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Inductance Meter

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Abstract

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Inductor is a commonly used electrical component (along with resistors and capacitors) that uses magnetic field for dealing with energy storage in the presence of electric current. Inductance meter, as the name implies, is used when inductance needs to be measured. In short, inductance meter measures the inductance value of an inductor (or coil/choke).

This thesis focuses on different theoretical methods that can be used to create an inductance meter, and one of those methods is used for the purposes of this report to realize the meter in real world, and its accuracy is measured and compared to reference inductance meter devices found in the lab.

The result of this thesis project is an accurate and reliable inductance meter. Accuracy is good, and measurement range is also wide, of the inductance meter built for this thesis project.

Keywords: Inductance Meter, inductor

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I2C: Inter-Integrated Circuit

LCD: Liquid Crystal for Display

SDA: Serial Data

SCL: Serial Clock

GND: Ground

1 Introduction

The purpose of this thesis work was to create an Inductance Meter. There are multiple ways to make an Inductance Meter, theoretically. The first task was to choose the best theoretical method for the purposes of this thesis and the second task was to actually create the Inductance Meter with real components, and to check its accuracy against reference devices.

The making of the inductance meter entails many steps, first is theoretical understanding and research, then the theoretical method preferred has to be realized using Multisim simulation. If the simulation works, then the method can be pursued and the chosen method should be such that it can potentially yield results positively, thus the Multisim simulation has to work fine. Then the chosen method can be done using components from the lab; if components cannot be found, for instance, in the lab, they have to be ordered. After the setup is working and running – if it is not, it has to be tweaked and troubleshot to make it work – required measurements can be done and the measurement results can be reported in this thesis.

The goal for this inductance meter is the measurement range of 2mH-20H.

2 Theoretical Aspects and Circuitries for an Inductance Meter

2.1 Inductor

Inductor is a commonly used electrical component (along with resistors and capacitors) that uses magnetic field for dealing with energy storage in the presence of electric current. By application of Lenz’s law, an inductor resists change of current through it, as it resists change in magnetic field. Figure 1 shows its symbol, as used in electronics.

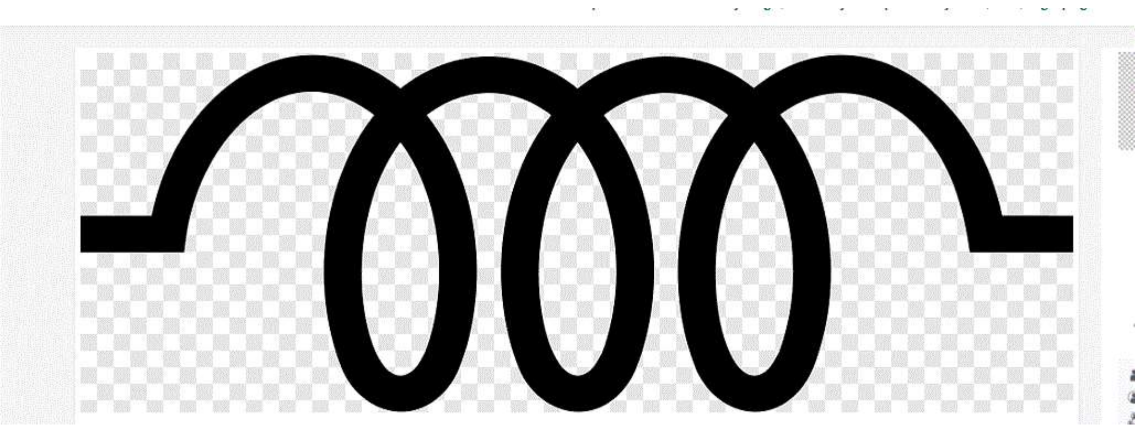


Figure 1. Symbol of an inductor [1].

Inductance, L, of an inductor is defined as the ratio of the magnetic flux linkage of a conductor with the current generated by it.
In other words,

L = $\frac{\Phi}{I}$ (1)

Following, by Faraday’s laws of induction, we get the fact that induced voltage by magnetic flux is given by

Electromotive force, E = $\frac{\mathrm{d}\Phi}{dt}$ (2)

By combining the formulae, we get,

E = $\frac{-\mathrm{d}(\mathrm{LI})}{dt}$ (3)

Thus, E = $-L * \frac{\mathrm{d}(\mathrm{I})}{dt}$ (4)

Thus, inductance is defined as the measure of electromotive force (voltage) generated for a given change of current. [2.]

Voltage and current in an inductor are shown in Figure 2.

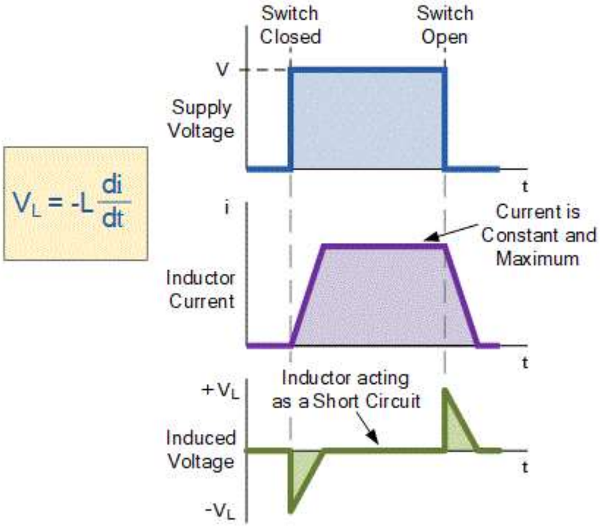


Figure 2. Voltage and current in an Inductor [3].

In conjunction with Lenz's law, induced emf direction opposes the change that is its cause. Thus, with a decreasing current, voltage polarity acts as a source and with an increasing current, it acts as a load. This means that increasing and decreasing magnitude of the induced emf would be the same for the same rate of current change through the coil. [3]

2.2 Inductance Meter and its Use

Inductance meter, as the name implies, is used when inductance needs to be measured. In short, inductance meter measures the inductance value of an inductor (or coil/choke). Inductance value needs to be measured as the inductance calculations help in understanding functioning of the given circuit, in relation to the inductance and its effects on the circuit; and also in troubleshooting the circuit/making the circuit better. For example, inductance values, when measured by inductance meter, can be tweaked to get the desired result in the circuit, and in case if the value of the inductor is wrong, it can be changed by use of an inductance meter to measure its value.

There are different circuitries for an Inductance Meter, as described below.

2.2.1 Using a Tank Circuit

The circuit with a capacitor in parallel with an inductor is called a tank circuit. In our circuit for measuring unknown inductance, the value of the capacitor in the tank circuit has to be known so that the inductance value can be calculated. The inductor here has an effect in the tank circuit (shown in Figure 3) that it affects the resonating frequency of it, thus by calculating resonating frequency and having the value of the inductor unknown, an inductance meter circuit can be formed, with the value of the capacitor known beforehand. [4.]

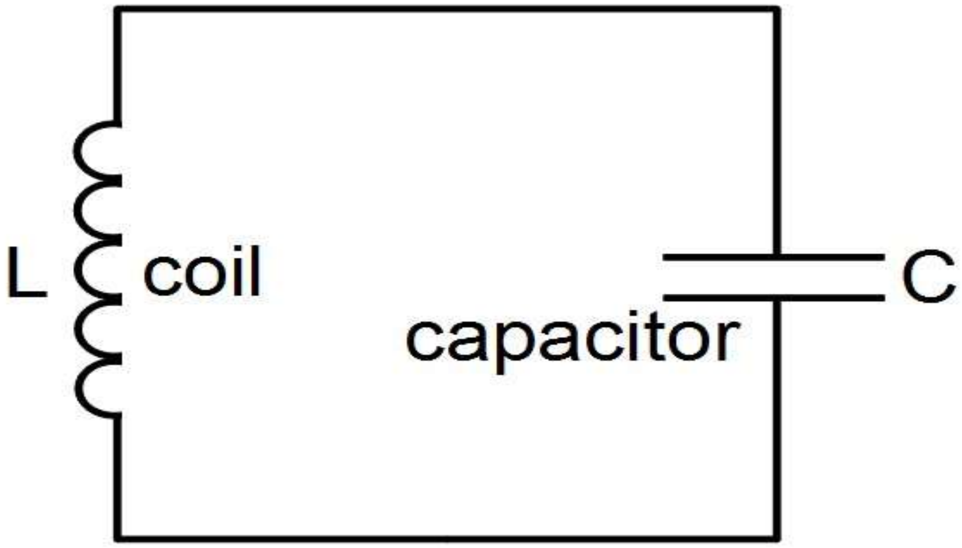


Figure 3. Showing parallel LC circuit/tank circuit [5].

The tank circuit has a certain natural resonating frequency and it resonates at it when it is made to be discharged after it is charged. For instance, after a period of charging, it can be discharged and it will resonate at its resonating frequency; however, the amplitude of oscillation will decrease. This is shown in Figure 4. For the tank circuit to be completely discharged means that the amplitude of oscillation shortens and becomes zero. [4.]

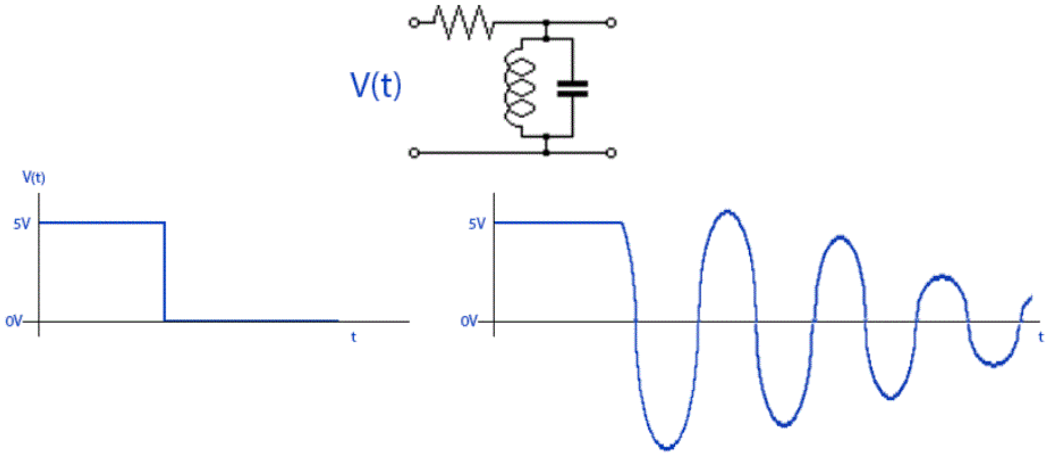


Figure 4. Showing damped oscillation and inductance meter theory [6].

The resonating frequency for an LC circuit is given by the Equation 5, as follows:

$$F = \frac{1}{2*pi*\sqrt{LC}} \tag{5}$$

In this concept of making an inductance meter, the Arduino board used here (if used) is used for charging of tank circuit; then it is let to discharge (shown in Figure 5) – when this happens, the circuit resonates at its resonating frequency. Thus, when the resonating frequency can be measured, the value of the inductance can be figured out. [4.]

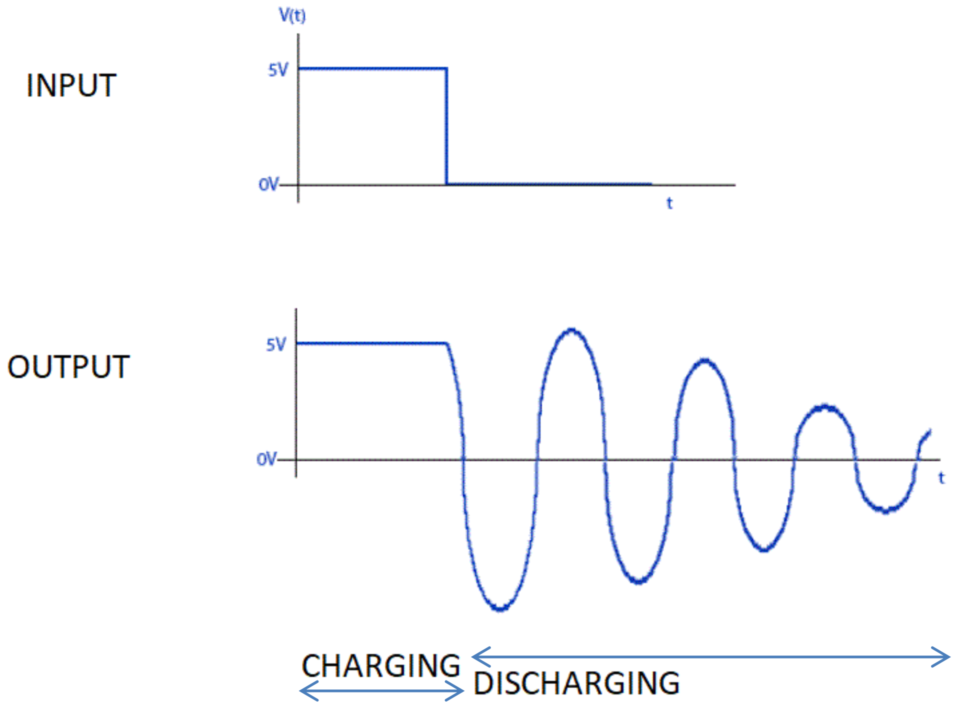


Figure 5. Showing charging/discharging of a tank circuit [4].

