



Scalar Dielectric Constant Extraction of Planar Materials from Reflection Measurements

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Abstract

Industrial plastics are widely used in warfare electromechanical systems to protect the internal electronic circuitry from environmental effects. Depending the purpose of the warfare system, the surface interaction with electromagnetic fields play a key role and the main parameter that determines reflection and the shielding of the electromagnetic fields from material surface is the dielectric constant of the material itself. In this paper, extraction of scalar dielectric constant from electromagnetic reflection measurement using an alternative two standard calibration technique in a low cost aluminum compact chamber is obtained. Calibration technique uses time domain measurements and converts them to frequency domain. Especially in R&D phase of electromechanical integration of warfare systems, this technique is quite useful where the exact values of dielectric constants of planar industrial plastics are not required. Obtained reflection coefficient error level is 0.67dB for 10mm while it reaches 1.62dB for 40mm thickness materials. It is shown that calculated values are in good agreement with the reference measurement method performed by precision airline setup Agilent 85050C.

Keywords: Scalar Dielectric Constant, Planar Materials, VNA Reflection Measurement, Time Gating, Calibration.

1. INTRODUCTION

Characterization of dielectric materials can be performed by S parameters using Vector Network Analyzers (VNA). Measurements can be performed either in free space [1-5] or in coaxial or waveguide systems [6]. Each system has different sources of error [1]. Gating in the time domain is the most used technique to remove them. But it requires a careful investigation on the phase shift information of the reference plane. Also, the sample plate thickness is so important to define these phase shifts. In order to find alternative more accurate solutions, the new calibration techniques are developed for both measurement systems and VNA [7]. On the other hand, scalar network analyzer or tracking generator and spectrum analyzer combination can also be used [8]. All these techniques use S_{11} and S_{22} . This paper presents an application of technique which uses only S_{11} and two calibration standards for error reduction on the extraction of scalar dielectric constant in a low-cost compact screened test chamber [9-10]. The advantage of this technique is in simplicity originating from two calibration standards and free-space medium compare to near field medium [11]. The metallic screened test chamber is inexpensive due to its compact size

and fixed position reference plane. Also because of the technique, the requirement of sensitivity to the reference plane phase shift information is removed. Measurements are done with a wide band horn antenna works in 2-18 GHz region. Since the details of the technique are given at [10]. It is focused in this paper to use this technique to extract the dielectric coefficient of planar samples. A brief information about the measurement system is given in section II. The basic set of extraction formulas are given in section III. Obtained results are given in section IV and a conclusion is followed.

2. MEASUREMENT SETUP

The material characterization chamber is given in Fig. 1. It has 2m x 1m x 1m dimensions with a 2 mm aluminum shield to remove the interference from the outside environment in order to obtain a more silent test environment. The reflections are removed by polyurethane absorbers in the walls of the screen.

The distance between the reference plane and the antenna is given Fig. 2. Thanks to absorbers to decrease the aluminum wall reflections for easier interpretation of the results.

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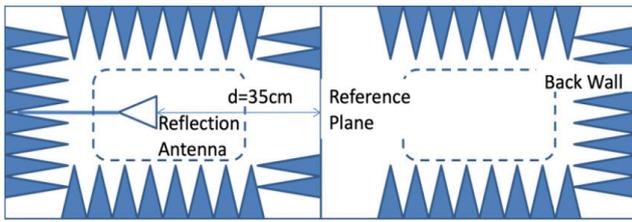


Figure 1. Metallic compact material characterization chamber.

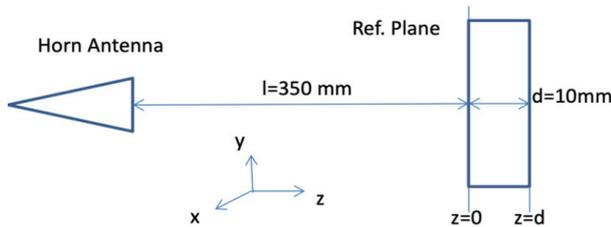


Figure 2. Distance and the geometry between the reference point and antenna.

