PhD PROJECT PROPOSAL

## **PhD Project Title**

Topological Design in Liquid-metal based High Frequency Devices and Sensors

## **PhD Supervisory Team**

Principal Supervisors: Dr Yi Wang, [y.wang.1@bham.ac.uk](mailto:y.wang.1@bham.ac.uk), Comms and Sensing Research Group, School of Engineering

Industrial Supervisor: Sampson Hu, Novocomms Ltd

Co-supervisors: Dr Shiyang Tang, [s.tang@bham.ac.uk](mailto:s.tang@bham.ac.uk), School of Engineering

Associated Academic: Dr James Kelly, [j.kelly@qmul.ac.uk](mailto:j.kelly@qmul.ac.uk), Queen Mary University London

## **Project Abstract**

Liquid metal is a weird and wonderful material. New non-toxic liquid metal alloys have found a wide range of applications from heat transfer, motors, flexible electronics to soft robotics, for their fluidic, thermal and shape-shifting properties. Liquid metals can be pumped, electrically or magnetically actuated or even 3D printed! This project will explore the use of liquid metals in functional RF and microwave devices and sensors. In particular, it will develop device technologies using microfluidics and micromachining and by topological design, mimicking the functionality of field-programmable-gate-arrays (FPGA), that enable reconfigurable, programmable or adaptive high-frequency electronics.

## **Detailed Project Description**

Research background

In digital electronics, Field Programmable Gate Arrays (FPGAs ) have greatly simplified the hardware development cycle, reducing the time and cost associated with developing hardware. This proposed research will pave the way for the development of the equivalent of an FPGA in the domain of microwave electronics. The key novelty of the proposed research lies in reusing printed circuit board (PCB) real-estate to perform different circuit functions. This will be facilitated by Gallium-based Liquid Metal (LM), whose unique properties have led people to refer to it as the ‘terminator’ metal. Whilst solid metals are fixed, LM is easily reconfigurable.

Aims and objective

The aim of the project is to develop device technology for reconfigurable, programmable or adaptive electronics using liquid metals. The design and implementation of the actuation mechanism for liquid metals is a key challenge. The specific objectives of the PhD project are:

1. To use topological design approach to design and optimise the actuation mechanism for liquid metals in microfluidic channels, considering the interplay between the channel geometry, surface tension of the liquid metal and the external actuating forces.
2. To co-design the actuation mechanism with the microwave circuits, applying topological optimisation on the latter (electromagnetic topological design)
3. To demonstrate a reconfigurable, programmable or adaptive circuit function for a communication device.
4. To demonstrate a flexible or wearable liquid-metal based sensor for health monitoring applications.

Methodology

The project will involve theoretical formulation, fluidic and electromagnetic design, computer modelling and simulation, device fabrication (soft lithography and/or micromachining) and experimental verification. The student will see through multiple design cycles of high-frequency devices and sensors. The design will be multidisciplinary and multiphysical.

A key part of the research is to investigate, model and simulate, by topological design, the interplay between geometry of the microfluidic channels, the surface tension (internal forces) of liquid metals with or without auxiliary liquids such as electrolytes, and the external actuation forces. These could be from pneumatic, electric, magnetic, or electrochemical forces. It is expected 2D modelling (including some theoretical formulation) and simulation will be required. In particular, a metastable locking structure will be designed and prototyped. This is used to accurately maintain and switch between different states of the circuits to afford reconfigurable functions such as switches, phase shifters, tunable filters or reconfigurable antennas.

Topological optimisation is also an intrinsic part of high-frequency circuit design where most circuit elements will be ‘distributed’ with non-uniform electromagnetic field patterns. However, this topological design is different from those for the actuation mechanism. They are in two different physical domains. Co-design may be required. However, the two domains will be weakly coupled. So co-design is not expected to be a major part of the project.

Apart from the strong presence of ‘design’, the implementation will also be an important part of the project. This may require a combination of different manufacturing techniques – soft lithography, cleanroom-based micromachining, and 3D printing. Circuit functions may be demonstrated using printed circuit boards, microcontrollers, and various actuators.

Training and skills to be developed over the PhD

Apart from the transferrable skills and theoretical knowledge on topological design expected from the CDT cohort, this PhD programme will also develop the following project specific skills:

* Design of microfluidic channels, liquid actuation and manipulation
* Design of high frequency circuits
* Design of wearable sensors
* Manufacturing (e.g. soft lithography and 3D printing)
* Use of microwave measurement systems

Training will be provided on all these areas. Some manufacture service will be provided by specialist technicians in the workshop and the Engineering Cleanroom or by external suppliers.

Explanation of why the project is suitable for the CDT in Topological Design

The project has a strong element of ‘topological design’ as explained in Section 2. It is also interdisciplinary. The interaction of the student (and the supervisor) with other people from different disciplines will be invaluable. The student will also benefit from the systematic training in transferrable skills as well as in topological design.

Links with research in the research groups of the supervising team

The PhD project will run alongside and support the EPSRC grant EP/V008382/1 on the topic of ‘Programmable Microwave Hardware Based on Liquid Wires (PROGRAMMABLE)’. The student will also work closely with a research fellow employed on the grant. The lead supervisor Dr Yi Wang’s Emerging Device Technology group currently has 7 PhD students and 3 postdoc research fellows.

Dr Shiyang Tang from School of Engineering is an expert on soft materials. He has ample experience and has pioneered some novel actuation techniques for liquid metals. This programme was designed with the input from Dr Tang.

Dr James Kelly from Queen Mary University of London is a project partner who is an expert on liquid-metal based antennas. He will be able to provide technical advice on the design and implementation using complementary approaches.

An ideal/acceptable undergraduate background and interests

Physics or engineering students with keen interested in design and hand-on practical work