Analog Voltmeter

Group MetraWave

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EN 2091 Laboratory Practice and Projects

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Abstraction

This report provides an overview of the design process for an analog inductor-capacitor measurement circuit aimed at determining the values of inductors and capacitors in electronic circuits. The circuit is capable of measuring inductors with values greater than 70 μH and capacitors with values starting from 800 pF, making it versatile for a range of applications.

The design utilizes precision analog components, including BJTs, capacitors, inductors, operational amplifiers (Op-Amps), and resistors, to ensure accurate measurements. Simulations and testing were conducted using LTspice for circuit analysis, SolidWorks for mechanical design, and Altium Designer for PCB layouts, ensuring an optimized and user-friendly solution. This project emphasizes precision, reliability, and cost-effectiveness, making it an ideal tool for educational and professional applications.

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1 Introduction and Functionality

Introduction

This inductor-capacitor measurement circuit project aims to address the common challenge of reliably and accurately measuring inductance and capacitance values frequently used in electronic applications. The primary objective is to design a cost-effective and high-precision system capable of determining the values of inductors and capacitors without requiring advanced or expensive equipment.

Functionality

The primary functionality of this inductor-capacitor measurement circuit is based on utilizing oscillator frequencies to determine the corresponding values of inductors and capacitors. For inductor measurements, a Colpitts oscillator is employed, ensuring reliable and accurate determination of inductance values by analyzing the oscillation frequency. For capacitor measurements, an astable multivibrator circuit is used, leveraging its frequency characteristics to calculate the capacitance accurately.

This approach ensures precise and efficient measurements while minimizing complexity. By designing circuits that are specifically optimized for these tasks, the system offers a dependable solution for measuring commonly used inductors and capacitors in electronic applications.

2 System Architecture

Functional Block Diagram

The system comprises four blocks: capacitor input, inductor input taken using crocodile clips, output display, power supply and regulator,and main PCB.

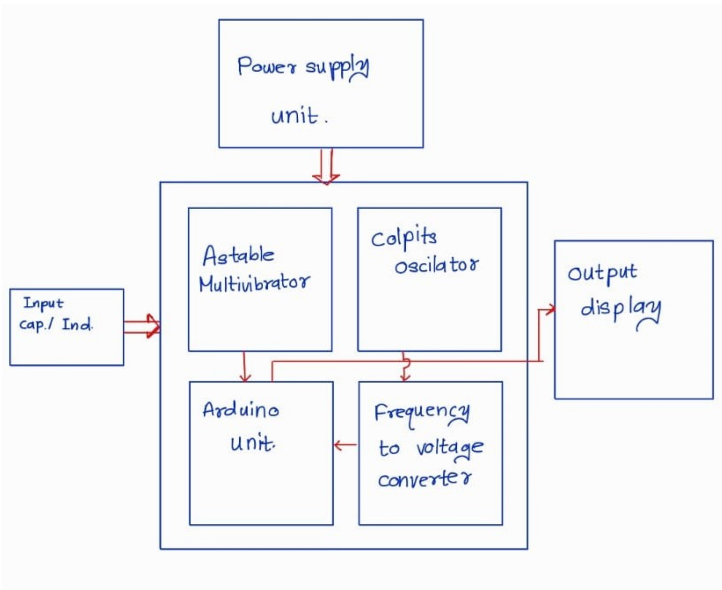

Figure 1: Functional block diagram

Inductor Measurement

The system architecture for inductor measurement utilizes a Colpitts oscillator and a frequency-to-voltage converter circuit. This approach converts the frequency of the generated sine wave into a corresponding DC voltage, which can be used to determine the value of the inductor. The Colpitts oscillator is selected due to its simplicity, stability, and ability to produce a consistent oscillation frequency based on the inductance in its tank circuit.

