Permittivity and Permeability Extraction of Magnetically Loaded Absorbing Materials

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***Abstract*-New procedure for permittivity and permeability extraction of two composite (dielectric matrix + magnetic inclusions), isotropic and homogeneous absorbing material is presented. It calculates mentioned parameters by fitting measured transmission data with Debye relaxation model (for complex dielectric permittivity extraction) and with Lorenzian resonant model (for complex permeability extraction). Proposed method gives good results even with noisy data and does not need initial guesses of unknown parameters. As a proof of concept, some results of extracted permittivity and permeability of Eccosorb CR110, CR114 and CRS117 [1] absorbing materials are presented.**

I. INTRODUCTION

Absorbing materials are in use for different purposes: in anechoic chambers, for electromagnetic shielding, in antenna design, for calibration targets of radiometers, etc. It is very important to characterize them in terms of frequency dependent complex permittivities and permeabilities for a broad frequency range.

Permittivities and permeabilities of materials are extracted from scattering parameters - transmission and/or reflection. There are different methods for measurements of scattering parameters. Coaxial line, rectangular and cylindrical waveguide measurements are widely used measurement techniques due to their simplicity [2, 3]. In these methods, material sample is placed inside of section of the waveguide or coaxial line and scattering parameters are measured with a vector network analyzer. Major problem in transmission line measurements is possible existence of air gaps between the sample and walls of the waveguide, which means that material sample must be machined very precisely.

Free space measurement is non invasive broadband technique for transmission and reflection measurements. Scattering parameters are measured on the sample that is plane parallel. Measurement setup consists of two identical antennas (for broadband measurements, horn antennas are good candidates) that operate in certain frequency range and vector network analyzer. Antennas are aligned and one of them transmits signal while the other antenna works as receiver. Material sample is placed between two antennas so sent signal passes through material and is registered by the other antenna.

To extract permittivity and permeability parameters from measured scattering parameters following approaches can be applied. Analytical approach (Nicholson Ross Weir derivation) [2] for permittivity and permeability extraction needs both transmission and reflection measurements and is very sensitive to noisy data. Numerical and iterative methods [2, 4] usually need initial guesses of unknown parameters to be within 10 to 20 percents of the true values in order to converge to the correct solution.

If we examine material that is not characterized before, it is difficult to have good starting values of unknown parameters. Procedure that we propose use only free space transmission measurements (both amplitude and phase) and does not need any initial guesses of unknown parameters.

II. PROCEDURE FOR PERMITTIVITY AND PERMEABILITY EXTRACTION

In our approach, we use only free space transmission measurements and least square fitting routine. Materials that we examined are Eccosorb CR110, CR114 and CRS117. In the CR materials, the particles of the magnetic filler are embedded in a castable epoxy resin, which forms a rigid material once it is cured. The CRS materials are based on a Silicone rubber which remains flexible after has been cured. A higher product number indicates a higher filling factor of the magnetic loading and the higher absorption. CR and CRS materials (with the same product number) should have the same properties in terms of complex and frequency dependent permittivities and permeabilities. Permittivities and permeabilities of Eccosorb materials are characterized by manufacturer up to frequency of 18GHz. Some examples of extracted permittivity values of Eccosorb absorbers are in [1, 5-6]. The extracted permittivities are for frequencies above 100GHz.

Samples that we examined are 2.00mm thick with plane parallel circular surfaces. For free space measurements (for both transmission and reflection) instead of placing a sample between the two antennas on some distance from each of them, we place sample at the antenna's aperture. Antennas that we used are corrugated horn antennas which have better approximations of free space propagation at the aperture than rectangular horn antennas. Starting assumptions are that absorbing material is isotropic, homogeneous and two composite (contains dielectric matrix and magnetic inclusions).

Debye relaxation model represents permittivity (1) while permeability is modeled by Lorenzian resonant model (2) [7]. Free unknown parameters in Debye model are: ε_s is static permittivity, ε_∞ is permittivity at high frequencies and f_r is relaxation frequency. Free unknown parameters in Lorenzian model are: μ_s is static permeability and f_m is resonant frequency.

$$\varepsilon(f) = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + j\dfrac{f}{f_r}} \tag{1}$$

$$\mu(f) = 1 + \frac{\mu_s - 1}{\left(1 + j\dfrac{f}{f_m}\right)^2} \tag{2}$$

Debye and Lorenzian models can have slightly different forms if they include asymmetric and damping factors [8].

