Characterization and Modeling of Microwave Absorbers in the RF and Antenna Projects

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***Abstract* — Some practical problems concerning the characterization and modeling of microwave absorbers are discussed in this paper. First, a number of measurement methods are considered for determination of the relative and absolute absorbing ability of the most popular absorbing materials – foams, rubber sheets, coatings and thin films. Next, several more complicated methods for characterization of the complex dielectric parameters of the absorbers are presented and discussed. Finally, examples for modeling of microwave absorbers by 3D simulators are given.**

***Keywords* — absorbing media, permeability measurement, permittivity measurement.**

I. Introduction

Most of the modern communication RF devices and antennas look smaller than users might expect, according to their frequency band of operation. There are lots of methods for obtaining a "very large scale of integrations" (VLSI) in these devices: complex integrated circuits, systems on chips, multi-layer implementation, effective screening between the components, suppressing of the mutual interactions, applying of metamaterials. A very effective method is the utilization of *absorbing materials*: absorbing foams, rubber sheets, sprayed coatings, thin films, etc. – see Fig. 1. Let us give an example. Modern multi-layer antenna arrays contain a number of RF-layers with active and passive components and usually the mutual influence between them is inevitable [1]. Depending on the distance between layers, the method of "grounding" of the structure and the density of the feed lines and mounted components, different parasitic modes and resonance excitations might exceed the admissible power level and destroy the antenna RF performance. As a rule, these unwanted processes (parallel-plate modes, surface waves, self-excitation in low-noise amplifiers, etc.) are very difficult to be foreseen during the design process. A reasonable solution of this problem in the multi-layer antennas is the utilization of appropriate microwave absorbers, in order to properly "isolate" the RF-layers and devices. How the RF engineers are using the microwave absorbers in their work? Usually they are looking for absorber materials with appropriate attenuation in a given frequency range. In this case the users have a necessity to verify the absolute or even the relative *absorbing ability* of the used materials, and they can pass over the problem of knowing the complex permittivity and permeability. Thus, the values of the attenuation in dB/mm through a given absorber layer in the frequency range of interest are fully enough to characterize the absorbing abilities of the materials. We summarize and compare in this paper several measurement methods, which can be used for this purpose.

Lately, another need has appeared in the RF designer work, namely to have possibilities to simulate the whole devices or antennas by 3D simulators, when the absorbing layers are incorporated in the structures. Now they have to know the complex permittivity and permeability of the used materials. Unfortunately, most of the producers do not give enough information for the absorber material parameters. Therefore, users must measure the complex permittivity and permeability of the samples in their laboratories. The determination of the material parameters (especially of the permeability) is considerably more difficult than the measurement of the absorbing abilities of the same materials. We describe here several simple methods for this purpose. Finally, we present examples for simulation of simple structures with microwave absorbers.

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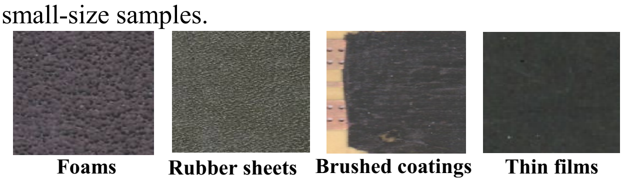
II. Determination of the Absorbing Abilities of the Microwave Planar Absorbers

The classical method for absorber characterization is the free-space method – see Fig. 2a. The measurement setup consists of two well-matched antennas (usually horns) installed at a large enough distance from the sample (~$10\lambda_0$), thus ensuring the far-field plane-wave behavior of the system [2]. However, this method is more or less inconvenient, because it requires very large absorber samples. The sample dimensions can be decreased, if spot-beam antennas are used (spot-focusing lens horns; distance ~$3\lambda_0$). Two main sources of errors are typical for these measurement systems – diffraction effects from the specimen edges and multiple reflections. Therefore, a number of near-field methods can be implemented for small-size samples.



Foams **Rubber sheets** **Brushed coatings** **Thin films**

Fig. 1. View of the surfaces of the most popular planar absorbers.

