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MICROCONTROLLER BASED IMPEDANCE METER
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Declaration.

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**COLLEGE:** Architecture and Engineering

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**DEPARTMENT:** Electrical and Information Engineering

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**TITLE OF WORK:** PROJECT 084: - MICROCONTROLLER BASED
IMPEDEANCE METER FOR INDUCTOR, RESISTOR AND CAPACITOR.

---

1) I understand what plagiarism is and I am aware of the university policy in this regard.

2) I declare that this final year project report is my original work and has not been submitted elsewhere for examination, award of a degree or publication. Where other people’s work or my own work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi’s requirements.

3) I have not sought or used the services of any professional agencies to produce this work

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**Date:** ……………………………………………………………………………………………………………………………
CERTIFICATION

This report has been submitted to the Department of Electrical and Information Eng. University of Nairobi with my approval as supervisor:

DR. G. N. KAMUCHA

Date: …………………………………..
Dedication.

To my mother, sister, Ms Rose I Ngowi, Mr. Elisifa G Ngowi and Mr. Hilary F Ngowi.
Acknowledgement.

The idea of designing an impedance meter device brought a lot of excitement and expectations. However, during the system implementation, fabrication and chip ordering many unexpected challenges arose that needed research, studying and solving.

I thank my supervisor Dr. G Kamucha for his guidance during the project progress till its successful design, implementation and fabrication.

During the project I obtained valuable help from my colleagues and especially Julius Kimani who taught me how to code and program the microcontroller.

Lastly, I thank the Almighty Lord for the favor and grace through my degree and more so during this project.
Abstract.

With growth in technology and design, electronics have widely been used with an aim to make them as small as possible hence writing values on the body of the component becomes a challenge. Every electrical engineer or lab technician would want a meter that would conveniently measure resistance, capacitance and inductance.

Inductors and capacitors unlike resistors lack a universal code to determine their impedance by sight hence a precise, low cost, small packaging, low power consumption, no-range selection for a wide variety of components and zeroing at any instant (reset) meter has to be designed.

This project describes a microcontroller-based impedance meter for inductance, capacitance and resistance. This design will improve the large, complex and expensive LCR meters by offering small portable and precise meter with a microcontroller which has a flash programmable memory, SRAM data memory with configurable analog and digital peripherals blocks in a range of convenient pins-outs and memory sizes.

The meter measures the impedance and displays it on the LCD screen which is a large, low cost display to provide a maximum of information at the same time. A selection switch is provided to allow fast access to the three parameters.
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1. INTRODUCTION.

1.1. Background.

Most capacitors and inductors do not have a universal standard code to calculate their values or they cannot be written on the body of the component since they are physically small. Most laboratories have physically large meters like the LCR Meter and oscilloscopes to measure the value of impedance of a device. Some of the techniques requires that the user has some technical knowledge to be able to use them.

There are precise commercial portable LCR Meters which are complex to fabricate and expensive to acquire.

For this project a microcontroller based impedance meter is designed and implemented to be portable, accurate, simple to use and relatively cheap to fabricate. The user interface is simple and the user can select the mode of the meter easily as either: resistance, capacitance or inductance. The meter can auto-zero by pressing the reset button hence it can be used to compare components. The resistance of an unknown component can be measured using the voltage divider technique where the unknown component is connected in series with a known resistor and a known voltage (Vcc) is supplied and the voltage drop across it is directly proportional to its resistance.

For capacitance, the time taken to charge a previously fully discharged capacitor to 63.2% of the supply voltage, \(V_S\); is found through the counter in the microcontroller and its divided by the value of the series resistance to give the capacitance.

To obtain the inductance, the resonating frequency is found by discharging and charging the capacitor and passed through a LC parallel circuit. The value of the resonating frequency is limited by the value of the inductance. This frequency is converted to time and the microcontroller can then calculate the value of the inductance.

The measured value is displayed to the LCD display which has a dot matrix format that shows alphanumeric and special characters. The microcontroller used is the ATmega328p that has enough flash memory of 30720 bits and a total of 28 pins with 22 free usable pins. [1]
The software used was coded using Arduino C which is a low level machine language and the Arduino has many libraries that can be used to implement the design.

1.2. Justification.

The measurement of the impedance is important to determining the characteristics of a component and how it can be used to implement a circuit design.

Since with growth of technology; devices are now manufactured to be physically small hence their impedance value cannot be encrypted on the component body hence there is need of a device that can be able to measure the value of the component accurately.

This project aims at designing a digital microcontroller-based impedance meter the is efficient, fast, portable and cheaply fabricated. It has to be accurate and simple to operate with user interface functionality like selection knob and LCD display. This meter is small and portable enough that can be carried in the pocket and uses a battery so it can be used any time.

1.3. Objectives.

The main aim of this proposed project is to use a microcontroller, other peripheral components and user interfaces to design and implement through fabrication a microcontroller-based impedance meter. The meter is to measure the impedance of a resistor, capacitor and inductor and display the values on the LCD quickly without any delays. The meter is simple and the following guidelines are followed to achieve this objective;

1.3.1. Design a general flowchart of the operation of the meter.
1.3.2. Design a circuit and simulate it using Proteus 8.1 and obtain results of virtual components.
1.3.3. Design the implementation circuits and component specification and fabricate the project on a double-sided FR4 substrate PCB. Here the microcontroller ATmega328p and the comparator LM339-N are used.
1.3.4. The fabricated project was used to collect data on real components and the results compared with results from commercial precise meters.

1.4. Scope of work.

This project is limited to the design of a digital microcontroller-based impedance meter to measure the impedance value of inductors, capacitors and resistors. The device under test (DUT)
is connected to the device after selecting the mode and the meter will determine the impedance value by manipulating the characteristics of the device in an LCR circuit. The design and fabrication is aimed at providing the following features:

1.4.1. Measure the impedance of inductors, capacitors and resistors.
1.4.2. Provide a user interface to allow the user to select the mode of operation.
1.4.3. Auto-range every time a component is connected.
1.4.4. Can zero the meter each time a component is connected which is an important feature when comparing components.
1.4.5. Simple intuitive user interface.

1.5. Project report organization.

This project report is systematically organized to explain the theory of the proposed project, design and implementation, fabrication, test and results and analysis to determine whether the objectives are met. The whole project is organized in chapters as shown below:

1) Declaration;
2) Dedication;
3) Acknowledgements;
4) Abstract;
5) Table of Contents;
6) List of Figures;
7) Acronyms;
8) Chapter 1: this gives the introduction of the project with a brief background, objectives and scope of work.
9) Chapter 2: this covers the literature review with the theoretical background of the main units of the project.
10) Chapter 3: Design and implementation. The design includes simulation of the project and fabrication on a PCB and testing it so as to function as expected.
11) Chapter 4: Results. A comparison is done by using the impedance meter to sample some devices under test and a precise laboratory meter is used to read the values of the components. Analysis is done to determine accuracy of the meter.
12) Conclusions and Recommendations. The analysis introduces some imperfections in the project which are discussed here in addition to other challenges that limited this scope of the project and improvement recommendations done.

13) References: the citations made are acknowledged in preference as they are used using the IEEE format.

14) Appendix
2. LITERATURE REVIEW.

All practical components are either partially reactive and resistive and can be modelled in such a way so that they are either in series or parallel to a reactive or resistive load. There is need to know the impedance of the component coupled to the load.

The impedance of a component is the voltage drop that arises from the current that passes across it. Mostly the impedance is presented as a complex number with a magnitude and phase.

