An overview of the techniques for measuring the dielectric properties of materials

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Abstract

Abstract— The review of techniques used for measurements of permittivity and permeability of materials for quasi-static electromagnetic field.

1. Introduction

Continually increasing demands in terms of speed, power and size requires the improvement of existing technology solutions. Passive devices dominate size, reliability and cost of printed circuit board (pcb). Such devices are used to prevent EMC problems. The costs due to such 'EMC' components (i.e. not only the components themselves, but placement etc.) can reach more than 70-75% of the total cost of the product, and this number is increasing rapidly.

As claimed in National Electronics Manufacturing Initiative (NEMI) Roadmap [1], embedded passive could be a key enabling technologies. Embedded passives are fabricated within substrates, according to [2]. They provide potential advantages for many applications including: increased circuit density, decreased product weight, improved electrical properties, and (possibly), cost reduction, increased product quality and improved reliability.

However, to date embedded passives have found only limited applications. One of the major limitations preventing the wider adoption of embedded passives is cost, as well as the complexity of suitable mass production technology. Various cost analyses of embedded passive systems have demonstrated that one of the major components of overall system price is material cost [3]. For this reason, research into new materials suitable for embedded applications which takes into account EMC requirements is needed.

Over the last decade, the creation of artificial materials that have tunable physical characteristics has been one of the growing areas of interest in the materials science community. Some of these materials, such as nanocrystalline alloys (ex. Fe73.5Cu1Nb3B9Si13.5), have excellent properties for preventing EMI, but are not available yet in a structure which could be helpful to reduce production costs for printed circuit board technology. Ferrite-loaded thin foam structures are available, but can be applied only in experimental setups.

One of the most promising approaches in current research is the modification of embedded electromagnetic interference filters (EMI) through the improvement of their design and choosing material with the required qualities at an acceptable cost. Appropriate permittivity values are amongst the key parameters for material selection. Therefore, it is very important to measure accurately these key valves within the frequency ranges of interest. This paper presents techniques for measuring the complex permittivity of materials.

2. Permittivity

According to [4], permittivity (ε), also termed the dielectric constant, describes the interaction of material with an electric field. The dielectric constant (k) is equivalent to relative permittivity (ε_r) or the absolute permittivity (ε) relative to the permittivity of free space (ε_0). The real part of permittivity (ε_r') is a measure of how much energy from an external electric field is stored in a material. The imaginary part of permittivity (ε_r'') is called the loss factor and is a measure of how dissipative or lossy a material is in the presence of an external electric field. However, the dielectric "Constant" is constant neither over frequency nor temperature.

The relative "lossiness" of a material is the ratio of the energy lost to the energy stored and is termed tangent loss. For embedding passives into a pcb, the frequency band of interest is less than 6 GHz, and the materials used are mostly solid.

To measure these parameters several national and international standards are applicable and these include:

- ASTM (American Society for Testing and Materials) Standards;

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- NIST (National Institute of Standarts and Technology) Technical notes
- IPC (Institute for Interconnecting and Packaging Electronic Circuits)
- Russian national standards
- Notes of The National Physical Laboratory (NPL), the UK's National Measurement Institute

3. Measurement techniques

Usually the choice of techniques depends on such factors as [4] the frequency of interest, the expected value of ε_r , the required measurement accuracy, material properties (i.e., homogeneous, isotropic), the material form (i.e., liquid, powder, solid, sheet), sample size restrictions, destructive or non-destructive, contacting or non-contacting and temperature. Figures 1 and 2 represent summary of measuring techniques.

