Modelling and Optimization of Planar Inductors

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SHINE — Summer High School Intensive in Next-Generation Engineering

Introduction

Inductors are important components in analog/RF electronics and are particularly crucial in emerging applications like single-chip biomedical sensors, wearable medical devices, and wireless body area networks (WBANs). Designing optimal inductors is difficult as Maxwell's equations cannot be analytically solved for complicated geometries, thus usually requiring iterative field simulations. The goal of my project was to develop a machine learning model that can optimize an inductor geometry, to decrease the effort required in design.

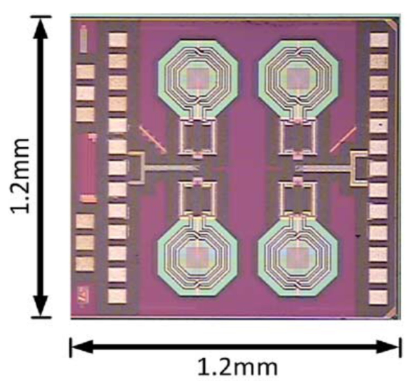


Fig. 1. Magnetic particle spectrometer IC with on-chip inductors.

C. Sideris and A. Hajimiri, TBioCAS (2013).

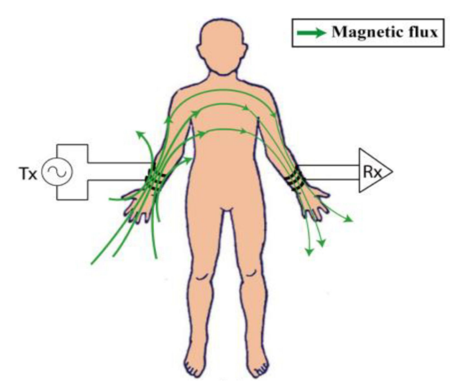


Fig. 2. Magnetic coupling data transfer link in a WBAN

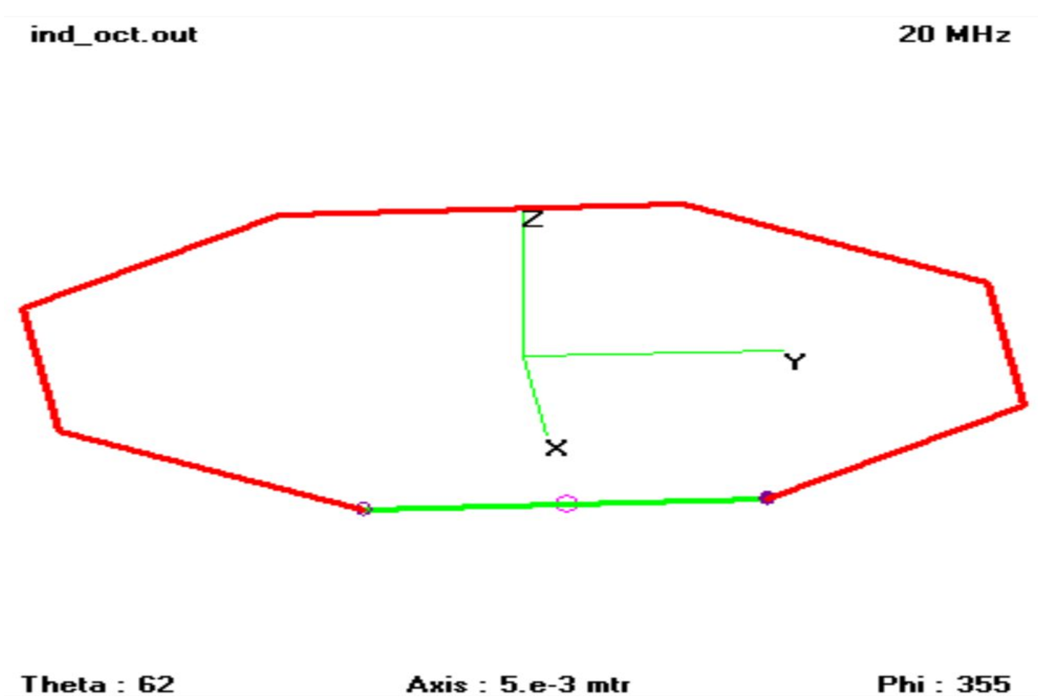
J. Park and P. P. Mercier, Conf. IEEE EMBS (2015).

