# Material Characterization Uncertainty Analysis for Rectangular to Square Waveguide

Alexander G. Knisely*†, Michael J. Havrilla and Milo W. Hyde IV
Department of Electrical and Computer Engineering
Air Force Institute of Technology (AFIT)
2950 Hobson Way, Wright-Patterson A.F.B., OH, 45433

The advent of physically realizable bi-isotropic, anisotropic and bi-anisotropic media poses new challenges to material characterization techniques and requires better measurement uncertainty understanding to accurately quantify complex media performance. A Waveguide Rectangular to Waveguide Square (WRWS) biaxial anisotropic material measurement capability has been developed to evaluate 3-D printed anisotropic samples. The X-band WRWS system has tapered waveguide transitions that mount to a cubic sample holder for 2-port network analyzer measurements. The WRWS transitions adapt WR-90 rectangular waveguides to the square aperture of a cubic sample holder without exciting higher order modes. A closed form, analytic biaxial anisotropic material parameter extraction methodology has been developed to evaluate a 3-D printed cubic biaxial anisotropic sample about its six orientations.

A Monte Carlo uncertainty analysis is developed here to accommodate experimental random error sources including WRWS system calibration and sample to WRWS sample holder fit. Extracted constitutive parameter results are impacted by uncertainties in sample gaps, position and thickness and are further complicated by indexing the sample to accommodate all of the necessary measurement orientations. Vector network analyzers and (Thru, Reflect, Line) TRL system calibration measurements also have their own associated uncertainties which contribute measurement error as well and further impact results. Additionally, fabrication uncertainty in the 3-D printed anisotropic samples also contributes error. The sample fabrication errors are also explored here by utilizing a computational electromagnetic model of the WRWS and 3-D printed sample.

This presentation addresses uncertainties from WRWS measurements and sample fabrication. Monte Carlo results in the form of constitutive parameter error bars demonstrate the measurement validity of the WRWS in the context of potential error sources and indicate anisotropy significance. Enhancing anisotropic sample measurement performance by understanding uncertainty supports better complex media measurement techniques. Uncertainty analysis results of a biaxial sample will be provided and future work will also be discussed.

† The views expressed in this article are those of the author and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the U.S. Government.