Towards a New Form of National Impedance Standard for Millimetre Wavelengths using Dielectric Waveguide

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***Abstract* — For RF and microwave measurements, UK national impedance standards are currently available using coaxial lines to 50 GHz and metallic rectangular waveguide to 110 GHz. At present, no standards exist above these frequencies. Therefore, a new form of impedance standard (utilising dielectric waveguide) is currently being investigated for precision metrology applications across the entire millimetre-wave band (i.e. extending to at least 300 GHz, and perhaps beyond). This paper reports on the progress to date with this work.**

I. Introduction

Many newly proposed applications exploiting the millimetre-wave frequency band above 110 GHz have opened up demands for suitable impedance standards [1]. Currently available national standards only exist up to 110 GHz and are based on coaxial line and rectangular metallic waveguide. As the frequency extends beyond 110 GHz, the physical size of these standards (needed to ensure mono-mode propagation) becomes too small to manufacture reliably and the necessary dimensional accuracy cannot be easily guaranteed. The conductor losses and connection reliability of these standards also creates severe difficulties for precision metrology applications.

An alternative transmission line suitable for use at millimetre wavelengths is dielectric waveguide. This form of transmission line has several advantages over the existing transmission lines used for standards. Firstly, the necessary mechanical sizes and tolerances of the dielectric waveguide dimensions are easier to maintain. These dimensions are also easy to verify using simple mechanical measurement techniques. Secondly, due to the absence of metallic conductors, the transmission losses are much smaller than metallic transmission lines. Finally, the connection between a pair of dielectric waveguides is less dependent on accurate alignment of the conductors and therefore this will provide more reliable connections.

There are several tasks necessary to design new forms of impedance standards using dielectric waveguide. Firstly, it is necessary to choose a suitable material to form the dielectric waveguide transmission lines. The material must have low dielectric loss at the frequencies of interest, have suitable mechanical properties (in terms of rigidity and machining capabilities) and have a low coefficient of thermal expansion. Secondly, transitions from metallic rectangular waveguide to dielectric waveguide must be designed to form suitable test port reference planes. Finally, a range of standards must be fabricated suitable for performing high accuracy calibrations of the measuring instrument, i.e. a Vector Network Analyser (VNA). This includes establishing a method for determining the characteristic impedance of the dielectric waveguide.

The work undertaken on the above tasks is described below.

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II. Selection of Dielectric Material

The following materials were tested for dielectric loss (to 110 GHz): PEEK, PTFE, PP, Rexolite, HDPE and TPX.[1] Figure 1 shows loss measurements for four of these materials – PEEK was found to have very high loss at these frequencies, i.e. typically up to 20 dB, even for short lengths of line (e.g. 100 mm).

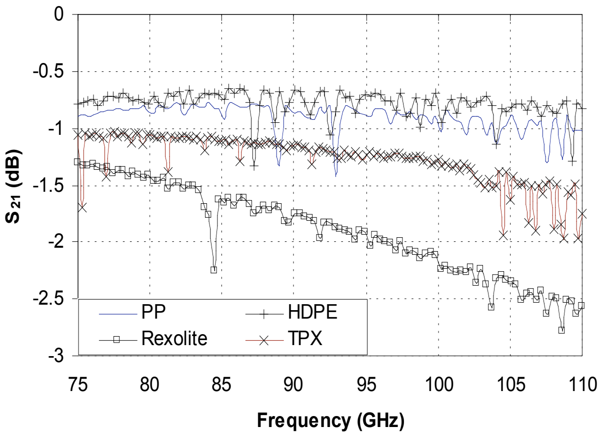

Figure 1. *The measured dielectric loss (as S_{21}) for PP, HDPE, Rexolite and TPX, for short lengths of line (i.e. around 100 mm).*

Although PTFE and HDPE have very low dielectric loss, they are not sufficiently mechanically rigid to be used as standards. The mechanical properties, in terms of rigidity and machining capabilities, of TPX and Rexolite are very good, but their dielectric loss increases with frequency so they are unlikely to be suitable as standards above 110 GHz. This reduces the choice of material to just PP (polypropylene), which has low loss, reasonable rigidity and possesses an acceptable coefficient of

[1] The full chemical names and some of the physical properties of these materials can be found in [2].

thermal expansion (see [2]). PP has therefore been chosen as the material used to form the dielectric transmission lines and standards.