As a starting value for the static permittivity ε_s in the Debye model (1) we measure the sample's capacitance in a calibrated capacity bridge operating between 10Hz and 20 kHz. At frequencies higher than ~70GHz permeability is equal 1 because magnetization is not possible since applied field is very fast and magnetic domains cannot follow the field. To find unknown parameters of permittivity model we use unconstrained nonlinear optimization routine. We minimize the differences (in both amplitude and phase) between simulated and measured transmission data at high frequencies (where permeability is equal 1) and in that way we retrieve permittivity model (we find ε_∞ and fr). In the same way we extract permeability model (2) from the fitting of measured and simulated transmission data at low frequencies (where permeability is different than 1). For transmission data simulations at low frequencies we use permittivity model extracted by fitting with high frequency data.

Fig. 1 and Fig. 2 represent measured and fitted amplitude and phase (respectively) of examined Eccosorb samples. A phase offset of one π (Fig. 2) has been applied between phases of different samples for clarity. By looking in amplitude behavior we can say that if permittivities and permeabilities are not frequency dependent, transmission coefficient would decrease with increasing frequency. The fact that measured transmission coefficient decreases in some frequency range and increase in the other, says about frequency dependent material parameters. If we look at phase behavior, the difference in phase slope of the samples again comes from different permittivities and permeabilities of each material.

To validate extracted models for both permittivity and permeability, we compare simulated reflection parameters with measurements. Good agreement is obtained.

III. RESULTS

Fig. 3 to Fig. 6 represent extracted frequency dependent real and imaginary parts of permittivities and permeabilities of CR110, CR114 and CRS117 absorbing material samples.

From the Fig. 6 we see that imaginary part of permeability shows resonance behavior for CR114 and CRS117 samples, while for CR110 sample it is relaxation form. That is because CR110 sample contains the smallest amount of magnetic inclusions (and exhibits the smallest absorption). One very important thing is that imaginary parts of permeabilities and permittivities cannot be smaller then 0 because in that case material would produce gain, which is not possible in the case of absorbing materials.

IV. CONCLUSIONS

In this paper we described a method for frequency dependent permittivity and permeability parameters extraction of magnetically loaded absorbing materials from free space transmission measurements.

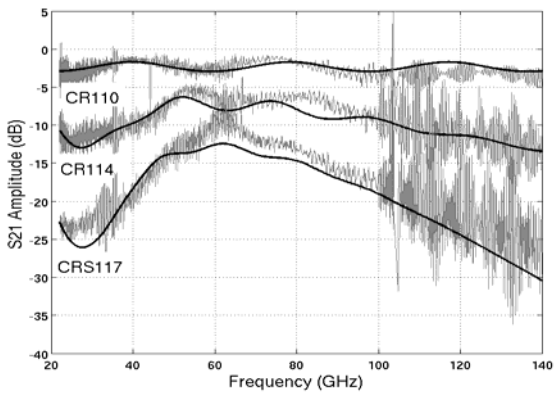

Figure 1. Measured and simulated transmission parameters for Eccosorb CR110, CR114 and CRS117 absorbing materials. Simulations are based on extracted permittivity and permeability models.

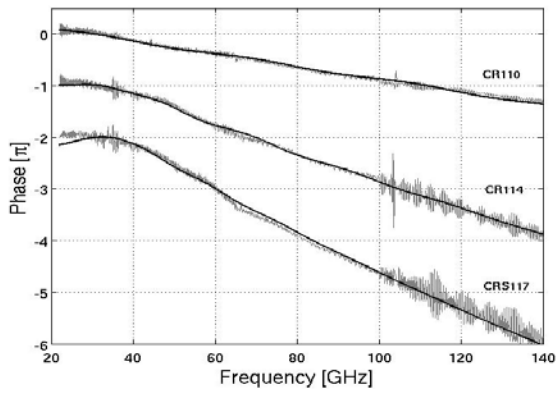

Figure 2. Measured and simulated phase of transmission parameters for Eccosorb CR110, CR114 and CRS117 absorbing materials. Simulations are based on extracted permittivity and permeability models.

