A Micromachined WR-3 Waveguide with Embedded Bends for Direct Flange Connections

Talal Skaik[*1], Yi Wang[*2], Maolong Ke[*3], Shilong Qian[*4], Michael Lancaster[*5]

[*]*School of Electronic, Electrical and Computer Engineering, University of Birmingham, B15 2TT, U.K*

[1]talal_skaik@hotmail.com
[2]aeony_wang@hotmail.com
[3]m.l.ke@bham.ac.uk
[4]qianshilong@hotmail.com
[5]m.j.lancaster@bham.ac.uk

***Abstract*— A novel micromachined waveguide bend operating in the frequency range 220-325 GHz is presented. It provides for a direct and accurate connection with standard waveguide flanges. A structure of two back-to-back right angle bends and a straight 16mm long WR-3 rectangular waveguide has been fabricated and tested using a UG-387 flange. The structure is made of four layers of metallised SU-8 pieces using a micromachining technique. The measurements show a return loss of -20dB and a normalized insertion loss of 0.134 dB/mm at 300 GHz.**

I. INTRODUCTION

The growing demand for higher bandwidths in communications systems and for higher resolution imaging has increased the interest in components working in the millimetre and the terahertz frequency ranges. The fabrication of high precision waveguide components operating at these frequencies using standard metal machining is very expensive. Alternatively, micromachining can be used to produce millimetre wave components with good dimensional accuracy, high performance and reduced cost. Here we use SU-8 as the micromachining technology.

The fabrication of various SU-8 based waveguide sections and the measurement using a specially designed metal block have been demonstrated in [1]. The measured WR-3 waveguide showed an insertion loss between 0.625 dB/mm and 1.125 dB/mm over the range 220-325 GHz. A straight SU-8 based WR-3 waveguide has also been reported in [2]. The waveguide exhibited normalized insertion loss between 0.09 dB/mm and 0.44 dB/mm over the range 220-325 GHz, and reflection response with many undesirable spikes. This was attributed to a loose connection between the test port flange and the device under test. It is particularly difficult to accurately connect to such tiny waveguides, and here we investigate one solution to the problem.

This paper presents the fabrication and measurement of a WR-3 rectangular waveguide section with two back-to-back matched bends enabling accurate positioning of the flange alignment pins and waveguide. The device is made of four layers of metal coated SU-8 using photolithography to produce the micromachined circuit. The proposed structure provides accurate and repeatable connection between the micromachined device and the flanges, and the measured results exhibit normalized insertion loss of 0.134 dB/mm at 300 GHz. To the best of the authors' knowledge, the measured results represent the best performance ever demonstrated on any micromachined waveguides at the same frequency range.

A cross section of the waveguide is shown in Fig. 1. It is composed of four layers of metal coated SU-8, each of a thickness of 432 µm. Layer 1 and 2 are bonded together using conducting glue to make half of the split blocks, and layer 3 and 4 are bonded to form the other half. To minimize the resistive losses, and to avoid any gaps between the SU-8 layers, a second metal evaporation has been done on each of the two halves.

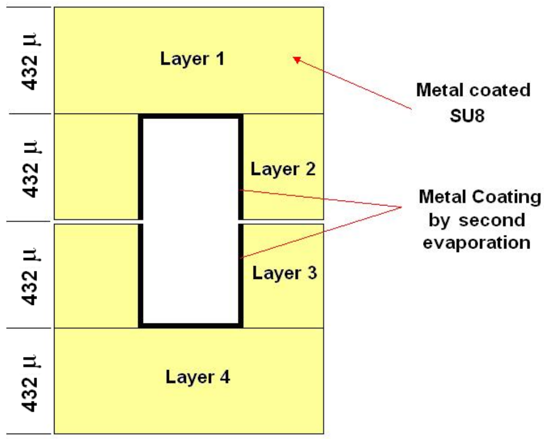

Fig. 1 Cross sectional view of the micromachined waveguide structure.

II. BEND DESIGN

Waveguide right-angle corners exhibit narrowband and mismatched response. Conventionally, a broadband matching is achieved by using a smooth transition such as multi-stepped or multi-mitred corners [3], [4]. However, these configurations are not compatible with the layered structures proposed in this paper. A modified waveguide bend that can be fabricated using the micromachining technology is therefore presented here. The bend has two ridges at the junction region; each contributes a resonance into the desired frequency band and broadens the matched bandwidth. The bend structure, with the optimized dimensions is shown in Fig. 2, and the simulated response is given in Fig. 3. The geometries of the ridges have been adjusted by EM optimization [5] to achieve matching in the range between 250-320 GHz with a return loss of -20dB or better. A more complicated structure would be required to achieve matching over the whole WR-3 band (220-325 GHz).

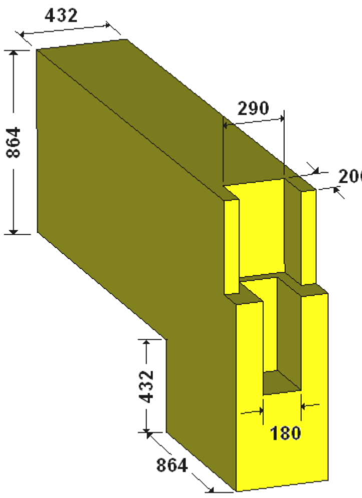

Fig. 2 Structure of the bend. Dimensions are in micrometers.

