EVALUATING RESIDUAL ERRORS IN WAVEGUIDE NETWORK ANALYSERS FROM MICROWAVE TO SUBMILLIMETRE-WAVE FREQUENCIES

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Abstract
Vector Network Analysers (VNA) are used extensively for many types of measurement that are made at frequencies ranging from a few kilohertz to at least one terahertz. At radio and microwave frequencies, there are well-established methods for assessing the quality and integrity of these measurements, when they are made in coaxial lines. These methods are usually based on determining the size of residual errors that remain in the VNA after calibration. However, to date, the performance of these methods has not been investigated in rectangular waveguide, and, at higher frequencies (i.e. at millimetre- and submillimetre-wave frequencies). This paper investigates the application of one of these techniques to VNAs configured for waveguide measurements at microwave, millimetre- and submillimetre-wave frequencies. Typical values of residual errors in voltage reflection coefficient (VRC) obtained over microwave and millimetre-wave frequency ranges were between 0.002 to 0.021 linear units. Submillimetre-wave frequency waveguide configurations were found to exhibit significantly larger residual errors and are being investigated further to assess whether the ripple extraction technique is valid at those frequencies. Residual error values obtained in this investigation are considered representative for this technology and so can be used by other users of waveguide VNAs to compare with values obtained on their own systems, therefore helping to verify the performance of their systems.

Introduction
Terahertz frequency electromagnetic measurements performed using vector network analysers (VNA) present additional challenges when compared with those performed at radio and microwave frequencies. Desirable single-mode propagation at such short wavelengths is not supported in conventional precision coaxial lines, so new sizes of high-precision subminiature metallic rectangular waveguide have been standardised as an alternative [1]. Most state-of-the-art VNAs have an upper frequency limit of less than 100 GHz so extender heads must be added to the signal path to connect and measure THz devices. The responses of these heads and test port waveguides are included as additional systematic errors in raw VNA measurements of any device-under-test and must be corrected for by a prior calibration.

Calibration of a VNA requires the measurement of a set of standards, with assumed knowledge about the VRC and/or the impedance of each. As the true value of these properties can never be known, the quality of any calibration must be verified. The EURAMET Guide “cg-12” [2] is a widely used reference that contains a procedure for assessing the performance of calibrated VNAs at radio and microwave frequencies using coaxial line. To measure the residual systematic errors, a technique known as ripple extraction is used. To date, there has been no formal investigation of the suitability of this technique for use in waveguide at any frequency.

Methodology
The ripple extraction technique uses a matched load and short-circuit, each offset by a short section of line, to measure the residual directivity and test port match (TPM) of a calibrated VNA, respectively. The magnitude of the VRC when plotted against frequency appears as a rippled trace. The worst-case value of each residual error can be determined from the half-amplitude of the largest ripple. Because the artefacts required for the technique are common components in both coaxial line and waveguide, application of the technique to waveguide is possible.

This investigation consisted of three stages. Initially, an evaluation of residual directivity and TPM using the ripple extraction technique in microwave frequency waveguide was undertaken, and compared to the same evaluation made using coaxial transmission line at similar frequencies. The waveguide sizes used were WR-90 (8.2 GHz to 12.4 GHz) and WR-42 (18 GHz to 26.5 GHz). The evaluation was then repeated for millimetre-wave frequency waveguides of sizes WR-15 (50 GHz to 75 GHz) and WR-5 (140 GHz to 220 GHz), extending the investigation to frequencies...
unattainable with coaxial transmission line. Finally, the ripple extraction technique was performed in submillimetre-wave frequency waveguide, WR-1.5 (500 GHz to 750 GHz), but significantly larger residual errors (an order of magnitude) have led to a further, subsequent investigation on the validity of the technique at these frequencies. Therefore, the results for WR-1.5 are not presented in this paper. Two common types of calibration, Through-Reflect-Line (TRL) and Short-Open-Load-Through (SOLT), were chosen for this investigation. For waveguide measurements, the open standard used in SOLT calibration was replaced with an offset short (SOSLT). When measuring WR-1.5 waveguide, only one test port was available. Therefore, the TRL calibration was omitted as two ports are required to perform it.

Results

Figure 1 shows typical ripple traces obtained in both coaxial line and two waveguide sizes that support similar frequencies, i.e. WR-90, from 8.2 GHz to 12.4 GHz, and WR-42, from 18 GHz to 26.5 GHz. Table 1 shows the residual errors obtained in our investigation up to 220 GHz. These values were obtained using standard laboratory practice and can be considered representative for this class of measurement.

<table>
<thead>
<tr>
<th>Usable Frequencies (GHz)</th>
<th>Waveguide Size</th>
<th>Residual Directivity (Linear Units)</th>
<th>Residual Test Port Match (Linear Units)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SOLT/SOSLT</td>
<td>TRL</td>
</tr>
<tr>
<td>0 - 26.5</td>
<td>Coaxial</td>
<td>0.0070</td>
<td>0.0073</td>
</tr>
<tr>
<td>8.2 - 12.4</td>
<td>WR-90</td>
<td>0.0043</td>
<td>0.0045</td>
</tr>
<tr>
<td>18.0 - 26.5</td>
<td>WR-42</td>
<td>0.0035</td>
<td>0.0020</td>
</tr>
<tr>
<td>50 - 75</td>
<td>WR-15</td>
<td>0.0015</td>
<td>0.0018</td>
</tr>
<tr>
<td>140 - 220</td>
<td>WR-5</td>
<td>0.0083</td>
<td>0.0075</td>
</tr>
</tbody>
</table>

Table 1: Values for residual error in VRC measured using the ripple extraction technique in rectangular metallic waveguide. Coaxial transmission line is included for reference.

Conclusion

The ripple extraction technique was used to assess residual directivity and TPM in VNAs configured for use with rectangular metallic waveguide at microwave, millimetre- and submillimetre-wave frequencies. Typical values of microwave and millimetre-wave frequency assessments were in the range of 0.001 to 0.01 linear units for residual directivity, and 0.001 to 0.021 linear units for residual TPM. Submillimetre-wave residual errors were significantly larger and future work will investigate the validity of the ripple extraction technique at these frequencies. A likely cause for the larger errors approaching terahertz frequencies is misalignment between waveguide ports, which new flange configurations detailed in a recent IEEE draft standard should improve [3].

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References