Colpitts Oscillator

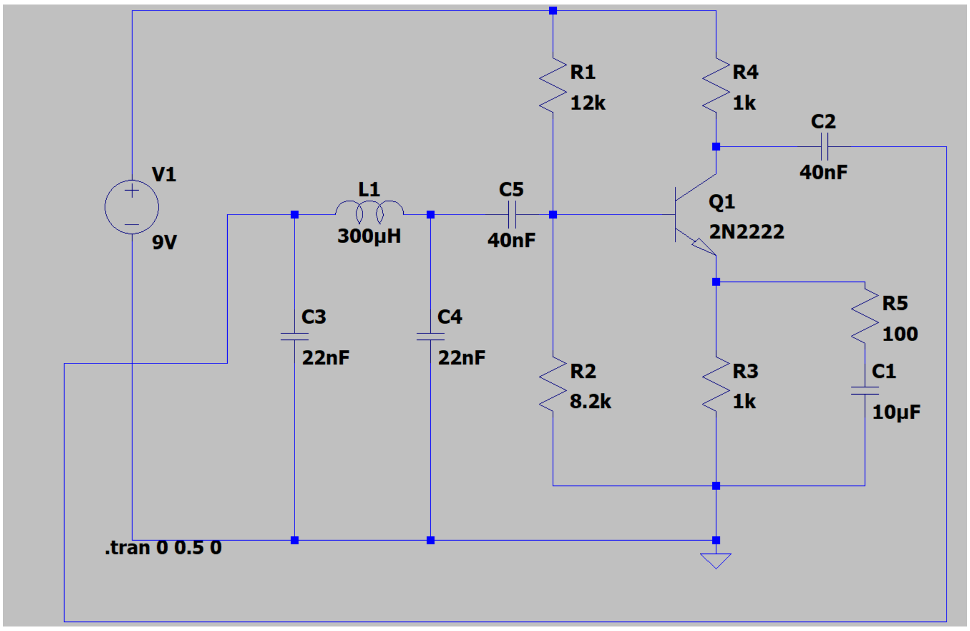

Figure 2: Colpitts oscillator circuit diagram

The key component of the Colpitts oscillator is the tank circuit, which determines the oscillation frequency. The frequency f of oscillation is governed by the equation:

$$f = \frac{1}{2\pi\sqrt{L \cdot C}}$$

where L is the inductance and C is the equivalent capacitance of the tank circuit. By measuring the frequency of the sine wave output, the inductance L can be calculated if the value of C is known.

Frequency-to-Voltage converter

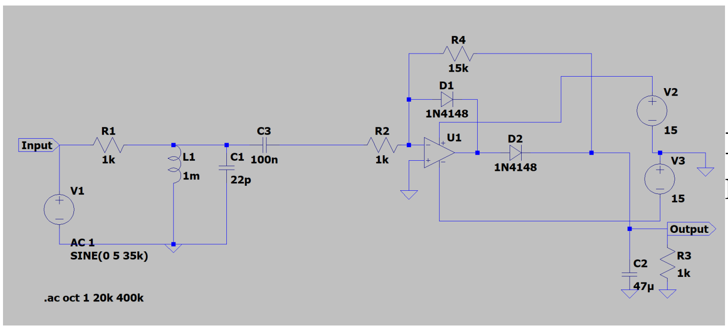

Figure 3: This is the caption placed beside the image.

To translate the frequency into a measurable DC voltage, a frequency-to-voltage converter circuit is employed. This circuit takes the sine wave frequency as input and outputs a proportional DC voltage. The DC voltage is then usd to determine the inductance value using calibration data that maps specific voltage levels to inductance values.

This include main 3 parts. First is pass band filter frequency range 20kHz- 170kHz . Next is the precission rectifire This design ensures high accuracy and reliability in inductance measurement, leveraging the relationship between oscillation frequency and inductance.

