Use of AEM in the evaluation of MKID design sensitivity to fabrication tolerances

Oisín Creaner[1], Cáthal McAleer[2,3], Gerhard Ulbricht[2,3], Gary Donegan[2,3], Colm Bracken[2], Mario De Lucia[4], Tom Ray[3]
1: Dublin City University, School of Physical Sciences, Glasnevin, Co. Dublin, Ireland
2: Maynooth University, Department of Physics, Maynooth, Ireland
3: Dublin Institute for Advanced Studies, School of Cosmic Physics, 31 Fitzwilliam Place, Dublin 2, Ireland
4: Dipartimento di Fisica, Universita di Pisa, Largo Bruno Pontecorvo, 56216 Pisa, Italy
INFN sezione die Pisa, Largo Bruno Pontecorvo, 56216 Pisa, Italy

What are MKIDs?

Microwave Kinetic Inductance Detectors (MKIDs) are superconducting, cryogenic detectors consisting of a capacitor-inductor junction each with a distinctive resonance frequency (f_0).

MKIDs can detect single photons and achieve time, spatial and energy resolution using frequency-domain multiplexing: multiple MKIDS read through a single feedline and the signal extracted using an FFT.

For a 1 MHz FFT, spacing between resonators must be $\Delta f_0 \geq 2$ MHz

Resonators with $\Delta f_0 \leq 2$ MHz are said to be "clashing"

Scanning Electron Microscope (SEM) image of an MKID resonator. This resonator is approximately 500μm across, and the fingers of the interdigitated capacitor are 2μm in breadth. Deviations from an idealised design are visible in the image.

Multiplexing Challenges & Simulation

MKIDs are simulated with Sonnet[1] geometry files which define the resonator as a set of 2-d polygons with defined electronic properties

Manual design of resonators is time consuming. Design of resonator arrays historically relied on interpolating between several manually designed resonator designs for the bulk of the array.

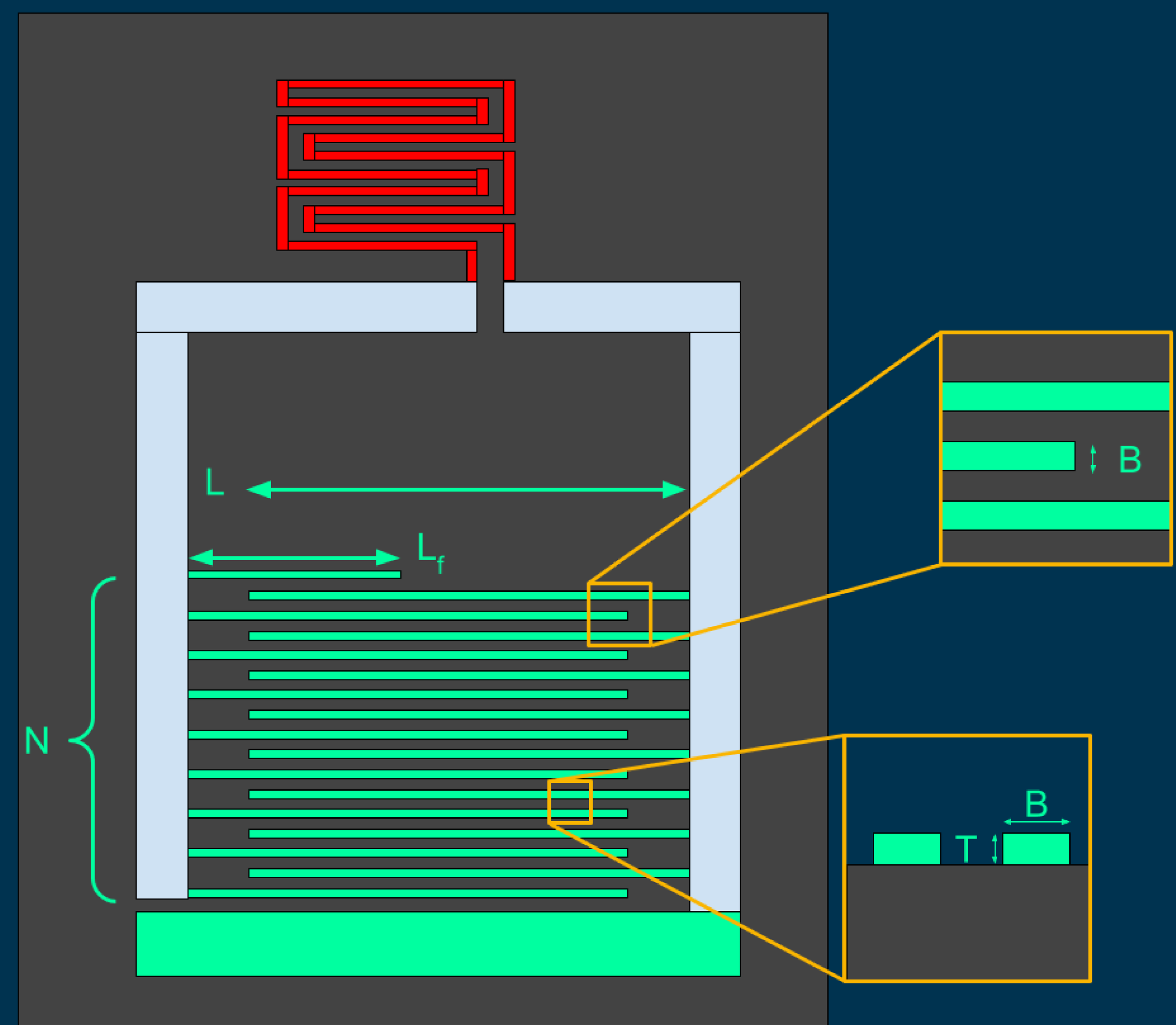
AEM (Automated Electromagnetic MKIDs simulations)[2] enables the automatic generation of arrays of MKIDs, each with unique f_0 and demonstrated that some interpolation methods can lead to clashing resonators, reducing pixel yield

