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EE-202 LAB 5 FINAL REPORT

1-Introduction

Lab 5 explores the principles and applications of inductors in detail. In this lab, students will engage in hands-on activities such as winding an inductor coil and measuring its characteristics, optimizing the quality factor (Q), calculating mutual inductance, and analyzing phase differences between inductors. These tasks aim to deepen the understanding of inductive behavior and its practical implications in electrical circuits.

2- Preliminary Work and Analysis

Step.1: Serial Connection, Positive Coupling

$$L_{total} = L_1 + L_2 + 2M$$

Step.2: Serial Connection, Negative Coupling

$$L_{total} = L_1 + L_2 - 2M$$

Step.3: Calculation method for mutual inductance M

Let us think about two sets of inductors. Setup A consists of two inductors (inductor a & inductor b) positively coupled. Setup B consists of two ***same*** inductors (inductor a & inductor b) negatively coupled. Difference between these two setups gives us only M.

$$L_A = L_1 + L_2 + 2M$$

$$L_B = L_1 + L_2 - 2M$$

$$L_A - L_B = 4M$$

$$M = \frac{L_A - L_B}{4}$$

$$M = \frac{L_A - L_B}{4}$$

This equation basically show that mutual inductance can be found by subtracting one inductor from another and divide this subtraction by 4.

Alternative method:

$$M = k\sqrt{L_1 L_2}$$

where 0 ≤ k ≤ 1

Step.4:

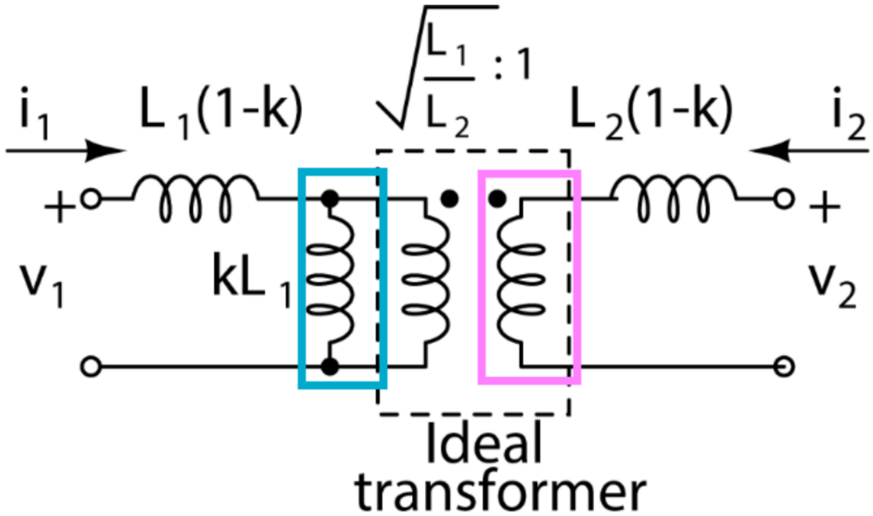

Figure.1: Transformer Voltage Division

$$v_{coupling}(v_{kL_1}) = v_1 \cdot \frac{kL_1}{(1-k)L_1 + kL_1} = \frac{kL_1}{L_1} = k$$

$$Since\ i_2 = 0,$$

$$v_2 = v_{kL_1} \cdot \sqrt{\frac{L_2}{L_1}} = k\sqrt{\frac{L_2}{L_1}}$$

There is a small mistake in preliminary work, about V2. However, in final report it was edited.

L1 was chosen 100μH and L2 was chosen 50μH

Step.5 & Step.6:

