BROADBAND ELECTROMAGNETIC CHARACTERIZATION OF MATERIALS FOR ACCELERATOR COMPONENTS

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Abstract

Electromagnetic (EM) characterization of materials up to high frequencies is a major requirement for the correct modeling of many accelerator components: collimators, kickers, high order modes damping devices for accelerating cavities. In this scenario, the coaxial line method has gained much importance compared to other methods because of its applicability in a wide range of frequencies. In this paper we describe a new coaxial line method that allows using only one measurement setup to characterize the material in a range of frequency from few MHz up to several GHz. A coaxial cable fed at one side is filled with the material under test and closed on a known load on the other side. The properties of the material are obtained from the measured reflection coefficient by using it as input for a transmission line (TL) model or for 3D EM simulations, which describe the measurements setup. We have applied this method to characterize samples of SiC (Silicon Carbide) which could be used for LHC collimators and for CLIC accelerating structures and NiZn ferrite used for kicker magnets.

INTRODUCTION

The electromagnetic (EM) characterization of materials is required in different domains of accelerators research. For example it plays a crucial role in the impedance modeling for the SPS accelerator complex at CERN or for damping materials in CLIC accelerating structures.

Up to now the characterization of dielectric materials for CLIC was based on the waveguide method. A sample of material is inserted in a waveguide of dimensions depending on the range of frequencies to be characterized. Therefore the complex transmission coefficient S_{21} in a certain range of frequencies is measured. This quantity is related to the propagation constant and then to the electromagnetic material properties (permittivity and permeability). Therefore from the knowledge and inversion of this function (calculated numerically) it is possible to infer the EM material characteristics [1, 2]. Anyway this method needs different setups to investigate a wide range of frequencies and is not easy to treat analytically. For these reasons we decide to resort to a coaxial cable method. In this way it is possible to overcome the limitations set out above.

COAXIAL METHOD

A short standard coaxial line filled with the material to characterize is closed on a well-known load. Using a network analyzer the reflection coefficient is measured (see Fig.1). Similarly to the waveguide also in this case the measured parameter is related to the unknown material properties. This function can be obtained numerically (from 3D finite elements simulations) or from basic TL theory.

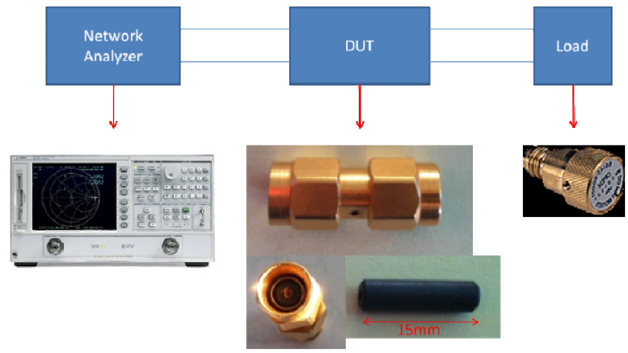

Figure 1: Measurements setup (DUT stands for device under test)

Study of feasibility of the method

The feasibility of the adopted method was studied using a 3D EM simulator as the environment for ideal measurements and a TL model to obtain the reflection coefficient as function of the material properties [3, 4]. The same function is obtained also numerically from the 3D EM code CST Microwave Studio. The flowchart of Fig. 2 explains the procedure with these two different methods.

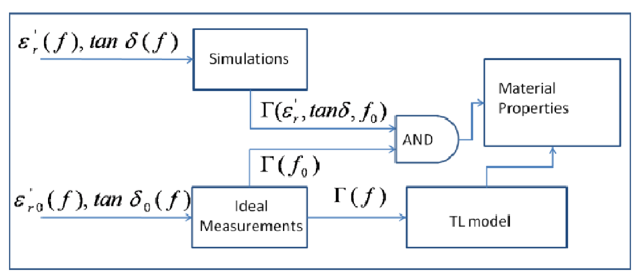

Figure 2: Flowchart for simulations and TL model techniques.

