**Dielectric Measurements of High Permittivity 3D Printed Substrates**

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As antenna requirements move towards multi-function and multi-band applications, functionality of disparate radio frequency (RF) systems must be integrated into a scalable system architecture. This requires planar and vertical integration of apertures, substrates, and feed networks to enable multiple modes of operation. Three dimensional integration and hybrid material approaches needed to achieve these designs makes additive manufacturing critical to the future of antennas and other RF devices.

Additive manufacturing can facilitate complex designs that are not suitable for current manufacturing processes. While strides in additive manufacturing demonstrate production of robust and repeatable mechanical parts, less attention is paid to developing and characterizing RF properties of printed materials. Typically low dielectric constants ($\varepsilon_r$<4) and relatively high loss tangents (tan$\delta$>0.01) of thermoplastic and polymer substrates printed from commercial inks, filaments and pastes limit achievable additive manufacturing designs for antennas and other RF devices.

Increased versatility of additive manufacturing in the RF design space requires high dielectric substrates; however additive manufacturing of RF devices and hybrid material structures has hurdles to overcome. These hurdles include bonding interfaces between printed layers, anisotropic nature due to the orientation of the printed material layers, surface roughness, and porosity. The above characteristics will vary from print to print making characterization of printed dielectric materials paramount for verification of measured devices to simulation and modeling.

This presentation will give an overview of the measured complex permittivity (2<$\varepsilon_r$<10) of various printed materials. The main focus will be to compare measured permittivity to the predicted permittivity supplied by the manufacturer. We utilize a rectangular waveguide and a coaxial waveguide to characterize and compare permittivity from VHF to X-band utilizing a Nicholson-Ross-Weir based technique. We verified this method using materials with known dielectric properties such as Duroid and FR4. The coaxial waveguide is especially important because it allows material characterization over an extremely wide bandwidth in a small form factor even at low frequencies. We will fabricate a highly resonant prototype antenna utilizing the measured properties of our 3D printed materials. We will use the measured versus simulated resonances to further demonstrate accuracy of the characterization of the printed dielectric material.