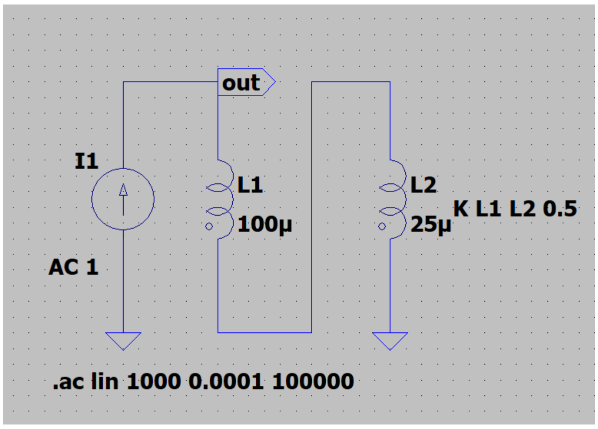

Figure.2: Series Connected Inductors

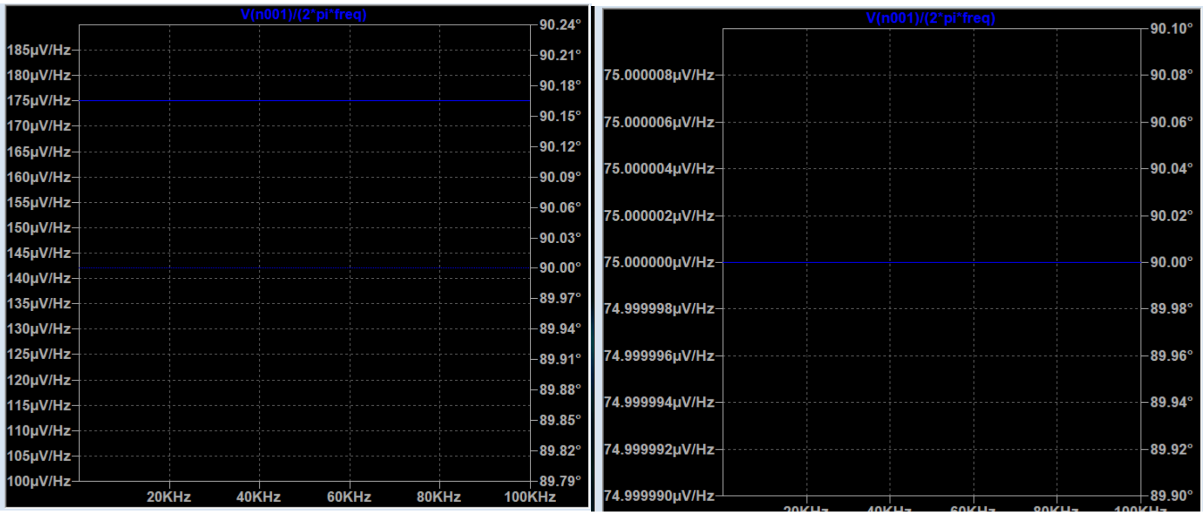

Figure.3: Series Inductors, Normal Direction (Case-1) & Reverse Direction (Case-2) Responses

Verifying the results using equations from Step.1,

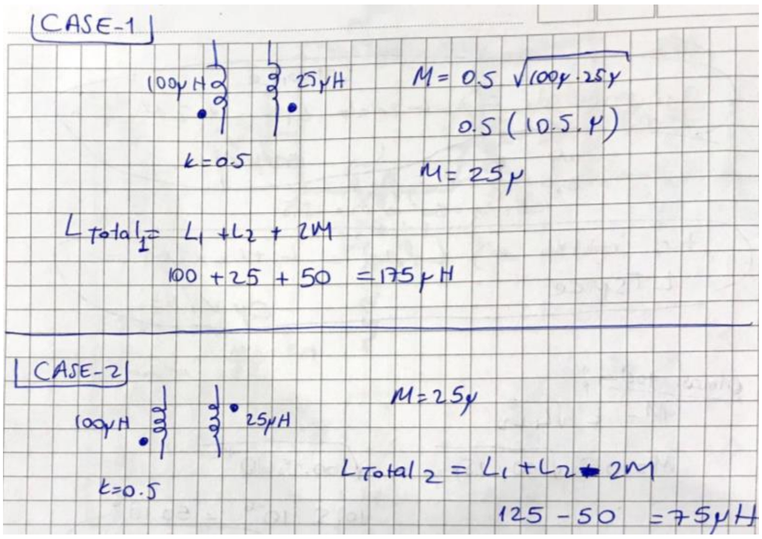

Figure.4: Verifying results for Normal Direction & Reverse Direction Responses

Step.7:

Q7) $L_A - L_B = 4M$

$175\mu H - 75\mu H = 100\mu H = 4M$ $\qquad M = 25\mu H$

from LTs. simulation #1 $\quad$ from #2 $\qquad$ from LTs simulation

Figure.5: Finding M using LTspice data

From LTspice simulation, we know that $L_A = 175\mu H$ *and* $L_B = 75\mu H$

$M = k\sqrt{100\mu \cdot 25\mu}$

$M = 0.5 \times \sqrt{100\mu \cdot 25\mu}$

$M = 0.5 \cdot 10.5 \cdot \mu$

$M = 25\mu$

Figure.6: Finding M using inductor values

Step.8:

$r = \frac{wL}{Q}$

$L1 \rightarrow \frac{(100000)\times(100\times10^{-6})}{60} \approx 1\Omega$

$L_2 \rightarrow \frac{(100000)\times(25\times10^{-6})}{60} \approx 0.2\Omega$

Figure.7: Finding r, resistance of inductors and v_2

Series resistances included into both inductors by right clicking to the inductor and adding series resistance value.

