Setup for Material Characterization in the 110-170 GHz Band

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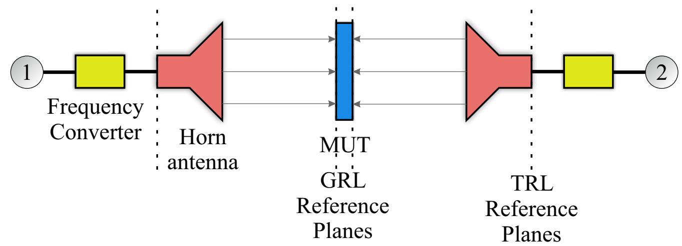
***Abstract*—This work outlines the procedure to establish a system for assessing materials' complex permittivity and permeability within the 110-170 GHz frequency range. We present the employed methodology and the calibration procedure for the system, incorporating a dual approach using TRL (Thru-Reflect-Line) and GRL (Gated-Reflect-Line) methods. Following that, a smoothing technique is used to enhance the accuracy of the results. Tests were conducted on a HIPS sample to validate the system's performance, demonstrating the results' reliability across the entire measured bandwidth.**

I. Introduction

Characterizing the electromagnetic properties of materials used in the communications industry has always been a critical task, focusing on the electrical permittivity and magnetic permeability crucial for designing radiofrequency devices, such as antennas, reflectarrays, or absorbers. Traditional methods for material characterization, commonly divided into resonant [1] and broadband approaches [2], are explored, with the Nicolson-Ross-Weir (NRW) [3] method and the Baker-Jarvis [4] variant highlighted in the latter category. Our starting point is the method presented in [5]. We will do a variation to characterize materials in the millimeter-wave band (110-170 GHz) to characterize a sample of HIPS [6], a material available for 3D printing that has gained importance in recent years due to its low losses and permittivity close to 2.5. The presented broadband method is based on free-space measurement and reference-plane invariance.

II. Measurement method

In the study referenced by [5], the authors advocate for employing an air-dielectric coaxial guide that facilitates the propagation of a TEM mode. This approach relies on precise knowledge of the distance between ports (antennas in our case) and the thickness of the material under test (MUT). A key feature of their proposed system is its inherent invariance to the relative position of the material concerning the reference planes, allowing flexibility in placement along the transmission line. However, a notable limitation arises from the necessity of having an air-filled coaxial guide to accommodate the material samples for characterization. To address this limitation and streamline the measurement process, in this work, we propose a free space measurement setup employing horn antennas to generate a flat wavefront, as depicted in the schematic in Fig. 1(a). In this configuration, accurately determining the distance between antennas becomes crucial.



(a)

(b)

Fig. 1: (a) Measurement scheme used for characterization of materials in free space. (b) Photograph of the setup used for material characterization.

Two calibration methods are used. Firstly, a TRL calibration is executed at the waveguide's end, feeding the antenna using the WR-6 waveguide standard. Following this, a free space GRL calibration is performed. This calibration involves two measurements: one of the empty sample holder and another of the sample holder with a metal plate, assuming total reflection of the plane wavefront. Similar to the TRL calibration, a process is applied from both measurements but with a time-gating process to isolate the propagation effects to the sample holder. Upon calibration, the reference planes are considered to be within the material where normal incidence of a plane wave is taking place.

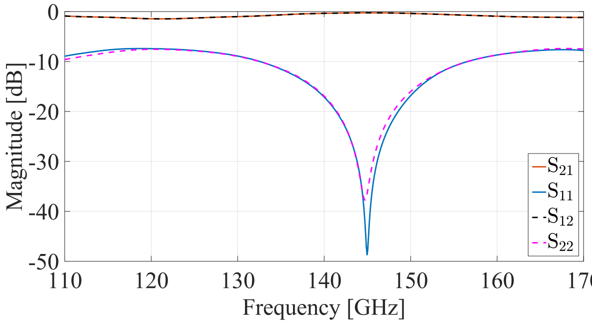


Fig. 2: Measured S-parameters of the HIPS sample, after the calibration process.

Measurement results are susceptible to spurious signals that can compromise the accuracy of material parameter estimation. Various techniques for enhancing reliability by smoothing results are available, highlighting Savitzky-Golay filters. This technique has proven equivalent or more efficient than alternatives like time-gating in mitigating potential signal interferences, including reflections in the measurement system. Consequently, Savitzky-Golay filters with second-order polynomials and 51-point windows have been employed for this study to process and improve the results.