Capacitor Measurement Circuit

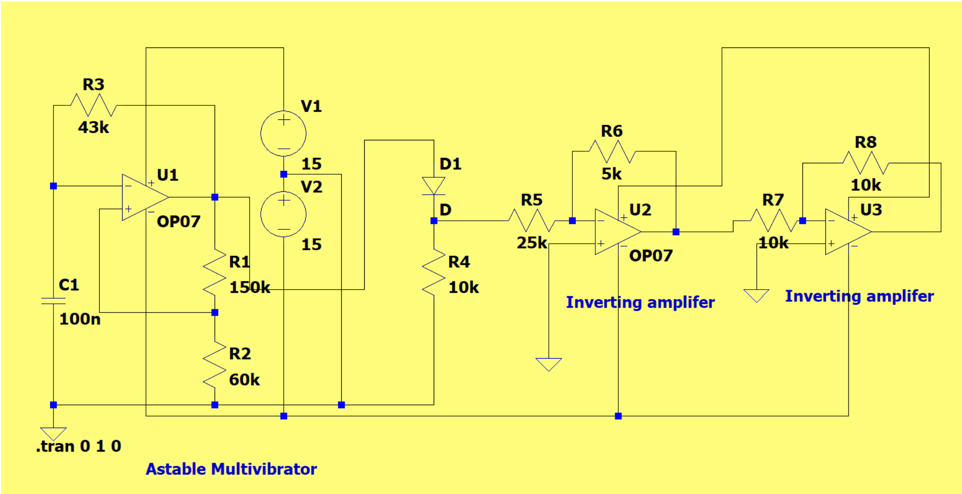

Figure 4: circuit diagram of capacitor measurement circuit

The capacitor measurement circuit operates on the principle of frequency-based measurement using an astable multivibrator. The circuit is designed using a TL072 operational amplifier configured as an astable multivibrator to generate a square waveform. The frequency of the waveform depends on the values of the resistors and the capacitor in the circuit.

The frequency is determined using the following equations. First, the feedback ratio (β) is given by:

$$\beta = \frac{R_2}{R_1 + R_2}$$

The time period (T) of the oscillation is calculated as:

$$T = 2RC \cdot \ln \left(\frac{1 + \beta}{1 - \beta} \right)$$

The frequency (f) is the reciprocal of the time period:

$$f = \frac{1}{T}$$

In this circuit, the generated frequency corresponds to the value of the capacitor being measured. The output of the astable multivibrator, which is initially a square waveform, is rectified into a pulse waveform. This pulse signal is then fed into an Arduino microcontroller, which uses the above equations to calculate the capacitance value accurately.

This method ensures precise and reliable capacitor measurements by leveraging the frequency-dependent characteristics of the circuit.

Measurement Ranges

The designed measurement circuits for capacitors and inductors operate within specific frequency ranges, ensuring accurate and reliable readings. The frequency-to-voltage (f-to-V) converter used in both circuits supports frequencies ranging from 20 kHz to 176 kHz, providing a broad measurement capability.

Capacitor Measurement Range

The capacitor measurement circuit is designed to measure capacitance values greater than 800 pF. The circuit uses an astable multivibrator, which generates a frequency inversely proportional to the capacitance value. By rectifying the square waveform output and converting the frequency to a corresponding voltage using the f-to-V converter, capacitors above 800 pF can be reliably measured.

Inductor Measurement Range

For inductance measurements, the circuit employs a Colpitts oscillator, where the oscillation frequency depends on the inductor and capacitor values. Using the same f-to-V converter, inductors with inductance values exceeding 35 μH can be measured. The oscillator generates frequencies within the supported range of 20 kHz to 176 kHz, ensuring accurate inductance calculations.

These measurement ranges make the circuit versatile and capable of handling components commonly used in electronic systems. By leveraging the high precision of the f-to-V converter and the analog design of the circuits, the solution ensures efficient and reliable measurement for capacitors and inductors.

Digital Display and Calibration

The project incorporates a digital display to show the measured values of inductors and capacitors accurately. The digital display provides a user-friendly interface to read measurements directly, eliminating the need for manual calculations.

Inductor Measurement Circuit

In the inductor measurement circuit, the inductor value is determined based on the voltage levels corresponding to specific inductance values. These values are pre-calibrated using interpolation techniques derived from practical measurements. The Arduino Uno R3 microcontroller is used to process the voltage levels and translate them into the corresponding inductance values, which are then displayed on the digital screen.

Capacitor Measurement Circuit

For the capacitor measurement circuit, the frequency of the pulse waveform generated by the astable multivibrator is utilized. The frequency is mapped to capacitance values based on an established mathematical relationship. The Arduino Uno R3 is programmed to convert the pulse wave frequency into a corresponding capacitance value through calibration, ensuring accurate measurements. These capacitance values are then displayed on the digital display.

By integrating the digital display and Arduino Uno R3, the system achieves a seamless and precise method for presenting measurement results, enhancing usability and reliability.

