EXTENSION OF REFERENCE MATERIALS FOR STANDARDIZATION IN THE PRODUCTION OF LARGE DEPLOYABLE ANTENNAS

Lukasz Nowicki(1), Malgorzata Celuch(1), Marzena Olszewska–Placha(1), Janusz Rudnicki(1)

(1)QWED Sp. Z o. o.
Warsaw, Poland
Email: lukasznowicki@qwed.eu

***Abstract* – This paper addresses the critical need for characterizing and evaluating materials in antenna research and industry, particularly in the context of mmWave frequencies. Extensive round-robin testing has revealed the challenges posed by increased dielectric losses in microwave materials when applied to mmWave. The study utilizes new measuring setup which results will be include into standardized benchmarking, extracting electromagnetic parameters using consistent principles across laboratories. The focus is on low-loss materials like Cyclo Olefin Polymer and Precision Teflon. Additionally, the paper previews research on standardizing Fused Silica and highlights the role of standardization in space industry, showcasing characterization methods and Digital Twins principles for extracting electromagnetic parameters.**

I. INTRODUCTION

The purpose of the paper is to fill the gap in identifying the characterization and evaluation of materials used in antenna research and industry. An extensive round-robin campaign has confirmed that many materials used at microwave frequencies may not be suitable for mmWave. This is a consequence of increased dielectric losses. The International Electronics Manufacturing Initiative (iNEMI) project [1] reveals the challenges faced in characterizing low-loss and ultra-thin materials. A common benchmark was chosen for all laboratories involved in the project. Three types of resonators were selected based on availability, published standards and test data:

- The first is the Split Post Dielectric Resonator (SPDR)[2], which is standardized by the International Electrotechnical Commission (IEC). The frequencies range from 1.1 to 20 GHz.
- Another resonator is the Split Cylinder Resonator (SCR) [3], which is standardized by the Association Connecting Electronics Industries (IPC). The frequencies range from 10 to 80 GHz.
- The last type of resonator used is the automated Fabry-Perot Open Resonator (FPOR) [4], measurements cover frequencies from 20-110 GHz with a frequency step of 1.5 GHz.

The same laws of physics were used to extract electromagnetic parameters. The resonant frequency was measured using a vector network analyzer (VNA) from which Q-factors were derived. Extraction methods are described here [5].Samples with low dielectric constant and low dispersion coefficient were used to compare the methods. Sample dimensions were optimized according to the requirements of the resonance techniques used. Rigorous transport and storage procedures prevented the destruction of test samples minimizing the impact on differences in results between laboratories. The project's work focused on Cyclo Olefin Polymer (COP) [6] and Precision Teflon [7] materials. This paper reports the latest research on the standardization material of the iNEMI project - Fused Sillica. Emphasizing the idea of promoting standardization and their important role in today's radio communications. Accordingly, there will be shown popular methods to characterize materials in the microwave and mmWave range, including 2D scanners. Also how electromagnetic parameters are extracted using Digital Twins principles. A new measurement setup using the 5 and 10 GHz SPDR and the features of the fused silica are presented in Section II. The results obtained and how they compare to those materials already obtained in the iNEMI project will be presented in Section III.

II. MEASUREMENT METHOD

Fused silica, also known as fused quartz or silica glass, is a high-purity amorphous form of silicon dioxide (SiO_2). It is distinguished by its excellent optical transparency, low thermal expansion coefficient, and high resistance to temperature extremes. Fused silica finds applications in various industries, including optics, electronics, and telecommunications, due to its remarkable material properties. Understanding the electromagnetic characteristics of fused silica, particularly its permittivity ε and loss tangent $\tan\delta$, is crucial for optimizing the performance of large deployable antennas. To extract material parameters using SPDRs, we need to consider the following steps.

The first step in characterizing ε and $\tan\delta$ of fused silica involves creating a detailed electromagnetic model of SPDR. The modeling process is carried out through simulation using QuickWave software [8], a versatile tool for electromagnetic analysis. The considered model includes the geometric parameters of the SPDR and the properties of the unknown material. A number of simulations are performed with predefined material parameters in a given range. Obtaining a family of multiple resonance curves.

The second crucial aspect of our characterization process involves conducting experimental measurements of the SPDRs. These measurements are performed with and without a sample of fused silica inserted into the slot of the resonator. Two key parameters are obtained. The resonant frequency of two used SPDRs which occurs at 5 and 10 GHz. The presence of the sample inside the slot affects the resonant frequency, allowing us to infer information about the permittivity ε. Second is a quality factor (Q-factor) of the SPDR is a measure of its energy storage and loss. It is determined by analyzing the width of the resonance peak in the frequency domain. Changes in the Q-factor in the presence of the sample are indicative of its loss tangent tanδ.