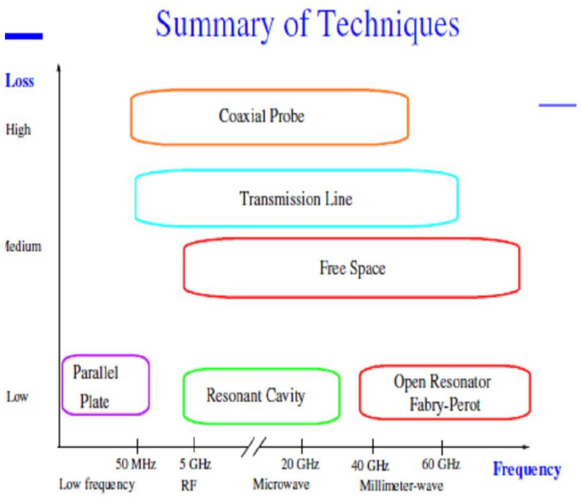


Figure1. Summary of Techniques (part 1) [4]

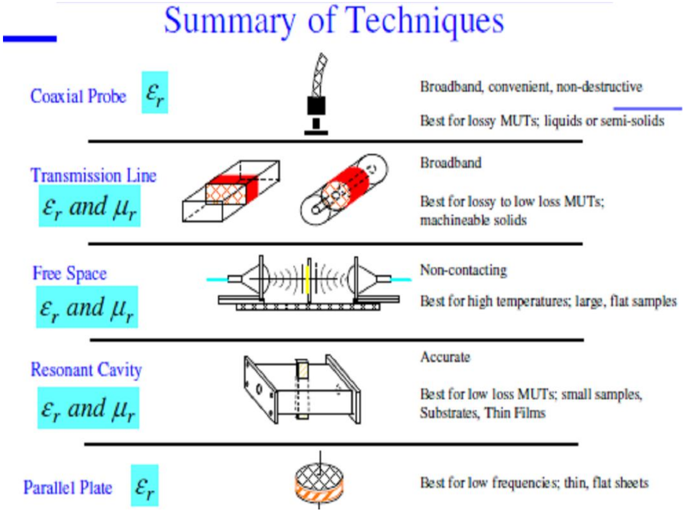


Figure2. Summary of Techniques (part 2) [4]

The Transmission line method for low frequency band requires large size of the material sample. For the Coaxial probe technique the sample should be precisely machined. Therefore for the frequency band of our interest (less than 5 GHz) the most suitable measurement techniques are the Parallel plate method and the Free space method.

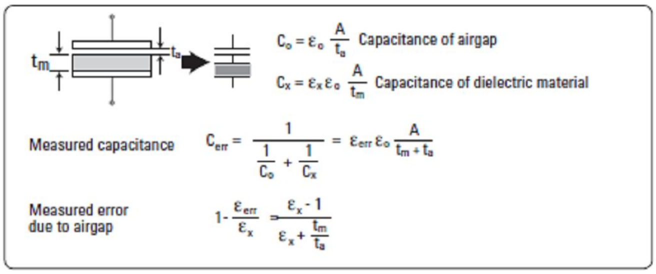
4. The parallel plates method or Capacitor method

Parallel plate capacitor system uses a parallel plate capacitor as a sample holder, with the material under the test sandwiched between. This method requires an impedance analyzer or LCR meter. The measurements are at low frequencies, typically below 1 GHz. The material is stimulated by an AC source and the actual voltage across the material is monitored. The material test parameters are derived by knowing the dimensions of the material and by measuring its capacitance and dissipation factor. After putting a sample into a sample holder, a capacitor is formed.

This method uses a wide frequency range from 20 Hz to 1 GHz, has high measurement accuracy and involves very simple sample preparation and setup.
Typically ±1% for ε_r' and 5% ± 0.005 for tanδ. The measured capacitance is then used to calculate the permittivity.

