EpsiMu : A New Microwave Materials Measurements Kit.

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1. Introduction

Since several decades, measurements of dielectric constant (permittivity) and permeability of materials in the microwave domain have been of great interest for stealth issues involving RAM (Radar Absorbing Materials) [1]. These measurements are still important, not only in military applications, but also in the civil arena with EMC/EMI problems in aviation, automotive, telecommunications, etc. Today, many people need to know permittivitty for a variety applications. There are several well-known techniques based on measurements in free space, in guided configuration and in resonant cavities. We propose a new kit (called *EpsiMu*) with an extremely simple coaxial cell using propagating guided waves, together with its associated software. The most important characteristic of this new kit is that it provides measurements in real time over a wide range of frequencies, and requires only one measurement to obtain all information on electromagnetic characteristics of material samples.

In the first part of this article, we give a brief history of permittivity measurements to explain the importance of this measurement method. In the second part, we describe the new kit and present some illustrative results.

2. Why *EpsiMu* ?

For an isotropic media, the complex relative permittivity ε_r and permeability μ_r depend on frequency:

$\varepsilon_r = \varepsilon'(f)-j\varepsilon''(f)$ and $\mu_r = \mu'(f)-j\mu''(f)$.

It is commonly known that the determination of the complex dielectric permittivity and the complex permeability in microwave range is quiet difficult. As already said, several different techniques are used in different laboratories [2,3]: free space techniques or guide line techniques (rectangular, circular or coaxial guide line). In general, all common experimental techniques are difficult to use: after calibrating the vectorial network analyser (VNA) to fix reference planes of phases, it is necessary to recalibrate the cell each time before introducing a different material sample. After a study of the performance of different methods, we have adopted a reflexion/transmission technique in a coaxial line [4]. This method allows us to make wide-band measurements [5,6] in real time by using the de-embedding technique [7].

This de-embedding is possible because we characterise the cell in terms of fixed parameters: the electrical length and linear attenuation, they form an Identity Card off the cell. With this method, we do not need to recalibrate the cell every time. Only the calibration of the VNA is necessary.

EpsiMu is a new method, because only one measurement of the [S] matrix of the sample is sufficient to determine both dielectric permittivity and permeability. Consequently, from the same data set, it is possible to calculate other quantities of interest such as tanδ or additional diagrams (for example a Cole-Cole diagram).

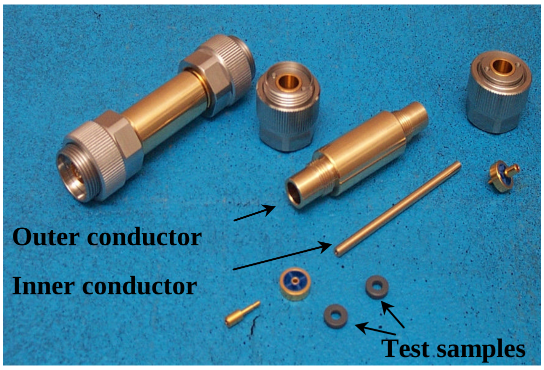
3. Description of *EpsiMu* kit

3.1. Measurement Cell

EpsiMu kit is composed of three parts: a special coaxial cell, a associated software and a measurements guide.

The cell is manufactured in our laboratory and could therefore be modified to address a variety of physical problems (liquids, powders, and studies versus temperature, *etc*). The standard cell is around 144 mm long. The outer diameter is 7 mm. Connectors are of the type PC7. The dimensions determine the frequency range, the highest frequency is over 19 GHz. We fix frequency range from 1GHz to 18GHz.

Two coaxial cells and a sample of a test material are shown in the first photograph. One of the cells is taken apart to view all the components of the cell.



Photograph 1: Coaxial cell

This cell is characterised with its electrical distances from the reference phase planes and with its attenuation. These characteristics form the Identity Card. Each cell must be measured to determine its "Identity Card". Knowing these characteristics, the de-embedding technique can be performed.

3.2. Associated Software

The software of *EpsiMu* is not restricted to a particular VNA. In fact, any analyser could be used with *EpsiMu*. Tests were performed with Agilent 8510 and 8720 family, Anritsu MS462x family and Rodhe & Schwarz ZVR or ZVM. However, it is assigned to one particular cell versus its Identity Card. This sowftare have two parts: the first part performs measurements in real time. This is the "*Epsilon-meter*". The second part is used post-treatments, for example, visualisation, comparisons of several results, *etc*.

