Chapter 4

A New Technique to Determine the Complex Permittivity of Each Layer for a Bi-Layer Dielectric Material at Microwave Frequency

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ABSTRACT

A new technique is presented to determine the complex relative permittivity of each layer of a bi-layer dielectric material. The bi-layer material sample is loaded in a Ku-band rectangular waveguide and its two port S-parameters are measured as a function of frequency using a Network Analyzer. Also, by applying the mode matching technique, expressions for the S-parameters of the bi-layer dielectric material as a function of complex relative permittivity of each layer are developed. To estimate the complex permittivity of each layer for a bi-layer dielectric material, the square sums of errors between the measured and calculated S-parameters are minimized using a nonlinear optimization algorithm. The complex permittivity of each layer for a bi-layer dielectric material such as FR4-Teflon, FR4-Delrin and Delrin-Teflon are determined at the Ku-band frequencies, the average relative errors between the individual dielectric materials and those of each layer of bi-layer dielectric materials are calculated.

INTRODUCTION

The application of bi-layer dielectric materials in the microwave and communication industries requires the exact knowledge of complex dielectric properties of each layer for composite bi-layer materials. By choosing the appropriate thicknesses and material parameters for the layers, it is possible to synthesize composite materials with novel electromagnetic properties otherwise not found in a single dielectric material (Deshpande & Dudley, 2003). The choice of a technique of characterization is initially determined by the exploited frequency band, then by the physical properties of material.

A number of techniques have been developed and used to determine the complex relative permittivity of a single layer material (Kassem et al., 2010; Baker-Jarvis, 1990). These include lumped circuit techniques, free space methods, cavity resonators techniques, and transmission line or waveguide techniques. Each technique has its distinct advantages and drawbacks. The lumped circuit techniques are only suitable for low frequencies and high loss materials (Nyfors & Vainikainen, 1989). The free space methods are used when the material is available in a big sheet form (Hasar & Simsek, 2009; Awang et al., 2013). These measurements are less accurate because of unwanted reflections from surrounding objects. Resonant methods have much better accuracy and sensitivity than non resonant methods (Rubinger & Cost, 2007; Li, Nie, Guo, Zhang, Li, & He, 2009). They are generally applied to characterization of low-loss materials. In a recent study, it has been shown that they are also applicable to high-loss materials, provided that very small samples are prepared or higher volume cavities are constructed (Rubinger & Costa, 2007). The disadvantage of this technique is that it is narrowband. For measurements of complex permittivity of a material over a wideband of frequencies, transmission line, or waveguide techniques are widely used (Terhzaz et al., 2006; Blasi & Queffelec, 2008). The waveguide technique and open-ended waveguide technique are accurate for the measurement of complex permittivity. Furthermore, the material sample must be sufficiently thick and the surface in contact with the probe must be flat and free of air gaps. These non-destructive techniques are based on the reflection coefficient and transmission coefficient measurement from which the dielectric or magnetic properties of materials can be determined. Nicholson-Ross method allows the simultaneous determination of the complex permittivity and complex permeability in wideband frequencies from the measurement of S-parameters in the plans of the measurement in transmission / reflection. These plans are defined by the TRL (Thru, Reflect, Line) calibration of the vector network analyzer. This method has the drawback of having inaccuracies peaks for materials with low losses at frequencies where the sample length is a multiple of half the wavelength of the waveguide. To overcome this problem, several researchers have combined the Nicholson Ross method with iterative optimization techniques (Elmajid et al., 2014). But all of these techniques are not used to determine the complex relative permittivity of each layer for a bi-layer dielectric material in wideband frequencies.

The (Nelder & Mead, 1965) simplex method (Nelder-Mead) is an optimization routine that is commonly used in problems with irregular objective functions. It is a robust method that can overcome kinks, local solutions, indeterminacies, and discontinuities in functions being evaluated. However, a standard serial implementation can be prohibitively expensive for problems with a large number of parameters or with costly objective functions. In this chapter, we propose a method to implement Nelder-Mead in parallel using a distributed memory implementation. Nelder-Mead minimizes a function of n parameters by comparing function evaluations at the n+1 vertices of a general simplex, and updating the worst vertex by moving it around a centroid. A centroid is a new vertex that is an average of the remaining (best) vertices. We modify Nelder-Mead in the following way. For p processors, each processor is assigned (n+1)/p vertices at each iteration. Each processor then updates its k>1 worst local vertices, communi-

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