Design and Implementation of a Broadband and Compact 90-degree Waveguide Twist with Simplified Layout

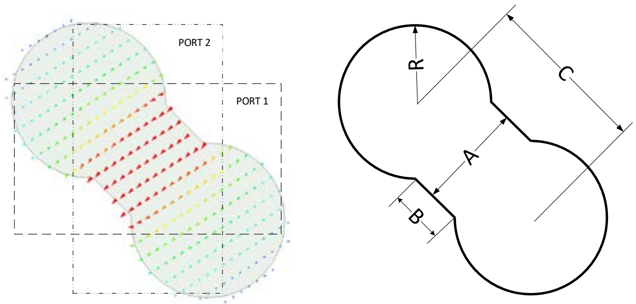
C. Lopez[1], V. Desmaris[1], D. Meledin[1], A. Pavolotsky[1] and V. Belitsky[1]

***Abstract*— We report on a novel wideband single step 90-degree twist with a tolerant geometry, hence allowing for a simplified manufacturing process achieved through direct milling. Experimental verification shows a return loss of less than 20 dB over the 140-220 GHz band, which constitutes a 44% fractional bandwidth. Furthermore, the insertion loss is comparable with a continuous twist for the same band. The performance, compactness and fabrication tolerance insensitivity make it very suitable for use in various waveguide systems from cm to mm wavelength range.**

***Index Terms*—waveguides, waveguide twist, simplified manufacturing process, single step twist.**

I. Introduction

WAVEGUIDE twists are an essential interconnection part in many millimetre and sub-millimetre systems, especially for modern polarization sensitive THz receivers [1]. Among the different types, the 90-degree twist is the most common one. As a consequence, it has been largely studied and many implementations can be found in the literature [2-7]. Nevertheless, the main solutions are the continuous rotation and single step twist. The first approach is frequently adopted in a commercially available twists. Although the smooth rotation guarantees low insertion loss and minimizes the reflection over larger bandwidths, it requires length of several wavelengths and implies complicated and time-consuming fabrication processes. As compactness is often a key aspect for instrumentation receiver systems, most of the research in this field has focused on a single step twist. There have been numerous studies to investigate step twist with cross sections based on corner cut waveguides [2]. More complicated geometries with multiple sharp corners or ridge waveguides [3,4,5] have also been proposed. These geometries usually introduce additional cuts that maximize the bandwidth of the twist. Nonetheless, the performance of such twists is frequently rather sensitive to their geometrical dimensions, hence requiring tight fabrication tolerances. Therefore, simple fabrication techniques such as milling often are not applicable. For instance, in [6], the design proposed in [7] is implemented using micromachining techniques.



(a) (b)

Fig. 1. WR-5 Twist. (a) Cross Section view of twist and waveguide ports. Electric field illustration of the twist dominant mode. (b) Design of WR-5 waveguide Twist: R= 420µm, A= 560 µm, B= 294 µm and C= 920 µm. The thickness is 500 µm.

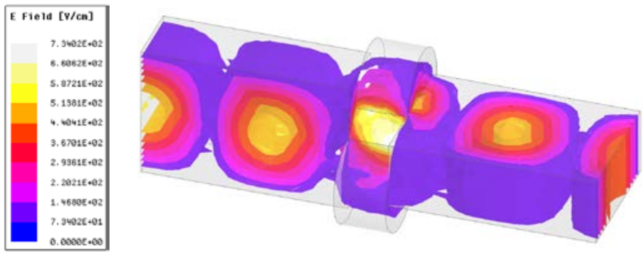


Fig. 2. Visualization of 90 º EM field rotation. The TE10 mode is transformed into TE01 through the dominant mode of the twist.

In this paper, we present a novel single step 90-degree twist with more tolerant geometry, hence allowing for a simplified manufacturing process.

II. Design and Fabrication

The proposed waveguide twist is depicted in Fig. 1. It comprises two circular waveguides with radius R interconnected by a rectangular waveguide defined by the parameters A and B. The distance between the centres of the circular waveguides is defined by C. The thickness is approximately a quarter of the guided wavelength inside the structure at the centre frequency, i.e. 500 µm for our designed Twist.

The twist transforms the TE_{10} mode into TE_{01} through the dominant mode of the structure. This mode allows the rotation of the polarization from 0 to 45 degrees inside the twist, and

[1] Group for Advanced Receiver Development, Chalmers University of Technology, SE412 96, Gothenburg, Sweden.

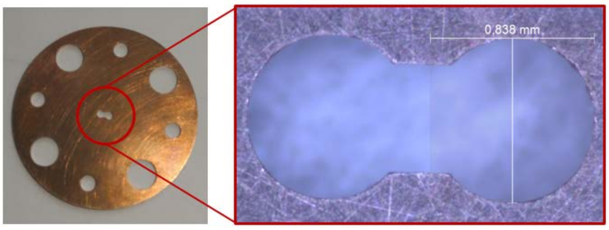


Fig. 3. Photograph of fabricated twist and detail of structure.

finally to 90 degrees as it is shown in Fig. 2. The shape of the twist allows easy fabrication using milling or combination of drilling and milling.

The waveguide twist has been optimized using the full-wave 3D simulator Ansys HFSS aiming frequency range 140-220 GHz. Tolerance analysis has shown that a maximum deviation of 10µm in each parameter could be allowed for the twist operating in this frequencies.

