Measuring Negative Inductance

OELP Final Report

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Contents

Chapter 1

Introduction

A quantity like negative inductance is a strange concept that was inspired by the existence of negative capacitance. In ferro-electric capacitors a property can be observed where when the voltage reduces, the amount of charge on the capacitor increases.
In essence:

$$C = \frac{dQ}{dV} < 0$$

Similarly, Dr. Arvind Ajoy and Priyankka hypothesised of the existence of negative inductance, which had the property of flux increasing as current decreases. Hence:

$$L = \frac{d\phi}{dI} < 0$$

Initially, building off on Landau Theory of Phase Transitions, the "theoretical existence" of the negative inductance can be verified. After which, building on a more realistic simulation model and measurement through experiment can verify the existence of Negative Inductance.

Chapter 2

Methodology

2.1 Simulations

2.1.1 Based on Landau Theory

A model of the negative inductor based on Landau theory was realised on python. The Landau theory model is a single domain model in which the domain has two spin states. The energy landscape of this model is a double well as seen in the Figure 2.1. This double well is represented by the equation:

$$U = \alpha\phi^2 + \beta\phi^4 - I_L\phi$$

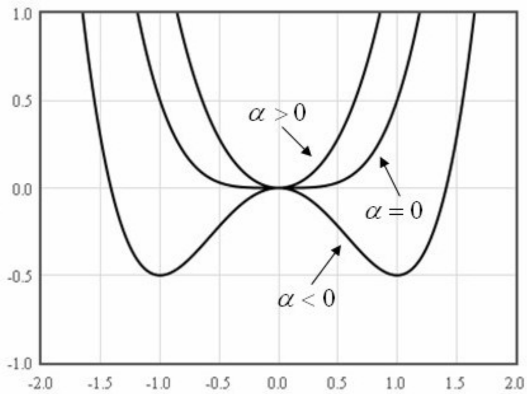

Fig. 2.1: Free Energy LandScape(U vs ϕ)

The field applied here is the current flowing through the inductor. The current causes one of the wells to become deeper, making one the wells more stable than the other facilitating the change in state. This can be seen in Figure 2.2.

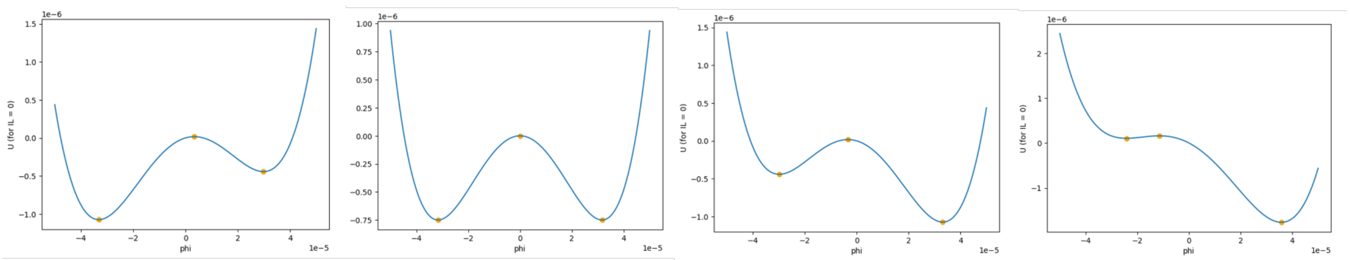

Fig. 2.2: Changing with I_L

Minimising the free energy by differentiation yields:

$$\frac{dU}{d\phi} = 2\alpha\phi + 4\beta\phi^3 - I_L = 0$$

When plotted, this yields the S curve as seen in Figure 2.3.

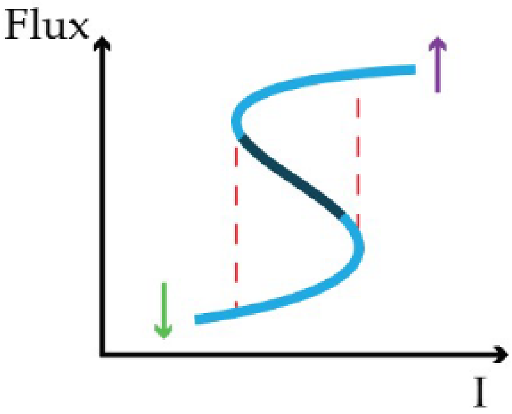

Fig. 2.3: S Curve

And combining it with the Landau-Ginzberg yields:

$$-\rho\frac{d\phi}{dt} = \frac{dU}{d\phi} = 2\alpha\phi + 4\beta\phi^3 - I_L$$

which can be used within the simulation. Considering an algorithm as shown in Figure 2.4.

