ND*nano* Undergraduate Research Fellowship (NURF)
2015 Project Summary

1. Student name: **Áine Cahill**

2. Faculty mentor name: **Prof. György Csaba and Prof. Wolfgang Porod**

3. Project title: **Signal processing using LC lattice microwave networks**

<u>New skills acquired during your summer research:</u>

I developed proficiency designing microwave circuits, defining their structure using text-edited netlists and simulating their behavior using SPICE, an analogue electronic circuit simulation program. I acquired strong MATLAB programming skills which enabled me to design netlists modelling electronic circuits and analyse the results of SPICE simulations. Learning how to interact with Notre Dame's Centre for Research Computing (CRC) allowed me to perform parallel simulations using the university's extensive network of computer cores.

I broadened my knowledge of transmission line theory, microwave networks and Fourier optics. My critical-thinking skills were challenged and I gained experience theoretically proving results and designing experiments to objectively test hypotheses.

<u>Project summary:</u>

Signal processing is ubiquitous in modern society: It allows audio signals, speech signals, images and videos to be processed for compression, recognition and enhancement; filtering, equalisation and modulation to be applied in telecommunication systems; weather, economic and seismic forecasting to be executed; and medical imaging, including CAT scans and MRI, to be performed.

Fourier transforms are very important in signal processing. The Fourier transform of a signal indicates which frequencies are present in the signal, and in which proportions, and the power of the signal at a particular frequency. The Fourier transform also simplifies many mathematical operations on signals, including convolution and cross-correlation operations. The discrete Fourier transform of a function of finite extent can be calculated using fft algorithms in programming languages, specifically engineered physical devices and optical lenses. My research investigated how 2D rectangular arrays of LC oscillators could be designed to generate an approximate discrete Fourier transform of any finite input vector, by applying the principles of operation of optical lenses. This research will allow many useful devices to be constructed in nanoscale LC lattice circuits for signal processing applications.

MATLAB code was written to model finite 2D LC lattice networks with boundary termination conditions and to construct graded-index constant-thickness lenses and biconvex lenses in the lattice to perform phase-shifting of the input vector and to generate an approximate discrete Fourier transform of the input vector to the lattice.

The Fourier transform performance of both lenses was analysed and compared extensively for various input functions. Reflections in the lattice due to the lens and lattice boundary conditions limit the resolution of the lattice as an analogue Fourier transform device and this resolution was defined as a function of different parameters of the lattice, including the frequency of the input signals, lattice dimensions and the inductance and capacitance values of the lattice and lens.

It was shown that 2D LC lattices can be used to determine the approximate discrete Fourier transform and inverse Fourier transform of any finite input vector by manipulating the capacitance values throughout the lattice. The MATLAB codes and functions written provide comprehensive control of all parameters in the lattice and lenses as well as thorough analysis of the results of SPICE simulations of the LC lattice. These functions provide insight into wave propagation in the lattice as a function of time and space, voltage and current distribution in the lattice and the comparison of averaged absolute voltage values along specific columns, rows or regions of the lattice. Equations have also been derived determining the optimum simulation time for specified lattice dimensions, the relationship between the resolution of the lens and the inductance and capacitance of the lattice and the focal-length and refractive index of the two types of lenses as a function of capacitance in the lens region(s) of the lattice.

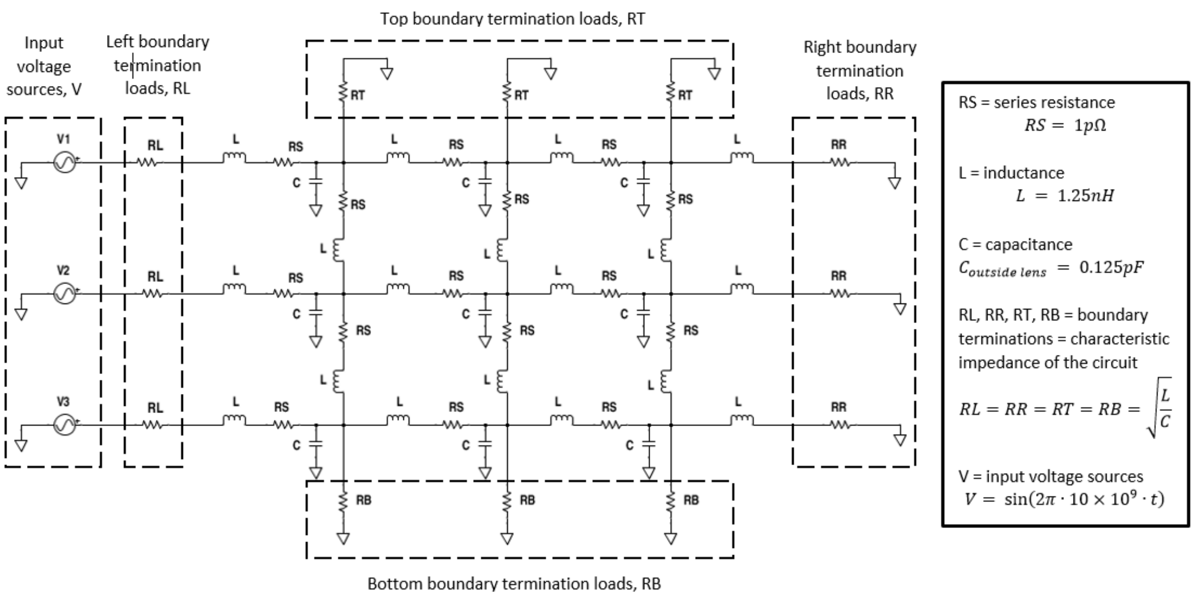

Figure 1: Schematic of a 3x3 LC lattice

Practical applications/end use of your research:

My research on the fundamental operation and limitations of a 2D LC lattice as an analogue Fourier transform device will enable the design of complex low latency and high throughput filters for signal processing applications in 2D LC lattices.

Equations have been derived and MATLAB functions have been designed which provide comprehensive control of all parameters in the lattice and lenses and provide insightful analysis of the behavior of the lattice as a filtering or Fourier transforming device. These functions and formulae will underpin the future design and testing of complex filters in the lattice and the construction of the lattice to perform signal processing applications in novel ways, which are efficient in terms of economy, space and power consumption.

Publications (papers/posters/presentations):

Scientific poster at the 2015 Notre Dame Summer Undergraduate Research Symposium:

“Signal processing using LC lattice microwave networks”

Final report, including simulation results, derived formulae and MATLAB codes for modelling LC lattices with optical lenses and processing SPICE simulation results:

“Signal processing using LC lattice microwave networks”