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A new solution of permittivity and permeability measurement system with temperature variation

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Abstract. Nowadays, permittivity and permeability measurement are well-known in the industrial domain and research laboratory. It became unavoidable in few domains as biomedical and aeronautics. In this way, many researchers or engineers are committing to working on new measurement setup, complex or not working on a wide band of frequency. However, the thermal dependence of dielectric and magnetic structure is quite complicated to determinate, even though it became more and more important to know. As in the case of radomes antennas, the air friction produces increasing of temperature and thereby electromagnetic characteristics variation. Accordingly, we propose in this paper, a new characteristics measurement system of solid material between 100MHZ and 15GHz coupled to a high-temperature thermoregulation system designed to reach a few hundred degrees.

1. Introduction

Contrarily to the classic electromagnetic characteristics measurement setup which is well known [1, 2, 3], the measurement with a variation of temperature is not still well developed. Few measurement systems based on resonant setup [4, 5, 6] and some with waveguide line [7, 8, 9, 10] exist but especially in the research domain. The complexity of those systems made them expensive and hard to use. Furthermore, there are often made for a specific application and so at a specific frequency or closed range. The ideal setup should have a wide band of frequency to be useful for many applications and combined with a wide thermoregulation system. But this one does not exist. In this paper, we propose a new measurement setup with a wide band of frequency to reach higher temperatures, based on coaxial waveguide correlated with a specific oven. The aim of this study is to demonstrate our possibility to characterize solid material, magnetic or only dielectric at high temperatures. As a first step, we describe the measurement setup followed by all the issues we met. Finally, we present different results obtained on two different material. One is only dielectric (PEEK [11]) and the other is dielectric and magnetic (APU10).

2. Experimental setup

2.1. Measurement setup

An electromagnetic (EM) characteristics measurement system, based on a 35cm length coaxial line (7mm diameter for the external diameter) as a transmission-reflection line, has been

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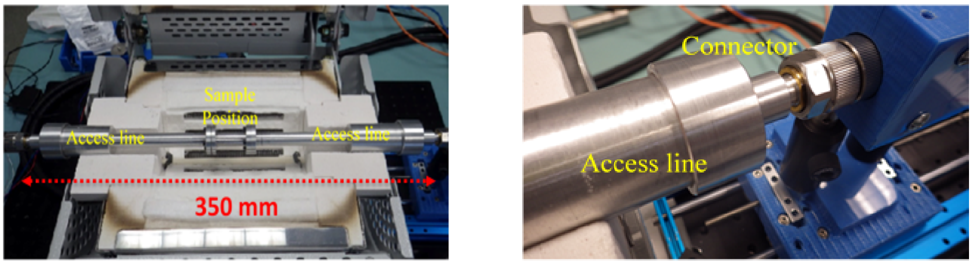
developed in our laboratory. This setup has been combined to a tubular oven (Carbolite-Gero) in order to control the temperature inside the coaxial line and finally in the sample. This kind of setup is designed to reach high frequency (20GHz) and high temperature (over 1 thousand degrees) along the cell (Fig. 1 (a)).



(a) (b)

Figure 1. (a) EM measurement system for solid material at high temperature.(b) New connectors system with thermal isolation for coaxial line.

The sample to test is placed in a sample holder in the center of the cell to isolate the other part of the cell. To obtain the Scattering parameter of the sample, a calibration is performed before the measurement. The calibration procedure consists on a Thru-Reflect-Line (TRL) technique. Two lines have been chosen (40mm and 24mm) in order to improve the calibration. In addition to the thermoregulation system, the cell is connected to a Vector Network Analyzer (VNA) to obtain the scattering parameter (S-Parameter) of the setup. Thanks to the calibration and the S-parameter of the setup we easily obtain the S-parameter of the sample. The link between the S-parameter and EM characteristics of a sample has been well developed in the literature as the Nicholson and Ross [12] method we chose for this setup. The specificity of this setup is the connection between the cell and coaxial cable of the VNA. With the aim of reducing the heat transfer between the cell and the cables, we designed specific connectors based on a temporary connection (Fig. 1 (b)). In a heating cycle, the cell is completely exposed to temperature variation. Without caution, it could damage classic connectors or cables.

2.2. Issues

The thermoregulation system correlated with radio-frequency setup can bring many issues. In order to correct those issues, we studied each case separately :

- Heat transfer : The actual measurement setup has been done to solve this issue. Classical connectors like APC7 by Rosenberger works only below 85°C. To solve this issue, the solution adopted is a temporary connection on each side of the cell. In fact, in a heating phase, the coaxial line is isolated from the vna cable. In this way, we can wait enough time to let the temperature of the cell and finally of the sample, increase. When the temperature is reached, the connection between cable and cell is done, the measurement is processed, and contact is broken.
- Sample heating : As said in the previous issue, our connectors let the coaxial line heat up without any contact with VNA cable. Thanks to this its possible to heat the sample as long as we want. Indeed, the main problem of this setup is how to know the temperature of the sample. Because the thermometer isnt placed inside the sample holder, we have no information about the samples temperature. Whereas we know that after a certain time the temperature will be homogeneous in all the cell. We decided to choose for each step of temperature and depending on the material, a time t we have to wait to consider a homogeneity inside the coaxial line.