The circuit generates a sine wave as the output, so an LM339 can be used as a comparator to detect when the output crosses zero in the positive half cycle. This means that it generates a square wave in the positive half cycle of the sine wave during damped oscillation, with its time period half the time period of the sine wave in consideration. Generating a square wave is necessary because Arduino cannot measure the sine wave damped oscillation. The generation of square wave is shown in Figure 6. [4.]

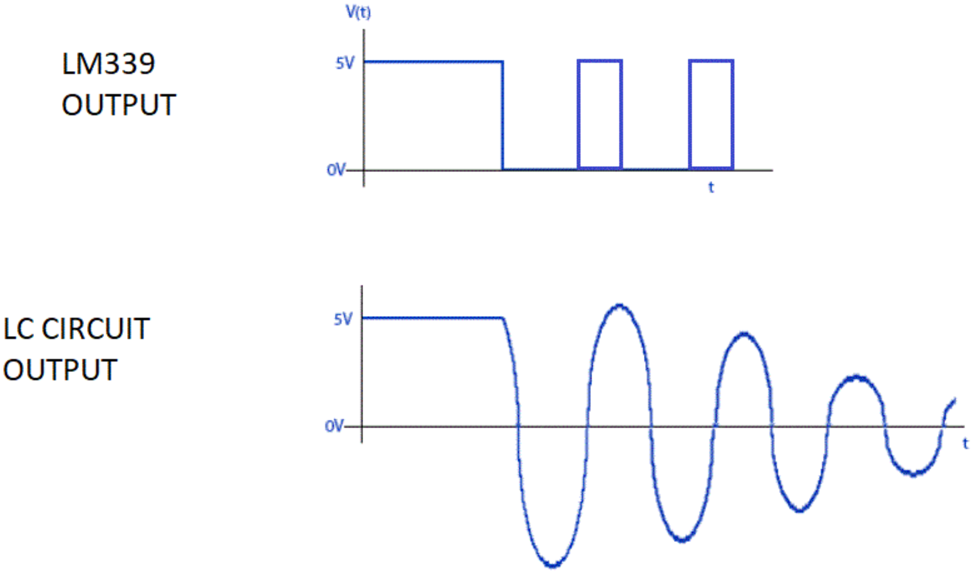


Figure 6. LM339 output waveform and output without LM339 [4].

If the square wave takes time T for half period, then,
For the sine wave,

$$F = \frac{1}{2T} \tag{6}$$

Thus,

$$L = \frac{1}{4*\text{pi}\textasciicircum 2*F\textasciicircum 2*C} \tag{7}$$

2.2.2 Using an Oscillator Circuit

The design of an inductance meter can also be realized by using another oscillator circuit, as shown in Figure 7.

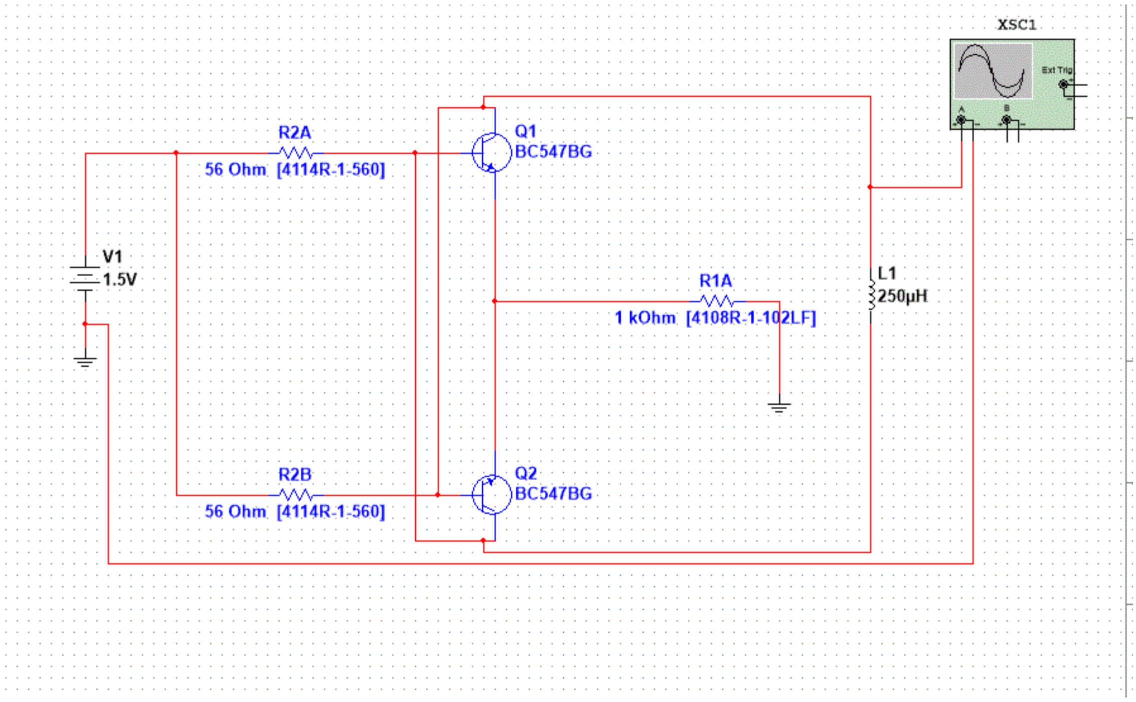


Figure 7. Oscillator circuit [7].

The concept is similar to one used for tank circuit, the frequency of oscillation is dependent on the value of the inductor that we put in the circuit. By using one inductor to tune the potentiometer to get the desired frequency, we can know the value of another inductor in the next attempt.

The concept and the formula to use are as shown below

$$f = \frac{50000}{\mathrm{L}} \tag{8}$$

Also, oscillator circuit waveform image is as shown below in Figure 8.

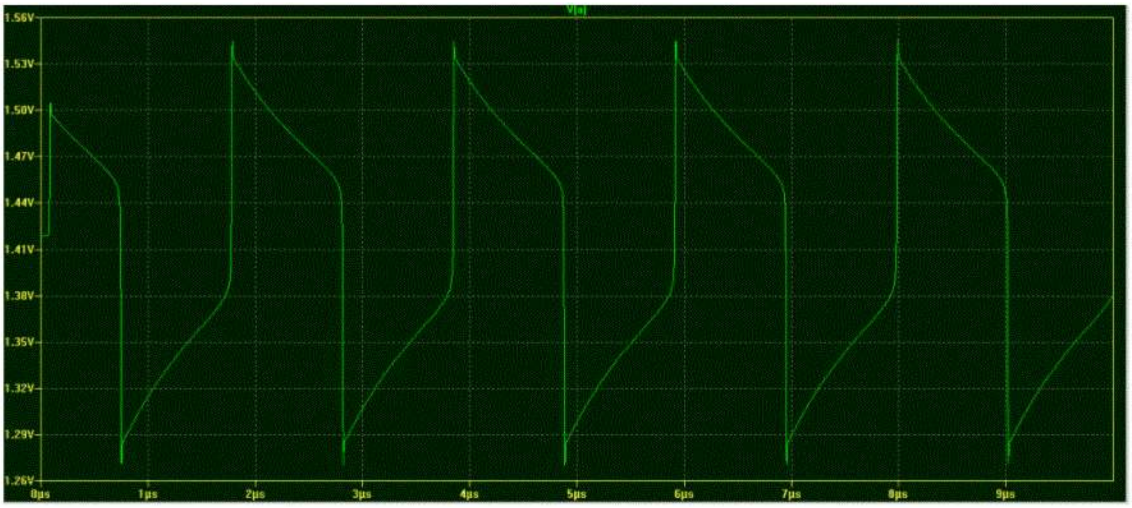


Figure 8. Waveform Image (using a 100uH inductor) [8].

The frequency of oscillation depends on the L/R time constant comprising the inductor and resistors. The time the waveform takes to change its state is directly proportional to the inductance. In the waveform, the time taken for one complete cycle is 2µs for a 100µH inductor.

That is,

inductance (100µH) = Time period (2µs) x 50

And we know, Frequency = 1 / Time Period, or Time Period = 1 / Frequency

We get,

Inductance (µH)

= 50 x (1 / Frequency)
= 50 / Frequency (Hz)
= 50 x 1000 / Frequency (Hz) x 1000
= 50,000 / Frequency (kHz)

This is how we get the figure “50000” in the formula. [8.]

If L1 = 200 uH (known)
f = 50000/200 kHz = 250 kHz

L1 is used for calibration

Taking unknown L2, we note the frequency

L2 = 50000/f(kHz) uH

If f = 426 kHz

L2 = 50000/426 = 117.4 uH (from Equation 8)

Thus, the value of an unknown inductor can be found out using two known resistors, a potentiometer and a couple BC547 transistors.

2.2.3 Using Colpitts Oscillator

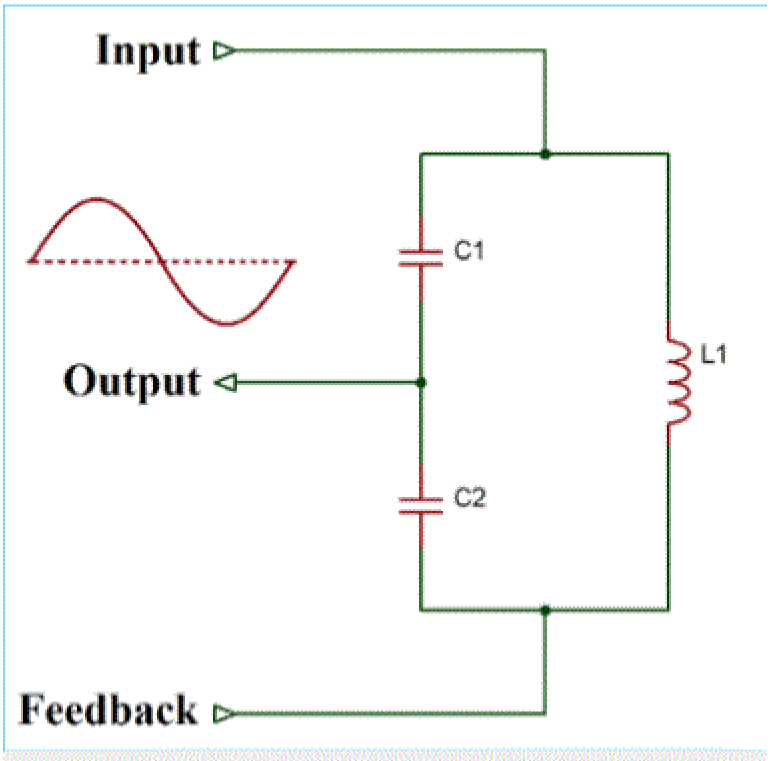


Figure 9. Colpitts Oscillator [9].

Figure 9 shows a Colpitts oscillator. This circuit can be used for the realization of an Inductance Meter as well.

The theory involved is as follows:

$F0 = \frac{1}{2*pi*\sqrt{LCt}}$ (9)

C_t = series capacitance for C1 and C2

Also,

$\frac{1}{Ct} = \frac{1}{C1} + \frac{1}{C2}$ (20)

<=> $C_t = \frac{C2+C1}{C1*C2}$ (13)

<=> $C_t = \frac{C1*C2}{C1 + C2}$ (42)

$f1 = \frac{1}{2*pi*\sqrt{LC}}$ (13)

$f2 = \frac{1}{2*pi*\sqrt{L(C+Ccal)}}$ (14)

$f3 = \frac{1}{2*pi*\sqrt{L(C+Cdet)}}$ (15)

$f4 = \frac{1}{2*pi*\sqrt{(L+Ldet)C}}$ (16)

$Cdet = \frac{\left(\frac{F1}{F3}\right)^2 - 1}{\left(\frac{F1}{F2}\right)^2 - 1} * C_{cal}$ (17)

$Ldet = \left(\left(\frac{F1}{F4}\right)^2 - 1\right) * \left(\left(\frac{F1}{F2}\right)^2 - 1\right) * \frac{1}{Ccal} * \frac{1}{2*pi*F1}$ (18)

Using formulae 13-18, following calculations can be done:

$Cdet = \frac{\left(\frac{F1}{F3}\right)^2 - 1}{\left(\frac{F1}{F2}\right)^2 - 1} * C_{cal}$

<=> C_{det} = (($\frac{1}{2*pi*\sqrt{LC}}$/$\frac{1}{2*pi*\sqrt{L(C+Cdet)}}$)^2 – 1)/(($\frac{1}{2*pi*\sqrt{LC}}$ / $\frac{1}{2*pi*\sqrt{L(C+Ccal)}}$)^2/-1)*Ccal

After a series of calculations, this finally resolves into:

$C_{det} = C_{det}$

QED

Similarly,

$L_{det} = (\frac{4*pi^2\ (L+Ldet)*C}{4*pi^2*LC} - 1)*\ (\frac{4*pi^2\ (C+Ccal)}{4*pi^2*LC} - 1)*\ \frac{1}{Ccal}*\frac{1}{4*pi^2/(4*pi^2*LC)}$

After a series of calculations, this finally resolves into:

$L_{det} = L_{det}$

QED

The above equations can be used to calculate both unknown inductances and capacitances. For the calculations, we start with F1 to F4, thus they are essential [10].

For the purposes of this thesis project, we use the tank-circuit method to make an inductance meter.

3 Practical Steps for the Making of an Inductance Meter

3.1 Multisim Simulation

It was decided to use the first method, by using a Tank Circuit, to realize an Inductance Meter, for convenience, as components were readily available and the method was not too short (Method II), or too long (Method III).

The first practical step was to do a Multisim simulation of the whole circuit. The results of the simulation are shown in Figures 10, 11, 12, 13 and 14.

