PhD PROJECT PROPOSAL

## **PhD Project Title**

## Topological optimisation of 3D printable THz waveguides for on-chip applications

## **PhD Supervisory Team**

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## **Project Abstract**

## Driven by our data hungry society, chip-to-chip and device-to-device data bit rates will need to reach terabits per second in a not distant future. Such data rate will only be met if there is a shift from microwaves to mm-waves (ca. 30 – 300 GHz) or even Terahertz frequencies (ca. 0.3 – 1 THz). Current on-chip interconnect technology relies on printed circuit board (PCB), which is not suitable for high frequencies due to loss and dispersion limitations. Tackling these problems with complex equalization techniques will not be possible because of their high power consumption and needed area. To address the need for high-speed links for THz interconnects, this project will focus on the topological optimisation of the promising dielectric-lined metallic waveguide. The recent fabrication flexibility enable by two-photon polymerisation 3D printing rationalizes the use of the powerful topological optimisation.

## **Detailed Project Description**

Current on-chip interconnect technology is not scalable to provide wide bandwidth beyond Gbps. It is well accepted that to achieve in the future terabit per second data rates, technology will need to migrate to terahertz frequencies (i.e., 0.1-3 THz) [1]. However, at such high frequencies the standard transmission lines display excessively large attenuation (hundreds of dB/m) and cross-talk. Tackling these problems with complex equalization techniques will not be possible because of their high power consumption and required area.

The dielectric-lined metallic waveguide [2] is a potential solution to this problem. Although this metallo-dielectric hybrid waveguide is multimode, it supports a quasi-single mode propagation due to an effect known as self-filtering, whereby all modes suffer significant attenuation except for the desired HE11 mode [3]. This fundamental mode is concentrated in the waveguide’s air core and can show an attenuation coefficient below 10 dB/m. This is at least one order of magnitude smaller than the attenuation of dielectric waveguides (i.e., the microwave equivalent of an optical fibre), which are greatly penalized by the increasing absorption of dielectrics in the THz range. In addition, the dielectric-lined metallic waveguide shows very low dispersion, which benefits the design of any digital link.

Although several fabrication techniques have been used to realize dielectric-lined metallic waveguides in the past [3], none of them is flexible enough to enable fabrication across the entire THz band and to enable patterning the dielectric coating to provide functionalities seen in optical fibres or microwave waveguide technology like dispersion management, filter effects, etc. Additive manufacturing based on two-photon polymerisation may resolve this by providing a flexible platform for the fabrication of these waveguides for any region of the THz band and devices (e.g. filters) based on these devices.

This project will include two strands: experimental and numerical.

The experimental strand will be devoted initially to material characterisation; namely, to extract the dielectric properties of the available materials for two-photon polymerisation based 3D printing at Terahertz frequencies using a time-domain spectroscopy system hosted by the Metamaterials Research Group and the Terahertz Measurement Facility hosted in the School of Engineering. Subsequently, the experimental strand will focus on the fabrication (using the world's highest resolution 3D printer Nanoscribe Photonics Professionals available in the Metamaterials Research Group) and testing of devices (using a near-field version of the existing time-domain spectroscopy system and the Terahertz Measurement Facility), including a demonstrator of the chip-to-chip performance.

The numerical strand will be devoted to the design, topological optimisation and modelling of the THz interconnects and other devices based on advanced waveguide technology.

[1] Semiconductor TeraHertz Technology: Devices and Systems at Room Temperature Operation, Wiley-IEEE Press, (2015).

[2] IEEE Trans. THz Sci. Tech. 1, 124, (2011)

[3] J Infrared Milli Terahz Waves 36, 542, (2015)er chemistry and nano-formulation.