# A GENERALIZED APPROACH FOR MEASURING THE DIELECTRIC PROPERTIES OF LOSSY COMPOSITE MATERIALS

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## ABSTRACT

A generalized technique is presented to measure the dielectric properties of lossy composite materials. The overall method is based on measuring the spectral domain reflection and transmission coefficients of the material-under-test (*MUT*) using a Vector Network Analyzer (VNA), and then finding the dielectric properties of *MUT* from the measured scattering data using a proposed reconstruction algorithm. The effect of noise on the reconstruction is examined, and it is observed that even with 5% relative error in the scattering data, the proposed algorithm produces a stable inversion.

## INTRODUCTION

The use of microwaves for the curing of composite materials has got much attention in recent years. The microwave processing provides the uniform, rapid and selective heating of reinforced materials, which can generally not be achieved with the conventional autoclave curing [1]. A fully automated system for the microwave processing of composite materials has also recently been developed and tested to provide a uniform temperature for even very large structures [2]. However, till now the complex nature of interaction of electromagnetic waves with composite materials has not been fully understood. It is also not fully clear that how the dielectric properties of these reinforced materials may change with different parameters such as the cure cycle, the composite thickness, and the proportion of different fibers and resins. The determination of dielectric properties of composite materials at different stage of curing may provide some information about the absorption and reflection characteristics of these materials.

The methods presently available to measure the dielectric properties of materials can be broadly classified into two major categories. The first category requires the material to be placed in some cavity, and the dielectric property of the material is determined from the changes in the resonant frequency and the quality factor of the cavity. This method some time provides an accurate estimate, but this is a resonant method and it requires the sample to be machined very precisely to be fitted inside the cavity. The second category of method is generally broadband, which requires the sample to be placed either in the transmission line or in free-space. The present paper describes a technique for the measurement of dielectric properties of lossy composite materials, which comes under the second category. The proposed method is quite general in the sense that it can be applied for the dielectric samples, which are either placed in transmission lines (such as waveguide), or in free space, and can also be extended for multi-layer structures.

## BASIC FORMULATION

In the proposed work, the material-und-test (MUT) is simulated by air-dielectric-air layer to comply with the actual measuring condition. It may be mentioned here that when the sample is placed either in the transmission line or in free-space, then there is always an air-dielectric interface at both sides of the sample, and this effect should be taken into account in order to have an accurate formulation. We have used the general transmission line theory to obtain analytic expressions for the frequency-dependent reflection and transmission coefficients of the MUT [3]. The air-dielectric interfaces at both sides of the sample are represented by 2X2 scattering matrices. These scattering matrices are then converted into wave-amplitude transmission matrices [4], so that they can simply be cascaded with the transmission matrix of MUT. Finally the transmission matrices [T] of the three layers are combined together, and accordingly expressions to compute the frequency-dependent reflection and transmission coefficients of the dielectric sample are developed.

In the next step, an object function is defined, which represents the difference between the computed and measured scattering data. As both amplitude and phase of the reflection and transmission coefficient data can nowadays be easily measured with any modern VNA, hence an object function is defined for both amplitude and phase of the scattering data. The measurement of both amplitude and phase of the scattering parameters is quite advantageous, because it doubles the number of object functions, which are to be minimized for a given number of unknowns. These object functions are minimized using a non-linear large-scale optimization algorithm. The optimization algorithm is a subspace trust region method based upon the interior-reflective Newton method [5], where each iteration involves the approximate solution of a large linear system using the method of preconditioned conjugate gradients (PCG). It may be mentioned here that in any optimization algorithm, the main problem is the appearance of local minima, which might some time overlap the actual solution. To avoid the local minima problem, the algorithms are executed with different initial conditions and the value of the dielectric constant and the loss tangent corresponding to the minimum residual error is taken as the correct value. The minimum and maximum expected values of the dielectric parameters are also given as a priori information in order to achieve a fast convergence. To test our proposed method with respect to the presence of noise in the scattering data, we have added some additional noise to the actual data. It is observed that even with 5% relative error in the scattering data, the proposed method produces a stable solution.

## REFERENCES


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