3. APPLIED TECHNIQUE

The reference plane is the front face of the first calibration standard. Reflection occurs at both the front face and the back face of the planar sample. The total value of both reflections, Γ_{dB} , at the front face is given below [8].

$$\Gamma_{dB} = 20 \log_{10} \left(\frac{r_{12}(1 - e^{-j2\Theta})}{1 - r_{12}^2 e^{-j2\Theta}} \right) \quad (1)$$

where,

$$\begin{aligned} \Theta &= k_s d \\ k_s &= \frac{2\pi}{\lambda_0} \sqrt{\epsilon_r} \\ r_{12} &= \frac{1 - \sqrt{\epsilon_r}}{1 + \sqrt{\epsilon_r}} \end{aligned} \quad (2)$$

The thickness is defined with d , the wavelength is given with λ_0 and dielectric constant is defined with ϵ_r .

Since the samples are planar material it is well known that both edge reflections are canceled and add each other at the frequency spectrum periodically. Finally, it is obtained maximum and minimum points in the frequency spectrum. The extraction method is based on this fact.

We used the peak values while dip values also able to give this extraction. Peak values, f_{max} , depend on the thickness and the dielectric constant of the planar sample.

$$f_{max} |_{n} = \frac{c}{4d\sqrt{\epsilon_r}} (2n+1) \quad n=0,1,2,\dots \quad (3)$$

where c is the speed of light.

Period of the peak values, T , easily calculated by subtracting two sequential peak or null points.

$$T = (f_{max} |_{n=0}) - (f_{max} |_{n=1}) \quad (4)$$

If we organize (4) by using (3), dielectric constant will be obtained.

$$\epsilon_r = \left(\frac{c}{2dT} \right)^2 \quad (5)$$

After performing the reflection measurement, the dielectric constant is firstly calculated by (5). This first calculation includes measurement errors that originated from the mentioned calibration process [10]. Error level of extracted dielectric constant highly dependent to the error level of the measured reflection coefficient results since the period of the maximum points is obtained through these measurements. Therefore, the calibration process plays an important role in the whole system. Since the calibration technique [10] is based on the two standards, it is necessary to compare the calculated results with measured ones. The difference between them is assigned as error term e_k (in dB).

$$e_k = |R_{dB} - \Gamma_{dB}| \quad (6)$$

For the whole range of the measurement, an average term is given as below by using each error term at frequency points ($k=1..i$)

$$e_T = \sum_{k=1}^i \frac{e_k}{i} \quad (7)$$

4. RESULTS

Four different thickness polypropylene plates are used in measurements and each one error analysis is done. As a comparison, a small part from the dielectric plate is machined in a toroid shape to insert in a precision airline setup namely Agilent 85050C coaxial material characterization kit and the dielectric constant is measured averagely between 5 GHz to 15GHz as 2.20. For each thickness dielectric constant is calculated from the measured values with (5) by minimizing the error term. Theoretical values of dielectric constant are obtained by using (1). Found dielectric constant values are given for each thickness in Fig. 3-6.

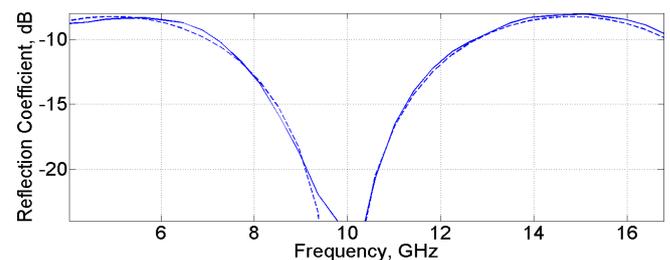


Figure 3. Calculated reflection coefficient for the parameters of $d=10$ mm (Solid: measured, dashed: theoretical). The total error is minimum for $\epsilon_r=2.26$ and equal to 0.67dB