Objective & Impact of Professor's Research

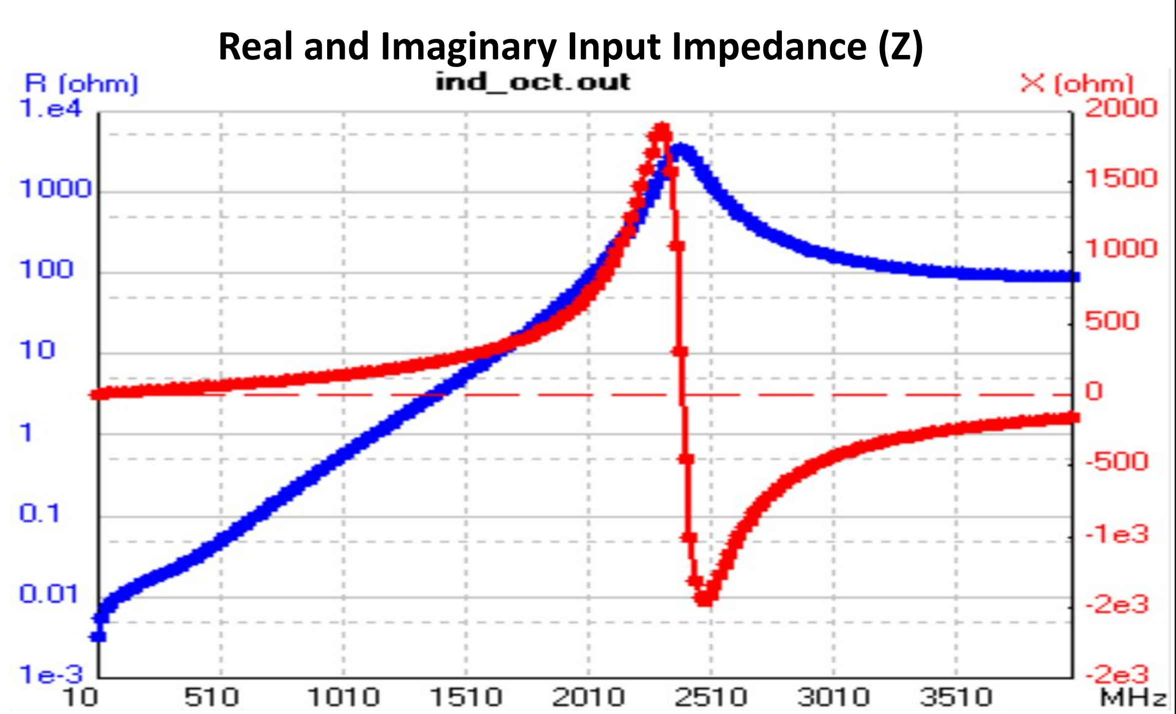
Professor Sideris's research group focuses on the design of analog/RF integrated circuits and systems for biomedical and wired/wireless communications applications, as well as computational methods for efficient modelling and design of electromagnetic devices. The goal of this project is to develop a model for inverse design of inductors, focusing on single-turn planar geometries. Optimal designs for both on-chip and off-chip spiral inductors are of particular interest for highly integrated, low-cost, sensitive single-chip biosensors and wireless communication/ localization links that the research group has implemented. The results of this project would be helpful to Professor Sideris's work, facilitating the development of systems that use inductors for applications such as sensing or magnetic induction links.