The test structure was fabricated of tellurium copper through direct milling and illustrated in Fig. 3.

III. Measured Performance

The fabricated twist was characterized using VNA frequency extension modules (VDI Inc. extension modules and a Keysight PNA-X). A SOLT calibration was applied.

The simulated and measured results are compared in Fig.4. The return loss is below -20dB over the whole band, which implies a 44% fractional bandwidth. It can be seen that return loss measurements show good agreement with simulation.

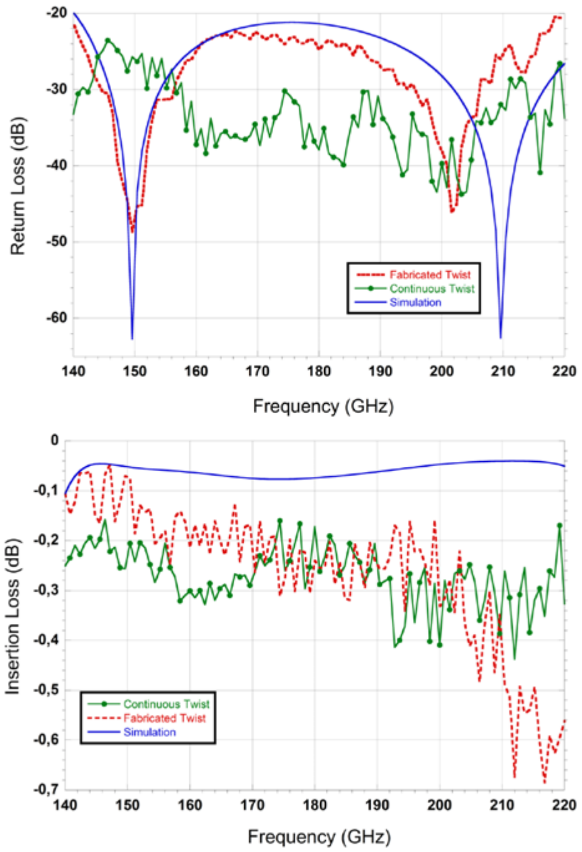


Fig. 4. Measured and simulated scattering parameters of the proposed design. The measure performance of a continuous commercial twist is also included for comparison purposes.

However, the predicted resonance at 210 GHz seems to be shifted down by 8 GHz due to fabrication inaccuracy. Regarding the insertion loss, it is less than 0.4dB between 140 GHz and 200 GHz. However, it rapidly degrades for frequencies above 200 GHz. It is clear from the graph that the fabricated twist presents additional losses that were not predicted by the simulation. We proposed that this phenomenon can be due to fabrication tolerances. Misalignment of the twist with respect to the input and output waveguides could excite non-dominant modes inside the twist cavity. Therefore, energy transfer between modes is promoted and the overall insertion loss is increased. Simulations initially confirm this hypothesis. Nevertheless, further investigation is required.

For the sake of comparison, a commercial 4mm long continuous twist fabricated through electroforming was measured using the same setup. It is easy to see that the overall insertion loss of the continuous twist is in the same range as our design for almost the entire band.

IV. Conclusion

A novel 90° single step twist with a simple and compact geometry has been presented. It has been shown that the design is well-suited for fabrication through standard milling techniques. Experimental results have shown a 44% fractional bandwidth with return loss better than -20dB. Although the measured transmission loss is similar to a continuous twist, it is higher than expected. A possible explanation could be that the excitation of higher order modes caused additional loss. However, further research is needed in order to fully describe the complete set of modes inside the twist and its relation with structure alignment.

Acknowledgments

The research leading to these results has received funding from the European Commission Seventh Framework Programme (FP/2007-2013) under grant agreement No 283393 (RadioNet3).

References

[1] Belitsky et al, "SEPIA – a new single pixel receiver at the APEX telescope", Astronomy and Astrophysics, vol. 612, A23, 2018.

[2] Wu, J. M., Zhou, D. F., Lei, X., Gao, J., & Hu, H. M. , "Design of a compact broadband 90 waveguide twist based on double-corner-cut square slots.", International Journal of Antennas and Propagation, 2017.

[3] Asao, H., Hiraiwa, G., & Katayama, A, "A compact 90-degree twist using novel ridged waveguide for integrated waveguide subsystems.", 2006 European Microwave Conference , pp.1185-1188, IEEE, September 2006.

[4] Sun, M., Xu, Y., Peng, T., Shang, Y., & Zhen, Q.,"Design of a compact and broadband 90-degree waveguide twist.",*2018 IEEE International Vacuum Electronics Conference (IVEC)* , pp.203-204, IEEE, April 2018.

[5] Cano, Juan Luis; Mediavilla Sanchez, Angel, "Arbitrary-angle single-step waveguide twist for quasi-octave bandwidth performance", Progress In Electromagnetics Research, vol 162, pp. 73-79, 2018.

[6] Chen, L., Arsenovic, A., Stanec, J. R., Reck, T. J., Lichtenberger, A. W., Weikle, R. M., & Barker, N. S. (2011). "A Micromachined Terahertz Waveguide 90 Twist." *IEEE Microwave and Wireless Components Letters*, vol *21*(5), pp. 234-236,2011

[7] Litvinov, V. R., Rud, L. A., & Sverdlenko, E. A. "Compact 90° twists into rectangular waveguides", *Radioelectronics and Communications Systems*, vol. *53*, pp. 162-166, 2010.