Nowadays, the software is in its first version, but a new one is under preparation to propose greater possibilities, like a linearization of results, or visualisation of Cole-Cole diagram, *etc*.

3.3. *EpsiMu* Kit

We show the complete kit in the second photograph. It contains one measurement cell, some accesories to make and verify materials samples and one CD, containing the associated software, the measurement guide and some data to verify the kit. In addition, a sample of the reference material is in the kit.

Photograph 2: *EpsiMu* kit

4. Results

To illustrate the performance of this new kit, we chose several particular materials: a dielectric material (polyethylene), a magnetic material (Emerson and Cuming SF10) and air sample.

At first, we can verify if the measurements with *EspiMu*, are correct by using the visualisation of the S-parameters of the sample. In particular, we can determine if the sample is too long or manufactured not perfectly.

Second, we can proceed to measurements in real time. The result of these measurements are shown in the next figures.

4.1. Dielectric Material: Polyethylene

The thickness of the sample is 1.85mm. Four curves are plotted on these graphics presenting permittivity and permeability, two for the real parts (forward and reverse measurements with VNA) and two for the imaginary parts.

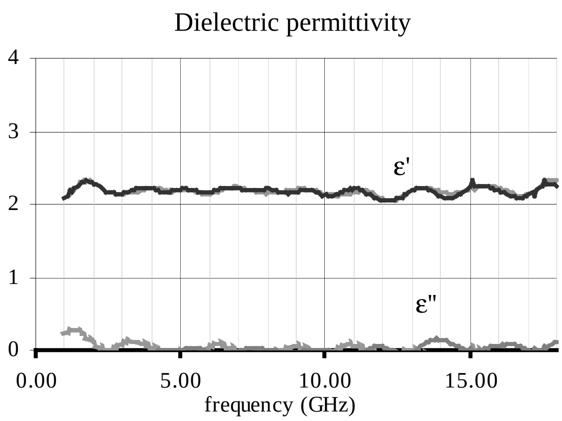


Figure 1:Polyethylene : permittivity

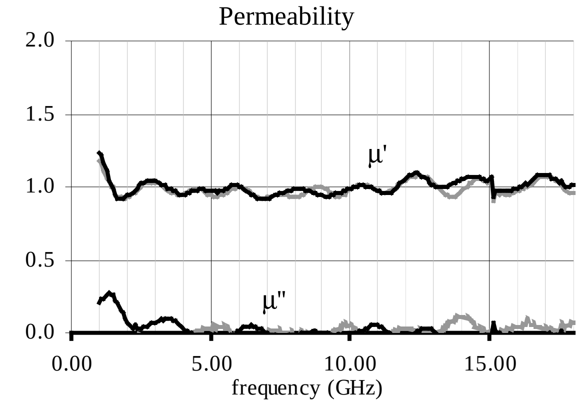


Figure 2: Polyethylene: permeability

4.2. Magnetic Material: SF10

This material is magnetically-loaded, electrically non-conductive silicone sheet. It is manufactered by Emerson and Cuming. The true thickness of the test sample is 1.8mm (the nominal thickness given by the manufactured is 1.4 mm).

We can verify in figure 2 that this material is magnetic because the real part of its permeability differs from unity. The black curves are obtained with foward measurements with VNA (S_{11} and S_{21}) and the grey curves are obtained using reverse measurements (S_{22} and S_{12}).