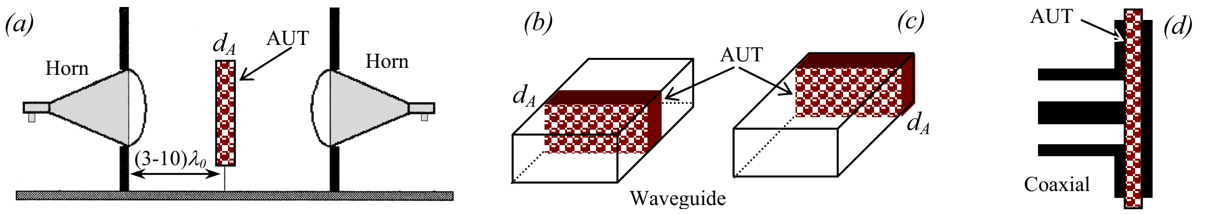


Fig. 2. Three classical methods: a) free-space method; two focused-beam horns and relatively large sample – absorber under test (AUT); b, c) transmission- and reflection-type-waveguide WG method; d) open-ended coaxial probe; d_A – sample thickness.

A. *Waveguide and coaxial methods*

The near-field methods are very effective for absorber ability test due to the utilization of small-size samples with thickness d_A inserted into waveguides, coaxial lines, etc. Two of these methods are the most popular (Fig. 2 b, c, d) – transmission- or reflection-type measurements between two open-end rectangular waveguides [3] and reflection-type measurements by open-end coaxial probes, where the opposite end of the sample is well grounded [4]. The WG methods are classical methods for absorber tests. They can be implemented in many options. We are using here transmission- and reflection-power regimes for relatively thin samples ($d_A \langle\langle \lambda_g/2$) without any resonance effects, which fully fit the waveguide cross section (WGt1, WGr1 in Fig. 3, 4) or are placed between two waveguide flanges (WGt2, WGr2). We present in this paper lots of comparative results for the attenuation and phase delay of three typical absorbers: rubber-sheet absorbers BSR-1 (Emerson& Cumming) and FM8 (Kolector Magma) and foam absorber Ecossorb LS26 (E&C). First of all, we can note that the absorbing ability of the investigated materials is clearly separated in the frequency range of the measurements. Second, the differences between the results for samples with different shape (methods WGt1 or WGt2) are relatively small (Fig. 3a). An important advantage of the transmission-power measurements is that a simple de-embedding of the mismatch losses from the total losses in the structure should be used only.

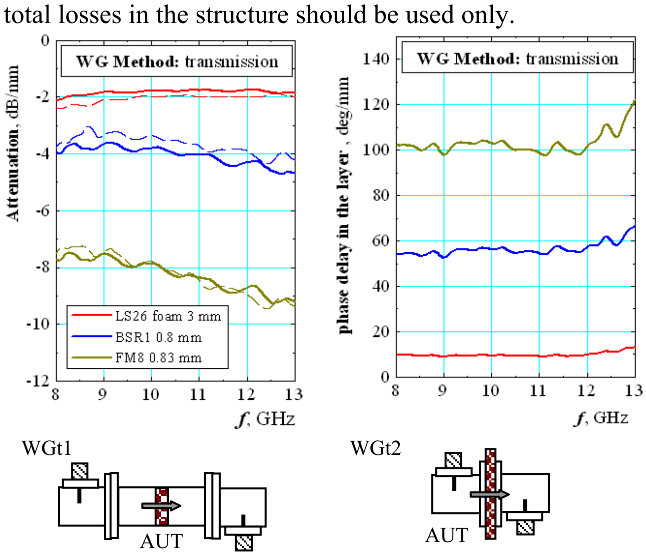
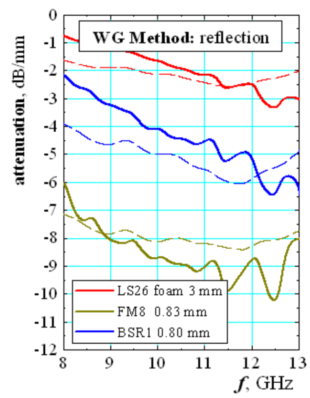


Fig. 3. Measured attenuation and phase delay in three absorbing samples by waveguide transmission-type methods: solid lines (WGt1); dashed lines (WGt2).

