Accurate Materials' Testing as an Enabler for Microwave and Millimeter-Wave Industries

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ABSTRACT

Progress of microwave technologies, and especially their expansion into millimeter-wave ranges and for 5G/6G applications, is dependent on the availability of ultra-low-loss materials as well as accurate and reliable material testing methods. While Computer Aided Design (CAD) software has become a must-have tool of a microwave engineer, it is recognized that simulation-based design can only be as good as the materials' data fed into it. To the contrary, erroneous or missing materials' data lead to a costly iterative design process, which is unacceptable in the today's competitive microwave world.

At lower microwave frequencies, various material measurement techniques are known and trusted, due to a traceable link between metrology institutes, factory calibrations, and in-house standards. At higher frequencies (and actually as "low" as 10 GHz) no adequately widespread and consistent methodology exists. This stimulates the work of microwave researchers and test equipment manufacturers worldwide, aiming to develop accurate and reproducible methods and instruments. It is also desirable that the results and methodologies of materials' testing be compatible with popular CAD and modeling methodologies. This is the approach that QWED team has followed for nearly three decades, building upon the contributions of two IEEE MTT-S Fellows: Wojciech Gwarek "*to the theory and applications of electromagnetic modeling*" (2001) and Jerzy Krupka "*to high frequency measurements of electromagnetic properties of materials*" (2012).

By today, QWED has become one of the key players in the field. It offers a family of instruments [1] supported by full-wave modeling and applicable to the microwave and millimeter-wave testing of dielectrics, low- and high-resistivity semiconductors, resistive films, copper foils, liquids, and granulate materials. Additionally, the team actively contributes to international benchmarking initiatives, concerned with the assessment and validation of the available and emerging materials' testing techniques. Last but not least, it participates in multidisciplinary projects, promoting the microwave modeling and characterisation beyond the traditional microwave industries, which gave the team a recognition as a European Horizon Innovation Radar.

This talk will summarise the performed work and recent results, and feature:

- the **instruments and methods for materials' characterization**, developed and commercialized by QWED,
- the **results of round-robin benchmarking** covering the techniques by QWED as well as other vendors, performed by consortia assembled by the Electronics Manufacturing Initiative, e.g. [2], comprising material developers, electronics' manufacturers, vendors of test equipment, academia, and standards' institutes,
- **computational modeling** examples, which illustrate the physics behind the considered material testing methods and serve to interpret correlations between the most popularly used testing instruments,
- **new applications** of the above methodologies pursued in the European Horizon (MMAMA, NanoBat), M-ERA.NET (ULTCC6G_EPac, I4Bags), and EUREKA-Eurostars (5G_Foil) projects.

[1] QWED (2023). Test Fixtures and Setups for Precise Measurements of Electric and Dielectric Properties of Materials at Microwave Frequencies. [Online]. Available: https://www.qwed.eu/test_fixtures_brochure.pdf

[2] iNEMI (2024). mmWave Permittivity Reference Development – End-of-Project Webinar. [Online]. Available: https://thor.inemi.org/webdownload//2024/mmWave_permittivity_EOP.pdf