Department of

Electrical & Electronics Engineering

Abdullah Gül University

Project Report

EE1200 Electronic Circuit Design (ECD) Capsule

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OBJECTIVE

This project aims to manufacture and test inductors and includes examination of hypothetical cases with the help of mathematical tools. Throughout the project, cylindrical and toroidal inductors are created, their physical characteristics are defined, and a test procedure is established. Moreover, theoretical inductance calculations and experimental results are compared with each other and the reasons for any differences are investigated. The main objectives of our project can be listed as follows:

1. Fabrication of Cylindrical Inductors: Two cylindrical inductors with a minimum length of 1 cm and a minimum diameter of 3 mm will be prepared, one of which is wrapped around a dielectric and the other a ferromagnetic material, using conductive wire covered with an insulator. The number of turns, dimensions, diameters and relative permittivity of the core material of these inductors will be determined.
2. Fabrication of Toroidal Inductors: Two toroidal inductors with a minimum diameter of 5 mm will be prepared by wrapping one around a dielectric material and the other around a ferromagnetic material, using conductive wire covered with an insulator. The number of turns, dimensions, diameters and relative permittivity of the core material of these inductors will be determined.
3. Development of the Test Process: In our project, a circuit that can measure the current flowing through the inductors will be designed and these current values will be recorded. In addition, a circuit that can measure the inductance values of solenoids and toroids will be designed and the obtained inductance values will be reported.
4. Comparison of Theory and Experimental Results: By using the inductance formulas for cylindrical and toroidal inductors, the theoretical inductance values of the prepared inductors will be calculated and these values will be compared with the experimental results.
5. Hypothetical Inductors: A function will be designed to calculate the total inductance of a solenoid and determine the voltage across the inductor. Additionally, the voltage at a particular point on a solenoid will be calculated as a function of time and space, and critical regions will be analysed.

This project aims to compare the inductance values with theoretical calculations by combining the construction and testing of inductors with mathematical tools. This initiative is an important step in understanding the performance of inductors, improving the design process, and testing the accuracy of mathematical models used in examining speculative situations.

BACKGROUND

Magnetic inductors are an essential component for the conversion and transmission of electrical energy. These inductors are devices that induce and store electric current using a magnetic field. Cylindrical and toroidal inductors are two types of inductors commonly used.

Cylindrical inductors are cylindrical-shaped inductors with a winding of insulator-covered conductive wires. These are often called solenoids and are used in many applications because of their ability to efficiently generate the magnetic field. The design of cylindrical inductors includes factors such as the number of turns, length, diameter and relative permittivity of the core material.

Toroidal inductors are annular inductors made of insulator-coated conductive wires. These inductors allow the magnetic field to follow an annular path and therefore offer a more suitable structure for storing magnetic energy. The design of toroidal inductors includes factors such as the number of turns, diameter, length, and the relative permittivity of the core material.

The aim of this project is to fabricate and test cylindrical and toroidal inductors to analyze hypothetical scenarios using mathematical tools. During the manufacture of inductors, inductors with different properties will be prepared using dielectric and ferromagnetic materials. In order to measure the current passing through these inductors, circuits will be designed and necessary measurements will be made.

In the "Hypothetical Inductors" section of the project, it is aimed to calculate the total inductance of the solenoid as the function time and to determine the voltage in the inductor of the current passing through the circuit, by working on the given hypothetical scenario. It is also intended to calculate the voltage at any point on the inductor as functions of z and t and to analyze its critical points.

This study will provide a background on inductors' design, performance, and comparison of theoretical calculations with experimental results, and will highlight the importance of inductors in electrical energy transmission and storage processes.

In conclusion, this project provides a fundamental understanding for the fabrication and performance analysis of cylindrical and toroidal inductors, emphasizing the importance of magnetic inductors. This study will provide information on the effective use of inductors in prospective design and applications and will contribute to increasing the efficiency of electrical and electronic systems.

ANALYTICAL AND SIMULATION PROCEDURES

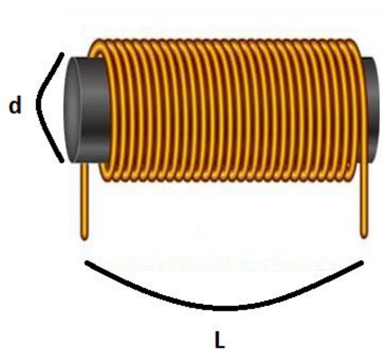
A- Theoretical Part:

In this section, first the theoretical calculations of the hypothetical inductor (5A and 5B) specified in the project, then the inductance values obtained by the theoretical calculation of fabricated inductors, and in the last part, the theoretical calculations of the circuit designed to measure the current passing over the fabricated inductors are given.

1) Theoretical Calculation of Hypothetical Inductors (Part 5A-5B).

- **Part 5A.**

The length of the given solenoid is l and its diameter is d. This solenoid is wound around material whose relative magnetic permeability is a function of space and time such that $\mu r(z,t)$=4t+5z. The density of the wires around the core material also depends on space and time according to $N(z,t)$=2z.



$Lenth\ of\ selenoid \rightarrow l$

$Diameter\ of\ selenoid \rightarrow d$

$\text{Relativeagneic Permeability} \rightarrow \mu r(z,t) = 4t + 5z$

$\text{Density Thiresroundhe Core Material} \rightarrow N(z,t) = 2z$

a) Calculating the total inductance of the solenoid as a function of time.

The inductance L of a solenoid is:

$$L = \frac{\mu_0 * \mu_r * N^2 * A}{l} \quad (1.1)$$

- L is the inductance,
- μ_0 is the magnetic permeability of free space (4 x 10^{-7} T m/A),
- μ_r is the magnetic relative permeability,
- N is the number of turns,
- A is the cross-sectional area of the solenoid,
  - l is the length of the solenoid,

$$L(z,t) = \int_0^l \mu_0 * \mu_r(z,t) * N^2(z,t) * Adz \quad (1.2)$$

$$L(z,t) = \mu_0 * \frac{\pi * d^2}{4} \int_0^l (4t + 5z) * (2z)^2 \, dz =$$

$$L(z,t) = \mu_0 * \frac{\pi * d^2}{4} \int_0^l 8tz^2 + 20z^3 \, dz =$$

$$L(z,t) = \mu_0 * \frac{\pi * d^2}{4} [8tz^3/3 + 5z^4]_0^l =$$

$$L(z,t) = \mu_0 * \frac{\pi * d^2}{4} [8tl^3/3 + 5l^4] \quad (1.3)$$

b) If the current passing through this circuit is $i(t) = 3cos(2t)$, what is the voltage on the inductor?

$$V(z,t) = L * \frac{d\big(i(t)\big)}{dt} \quad (1.4)$$

$$V(z,t) = \left[\mu_0 * \frac{\pi * d^2}{4} [8tz^3/3 + 5z^4]\right] * (-6 * \sin(2t)) \quad (1.5)$$

c) Calculate the voltage at an arbitrary point on the inductor as a function of z and t. Analyze its critical points as the functions of z and t.

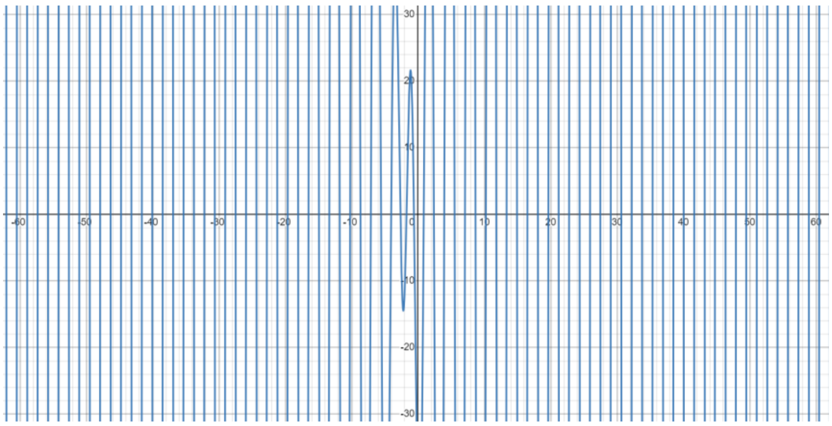
The critical points of this function occur when its derivative with respect to z and t are zero. So that,

- It's critical points as the functions of t.

$$\frac{\partial[V(z,t)]}{\partial t} = 0 \ (1.6)$$

$$\frac{\partial\left[\left[\frac{8tz^3}{3} * \mu_0 * \frac{\pi * d^2}{4} + 5z^4 * \mu_0 * \frac{\pi * d^2}{4}\right] * (-6 * \sin(2t))\right]}{\partial t} = 0$$

$$-4z^3 * \sin(2t) * \mu_0 * \pi * d^2 - 12\cos(2t)\left(\mu_0 * \pi * d^2 * 2 * t * \frac{z^3}{3} + \mu_0 * \frac{\pi * d^2}{4} 5z^4\right) = 0 \ (1.7)$$



(Graph 1.1 - Graph of the Derivative of the Function V(z,t) with Respect to t.)