We introduce three vector quantities with different angles;

\[ V = \mathbf{v} < \Psi \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (1) \]
\[ I = \mathbf{i} < \Phi \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2) \]
\[ Z = \mathbf{z} < \Theta \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3) \]

For a resistive component the impedance has an angle of zero hence the current is in phase with the voltage. The impedance has an angle value and expressed as: \[ Z = R + jX. \]

Theoretically, the resistance parameter does not change with change in frequency and the reactive parameter will change with change in frequency. In practice the impedance is a combination of the resistive and reactive element forming a complex impedance.

**Resistors.**

A resistor is a device that limits the flow of current in an electrical circuit. The measuring unit of a resistor is Ohm and is given by the symbol \( \Omega \). There are different types of resistors namely: Carbon, Film and wirewound.

Most resistors are identified by the color coding on them that gives their resistance. Very large resistors are identified by the BS1852 Standard of coding. This coding system is not accurate and provides a tolerance percentage which is either: 20%, 10%, 5% or 1%.

The accurate value of the resistor is important to be found so that when connected in a circuit, the desired characteristics are achieved. Several resistors can be combined as series or parallel to meet a desired resistance.

When resistors are in operation they dissipate power. A power rating is provided so that the power dissipated is not exceeded which may damage the resistor. Low ohmic value power resistors are generally used for current sensing or power supply application. The power rating of resistors can be calculated as:
\[ Power (P) = V \times I = I^2R = \frac{V^2}{R} \quad \ldots \ldots \ldots \ldots \ldots \quad (4) \]

In AC circuits the voltage and current flowing in a pure resistor are in phase i.e. have a 0º phase shift.

To know the accurate value of a resistor is very instrumental in the design of electronics and different techniques have been used such as:

1. Kelvin (4-wire) Resistance Measurement. [2] This method involves using both an ammeter and a voltmeter. From Ohm’s Law; the potential difference (voltage) across an ideal conductor is proportional to the current through it. The constant of proportionality is the resistance, R. Ohm’s law is given by: [3]

\[ V = IR \quad \ldots \ldots \ldots \ldots \ldots \quad (5) \]

Equation (5) can be manipulated to find the resistance as shown in equation (6) below:

\[ R = \frac{V}{I} \quad \ldots \ldots \ldots \ldots \ldots \quad (6) \]

The figure below shows how to determine the resistance of unknown device using Ohm’s Law:

\[ R_{\text{subject}} = \frac{\text{Voltmeter indication}}{\text{Ammeter indication}} \]

\[ Figure \ 2-1 \ Resistance \ Determination \ by \ Ohm’s \ Law. \ [2] \]

Kelvin or 4-wire method avoids errors caused by the measuring wires.

2. Kelvin’s double bridge method: this is a modification of the Wheatstone bridge and provides greatly increasing accuracy in the measurement of low value resistance.

3. Wheatstone bridge method which uses three known resistors and the unknown resistor which are then balanced to obtain the value of the unknown fourth resistor.
Capacitance.
The capacitor is a component that stores electric charge on its plates which are separated by a dielectric which is equivalent to the input voltage:

\[ q = CV \] \( (7) \)

Where \( C \) is the capacitance of the device which is the property of a capacitor to store charge on the form of electrostatic field;

\( V \) is the input voltage that charges the plates;

\( q \) is the charge stored.

The capacitance stored on the plates is directly proportional to the area, \( A \) and inversely proportional to the distance of separation, \( d \). The generalized equation for the capacitance is given as:

\[ C = \epsilon \left( \frac{A}{d} \right) \] \( (8) \)

Where \( \epsilon \) represent the absolute permittivity of the dielectric material used.

Capacitance is the electrical property of a capacitor and a measure of a capacitor’s ability to store an electrical charge in units called Farad, F. Hence capacitance of one Farad can now be defined as the charge of one coulomb stored on the plates by a voltage of one volt as expressed in equation (7). [4] A Farad is a very large unit of measurement to use in the fabrication of electrical components hence capacitors are available in smaller multiples:

- Microfarad (\( \mu \text{F} \)) \( 1 \mu \text{F} = 1/1,000,000 = 0.000001 = 10^{-6} \text{ F} \)
- Nanofarad (nF) \( 1 \text{nF} = 1/1,000,000,000 = 0.000000001 = 10^{-9} \text{ F} \)
- Picofarad (pF) \( 1 \text{pF} = 1/1,000,000,000,000 = 0.000000000001 = 10^{-12} \text{ F} \)

All capacitors have a maximum voltage that should not be exceeded otherwise it will be damaged by breaking down the dielectric and arcing occurs between the plates.

The capacitor does not instantly get charged or discharged. It takes some time to fully charge or discharge a capacitor. The time required for a capacitor to reach its charge is proportional to the capacitance value and the resistance value. This time is the time constant, \( \tau \) in seconds. The time constant of an RC-circuit is:

\[ \tau = R \times C \] \( (9) \)
The time here is the time taken for the capacitor to acquire 63.2% of the source voltage. [4] It takes five time constants to fully charge a capacitor. This property is taken advantage of in the design of a capacitance meter in this project.

With this knowledge of capacitance, it is hence important know the actual capacitance of a capacitor. Over the years, many techniques have been uses to determine capacitance by manipulating its properties; they include:

1. Measuring with a squarewave: the capacitor to be known is supplied with a squarewave from a signal generator and the output is analyzed by checking the voltage shape and internal series resistance; the capacitance is found. [5]

2. Measuring with a sinewave: The capacitor is inserted in a half bridge configuration which is supplied with a sinewave from a signal generator. The capacitance is found by measuring the voltage output and the phase difference. [5]

3. Resonance measurement. This arrangement has a reference inductor connected to a sinewave generator where the unknown capacitor is connected. The frequency range where the resonance frequency is expected is slowly varied to get the exact frequency which is characterized by a sharp voltage drop. With the resonance frequency, $f_o$, the unknown capacitance, $C_X$ can be calculated as:

$$C_X = \frac{1}{(2\pi f_o)^2 L_{ref}} \ldots \ldots \ldots \ldots \ldots (10)$$

Where $L_{ref}$ is the reference inductor. [5]

Of the used techniques, their accuracies are affected as they are using measuring equipment which have their own errors. In this project design, the time constant property of the capacitor is used to measure the capacitance using a microcontroller.

**Inductance.**

When current flows through a wire wound coil, it produces magnetic flux around it that is proportional to the flow of the electric current.

An inductor is a passive component that is a coil of wires around a core that takes advantage of the magnetic flux and emf generated when the current passes through it. They are normally categorized according to the inner core they are wound around.

Inductors oppose changes in currents through it but will easily pass a steady current through it. [6] Hence inductance is the ability of an inductor to resist changes in current $i$, and cause
magnetic flux linkage $N\Phi$, as a constant of proportionality. [6] Inductance is symbolized as $L$ and is measured in units called Henry, H. Henry is a large SI Unit and is mostly given in other smaller derivatives such as:

Table 1: Inductance Prefixes

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Symbol</th>
<th>Multiplier</th>
<th>Power of Ten</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milli</td>
<td>M</td>
<td>$\frac{1}{1000}$</td>
<td>$10^{-3}$</td>
</tr>
<tr>
<td>Micro</td>
<td>M</td>
<td>$\frac{1}{1000000}$</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>Nano</td>
<td>N</td>
<td>$\frac{1}{1000000000}$</td>
<td>$10^{-9}$</td>
</tr>
</tbody>
</table>

The current in the inductor does not change instantly; it takes time to change and induces back emf in it.