Power Supply and Regulator Unit

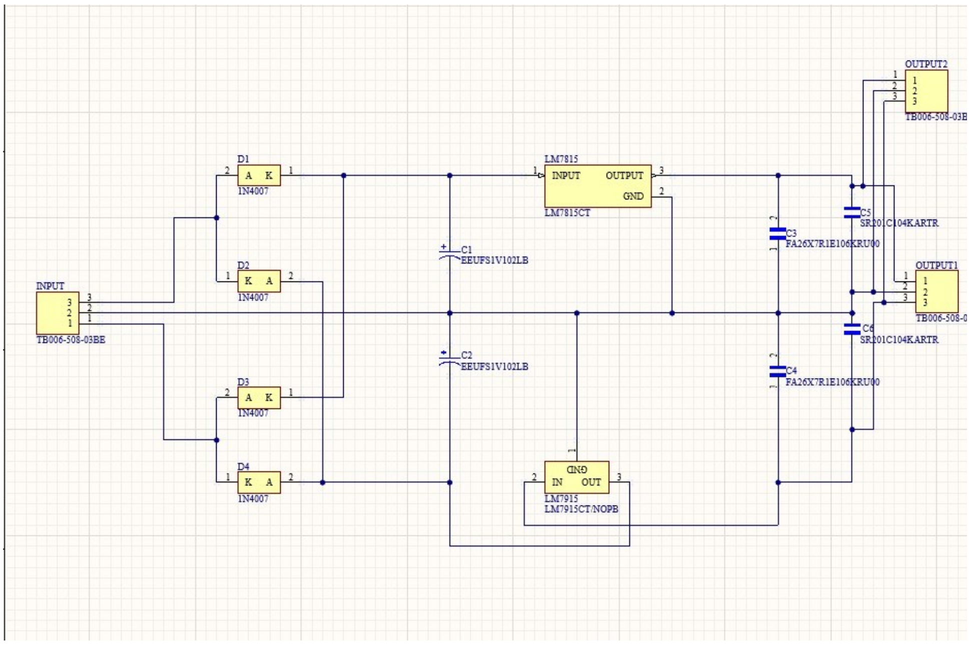

Figure 5: Power supply unit circuit diadram (+15v and -15v output)

The power supply and regulator unit is a crucial component of the project, ensuring stable and reliable voltage levels for various circuit components. A dual voltage supply of +15V and -15V is employed to power the operational amplifier circuits, while a regulated 9V supply is used to power the Arduino Uno R3 and the Colpitts oscillator.

The design begins with a step-down transformer that reduces the 230V AC mains voltage to 18V AC. This lower voltage is then rectified using a full-wave bridge rectifier composed of four diodes. The rectified output is filtered using capacitors to produce a stable DC voltage.

For dual voltage requirements, two linear regulator ICs are utilized:

- **LM7815** for +15V
- **LM7915** for -15V

These regulators provide stable dual voltages required for the operational amplifier circuits. Additionally, a **7809 regulator** is employed to derive a 9V supply from the +15V output. This 9V supply powers the Arduino Uno R3 and the Colpitts oscillator, ensuring reliable operation.

By incorporating this power supply and regulation setup, the system maintains the required voltage levels, ensuring consistent performance across all components.

3 Component Selection

The design and implementation of this analog voltmeter and measurement system require careful selection of components to ensure accuracy, reliability, and efficient operation. Key components used in the project include the **2N2222 BJT**, **TL072 Op-Amp**, and various regulator ICs. Below is an overview of these components and their roles in the system:

1. **2N2222 Bipolar Junction Transistor (BJT)** The **2N2222** is a versatile NPN BJT known for its high gain and ability to operate at low power levels. It is primarily used in switching and amplification applications. In this project, the 2N2222 plays a critical role in oscillator circuits and as a buffer in signal processing stages. Its wide operating range and robustness make it ideal for analog circuit designs.

2. **TL072 Operational Amplifier (Op-Amp)** The **TL072** is a dual low-noise JFET-input operational amplifier. It is selected for its excellent input impedance, low noise, and high slew rate, making it perfect for precision analog applications. The TL072 is used in both the Colpitts oscillator circuit for inductor measurement and the astable multivibrator circuit for capacitor measurement. Its low offset voltage ensures accurate signal amplification without introducing distortion.

3. **Regulator ICs (LM7815, LM7915, 7809)**

    - **LM7815**: This positive voltage regulator ensures a stable +15V output for the operational amplifier circuits and other components requiring dual voltage.
    - **LM7915**: This negative voltage regulator provides a steady -15V supply, complementing the LM7815 to meet the dual-voltage requirements of the op-amp circuits.
    - **7809**: The 7809 voltage regulator derives a precise 9V output from the +15V supply. This 9V is used to power the Arduino Uno R3 and other low-voltage components, such as the Colpitts oscillator.