Fabrication Tolerances

Fabrication of MKIDs is a multi-stage process involving deposition and etching of the superconducting material.

The potential for over– or under-deposition or etching creates uncertainty in the final dimensions of the resonator as illustrated below

By simulating the resonator with differing values of these parameters, we can specify fabrication tolerances to minimise resonator clashes



Schematic of an MKID resonator. Shown in **green** is the interdigitated capacitor and shown in **red** is the meandering inductor. In this poster, we investigate the impact of varying the labelled properties of the capacitor on resonant frequency.

Automation Software

Written in Python3 with numpy, os, decimal and argparse libraries

Initial design uses known resonator geometry as a template

Parameterises resonator dimensions at command line, iterates through user-specified variations in these dimensions, creating new geometries

Geometries are processed in Sonnet 18.58 and resonances extracted

Layer Thickness (T≈18-33nm) is proxied by varying kinetic inductance, because Sonnet simulations use 2-dimensional models

Sonnet simulation runtime is dominant contribution to overall analysis, and demonstrates greater than linear scaling with resolution

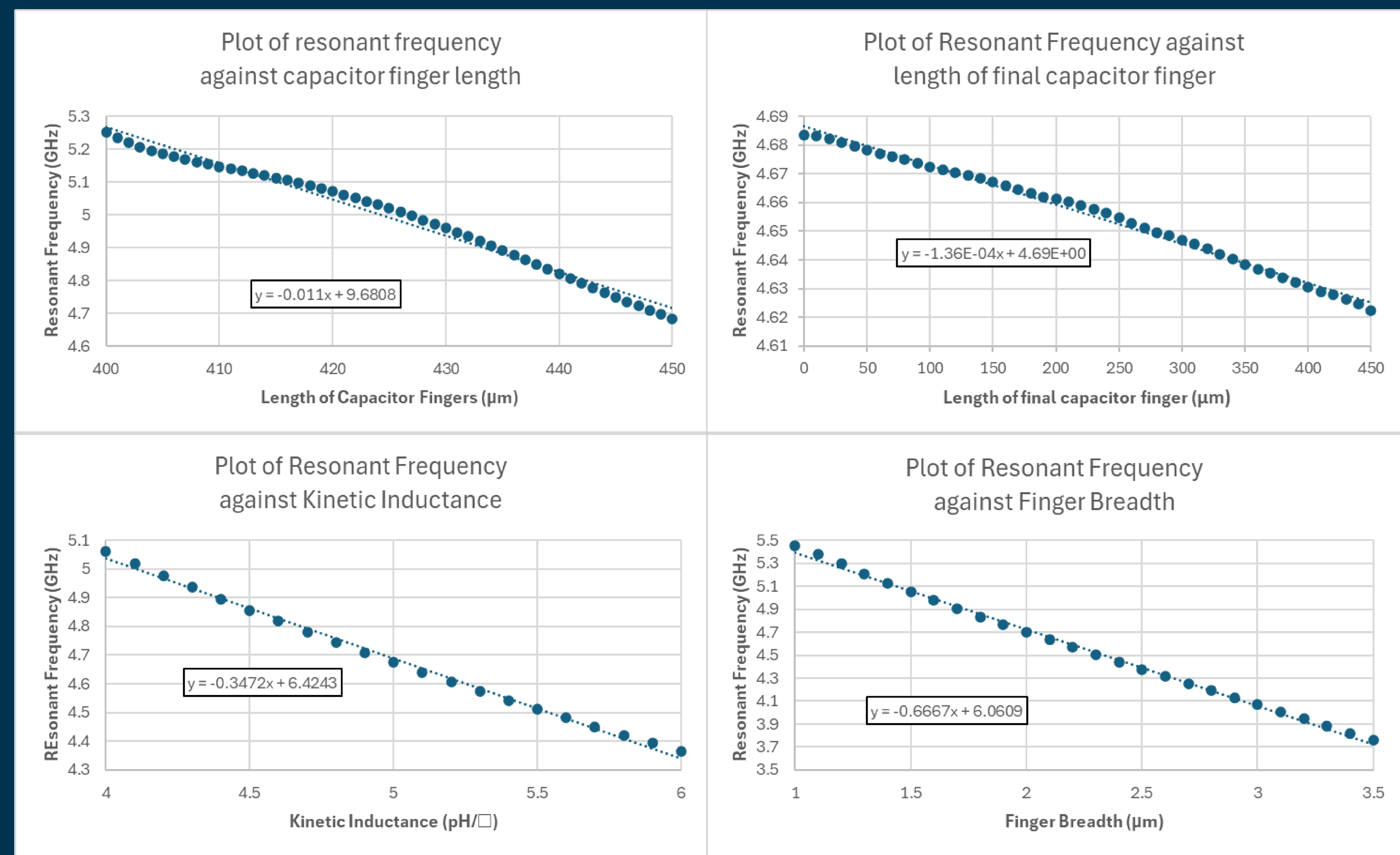
github.com/creanero/mkid_sonnet_variation

Simulation Results

Below are the results of simulations based on a resonator with 27 complete interdigitated capacitor fingers and an final incomplete finger.