Contrary to this, a relatively complex theoretical model should be used in the reflection-power measurements due to the multireflection effects. Fig. 4 presents results for attenuation of the same samples, obtained by the reflection-type methods WGr1 and WGr2. The utilization of the WG methods is restricted to the frequency bandwidth of the used waveguides. On the contrary, the coaxial-probe methods are broad-band; some of them are especially developed for absorber characterization [4, 5]. We have obtained results for the attenuation of the considered materials in a wide frequency range – see Fig. 5, which confirm the results from the WG methods. The utilization of the open-end coaxial-probe method is extremely easy, but the measured S-parameters should be treated by a relatively complex mathematical procedure [4] in order to obtain the sample's parameters.



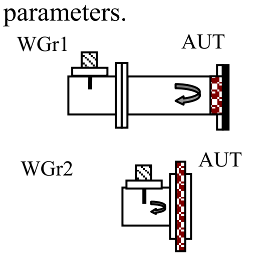
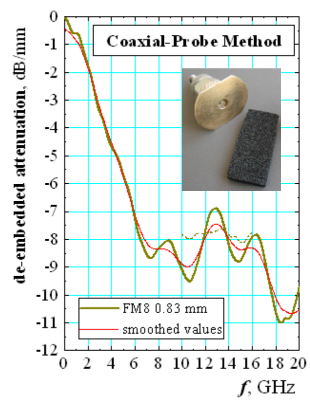


Fig. 4. Measured attenuation by waveguide reflection-type methods: solid lines (WGr1); dashed lines (WGr2).



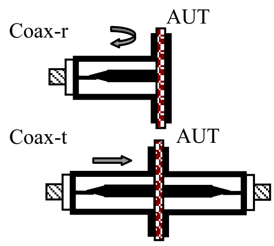


Fig. 5. Measured attenuation by coaxial open-end probe: solid lines (Coax-r); dotted lines (Coax-t).

B. *Fast test of the relative absorbing ability*

In many cases users need to know only, which absorber is better in the frequency range of interest. For this purpose we apply a fast, but accurate planar transmission-line method, presented in Fig. 6. It has two options. In the first option equal-in-thickness absorber samples are placed directly over 50-Ohms microstrip line (MSL1) (or grounded coplanar waveguide) – Fig. 6a.

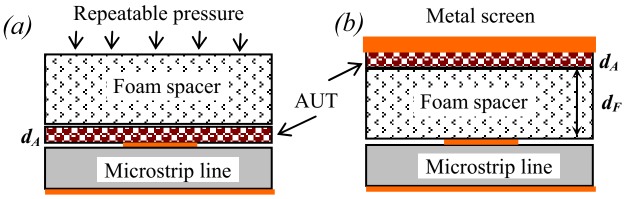


Fig. 6. Fast and accurate planar-line method for determination of the relative absorbing ability of samples with equal thickness d_A: a) placed directly over 50-Ohms microstrip line (MSL1); b) placed on a metal screen at distance d_F (MSL2).

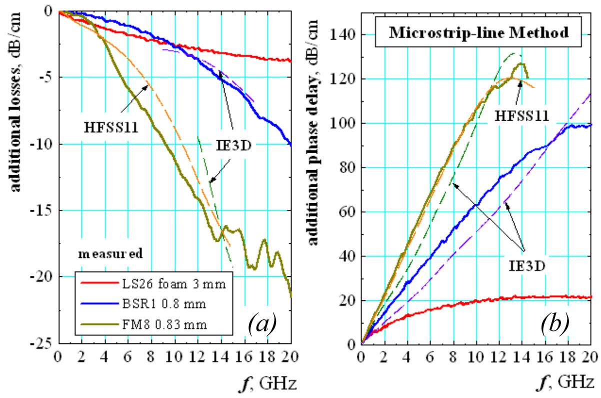


Fig. 7. Measured and simulated additional losses, dB/cm and additional phase delay deg/cm due to the absorber samples placed directly over 50-Ohms microstrip line (method MSL1).