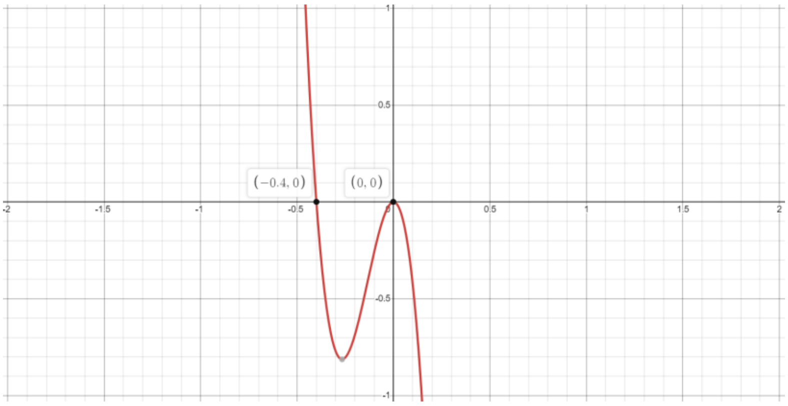
When we examine the graph of the derivative of the function V(z,t) with respect to t, it is seen that it is equal to 0 at the point (0.874 , 0), and from this point it becomes equal to 0 with approximately 1.56 periods. From this result, V(z,t) function has more than one local maximum and minimum values. That points are extremum points for the function of V(z,t)

- It’s critical points as the functions of z.

$$\frac{\partial[V(z,t)]}{\partial z} = 0$$

$$\frac{\partial\left[\mu_0 * \frac{\pi * d^2}{4}\left[\frac{8tz^3}{3} + 5z^4\right] * (-6 * \sin(2t))\right]}{\partial z} = 0$$

$$\left[\mu_0 * \frac{\pi * d^2}{4}\right] * (-6 * \sin(2t) * (8 * t * z^2 + 20 * z^3) = 0 \ (1.8)$$

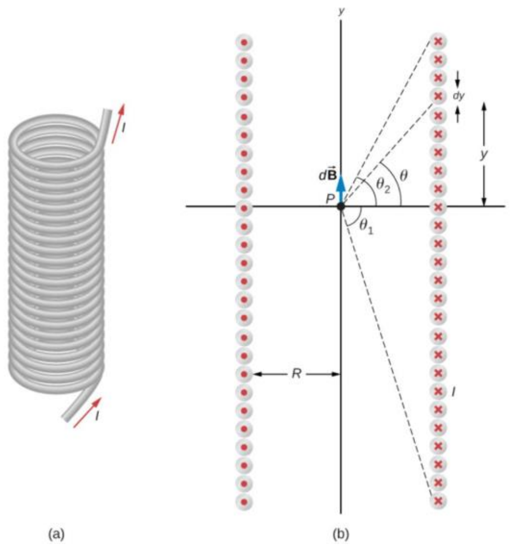


(Graph 1.2 - Graph of the Derivative of the Function V(z,t) with Respect to z.)

When we examine the graph of the derivative of the V(z,t) function with respect to z, it is seen that it is equal to 0 at the points z=-0.4 and z=0 [(-0.4,0) and (0,0). When these points are examined, the sign function changes sign at (-0.4,0), while there is no sign change at (0,0). From this result, the point V(z,t) (-0.4 , 0) is one of the extreme points of the V(z,t) function and is the maximum point. However, since there is no sign change at the point (0,0), it is not an extremum.

- **Part 5B**

Consider the finite solenoid (see Fig.) with the current I, radius R, and N turns of wire tightly-wound over a length L. Compute the magnetic field B along the central axis y of the solenoid (i.e.at the point P), if the angles θ1 and θ2 are given. At which point the field has a maximum?



(Figure 1.2 -Solenoid on Part B)

The magnetic field B inside a solenoid is given by Ampere's law as:

$$\mathrm{B} = \mu^0 * \mathrm{n} * \mathrm{I}\,(1.9)$$

$$\mu^0, \text{space permeability}$$

$$n, winding\ density\ into\ unit\ length$$

$$\mathrm{I}, \text{current along the wire}$$

n is also represent as $\frac{N}{l}$; N is turn of winding and l is length of the solenoid, then;

$$\mathrm{B} = \mu_0 * \frac{\mathrm{N}}{\mathrm{l}} * \mathrm{I}\,(1.10)$$

Current flowing through each infinitesimal part after dividing the solenoid into infinitesimal parts;

$$dI = \frac{N * I}{l} dy\ (1.11)$$

$$d\vec{B} = \frac{\mu^0 * \mathrm{R}^2 * dI}{2 * (y^2 + R^2)^{\frac{3}{2}}} \hat{\boldsymbol{j}} = \left(\frac{\mu^0 * \mathrm{R}^2 * I * N}{2 * l} \hat{\boldsymbol{j}} \right) \frac{\mathrm{dy}}{(y^2 + R^2)^{\frac{3}{2}}}\,(1.11)$$

Since it will facilitate the integral process by changing the y variable θ,then

$$sin\theta = \frac{\mathrm{y}}{\sqrt{y^2 + R^2}}$$

$$cos\theta * d\theta = \left[-\frac{y^2}{\left(\sqrt{y^2+R^2}\right)^3} + \frac{1}{\sqrt{y^2+R^2}}\right] * dy$$

$$d\vec{B} = \left(\frac{\mu^0 * R^2 * I * N}{2 * l}\hat{\boldsymbol{j}}\right)\frac{dy}{(y^2+R^2)^{\frac{3}{2}}} = \left(\frac{\mu^0 * R^2 * I * N}{2 * l}\hat{\boldsymbol{j}}\right) * \frac{\frac{cos\theta * d\theta}{\left[-\frac{y^2}{\left(\sqrt{y^2+R^2}\right)^3} + \frac{1}{\sqrt{y^2+R^2}}\right]}}{(y^2+R^2)^{\frac{3}{2}}} =$$

$$d\vec{B} = \left(\frac{\mu^0 * R^2 * I * N}{2 * l}\hat{\boldsymbol{j}}\right) * \frac{cos\theta * d\theta}{R^2} = \left(\frac{\mu_0 * I * N}{2 * l}\hat{\boldsymbol{j}}\right) * cos\theta * d\theta$$

$$\int d\vec{B} = \int \left(\frac{\mu_0 * I * N}{2 * l}\hat{\boldsymbol{j}}\right) * cos\theta * d\theta$$

$$\vec{B} = \frac{\mu_0 * I * N}{2 * l}\hat{\boldsymbol{j}} * \int_{\theta_1}^{\theta_2} cos\theta * d\theta$$

$$= \frac{\mu_0 * I * N}{2 * l}\hat{\boldsymbol{j}} \int_{\theta_1}^{\theta_2} cos\theta * d\theta = \frac{\mu_0 * I * N}{2 * l}\,[sin\theta_2 - sin\theta_1]\hat{\boldsymbol{j}} \quad (1.13)$$

In order to find out at which point it reaches the maximum magnetic field, $[sin\theta_2 - sin\theta_1]$ has to have the biggest value. It is known that the sin function is a function ranging from -1 to 1. So that if θ_2 is equals to 90° and $\theta_1$is equals to -180°, the maximum value of magnetic field can be obtained.

$$\vec{B} = \frac{\mu_0 * I * N}{2 * l}\,[sin\theta_2 - sin\theta_1] = \frac{\mu_0 * I * N}{2 * l}\,[\sin(90°) - \sin(-180°)]\ (1.14)$$

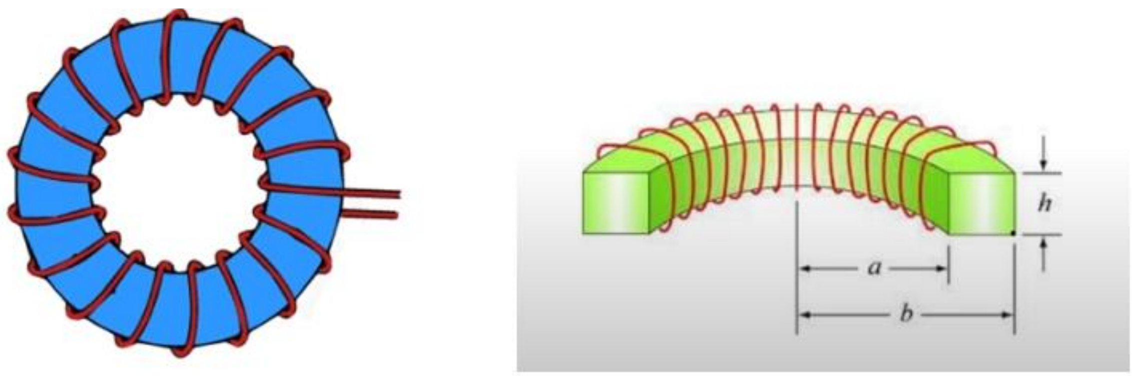
$$\vec{B} = \frac{\mu_0 * I * N}{2 * l}\,[1 - (-1)]$$

$$\vec{B} = \frac{\mu_0 * I * N}{l}$$

2) Theoretical Calculation of Hypothetical Inductors (Part 4)

a) Calculating the Inductance Value of the Of Fabricated Inductors

- **Calculating Inductance Value of Toroidal Indictor**



(Figure 1.3 -Toroidal Inductor)

$$N, Number\ of\ turns$$
$$\mu_0, vacum\ permittivity$$
$$\mu_R, reliative\ permittivity$$
$$I, current\ on\ the\ cable$$
$$h, height\ of\ the\ torid$$
$$b, outer\ radius$$
$$a, inner\ radius$$

$$B = \frac{\mu_0 * N * I}{2 * \pi * r}\ (2.1)$$
$$\phi_B = \int \vec{B} * d\vec{A} = \int B * dA$$
$$\phi_B = \int_0^h \int_a^b \left(\frac{\mu_0 * N * I}{2 * \pi * r}\right) * dr * dz$$
$$\phi_B = \frac{\mu_0 * N * I}{2 * \pi} \int_0^h \int_a^b \left(\frac{1}{r}\right) * dr * dz$$

$$Then, magnetic\ flux\ of\ the\ toroid,\ \phi_B = \frac{\mu_0 * N * I * h}{2 * \pi} * \ln\left(\frac{b}{a}\right). (2.2)$$

$$L = \frac{N * \phi_B}{I}$$

$$Then, inductance\ of\ the\ toroid, L = \frac{N * \frac{\mu_0 * N * I * h}{2 * \pi} * \ln\left(\frac{b}{a}\right)}{I}$$

$$L = \mu_R * \frac{\mu_0 * N^2 * h}{2 * \pi} * \ln\left(\frac{b}{a}\right) (2.3)$$