An inductor is hence very important in a circuit and in the design it is important to know the exact value. Different techniques have been used to find the value of inductance.

In the development of meter to measure the components: inductance, capacitance and resistance; a single meter is designed with simple interface to enable ease usage. Different techniques have been used to measure the three components as discussed below:

1. **Digital LCR Meter.**

The Digital Microcontroller Based LCR Meter has simple user interface that makes it usable and can automatically detect whether the device under test (DUT) is a capacitor or inductor and has zeroing capacity that can enable comparing. The measured value is displayed on the LCD and the user can hold the data on the display. In addition, this meter can accurately measure the resistance of the component and also check continuity. The ATmega165p [7] is used to in the fabrication and the program is coded in C. When a DUT is connected to the LCR Meter, the value of its impedance is found by comparing its impedance with that of a known series resistor connected in series.

An inductor forms an LR-high pass filter [7] which is driven by a 100kHz sine wave and the response of the filter to the driving frequency will determine the inductance of the DUT. Inductance increases with increasing frequency. The high impedance tends to block high-
frequency signals from getting through. A capacitor forms a CR-low pass filter [7] driven by a frequency of 100kHz sine wave and the filters response will determine the capacitance of the DUT. The capacitive impedance decreases with increasing frequency. This low impedance in parallel with the known resistance tends to short out high frequency signals hence referred to as high pass filter. The block diagram of this technique is shown below:

![Block Diagram](image)

*Figure 2-2 Digital LCR Meter [7]*
2. **A real time FFT-based impedance meter with bias compensation.**

This mode of impedance measurement uses a personal computer (PC) that is connected to some biasing channel that measure the impedance value and present it to the computer that analyses the result using a software. Channel biasing problems are reduced by use of effective algorithm that is of ad hoc cost effective and through synchronous sampling of the channels, leakage error is eliminated.

This method eliminates the limitation of aliasing and spectral interference by using anti-aliasing filter and sinusoidal signals that have low distortion. With the use of customized software on the PC then more features can be added and displayed on the screen.

This method utilizes the efficiency, accuracy and low cost measurement of the impedance at different frequencies based on the Fast Fourier Transform (FFT). [8]

To obtain the impedance of a device; it is connected in series with a reference resistor and a sinusoidal signal is supplied by a sinusoidal generator and analyzed by the software in the PC. [8]

Since this method uses two channels to obtain the values, some errors are introduced namely: phase and amplitude errors and they propagate through the FFT hence reducing the accuracy of the meter.

The use of a PC enables taking of few readings as opposed to other methods and allows very fast computation using FFT to get an average impedance value at several frequencies. [9] [10]

![Diagram](image.png)

*Figure 2-3 Adopted scheme to measure the unknown impedance. The voltage is generated via software and applied via the output of the acquisition board; the voltages across the two resistors are fed back to the acquisition board via the input channel and stored in memory [8]*
The voltage through the DUT is generated via the software in the PC from the acquisition board. The voltage across the reference resistor is taken to the acquisition board through the two channels and analyzed by the software and stored in memory. \[8\]

During the implementation of this method, parameters are selectively chosen to eliminate errors by the FFT. The converters are driven by the same clock pulse to minimize leakage errors.

This system still suffers from limitation like aliasing, spectral leakages and harmonic interference (HI) which reduce the accuracy of the final impedance value. \[8\]

3. A microcontroller Based Vector Impedance Meter with Reduction.

This technique takes four sample reading from the device under test which are essentially voltage signals. One of the signals is proportional to the voltage across the DUT and the second is the voltage proportional to the current across the DUT. This values then give the digital profile of the impedance magnitude and angle through a microcontroller. This is done by taking the sample at different frequencies. The four values are taken quickly and the topology of the component s is maintained at the varying frequencies.

The flow chart below shows how the microcontroller program operates. A control sampling circuit is essential for this method to ensure that $V_1(t)$ and $V(t)$ are taken at the same time and separated by a time $\Delta t$ from the second set of samples $V'_1(t)$ and $V'_2(t)$.

The Schmitt trigger squares the voltage signal which is then input to the PLL based frequency multiplier which then obtains samples at N samples/ input cycles. \[11\]

One of the outputs of the Schmitt trigger is fed to the output of a divide by N counter.

The frequency difference from the output of the trigger is very small which is output by the phase detector as a voltage proportional to the difference. This difference is then applied to the loop filter which gives the characteristics of the PLL. The PLL then clocks some D-Flip-flops to start the sampling process after the microcontroller sends the start signal with logic high. The
The microcontroller then waits for the End signal to be high before it starts the reading of the analogue channels. [11] The microcontroller through the program coded in it calculates the impedance from the general equations and display it. The operation flow chart is shown below:

![Operation Flow Chart](image)

*Figure 2-4 Microcontroller Based Vector Impedance Meter with Reduction Flowchart [11]*
In the above discussed techniques, voltage and current signals are passed through the DUT and its response proportional to the signal is taken through transducers which are mainly differentiator operation amplifier and ADC that takes the digital resulting signal to the AVR microcontroller that will give a numerical value that is displayed on the LCD.

In earlier versions of an LCR meter, the impedance was determined using Bridge circuits. In the latest designs, emphasis is put on making the meter to be varying portable, fast and accurate and to digitally display the value of the impedance for ease reading. This leads to the use of microprocessors/microcontrollers in the design.

The use of microcontroller has the following advantages:

1. The microcontroller introduces many functionalities that the meter can perform in addition to measurement of impedance. These functions may include: interface to the computer through a RS-232 serial port, saving the impedance measured in a memory location, auto-range and indicators.

2. Using microcontroller reduces the meters to be small, portable and easily operated compared to the earlier versions. [12]

3. The meter can quickly run a self-test each time its put on and can display any error that may lead to inaccurate reading and a troubleshooting can be done.

4. The level of accuracy and speed at which several components are measured is high.

With the use of microcontroller, the following disadvantages are shown:

1. There is complexity in writing a program to run in the microcontroller.

2. Complex circuitry design and very accurate fabrication as most components are on-surface-mount.

3. Susceptible to transient since they are delicate and cannot stand rough handling like high level drop.

**Implementation Technique.**

In this project proposal, the design is to have a single microcontroller-based meter that measures impedance: inductance, capacitance and resistance. This meter has simple use interface to select the mode which is the type of impedance that is to be determined. The meter is powered by a 12V battery hence makes the meter portable and easily carried when under use.

The microcontroller used is the ATmega328p.
To determine the value of DUT, the voltage divider technique is used where the amount of voltage drop from the reference resistor connected in series with DUT is determined and digitized using the ADC in the microcontroller and the value of impedance is determined.

For capacitors, the time constant characteristics for charging and discharging are used to determine the value of the capacitance. The time used to charge an initially fully discharged to 63.2% of the supply voltage is determined and then the time used to calculate the capacitance using a reference resistance connected in series with the capacitor under test.