4. **Arduino Uno R3** The **Arduino Uno R3** microcontroller acts as the central processing unit for converting frequency signals into corresponding capacitance and inductance values. Its robust I/O capability, combined with precise timing functions, ensures accurate measurements and seamless integration with the display system.

5. **Other Components**

    - **Transformers**: Step-down transformers are used to reduce the 230V AC mains voltage to 18V AC for the power supply unit.
    - **Diodes (Bridge Rectifier)**: Four diodes are configured as a full-wave bridge rectifier to convert AC to DC voltage.
    - **Capacitors**: Filtering capacitors are employed to smooth the rectified DC voltage, ensuring stable supply to the regulator ICs.
    - **Resistors and Inductors**: Precision resistors and inductors are incorporated in the oscillator circuits to maintain the desired frequency range for measurement.

4 PCB Design

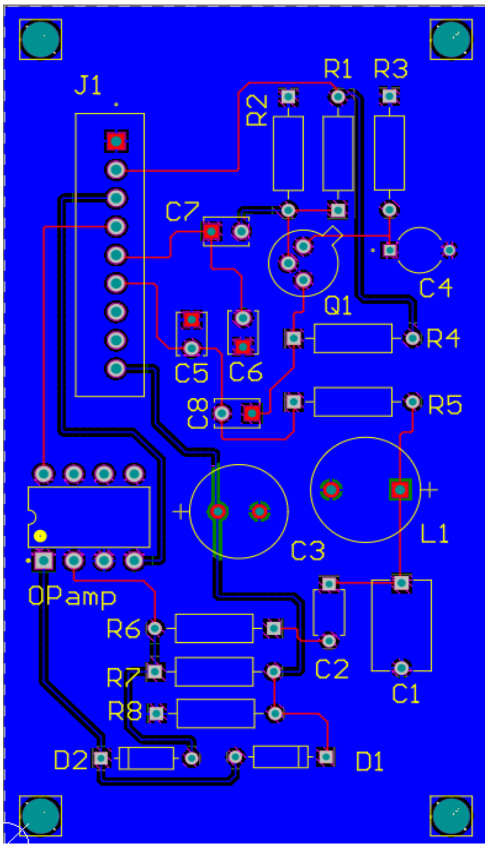

Figure 6: PCB document of Inductance measurement circuit

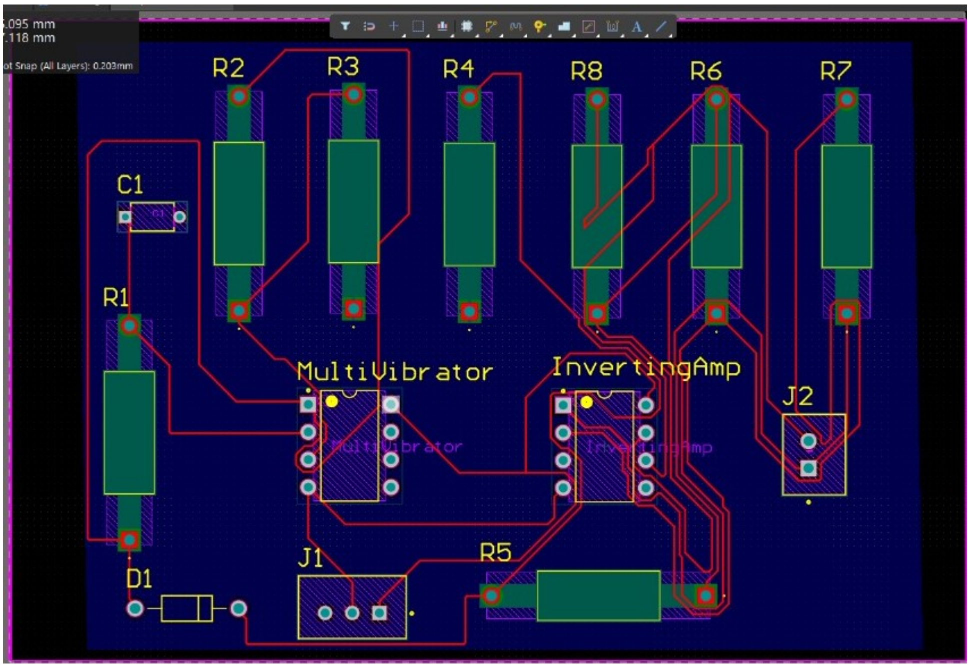

Figure 7: PCB document of capacitor measurement circuit

The PCB design was created using Altium software, ensuring compactness and efficient routing. Dual-layered for the colpitts oscillator, frequency converter and power supply unit. Single-layered for the Astable multivibrator 9V regulator.

