RADIO-FREQUENCY REFLECTOMETRY:
DESIGNING AN IMPEDANCE MATCHING CIRCUIT FOR SENSITIVE QUANTUM DOT READ-OUT

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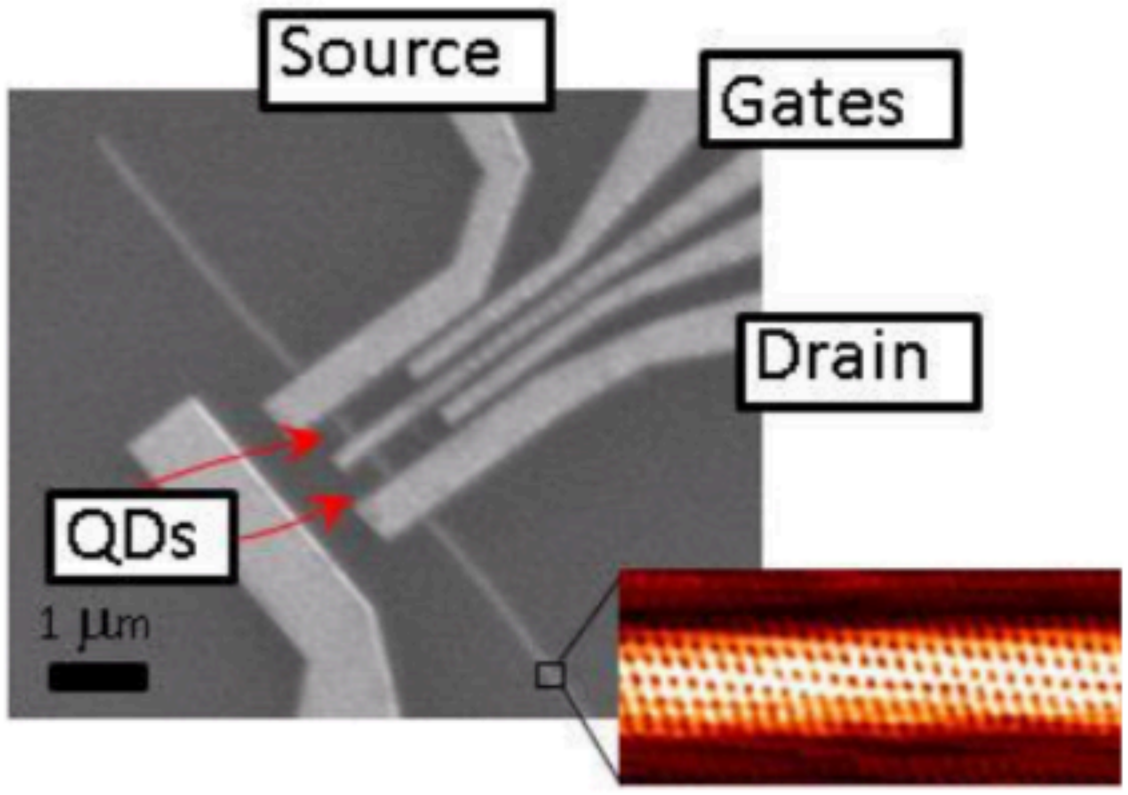
Abstract: The aim of the summer project is the design, measurement and analysis of an electrical resonator network that can be used to 'match' the impedance of quantum dot devices to the transmission lines that connect to them. This will significantly improve the measurement sensitivity of our set-up with the ultimate aim of achieving single-shot readout of spin qubits defined in the quantum dots that host them. The work will furthermore involve the integration of Josephson parametric amplifiers (JPAs) in our set-up, in collaboration with partners at VTT, Finland. The JPAs are quantum-limited meaning they add little noise, further improving our readout sensitivity. This summer project feeds into ongoing work that is part of the ~8M QUES2T investment by EPSRC at UCL (EPSRC Reference: EP/N015118/1) and an ERC Consolidator Grant by the PI.

Motivation and Background: The elementary unit of quantum information is the qubit: a two-level system but with the intriguing ability to exist in a superposition of states. This means it can be in the on and off state at the same time which has profound implications if we consider quantum systems of more than one qubit. Instead of each qubit carrying any well-defined information of its own, the information is encoded in their joint properties. In quantum mechanics, the qubits are described as being entangled. The challenge is to find ways to harness quantum phenomena such as superposition and entanglement to construct a quantum computer that is able to perform computational tasks that are unattainable in a classical context.



A carbon nanotube double quantum dot. The inset shows an atomically resolved scanning tunneling microscopy image.

A very natural qubit is the electron spin. The energy difference between spin states of an electron can be precisely controlled by magnetic fields and, using the electron's charge, it is also possible to isolate and manipulate individual spin electrically. In our group we use electrons trapped in carbon nanotube quantum dots – that is, small sections of carbon nanotube in which the electrons are confined in all three dimensions, see figure. How to achieve entanglement in carbon nanotubes? One route to pursue is to use the interaction of neighbouring qubits due to their electron wavefunction overlap. But a large scale quantum processor built with this technology would rapidly become impractical, as distant qubits can only be entangled through the use of qubits in between. We want to develop an alternative method which makes use of an intriguing quantum mechanical effect by which two *spatially separated* quantum bits become entangled if a measurement cannot tell them apart. Some of the tools we use to measure (and thus entangle) carbon nanotubes are based on radio-frequency (rf) reflectometry developed in our group [1] which allows readout on µs timescales. This summer project has as its aim to improve the read-out sensitivity of this rf reflectometry technique using a matching circuit to tune our device impedance to match the 50 Ω of the transmission lines that connect to them. We expect that this will greatly improve our signal-to-noise ratio.

Workplan: The project for will consist of approximately 8 weeks of work. During the first 1-3 weeks, work will focus on the design of a matching circuit consisting of varactors (voltage-tunable capacitors) for the *LC* resonators used in our experimental set-up. The work in weeks 4-7 will consist of testing the circuit at mK temperatures in a dilution refrigerator; including the addition of JPAs fabricated at VTT in Finland [2]. The work will be under the supervision of Dr. Mark Buitelaar at the London Centre for Nanotechnology (LCN) at UCL – but will be working closely on a day-to-day basis with PhD student Pavlos Apostolidis and Postdoc Byron Villis who will be responsible for the nanotube device fabrication and providing assistance with the dilution refrigerator operation. Work in week 7-8 will consist of data analysis and the writing of a short report on the findings during the summer project.

Essential skills acquired by the student during the project: Microwave circuit analysis. High-frequency (rf and mw) read-out techniques (use of signal generators, directional couplers, amplifiers, filters, etc). Low-temperature measurement techniques.

[1] Penfold-Fitch et al, PRA **7**, 054017 (2017)   [2] Vesterinen et al, SST **30**, 085001 (2017)