III. Validation and Conclusions

The proposed theory was tested within the 110 to 170 GHz band. The setup comprised a Keysight N5247B network analyzer, frequency extenders, and horn antennas. A photograph of the setup is shown in Fig. 1(b). A 2.94 mm thick sample of HIPS was placed on the sample holder, located in the optical table, without ensuring the sample was in the midpoint between antennas. The measurement process involved setting frequency limits, TRL calibration, and connecting antennas. GRL calibration in MATLAB isolated sample effects. The measured S-parameters exhibited cleanliness post-calibration, as shown in Fig. 2, indicating accurate measurement and calibration completion. The complex relative permittivity results, presented in Figs. 3, closely align with expectations for the material (relative permittivity, $\varepsilon_r^{'}$, close to 2.5 and relative permeability, $\mu_r^{'}$ close to 1) [6]. The real part remains relatively flat, affected only at resonance points in which the wavelength is a multiple of the sample thickness. This behavior is typical of this type of broadband method. It is due to a variation in the estimated impedance. On the other hand, the imaginary part shows more significant variations influenced by sample position, emphasizing the importance of precise alignment for accurate estimations. The method used is a serious candidate for the characterization of materials in free space above 100 GHz.

Acknowledgements

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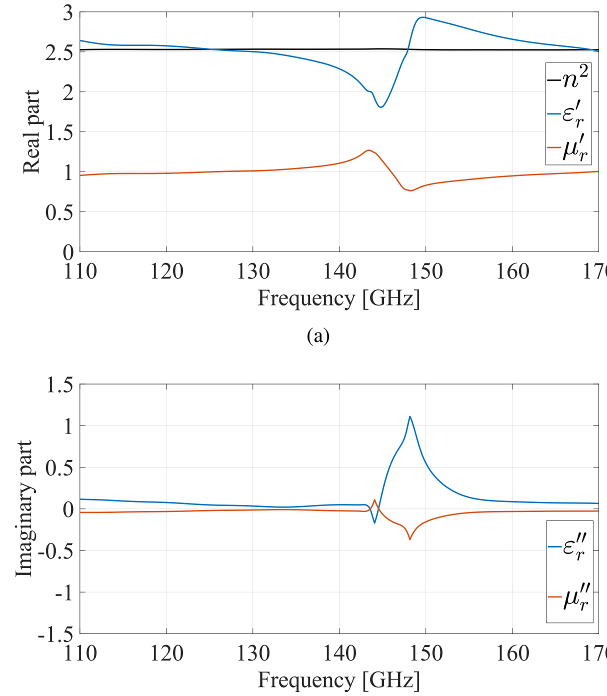

(a)

(b)

Fig. 3: Estimated real (a) and imaginary (b) part of the complex relative permittivity (ε_r, blue) and relative permeability (μ_r, orange) of the HIPS sample. The refraction index obtained by the propose method, n^2 is also depicted in (a).

References

[1] M. Santra and K. Limaye, "Estimation of complex permittivity of arbitrary shape and size dielectric samples using cavity measurement technique at microwave frequencies," *IEEE Transactions on Microwave Theory and Techniques*, vol. 53, no. 2, pp. 718–722, 2005.

[2] L. A. Bronckers and A. B. Smolders, "Broadband material characterization method using a cpw with a novel calibration technique," *IEEE Antennas and Wireless Propagation Letters*, vol. 15, pp. 1763–1766, 2016.

[3] A. M. Nicolson and G. F. Ross, "Measurement of the intrinsic properties of materials by time-domain techniques," *IEEE Transactions on Instrumentation and Measurement*, vol. 19, no. 4, pp. 377–382, 1970.

[4] J. Baker-Jarvis, E. Vanzura, and W. Kissick, "Improved technique for determining complex permittivity with the transmission/reflection method," *IEEE Transactions on Microwave Theory and Techniques*, vol. 38, no. 8, pp. 1096–1103, 1990.

[5] K. Chalapat, K. Sarvala, J. Li, and G. S. Paraoanu, "Wideband reference-plane invariant method for measuring electromagnetic parameters of materials," *IEEE Transactions on Microwave Theory and Techniques*, vol. 57, no. 9, pp. 2257–2267, 2009.

[6] M. Pérez-Escribano and E. Márquez-Segura, "Parameters characterization of dielectric materials samples in microwave and millimeter-wave bands," *IEEE Transactions on Microwave Theory and Techniques*, vol. 69, no. 3, pp. 1723–1732, 2021.