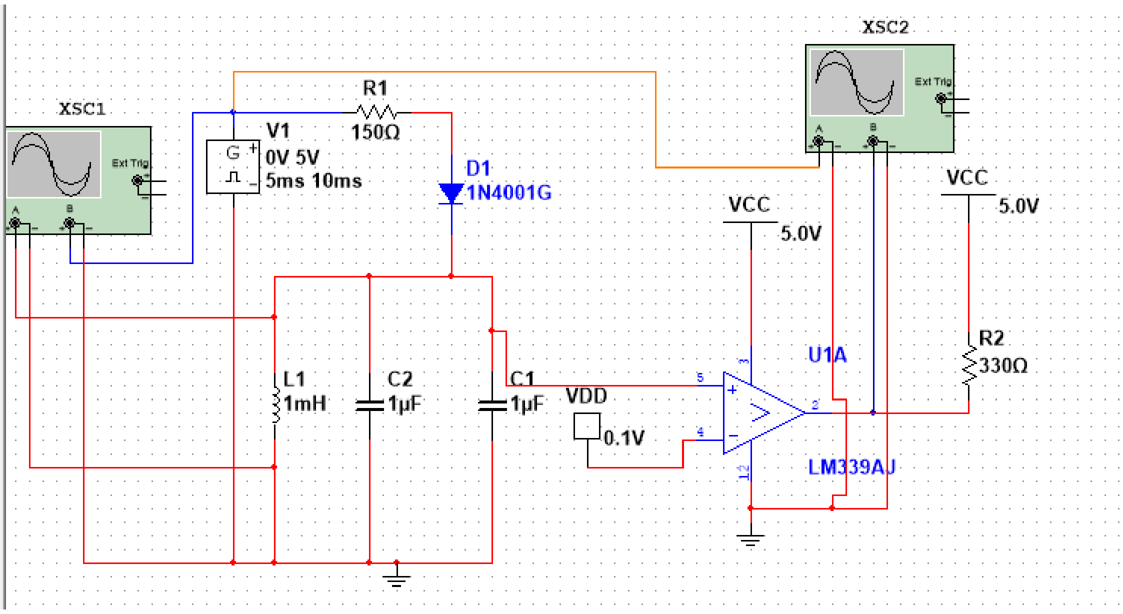
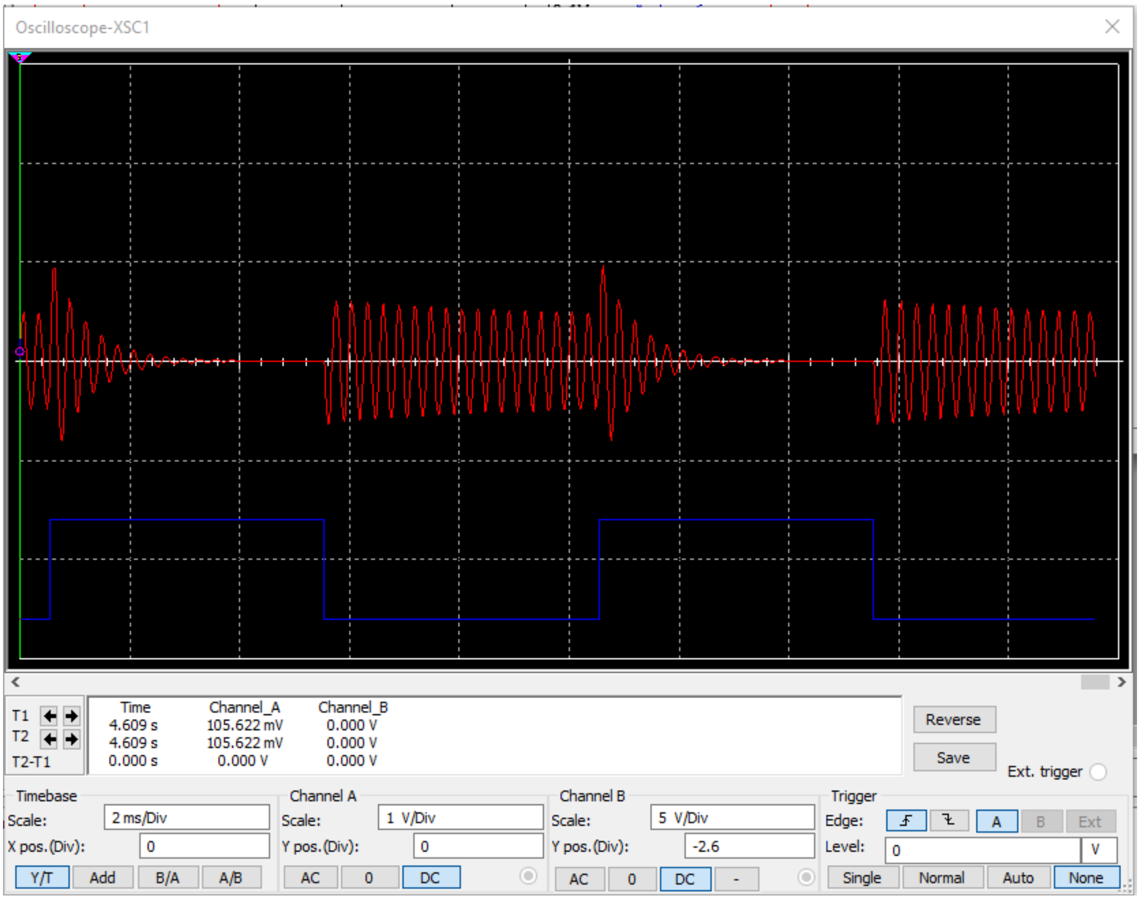


Figure 10. Multisim simulation, circuit shown



	Time	Channel_A	Channel_B
T1	4.609 s	105.622 mV	0.000 V
T2	4.609 s	105.622 mV	0.000 V
T2-T1	0.000 s	0.000 V	0.000 V

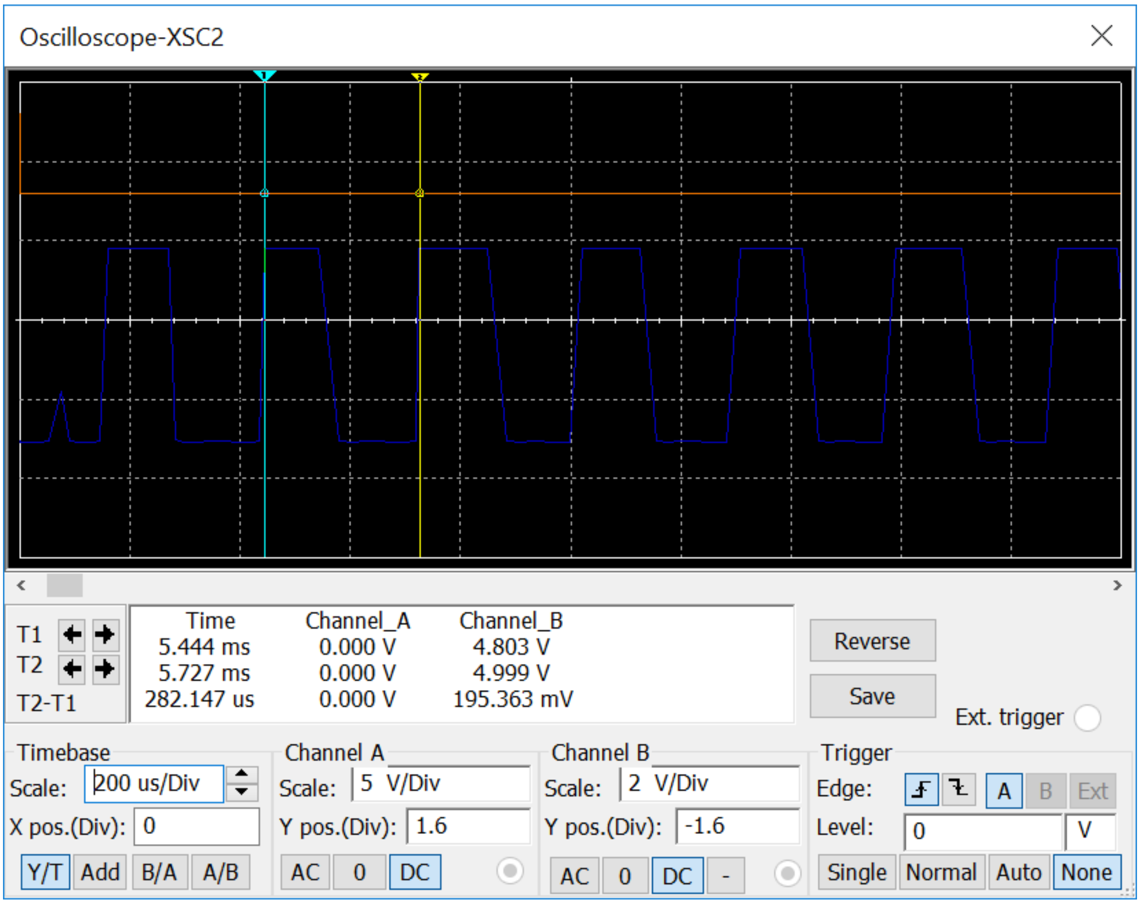
Timebase
Scale: 2 ms/Div
X pos.(Div): 0

Channel A
Scale: 1 V/Div
Y pos.(Div): 0

Channel B
Scale: 5 V/Div
Y pos.(Div): -2.6

Trigger
Edge: A
Level: 0 V

Figure 11. Multisim simulation, oscilloscope-XSC1 output



	Time	Channel_A	Channel_B
T1	5.444 ms	0.000 V	4.803 V
T2	5.727 ms	0.000 V	4.999 V
T2-T1	282.147 us	0.000 V	195.363 mV

Timebase
Scale: 200 us/Div
X pos.(Div): 0

Channel A
Scale: 5 V/Div
Y pos.(Div): 1.6

Channel B
Scale: 2 V/Div
Y pos.(Div): -1.6

Trigger
Edge:
Level: 0 V

Figure 12. Multisim simulation, oscilloscope-XSC2 output, 1mH inductor

For oscilloscope-XSC2 output:

For the selected part, time = 282.147 us

Thus, frequency = 1/(282.147us) = 3544.25 Hz

Also, for the whole simulation, expected oscillation frequency (given 1mF inductor, known inductance) = $\frac{1}{2*pi*\sqrt{1m*2u}}$

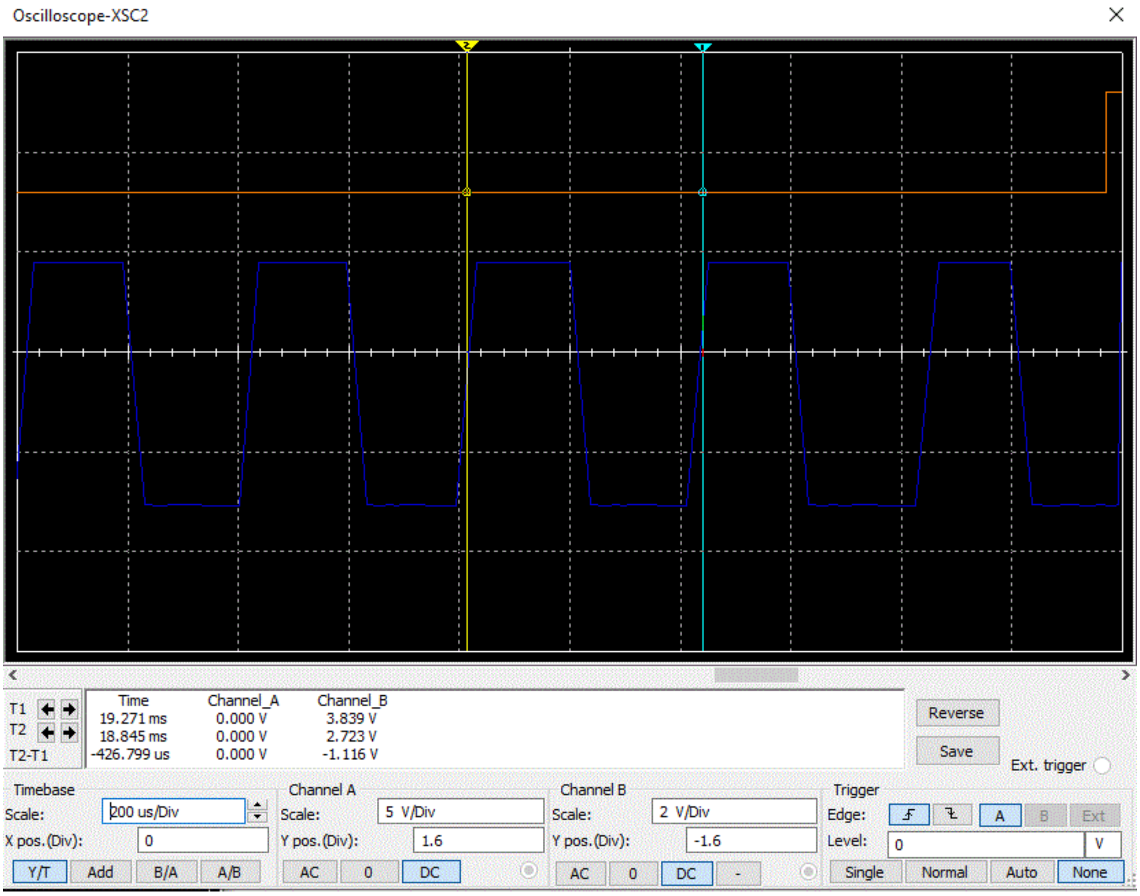
= 3558.81 Hz

This is almost identical to Multisim output.

