidth and small size can be determined from scratch using topology optimization. Also, resulting three-dimensional (3D) designs were realized using advanced Solid Free Form fabrication techniques. Nevertheless, the focus so far has been on two constituent compositions such as high contrast ceramic-polymers. Specifically, fabrication methods capable of realizing designs for ceramic oxide metamaterials used for spatially variable dielectric substrates, periodic band-gap structures, and magnetodielectric composites were investigated. However, to optimize for a more generalized metamaterial profile possibly with more dielectric shades varying in 3D in order to achieve superior RF performance, none of pre-existing advanced fabrication methods are adequate. Some new fabrication methods need be devised capable of achieving control of local composition and microstructure in two or three dimensions with sub-millimeter spatial resolution of multiple ceramics. A simple manual -Dry Powder Compacting Method (DPD)- "Sand Painting" was invented that is capable of producing *multi-layer multi-ceramic variations in 3D.* This technique was specifically devised to produce volumetric multi-material variations resulting from stringent performance specifications for a SATCOM antenna using off-the-shelf powders. It has been originally developed to avoid the long heat treatments to remove binder - a tedious and problematic process for multi-material conventional ceramic processing. The new manual yet simple method of DPD proved that it is capable of producing only subsections of large monolithic bodies with functional gradients. Despite its lengthy procedure, the main advantage of DPD over traditional assembly processes is that during dry powder pressing, the deformation is axial, so any transverse design can be preserved. It is named "Sand Painting", in analogy with art of Navaho Sand Painting, which uses dry sand of many colors to define a two-dimensional design. Here efforts will be presented to readily adapt DPD for conventional industrial practice, replacing the simple powder feed in an automated compaction machine with an appropriate feed mechanism for each composition. Challenges and promises will be discussed and the automation of DPD will be demonstrated for a SATCOM antenna resulting in a versatile and effective 3D fabrication technique that will allow the practical exact fabrication of entire designs in feasible time spans. It will be shown that it presents an ideal practical technique to produce multi-material novel material compositions of future antennas. Additional practical aspects related to the extension of the method to allow for magnetic and conductor inclusions to produce a complete antenna structure will be also discussed. The design and realization of these materials can be seamlessly combined to provide previously unobtainable figures of merit and new capability for a wide range of operating frequencies.