PhD PROJECT PROPOSAL

PhD Project Title

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

PhD Supervisory Team

Primary Supervisor: Dr Miguel Navarro-Cía, m.navarro-cia@bham.ac.uk, School of Physics and Astronomy, Metamaterials Research Group.

Co-supervisor/s: Dr Yi Wang, y.wang.1@bham.ac.uk, School of Engineering, Communications and Sensing Group; Dr Stephen Hanham, s.hanham@bham.ac.uk, School of Engineering, Communications and Sensing Group.

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.

How does the project utilise topology or topological design?

In Topological Optimisation, the structure or topology of the device is a 'free variable' and the optimisation technique attempts to optimise it such that one or more functional characteristics of the device are satisfied. The topology can range from a dielectric or conductivity distribution in two or three dimensions where 3D printing may be utilised.

Detailed Project Description

Research background, intended outcomes and methodology;

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 others 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)

Training and skills to be developed over the PhD;
This PhD project offers training in diverse areas of research in computational and applied electromagnetics. The student will develop critical thinking and analysis capability through strong linkage between the computational/theory and experimental outcomes. S/he will be supported in developing project management and leadership skills, and be active in the direction of the research. S/he will develop her/his communication skills through reporting, and disseminating the research outputs through publication and conferences.

Explanation of why the project is suitable for the CDT in Topological Design;
The new fabrication opportunities opened up by two-photon polymerisation (Nanoscribe Photonics Professional) for THz devices pave the way for full topological optimisation of the devices.

Links with research in the research groups of the supervising team;
This project will benefit from close synergy with other projects successfully completed or still active in the Department of Electronic Electrical Engineering as well as in the School of Physics and Astronomy. Namely, the following EPSRC projects “Towards a 3D printed terahertz circuit technology”, “PATRICIAN: New Paradigms for Body Centric Wireless Communications at mm Wavelengths”, “Anisotropic Microwave/Terahertz Metamaterials for Satellite Applications (ANISAT)” and “Multi-functional metamaterials and antennas for RF/Microwave communication and sensing devices (MULTIMET)”; the following Royal Society-funded project “Experimental demonstration of transmissive-type terahertz digital metamaterials based on microfluidic system”; and the EU-funded H2020 Rise "Non-Conventional Wave Propagation for Future Sensing & Actuating Technologies" project. The Metamaterials Research Group is also actively involved in the recently-launched EPSRC UK Metamaterials network led by the University of Exeter, whose remit covers this CDT PhD project.

Links with research strategies, possibly including UoB, EPSRC, partner organisations;
The project falls within two of the UoB strategic priority areas within the overarching themes ‘Science Frontiers’ and ‘Advanced Manufacturing Research’.

The project will make full use of a recent investment in the School of Engineering in a new anechoic chamber and associated facilities for antenna characterisation (£2.5M) and the THz testing equipment (£1.2M EPSRC investment).

The proposed research is a foundational topic situated at the intersection of the ICT and Physical Sciences EPSRC thematic portfolio areas, specifically the RF & Microwave Communications area. This in turn, underpins much of the strategic priority themes of Digital Economy, Healthcare Technologies, Engineering (e.g. Sensors and Instrumentation) and Living with Environmental Change (e.g. Information Infrastructure).

An ideal/acceptable undergraduate background and interests.
First degree in Physics, Electronic Engineering or closely related subject, with background in basic electromagnetics, and advanced mathematics and preferably some experience or interest in microwave communications systems.