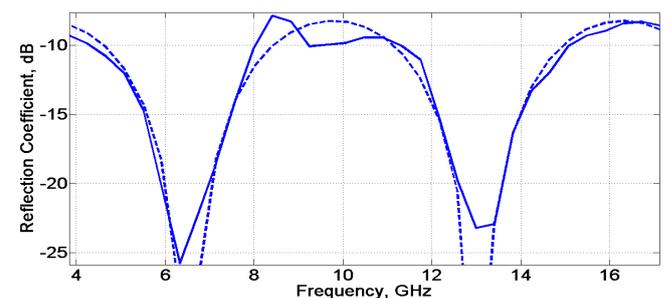


Figure 4. Calculated reflection coefficient for the parameters of $d=15$ mm (Solid: measured, dashed: theoretical). The total error is minimum for $\epsilon_r=2.25$ and equal to 1.37dB

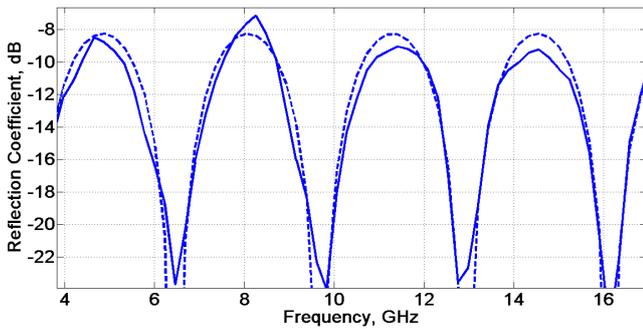


Figure 5. Calculated reflection coefficient for the parameters of $d=30\text{mm}$ (Solid: measured, dashed: theoretical). The total error is minimum for $\epsilon_r=2.25$ equal to 1.51dB

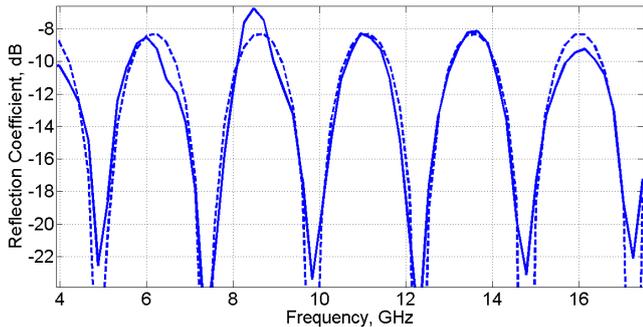


Figure 6. Calculated reflection coefficient for the parameters of $d=40\text{mm}$ (Solid: measured, dashed: theoretical). The total error is minimum for $\epsilon_r=2.24$ equal to 1.62dB

It is shown that calculated values are in good agreement with the reference measurement method performed by precision airline setup Agilent 85050C. Error is rising by increasing the thickness of the sample because the peak and null numbers in the specified wideband are increasing. Since the dielectric constant is extracted from this information, the measurement is more sensitive to the at higher thickness values.

5. CONCLUSION

A technique is proposed to be used on the extraction of scalar dielectric constant from reflection measurement using an alternative two standard calibration in a low-cost compact chamber. Advantage of this technique is in simplicity and reducing the number of calibration standards. It is simple because, there is no need to consider the possible gating errors originating from the positioning of the sample. Especially in R&D phase of electromechanical integration of warfare systems, this technique is quite useful where the exact values of dielectric constants of planar industrial plastics are not required. This technique is quite useful where the exact values are not required. Obtained reflection coefficient error level is 0.67dB for 10mm while it reaches 1.62dB for 40mm thickness materials. Extracted dielectric constant is in good agreement with the theoretical value. Validation of the technique is done by a precision airline setup namely Agilent 85050C. It is shown that the calibration technique can be used for the extraction of the dielectric constant of planar materials especially in fast R&D phase of the electromechanical systems.

6. REFERENCES

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