If our inductance meter is to measure values of inductance ranging 2mH – 20H, the frequency range would be:

$\frac{1}{2*pi*\sqrt{2m*2u}}$ to $\frac{1}{2*pi*\sqrt{20*2u}}$ = 2516.46 Hz to 25.16 Hz

Oscilloscope-XSC2 output for 2mH inductor:



	Time	Channel_A	Channel_B
T1	19.271 ms	0.000 V	3.839 V
T2	18.845 ms	0.000 V	2.723 V
T2-T1	-426.799 us	0.000 V	-1.116 V

Timebase
Scale: 200 us/Div
X pos.(Div): 0

Channel A
Scale: 5 V/Div
Y pos.(Div): 1.6

Channel B
Scale: 2 V/Div
Y pos.(Div): -1.6

Trigger
Edge:
Level: 0 V

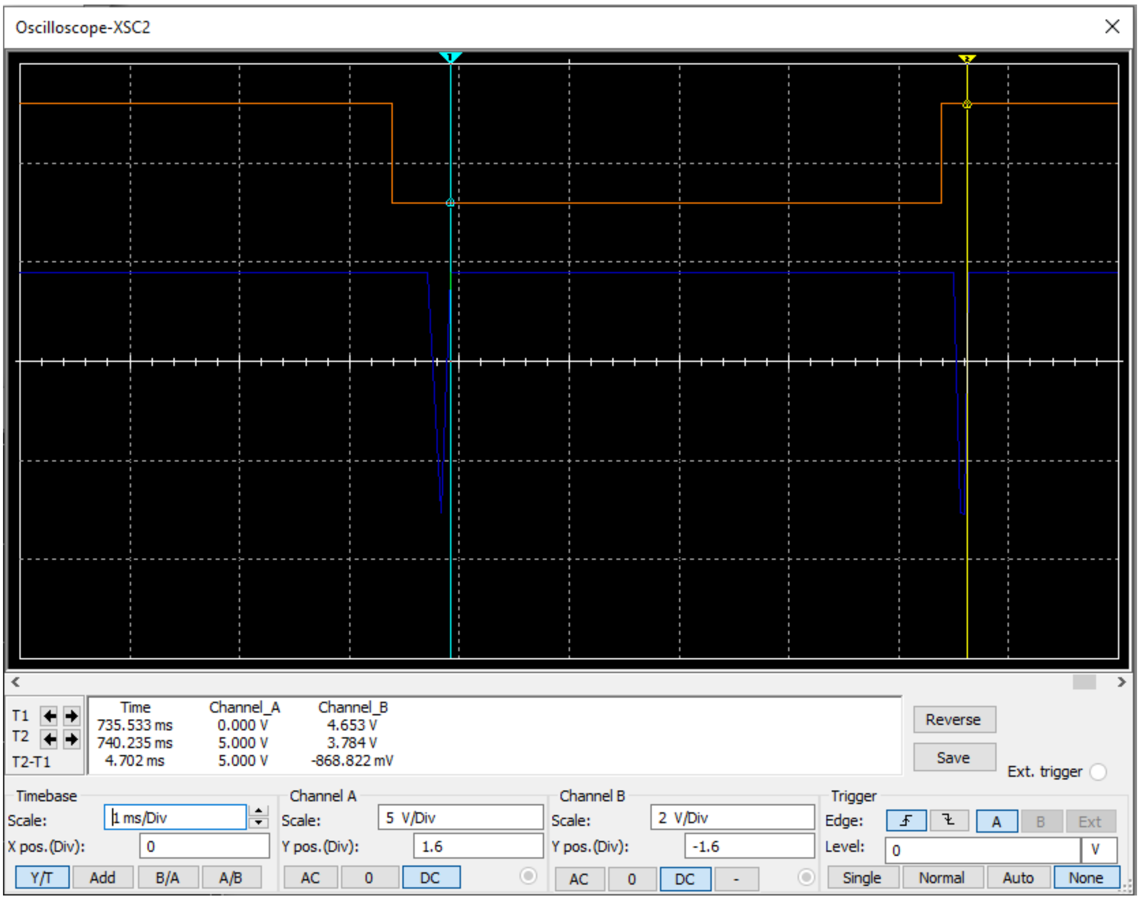
Figure 13. Multisim simulation, oscilloscope-XSC2 output, 2mH inductor

For the selected part, time = -426.799 us

Thus, frequency = $1/(426.799\ \text{us})$ = 2343.02 Hz

This is not so close to the above calculated frequency, which is 2516.46 Hz

Oscilloscope-XSC2 output for 20H inductor:



	Time	Channel_A	Channel_B
T1	735.533 ms	0.000 V	4.653 V
T2	740.235 ms	5.000 V	3.784 V
T2-T1	4.702 ms	5.000 V	-868.822 mV

Timebase
Scale: 1 ms/Div
X pos.(Div): 0

Channel A
Scale: 5 V/Div
Y pos.(Div): 1.6

Channel B
Scale: 2 V/Div
Y pos.(Div): -1.6

Trigger
Level: 0 V

Figure 14. Multisim simulation, oscilloscope-XSC2 output, 20H inductor

For the selected part, time = 4.702 ms

Thus, frequency = $1/(4.702 \text{ ms})$ = 212.67 Hz

This is not close to the above calculated frequency, which is 25.16 Hz.

Since the used Multisim circuit does not work so well for 2mH and 20H inductance values, the following changes had to be made to the Multisim circuit: two settings in pulse voltage were changed, and the negative input to LM339 was changed to 0.05V. Additionally, pulse width and period were increased to 5 and 10 seconds. The resulting simulation works somewhat for 20H inductor, but still not so well for 2 mH inductor, so measurement range has to be limited, as a consequence.

The changed simulation is shown in Figure 15, as follows:

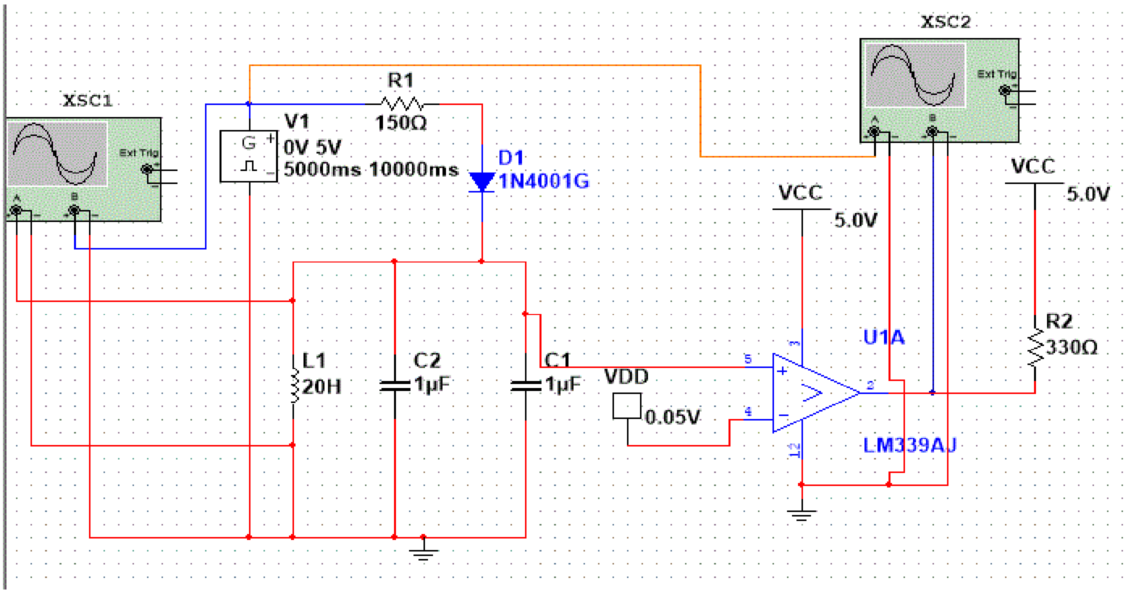


Figure 15. Changed Multisim simulation

For 20H inductor,

Oscilloscope-XSC1 output is as shown in Figure 16, and oscilloscope-XSC2 output is as shown in Figure 17.

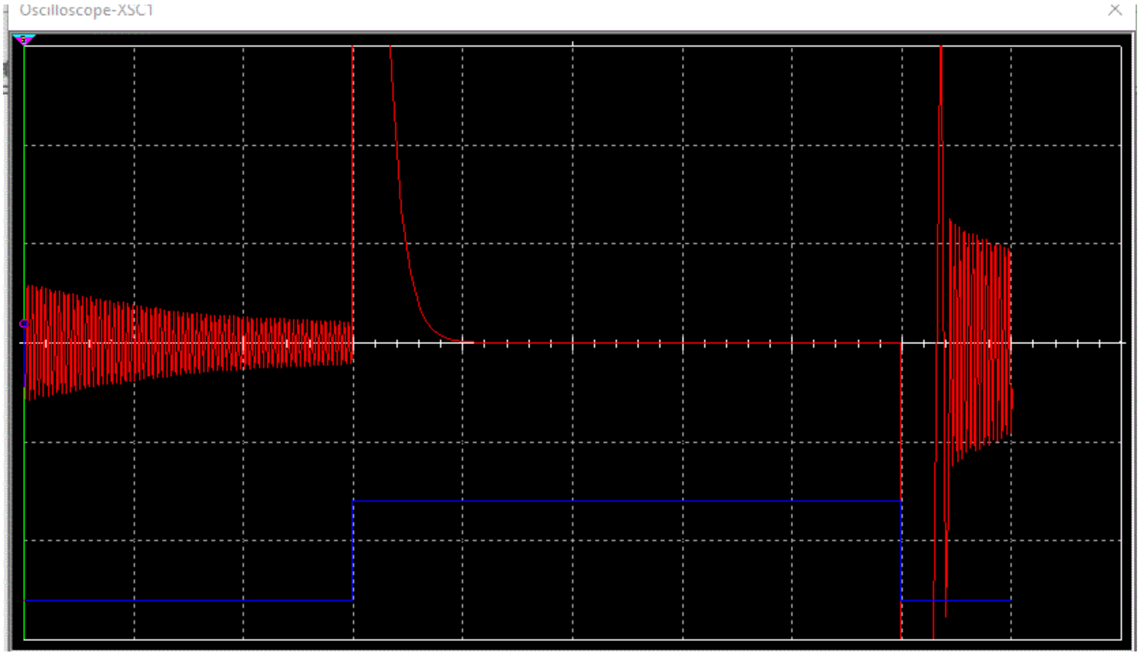
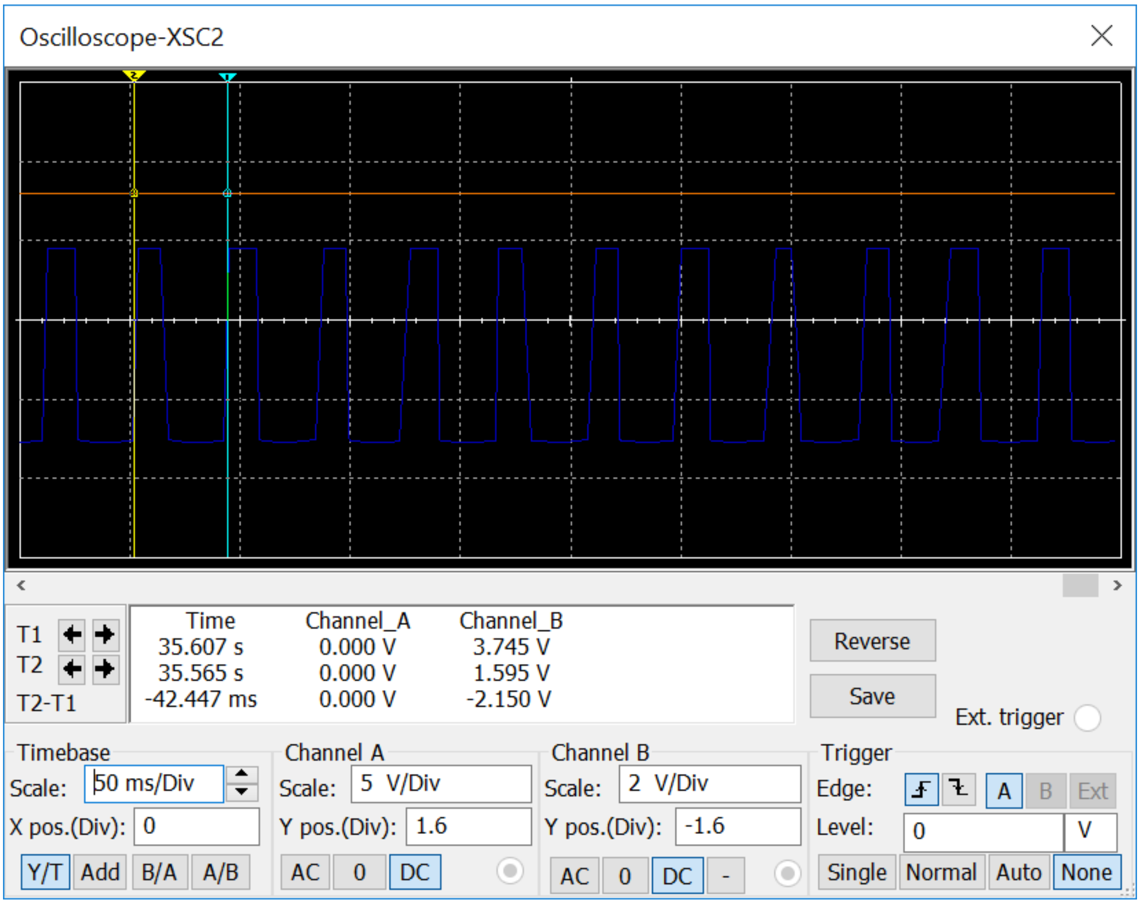