For Dielectric Toroidal Fabricated indictor:

$N = 31$
$\mu_0 = 4 * \pi * 10^7$
$\mu_R\ of\ Pet = 3.9$
$h, = 5 * 10^{-3}\ m$
$b = 2.5 * 10^{-3} m$
$a = 1.5 * 10^{-3} m$

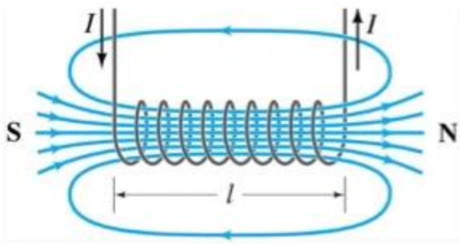
$$L = 2.9 * \frac{4 * \pi * 10^7 * 31^2 * (5 * 10^{-3})}{2 * \pi} * \ln\left(\frac{2.5 * 10^{-3}}{1.5 * 10^{-3}}\right)$$
$$L = 2.9 * \frac{4 * \pi * 10^7 * 31^2 * (5 * 10^{-3})}{2 * \pi} * 0.5108$$
$$L = 1.914422732 * 10^{-6} H = 1.914\ \mu H$$

For Ferromagnetic Toroidal Fabricated indictor:

$N = 39$
$\mu_0 = 4 * \pi * 10^7$
$\mu_R\ of\ rusting\ steel = 500$
$h, = 5 * 10^{-3}\ m$
$b = 4.5 * 10^{-3} m$
$a = 3.3 * 10^{-3} m$

$$L = 500 * \frac{4 * \pi * 10^7 * 39^2 * (5 * 10^{-3})}{2 * \pi} * \ln\left(\frac{4.5 * 10^{-3}}{3.3 * 10^{-3}}\right)$$
$$L = 500 * \frac{4 * \pi * 10^7 * 39^2 * (5 * 10^{-3})}{2 * \pi} * 0.3101$$
$$L = 29.119545 * 10^{-6} H = 29.11\ \mu H$$

- **Calculating Inductance Value of Solenoid Indictor**



(Figure 1.4 - Solenoid Inductor)

$$N, Number\ of\ turns$$
$$\mu_0, vacum\ permittivity$$
$$\mu_R, reliative\ permittivity$$
$$I, current\ on\ the\ cable$$
$$l, length\ of\ the\ torid$$
$$R, radius\ of\ the\ core$$

$$\phi_B = \int \vec{B} * d\vec{A} = \int B * dA = B * A \ (2.4)$$

$$Ampere's\ law \rightarrow \int \vec{B} * d\vec{l} = \mu_0 * I_{en}\ (2.5)$$

$$B * l = \mu_0 * (I * N) \rightarrow B = \mu_0 * \left(I * \frac{N}{l}\right)\ (2.6)$$

$$Then, magnetic\ flux\ of\ the\ selenoid, \phi_B = \mu_0 * \left(\frac{N}{l}\right) * I * (\pi * R^2)\quad (2.7)$$

$$L = \frac{N * \phi_B}{I}\ then, L = \frac{N * \mu_0 * \left(\frac{N}{l}\right) * I * (\pi * R^2)}{I}$$

$$L = \frac{N * \phi_B}{I}\ (2.8)$$

$$Then, inductance\ of\ the\ selenoid, L = \mu_R \frac{* \mu_0 * N^2 * (\pi * R^2)}{l}\ (2.9)$$

$$L = \mu_R \frac{* \mu_0 * N^2 * (\pi * R^2)}{l}$$

$$(\pi * R^2)\ is\ cross\ section\ area\ (A) \rightarrow\ L = \mu_R \frac{* \mu_0 * N^2 * A}{l}\quad (2.10)$$

For Dielectric Toroidal Fabricated indictor:

$$N = 54$$
$$\mu_0 = 4 * \ \pi * 10^7$$
$$\mu_R \ of \ wode \sim 1$$
$$l, = 9.5 * 10^{-2} \ m$$
$$A = 1.1309 * 10^{-4} m$$

$$L = 1 * \frac{* 4 * \ \pi * 10^7 * 54^2 * (1.1309 * 10^{-4})}{9.5 * 10^{-2} \ m}$$
$$L = 4.356 * 10^{-6} H = 4.356 \ \mu H$$

For Ferromagnetic Solenoid Fabricated indictor:

$$N = 23$$
$$\mu_0 = 4 * \ \pi * 10^7$$
$$\mu_R \ of \ rusting \ steel = 500$$
$$l, = 5 * 10^{-2} \ m$$
$$A = 2.0106 * 10^{-4} m$$

$$L = 500 * \frac{4 * \ \pi * 10^7 * 23^2 * (2.0106 * 10^{-4})}{5 * 10^{-2}}$$
$$L = 1.20194301 * 10^{-3} H = 1.201 \ mH$$

b) Calculation Of the Current Flowing Through the Inductor

$$V = L * \frac{di}{dt} \ (2.11)$$

$$di = \frac{V * dt}{L} \ \ (2.12)$$

$$\int di = \int \frac{V * dt}{L} \rightarrow \frac{1}{L} \int V * d\tau \ (2.13)$$

$$i = \frac{1}{L} \int_{-\infty}^{t} V * d\tau$$

$$t = 0, i(0)$$

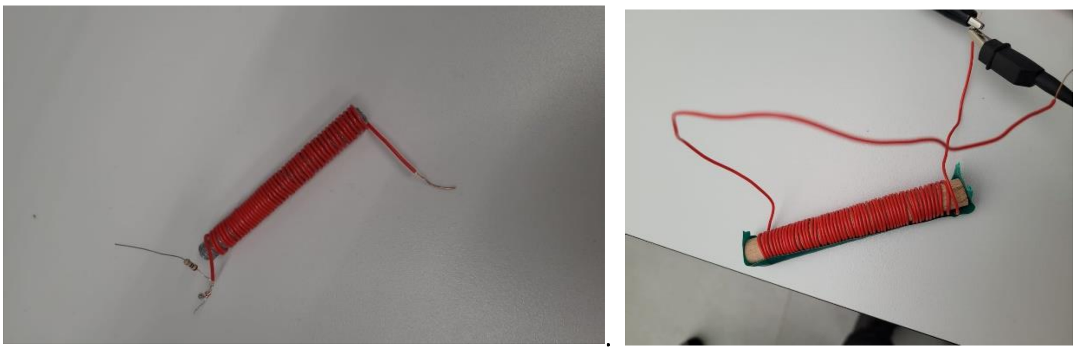
$$i = \frac{1}{L} \int_{0}^{t} V * d\tau + i(0)$$

$$i(t) = \frac{1}{L} \int_{-\infty}^{t} V * d\tau + i(0) \ (2.14)$$

B. Experiment Part

In this part, the steps taken during the production of the desired cylindrical and toroidal inductors in the project and during the measurement of the current passing through the circuits created using the produced inductors are explained respectively.

1. **Fabrication of Cylindrical and Toroidal Inductors:**
   a. **Fabrication of Cylindrical Inductors:**
      i. Two cylinders, 5 cm long, 8mm radius ferromagnetic core which is made from iron, 9.5cm long 12 mm radius dielectric core which is made from wooden, which we will use to manufacture cylindrical inductors; The cable covered with insulating material was provided.
      ii. The insulating cable was first wrapped as tightly as possible around the wooden core, which is a dielectric material.
      iii. The cables remaining at the ends of the cylinder were attached to the core with the help of tape and the ends were stripped.
      iv. The same procedures were performed for the ferromagnetic core, respectively.
      v. At the end of these processes, a ferromagnetic inductor made of iron core with 8 mm radius, 5 cm length and 23 windings; An inductor was obtained from a wooden core with a diameter of 12 mm and a length of 9.5 cm and 54 windings.