The measurement system is simulated using the material properties (real permittivity and electric loss tangent) as free parameters; the output of the simulations is always the reflection coefficient in a certain range of frequencies. From simulations we extrapolated the 3D surfaces that display the complex reflection coefficient as a function of real permittivity and loss tangent at a given frequency. The same function can be easily obtained also

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analytically by modelling the measurement system with the TL theory (see Fig. 3):

$$\Gamma(z) = \frac{Z(z) - Z_0}{Z(z) + Z_0}$$

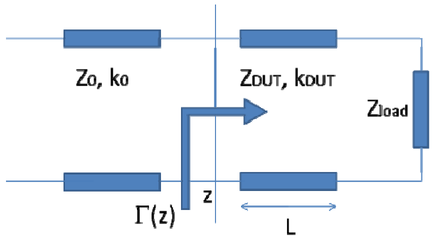

Figure 3: Transmission line model.

By using the function as calculated numerically we found the possible solutions of real permittivity and loss tangent from the contour plot that results from the intersections between the 3D surfaces, obtained numerically, and the ideal measurements i.e. the simulation of the reflection coefficient Γ at one single frequency for given material properties. Figure 4 shows the intersection of one 3D surface with the ideal measurements at a certain frequency.

Figure 5 shows contour plots for different 3D surfaces and points from the TL model. Different contour plots are displayed for different terminations of the transmission line (open ended and short ended) and for the real part and the imaginary part of Γ. The solution is the confluence point of all configurations. In this example the solution gives 10 for the real part of the complex permittivity and 0.2 for the loss tangent. These results are confirmed by the TL model and in fact the solutions for the short and the open end lie exactly on the intersection of all contour plots.

The encouraging simulation results, even in the limitation of the non-ideal world, encouraged us to proceed in the realization of the measurement set-up.

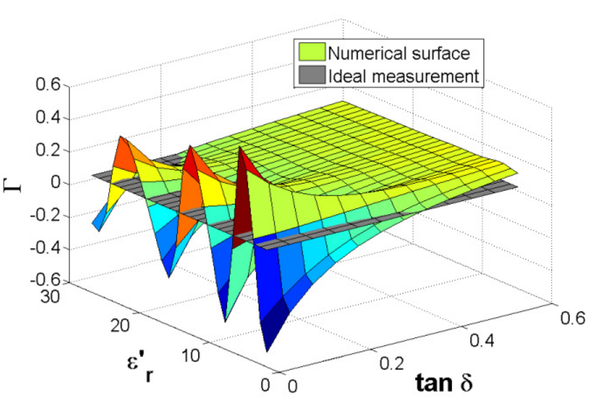

Figure 4: Reflection parameter as function of loss tangent and real permittivity.

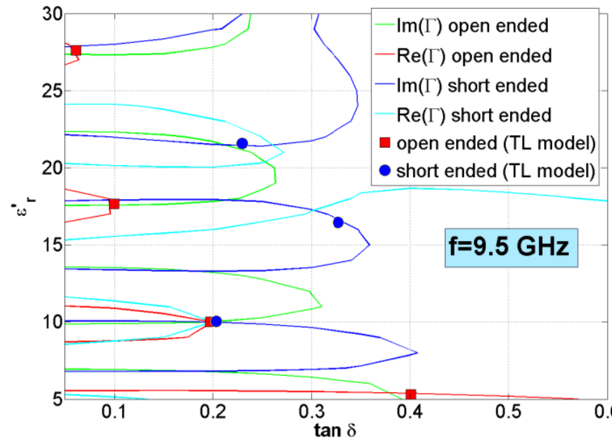

Figure 5: Contour plots for different 3D surfaces. The squared and round dots are calculated from transmission line model.

Measurements of dielectric materials: air-gap correction

One complication of the coaxial method is the presence of air-gap in the fabrication process for the sample under test. Because of limitations in our machining tools we accepted to have an air-gap between the inner conductor of the coaxial line and the material under test. A correction to the characteristic impedance was introduced to take into account the air-gap effect. Due to the air-gap the capacitance and the inductance have the following expression:

$$\frac{1}{C} = \frac{1}{C_{coax}} + \frac{1}{C_{gap}}$$

$$L = L_{coax} + L_{gap}$$

where C_{coax} and L_{coax} are the classical capacitance and inductance of a coaxial cable and C_{gap} and L_{gap} the additive capacitance and inductance due to the air gap [5]. The characteristic impedance of the line, taking into account also the air gap effect, has been then calculated.

Measurements of dielectric materials: some examples

EM properties have been measured by means of reflection parameter of coaxial line setup. Both EM simulations and TL model have been used to invert the functional relation. Figure 6 shows measurements of loss tangent $tan\delta$ and the real relative permittivity ε'_r in a wide frequency range for the SiC CerasicB1 calculated with the transmission line model. Also some material supplier measurements are displayed in a narrow frequency range. Figure 7 shows properties of SiC EkasicF in the range 9.5÷11 GHz performed with TL model. The dots are measurements with waveguide method at different discrete frequencies. Figure 8 shows the contour plots for

EkasicF at 9 GHz. Furthermore a measured point with waveguide method is displayed at the same frequency [6].

