Implementation of a Partial Overlay Technique for the Characterization of the Electromagnetic Properties of Conductor-Backed Materials

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***Abstract*—A partial overlay technique is described for measuring the permittivity and permeability of conductor-backed material samples. Error analysis shows that the method is nearly as robust as the two-thickness method. Experimental results will be presented at the conference.**

I. Introduction

The electromagnetic properties of magnetic radar absorbing materials (MagRAM) must often be determined experimentally, by placing a sample into a field applicator system, such as a waveguide, and measuring the system S-parameters. Since both the permittivity and permeability are desired, two sufficiently independent measurements must be made. If the sample has a conductor backing that cannot be removed, standard reflection/transmission techniques, such as Nicolson–Ross–Wier, are not applicable. Instead, a reflection-only approach such as the two-thickness technique [1] may be employed. However, multiple samples of identical constituency are often not available, and other approaches must be sought.

It might be tempting to make two reflection measurements, one with only the conductor-backed sample present and one with an additional layer of material (or overlay) placed in front of the sample. However, it has been shown that these two measurements are not independent, and therefore do not supply sufficient information to determine both ϵ and μ [1]. Recently, a technique has been proposed in which an overlay material is added that does not fully occupy the cross-section of the waveguide [2]. Monte Carlo error analysis using theoretical data has shown that this *partial overlay* technique has the potential to produce results nearly as accurate as those given by the two-thickness method, which is often viewed as the gold standard of reflection-only techniques.

In this paper, an implementation of the partial overlay method is introduced, in which the partial overlay material is inserted into a holder fabricated using 3-D printing, and then placed against the conductor-backed sample. A theoretical analysis of the system is described and a Monte Carlo error propagation technique is undertaken using theoretical data to assess the performance of the extraction technique. Extracted values of ϵ and μ found using experimental data will be presented at the conference.

II. Extraction technique

Values of ϵ and μ are found by solving the equations

$$S_{11}^{T,S}(\epsilon,\mu) - S_{11}^{M,S} = 0, \qquad (1)$$

$$S_{11}^{T,O}(\epsilon,\mu) - S_{11}^{M,O} = 0. \qquad (2)$$

Here $S_{11}^{M,S}$ and $S_{11}^{M,O}$ are the measured reflection coefficients for the system with and without the partial overlay present, respectively. Similarly, $S_{11}^{T,S}$ and $S_{11}^{T,O}$ are the reflection coefficients obtained from a theoretical model of the system. Although a commercial solver, such as HFSS, could be used to find the theoretical reflection coefficients, the iterative nature of the solution, especially when conducting Monte Carlo error analysis, demands a rapid calculation based on analysis. Thus, a theoretical analysis which uses mode matching is described below.

III. Theoretical Analysis

A simple model of a rectangular waveguide measurement system is shown in Figure 1. A conductor-backed sample fills the cross-section of the guide in region 4. The overlay material partially fills region 3. The sample holder occupies the remainder of region 3 and also region 2. Region 1 is an empty waveguide extension.

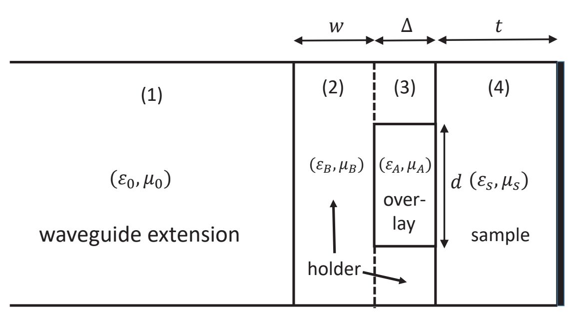

Fig. 1. Top view of a rectangular waveguide containing a partial overlay in a holder adjacent to a conductor-backed sample.

A TE_{10} mode is incident from the waveguide extension onto the interface of the sample holder. An infinite spectrum of

TE_{n0} modes are reflected back into the extension region, and also established in regions 2 and 4. The modes in region 3 are those of a partially filled guide, but because of symmetry are also vertically invariant TE modes. The theoretical value of S_{11} is the ratio of the amplitude of the reflected TE_{10} mode in region 1 to the amplitude of the incident TE_{10} mode.

To determine the modal amplitudes, the tangential fields are matched across each interface and weighted by a single mode to produce a system of linear equations. Each of the integrals resulting from the weighting operation may be computed in closed form, which leads to a rapid solution for the modal amplitudes. Numerical experimentation reveals that for typical materials and configurations, about 20 modes in each region produces S-parameters accurate to 4 digits.