Figure 16. Oscilloscope-XSC1 output, changed Multisim design, 20H inductor



Oscilloscope-XSC2

	Time	Channel_A	Channel_B
T1	35.607 s	0.000 V	3.745 V
T2	35.565 s	0.000 V	1.595 V
T2-T1	-42.447 ms	0.000 V	-2.150 V

Timebase
Scale: 50 ms/Div
X pos.(Div): 0

Channel A
Scale: 5 V/Div
Y pos.(Div): 1.6

Channel B
Scale: 2 V/Div
Y pos.(Div): -1.6

Trigger
Edge:
Level: 0 V

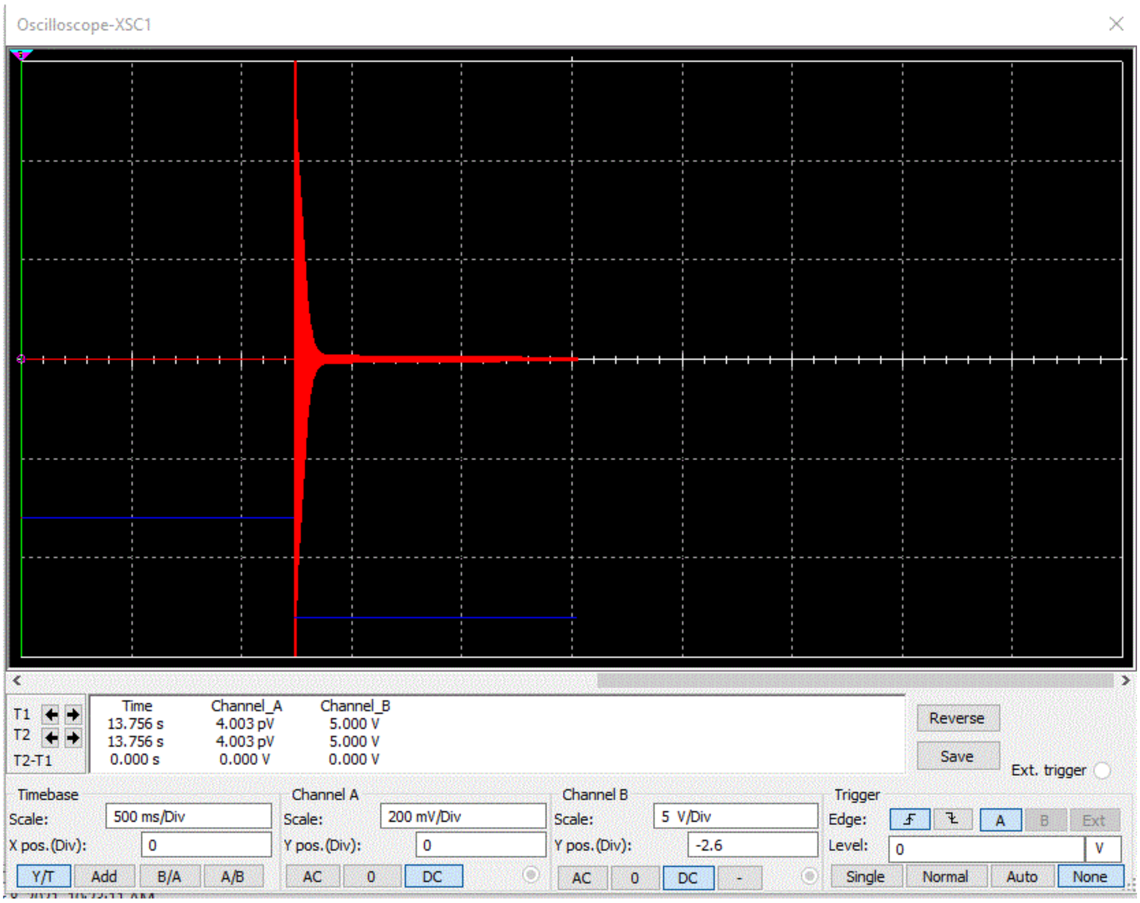
Figure 17. Oscilloscope-XSC2 output, changed Multisim design, 20H inductor

For the selected part, time = -42.447 ms

Thus, frequency = $1/(42.447\ \mathrm{ms})$ = 23.55 Hz

This is close to the above calculated frequency, which is 25.16 Hz.

However, the changed Multisim design works for 2mH inductor values, as shown in Figures 18 and 19.



	Time	Channel_A	Channel_B
T1	13.756 s	4.003 pV	5.000 V
T2	13.756 s	4.003 pV	5.000 V
T2-T1	0.000 s	0.000 V	0.000 V

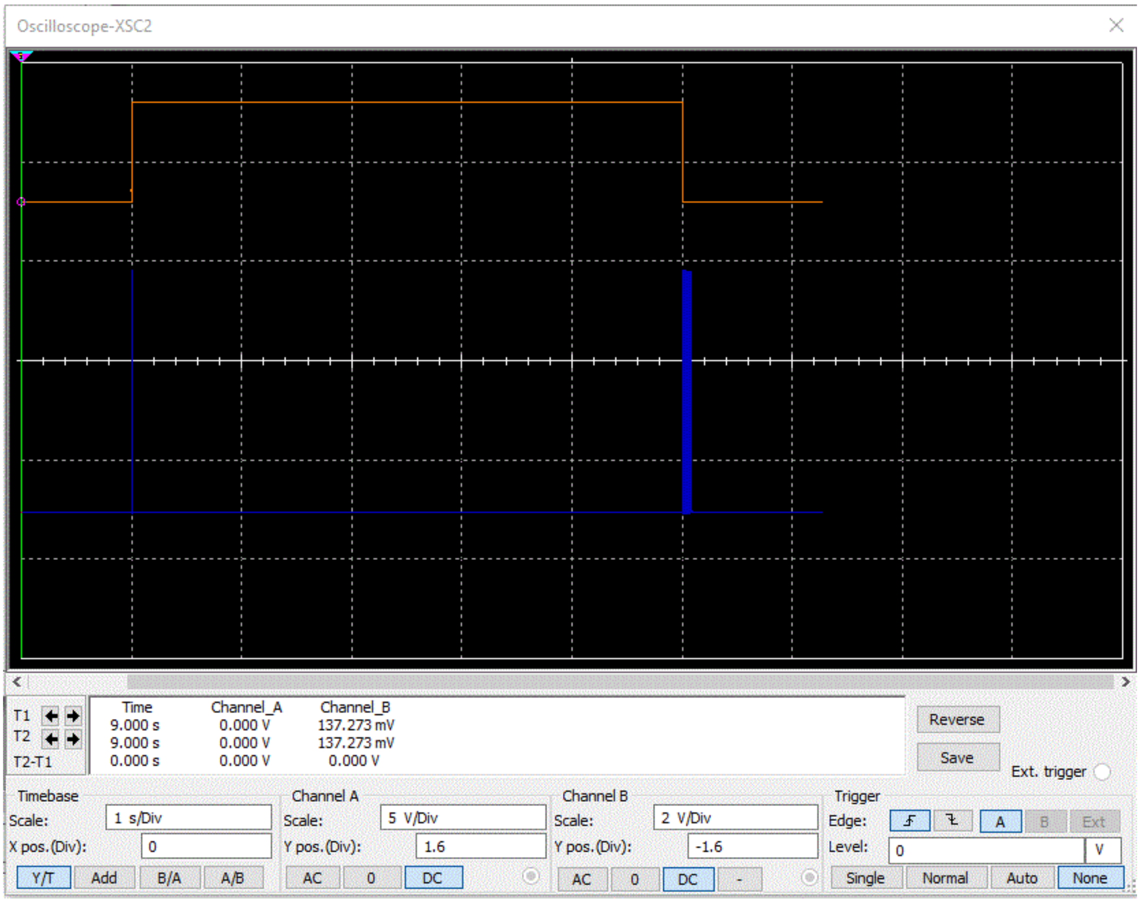
Timebase
Scale: 500 ms/Div
X pos.(Div): 0

Channel A
Scale: 200 mV/Div
Y pos.(Div): 0

Channel B
Scale: 5 V/Div
Y pos.(Div): -2.6

Trigger
Edge: A
Level: 0 V

Figure 18. Oscilloscope-XSC1 output, changed Multisim design, 2 mH inductor



	Time	Channel_A	Channel_B
T1	9.000 s	0.000 V	137.273 mV
T2	9.000 s	0.000 V	137.273 mV
T2-T1	0.000 s	0.000 V	0.000 V

Timebase
Scale: 1 s/Div
X pos.(Div): 0

Channel A
Scale: 5 V/Div
Y pos.(Div): 1.6

Channel B
Scale: 2 V/Div
Y pos.(Div): -1.6

Trigger
Edge: A
Level: 0 V

Figure 19. Oscilloscope-XSC2 output, changed Multisim design, 2 mH inductor

3.2 Components Used on the Circuit

The circuit resembles the following image.

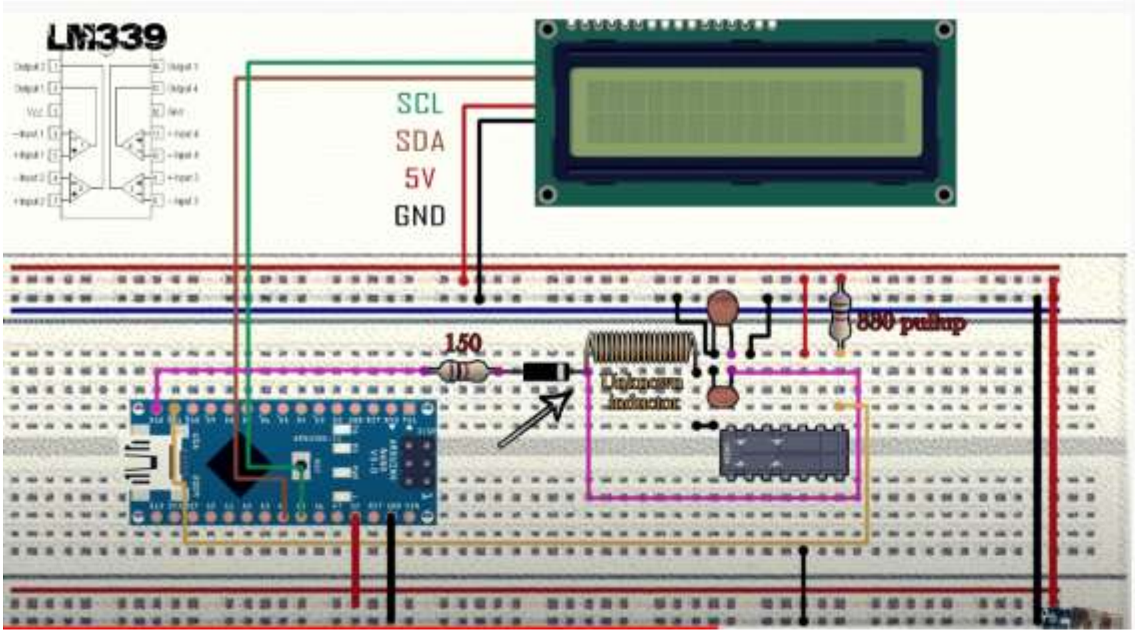


Figure 20. Inductance Meter Circuit [11].

Figures 21, 22, 23 and 24 show individual components used on the circuit on the breadboard.

Figure 21. Grove I2C LCD Display

SDA, SCL pins from the Grove I2C display are connected to A4 and A5 pins respectively on the Arduino UNO.