III. RECTANGULAR WAVEGUIDE TO DIELECTRIC WAVEGUIDE TRANSITION

In order to optimise the energy coupling between the rectangular waveguide ports on the VNA and the required dielectric waveguide reference planes, a taper has been designed utilising a standard waveguide horn for the transition. Figure 2 shows the different types of taper that have been studied.

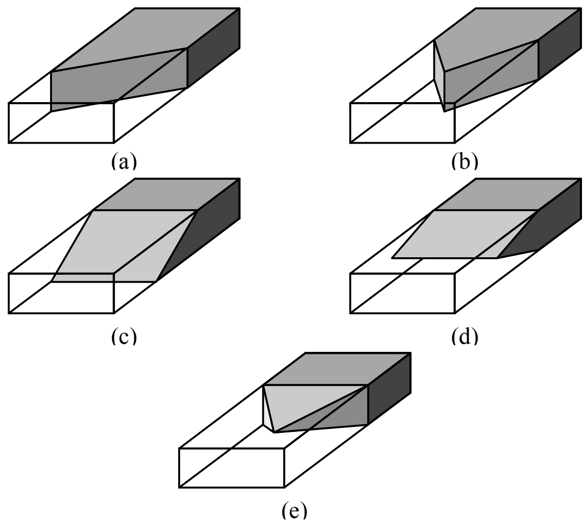

Figure 2. *Different taper designs: (a) H-plane asymmetric, (b) H-plane symmetric, (c) E-plane asymmetric, (d) E-plane symmetric and (e) pyramidal (i.e. tapered in both H- and E-planes).*

The performance of these designs was assessed using CST Microwave Studio® electromagnetic simulation software [3]. As an example, Figure 3 shows the predicted return loss for each taper design. In each design, the cross-sectional dimensions of the dielectric waveguide have been chosen to be the same as the dimensions of the metallic rectangular waveguide,[2] i.e. approximately 2.54 mm × 1.27 mm.

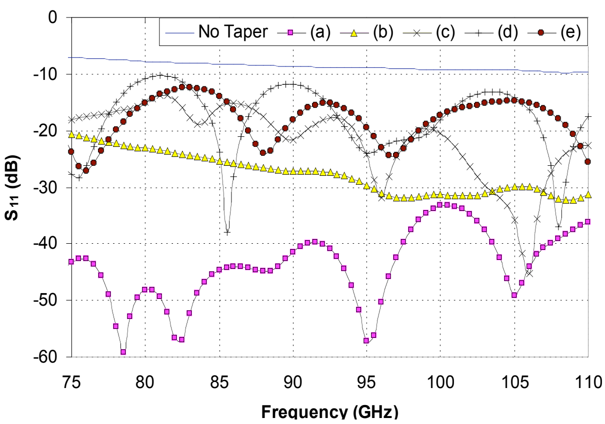

Figure 3. *Predicted return loss (as S_{11}) for the different taper designs.*

From these simulations, the H-plane asymmetric taper gave the best overall performance. These tapers have since been constructed and used as the VNA reference planes.

IV. CALIBRATION STANDARDS DESIGN

In order to calibrate the VNA, standards with known properties need to be attached to the test ports. In the simplest case, three standards with known reflection coefficient have been designed using different lengths of dielectric waveguide terminated with precision short-circuits (formed using a flat gold sheet placed across the end of the waveguide). The lengths of the dielectric waveguides are chosen to provide optimum phase separation in the complex reflection coefficient plane (i.e. 120º) at approximately the mid-band frequency. In future, two-port calibration schemes (e.g. TRL) employing a length of dielectric waveguide as the standard will also be implemented.

In both cases, a detailed knowledge of the characteristic impedance of the lines used to fabricate the standards is required. A technique for doing this, which has been verified in other transmission media [4], is currently being implemented.

V. CONCLUSIONS

This paper has reviewed progress to date on realising a new form of impedance standard suitable for use across the entire millimetre-wave band (i.e. to 300 GHz and beyond). This work has concentrated on measurements at frequencies up to 110 GHz (where current measurement instrumentation is readily available). After implementing and testing the proposed calibration schemes at these frequencies, it is planned that the next step in this research effort will be to apply this measurement strategy to the waveguide sizes covering frequencies from 110 GHz to 325 GHz.

VI. ACKNOWLEDGEMENT

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VII. REFERENCES

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[2] Known as either; WG27, R900, WR10 or W-band waveguide.

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