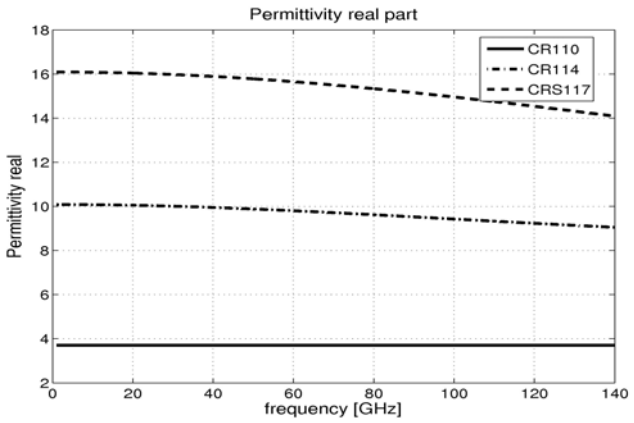

Figure 3. Extracted real part of permittivity of Eccosorb CR110, CR114 and CRS117 absorbing materials.

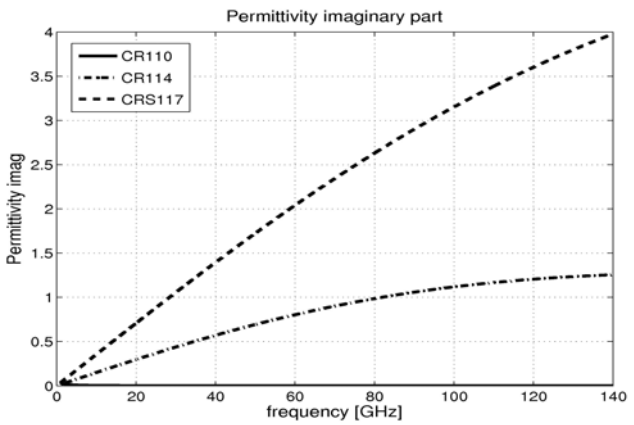

Figure 4. Extracted imaginary part of permittivity of Eccosorb CR110, CR114 and CRS117 absorbing material samples.

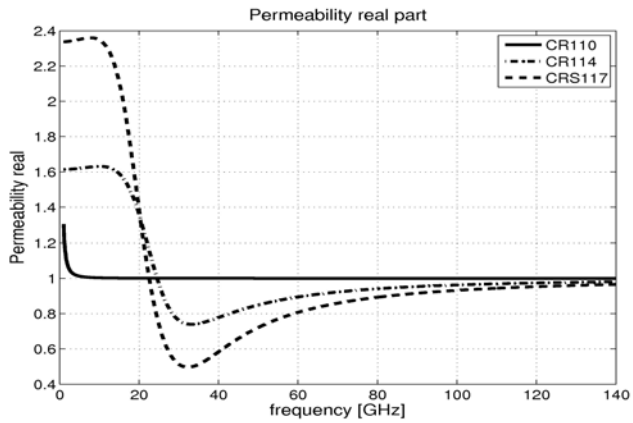

Figure 5. Extracted real part of permieability of Eccosorb CR110, CR114 and CRS117 absorbing material samples.

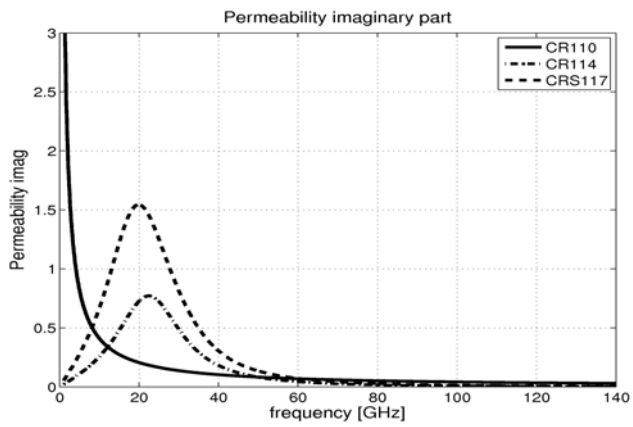

Figure 6. Extracted imaginary part of permittivity of Eccosorb CR110, CR114 and CRS117 absorbing material samples.

Our approach can be applied to noisy data and does not need anything to be known in advance.Starting assumption was based on the fact that material was two composite (dielectric matrix and magnetic particles). According to [7] about models that represent composite materials, dielectric property of our samples was modelled with simple Debye relaxation model, while complex permeability was modelled with Lorenzian resonant model. Important thing is that we restored first permittivity models of the samples by doing fitting at high frequencies where permeability is constant and equal 1. After that step we did fitting at low frequencies to extract permeability model. Proposed method is also suitable for permittivity extraction in dielectric materials in situations when we do not have any a priori information about material. Also, for the first time we presented extracted complex and frequency dependent values of permittivities and permeabilities of Eccosorb absorbing materials (CRS117, CR110 and CR114) up to frequencies of 140GHz.

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