5 Enclosure Design

A 20cm x 18cm enclosure was designed in SolidWorks with connector.

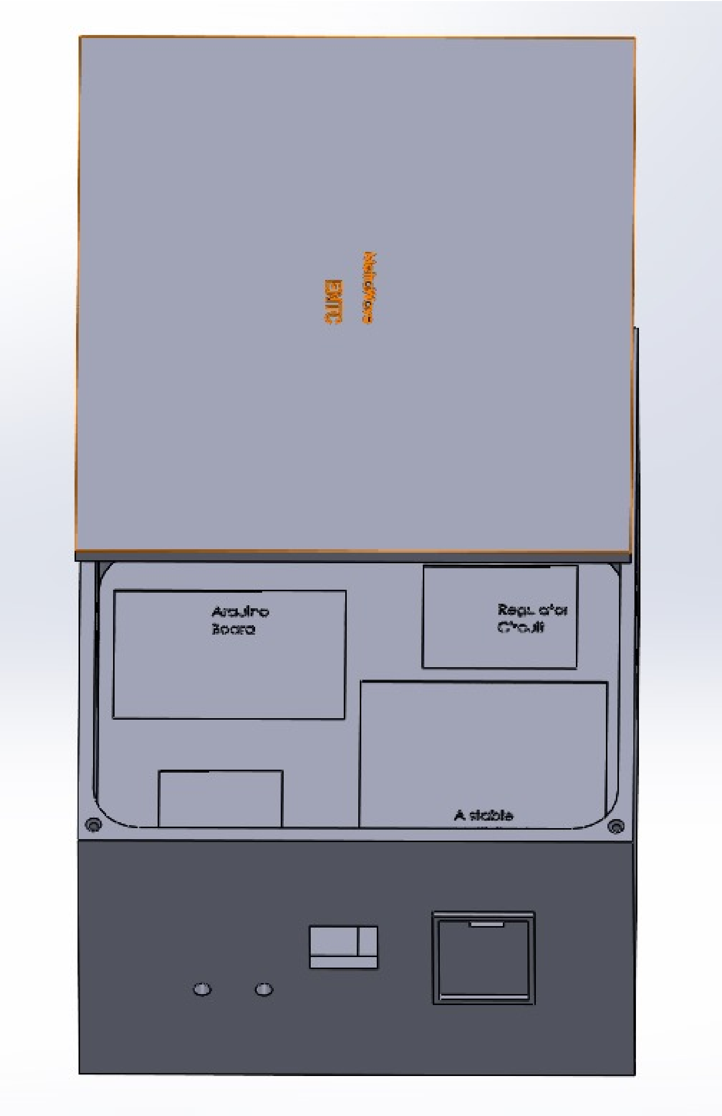

Figure 8: Enclosure top view

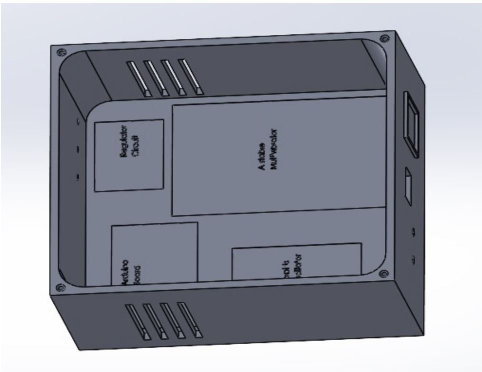

Figure 9: Enclosure inside

6 Software Simulation and Hardware Testing

To complete the software simulation and hardware testing for our project, we followed a systematic process to ensure accuracy and reliability.

6.1 Software Simulation with LTSpice

We began by designing and simulating our circuits in **LTSpice**. This allowed us to validate the functionality and performance of the circuits before moving to the hardware phase. Through simulation, we identified and resolved potential issues in the design early in the process.

6.2 Breadboard Implementation

Once the circuits were verified in LTSpice, we implemented them on a breadboard. This step helped us test the real-world performance of the design before committing to a final PCB.

6.3 Output Testing with Oscilloscope

During the breadboard testing phase, we used an **oscilloscope** to measure and verify the outputs. We recorded the values obtained and plotted two graphs using **Excel**. These graphs were interpolated to determine the best-fitting curves, and the equations for these curves were derived. We then programmed the microcontroller using these equations to ensure optimal performance. This step allowed us to confirm that the signals matched the expected values from the LTSpice simulations and optimized the circuit parameters accordingly.