(a) (b)

(Figure 3.1 Fabricated inductors – (a) made from ferromagnetic material, (b) made from dielectric material)

b. Fabrication of Toroidal Inductors:

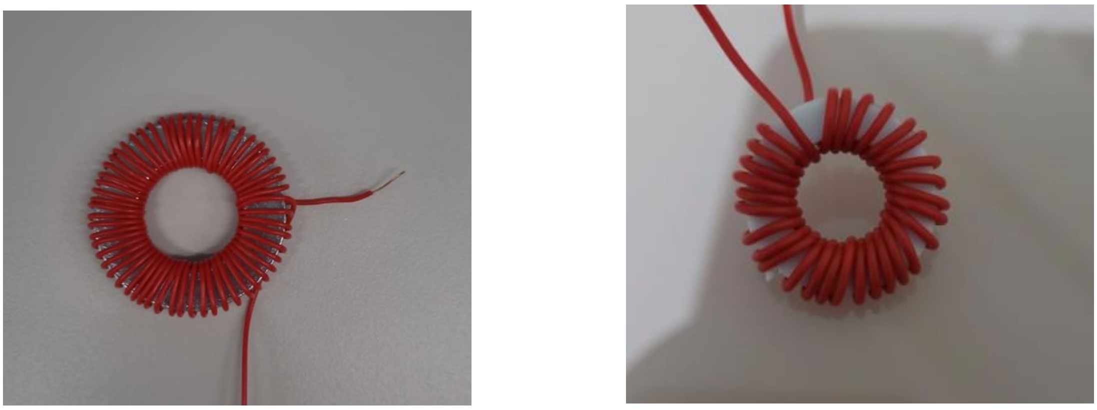
i. Two toroid, an inner radius of 33 mm and an outer radius of 45 mm ferromagnetic core made from iron, and an inner radius of 15 mm and an outer radius of 24 mm a dielectric core made from PET (polyethylene terephthalate), which we will use to manufacture the toroidal inductors; The cable covered with insulating material was provided.

ii. The insulating cable was first wound as tightly as possible around the pet core toroid whish a dielectric material.

iii. The cables remaining at the ends of the toroids were attached to the toroid with the help of tape and the ends were stripped, making it possible to connect to the circuit.

iv. The same operations were carried out for the ferromagnetic iron core Inductor.

v. At the end of these processes, inductors with an inner radius of 33 mm, an outer radius of 45 mm made of iron core and 39 windings and, an inner radius of 15 mm and an outer radius of 24 mm made of PET core were obtained and 31 windings.



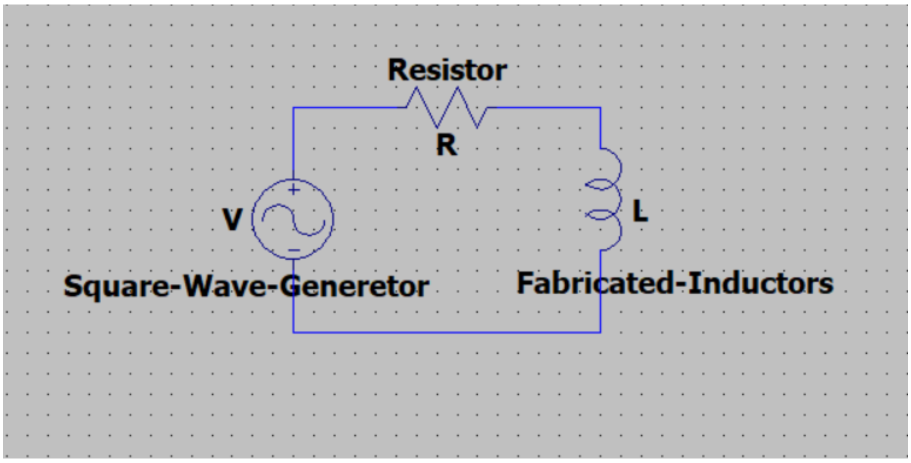
(a) (b)

(Figure 3.2 Fabricated inductors – (a) made from ferromagnetic material, (b) made from dielectric material)

2. Developing Test Procedure:

The test procedure was carried out in two stages. First, the value of the fabricated inductors was found. Then, the current was calculated with the inductance value we found at the beginning in the designed circuit.

a. Experimental Measurement Of The Inductance of Fabricated Inductors:



(Figure 3.3 – The Circuit Used to Find the Time Constant (Representational))

An RL circuit is set up for the measurement of inductance values. Square wave signals with a value of 1 Vpp were sent to the circuit with a signal generator and the discharge curve of the inductor was examined on the oscilloscope. The time constant (tau) obtained with the help of the oscilloscope was used to calculate the inductance value.

$$V(t) = i(t) * R \ (2.15)$$

$$V(t) = L * \frac{di}{dt} \ (2.16)$$

$$V_{in}(t) = i(t) * R + L * \frac{di}{dt} \ (2.17)$$

$$With\ homegenus\ solutiın \rightarrow 0 = i * R + L * \frac{di}{dt} \ (2.18)$$

$$0 = R + Ls \rightarrow s = * \frac{R}{L}$$

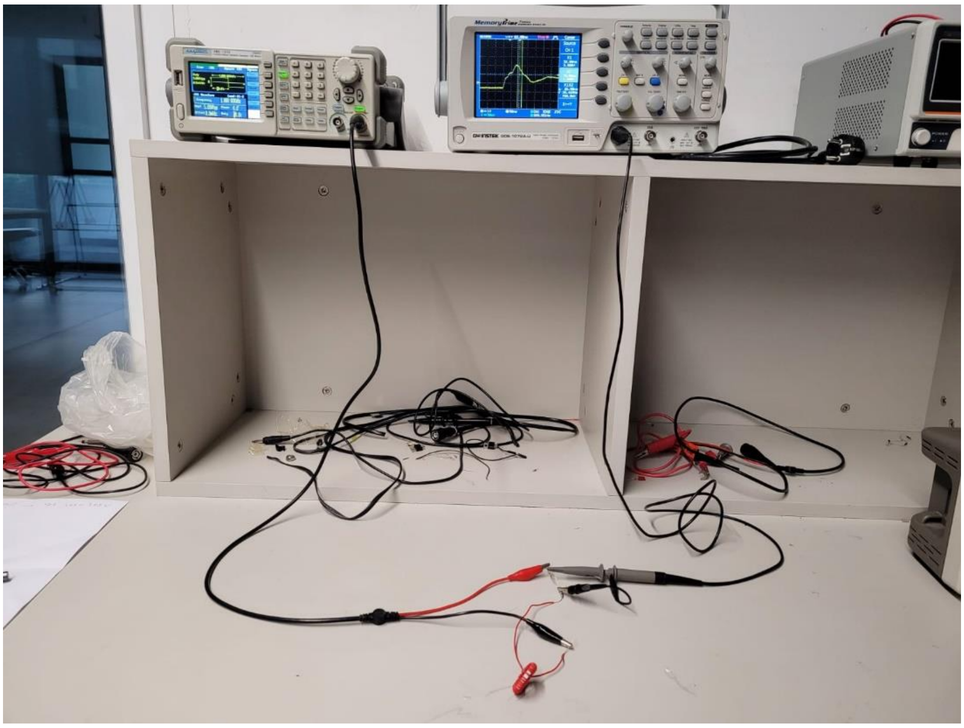
$$i_{in}(t) = c * e^{-\frac{R*t}{L}} = c * e^{-\frac{t}{\tau}} \ where, \tau = \frac{L}{R}$$

$$t_1 - t_2 = \tau = \frac{L}{R}$$

$$\tau * R = \Delta t * R = L \ (2.19)$$

B- **Measuring Inductance Value of Toroidal Inductors:**

i. **For Dielectric Toroidal Inductors:**



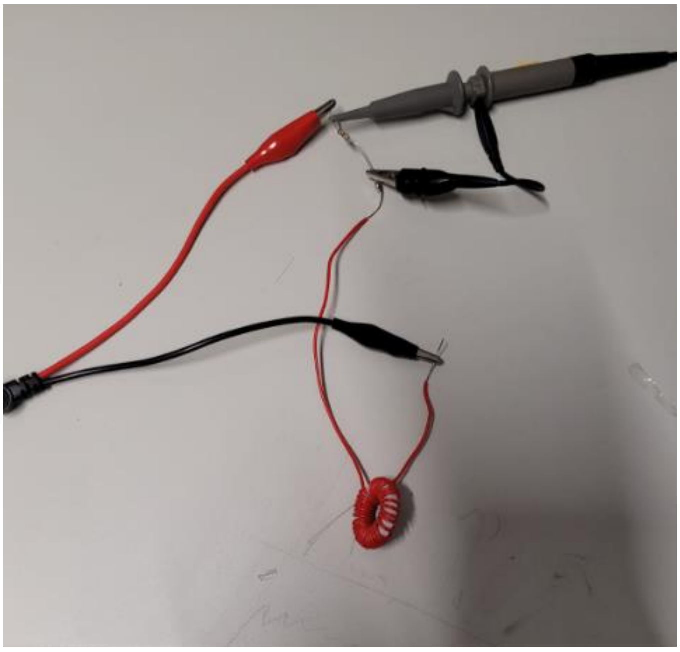
(Figure 3.4 – Measuring Time Constant of The RL Circuit, with Dielectric Inductor)