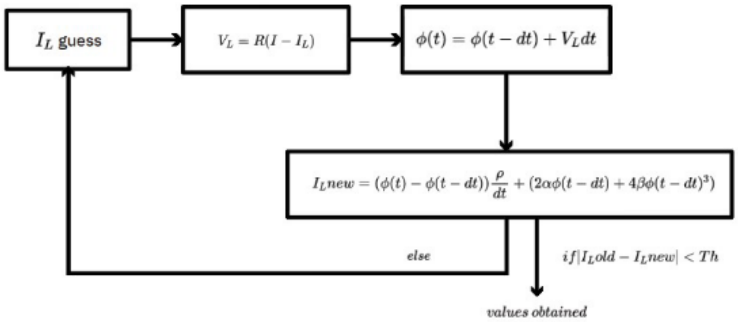

Fig. 2.4: Algorithm Flowchart For Landau Theory

Considering a current source supplying a resistor and negative inductor in parallel as seen in Figure 2.5 the simulation was run to calculate the response current for an applied current.

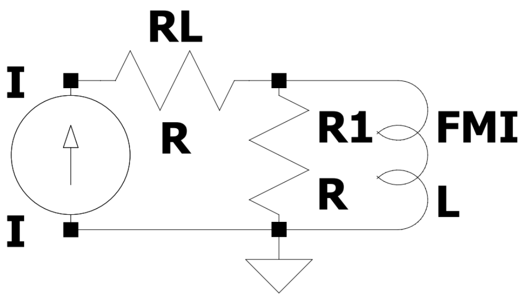

Fig. 2.5: Circuit realised

2.1.2 Multidomain Modelling

The Multidomain modelling of the negative inductor was achieved through the Ising Model. In this model, the torriod of size 70x25x25 domains with each domain having two states were realised. By applying the monte-carlo algorithm using the following algorithm shown in Figure 2.7 the response current can be observed for an input current. Here a current source supplies current to a resistor and negative inductor in series as seen in Figure 2.6.

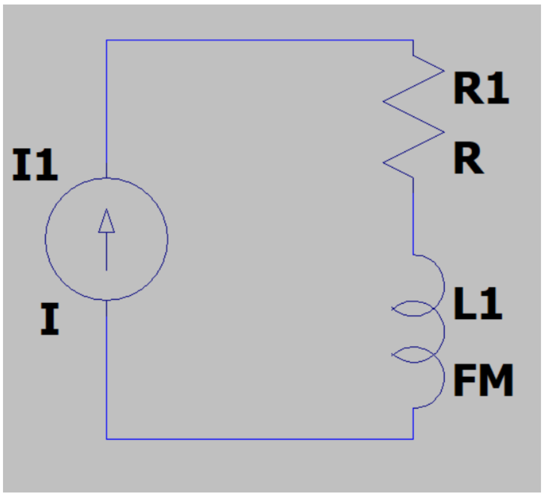

Fig. 2.6: Circuit Realised

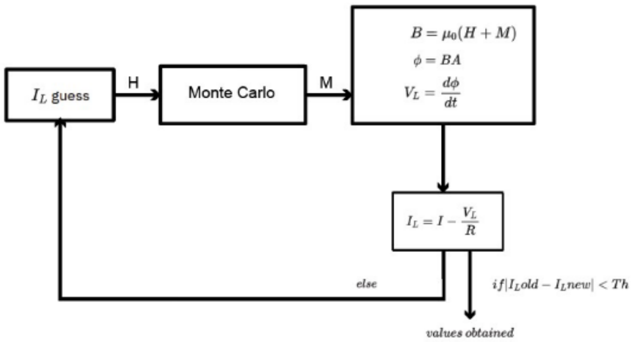

Fig. 2.7: Algorithm for Ising

2.2 Experiments

2.2.1 Hysteresis Measurement

The Hysteresis measurement set up has a voltage source set up where it is connected to a negative inductor and resistor in series. A ramp voltage is applied and the voltage across the resistor is observed. From these voltages, the current and other voltages can be calculated. From the voltage across the inductor and current through the inductor, the B-H curve can be plotted. The circuit used to supply the voltage is shown in Figure