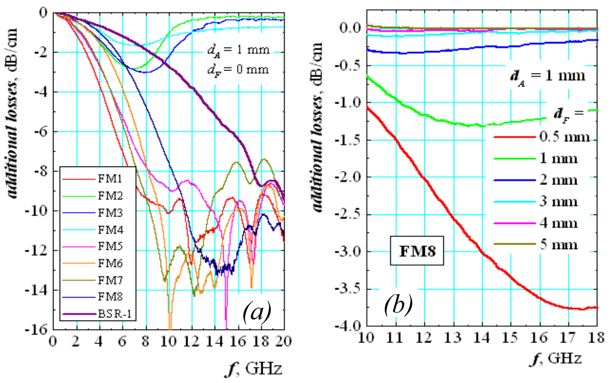


Fig. 8. Two typical implementations of the MSL method: a) Fast comparison between the absorbing abilities of different samples (MSL1); b) additional losses in 50-Ohms MSL due to a grounded absorber at different distances d_F (MSL2).

They cause additional losses in dB/cm and phase delay in deg/cm in these lines, which can be accurately measured – Fig. 7 a, b, if a repeatable pressure over the sample is applied. The frequency dependence of the additional losses is a relative measure of the absorbing ability of a given absorber sample. Fig. 8a illustrates how the frequency dependence of the absorbing ability of different samples with equal thickness could be compared in a wide frequency range. These dependencies show in which frequency range a given absorber can "work" and which absorber is better in this range. The second option (MSL2, Fig. 7b) is closer to the real conditions – grounded absorber samples are placed at a distance d_F from the plate surface. In this configuration we can measure the additional attenuation in the corresponding planar feed lines due to the influence of the used absorber (Fig. 8b) or verify how the absorber can suppress the parasitic excitation in the active RF devices on the plate.

III. Determination of the Complex Dielectric and Magnetic Constant of the Absorbing Samples

There are several methods especially developed for determination of the complex permittivity and permeability of absorber samples [4-8]. The main problem is the big losses in the samples, which decreases the sensitivity of the measurement setups. The considered WG methods (WGt1) or coaxial open-end methods (Coax-r) can be successfully used for the characterization of lossy materials (see [5, 7]). Another universal method for absorber characterization is based on the perturbation approximation [8]. For this purpose small samples (prisms, cylinders) can be inserted into rectangular resonators with TE_{10p} modes and after measurements of the resonance frequency shift and the quality factor, either a pure complex dielectric constant (for p = 1, 3, 5…) or a pure complex magnetic constant (for p = 2, 4, 6…) could be measured – see Fig. 9 (the results are presented in Fig. 10).

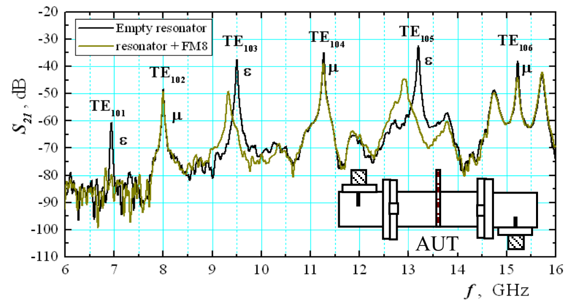


Fig. 9. Series of TE_{10p} resonances (p = 1-6) in an empty WG resonator and in a resonator with absorber sample FM8.

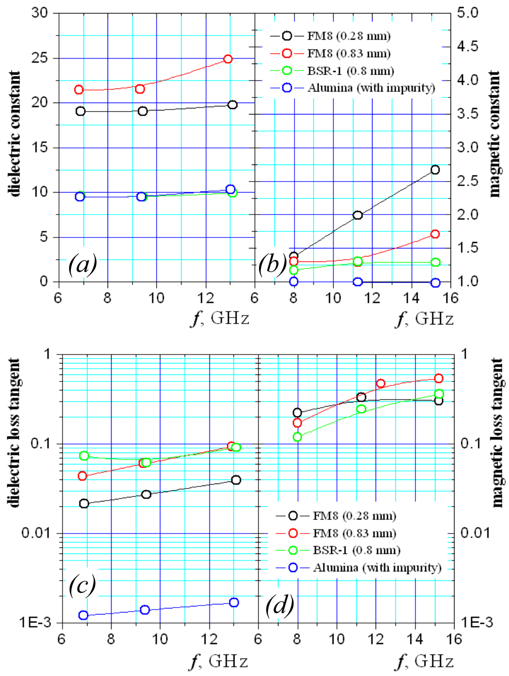


Fig. 10. Results obtained by two-resonator method for dielectric constant (a), magnetic constant (b), dielectric loss tangent (c) and magnetic loss tangent (d).

