Tianming Chen
Ph.D.
Electrical Engineering
Major Professor: Nicola Bower

Capacitive sensors for measuring complex permittivity of planar and cylindrical structures

Abstract: With the increasing use of low-conductivity structural and functional materials, there has been a greater need for the efficient and reliable nondestructive evaluation (NDE) of these materials. One approach to evaluate low-conductivity structural and functional materials is to characterize the material dielectric property. In this thesis, capacitive sensors are developed for measuring complex permittivity of planar and cylindrical materials. For each sensor configuration, models are developed to allow for inverse determination of material permittivity from measured capacitance, therefore realizing quantitative characterization of material dielectric properties.

In the first half of the thesis, coplanar concentric capacitive sensors are developed to meet the need of detecting water or excessive inhomogeneities caused by repairs in aircraft radome structures. Another important motivation is the absolute dielectric property characterization of laminar structures. Three coplanar sensor configurations are designed: the simple two-electrode concentric configuration, the interdigital spiral and the interdigital concentric configurations. Corresponding numerical models are developed to predict the sensor capacitance for given test-piece structures. The validity of the models is verified by comparing numerical predictions and measurement results. The advantage and disadvantage of each sensor configuration is discussed.

For the two-electrode concentric configuration, a prototype handheld probe is also fabricated, and has detected successfully 1 cc of low contrast liquid in a simulated radome structure. Curved patch capacitive sensors, presented in the second half of the thesis, are developed with the motivation of accurate and convenient permittivity measurement of cylindrical structures. It is demonstrated that the permittivity of homogeneous dielectric rods is inferred easily from measured sensor capacitance, based on analytical and numerical models developed here. Another practical application of the curved patch capacitive sensors is the quantitative evaluation of aircraft wiring insulation condition. In this work, wires are modeled as cylindrical dielectrics with a conductive core. A numerical relationship between the complex permittivity of the insulation and the sensor capacitance and dissipation factor is established. A prototype probe, developed based on this model, has distinguished successfully degraded wires from the control ones. The feasibility of utilizing the presented capacitive approach for quantitative evaluation of aircraft wiring insulation condition is demonstrated.

Although the development of the capacitive sensors in this thesis is motivated by aerospace engineering related applications, results presented in this work have the potential to be applied to other engineering fields. Potential sensor applications and recommended future research are suggested at the end of the thesis.