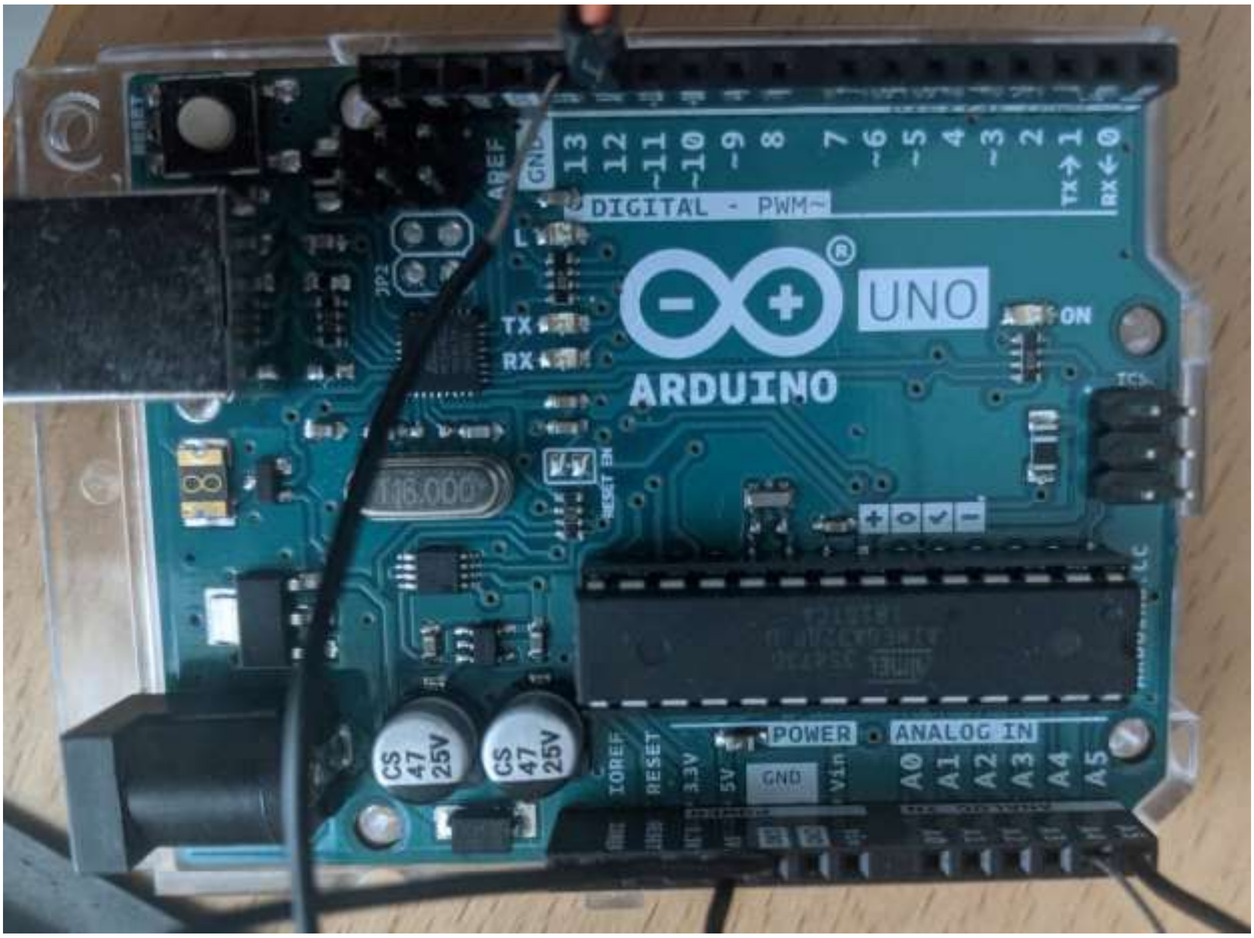


Figure 22. Arduino UNO

D11 pin connects to LM339N output 2, and D12 pin from the UNO connects to 150 ohm resistor. Also, the 5V and GND pins from the UNO power the circuit, including the Grove LCD display.

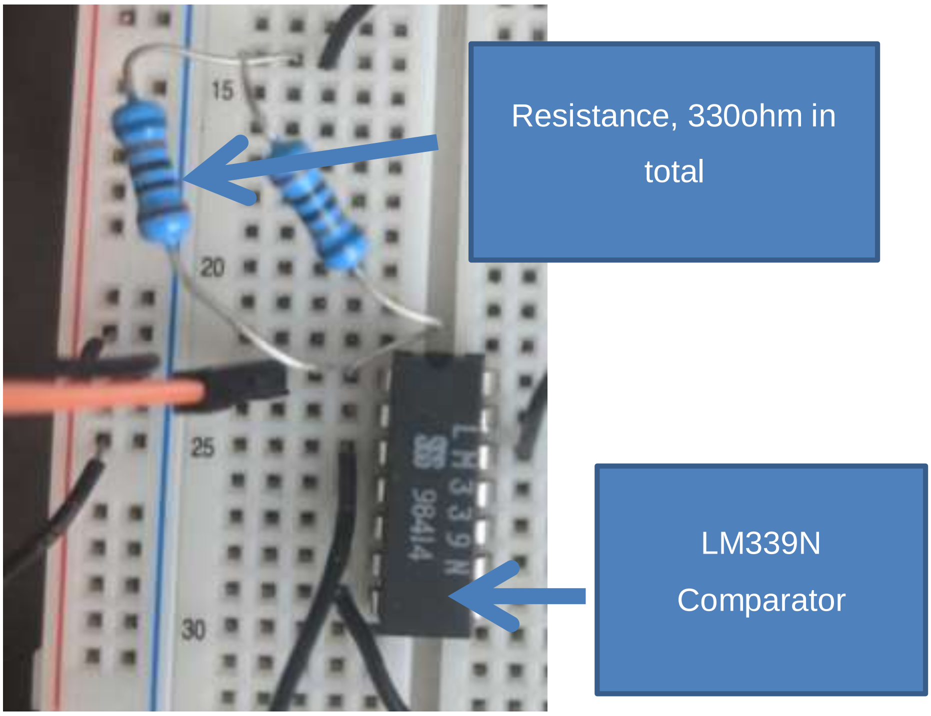


Figure 23. LM 339N Comparator, also connected to about 330 ohm resistance

330ohm resistance is pull-up, and it is connected to the positive voltage terminal. LM339N also connects to the tank circuit, power supply and ground, and to D11 on the Arduino UNO.

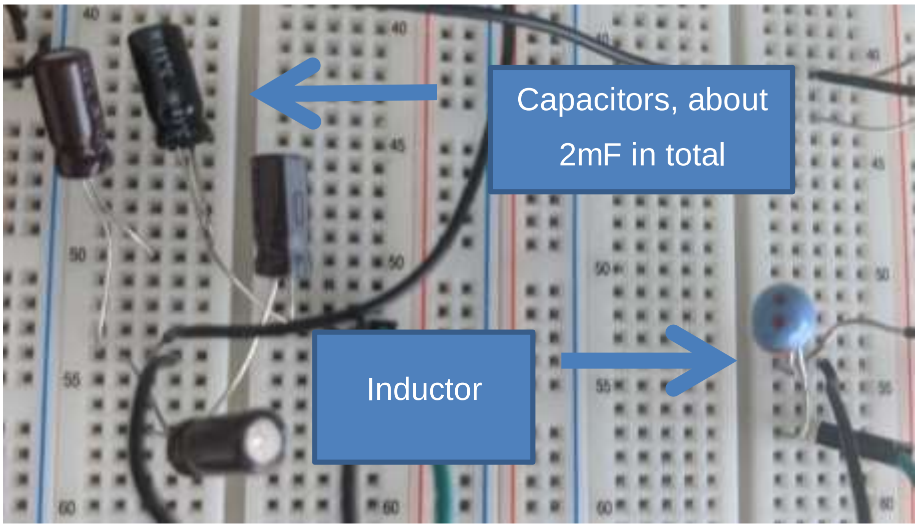


Figure 24. Tank circuit

One end of the capacitor circuit is grounded, another end is not. The ungrounded end connects to LM339N, while both ends connect to the inductor, thus being in parallel combination with it. Inductor also connects to a diode.

3.3 Code Explanation

For this snippets of code were taken and their functionality was explained by text.

```
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 = 2.E-6; //
```

Listing 1. Pulsein code

Pulsein takes the value of the pulse when the state of pin 11 is HIGH (before it goes to LOW, that is, for half a wave), and returns 0 if there is timeout within the given timeframe. (Code in Listing 1)

```
frequency = 1.E6/(2*pulse);
inductance = 1./(capacitance*frequency*frequency*4.*3.14159*3.14159);
inductance *= 1E6;
inductance_mH = inductance / 1000;
```

Listing 2. Inductance calculation code

Inductance is calculated using formula 1. Then multiplying the inductance value by 10^6 gives inductance in uH, and then again multiplying it by 1000 gives inductance in mH. (Code in Listing 2)

3.4 Measurement Tables

The inductance meter circuit was designed in lab. Its functionality was also measured and tested using the following measurements. Inductance values from micro Henrys to 10mH were measured with our inductance meter, and then with a reference device. The results of the measurements are shown in Tables 1 and 2; measurement is shown in Figure 25.

Table 1. Inductance values as measured with our inductance meter

Inductance value	Measured value (Inductance Meter)
10mH	9.45mH
820uH	817.11uH
680uH	658.39uH
47uH	42.61uH
3.3uH	4.1uH

Table 2. Inductance values as measured with a reference device

Inductance value	Measured value (Reference Device)
10mH	9.83mH
820uH	0.868mH
680uH	0.530mH
47uH	Does not measure such small inductance value
3.3uH	Does not measure such small inductance value

It can be concluded that the inductance meter is reliable, and has a range, for instance, in low micro Henrys, where even the reference device cannot measure. Also, the inductance meter is accurate.

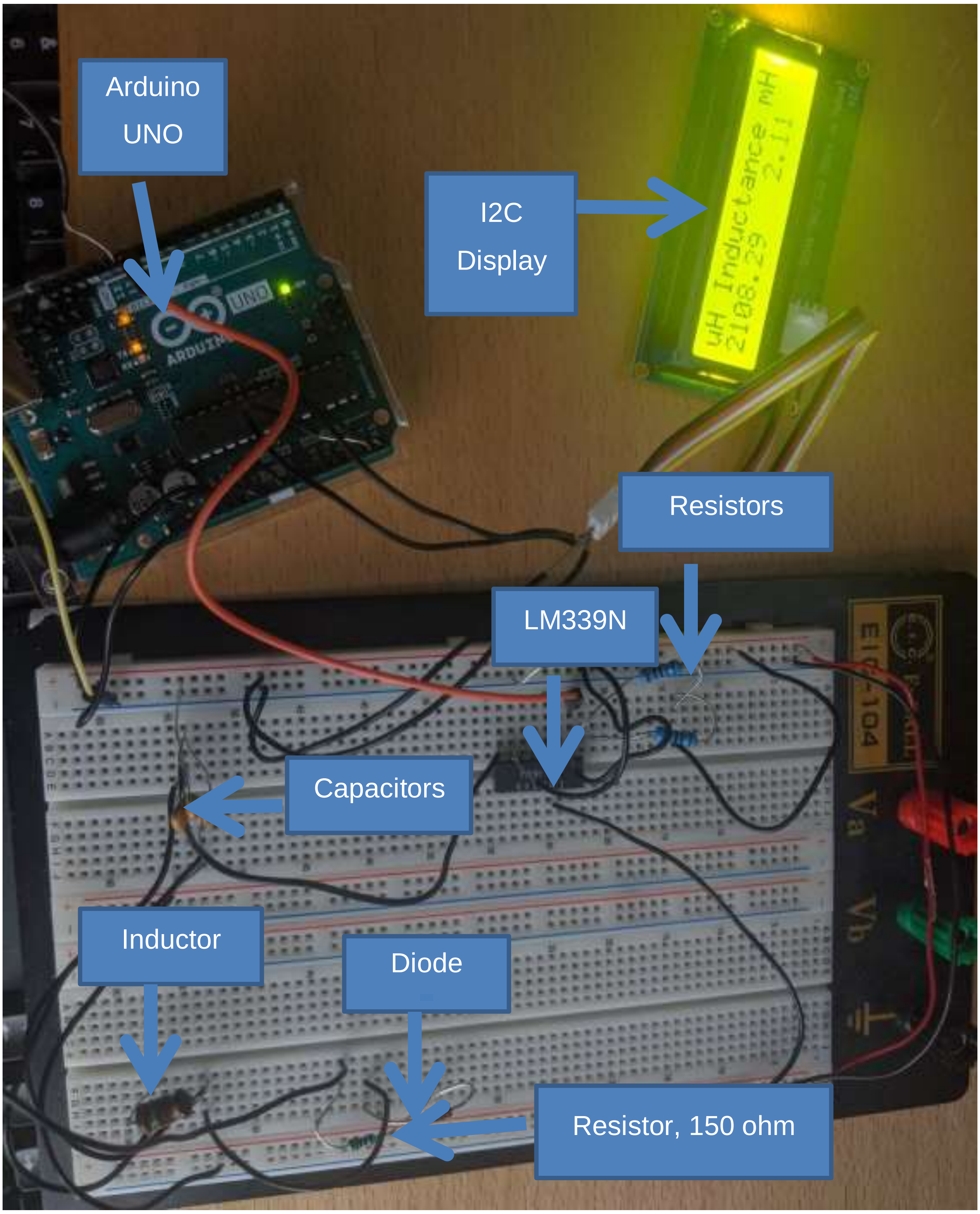


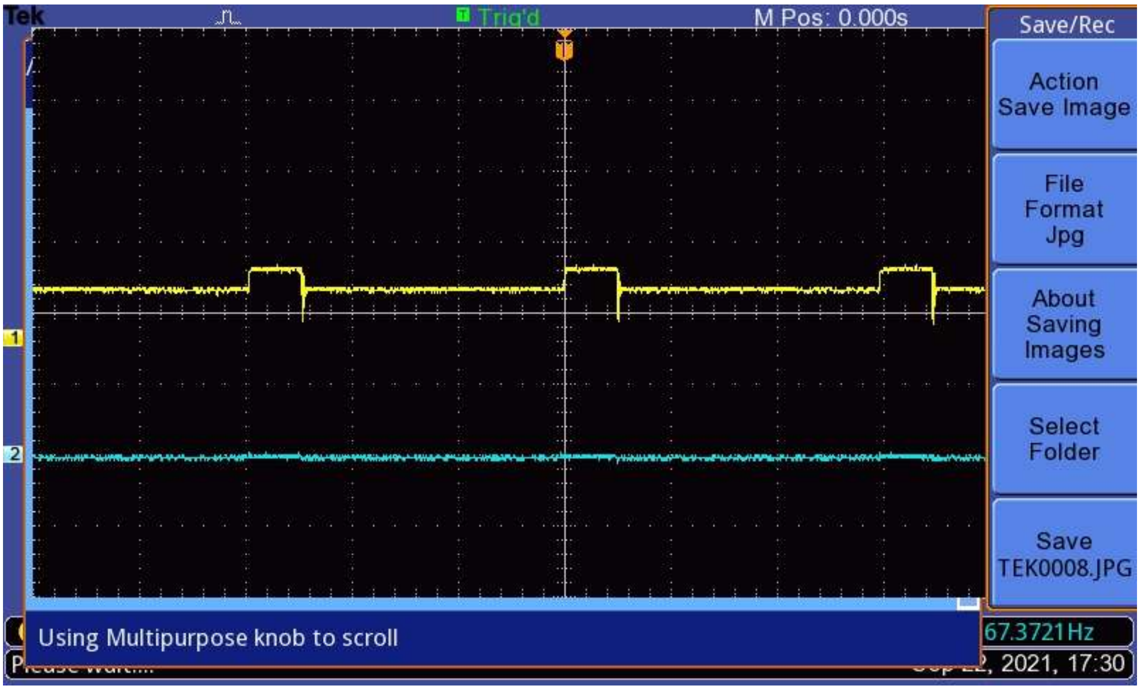
Figure 25. Measurement with our inductance meter