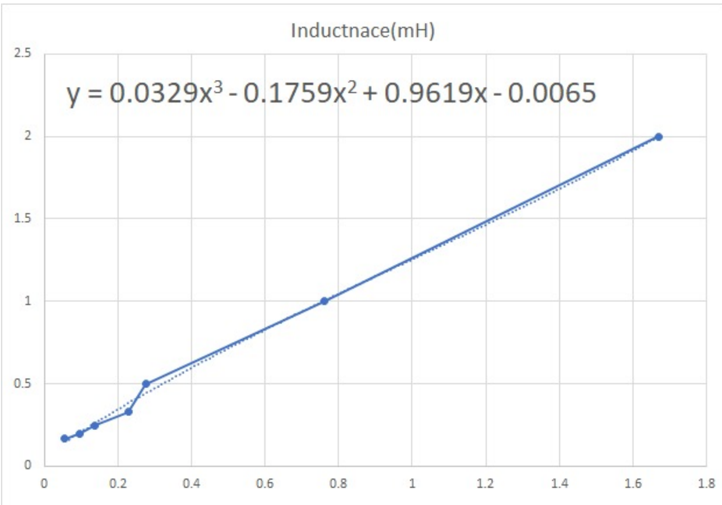

Figure 10: Interpolated output graph for inductance

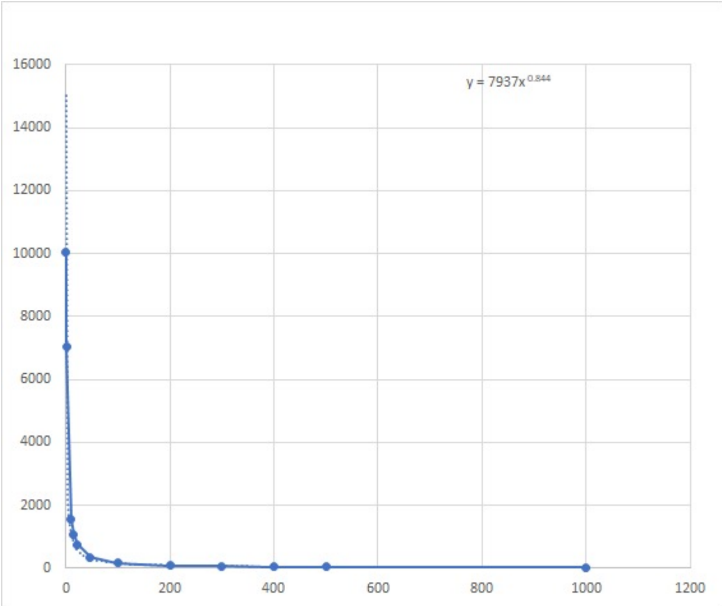

Figure 11: Interpolated output graph for capacitance

6.4 PCB Testing

After receiving the printed circuit boards (PCBs), we soldered the components and tested the assembled boards. This involved:

- Checking for continuity and shorts on the PCB.
- Powering the circuit carefully and verifying the outputs again using the oscilloscope.
- Ensuring all components were functioning correctly under real conditions.

6.5 OLED Display Integration

Once the circuit was fully tested and functional, we integrated an **OLED display** to show the measured values and outputs.

7 Conclusion and Future Works

Conclusion

The project achieved accuracy within ±1%, addressing most design objectives. Power supply challenges were resolved with a dual-channel laboratory setup.

Future Works

Future improvements Enhancing measurement range and implementing static calibration.

8 References

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3. https://www.alldatasheet.com/datasheet-pdf/pdf/28775/TI/TL072.html
4. https://www.alldatasheet.com/datasheet-pdf/pdf/33410/UTC/LM7809.html
5. https://www.alldatasheet.com/datasheet-pdf/view/956542/FCI/2N2222A.html

Task Allocation

Name	Task
Ranaweera R.P.D.D.H.	Software simulation, Circuit implementing, PCB designing, Report writing
Anuradha D.M.B.P.	Circuit designing, Troubleshooting, Report writing
Vidmal S.S.A.A.	Enclosure design
Kulasinghe H.P.G.N.A.	Circuit designing, PCB designing

Table 1: Task Allocation Table