Microwave Nondestructive Detection and Evaluation of Voids in Layered Dielectric Slabs

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Abstract. A microwave nondestructive testing technique is discussed for detection and evaluation of voids in layered dielectric media backed by a conducting plate. This technique utilizes the phase properties of the effective reflection coefficient of the medium as a microwave signal penetrates inside the dielectric layers and is reflected by the conducting plate. Properties of the difference between this phase in the absence and presence of an air gap is investigated as a function of the void thickness, frequency, and dielectric properties of the layers. Utilizing a simple experimental apparatus measurements were also conducted, the results of which were compared with the theoretical predictions.

Introduction

Materials composed of layered dielectric slabs, which are manufactured by adhesively bonding several dielectric slabs, are used in many applications. In most applications, such as the aerospace and construction industries these materials are backed by a conducting plate. This construction technique prevents access to the plates from both sides. Clearly, it is desirable to develop a noncontacting technique for detecting and sizing air gaps (usually pancake shaped) in each individual slab or in between the slabs. This paper discusses a technique that utilizes the phase of the reflection coefficient of a microwave signal that passes through the dielectric plates and is reflected by the conducting plate.

Zoughi et al. have used microwave phase measurements to determine thicknesses of dielectric slabs and their permittivities at microwave frequencies [1]. Other investigators have used microwave amplitude sensitive reflectometers for delamination detection [2, 3]. Layered dielectric media have been the focus of attention of many investigators, particularly in determining impedances and reflection coefficients of these materials [4–6]. Zoughi et al. have developed a very similar technique to detect and evaluate delamination between layered dielectric slabs [7].

Relative permittivities of dielectric slabs are generally complex; \( \varepsilon = \varepsilon_0 \varepsilon_r \), and \( \varepsilon_r = \varepsilon'_r - j \varepsilon''_r \), where \( \varepsilon'_r \) is known as the relative dielectric constant and \( \varepsilon''_r \) is
the loss factor. For low loss material, $\varepsilon''$ is much smaller than $\varepsilon'$. The technique outlined in this paper is applicable to lossy materials, provided the losses do not prevent reasonable signal penetration into the material. The technique is also applicable to multilayer slabs, but we limit our discussion to media consisting of one or two dielectric slabs and another layer representing an air gap.

**Approach**

An incident signal, $E_{0i}$, is transmitted into the medium and once reflected by the conducting plate, it is detected as $E_{ro}$. The ratio of these two signals gives the effective reflection coefficient of the medium. The phase difference between the effective reflection coefficient for a medium with an air gap and one without an air gap is related to the thickness ($d$) of the gap. Figure 1 illustrates a general layered medium consisting of two dielectric plates (which can be identical) and a middle layer representing an air gap (i.e., $\varepsilon_r = \varepsilon_0$), all backed by a conducting plate. Figure 2 shows a simple and common occurrence of an air gap inside a single layer of dielectric, and Fig. 3 shows the presence of an air gap in an adhesive region between two dielectric layers (void occurring during the application of the adhesive layer). Calculation of the effective reflection coefficient for any of these homogeneous and uniform layered media involves the derivation of the forward and backward travelling electric and magnetic field components in each layer based on a known incident field and the application of appropriate boundary conditions at each interface [8–11]. Referring to Fig. 1, the derivation of the field expressions in each layer for a three-layer dielectric medium backed by a perfect conductor are as follows (subscripts $i$ and $r$ denote incident and reflected fields, + and − subscripts represent forward and backward travelling waves respectively, and bold characters denote vector quantities). The incident electric field is a plane wave, polarized in the $x$-direction and travelling in the $z$-direction. The steady-state electric field is the