Approach / Results

- Considered 1-turn octagonal planar inductors
- Used NEC antenna software instead of a traditional electromagnetics field solver
- Obtain the real and imaginary input impedance of a given inductor geometry
- From the input geometry, obtain the inductance (L), quality factor (Q), and series resistance (Rs) as design metrics



Render of single-turn, 10mm radius, 2.5mm thickness inductor with excitation port



Skills Learned:

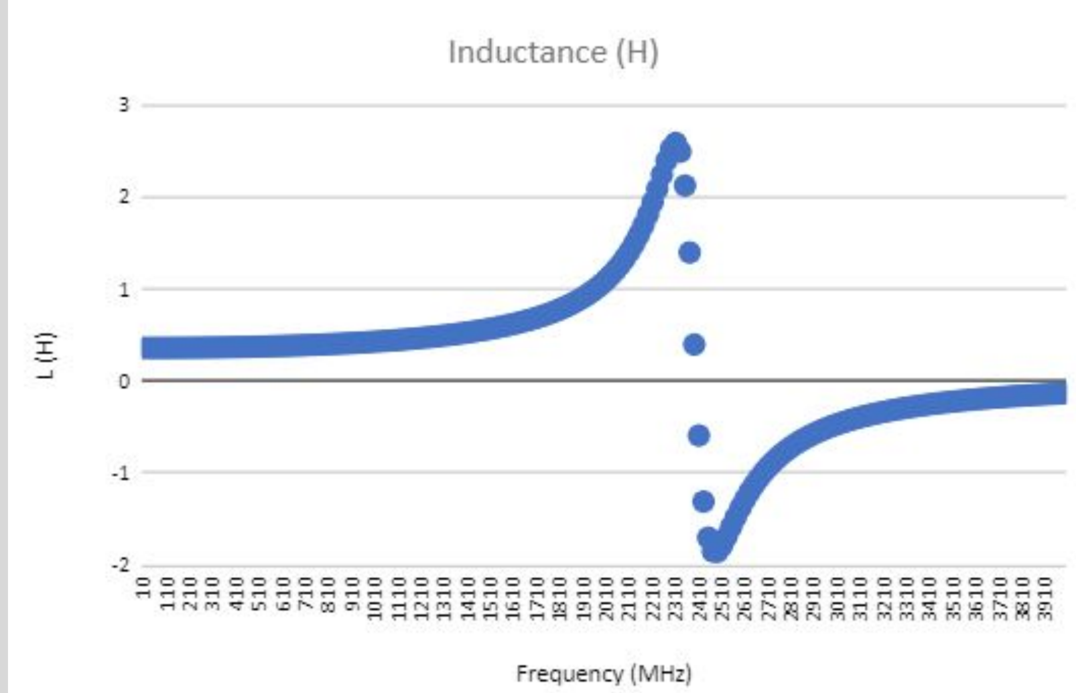
- Python and neural networks with Keras
- Scripting with Python
- Using CAD software (xnec2c) to simulate devices like antennas and inductors
- A lot of circuit / electromagnetics physics, which will be helpful in AP Physics C

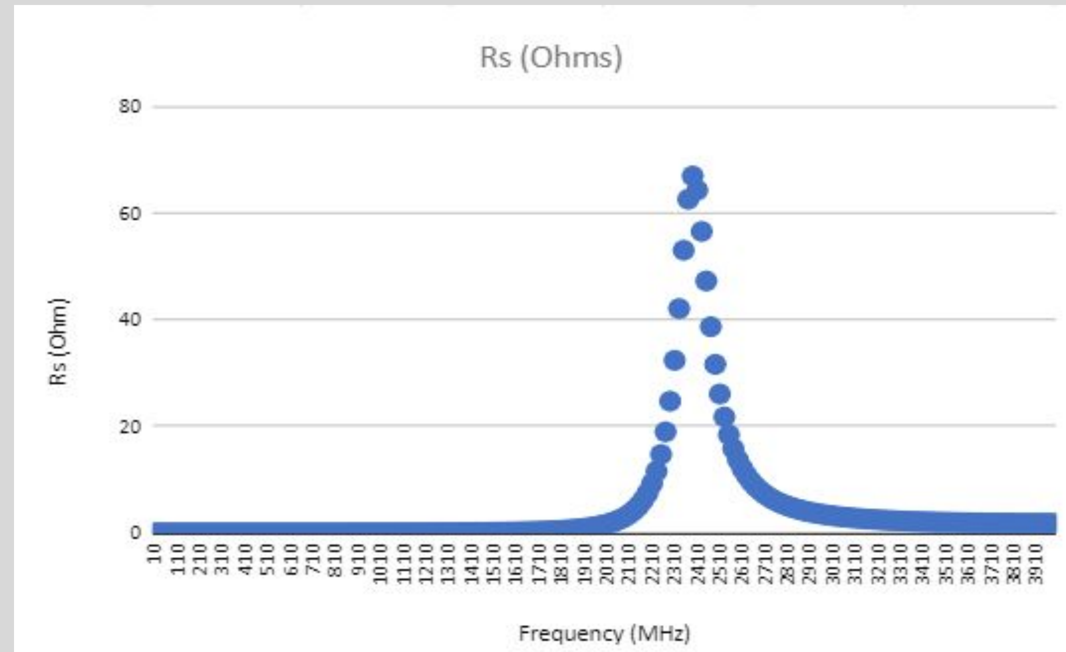
$$Z_{\text{in}} = \text{Re}(Z_{\text{in}}) + j\text{Im}(Z_{\text{in}}) = R_s + j\omega L$$