The collected simulation and experimental data are analyzed according to Digital Twins principles to extract permittivity ε and loss tangent tanδ of the fused silica sample.

A. Measurement Setup

A new measurement station (Fig.1) has been set up that uses a VNA, SPDR and a Laptop equipped with an application to operate the VNA and extract material parameters from the sample. The VNA measures complex scattering parameters (S-parameters), which describe how electromagnetic signals interact with a SPDRs. The VNA incorporated into this measurement station is the Keysight P5008 Streamline [9]. It's provides a frequency range spanning from 100 kHz to an 53 GHz. Such a range fills the need for the SPDR used in this case. To ensure accurate measurements, it is imperative that the fused silica samples are flat and uniform. Any irregularities in the sample can introduce errors in the permittivity ε and loss tangent tanδ extraction.

Fig.1. SPDR measuring station using VNA Keysight P5008 Streamline and dedicated software.

III. Results

To establish a benchmark, we selected three different types of resonators based on their availability in the resonator market and the existence of published standards and test data. The first category comprises SPDR-type resonators, which are standardized by the IEC and offered by QWED and Keysight in the frequency range of 1.1 to 15 GHz, with an additional 20 GHz SPDR model, although no longer commercially available, was included in study of COP and Teflon, but not usable now in study of Fused Sillica. The second type is a fully automated FPOR, for which we conducted measurements spanning from 20 to 110 GHz in 1.5 GHz increments. Lastly, we considered the SCR with a sample insertion slot, closely resembling the canonical cylinder cavity supporting TE011 mode. The SCR is standardized by IPC and comes in frequency variants of 10, 20, 28, 40, 60, and 80 GHz. For FPOR and SCR measuring will be compare in future.

Our study focused on samples characterized by a low dielectric constant, thickness from 0.2 mm to 0.8 mm, and minimal dispersion coefficients. Fused Sillica closes the upper limit of low dielectric constants. We chose these criteria to align with the requirements of 5G technology. Notably, to ensure consistency in our findings, samples were transferred between collaborating laboratories involved in the measurements, prompting the establishment of rigorous protocols for sample transportation and storage. Fig. 2 illustrates the dielectric constant measurements for CPO, Teflon and Fused Sillica samples, with each data point corresponding to independent measurements conducted in various laboratories as indicated in the legend. The results range from 1% to 2.34%. In Fig. 3, we present the loss tangent values for CPO, Teflon and Fused Sillica. For CPO, the loss tangent remains constant above 30 GHz as a function of frequency. Below this threshold, we observed an intriguing relationship, corroborated by other independent resonance methods. In the case of Teflon, there is some variability in the FPOR results obtained above 50 GHz, attributable to the switching of frequency extenders on the VNA used for measurements.

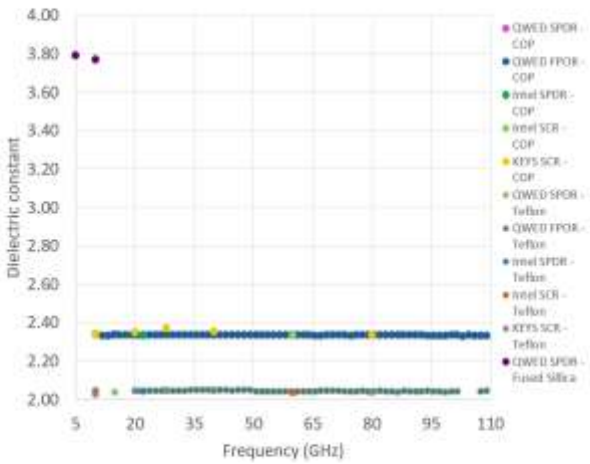

Fig.2. Summary of results of dielectric constant measurements obtained by SPDR, SCR and FPOR methods for Cyclo Olefin Polymer (COP), Teflon and Fused Sillica.