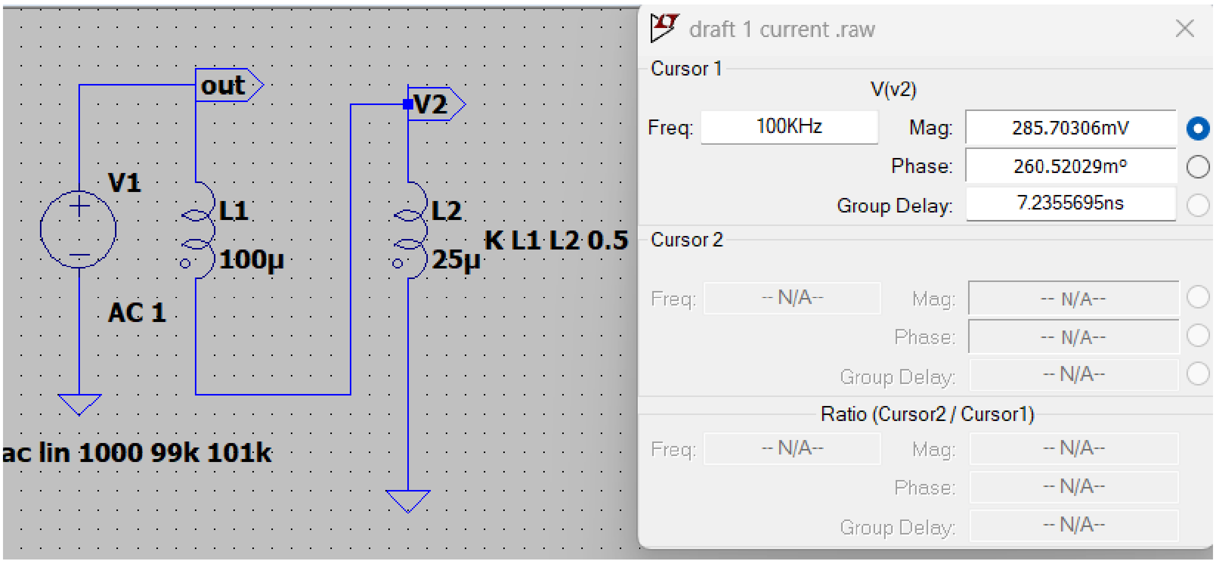

Figure.8: Included internal resistances of inductors

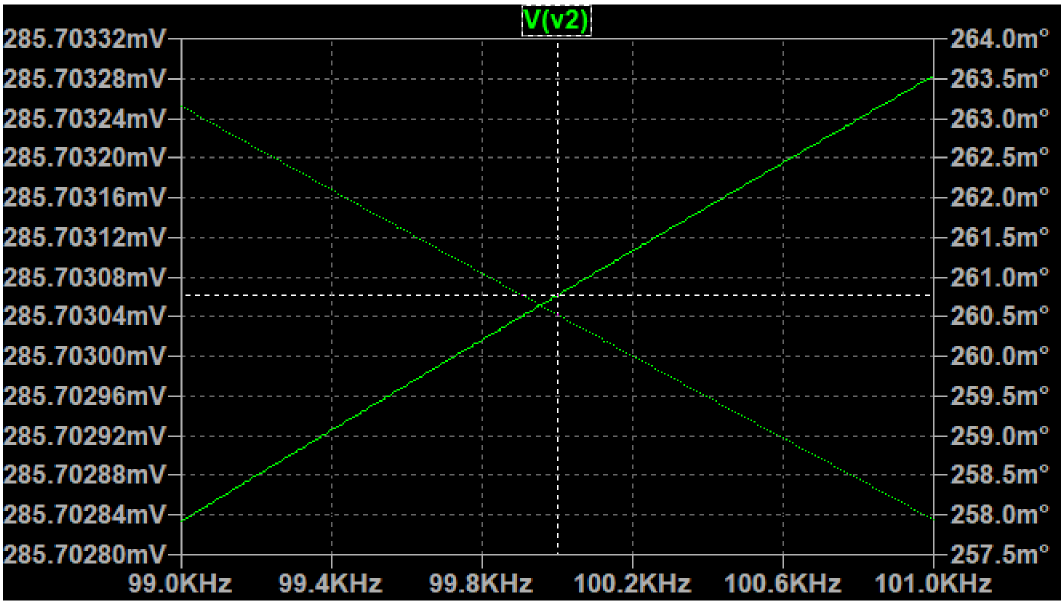

Figure.9: Graph of internal resistances included

	Frequency (Hz)	Magnitude (V)	Phase (Degree)