- Maximum temperature of the cell : In a heating up phase the temperature of the entire cell increase. In this way, its important to use only material useful for high temperature. All the coaxial line is made with steel but between the internal part and the external part, we use dielectric material to hold everything at the correct distance. As a dielectric material, we choose the PEEK which have high thermal and chemical stability. In the next work, we will change the PEEK with quartz to reach higher temperatures.
- Thermal expansion : Beyond the variation of the EM characterization of the material, the temperature can affect the physical structure of the coaxial line and the sample. This effect is the thermal dilatation and is solved by studying the measurement phase and compensate in post-processing.

2.3. Results

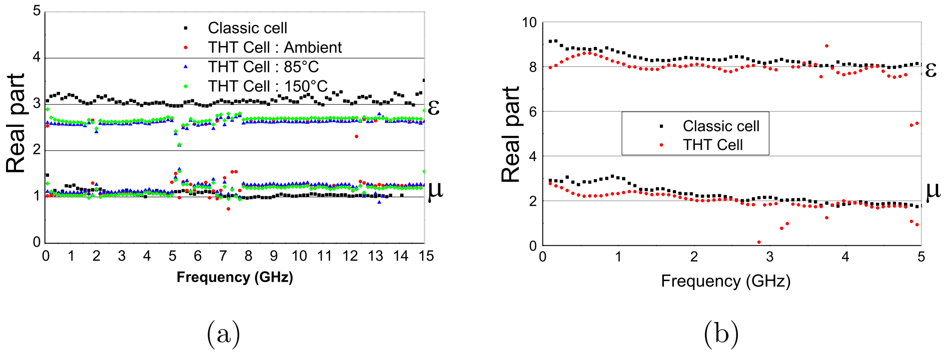


Figure 2. (a) Plot of the real part of the permittivity and permeability of PEEK with the new temperature measurement setup (THT Cell) a 3 different temperatures and a reference cell (Classic cell [13]) at ambient temperature. (b) Plot of the real part of the permittivity and permeability of SIEPEL APU10 with the new temperature measurement setup (High temperature cell) and a reference cell (Classic cell [13]) at ambient temperature

In this study, we choose two different samples. The first one is a sample of PEEK with a 6mm length. This sample has been realized thanks to 2 samples of 3mm length each (The same samples are used as washers in the cell). This material have a high thermal stability and can be exposed at high temperature (around 200°C) without permittivity variation. Moreover, PEEK is a non-magnetic material which can be measured with a permeability equal to 1 for the real part. The second material is a silicon material mixed with carbonyl iron powder named APU10 (SIEPEL APU10). The sample length of the APU10 is 1.8mm. For the PEEK, measurements were done between 100MHz and 15GHz. However the APU10 measurements were done between 100MHz and 5GHz. This difference of frequency range is explained by the the difference of sample length. The length of the APU10's sample was not big enough to have a good precision at high frequency. For each sample, permittivity and permeability was calculated. Nevertheless, each plot are focused on the real part only. The imaginary part cannot be considered because of the low value measured which have high uncertainties. In order to validate our measurement at ambient temperature, we compare it with a reference cell (classic cell [7]) on the same frequency range (Fig. 2 (a) and (b)). For the PEEK, we can notice a difference between the two measurements with the two setups in ambient temperature. We assume that this difference is impacted by the bad adaptation of the cell and bad contact between the two samples of PEEK. The two sample should be not well sticked together and produced air gaps between them. Furthermore, the insertion loss of the cell was not as accurate as we expected, due to impedance variation along the coaxial line. We are working on improving the adaptation, but we stay interesting in

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measuring EM characteristics with temperature variation. So, we tried to measure any variation of permittivity in the Sample of PEEK in Fig. 2 (a). We did 2 temperature measurements in addition to the ambient temperature, one at 85°C and the other at 150°C. The figure show that we measure no variation of the permittivity and permeability with temperature increasing which explains the temperature working range of PEEK (up to 250C). Furthermore it proves that the dilatation of the cell we could expect, is really small and allow us to continue temperature measurements on different sample as APU10.

3. Conclusion

Let's remember that many laboratory doesn't have access to electromagnetic characteristics measurement setup with temperature variation. This is why we decided to build a new setup solution to give the possibility to every researcher to characterize their materials. The aim of this paper was to demonstrate the ability of our setup to measure permittivity and permeability with temperature variation for solid material. In this campaign we study to different material, PEEK and APU10. The real part of the permittivity and permeability have been validated on different frequency range in ambient temperature. As we said in the results part the imaginary part has so much uncertainty and we still have to fix this. Concerning the temperature measurement, we focused only on the PEEK which is well-known in order to check the dilatation of our cell. The results confirmed what we expected and allow us to pursue our work on different materials. As future work we will improve the maximum working temperature of our setup which can theoretically go as more than 500°C. PEEK is used as washers in our cell will be then replaced by Quartz. Furthermore, we are still working on a new version of the coaxial line to improve the adaptation we consider as the issue of the permittivity and permeability measurement.

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