$$\tau * R = \Delta t * R = L$$

$$\Delta t = 52nS \ and \ R = 20 \ then,$$

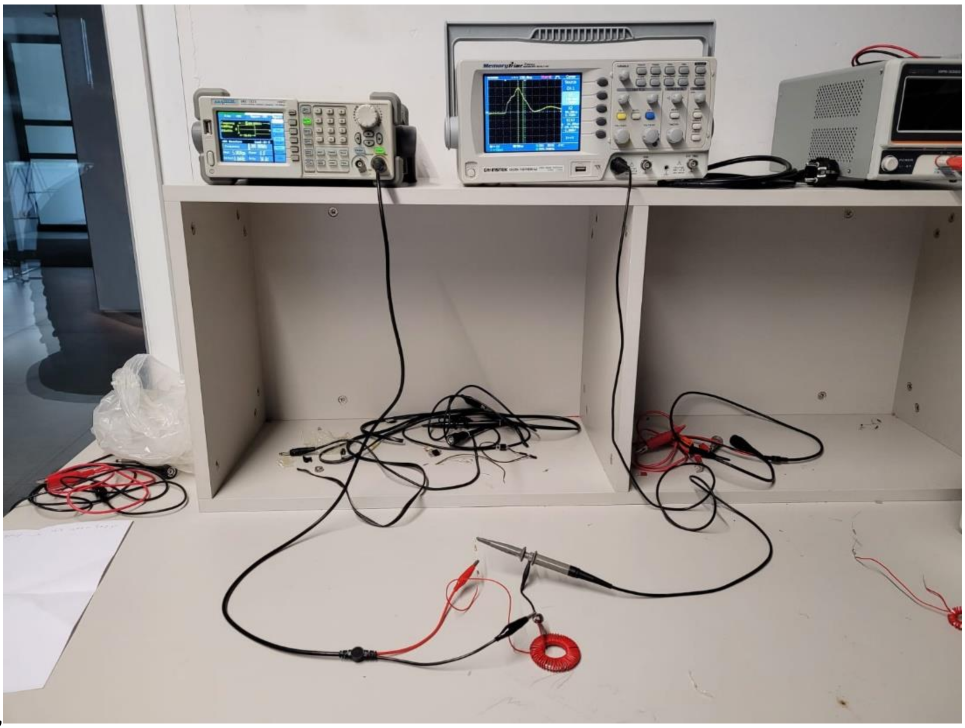
$$L = 52 * 10^{-9} * 20 = 1.144 * 10^{-6}H$$

$$L = 1.144 \ \mu H$$



(Figure 3.5 – RL Circuit Used in Circuit)

ii. **For Ferromagnetic Toroidal Inductors:**



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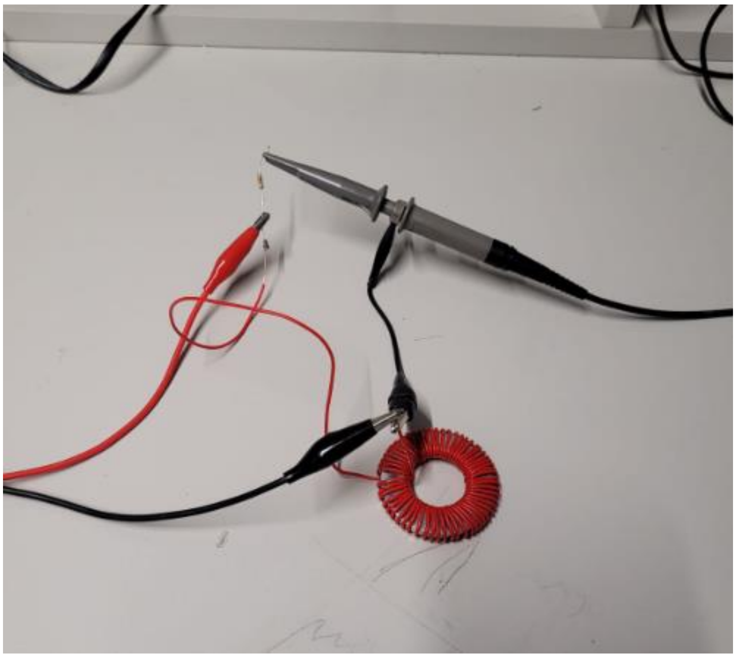
(Figure 3.6 – Measuring Time Constant of The RL Circuit, with Ferromagnetic Inductor)

$$\tau * R = \Delta t * R = L$$

$$\Delta t = 48nS \ and \ R = 100 \ then,$$

$$L = 48 * 10^{-9} * 100 = 4.8 * 10^{-6}H$$

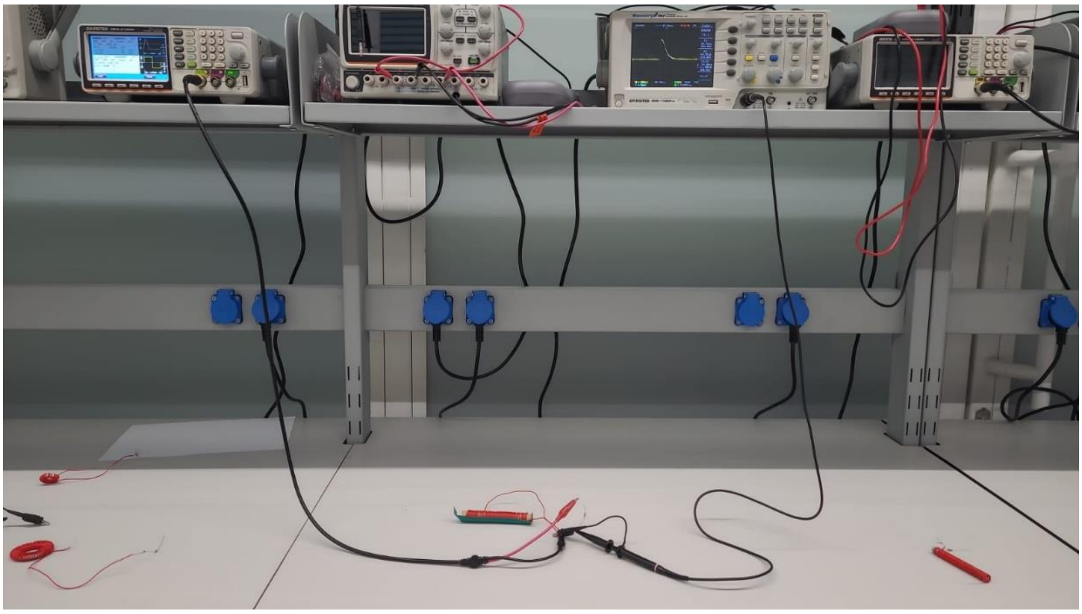
$$L = 4.8 \ \mu H$$



(Figure 3.7 – RL Circuit Used in Circuit)

C- Measuring Inductance Value of Solenoid Inductors:

i. For Dielectric Solenoid Inductors:



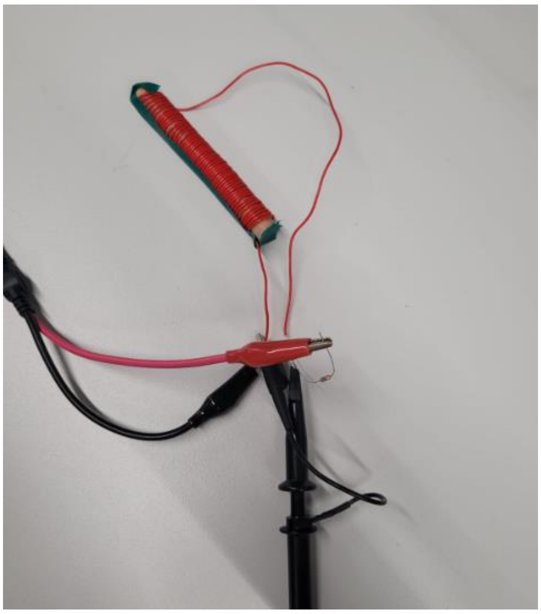
(Figure 3.8 – Measuring Time Constant of The RL Circuit, with Dielectric Inductor)