3.5 Oscilloscope Measurements

Figures 26, 27, 28, 29, 30, 31. 32 and 33 show Oscilloscope measurements done in the lab. For the measurements, channel 1 was connected to output 2 of

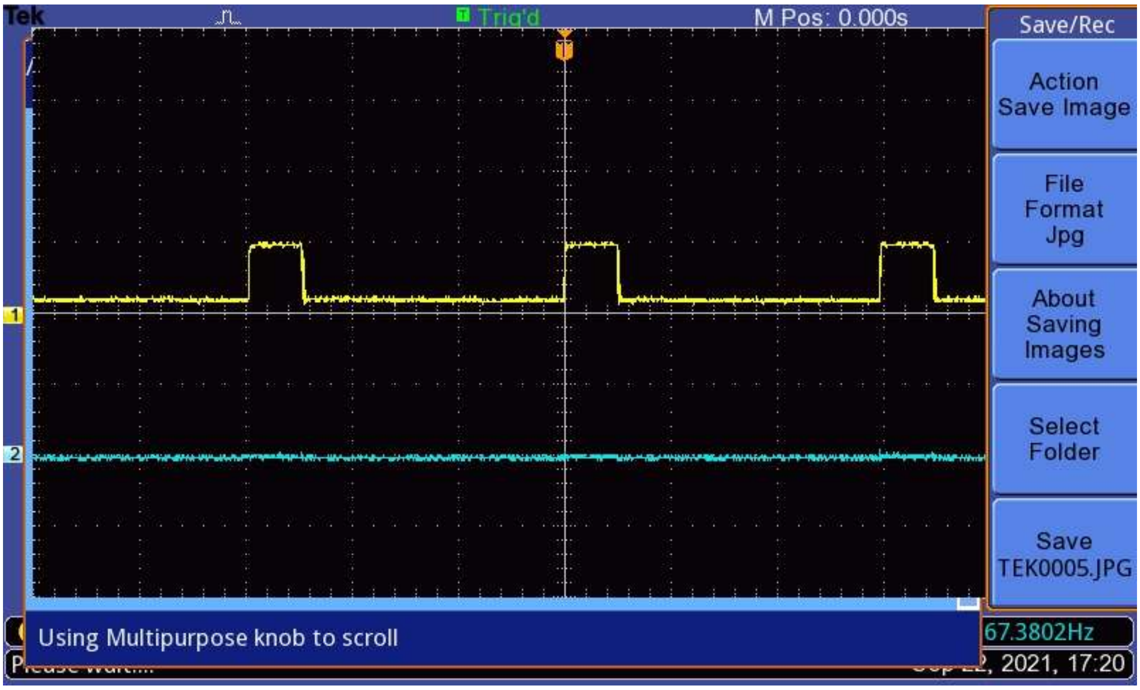
LM339N (or to the base of the 330 ohm resistor), channel 2 was connected to the ungrounded capacitor end, and external trigger was connected to the 150 ohm resistance.

No noticeable oscillations can be seen for small inductor values upto 450uH range. This can be seen in Figures 27-31.



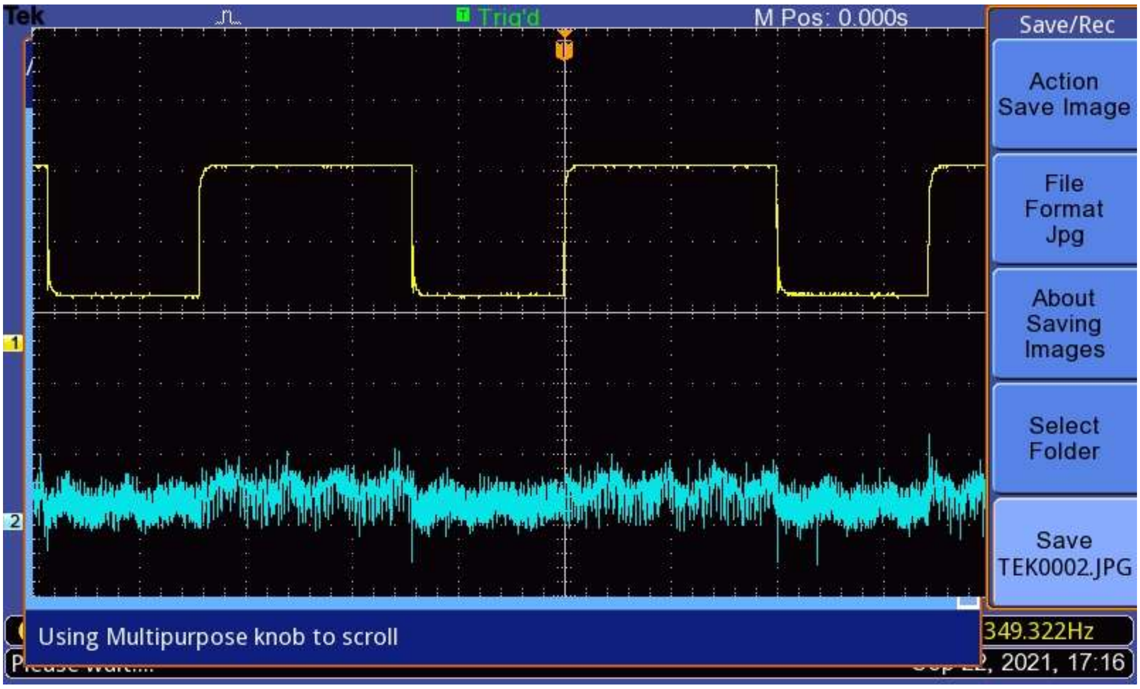
Using Multipurpose knob to scroll

Figure 26. Oscilloscope measurement (3uH inductor)



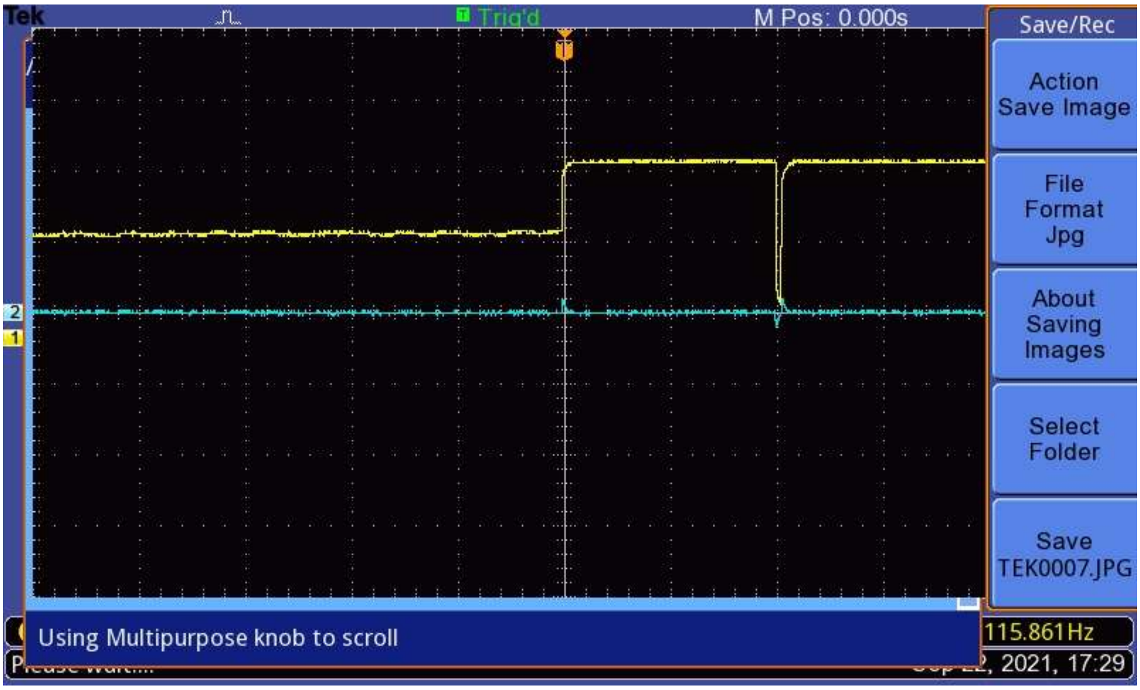
Using Multipurpose knob to scroll

Figure 27. Oscilloscope measurement (16uH inductor)



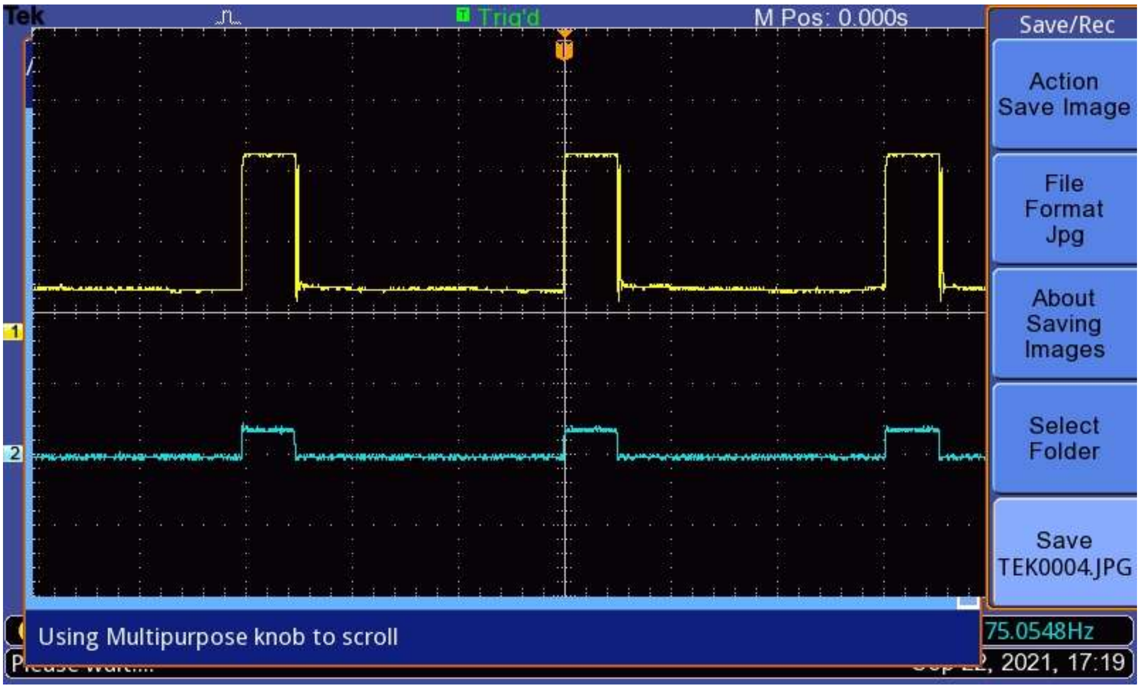
Using Multipurpose knob to scroll

Figure 28. Oscilloscope measurement (72uH inductor)



Using Multipurpose knob to scroll

Figure 29. Oscilloscope measurement (330uH inductor)



Using Multipurpose knob to scroll

Figure 30. Oscilloscope measurement (450uH inductor)

For inductor values starting 820uH in our measurements, oscillations are more noticeable. This can be seen in Figures 32-34.

