A New Technique for Vector Network Analyzer Calibration Verification Using a Single Reconfigurable Device

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***Abstract* — A novel technique for verifying the calibration of systems, such as vector network analyzers, used for measuring air-filled metal-pipe rectangular waveguides is presented. The key aspect of the proposed method is that the verification device can be reconfigured to enable its characteristics to be changed by known amounts. The device introduces relative changes in its reflected and transmitted waves and is insensitive to errors introduced by waveguide flange misalignments. These errors would normally become increasingly more significant as frequency increases from the microwave to terahertz frequency ranges. A suitably modified WR-15 waveguide, operating in the 50 to 75 GHz frequency range, is presented as a proof-of-concept verification device and experimentally validated.**

***Index Terms* — Waveguide, measurement, verification device, VNA, millimeter-wave, terahertz, reconfigurable/tunable.**

I. Introduction

Increasing activity by the engineering and physics communities in the millimeter-wave and sub-terahertz frequency regions [1-5], for both research and commercial purposes, has led to the need for improving the accuracy of measurement systems. While vector network analyzers (VNAs) are available that can operate up to 500 GHz and beyond [6-11], agreed methods for verifying their performance have yet to be established.

Therefore, the need for verification kits arises. However, waveguide verification kits are only readily available for frequencies up to 110 GHz [12, 13]. Typical verification kits include four distinct devices with known characteristics: a straight section of waveguide, a stepped impedance waveguide and two different attenuators. These individual components are implemented by permanent fixed structures and, therefore, cannot be tuned in real time (i.e., once connected to the VNA).

An alternative approach is to employ a single structure having reconfigurable characteristics. One way to implement such a device is by having an air-filled metal-pipe rectangular waveguide (MPRWG), patterned with a predetermined number of holes that are positioned at specific locations on its broad walls; such that metal pins can penetrate through the waveguide, as shown in Fig. 1.

II. Results

A standard WR-15 MPRWG, having internal spatial dimensions $a \times b = 3.76 \times 1.88$ mm^2, operating in the 50 to 75 GHz frequency range, was modified to act as a proof-of-concept verification device. For simplicity, the MPRWG is operating in its fundamental mode. Metal pins are able to penetrate through the waveguide, perturbing its electromagnetic field distributions by known amounts. The resulting verification device has tunable transmission and reflection characteristics from the (re-)positioning of individual pins.

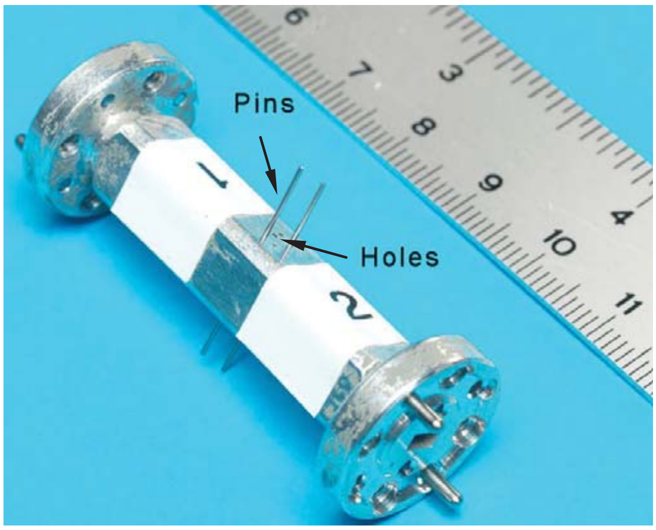


Fig.1: The verification device under test consists of a WR-15 waveguide patterned with five holes; metal pins can penetrate through the waveguide to alter its characteristics.

Fully calibrated S-parameter measurements were undertaken at the UK's National Physical Laboratory, using the Agilent PNA-X vector network analyzer setup shown in Fig. 2.

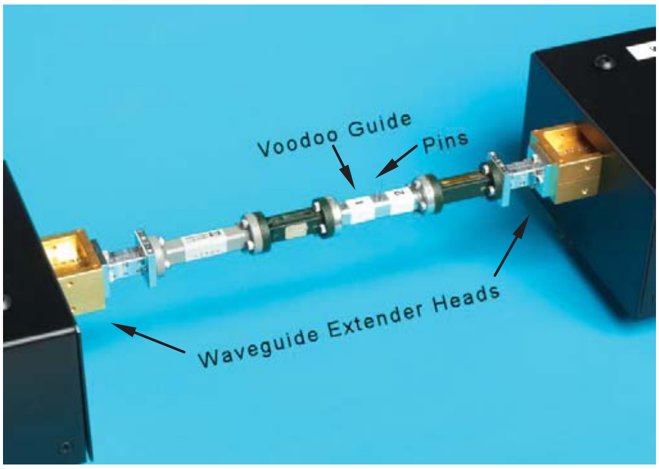
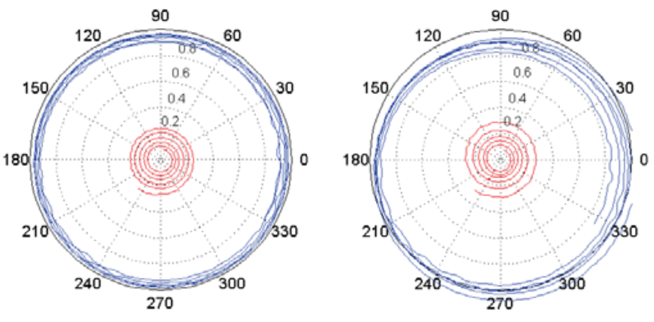


Fig.2: Experimental setup for measuring the verification device under test.

