Verifying Measurements at Millimetre-wave and Terahertz Frequencies Using Cross-connected Waveguides

N M Ridler[1], R G Clarke[2] and M J Salter[1]

[1]National Physical Laboratory, UK; [2]University of Leeds, UK

Summary

Verification of measurements made on instruments such as Vector Network Analysers (VNA) operating at microwave and lower millimetre-wave frequencies can be achieved using commercially available verification kits. These kits contain several components that provide different amounts of reflection and transmission. The transmission values are usually provided by two fixed attenuators of typically 20 dB, and, 40 or 50 dB. However, at frequencies above 110 GHz, such verification kits are not currently available. This has led to alternative methods being developed to achieve system verifications at these very high frequencies.

A recent paper [1] has described a new form of verification standard that comprises a short section of straight waveguide that is orientated during connection such that the waveguide aperture is at right-angles to the waveguide apertures on the VNA test ports. This 'cross-connected' waveguide (or 'cross-guide', for short) forms a section of waveguide that is effectively below cut-off and so its loss can be predicted from electromagnetic theory, e.g. using 3-D electromagnetic simulation software (such as CST Microwave Studio, HFSS, etc).

A cross-guide device can be connected to the VNA after calibration to verify the VNA's performance by comparing the VNA results either with values predicted by simulation software [2], or, with measured values supplied by another laboratory (i.e. a reference laboratory). The level of agreement is established by comparing the difference between the two sets of results with the uncertainty in the results.

Figure 1 illustrates the concept of a cross-connected waveguide. Different lengths of cross-guide give different levels of attenuation and so these can be used in the same way as attenuators in a conventional verification kit. Figure 2 shows the measured values of attenuation for two different lengths of cross-guide (0.62 mm and 1.36 mm) in the WR-05 waveguide size (i.e. from 140 GHz to 220 GHz).

In the presentation of this work, a comparison of measurements will be described that involved two laboratories (i.e. the University of Leeds, and NPL). Each laboratory used their own test equipment to make the measurements on two lengths of cross-guides. The comparison used the two cross-guides referred to in Figure 2. Results at selected frequencies for the 0.62 mm cross-guide line are shown in Table 1. The expected uncertainty in these results is derived from information given in [3, 4]. Since the differences between the two sets of results are less than the expected uncertainties, this indicates that the agreement between the measurement results is acceptable. This therefore demonstrates a successful verification of one set of results with respect to the other set of results.

Table 1: Selected results for the measured attenuation of the 0.62 mm cross-guide line

Frequency (GHz)	University of Leeds measurement (dB)	NPL measurement (dB)	Difference (dB)	Expected uncertainty (dB)
140	26.83	27.06	0.23	0.34
180	18.70	18.62	0.08	0.32
220	11.10	11.32	0.22	0.35

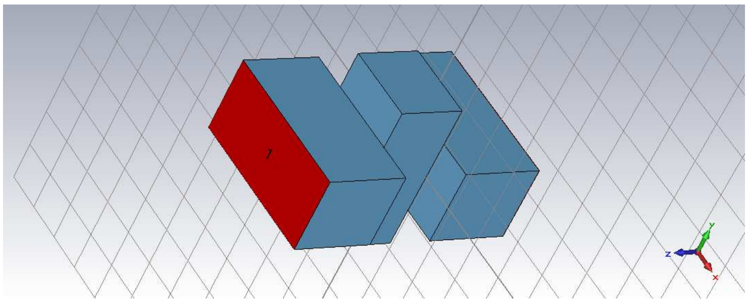

Figure 1: Illustration showing the concept of a cross-connected waveguide or 'cross-guide'

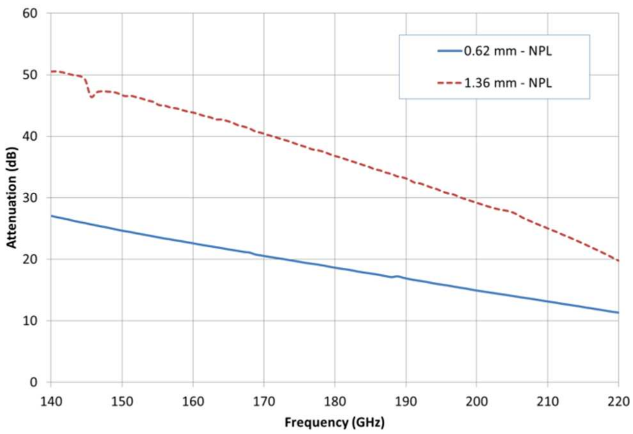

Figure 2: Measured attenuation values for a 0.62 mm length of WR-05 cross-guide and a 1.36 mm length of WR-05 cross-guide

References

[1] N M Ridler and M J Salter, "Cross-connected Waveguide Lines as Standards for Millimeter- and Submillimeter-wave Vector Network Analyzers", *Proc. 81st ARFTG Microwave Measurement Conference*, Seattle, WA, USA, June 2013.

[2] H Huang, N M Ridler and M J Salter, "Using Electromagnetic Modeling to Evaluate Uncertainty in a Millimeter-wave Cross-guide Verification Standard", *Proc. 83rd ARFTG Microwave Measurement Conference*, pp 93-97, Tampa, FL, USA, June 2014.

[3] H Huang, N M Ridler and M J Salter, "Connection Repeatability of Cross-connected Waveguide Verification Standards for Millimeter wave Vector Network Analysis", *Proc. 2014 Asia-Pacific Microwave Conference*, pp 907-909, Sendai, Japan, November 2014.

[4] N M Ridler, R G Clarke, M J Salter, and A Wilson, "Traceability to National Standards for S-parameter Measurements in Waveguide at Frequencies from 140 GHz to 220 GHz", *Proc. 76th ARFTG Microwave Measurement Conference*, pp 8-14, Clearwater Beach, FL, USA, December 2010.