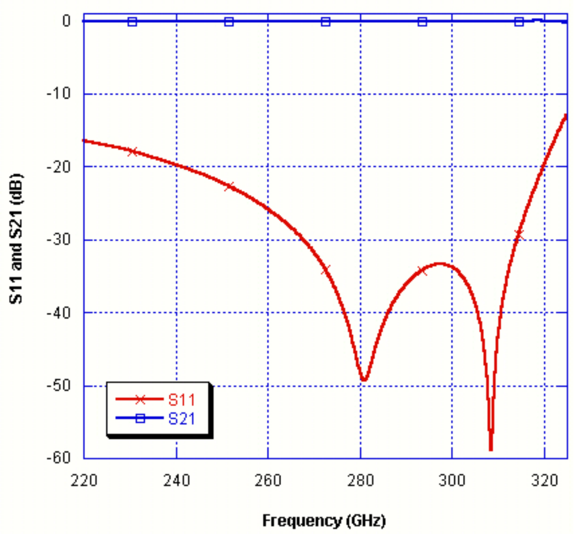

Fig. 3 Simulated response of the bend.

To measure the bend, a structure of two back-to-back bends and a straight waveguide section is constructed. It is formed of four micromachined layers; each contains holes to allow alignment pins and screws of the test flanges to pass through. The locations and diameters of these holes match those in the standard UG-387 waveguide flange. Fig. 4 depicts the back-to-back structure and the top view of layer 2. The waveguide length is around 16mm excluding the bends; this is made sufficiently long to permit fair separation between the flanges so that pins and screws are not blocked from the other side. The size of each SU-8 layer is 432 μm x 48 mm x 24 mm. Crucially the alignment pin holes and waveguide are now formed by the micromachining process, this enables the micromachining process to control the accuracy of the alignment. The bends allow the waveguide to be in the same plane as the SU-8 layers. This is distinct from the previous work [1, 2] where the waveguide flange was connected laterally to the SU-8 layers. The proposed structure will eventually allow other waveguide components such as filters to be interconnected between the bends. Moreover, it may be extended to include multiport components such as waveguide multiplexers.

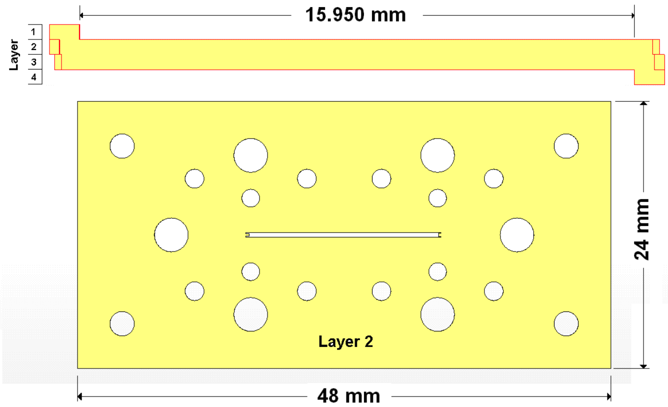

Fig. 4 Side view of back-to-back structure and top view of layer 2.

III. FABRICATION AND ASSEMBLY

SU-8 photolithography process has been utilized to produce the device. A more detailed description can be found in [6], [7]. Firstly, an amount of SU-8 was dispersed onto a 4-in silicon wafer for spinning, then the resist was pre-baked to evaporate the solvents, then the sample was exposed under UV light to define the right patterns by photolithography. Post-baking was then carried out to strongly cross-link the defined patterns, and then the wafer was developed in Ethyl lactate solvent and hard baked. The SU8 pieces were then released from silicon and metallised. The metal coating was done by firstly sputtering 5 nm of Cr adhesion layer, then evaporating just over 1μm thick silver and a thin protection layer of 20nm gold. The evaporation was done using an off-axis rotation in order to make sure the metal walls of the waveguide were well coated.

Once the four SU-8 layers were ready for assembly, layers 1 and 2 were aligned and bonded together using conducting glue, and then a second metal coating was performed to fill any gaps in the interface between the layers, as mentioned earlier. The same process was done for layers 3 and 4. Finally, the device was assembled and the pieces were aligned using pins, and then clamped together using conventionally machined metal plates made from brass. It should be noted that these brass plates bear no function for alignment, considering their inferior fabrication accuracy as compared with micromachining. A secure connection between the standard flange and the SU-8 device is realised since the flanges are directly connected to the first and the fourth layers using screws. A photograph of the assembled device is shown in Fig. 5.