As an example, consider a sample of the commercial MagRAM Eccosorb FGM-125 [3] ($\epsilon_r = 7.32 - j0.0464$, $\mu_r = 0.576 - j0.484$, $t = 3.175$ mm) in a WR-90 X-band waveguide. A ceramic overlay material (Kyocera SG440, $\epsilon_r = 44 - j0.00352$, $d = 2.286$ mm, $\Delta = 5.08$ mm) is embedded in a holder constructed from the 3-D printed material Verowhite [4] ($\epsilon_r = 2.8 - j0.112$, $w = 5$ mm). Figure 2 compares S_{11} computed using mode matching to that found using HFSS. Agreement is excellent, and thus the mode-matching solution is validated.

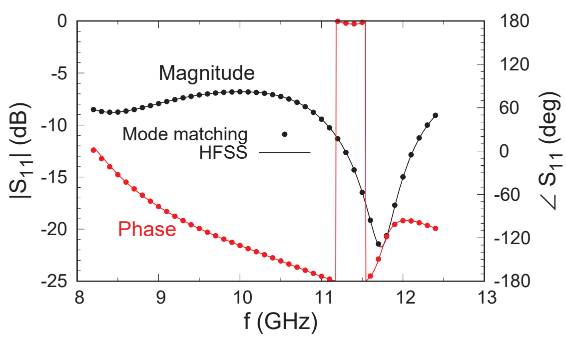

Fig. 2. S_{11} for FGM-125 with ceramic partial overlay.

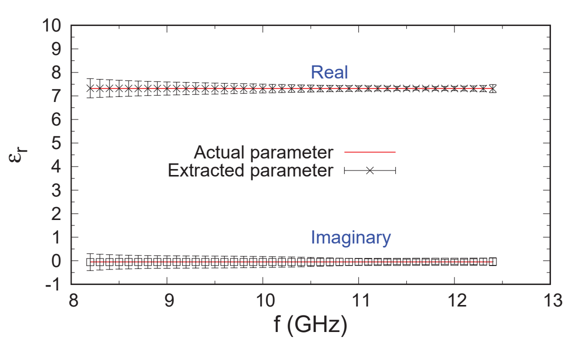

Fig. 3. Extracted permittivity values.

IV. Error Analysis

Monte Carlo error analysis allows the viability of the partial overlay technique to be assessed. S-parameters were generated

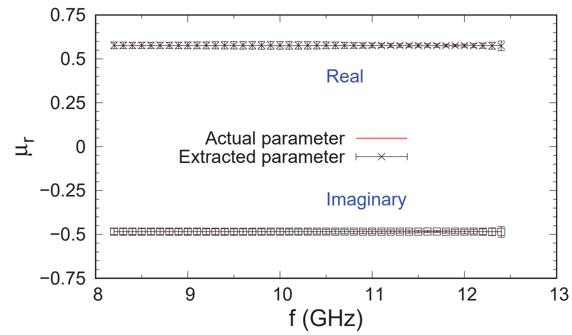

Fig. 4. Extracted permeability values.

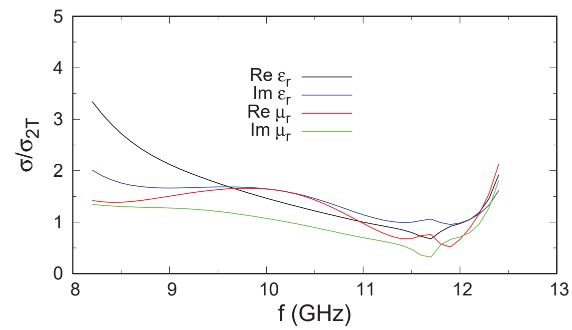

Fig. 5. Propagated error relative to the two-thickness method.

for the case of FGM-125 with a ceramic overlay embedded in a Verowhite holder, as described in the example above. Gaussian white noise was then added to the S-parameters and values of ϵ and μ were extracted using the approach of Section II. The standard deviation of the noise was set to 0.004 in absolute amplitude and 0.8° in phase (typical of network analyzer uncertainty.) The process was repeated 1000 times with the average values shown in Figures 3 and 4. The error bars in these figures are the standard deviation of the results and represent the propagated error. Figure 5 shows the error relative to that found using the two-thickness method. Results are comparable to the two-thickness method, and for some frequencies the partial overlay method performs better.

References

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