A problem may appear during the measurements of the permeability – if the sample has relatively bigger cross-section dimensions, the influence of a bigger dielectric constant of the absorbers may mask the resonance shift in the TE_{10p} modes (p = 2, 4…), caused by the pure magnetic properties. A specific geometric factor could be introduced in this case, but the corrections are usually below 10-15%. The success of the perturbation method is based on the small dimensions of the absorber samples. However, we can use other more accurate resonance methods, if the effect on the resonance characteristics is measurable (not so big). In this case we can use cylindrical resonators, for example – the two-resonator method [9, 10]. The idea of this method is to separate the effects of the influence of the sample dielectric and magnetic properties on the resonance characteristics of different suitable modes – see the illustrations in Fig. 11. For example, we can use TE_{011} mode for measurement of the pure dielectric parameters, TE_{112} mode – for measurement of the pure magnetic parameters or TM_{010} mode – for measurement of the magnetic parameters, if the dielectric ones are already measured. Fig. 12 presents comparative results for the product ($\varepsilon_r \times \mu_r$), obtained by different methods: perturbation, two-resonator method and WG transmission-power method WGt1.

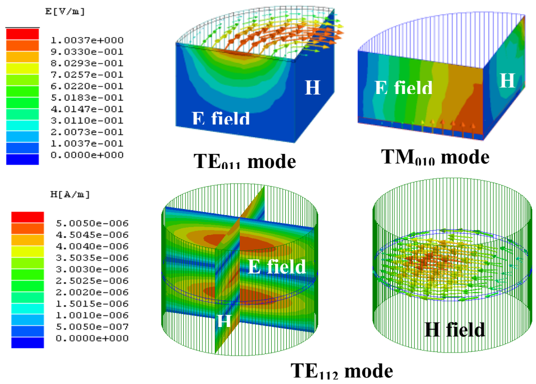


Fig. 11. Illustration of the E- and H-field distribution in measurement cylindrical resonators with different supported modes: TE_{011}, TM_{010} and TE_{112}.

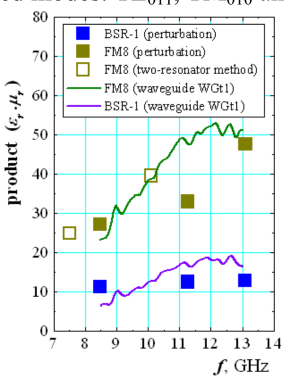


Fig. 12. Measured product ($\varepsilon_r \times \mu_r$) by different methods.

IV. Modeling of Microwave Absorbers by 3D Simulators

Finally, when the full set of the dielectric and magnetic parameters of the considered absorbing material is determined, the corresponding absorber layer can be successfully modeled and simulated by 2.5D or 3D electromagnetic simulators. Fig. 13 illustrates a simple structure, modeled in HFSS-11; the obtained simulation results are presented in Fig. 7. The observed differences from the measured data are small enough for simulation of such type of lossy materials. The main problem during the simulations is that the absorber parameters are usually frequency-dependent and the results are valid in a narrow frequency interval.

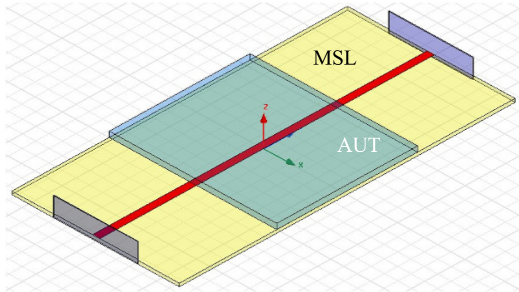


Fig. 13. 3D simulation model (HFSS-11) of microstrip line, covered by rubber-sheet absorber (see the results in Fig. 7). The structure can be used as a model of the method MSL1. The obtained parameters for the rubber absorber FM8 are: $\varepsilon_r \sim 18.0$; $\mu_r \sim 1.5$; $\tan\delta_\varepsilon \sim 0.2$; $\tan\delta_\mu \sim 1.0$ at $f \sim$ 11-13 GHz.

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