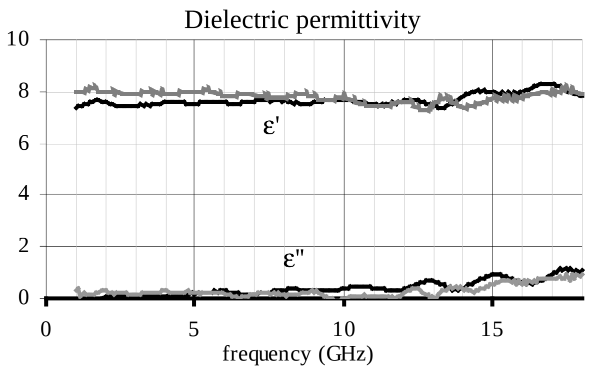


Figure 3: SF10 : permittivity

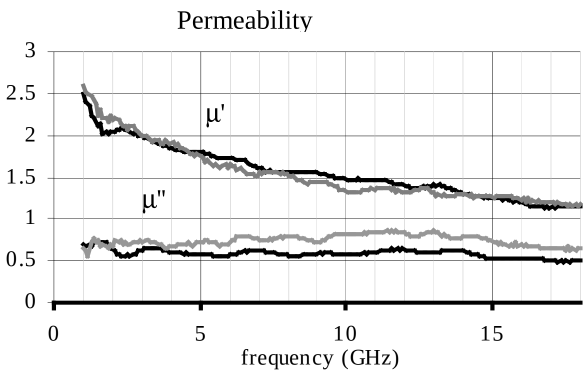


Figure 4: SF10 : permeability

4.3. Air

To test the kit, we measure an empty cell like an air-line. The thickness is not defined. So, we can choose any values to demonstrate several phenomena. In the same figure 3 a same graphic (figure 3), four curves are ploted with four arbitrary values of thickness: 3, 4, 5 and 6mm. All results are superposed, as could be expected.

The results for the other three parameters are identical (ε"≈ 0, μ' ≈1 and μ" ≈0).

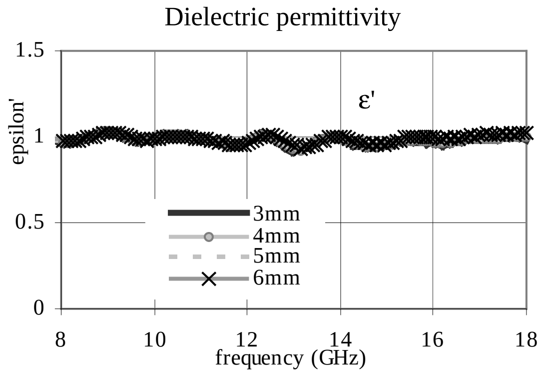


Figure 5: test with empty cell

The choice of sample thickness is very important because, a jump will appear when the thickness is higher than $\lambda_{mat}/2$. And indeed, for a thickness equal to 9mm of the same virtual air sample, the jump appears at 16.6GHz (figure 4).

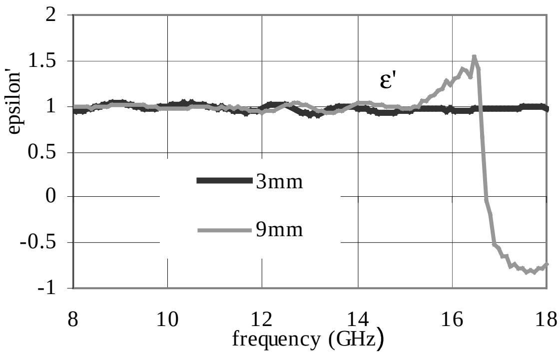


Figure 6: Choice of thickness (test with an empty cell)

Because of this jump, when using the first version of *EpsiMu*, the thikness of samples must be lower than $\lambda_{mat}/2$. In the next version of the software, we shall take into account these jumps.

The accuracy of measurements is around ±3% and ±10% depending on values of permittivity and permeability constants and on the nature of material.

5. Conclusion

EpsiMu is a new kit for measurements of dielectric constant and permeability and is easy to use. The results are obtained in quasi real time because only one measurement is necessary to obtain simultaneously all the data. *EpsiMu* is compatible with any vectorial network analyser.

The materials analysed in this article are different from the reference material included in the kit, which is a sample of APU10 made by SIEPEL, a company specialised in manufacturing shielded rooms, anechoic chambers, absorbers, reverberation chambers, stripline antennas, turntables, antenna masts and shielded cabinets. SIEPEL is associated with Institut Fresnel to commercialise *EpsiMu*.

Today, *EpsiMu* is a name which is reserved to this kit [8]. Today this kit is avaibale on the open market. *EpsiMu* presents a true evolution in the technique of electromagnetic characterisation of materials. The kit can be used with each kind of vectorial network analyser. Several new versions will be available in the future time.

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