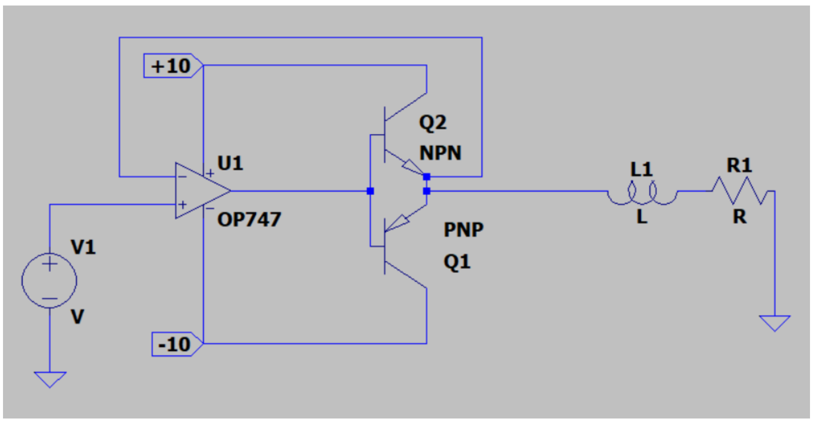

Fig. 2.8: Circuit for Hysteresis

2.2.2 Negative Inductance Measurement

In the negative inductance measurement, the inductor in connector in series with a resistor which is powered by the custom current source. This is the same set up as seen in the Ising Model. A

Square current wave will be applied on the inductor and its Voltage and Current will be recorded to make further conclusions.

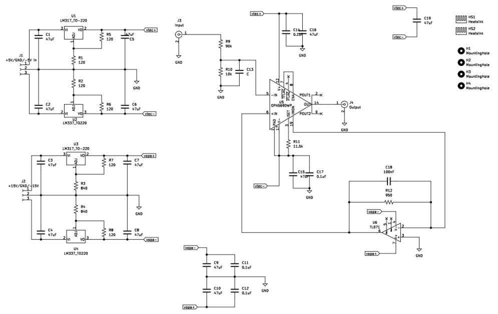

Fig. 2.9: Circuit Schematic

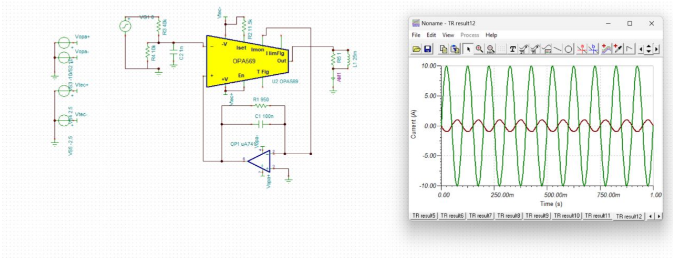

Fig. 2.10: Simulation of the Circuit

The Schematic of the circuit can be seen in Figure 2.9 and the simulation results of the circuit in Tinacloud are shown in Figure 2.10.

Chapter 3

Results And Discussion

3.1 Simulation Results

3.1.1 Landau Model

Using these data values, the current, voltage, flux can be plotted as shown in 3.1. Then using the values the S curve can be plotted as that is Figure 3.2. It is evident here that at the edge(where the transition occurs) there is a increase in current and decrease in flux or vice versa.