v_2	100 kHz	0.285 V	0.26°

Table.1: Values for v_2

Step.9:

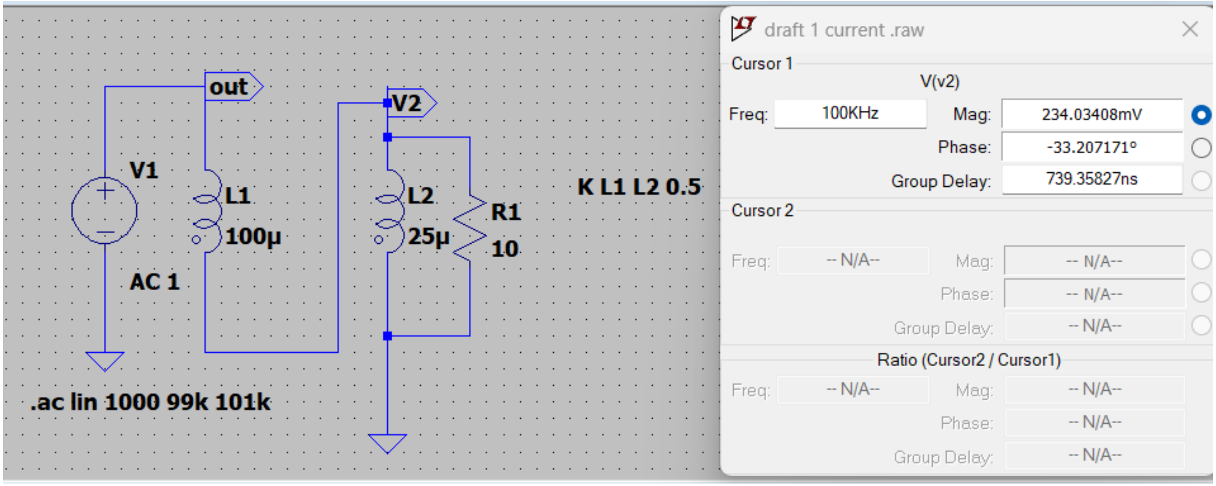

Figure.10: Schematics and values for the case included 10 Ω internal resistance for L_2