5.Contacting electrode method

This method derives permittivity by measuring the capacitance of the electrodes contacting the MUT directly. Then permittivity and loss tangent are calculated using special equations. Figure 3 represents contacting electrode method.



$$C_o = \varepsilon_o \frac{A}{t_a}$$ Capacitance of airgap

$$C_x = \varepsilon_x \varepsilon_o \frac{A}{t_m}$$ Capacitance of dielectric material

Measured capacitance $$C_{err} = \frac{1}{\frac{1}{C_o} + \frac{1}{C_x}} = \varepsilon_{err} \varepsilon_o \frac{A}{t_m + t_a}$$

Measured error due to airgap $$1 - \frac{\varepsilon_{err}}{\varepsilon_x} = \frac{\varepsilon_x - 1}{\varepsilon_x + \frac{t_m}{t_a}}$$

Figure 3. Contacting electrode method [5]

The contacting electrode method requires no material preparation and measurement straightforward. Therefore, it is the most widely used method. However, significant measurement error can occur if air gap and its effects are not considered when using this method.

When contacting the MUT directly with the electrodes, an air gap is formed between the MUT and the electrodes. No matter how flat and parallel both sides of the MUT. This air gap is the cause of measurement error because the measured capacitance will be the series connection of the capacitance of the dielectric material and the air gap. Measurement error is a function of the relative permittivity (ε_r') of the MUT, the thickness of the MUT (t_m), and the air gap's thickness (ta).

6.Non-contacting electrode method

This method was devised to incorporate the advantages and exclude the disadvantages of the contacting electrode method. It does not require thin film electrodes, but still overcomes the air gap effect. The permittivity is derived by using the results of two capacitance measurements obtained both with the MUT and without it. Theoretically, the electrode gap (tg) should be a little bit larger than the thickness of the MUT (tm).

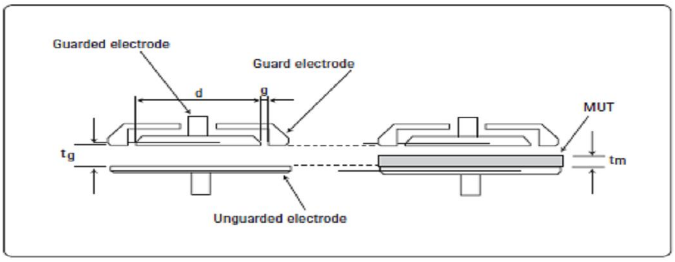


Figure5. Non-contacting electrode method [5]

In other words, the air gap should be extremely small when compared to the thickness of the MUT. These requirements are necessary for the measurement to be performed accurately. Two capacitance measurements are necessary, and the results are used together to calculate permittivity.

8. Free space method

This method uses large flat, parallel-faced samples of homogeneous materials. This method is non-contacting, nondestructive, and is applicable for high frequencies; but it is also possible to use low frequencies although this is limited by practical sample size. Antenna polarization may be varied for anisotropic materials. This method measures magnetic materials. Free-space methods use antennas to focus microwave energy on or through a slab of material without the need for a test fixture. Such a system is a free-space method that consists of a vector network analyzer, a "fixture" (antennas, tunnels, arches, etc.), software and hardware.

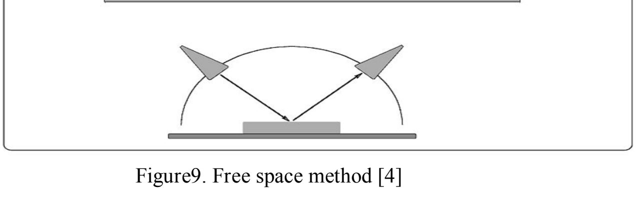


Figure9. Free space method [4]

9. Conclusion

The goal of our research is to design the embedded electromagnetic interference filters (EMI). It can be done by choosing the materials which were not used before in such an application. We are going to investigate and search for new materials with the required qualities at an acceptable cost. One of the criteria of choosing these materials is their dielectric parameters. We made a review of existing techniques for measuring the dielectric permittivity of the material to find out the most accurate method. For the frequency band of our interest the most suitable measurement technique is the Parallel plate method. We are going to perform some experiments and present the results in the next papers.

10. Acknowledgments

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