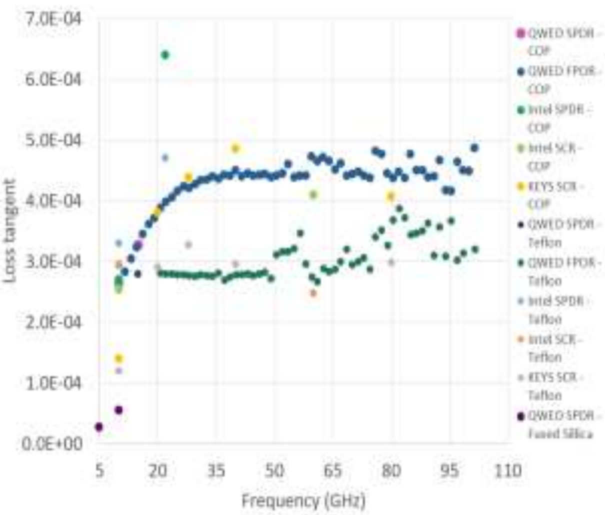

Fig.3. Summary of results of loss tangent measurements obtained by SPDR, SCR and FPOR for COP, Teflon and Fused Sillica.

Fused Silica measurements were conducted using the new measurement setup shown on Fig. 1. The frequencies of the 5 and 10 GHz SPDRs were assessed. A frequency span of 100 MHz centered around the resonance frequency was chosen. The frequency step within this range was fine-tuned to ensure that one data point coincided with the peak of the resonance. Ultimately, a total of 801 frequency steps were acquired. A Lorentzian curve was then fitted to the resultant resonance curve, from which the resonance frequency and q-factor was determined. The results were augmented with the permittivity ε and loss tangent tanδ measurements of the fused silica obtained through the 5 and 10 GHz SPDRs. The thickness of the test sample was 0.8 mm. Precise numerical values are presented in Tab. 1 and are graphically represented in Fig. 2 and Fig. 3, denoted by a purple dot.

Table 1. Results of Fused Sillica permittivity and loss tangent in a new measurement setup.

Frequency [GHz]:	ε	tanδ
5	3.792749	2.7371e-5
10	3.768553	5.4918e-5

IV. Conclusions

This paper concludes a comprehensive benchmark for dielectric materials, specifically tailored for high-frequency applications used in deployable antennas. The utilization of three different resonator types and the strict implementation of sample transportation and storage procedures ensure the reliability of our results. The dielectric constant and loss tangent measurements for COP, Precision Teflon and Fused Sillica provide valuable insights into their behaviour across a wide frequency range. This information is essential for engineers and researchers working on the development of high-frequency components and devices.

Our study underscores the significance of accurate characterization and the need for stringent procedures when conducting multi-laboratory investigations in the field of high-frequency dielectric materials. Further research in this area can lead to the development of more advanced and efficient materials for emerging high-frequency technologies. The inclusion of Fused Sillica in the standardization process will close the upper limit of materials with low permittivity ε, but will also expand its application area to fields such as aerospace, optics and photonics. In future work we will fill results of fused silica in consider frequency range with results taken in all iNEMI partners. Next benchmark material will be rexolite.

V. Acknowledgment

The authors wish to thank all the partners of the iNEMI 5G project for their collaboration in defining the benchmarking samples and techniques used in this work. QWED team further acknowledges the funding received in M-ERA.NET; ULTCC6G_EPac project under M-ERA.NET2/2020/1/2021 and I4Bags project M-ERA.NET3/2021/83/I4BAGS/2022.

VI. References

[1] https://www.inemi.org
[2] https://www.qwed.com.pl/resonators_spdr.html
[3] M. D. Janezic and J. Baker-Jarvis, “Full-wave analysis of a split-cylinder resonator”, IEEE Trans. Microwave. Theory Tech., vol. 47, no. 10, pp. 2014-2020, Oct. 1999.
[4] https://www.qwed.com.pl/resonators_fpor.html
[5] J. Krupka, A. P. Gregory, O. C. Rochard, R. N. Clarke, B. Riddle, and J. Baker Jarvis, “Uncertainty of complex permittivity measurements by split post dielectric resonator technique”, J. Eur. Ceramic Soc., vol. 21, pp. 2673 2676, 2001.
[6] M. Celuch, M.J. Hill, T. Karpisz, M. Olszewska-Placha, S. Phommakesone, U. Ray, B. Salski, "Benchmarking of GHz resonator techniques for the characterisation of 5G/mmWave materials", 51st European Microwave Conference, London 2-6 April 2022, pp. 568-571 (copyright European Microwave Association, EuMA)
[7] iNEMI 5G Project Report 2: Benchmark Emerging Industry Best Practices for Low Loss Measurements, Nov. 2020. Available: https://community.inemi.org/content.asp?admin=Y&contentid=676
[8] https://qwed.eu/quickwave.html
[9] https://www.keysight.com/us/en/product/P5008A/streamline-usb-vector-network-analyzer-53-ghz-2-ports.html