The proposed device under test was used as a means to verify the quality of the VNA calibration, particularly to verify its trustworthiness (i.e., a sanity check). For this reason, Short/Offset–short/Load/Thru (SOLT) calibrations were performed; one of which included a matched load having a return loss of approximately 25 dB (i.e., a poor matched load that results in a poor calibration).

After calibrations were performed, the verification device under test was connected to the test ports and its reflection and transmission responses measured, with results shown in Fig. 3. Comparing the results obtained with a good calibration (Fig. 3(a)) against those from a poor calibration (Fig. 3(b)), it is clear that they do not match. For example, Fig. 3(b) shows the reflection coefficient having a magnitude greater than unity, which is not possible with a passive component.



(a) (b)

Fig. 3: Reflection (blue) and transmission (red) responses in the WR-15 waveguide band (50 to 75 GHz) when a: (a) good calibration is performed; and (b) poor calibration is performed.

Once the proposed verification technique has been fully validated in the 50 to 75 GHz frequency band, the next stage is to apply the same concept for the 75 to 110 GHz frequency range. To this end, a WR-10 waveguide has been modified, as illustrated in Fig. 4.

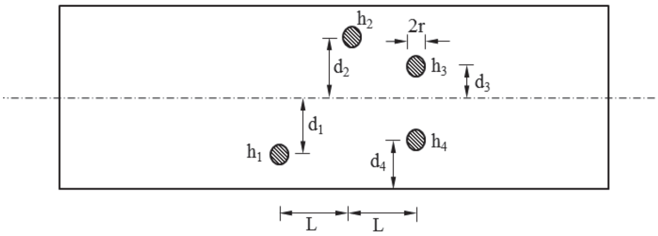
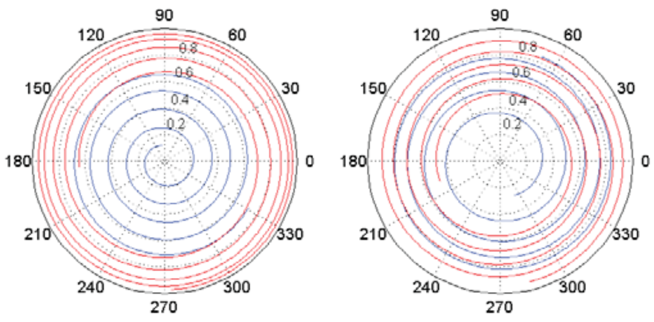
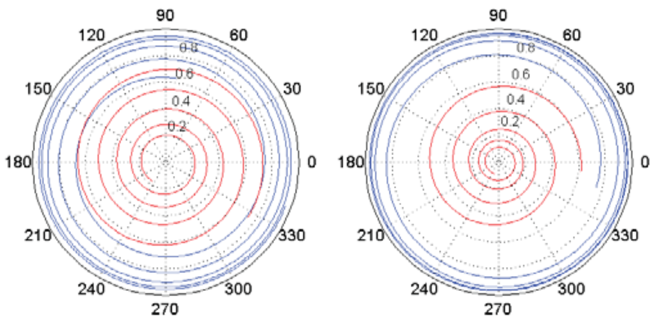


Fig. 4: Illustration of the proposed WR-10 verification device. The dimensions are: r = 250 µm, $d_1 = d_2$ = 750 µm, d_3 = 250 µm, d_4 = 650 µm, L = 750 µm.

The device's tunability offers the opportunity to establish configurations with a broad range of reflection and transmission coefficients, as shown in Fig. 5. The characteristic spiral responses for each S-parameter, in the complex plane, enable a larger part of the complex plane to be verified and hence a more comprehensive verification is obtained.



(a) (b)



(c) (d)

Fig. 5: Reflection (blue) and transmission (red) response in the WR-10 waveguide band (75 to 110 GHz) for various pins configurations with pins fully inserted into the following holes: (a) h_2, (b) h_4, (c) h_1 and h_2 and (d) h_2 and h_3.

III. Conclusion

A novel technique for verifying the calibration of systems, such as vector network analyzers, used for measuring air-filled metal-pipe rectangular waveguides has been presented. The proposed method is based on a single reconfigurable device whereby its electromagnetic characteristics can be adjusted in real-time. A proof-of-concept waveguide verification device has been experimentally demonstrated. It is believed that this approach could be adopted for waveguide measurement systems operating at sub-terahertz frequencies.

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