To determine the value of an unknown inductor, it is connected in parallel with a reference capacitor form in a LC-circuit. The property of the resonance frequency is used to determine the inductance. The value of resonance frequency and capacitance are known. The unknown inductance is then found by the formula below: 

\[ L = \frac{1}{4\pi^2 f^2 C} \]  

(11)

3. Design and implementation.

In this project, the design of components was done to achieve minimum error as the determination of the impedance values is dependent on the choice of design component. The microcontroller ATmega328p is used in this project brings great advantage in the overall implementation of this meter. The ATmega328p is an 8-bit AVR RISC-based microcontroller from Atmel which provides 32KB flash, 1KB EEPROM and 2KB SRAM. It provides 23 general purpose I/O lines. This chip can communicate using 12C, SPI 3 or 4 wire, UART, digital I/O and has a built in 6 channel 10-bit Analog to Digital converter (ADC). This chip can work with Arduino platform with an installed bootloader. This microcontroller can run on lower voltages and uses less power especially in a standby or sleep state. The maximum frequency produced by ATmega328p is 20MHz, for this project 16MHz is used to determine the impedance of the capacitance since \( \tau = \frac{1}{f} \) and gives the resonance frequency. The flash memory is enough to support the code and storage of the value and calculation of the impedance. Gives an operation voltage is -1.8V to 5.5V; for the Impedance Meter 5.0V are used. The microcontroller operation speed is adequate to achieve accurate results since the measurement of capacitance and inductance depends on the frequency hence speed response. The microcontroller has a system clock that synchronizes the whole system. The in-built analog/digital converter is essential to this
project as the response of the device under test gives an analog signal that is converted to a digital signal so that the microcontroller can manipulate the signal to give a reading. [13]

The pinout mapping for the microcontroller is shown in the figure below:

![Arduino Pin Mapping](image)

**Figure 3-1 ATmega328p-Arduino Pin Mapping [14]**

The C code is written in Arduino which offers ready to use libraries that are used directly in the coding of the program. The Arduino is an open-source prototyping platform based on easy-to-use hardware and software. Arduino can be integrated to perform many functions which can be coded through the Arduino programming language and Arduino Software based on processing.

For this project the Arduino was preferred because:

- Simplifies the process of working with microcontrollers.
- Simple and clear programming environment through the Arduino Software (IDE).
- Open source and extensive software. The Arduino software is published as open source tools, available for extension through C++ libraries and AVR C programming language on which it’s based and the AVR C-code can be directly added to the Arduino program. This feature is used in the programming of this project as the AVR C-code is used and then integrated in the Arduino program.
Open source and extensible hardware. [13]

The voltage regulator used here is to provide a steady smooth DC 5V to power the microcontroller. Smoothening capacitors are used to eliminate the fluctuating voltage and to have a small time delay in powering the system as the capacitors charge.

The voltage being DC needs to be in one direction. To facilitate this a diode is used. The 1N4007 is used in the design since it provides almost ideal characteristics with minimum loses.

The switches to select the operation of the meter are connected through a damp switch de-bouncing capacitor. The value of the capacitor is determined by the time constant desired. A pull-up resistor is used to pull the pins to 5V and form the RC circuit. A minimum current should be drawn in the form the circuit through the pull-up resistors. In the design pull-up resistor of 10KΩ is used which draws a current of 0.5mA and causes a switching delay of 0.1s. This delay is sufficient to cause a smooth switch and eliminate noise due to bouncing that will introduce errors.

The input pins are set to high impedance mode to measure even low signals. They are defined to be floating in the code and can take any state so as to read the signal input.

The discharging resistance of the unknown capacitor is made to be very small so as to quickly dissipate energy and discharge the capacitor very first. In the design, a resistance of 220Ω is used to give a discharging time of 0.11sec.

The RESET button is but manually reset the meter. The meter refreshes every 0.5s to eliminate ghosting. This is shown in the code. A user can manually reset to refresh the meter.

3.1 Principle of operation.

For the project, the impedance is design as shown in the circuit diagram below:
When the DUT is connected and the meter is powered by a 12V DC power supply (battery), the mode is selected through the DIP Switch as: SW O-P for resistance, SW M-N for capacitance and SW Z-W for inductance.
This kind of switch was used since it provides a manual electric switch that is packaged with others in a group in a standard dual in-line package (DIP). A Tandy 4-way DIP switched is used since all the pins are used as we have three modes to switch from and this switch give the following advantages: 25mA contact current and can work up to 24Vdc contact voltage and with Phosphor Bronze Contact with minimum contact resistance and maximum separation resistance.

The mode selected is indicated on the LCD. A 16X2 is used with a 4-bit mode. This LCD has 16 columns and 2 rows which is based on HD44780 LCD controller and gives a generic dot matrix display.

![Figure 3-4 LCD Pin Layout](image)

The pin layout of the LCD is as shown in the table below:

**Table 2: LCD Pin-Out [16]**

<table>
<thead>
<tr>
<th>Pin</th>
<th>Symbol</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>VSS</td>
<td>Ground (0V)</td>
</tr>
<tr>
<td>2</td>
<td>Vdd</td>
<td>Power (4.5V-5.5V)</td>
</tr>
<tr>
<td>3</td>
<td>V0</td>
<td>Contrast adjustment</td>
</tr>
<tr>
<td>4</td>
<td>RS</td>
<td>H/L register select signal</td>
</tr>
<tr>
<td>5</td>
<td>R/W</td>
<td>H/L read/write signal</td>
</tr>
<tr>
<td>6</td>
<td>E</td>
<td>H/L enable signal</td>
</tr>
<tr>
<td>7-14</td>
<td>DB0-DB7</td>
<td>H/L data bus for 4- or 8-bit mode</td>
</tr>
<tr>
<td>15</td>
<td>A (LED+)</td>
<td>Backlight anode</td>
</tr>
</tbody>
</table>
In this project the 4-bit mode of operation is used since every data is loaded in 2 of 4 bits each. A hardwired R/W line to ground is used to print on the LCD from the microcontroller.

Depending on the mode chosen the microcontroller send a signal and the response of the component is converted to a digital signal and through a formula to determine the value of impedance that is displayed on the LCD.

**ENABLE PIN:** This pin is key in the operation of the LCD. Data can only be latched into the LCD when high to low signal is passed into this pin. There should be at least 450ns delay between clearing and setting this pin, because of the higher frequency of the microcontroller relative to the LCD.

When: E = 0 LCD cannot be accessed

E = 1 LCD can be accessed

**R/W:** informs the LCD whether the information is supposed to be read or written on the LCD. When:

R/W = 0 Data is written to LCD

R/W = 1 Data is read from LCD

**RS:** helps the LCD to identify whether the information is data or command.

When: RS = 0: command

RS = 1: data

**D0-D7:** these are the data pins; information is sent/received via these pins.

The microcontroller used is the ATmega328p which mapped into the Arduino as shown in figure 3-1. The microcontroller is loaded with the C coded program that directs it on the sequence of measurement and the formula used to achieve the impedance of the unknown device. The general flow chart of the designed Impedance Meter is as shown below:
3.1.1. Inductance measurement.

The Impedance Meter measures the inductance of unknown inductor or coil connected to it using the microcontroller ATmega328p. The unknown inductor is connected in an RLC circuit with the LC connected in parallel as shown in the figure below:

![Flow-Chart of the general operation of the Impedance Meter](image)

**Figure 3-5 Flow-Chart of the general operation of the Impedance Meter**

**Figure 3-6 LCR Circuit to measure the unknown Inductance** [17]
The microcontroller produces a resonance frequency which passes through the capacitor and the unknown inductor and filtered by the comparator chip, then read back to the microcontroller. The resulting signal is a square wave, which can be used to calculate the inductor value. The resistance in series with the parallel LC is a small precision resistor of 150Ω.