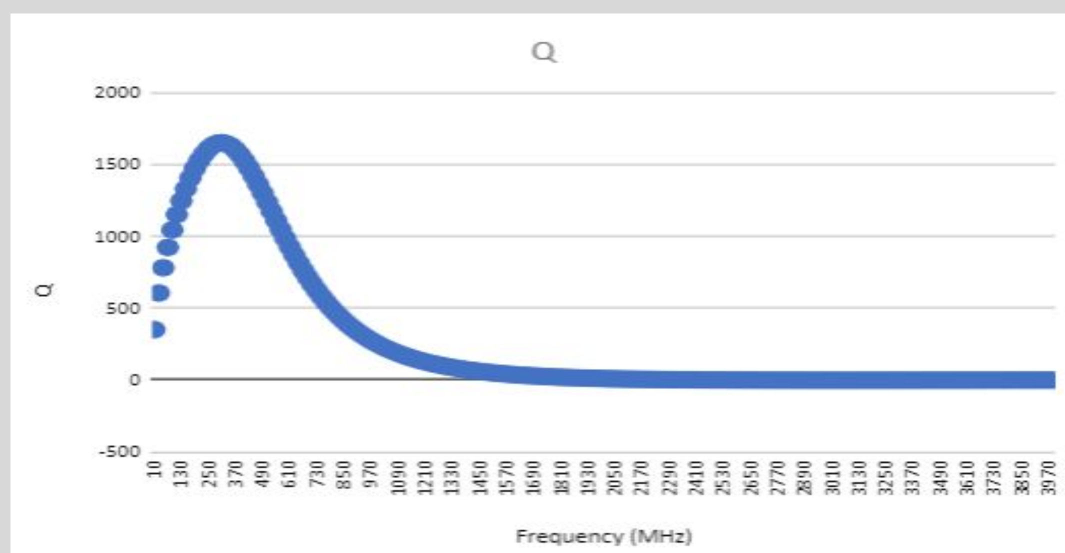
$$L = \frac{\text{Im}(Z_{\text{in}})}{\omega}$$

$$Rs = \text{Re}(Z_{\text{in}})$$

$$Q = \frac{\omega L}{R_s} = \frac{\text{Im}(Z_{\text{in}})}{\text{Re}(Z_{\text{in}})}$$







Next Steps

- Generate the training dataset, train the model, and demonstrate that model can produce inductors with desired metrics.
- Investigate coils with more than 1 turn
- Continue learning more advanced math and physics concepts to understand the theories and technology that are driving medical device innovation

How This Relates to My STEM Coursework

Identifying the most optimal inductor shape and size for a given application requires applying advanced physics and linear algebra concepts that I am working toward mastering through my high school STEM coursework. I look forward to building upon this foundation by studying more advanced physics concepts in my second year of college level physics (AP Physics C) during my senior year. To understand the effects of geometry on the inductor's performance, I ran simulations for the inductors using xnec2c, building upon what I learned in AP Calculus AB (Calculus 1) in obtaining the metrics of a given design through its input impedance. I am excited to build upon what I have learned in SHINE through more advanced classes in high school and college.

Acknowledgements

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