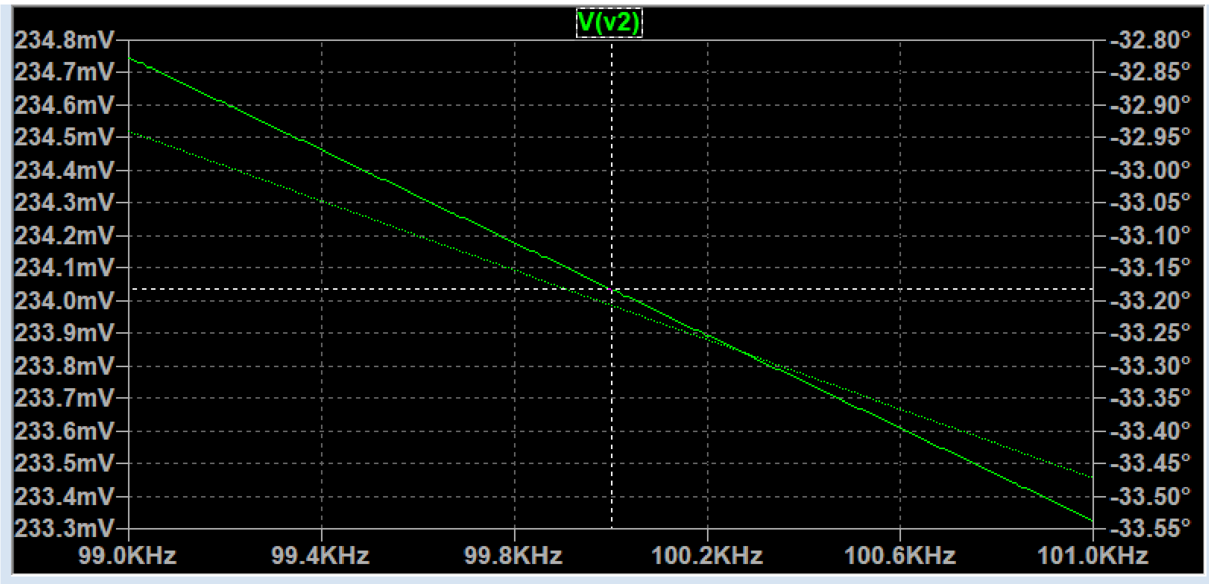

Figure.11: Graph of the case included 10 Ω internal resistance for L_2

	Frequency (Hz)	Magnitude (V)	Phase (Degree)
v_2	$\sim 100\ kHz$	0.234 V	$-33.2°$

Table.2: Values for v_2, 10 Ω internal resistance for L_2

3-Hardware Lab Analysis

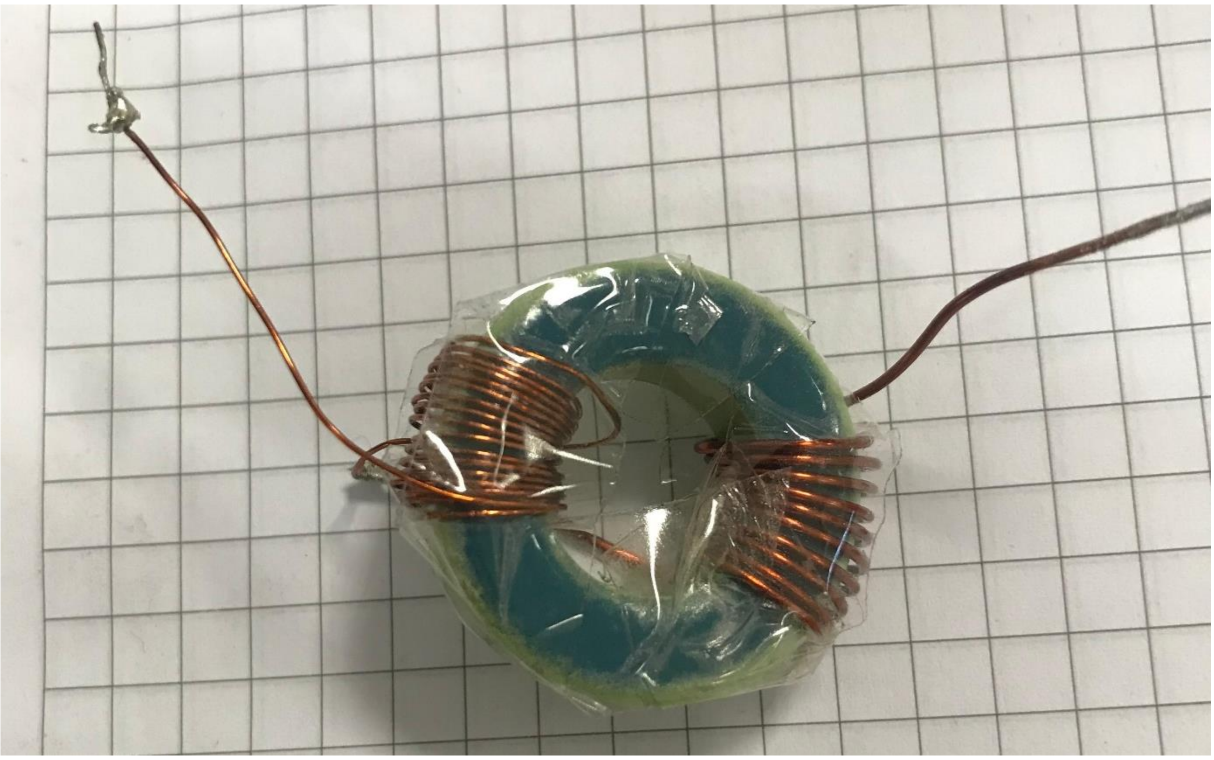

Figure.12: Inductors

To ensure the inductors remained stationary and their spacing did not change, a method of securing them with tape was employed. This approach effectively prevented any deviation in the measured values.