By varying the parameters L, L_f, B and KI in isolation, we are able to plot the effects that varying these parameters has on f_0.

We estimate a tolerance to random variance in these parameters based on a linear approximation corresponding to ±1MHz in f_0.



Plots of the variation of resonant frequency with various parameters of the resonator. While the relationship between these parameters and resonant frequency is visibly non-linear, a linear fit gives a first-order approximation of for the likelihood of inducing clash.

Property	Symbol	Values Analysed	Est'd Fabrication precision	Predicted tolerance
Finger Length	L	400-450μm	±0.1μm	±0.09μm
Final Finger Length	L_f	0-450μm	±0.1μm	±7μm
Finger Breadth	B	1-3.5μm	±0.1μm	±1.5nm
Kinetic Inductance	KI	4-6 pH/□	n/a	±3 fH/□

Table summarising the results of our simulations. These results suggest that the resonant frequency has the strongest dependence on the breadth and spacing of the capacitor fingers and the Kinetic Inductance.

References: [1] Sonnet Software Inc ,"Sonnet User's Guide", Release 16, (2018)
[2] McAleer, Cáthal, et al. "Automation of MKID Simulations for Array Building with AEM (Automated Electromagnetic MKID Simulations)." Journal of Low Temperature Physics (2024)

Acknowledgements: This publication has emanated from research conducted with the financial support of Taighde Éireann – Research Ireland, under Grants No. **15/IA/2880** and **21/FFP-P/10213.** We also would like to thank the Process & Product Development team at Tyndall National Institute, Cork for providing wafer-processing services for the presented devices.