These results show that using the coaxial method we can investigate a wide range of frequencies with only one measurement set-up (see Fig. 6) and furthermore that coaxial and waveguide method give similar results (see Figs. 7 and 8).

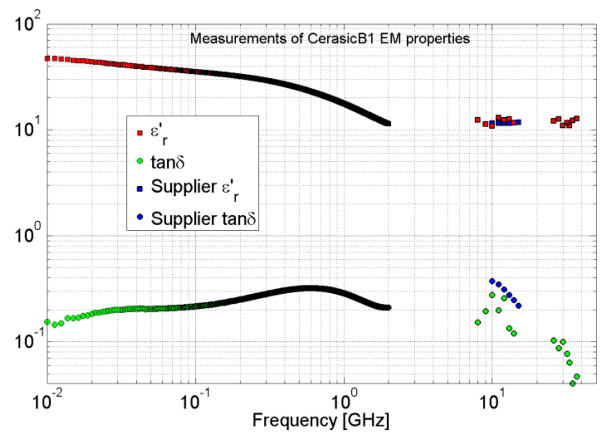

Figure 6: Measurements of real permittivity and loss tangent for SiC CerasicB1.

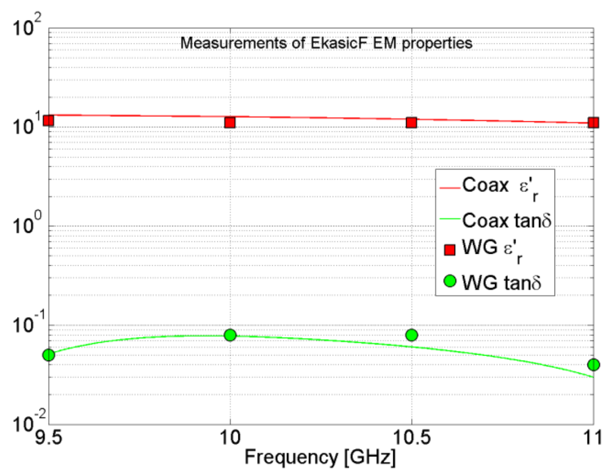

Figure 7: Measurements of real permittivity and loss tangent for SiC EkasicF

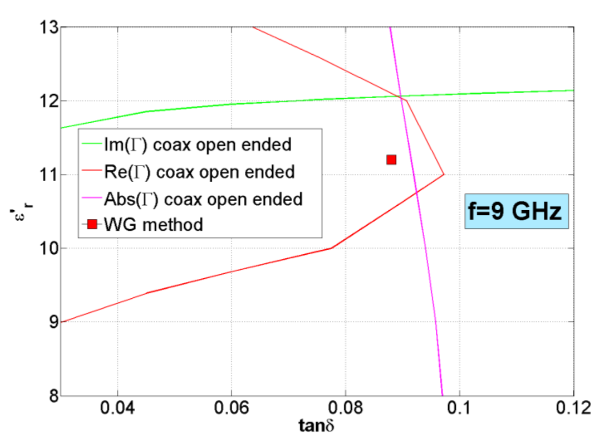

Figure 8: Contour plot for SiC EkasicF at 9 GHz.

CONCLUSION AND OUTLOOK

The coaxial method with its simple set-up and straightforward transmission line modeling has been used to characterize dielectric materials. Before starting measurements the feasibility of the method was demonstrated in virtual environment (see. Fig. 5). First results have been presented in a wide range of frequencies for CerasicB1. The EkasicF has also been measured and successfully benchmarked with the waveguide method in some frequency ranges.

One of the advantages with respect to the waveguide method is its wide range of applicability in terms of frequency, instead, one of the big limitations is the air-gap between the sample and the inner conductor due to machining limitations. The possible air-gap is taken into account not only in 3D EM simulations but also in the TL model. During measurements some high order modes have been noted and they can be suppressed by using different shapes for the sample under test. Measurements on new shape samples and new materials such as SiC EkasicP and aluminum nitride (AlN) have been planned [7].

Also measurements on ferrite materials have been done but the post-processing is much more complicated and requires further work.

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