Step 1

N1 = 10

N2 = 18

Step 2

$$\frac{2\pi f L_1}{Q_1} = \frac{2\pi(100KHz)(30.7\mu H)}{(\approx 41)} \cong 0.1\ ohm$$

$Series\ resistance\ for\ L_1 = 0.1$ ohm

$$\frac{2\pi f L_2}{Q_2} = \frac{2\pi(100KHz)(9.38\mu H)}{(\approx 41)} \cong 0.4\ ohm$$

$Series\ resistance\ for\ L_1 = 0.4$ ohm

	Measured μH	Measured Q	r	$A_L N^2$
L1	9.38	41	0.143	10.6
L2	30.7	40	0.470	34.34

Table 3: Inductance, Q, r and expected Inductance

	Measured μH	Measured Q
L1 & L2 series	18.82	43
Reverse of L1 & L2 series	60.38	37

Table 4: Series Connection

$$M = \frac{60.38 - 18.82}{4}$$

$$M = 10.39\ \mu H$$

$$10.39\ \mu H = k\sqrt{9.38\mu H.30.7\mu H}$$

$$k = 0.6123$$

3-Hardware Lab Implementation

Step 3 and Step 5

5 Vpp Sinusoidal Signal from Signal Generator

$$v_1 = 1.9\ V$$

$$v_2 = 4.5\ V$$

$$Effective\ turns\ ratio = \frac{v_2}{v_1} = 2.368$$

$$Delay\ (Phase\ Difference) = 120\ ns$$

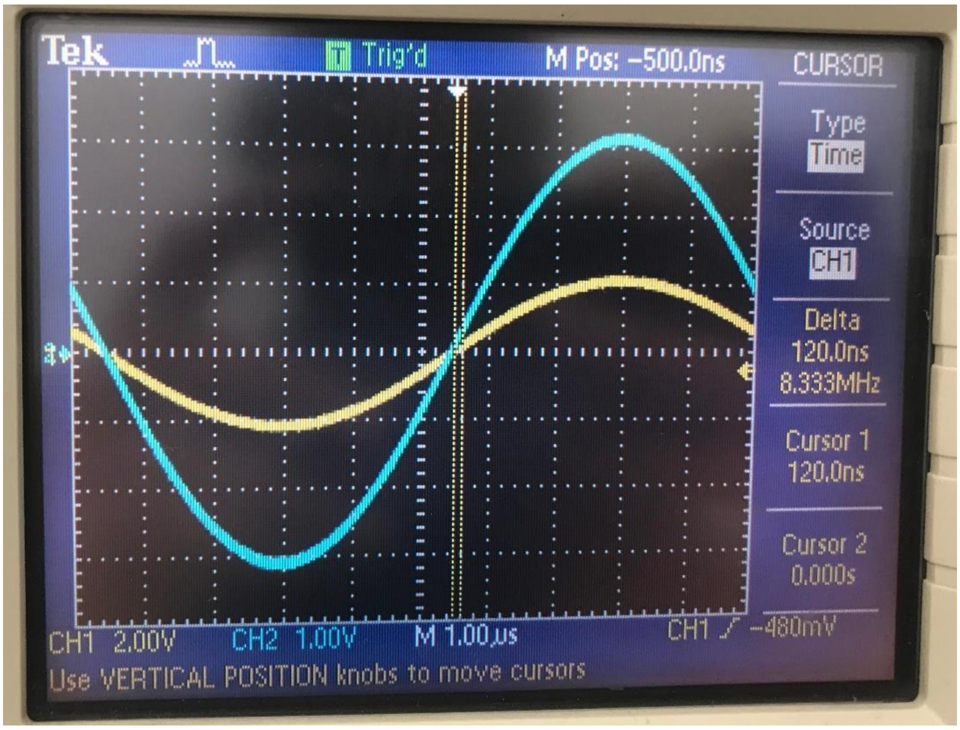

Figure.13: Experimental Delay

1V LTSpice Analysis:

$$\text{Applied } v_1 = 0.323\ V$$

$$\text{Simulated } v_2 = 0.676\ V$$

$$Effective\ turns\ ratio = \frac{v_2}{v_1} = 2.093$$

$$Delay\ (Phase\ Difference) = 11.8\ ns$$

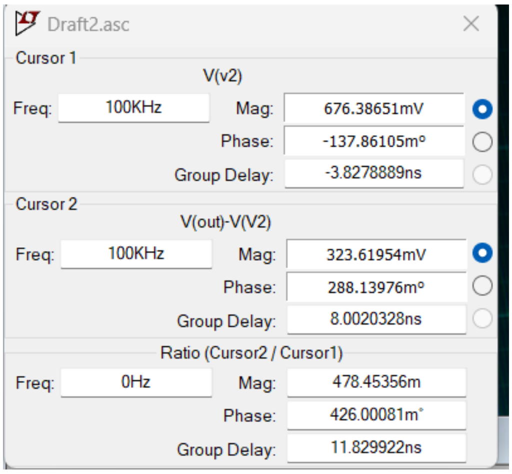

Figure.14: LTSpice Analysis

In the experimental setup, a 1V input was applied, and the same voltage was used in the hardware lab. Although the voltage values did not match because of the direction of the lab 5 document, the effective turns ratios were consistent, which indicates the experiment was successful. Additionally, there was an issue regarding delays, but this problem could not be resolved during the lab session. Nevertheless, the consistency of the ratio is a positive outcome.

Step 4 and Step 6

Including 10 ohm

5 Vpp Sinusoidal Signal from Signal Generator

$$v_1 = 0.8\, V$$

$$v_2 = 2.16\, V$$

$$Effective\ turns\ ratio = \frac{v_2}{v_1} = 2.7$$

$$Delay\ (Phase\ Difference) = 360\, ns$$

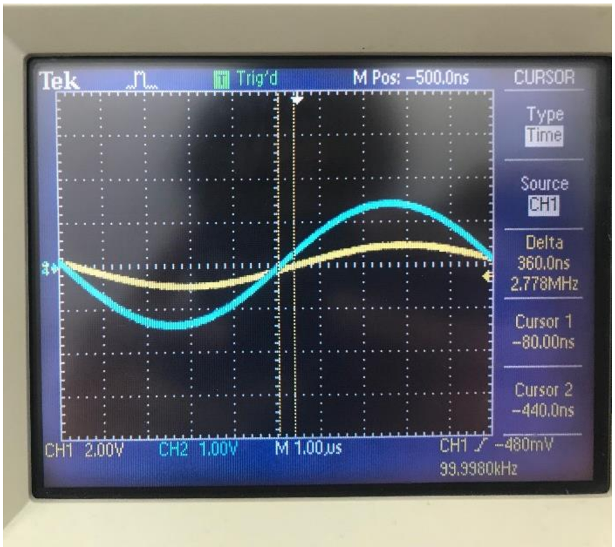

Figure.15: LTspice simulation, Phase difference, 10 ohm included

1V LTSpice Analysis:

$$\text{Applied } v_1 = 0.323\ V$$

$$\text{Simulated } v_2 = 0.676\ V$$

$$Effective\ turns\ ratio = \frac{v_2}{v_1} = 2.093$$

$$Delay\ (Phase\ Difference) = 287\ ns$$

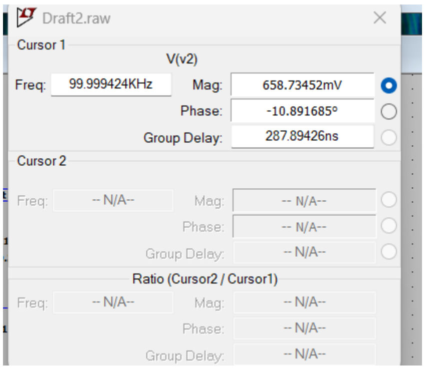

Figure.16: LTspice simulation, Phase difference, 10 ohm included

The consistency of the effective turns ratio and the approximate similarity of the delays indicate that, at this level of the experiment, a successful implementation was achieved.

6-Conclusion

In this lab, the coupling coefficient (k), series and parallel connections of inductors, the measurement of mutual inductance, and the concept of mutual inductance were thoroughly investigated. The phase difference caused by adding a load to the coil was also analyzed. The process of winding the coil and calculating its inductance, along with the mutual inductance, was found to be highly instructive.

To maintain consistent wire spacing throughout the experiment, the inductors were secured with tape, ensuring more reliable measurements. This method was considered both effective for the experimental setup and beneficial for obtaining consistent results.

In the hardware implementation phase, an initial inconsistency in delays was observed and could not be resolved. However, the alignment of nearly all other measured values indicated that the implementation was successful overall.