$$\tau * R = \Delta t * R = L$$

$$\Delta t = 84.80\ nS\ and\ R = 50\ then,$$

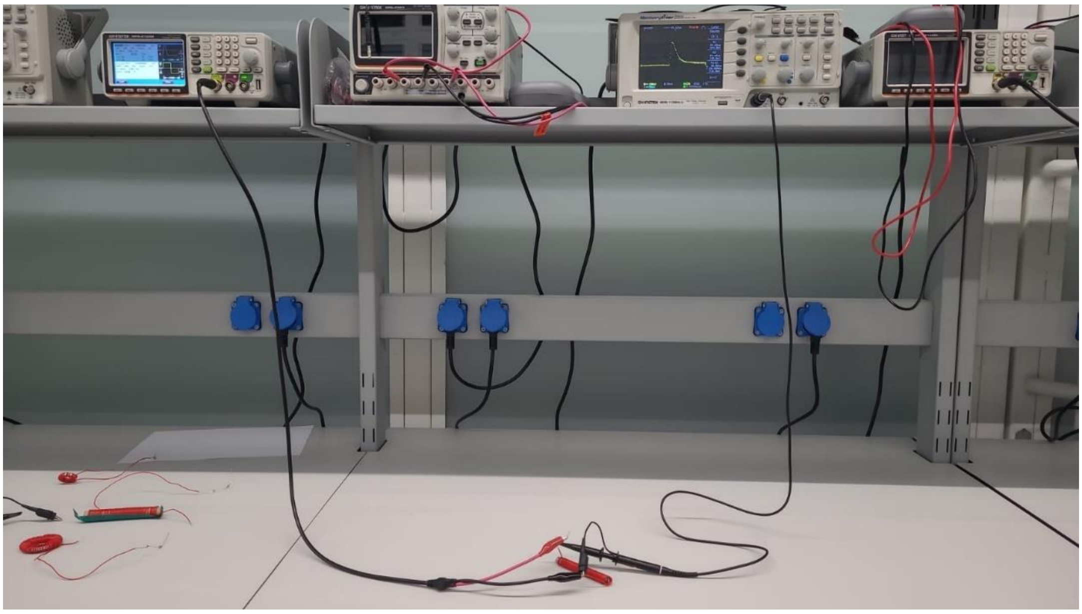
$$L = 84 * 10^{-9} * 50 = 4.24 * 10^{-6} H$$

$$L = 4.24\ \mu H$$



(Figure 3.9 – RL Circuit Used in Circuit)

ii. **For Ferromagnetic Solenoid Inductors:**



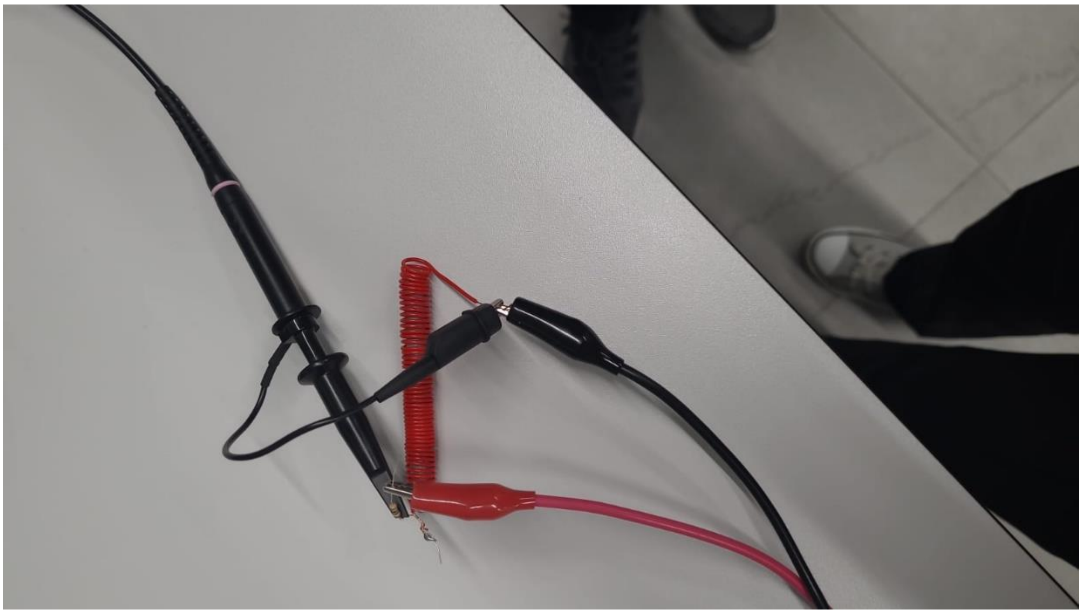
(Figure 3.10 – Measuring Time Constant of The RL Circuit, with Ferromagnetic Inductor)

$$\tau * R = \Delta t * R = L$$

$$\Delta t = 67.5\, nS \ and \ R = 50 \ then,$$

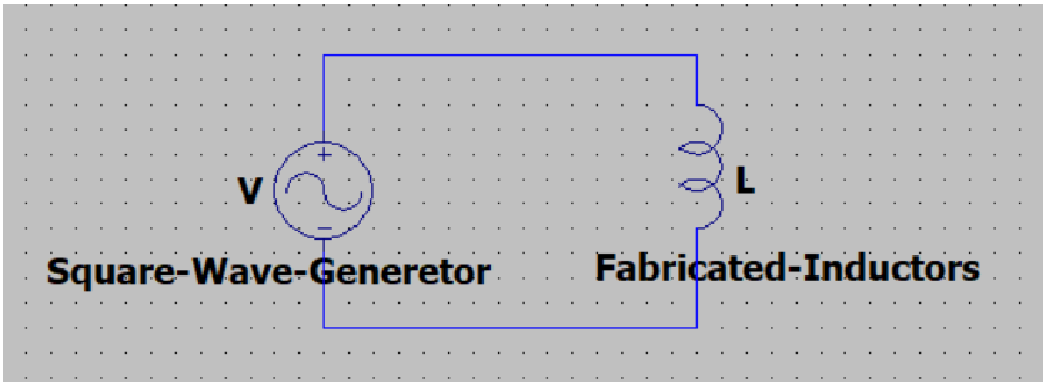
$$L = 67.5 * 10^{-9} * 50 = 337.5 * 10^{-6} H$$

$$L = 337.5\, \mu H$$

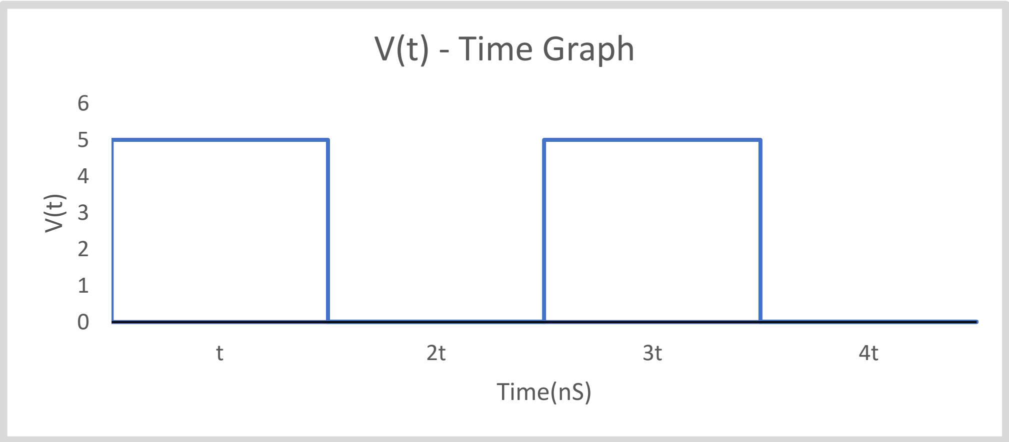


(Figure 3.11 – RL Circuit Used in Circuit)

b. Experimental Measurement of The Current Flowing Through the Inductor:



(Figure 3.12 – The Circuit Used to Find the Current Flowing Through the Circuit (Representational))

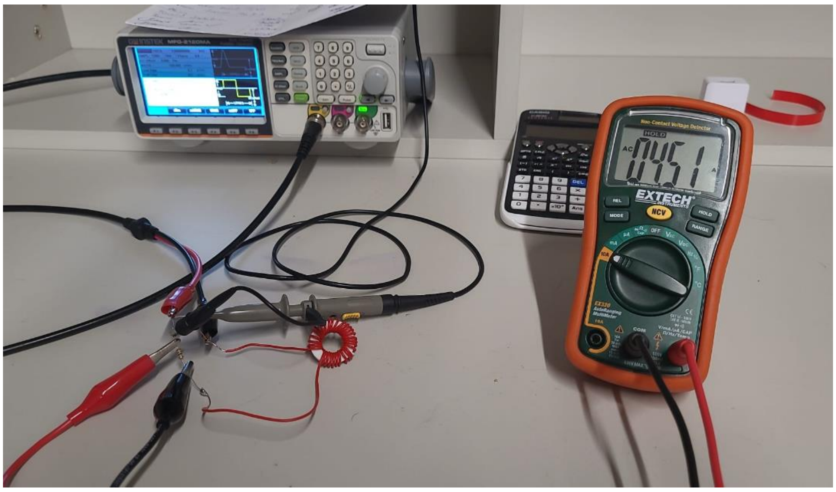


For the experimental measurement of the current flowing through the inductor, the following procedures were performed, respectively.

i. A square wave with an amplitude of 5 Volts is sent from the signal generator that provides voltage to the coil.
ii. When the signal generator provides 0 volts to the circuit, the current passing through the circuit is measured with the help of a mustimeter.
iii. The data obtained as a result of the measurement are noted.

a) Measurement of The Current Flowing Through the Toroidal Inductors:

i. For Dielectric Toroidal Inductors:

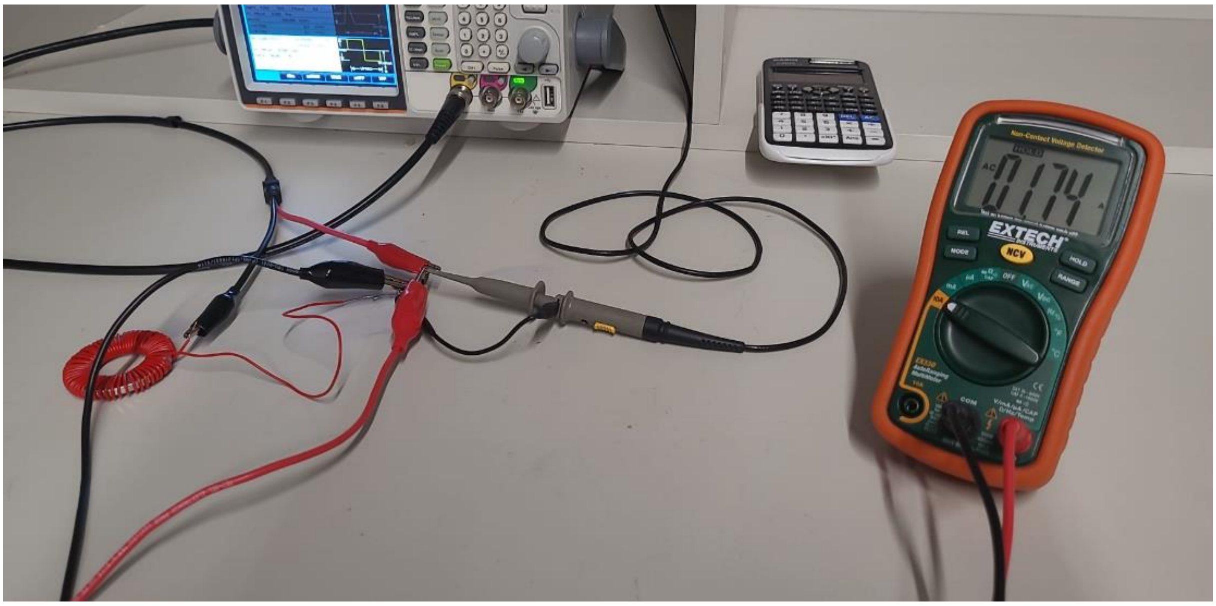


(Figure 3.12 – Measuring Current Flowing Through Dielectric Toroidal Inductor)

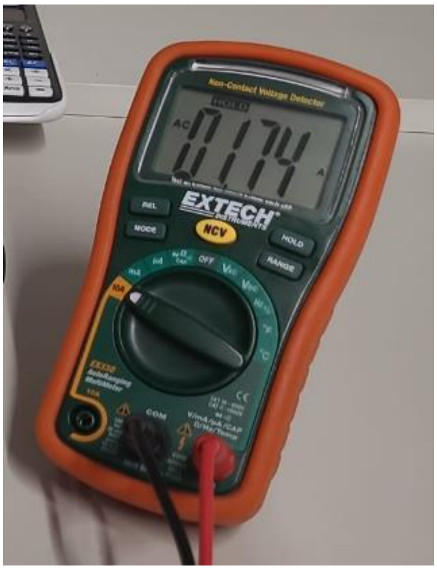
(Figure 3.13 – Measured Value for Dielectric Toroidal Inductor)

$$\textit{The measured current value in the designed RL circuit is } 4.51\ A.$$

ii. For Ferromagnetic Toroidal Inductors:



(Figure 3.14 – Measuring Current Flowing Through Ferromagnetic Toroidal Inductor)

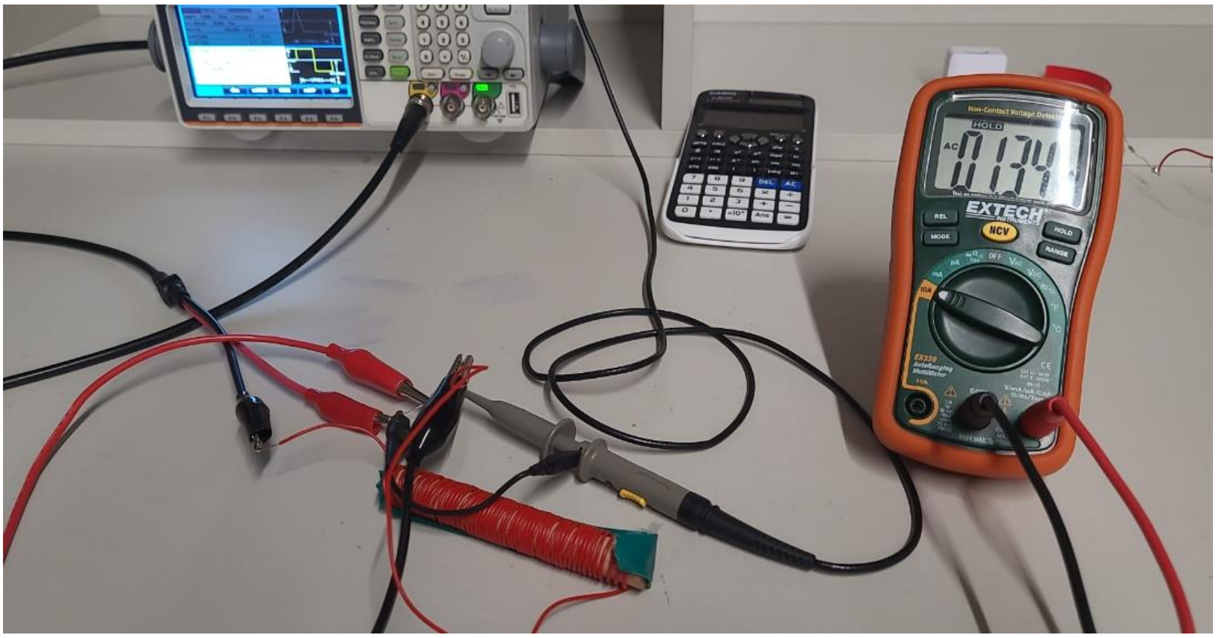


(Figure 3.15 – Measured Value for Dielectric Toroidal Inductor)

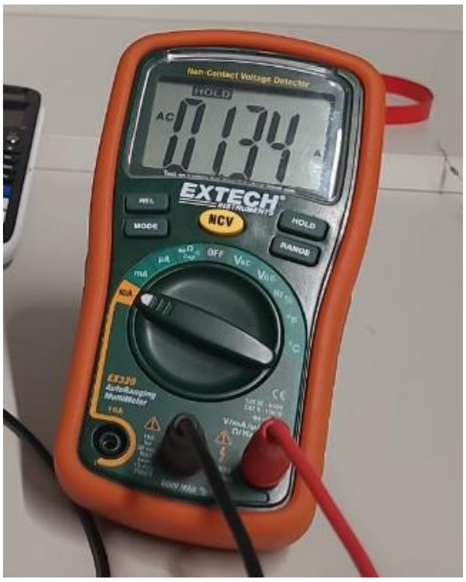
The measured current value in the designed RL circuit is 1.74 *A*.

b) Measuring Inductance Value of Solenoid Inductors:

i. For Dielectric Solenoid Inductors:



(Figure 3.16 – Measuring Current Flowing Through Dielectric Solenoid Inductor)



(Figure 3.17 – Measured Value for Dielectric Solenoid Inductor)

$$\textit{The measured current value in the designed RL circuit is } 1.34\ A.$$

ii. For Ferromagnetic Solenoid Inductors:

(Figure 3.18 – Measuring Current Flowing Through Ferromagnetic Solenoid Inductor)

(Figure 3.19 – Measured Value for Dielectric Solenoid Inductor)

The measured current value in the designed RL circuit is $2 * 10^{-2}\ A\ (20\ \mu A)$.

RESULTS AND DISCUSSION

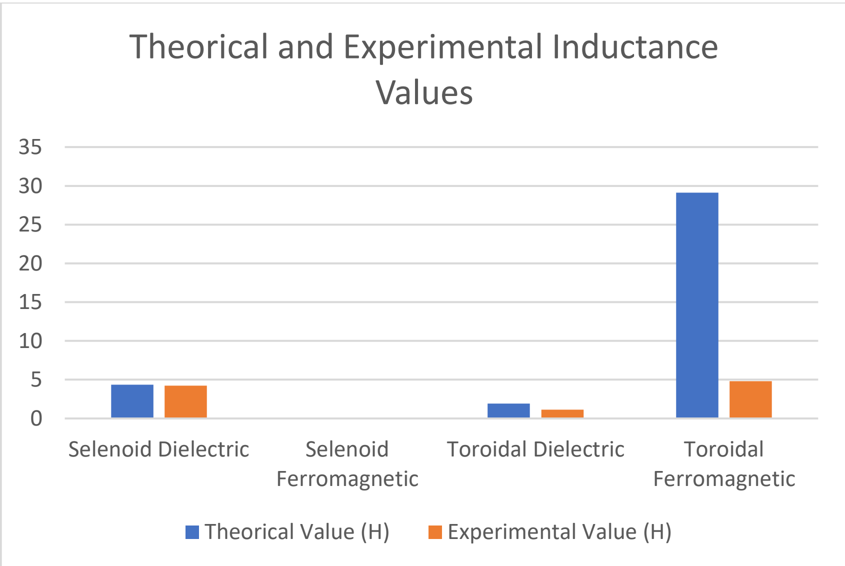
The calculations of the hypothetical inductors (specified in 5A and 5B) whose properties are specified in the project are made and the results are given in the theoretical part of the project.