Resonance frequency is the frequency at which $\omega L = \frac{1}{\omega C}$ i.e. the resonant frequency of the equivalent RLC circuit that gives the maximum impedance and the current is in phase with the voltage and with unity power factor. The frequency is found by the equation below:

$$\omega_0 \approx \frac{1}{\sqrt{LC}} \quad \ldots \quad \ldots \quad \ldots \quad (12)$$

Hence the LC circuit is basically known as a resonant circuit.

**Figure 3-7 Simple Resonant Circuit [17]**

To obtain the inductance, the frequency is varied with the unknown inductor connected. The capacitor is suddenly discharged after a period of constant charging and a frequency from the microcontroller is passed varyingly in oscillation. The amplitude of the oscillations will be decreasing till the capacitor is fully discharged. This is called damped oscillation and will give a value of the resonance frequency that can be used to calculate the inductor value.

**Figure 3-8 Damped Oscillation to find the resonance frequency [17]**

The frequency produced is limited by the value of the inductor L, and the capacitor C, as shown in the equation below:

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \quad \ldots \quad \ldots \quad \ldots \quad (13)$$

The microcontroller gives the natural frequency and it will measure the time period. This is driven by an interrupt signal based on timer that counts for every instance the interrupt happens.
The microcontroller will be able to measure how long a period takes for this resonance to determine the frequency between the two components. [18]

Rearranging the resonance equation, we can get the inductance as:

\[ L = \frac{1}{4\pi^2 f^2 C} \]  

(14)

The microcontroller cannot directly measure the output of the LC to determine the period and inductance. A SDC is used that is in the ATmega328p.

The frequency produced is sinusoidal and has to be converted to a square wave to accurately get the period by the microcontroller by detecting the high and low of the output and get the period of the unknown component. A high speed operational amplifier is used to convert the signal. In this project, the LM393-N is used which offers the following advantages in the design:

- Has two independent precision voltage comparators with offset voltage specification as low as 2.0mV.
- Low power supply current drain which is independent of the power supply

More features are shown in the Appendix B. [19]

This operational amplifier converts the signal to a square wave produced by the comparator and the pull up resistor that adds up the output of the comparator and for every value that is greater than ground is taken to high and any signal lower than ground is taken to ground. [18]

The microcontroller provides the signal of 5V with its duty cycle and measures the period of the output. The components used are non-ideal and their percentage tolerance adds up to the error of the final value. To reduce the error, the components used have been calculated to give the least tolerance. [18]

The value of the inductance is sent to the LCD display and is updated every 0.5 seconds to avoid any ghosting.

Hardware selection was done with the least amount of tolerance so that all parts when programmed will work near ideal nominal values. The technique of using resonance frequency is dependent on the components used in the design.

The following are the component values used in the design of inductance measurement:

- Capacitance \( C_{\text{ref}} \), = 2\( \mu \)F
- Resistance \( R_s \), = 150\( \Omega \)
For the code to measure the inductance the following code instruction was used:

```cpp
if(pulse > 0.1){ //if a timeout did not occur and it took a reading:
capacitance = 95.E-8; //insert capacitance here. Currently using 2uF
    frequency = 1.E6/(2*pulse);
    inductance = 1./(capacitance*frequency*frequency*4.*3.14159*3.14159);//this is the rearrangement of the resonance frequency equation as shown in equation (14)
    inductance *= 1E6; //note that this is the same as saying inductance = inductance*1E6
}
```

The Rs used is also a dissipating resistor of the oscillating energy.

The ATmega328p is able to sample analog signals of up to 9600Hz or 1ms. The resulting frequency from the oscillations made by the RLC circuit in the measurement of inductance is much higher than 9600Hz. To translate this high frequency signal to the inductor for measurement we use the LM393 comparator which gets the highest positive voltage signal than the inverting input. The high gain of the op-amp causes the output to saturate at the highest positive voltage can output.

The comparator is limited by the supply signal.

After the microcontroller gives a pulse signal to the LCR circuit, an oscillation starts which makes the LM393-N a floating gate and to stop this a pull-up resistor is used. The comparator has a very high capacitance and impedance hence a small pull-up resistance of 330Ω is enough.

When the signal to the non-inverting pin is lower than the inverting pin the comparator will pull-up the output to ground (0).

The LC produces a sinusoidal wave which is converted to a square wave by the comparator and the highest frequency which is the resonating frequency is picked. From the code:

```cpp
pulseIn(pin,HIGH,500);
```

the output is measured in microseconds from the rising edge to the falling edge. This time is doubled to give the full period since it is from a sinusoidal wave as shown in figure 3-8 below.
The resonance frequency is now:

\[ f = \frac{1}{2 \times \text{pulseln}} \] ...........................(15)

The presence of internal resistance makes the resonance amplitude die out. To get to this
resonance frequency quickly enough as first as the highest peak is achieved a low value
resistance is used with least tolerance (almost ideal) is used. In this design the 150Ω with 5%
tolerance is used.
Figure 3-9 Comparator LM393-N Output Signals [21]
3.1.2. Capacitance Measurement.

Capacitance of a device can be found by the manipulation of its properties. The aim is to have a standardized measurement that is also easy to read the value on a LCD. In this project, the basic principle is to charge and discharge of the capacitor is adopted through the use of a microcontroller.

The capacitor, C, charges as the voltage rises exponentially through a resistor, R. The capacitor is driven to high at its output once the voltage in the capacitor reaches the maximum value hence the capacitor is fully charged. The amount of time taken to charge the capacitor is taken to the microcontroller. The time taken to charge the capacitor is directly proportional to the capacitance of the device under test.

This is given by:

\[ \tau = CR \]  

Where \( \tau \) is the time constant in second the is equivalent to 63.2% of the supply voltage. The time taken to fully charge a capacitor is \( 5\tau \). Rearranging equation (15) will give the capacitance of DUT;

\[ C = \frac{\tau}{R} \]

\[ C = \frac{1.442 \times \delta t}{R} \]

Where C is the unknown capacitance to be determined.

R is the reference resistance that is known and determines the accuracy and the range of the meter since it affects the charging time.

\( \delta t \) is the difference in the time between charging and discharging of the capacitor.

During the measurement procedure, the capacitor is fully discharged prior to charging where a counter from the microcontroller is initiated. The reference resistor is known and fixed for a particular range. The counter starts charging and the comparators compares the capacitor voltage \( V_C \) to the 63.2% of the supply voltage which is equivalent to 3.16V. Total time that is counted which should be less than 1023 is recorded and the counter will give the time is second. Equation (16) is used to calculate the capacitance. If the time is longer than 1023 bits, then the capacitor is out of range and the meter will send an error message. To improve the range, the reference inductor is changed. For sensitivity and accuracy for this project, \( R_{ref} \) is 220Ω.
The process of charging and discharging is done repeatedly and an average is found to get a precise reading.

The algorithm for capacitance meter is as given below:

- Set discharge pin to INPUT so that the discharged capacitor is not discharged further.
- Record the start time $t_0$ which is initially 0.
- Set charge pin to OUTPUT and make it HIGH.
- Check the voltage repeatedly in a loop until it gets to 63.2% of the total voltage.
- After the capacitor is charged the counter time $t_1$, is recorded and subtracted from the starting time to get the charging time $\tau$.
- Divide the time in seconds by the charging resistance in ohms to find the capacitance.
- Report the value with serial print.
- Discharge the capacitor by setting the charge pin to input and the discharge pin to output and make it low and read the voltage to make sure that the capacitor is fully discharged.

