Investigation of Verification Artefacts in Rectangular Waveguides up to 325 GHz

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In RF and microwave engineering, vector network analyzers (VNAs) are employed to characterize one-, two- and multi-port networks in terms of scattering parameters (S-parameters). Over the past years, VNA instrumentation has been established to perform waveguide measurements at frequencies of several hundreds of GHz. At such higher frequencies, it becomes difficult to verify the calibration of the VNA system in order to achieve accurate measurements and traceability to the *International System of Units* (SI). In waveguide systems, such verification can be carried out using waveguide sections with reduced cross-sectional dimensions. However, at higher millimeter and sub-millimeter frequencies, it is mechanically challenging to manufacture the required high precision waveguide sections because the dimensions of the waveguide aperture become very small. Currently, verification standards for measurements above 110 GHz are either not available or do not provide traceability to the SI.

In the last couple of years, cross-guide devices were introduced as verification standards for measurements at frequencies of above 110 GHz (T. Schrader et al., *Advances in Radio Science*, 9, 2011, pp. 9–17), (N. M. Rilder et al., *81st ARFTG Microwave Measurement Conference (ARFTG),* 2013, pp. 1–7). A cross-guide device is a short precision waveguide section (shim) that is rotated by 90 degrees when connected to the VNA test port reference planes. It acts as a below cut-off section and thus provides significant transmission loss which can be numerically calculated by applying full wave analysis or mode matching software. However when using the cross-guides, the precision dowel holes of the UG-387 flange (MIL-DTL-3922/67E w/ Amendment 1) are no longer usable. On the other hand, the pair of vertical precision holes can be used if the shim is specially manufactured for this purpose. Alternatively, a shim consisting of a circular iris is easier to realize than a rectangular one. Such circular iris provides comparable transmission losses as a cross-guide device and thus can also be used as verification device.

In this paper, the transmission loss magnitude and phase uncertainty analysis for several types of verification standards is presented. The analyzed artefacts 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. The characterization of cross-guide and circular iris sections is performed by taking into account the dimensional tolerances as well as the flange misalignment. The data analysis is carried out using complex-valued quantities i.e., for complex-valued S-parameters. The measurement uncertainty due to different sources of error is computed according to the *Law of Propagation of Uncertainty*. The real and imaginary data along with their associated uncertainties are converted to magnitude and phase representation by linear propagation of uncertainties while taking into account the correlation between real and imaginary part of the S-parameters. The simulations are performed via *CST Microwave Studio*. The experimental results are found to be in a good agreement with the simulated values within the model-based uncertainty intervals.