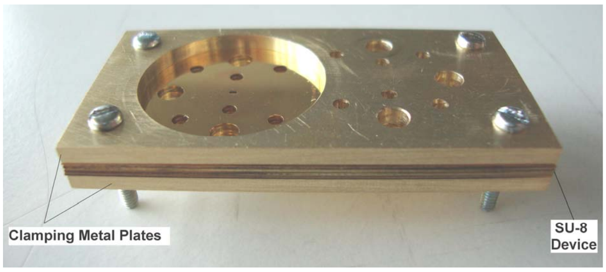

Fig 5 Assembled device

IV. Measurement Results

An Agilent E8361A Network Analyser with OML extension modules V03VNA2-T/R and V03VNA2-T (220-325 GHz) have been used to take measurements. Only one transmission measurement (S_{21}) and one reflection measurement (S_{11}) are possible by using one T/R module and one T module. The device has to be reversed to measure the parameters (S_{12}) and (S_{22}). Moreover, the return loss at any port has been measured with the other port connected to load. An Enhanced-Response calibration that combines a one-port calibration and a response calibration was performed first. A photograph of the measurement setup showing the SU-8 device clamped between the metal plates and connected to the test ports is depicted in Fig. 6.

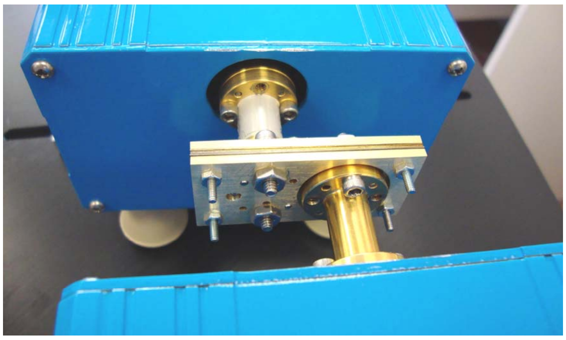

Fig. 6 Photograph of the measurement setup

Fig. 7 displays the simulated and the measured S-parameters of the back-to-back structure. The metal used in the lossy simulation in Fig.7 (b) is silver, which has a conductivity of $6.3x10^7$ S/m. The measured results show a return loss of better than -16dB and insertion loss of 2.5 - 3 dB in the frequency range 240-312 GHz. We believe that the imperfection of metal conductivity, and also the possibility of existence of gaps in the interface between the layers may have caused the higher-than-simulated insertion loss.

The measurements have shown good repeatability. This, together with the measured low return loss, indicates a reliable flange connection. The multiple nulls in the S_{11} response are due to signal reflections at the end of the waveguide sections.

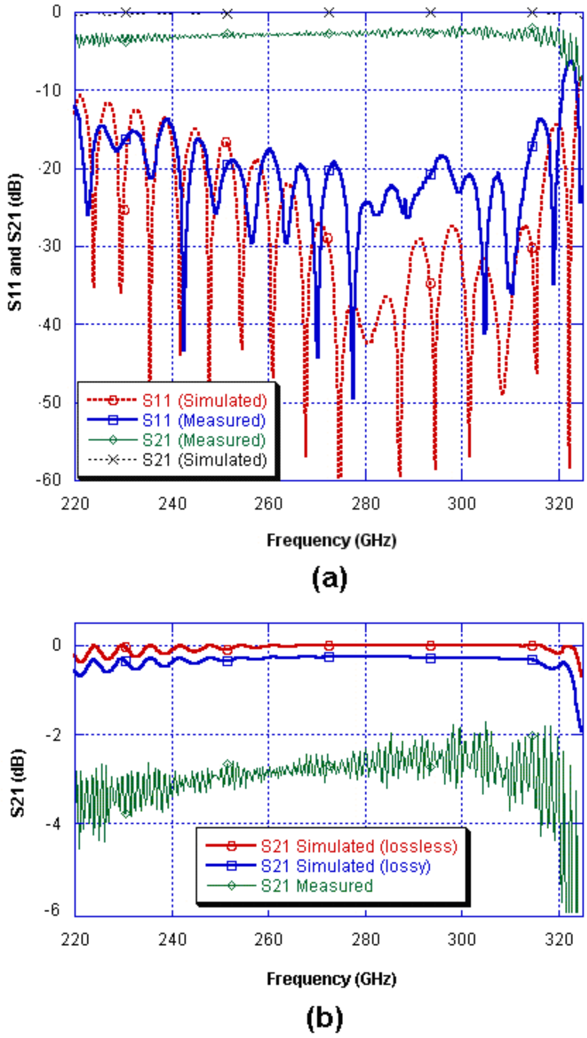

Fig. 7 (a) Measured and simulated results, (b) passband details

V. Conclusions

An SU-8 micromachined waveguide bend has been presented. Such a bend provides a direct and accurate connection interface with standard waveguide flanges and will allow interconnecting waveguide components such as cavity filters. A 4-layer SU-8 structure of two back-to-back bends and straight WR-3 waveguide has been fabricated and tested and the measured results show better performance than micromachined SU-8 waveguides elsewhere in literature. Two brass plates have been used to clamp the metal coated SU-8 pieces together. In the near future, 300 GHz devices such as a filters and diplexers will be fabricated and tested by employing the designed waveguide bends in the measurement.

Acknowledgment

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