[20]
3.1.3. Resistance Measurement

For this project, it is designed to measure the resistance of between 0-1MΩ and with a high accuracy percentage of ±5%. This is made possible by the use of ATmega328p microcontroller by using the concept of voltage divider.
The microcontrollers are good at directly working with voltages in the range 0V to 5V. This technique of voltage divider works with lower values of the reference resistance. The maximum supply voltage is 5V from the microcontroller. The voltage divider equation is given by:

\[ V_{out} = \left( \frac{R_{\text{unknown}}}{R_{\text{ref}} + R_{\text{unknown}}} \right) V_{in} \ldots \ldots \ldots \ldots (18) \]

In the design, the \( R_{\text{ref}} \) is connected to pull up to the 5V of the supply source and resistance we want to measure is connected with the ground and the other terminal of \( R_{\text{ref}} \). The voltage drop across the unknown resistance is determined with the help of the microcontroller. The value of \( V_{\text{CC}} \) or \( V_{\text{in}} \) is 5V and \( R_{\text{ref}} \) is 10KΩ. \( R_{\text{unknown}} \) can be calculated by the formula:

\[ R_{\text{unknown}} = \frac{R_{\text{ref}} \times V_{\text{out}}}{5 - V_{\text{out}}} \ldots \ldots \ldots \ldots (19) \]

\[ R_{\text{unknown}} = \frac{10000 \times V_{\text{out}}}{5 - V_{\text{out}}} \ldots \ldots \ldots \ldots (20) \]

The equation (20) is used in the program to get the unknown resistance.

In the program; the ADC is initialized to convert the voltage drop to a digital value for the microcontroller. Some important program instructions are:

\[
\text{LCD\_Init();} \quad //\text{this initializes the LCD functions} \\
\text{ADC\_Init();} \quad //\text{the ADC functions are initialized} \\
\text{Resistance=ADC\_Read(0);} \quad //\text{this stores the value of ADC in the variable resistance} \\
\text{Resistance=((float)(resistance))*0.0048828;} \quad //\text{this converts ADC binary value back into voltage output value.} \\
\text{Resistance=(unsigned long)((resistance*1000)/(V_{\text{CC}}-resistance));} \quad //\text{this converts the output voltage of the ADC into } R_{\text{unknown}} \text{ value by using voltage divider formula.} \\
\text{Inttostr(resistance,ohm);} \quad //\text{it converts resistance value into string to display it on LCD} \\
\]

The limiting value of the measurement is the voltage drop. If the unknown resistance is too large then the voltage drop over \( R_{\text{ref}} \) will be zero and it will be pulled up to low and hence the meter will be out of range. When a voltage drop greater than zero is detected it is converted to digital by the ADC and the equivalent resistance is found.
Figure 3-11 Resistance Measurement Flow-Chart

**Meter Range.**

The designed is limited to a specific range that will be with minion error. Above these ranges the meter will exhibit large error and/or not measure the impedance of the unknown component.


**Capacitance Range:**
For capacitance the time constant and the reference resistance limit the range.

$R_{ref}$ is 10KΩ

The ATmega328p is a 10-bit microcontroller hence there are 1024 counts all together. The minimum count is 1 and a maximum of 1024.

This gives the range of:

$0.1\mu F \text{ to } 100\mu F$

**Inductance Range:**
The inductance to be measured is affected by the impulse generated by the microcontroller and the reference capacitor; $C_{ref}$. (2.2μF)

The range is:

$1\mu H \text{ to } 100\mu H$

**Resistance Range:**
The resistance measured is limited by the voltage from the voltage divider. Very low voltage (~0V) will be the maximum resistance and this is theoretically all resistances. This is limited by the $R_{ref}$ which will give a constant voltage no matter change of resistance value. The point where the voltage barely changes hence introducing large errors is the maximum for the meter.

The range is hence:

$1\Omega \text{ to } 49k\Omega$

**Component Layouts.**
Figure 3-12 Power Supply Battery

Figure 3-13 Full fabrication of the Impedance Meter
Figure 3-14 Simulation components 1

Figure 3-15 Simulation components 2
Figure 3-16 PCB Layout
4. Results.

4.1. Meter Readings of unknown devices under test.

Table 3 Resistance Results

<table>
<thead>
<tr>
<th>Resistor Color Code value</th>
<th>Precision Meter Reading</th>
<th>Impedance Meter Reading</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow, Purple, Red</td>
<td>±5% 4.62 kΩ 4554.46 Ohms</td>
<td>4.55446 kΩ</td>
<td>1.418615</td>
</tr>
<tr>
<td>Brown, Red, Orange</td>
<td>±5% 11.98 kΩ 12473.68 Ohms</td>
<td>12.47368 kΩ</td>
<td>-4.12087</td>
</tr>
<tr>
<td>Green, Brown, Brown</td>
<td>±5% 0.552 kΩ 560.98 Ohms</td>
<td>0.56098 kΩ</td>
<td>-1.62681</td>
</tr>
<tr>
<td>Brown, Black, Yellow</td>
<td>±5% 102.2 kΩ 145285.71 Ohms</td>
<td>145.28571 kΩ</td>
<td>-42.1582</td>
</tr>
<tr>
<td>Brown, Black, Orange</td>
<td>±5% 10.05 kΩ 10505.62 Ohms</td>
<td>10.50562 kΩ</td>
<td>-4.53353</td>
</tr>
<tr>
<td>Red, Red, Brown</td>
<td>±5% 0.2155 kΩ 219.05 Ohms</td>
<td>0.21905 kΩ</td>
<td>-1.64733</td>
</tr>
<tr>
<td>Blue, Grey, Black</td>
<td>±5% 0.0689 kΩ 71.13 Ohms</td>
<td>0.07113 kΩ</td>
<td>-3.23657</td>
</tr>
<tr>
<td>Brown, Black, Black, Black</td>
<td>±1% 0.096 kΩ 98.71 Ohms</td>
<td>0.09871 kΩ 2.82292</td>
<td></td>
</tr>
<tr>
<td>Brown, Black, Black</td>
<td>±5% 0.0099 kΩ 10.86 Ohms</td>
<td>0.01086 kΩ</td>
<td>-9.69697</td>
</tr>
</tbody>
</table>

Table 4 Capacitance Readings

<table>
<thead>
<tr>
<th>Body Indication Capacitance</th>
<th>Voltage</th>
<th>Precision Meter Capacitance</th>
<th>Impedance Meter Capacitance</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 μF</td>
<td>50V</td>
<td>93.8 μF</td>
<td>89 μF</td>
<td>5.12</td>
</tr>
<tr>
<td>10 μF</td>
<td>50V</td>
<td>10.13 μF</td>
<td>9 μF</td>
<td>11.15</td>
</tr>
<tr>
<td>1 μF</td>
<td>50V</td>
<td>0.947 μF</td>
<td>1 μF</td>
<td>-5.6</td>
</tr>
</tbody>
</table>

Table 5 Inductance Reading

<table>
<thead>
<tr>
<th>Precision Meter Reading (μH)</th>
<th>Impedance Meter Reading (μH)</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.998</td>
<td>5.001</td>
<td>-0.06002</td>
</tr>
<tr>
<td>19.17</td>
<td>19.087</td>
<td>0.432968</td>
</tr>
<tr>
<td>0.9903</td>
<td>1</td>
<td>-0.9795</td>
</tr>
<tr>
<td>3.2062</td>
<td>3.2445</td>
<td>-1.19456</td>
</tr>
<tr>
<td>1.8709</td>
<td>2</td>
<td>-6.90042</td>
</tr>
<tr>
<td>10.4415</td>
<td>8.555</td>
<td>18.06733</td>
</tr>
</tbody>
</table>
The reading for the resistance were taken using:

ISO-TECH IDM 103N
S/N: 35100417
Lab No.: AW 112

The inductance readings were taken using:

LCR – 8101G – Precision LCRM
GWINSTEK

4.2. Data Analysis.

The readings from the Precision Meter were taken against the Impedance Meter for the different modes are shown below.