For the manufacture of cylindrical inductors, ferromagnetic and dielectric cores were used. A cylinder with a radius of 8 mm and a length of 5 cm was created using iron material for the ferromagnetic core. A dielectric core was formed using wooden material, and the diameter of this core was 12 mm and its length was 9.5 cm. The insulating cable was wrapped tightly around these cores and its ends were tied to the core with the help of tape. As a result, the iron core inductor had a radius of 8 mm, a length of 5 cm, and 23 turns, while the wood-core inductor had a diameter of 12 mm, a length of 9.5 cm, and 54 turns.

Ferromagnetic and dielectric cores were used for the production of toroidal inductors. A toroid core with an inner radius of 33 mm and an outer radius of 45 mm was formed using iron material. A dielectric core with an inner radius of 15 mm and an outer radius of 24 mm was formed using PET (polyethylene terephthalate) material. The insulating cable was wrapped around these cores and the ends were tied with the help of tape. As a result of these processes, 33 mm inner radius, 45 mm outer radius and 39 turns were obtained for the iron core inductor, and 15 mm inner radius, 24 mm outer radius and 31 windings were obtained for the PET core inductor.

	Theorical Value (H)	Experimental Value (H)	ERROR
Solenoid Inductors			
Dielectric Core	$4.356\ \mu H$	$4.24\ \mu H$	2.528735 %
Ferromagnetic Core	1.2019430 mH	$337.5\ \mu H$	75.03952 %
Toroidal Inductors			
Dielectric Core	$1.914427\ \mu H$	$1.144\ \mu H$	40.3398%
Ferromagnetic Core	$29.119545\ \mu H$	$4.8\ \mu H$	83.51%

(Table 1.1 -Theorical and Experimental Inductance Values)



(Graph 1.1 -Theorical and Experimental Inductance Values)

The table presents the theoretical and experimental values of solenoid and toroidal inductors, as well as error percentages. Inductors have been studied with two different core materials, both with a dielectric core and with a ferromagnetic core.

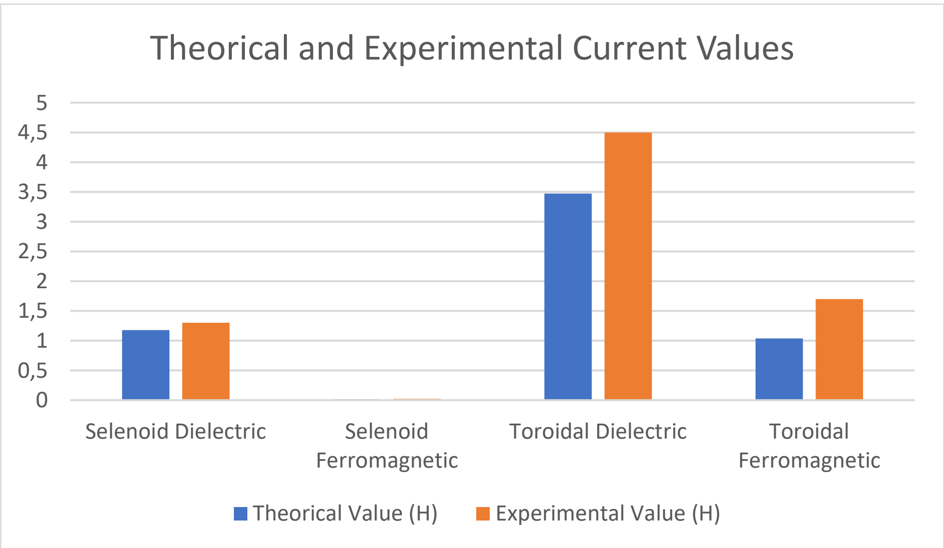
For solenoid inductors, the theoretical value of the one with a dielectric core is 4.356 µH, while the experimental value is 4.24 µH. This resulted in a very low margin of error of 2.528735%. In the solenoid inductor with a ferromagnetic core, the theoretical value was found to be 1.2019430 mH, while the experimental value was found to be 337.5 µH. This means a fairly high margin of error of 75.03952%.

In toroidal inductors, the theoretical value of the dielectric core is 1.914427 µH, and the experimental value is 1.144 µH. This resulted in an error rate of 40.3398%. The theoretical value of the toroidal inductor with a ferromagnetic core was 29.119545 µH, while the experimental value was measured as 4.8 µH. This resulted in a fairly high margin of error of 83.51%.

In general, it is seen that the experimental values are quite different from the theoretical values and the error rates are quite high, especially in inductors with ferromagnetic cores. This may be due to the fact that some factors were not taken into account during the experiment or that the magnetic properties of the core material could not be measured exactly.

	Theoretical Value (A)	Experimental Value (A)	ERROR
Solenoid Inductors			
Dielectric Core	$1.179\ A$	$1.3\ A$	10.26293 %
Ferromagnetic Core	$0.0148\ A$	$0.022\ A$	48.64864 %
Toroidal Inductors			
Dielectric Core	$3.47\ A$	$4.5\ A$	29.68299 %
Ferromagnetic Core	1.04	$1.7A$	63.46153%

(Table 1.2 -Experimental and Theoretical Values of Current Passing Through Inductor)



(Graph 1.2 - Experimental and Theoretical Values Of Current Passing Through Inductor)

The results of our report include a comparison of theoretical and experimental values of both solenoid and toroidal inductors with experiments using dielectric and ferromagnetic cores.

In solenoid inductors, the theoretical value of the dielectric core one is 1.179 A, while its experimental value is 1.3 A. This translates to a margin of error of 10,26293 percent. In the solenoid inductor with ferromagnetic core, the theoretical value was found to be 0.0148 A and the experimental value to be 0.022 A. In this case, the margin of error was calculated as 48,64864 percent, which is a higher value.

In toroidal inductors, on the other hand, the theoretical value of the dielectric core one was 3.47 A, and the experimental value was 4.5 A. This corresponds to an error rate of 29,68299 percent. The theoretical value of the toroidal inductor with a ferromagnetic core was 1.04 A, and the experimental value was 1.7 A. In this case, the margin of error was calculated as 63.46153 percent.

These results show that ferromagnetic cores lead to higher error rates in both solenoid and toroidal inductors. In inductors with a dielectric core, the error rates are lower, but are still distinctly present. These results are expected to help us better understand the discrepancies between theoretical and experimental values of inductors.

CONCLUSIONS

In the experimental process, cylindrical and toroidal inductors were produced successfully. When these inductors are used in circuits, the measurement of currents was made. The results of this experiment helped us to interpret and understand the physical and chemical properties of the core materials from which the inductors are made, and the number of turns and their effects on the inductance value.

Generally, when we consider the inductance values, we see that there are important differences between the experimental and theoretical results. It is worth noting that these differences affect the sensitivity and reliability of our reviews. We noticed that the error rates were higher, especially in inductors with a ferromagnetic core. This may be due to the incomplete understanding of the complex magnetic properties of inductors with ferromagnetic cores and their interactions.

In addition, the inability to measure the magnetic properties of the core material is another important problem. Accurately measuring and interpreting the magnetic properties of core material can be a process fraught with technical and experimental challenges. This may be due to the complexity of the material's internal structure and the variability of its magnetic properties.

In addition, another source of errors during the measurement process may be the error of the measurer or problems with the measurement tools used. Human errors can lead to misleading results. Likewise, calibration errors or malfunctions of the measuring instruments used can affect the measurement results. Therefore, accurate measurement and interpretation of inductance values requires careful experimental design and implementation.

Experimental current experiments in the RL circuit with Fabricated Inductors show that ferromagnetic cores lead to significantly higher error rates compared to dielectric cores in both solenoid and toroidal inductors. One possible reason why ferromagnetic cores cause greater errors may be the complex nature of the magnetic properties of the core material, which is difficult to meet theoretical predictions. The lower margin of error of dielectric cores may be due to the magnetic properties of this core material being more predictable and stable.

However, there is a significant error rate for both kernel types. This may point to both the shortcomings of our theoretical modeling and the experimental measurement errors. Measurement errors may be related to the accuracy of measuring instruments, experimental procedures, or experimental conditions.

These findings suggest that we need to seek new ways to improve our experimental design and theoretical modeling. This can be achieved both by better understanding and modeling the properties of materials and by improving our measurement procedures and techniques. It may also be important to examine in more detail the effect of different core materials on inductance. This can be invaluable for optimizing inductor design and applications.

This study covers an experimental process in which solenoid and toroidal inductors are successfully fabricated and used in circuits. The obtained findings enabled us to understand the physical and chemical properties of the core materials and the effect of the number of windings on the inductance value. Generally, we have found that there are significant differences between theoretical and experimental results, and these differences affect the precision and reliability of our interpretations. Error rates were particularly high in inductors with a ferromagnetic core. This may be due to our poor understanding of the complex magnetic properties and interactions of inductors with ferromagnetic cores. In addition, the difficulties of accurately measuring and interpreting the magnetic properties of the core material can also pose a significant problem. Other errors in the measurement process can be caused by errors in measuring tools or user errors. These findings suggest that we need to better understand and model the properties of materials and improve our measurement procedures and techniques. This can be invaluable for optimizing inductor design and applications.

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