Development and Electromagnetic Characterization of 3D Printable Material with High Dielectric Constant

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Additive manufacturing (AM), or 3D printing technology, has attracted microwave researchers' attention because it enables many new EM structures and novel applications. One of the most common techniques of AM is fused deposition modeling (FDM), which entails the 3D printing of a wide variety of geometries from thermoplastic materials. However the limited EM properties, i.e., permittivity ε, permeability μ and conductivity σ, of current 3D printable thermoplastics for FDM are limited. For instance, commonly used 3D printable materials, e.g., acrylonitrile butadiene styrene (ABS), polycarbonate (PC), etc., have a ε_r less than 3 at microwave frequency, whereas more compact EM components often require high permittivity material. Consequently, the development and characterization of 3D printable material with high ε_r becomes important. Besides, traditional printing techniques for conductors, e.g., conductive ink printing, often require high temperature (e.g., 80°C-550°C) processing, during which the substrate may be deformed or damaged. In addition, the conductivity obtained is often on the order of 10^6 S/m (more than a factor of 10 less than the conductivity of bulk metal), which limits applications at high microwave frequencies.

A continuing effort has been underway to develop 3D printable material with high ε_r (M. Liang *et al.*, 2014 IEEE APSURSI, 2014, 227–228; J. Castro *et al*, Journal of Microelectronics and Electronic Packaging, 13, 3, 102–112, 2016). The polymer matrix composite technique is a promising way to realize robust 3D printable materials with designed EM properties. By adding particles into a host material, the host's EM properties can be tailored. For example, by mixing $SrTiO_3$ ($\varepsilon_{r\_SrTiO3} = 233$) particles and Zeonix (cyclic olefin copolymer, $\varepsilon_{r\_Zeonix} = 2.247$) host with a 3:1 weight ratio, 3D printable polymer with a ε_r as large as 6.1 is achieved in this work. We also make a comparison between the measurement result and the theoretical value based on effective medium theory.

To improve the AM-fabricated conductor performance, ultrasound foil embedding (UFE) technique (M. Liang, *et al.*, IEEE AWPL, 14, 1346–1349, 2015) has been developed. It utilizes ultrasonic and thermal embedding for submerging metal foil into 3D printed polymer. This technique yields printed conductor components with bulk metal conductivity at microwave frequencies while avoiding high temperature processing.

To validate the developed printable dielectric material and the UFE technique for microwave applications as well as the seamless integration of FDM and UFE techniques, a compact patch antenna is designed and fabricated. The dielectric substrate is the 3D-printed polymer of 75% weight percentage of $SrTiO_3$ in Zeonix. The conductor part is fabricated by UFE technique. The measurement results will also be reported at the Symposium.