![Resistance Readings](image)

*Figure 4.1 Resistance Readings*
Figure 4-2 Capacitance Reading

Figure 4-3 Inductance Reading
It was observed that the meter responds well to the components connected to it and a mode is chosen. The percentage error was averagely ±5%. The error grows bigger as the component impedance value grows to the high limits of the range.

The percentage error is given by the equation below:

\[
\frac{\text{Theoretical Value} - \text{Experimental Value}}{\text{Theoretical Value}} \times 100\% \quad \text{(21)}
\]

The error shown was highly contributed by the components used and their response to the input signal from the microcontroller. The desired tolerance from the simulation was less than ±1% to its nominal value but the least tolerance obtain in this project is ±5%. At the upper limits of the range the meter hardly gives the accurate theoretical reading or the same reading from the Precision Meter.

In the capacitance mode, there was evidence of ghosting capacitance of about 199nF which is attributed to the de-bouncing capacitance used in the design.

Inductance measurement greatly depends on the choice of components used to make the design. The reference capacitance was designed to be used but the one used was 2.2μF and the resistor to form the RLC was design to be 150Ω ±1% but what was available and used was 150Ω ±5%.

The above challenges together added to the errors experienced in the measurement. The inductors used as unknown devices where made by winding insulated copper wires over many turns and air as the core.

This meter brings the advantage of portability, automation in the measurement after the mode is chosen. The fabrication cost was very small as shown I the bill of quantities unlike the commercial precise meters.
5. Conclusion and Recommendation.

The main objective of this project has been to design a microcontroller based impedance meter to measure Inductance, Capacitance and Resistance.

The objective was achieved as the meter works and can read the three components within the limits when the mode is selected and the unknown component is connected. The microcontroller will send a signal and measure the response of the components which is converted to a digital form and analyzed using programmed formulae in the microcontroller to give the impedance value. The result is sent to the LCD to be displayed.

The Impedance Meter, if put in use can serve the purpose of measuring impedance with greater advantage with the conversional large, expensive meters. This portable, cheap and small meter can be used to measure laboratory components and can be nicely carried around when properly packaged and the user interface is very basic for use.

The cost of implementing the system is relatively cheap as the components are few and can be cheaply found in the local market.

In circuit design the accurate value of the component is very important and it is then essential to have an accurate meter to measure the components used. This meter offers this solution to the user.

5.1. Limitation and future recommendations.

The demand for accurate, portable and cheaply available impedance meters is increasing with the increase in technology as more designs are being made and the need for precise component values is very important in the implementation.

Based on the work done in this project, the future Impedance Meter may demand some improvements among them are:

1. The process of measuring impedance is very sensitive to the selection of components and their tolerance because the microcontroller gives very small digital signals and determines the impedance from the response of these components to this signal. Therefore, the component used should strictly be of very low tolerance that will give the expected readings.
2. The range in the project was very small and limited as the meter gives large errors at the upper limits. This can be improved by having an auto-range selection or a manual knob selection. The inductor time out can be increased to 10,000 ms and the delay-microseconds to be have a value less than 500μS and a selector to change the reference capacitance value.

3. Instead of manually selecting the mode, the meter should automatically select a mode and give its impedance value.

4. More features can be increased in the meter to improve its functionality, namely:
   a. Data hold to hold the measured value on the screen.
   b. Continuity setting with a buzzer to quickly test continuity.
   c. Live raw data sent over RS-232 serial port to a computer for analysis.
   d. Low batter inductor.
References.


Appendix.

Appendix A

The source code is shown below.

Resistance:

```c
#include<SPI.h>
#include <LiquidCrystal.h>
#include<avr/wdt.h>

// initialize the library with the numbers of the interface pins
LiquidCrystal lcd(2, 3, 4, 5, 6, 7);

int analogPin = 0;
int raw = 0;
int Vin = 5;
float Vout = 0;
float R1 = 1000;
float R2 = 0;
float buffer = 0;
#define mode 8
int mode1;
#define mode2 12
int mode3;
#define analogPin2     1         // analog pin for measuring
                          capacitor voltage
#define chargePin      9         // pin to charge the capacitor
- connected to one end of the charging resistor
#define dischargePin  10        // pin to discharge the capacitor
#define resistorValue  10000.0F   // change this to whatever
resistor value you are using
```
// F formatter tells compiler it's a floating point value
unsigned long startTime;
unsigned long elapsedTime;
float microFarads;                  // floating point variable to preserve precision, make calculations
float nanoFarads;
//13 is the input to the circuit (connects to 150ohm resistor),
11 is the comparator/op-amp output. //reibot.org for guide
double pulse, frequency, capacitance, inductance;
#define ind 16
int mode7;

void setup()
{
  Serial.begin(9600);
pinMode(mode, INPUT);
pinMode(11, INPUT);
pinMode(13, OUTPUT);
pinMode(ind, INPUT);
lcd.begin(16, 2);
  pinMode(chargePin, OUTPUT);     // set chargePin to output
digitalWrite(chargePin, LOW);

}

void loop()
{
  mode1=digitalRead(mode);

if(mode1==LOW){
    lcd.clear();
    lcd.print("RESISTANCE");
    raw= analogRead(analogPin);
    if(raw)
    {
        buffer= raw * Vin;
        Vout= (buffer)/1024.0;
        buffer= (Vin/Vout) -1;
        R2= R1 * buffer;
        Serial.print("Vout: ");
        Serial.println(Vout);
        Serial.print("R2: ");
        Serial.println(R2);
        lcd.setCursor(0, 1);
        lcd.print(R2);
        lcd.setCursor(9, 1);
        lcd.print("OHMS");
        delay(500);
        softwareReset(WDTO_15MS);
    }
}
else{}
mode3=digitalRead(mode2);
if(mode3==LOW){
    lcd.clear();
cap();
    softwareReset(WDTO_15MS);
}
else{}
mode7=digitalRead(ind);
if(mode7==LOW){
lcd.clear();
induct();
softwareReset(WDTO_15MS);
}
else{}

lcd.print("IMPEDANCE METER");
delay(200);
lcd.clear();
}

Capacitance:
/* Capacitance Meter using RC_Time Constants
 *
 * Demonstrates use of RC time constants to measure the value
 * of a capacitor
 *
 * Theory: A capacitor will charge, through a resistor, in one
 * time constant, defined as T seconds where
 * TC = R * C
 *
 * TC = time constant period in seconds
 * R = resistance in ohms
 * C = capacitance in farads (1 microfarad (ufd) = .0000001
 * farad = 10^-6 farads )
* The capacitor's voltage at one time constant is defined as 63.2% of the charging voltage.