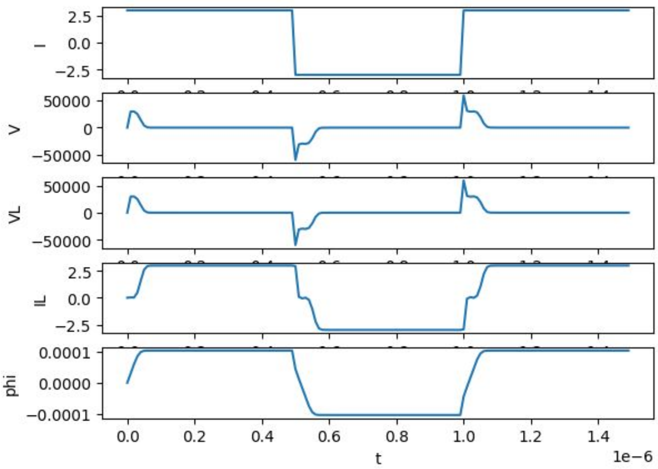

Fig. 3.1: Data values

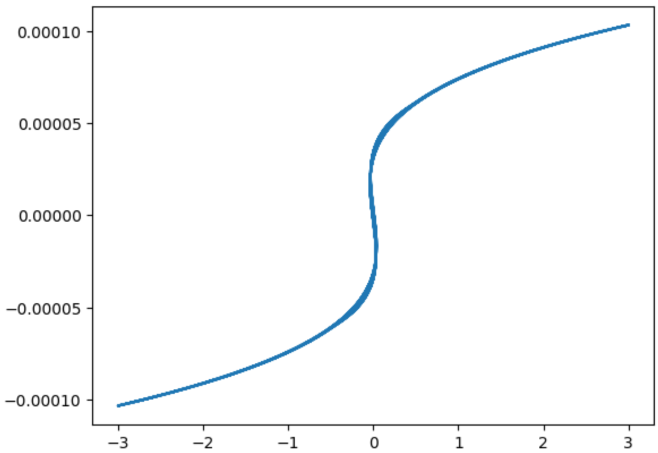

Fig. 3.2: S curve

3.1.2 Ising Model

Similarly, the values of the Ising model as shown in Figure 3.3. From this again the S curve can be plotted as shown in Figure 3.4. It is evident here that at the edge(where the transition occurs) there is a increase in current and decrease in flux or vice versa.

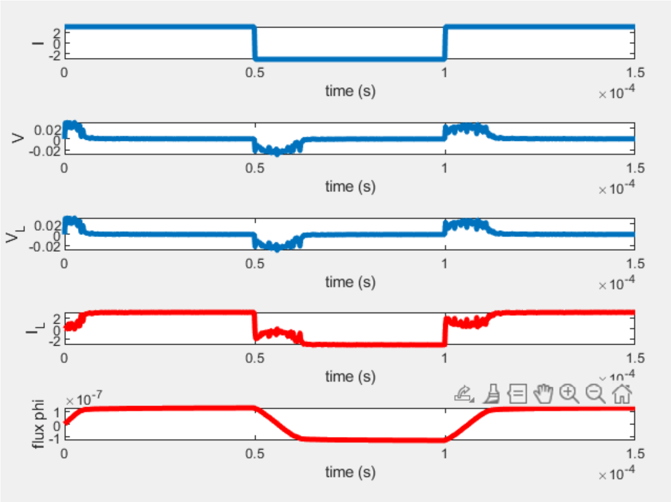

Fig. 3.3: Data Values

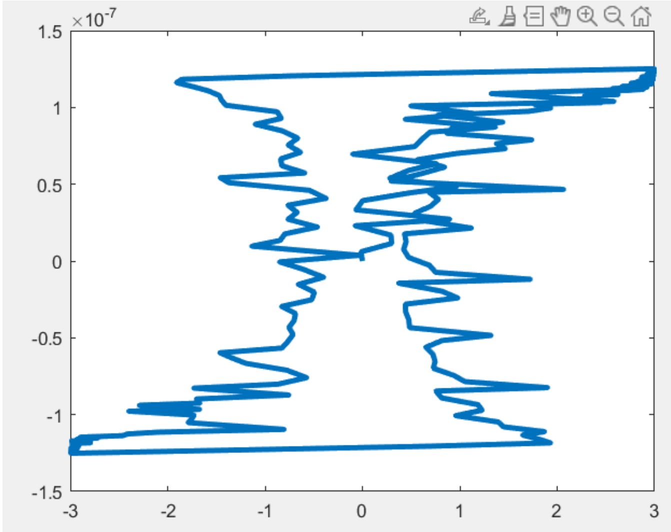

Fig. 3.4: S Curve for Ising

3.2 Experimental Results

3.2.1 Hysteresis

The hysteresis measurement was carried out and the data is given in Figure 3.7 and 3.8. The circuit is given in Figure 3.5 and the signal setup is given in Figure 3.6.

