Preface

During the last decade, the industrial and scientific applications are increasingly using the millimeter- and submillimeter-wave part of the electromagnetic spectrum. Some applications include the radar and remote sensing, climate research, wireless communication, security scanners and even medical diagnosis systems. This is due to the higher data rates, circuit miniaturization and higher spatial resolution properties of the high-frequency bands. The development of reliable, high-quality and safer products at these frequencies is highly dependent on the availability of the precise and reliable network analysis. Therefore, along with performing measurements, the associated uncertainty evaluation is also very important.

The vector network analyzers (VNAs) are commonly used for network analysis with great accuracy and precision. VNAs are complex and versatile instruments employed to characterize active and passive networks used in communication technologies. The network characterization is defined in terms of scattering parameters (S-parameters). The S-parameters are ratios of wave quantities which provide information about reflection and transmission characteristics of the device under test (DUT). The VNA measurements are associated with different sources of errors; mainly classified as systematic, random and drift errors. During a VNA calibration procedure, the systematic errors are characterized and most of them are mathematically removed afterwards. The other sources of errors can possibly be minimized; however, they affect the S-parameter measurements and become different sources of uncertainty associated with the measurements. Therefore, the uncertainty analysis is also an integral part while doing measurements with VNAs.

The aim of the book is to describe the VNA measurements and uncertainty assessments particularly in waveguide test-set environments, in order to establish the measurement traceability to the International System of Units (SI) for accurate and reliable characterization of communication networks. The frequency of interest ranges from few a MHz up to Terahertz frequency band. A fully analytical approach for uncertainty evaluation is discussed. The uncertainty sources considered are the definitions of the calibration standards, VNA noise, repeatability and drift. The interaction and the linear propagation of different uncertainty sources to compute the final uncertainties associated with the measurements are also shown. The dimensional characterization of standards is also the part of the discussion.

In the Chap. 1, a general introduction to the VNA measurements and uncertainty assessment is presented. The different measurement errors, calibration standards and the calibration techniques are also described. A brief description is also provided for the classification of the uncertainty components and the S-parameter uncertainty representation.

Chapter 2 basically deals with the S-parameter measurements and uncertainty evaluation at millimeter frequencies. The analytical treatment of uncertainty propagation is discussed. The uncertainty propagation flowchart is also presented which provides information about the interaction of different uncertainty sources associated with the VNA measurements. To elaborate the matter, the S-parameter measurements and uncertainty evaluation at millimeter frequencies (50–110 GHz) are presented. The electromagnetic computations based on mechanical characterization of the waveguide shim standards are also the part of the discussion. A compatibility assessment between different S-parameter data is also carried out.

In the Chap. 3, a comparison of different S-parameter calibration techniques at millimeter frequencies (75–110 GHz) is described. All the calibration standards are mechanically measured and different calibration techniques are used for tracing S-parameter measurements to the *SI*. The aim of this comparison is to analyze the efficiency of two different VNA calibration techniques in terms of S-parameter measurements and related uncertainty.

In the Chap. 4, the connection repeatability investigation of a waveguide VNA in WR05 (140–220 GHz) is presented. The connection repeatability investigation is important to analyze the variability of the repeated measurements and flange alignment mechanisms. In particular, this investigation is very important from metrological point of view at these frequencies because of the very small dimensions of the waveguide apertures.

Finally, in the Chap. 5, the suitable verification artefacts to check the performance of the VNAs, in particular the linearity, including their applicability to coaxial and waveguide systems are described. The waveguide verification standards considered for analysis are: WR-05 (140–220 GHz) and WR-03 (220–325 GHz) cross-guides and a custom-made WR-03 (220–325 GHz) circular iris section. Moreover, the analysis, design and fabrication of a novel type N coaxial verication standard architecture (DC-18 GHz) based on an air-line are presented.

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