Measurements of S-parameters and Characterisation of Dielectric Materials at Millimetre-wave and Terahertz Frequencies

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Summary — There is an increasing demand for accurate and traceable electrical measurements for devices and integrated circuits operating at millimetre-wave and terahertz frequencies. This is driven by a range of applications including 5G, Internet of Things (IoT), Connected Autonomous Vehicles (CAVs), space-borne radiometers for Earth observations, and security imaging, etc. A European project, entitled “TEMMT” [1], is devoted to tackling the measurement challenges at these high frequencies and to establishing traceability for three electrical measurement quantities: S-parameters, power, and material properties. The project is sponsored by the European Metrology Programme for Innovation and Research (EMPIR). The EMPIR initiative is co-funded by the European Horizon 2020 research and innovation programme and the EMPIR Participating States. This paper gives an insight into the TEMMT project which involves 19 partners across the world.

This paper is also intended to summarise the research and development at the UK’s National Physical Laboratory (NPL) for measurements of S-parameters and material properties at millimetre-wave and terahertz frequencies. Some latest measurement results are presented and discussed. The measurement capabilities for S-parameters, at NPL, are currently concentrated on two types of techniques, i.e. in rectangular metallic waveguides, to 1.1 THz (which includes equipment based at the University of Leeds), and on wafer, to 750 GHz. Fig. 1 shows the test results of several WM-380 (500-750 GHz) straight sections of commercial waveguides with different lengths (from 1” to 5”). Detailed discussion about the results including uncertainty analysis can be found in [2]. These measurements were performed on a Keysight N5247A PNA-X fitted with VDI WM-380 Extender Heads, and were subject to a two-port SOLT (Short/Offset-Short/Load/Thru) calibration. The SOLT calibration was verified using a TRL technique that is based on custom designed ½-wave line standards. These standards are the UK’s primary national reference standards, which are traceable to the basic quantities of the SI system, i.e. the metre, second, kelvin, etc.

Time-Domain Spectrometry (TDS) [3] has been the predominant technique utilised at NPL for characterising material properties at THz frequencies. This is a free-space technique capable of measuring complex permittivity over a wide frequency range, from around 200 GHz to several THz. NPL also makes material measurements using Vector Network Analyzers (VNAs). Such techniques complement the TDS technique, allowing measurement of material properties down to the lower limit of the operational range of the TDS. Recently, NPL launched a study into the use of Swissto12 Material Characterisation Kits (MCK), a guided free-space technique relying on VNAs. Some in-depth studies, undertaken by NPL, on material measurements using MCKs from 50 GHz to 750 GHz are reported in [4]-[5]. Fig. 2 shows the extracted dielectric constants of HDPE and TPX samples measured on the WR-15 (50-75 GHz) MCK [4].

Fig. 1. Measured $S_21$ responses of several WM-380 waveguide sections manufactured by VDI.

Fig. 2. Extracted dielectric constant $\varepsilon$, from measured S-parameters obtained using WR-15 MCK, of HDPE sample (thickness 11 mm) and TPX sample (thickness 2.81 mm).

The latest results of the above-mentioned studies, particularly for on-wafer and MCKs, will be presented and discussed.

References
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