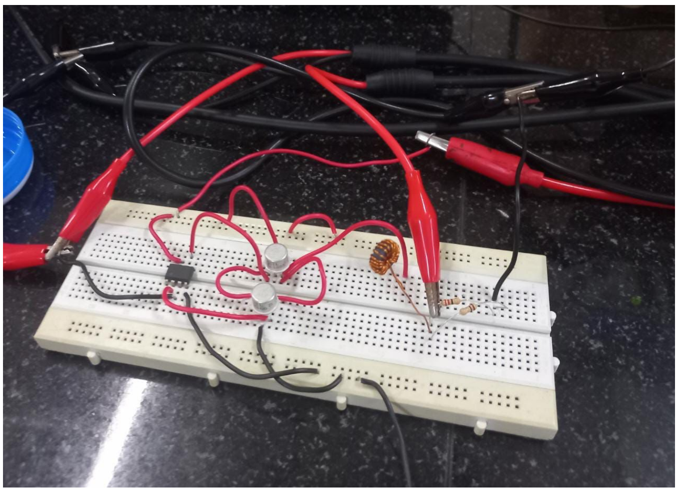

Fig. 3.5: Circuit

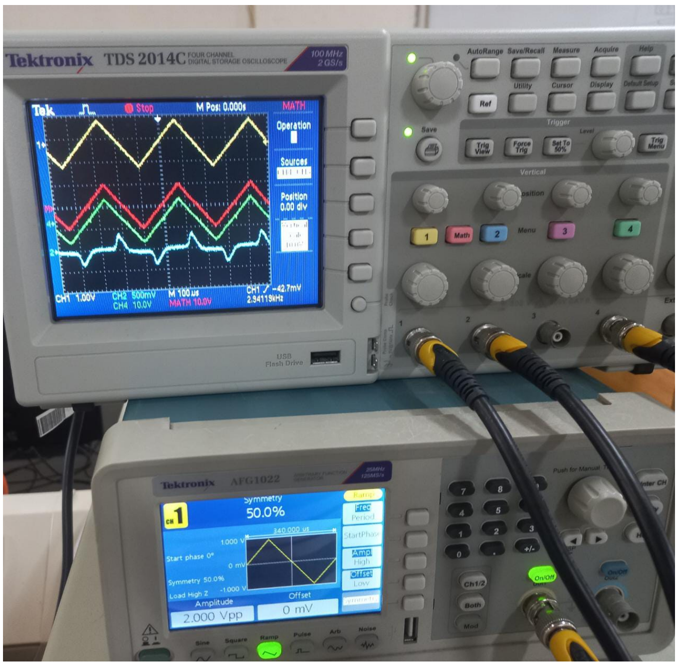

Fig. 3.6: Oscilloscope Output

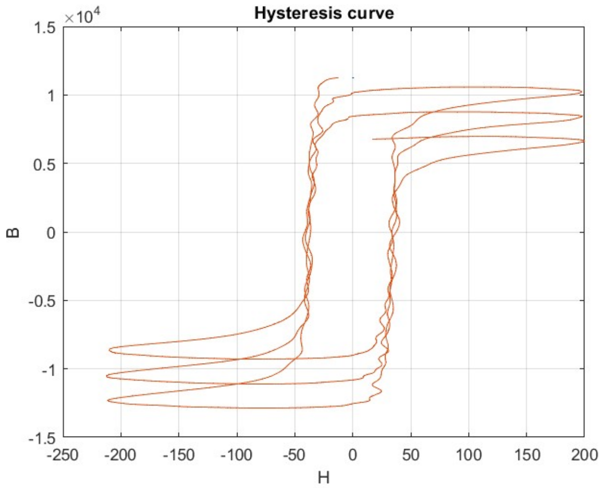

Fig. 3.7: BH Curve

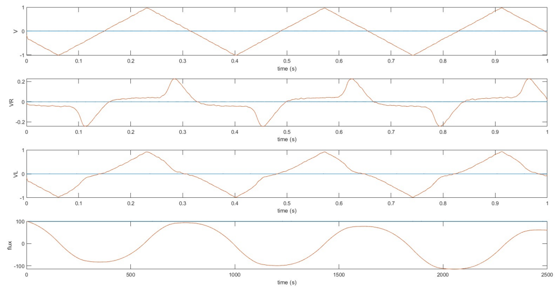

Fig. 3.8: Data Values

3.2.2 Negative Inductance

The current source that was populated is shown in Figure 3.9. This is is voltage following V to I converter. The voltage signal input is given through a signal generator and the current source converts the voltage into a current signal. As seen in Figure 3.10, a sine wave is given as the input but there is some noise in the output signal as in the figure.

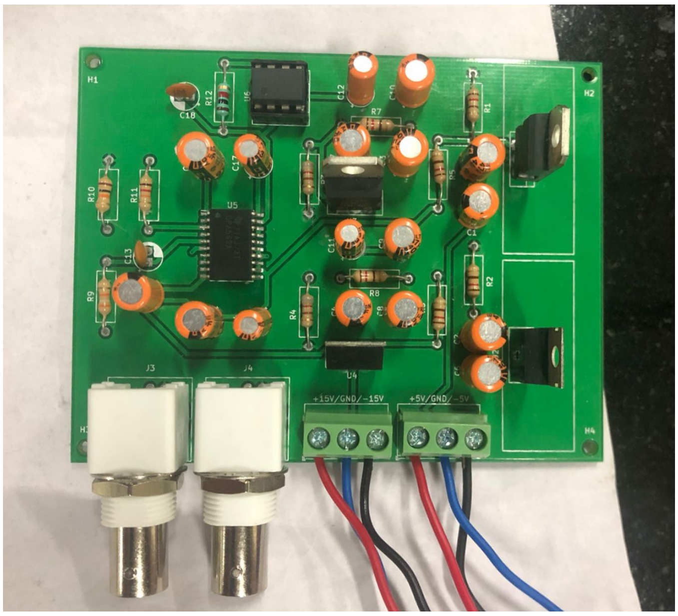

Fig. 3.9: Current Source

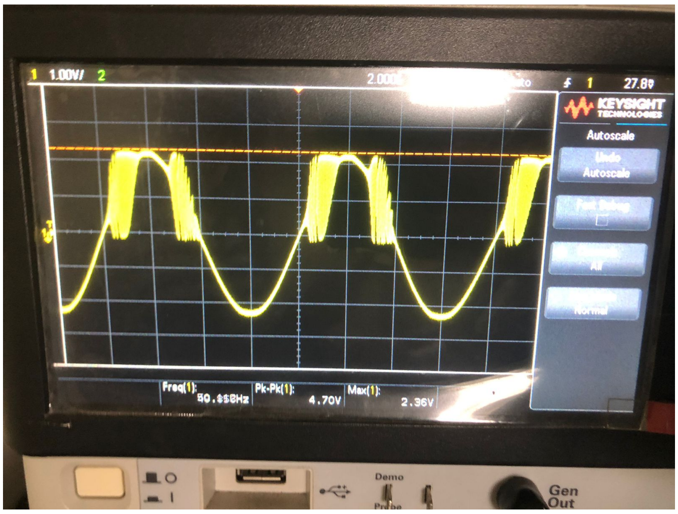

Fig. 3.10: Unstability in the PCB

Chapter 4

Conclusion

We were able to model negative inductance using single and multi-domain modeling using the theoretical frameworks of the Landau Theory and Ising Model. The experimental results from the hysteresis measurement provides parameters and saturation current for the torriodal core.

Future work

The current source designed has to be debugged and characterised so it can be used measure and provide the required amount of current in the circuit.

References

1. Transient Negative inductance in Ferromagnetic Materials - BTP by Priyankka G R.
2. S. Kumar and R. S. Williams, ”Tutorial: Experimental Nonlinear Dynamical Circuit Analysis of a Ferromagnetic Inductor,” in IEEE Circuits and Systems Magazine, vol. 18, no. 2, pp. 28-34, Secondquarter 2018, doi: 10.1109/MCAS.2018.2821758.