* Hardware setup:
  * Test Capacitor between common point and ground (positive side of an electrolytic capacitor to common)
  * Test Resistor between chargePin and common point
  * 220 ohm resistor between dischargePin and common point
  * Wire between common point and analogPin (A/D input)

*/

void cap(){
  digitalWrite(chargePin, HIGH); // set chargePin HIGH and capacitor charging
  startTime = millis();

  while(analogRead(analogPin2) < 648){ // 647 is 63.2% of 1023, which corresponds to full-scale voltage
    
  }

  elapsedTime= millis() - startTime;
  // convert milliseconds to seconds (10^-3) and Farads to microFarads (10^6), net 10^3 (1000)
  microFarads = ((float)elapsedTime / resistorValue) * 1000;
  Serial.print(elapsedTime); // print the value to serial port
  Serial.print(" mS "); // print units and carriage return
  return
if (microFarads > 1) {
    Serial.print((long)microFarads); // print the value to serial port
    Serial.println(" microFarads"); // print units and carriage return
    lcd.setCursor(1,0);
    lcd.print((long)microFarads); // print the value to serial port
    lcd.setCursor(0,1);
    lcd.print(" microFarads"); // print units and carriage return
}
else {
    // if value is smaller than one microFarad, convert to nanoFarads (10^-9 Farad).
    // This is a workaround because Serial.print will not print floats

    nanoFarads = microFarads * 1000.0; // multiply by 1000 to convert to nanoFarads (10^-9 Farads)
    Serial.print((long) nanoFarads); // print the value to serial port
    Serial.println(" nanoFarads"); // print units and carriage return

    lcd.setCursor(1,0);
    lcd.print((long) nanoFarads);
    lcd.setCursor(0,1);
lcd.print("nanoFarads");

}

/******** discharge the capacitor ********/

digitalWrite(chargePin, LOW); // set charge pin to LOW
pinMode(dischargePin, OUTPUT); // set discharge pin to output
digitalWrite(dischargePin, LOW); // set discharge pin LOW

while(analogRead(analogPin) > 0){ // wait until capacitor is completely discharged
}

pinMode(dischargePin, INPUT); // set discharge pin back to input

}

Inductance;
void induct(){
digitalWrite(13, HIGH);
delay(5); // give some time to charge inductor.
digitalWrite(13,LOW);
delayMicroseconds(100); // make sure resination is measured
pulse = pulseIn(11,HIGH,5000); // returns 0 if timeout
if(pulse > 0.1) { //if a timeout did not occur and it took a reading:
capacitance = 95.E-8; //insert capacitance here. Currently using 2uF
    frequency = 1.E6/(2*pulse);
inductance = 1./(capacitance*frequency*frequency*4.*3.14159*3.14159); //this is the rearrangement of the resonance frequency equation
inductance *= 1E6; //note that this is the same as saying
inductance = inductance*1E6
    if(inductance>=1000)
    {
        Serial.print("High for uS:");
        Serial.print( pulse );
        Serial.print("\tfrequency Hz:");
        Serial.print( frequency );
        Serial.print("\tinductance mH:"); Serial.println( inductance/1000 );
        lcd.print("Inductance");
            lcd.setCursor(2,1);
        lcd.print ((inductance/1000)-0.5); lcd.print ("mH");
        delay(300);
        lcd.clear();
    }
else {
    Serial.print("High for uS:");
Serial.print( pulse );
Serial.print("\tfrequency Hz:");
Serial.print( frequency );
Serial.print("\tinuctance uH:"); Serial.println(inductance);
lcd.print("Inductance");
    lcd.setCursor(2,1);
lcd.print (inductance + 10); lcd.print ("uH");
delay(300);
lcd.clear();
    }
}
else if(pulse < 0.1)
{
    lcd.print("Insert Inductor");
    delay(500);
    lcd.clear();
}
}

Reset:
void softwareReset(uint8_t prescaller){
wdt_enable(prescaller);
while(1){}
}
Appendix B: Data sheets.
Appendix C: Equation Derivations.

Resistance.

The referencing resistance, $R_{2\text{(ref)}}$ is fixed and the unknown resistance is now varied. The $V_{CC}$ is 5V from the microcontroller.

The voltage is the limiting factor and the $R_{2\text{(ref)}}$ the accuracy limiting variable.

\[
V_{\text{out(min)}} = 0.02V \\
V_{\text{out(max)}} = 5V \\
R_{2\text{(ref)}} = 1K\Omega
\]

$R_1$ is the unknown resistance

\[
V_{out} = \frac{1\text{K}\Omega}{1\text{K}\Omega+R_1} \times 5V
\]

Capacitance:

\[
\tau = RC
\]

Where $\tau$ is the time constant equivalent to 63.2% charged voltage of the supply.

$R$ is the reference resistance,

$C$ is the unknown capacitance.

Rearranging the equation gives:

\[
C = \frac{\tau}{R}
\]

Inductance:

\[
\text{Inductance} = \frac{1}{\text{Capacitance} \times \text{frequency} \times \text{frequency} \times 4 \times 3.14159 \times 3.14159}
\]

Capacitance = 2.2$\mu$F

\[
\text{Frequency} = \frac{1.0 \times E6}{2 \times \text{pulse}}
\]

Pulse>0.1

Discharging Equation:

The maximum measured capacitance is 100$\mu$F which will late the longest time to fully discharge.

From the time constant expression:
\[ \tau = RC \]

The desired fully discharging time is 0.11s

Total discharge is \( 5\tau \)

Therefore: \( 5\tau = 0.11 \)

\[ \tau = \frac{0.11}{5} = 0.022 \]

Hence the resistance;

\[ \frac{0.022}{100} = 220 \]

The discharging resistance is 220Ω

**Pull-Up resistor:**

The maximum current from the microcontroller is 0.06A.

To maintain a low power dissipation through the Impedance Meter, very low current should pass through the pull-up resistor; all most negligible and to allow voltage to be measured.

The desired current is 0.5A through the pull-up resistor.

\[ R = \frac{V}{I} = \frac{5V}{0.5mA} = 10k\Omega \]

**De-bouncing capacitors:**

When the switch is turned on, minimum delay for switching is desired and elimination of damping bouncing which introduces noise. De-bouncing capacitors are now introduced to eliminate the noise. A desired delay of 0.5s.

The time constant \( \tau \) that is desired is 0.1s.

\[ \tau = RC \]

\[ C = \frac{\tau}{R_{pull-up}} = \frac{0.1}{10k} = 10\mu F \]

**Range of the Meter:**

**Capacitance.**

\[ C = \frac{\tau}{R} \]

Lower Range: \[ \frac{1\text{ count}}{10k\Omega} = 0.1\mu F \]
Upper Range: \( \frac{1024 \text{counts}}{10K\Omega} = 102.4\mu F \approx 100\mu F \)

*Inductance.*

Impulse = 5ms

\( C_{\text{ref}} = 2.2 \mu F \)

Time out = 0.00001 to 0.01

Upper Range: 

\[
L = \frac{1}{4\pi^2 f^2 C} = \frac{1}{4\times3.141592\times\frac{1}{0.01\mu s}\times2.2\mu F} = 0.00012665 \approx 0.1mH
\]

Lower Range: 

\[
L = \frac{1}{4\times3.141592\times\left(\frac{1}{0.00001}\right)^2 \times2.2\mu F} = 1.15137\mu H \approx 1\mu H
\]
Appendix D: Bill Of Materials.

Table 1 Bill of Materials

<table>
<thead>
<tr>
<th>Quantity</th>
<th>References</th>
<th>Value</th>
<th>price</th>
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<tbody>
<tr>
<td>Resistors</td>
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<tr>
<td>6</td>
<td>R1-R5,R7</td>
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<td>R6</td>
<td>1KΩ</td>
<td>KES 5.00</td>
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<td>R9</td>
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<td>R10</td>
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<td>4</td>
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