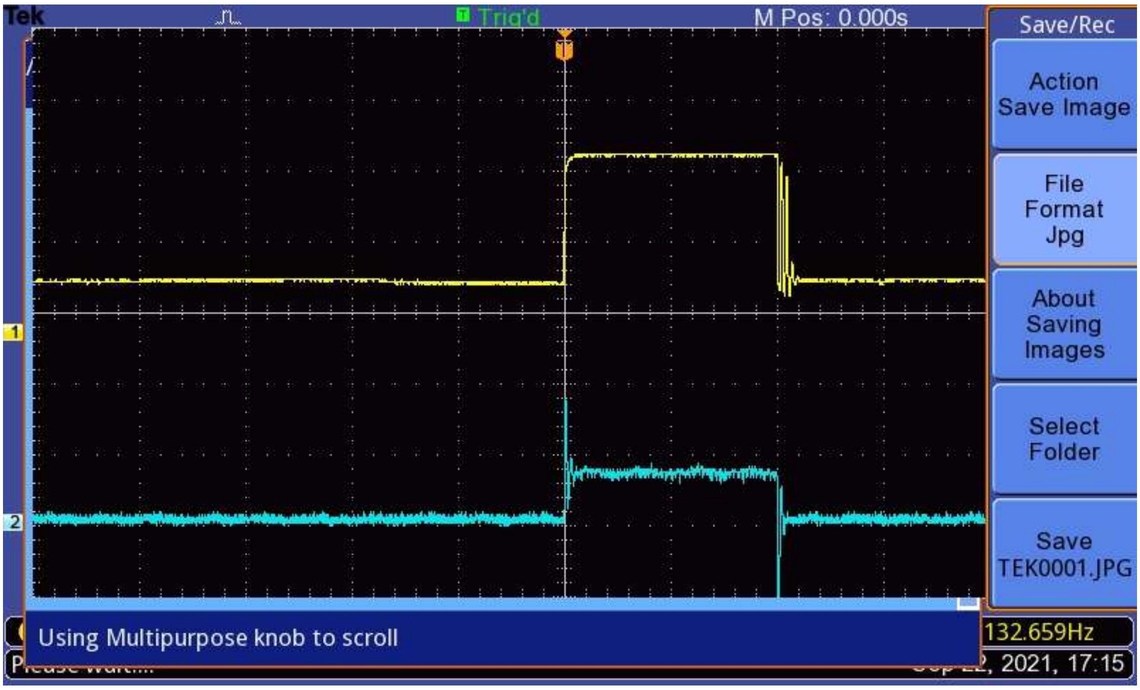


Figure 31. Oscilloscope measurement (820uH inductor)

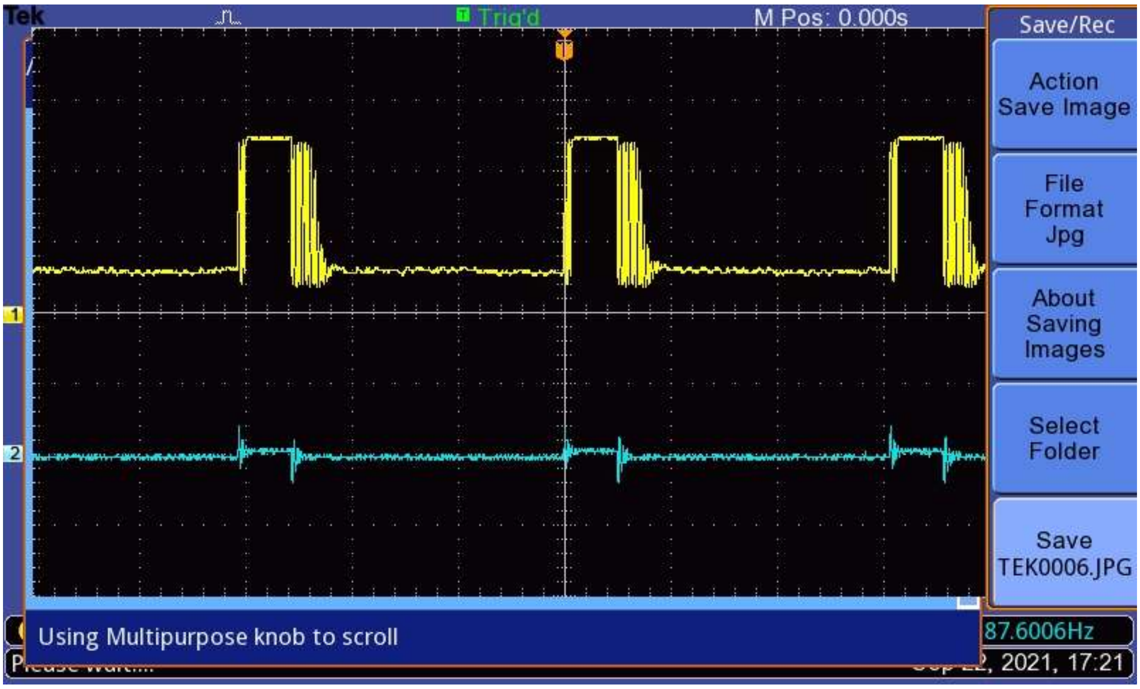
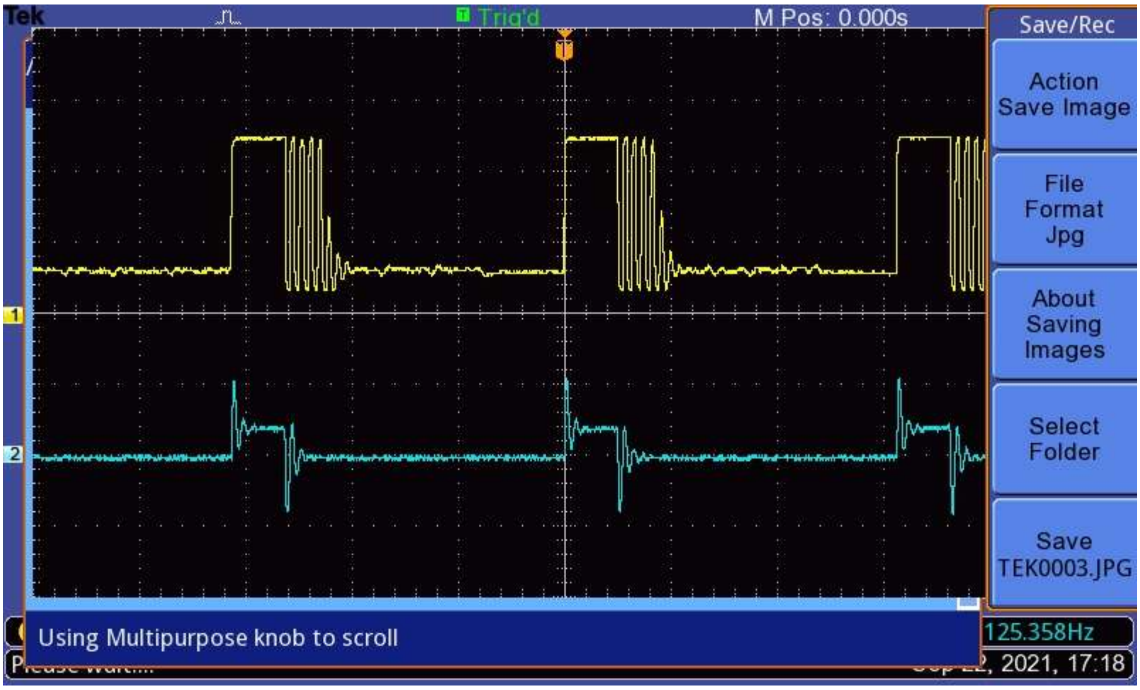


Figure 32. Oscilloscope measurement (1.5mH inductor)



Using Multipurpose knob to scroll

Figure 33. Oscilloscope measurement (10mH inductor)

4 Conclusion

The conclusion that can be drawn is that the inductance meter is suited to measure values from micro Henrys to 10mh, in line with the inductance values available in the labs. The accuracy sometimes is better than with the reference device found in the lab, and the device goes in small micro Henry range as well (for instance, for 3.3uH and 47uH values), where even reference device is unusable. The accuracy is very much acceptable. There are slight differences in the measurement range as expected from the simulation and practically for our inductance meter. This is because the components are ideal in Multisim simulation, not in real life.

Oscilloscope measurements show that oscillations are noticeable for big inductors, for example, for inductors in milli Henry range, and they are unnoticeable in small micro Henry range.

References

1 Inductor symbol [online].

URL: https://www.pngegg.com/en/png-etoqs. Accessed 15 September 2021.

2 Inductor [online].

URL: https://en.wikipedia.org/wiki/Inductor. Accessed 28 August 2021.

3 Inductor and the Effects of Inductance on an Inductor [online].

URL: https://www.electronics-tutorials.ws/inductor/inductor.html. Accessed 15 September 2021.

4 Inductance Meter [online].

URL: https://www.engineersgarage.com/inductance-meter/. Accessed 28 August 2021.

5 LC circuit [online].

URL: https://rimstar.org/science_electronics_projects/lc_circuit_aka_tank_or_resonant_circuit.html. Accessed 15 September 2021.

6 How to Make an Inductance Meter Using Arduino [online].

URL: https://electronoobs.com/eng_arduino_tut10_3.php. Accessed 24 September 2021.

7 Homemade Inductance Meter Circuit [online].

URL: https://www.youtube.com/watch?v=1YLepeKbFeQ&t=6s. Accessed 28 August 2021.

8 Simple 1.5V Inductance Meter Circuit [online]

URL: https://www.homemade-circuits.com/15-v-inductance-meter-circuit/. Accessed 24 September 2021.

9 Colpitts Oscillator [online].

URL: https://circuitdigest.com/tutorial/colpitts-oscillator. Accessed 15 September 2021.

10 LC Meter Build [online].

URL: https://www.youtube.com/watch?v=KhJiE4gL5T4. Accessed 28 August 2021.

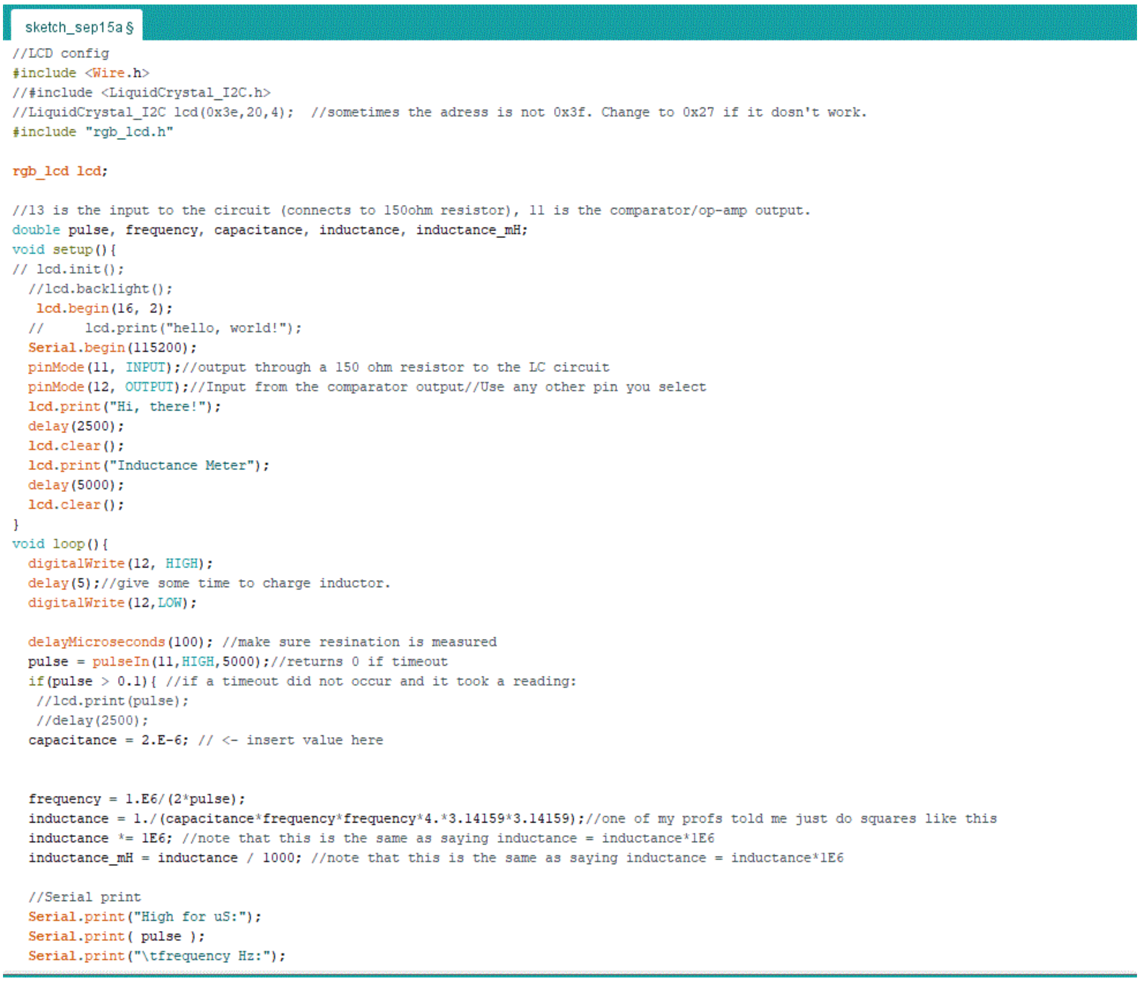
11 Inductance Meter With Arduino [online].

URL: https://www.youtube.com/watch?v=BGjV5vUvGPc. Accessed 24 September 2021.

12 Code [online].

URL: http://electronoobs.com/eng_arduino_tut10_3_code1.php. Accessed 28 August 2021.

The appendix contains the code used for the circuit [12].



sketch_sep15a §

```
//LCD config
#include <Wire.h>
//#include <LiquidCrystal_I2C.h>
//LiquidCrystal_I2C lcd(0x3e,20,4);  //sometimes the adress is not 0x3f. Change to 0x27 if it dosn't work.
#include "rgb_lcd.h"

rgb_lcd lcd;

//13 is the input to the circuit (connects to 150ohm resistor), 11 is the comparator/op-amp output.
double pulse, frequency, capacitance, inductance, inductance_mH;
void setup(){
// lcd.init();
  //lcd.backlight();
   lcd.begin(16, 2);
  //     lcd.print("hello, world!");
  Serial.begin(115200);
  pinMode(11, INPUT);//output through a 150 ohm resistor to the LC circuit
  pinMode(12, OUTPUT);//Input from the comparator output//Use any other pin you select
  lcd.print("Hi, there!");
  delay(2500);
  lcd.clear();
  lcd.print("Inductance Meter");
  delay(5000);
  lcd.clear();
}
void loop(){
  digitalWrite(12, HIGH);
  delay(5);//give some time to charge inductor.
  digitalWrite(12,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:
   //lcd.print(pulse);
   //delay(2500);
  capacitance = 2.E-6; // <- insert value here


  frequency = 1.E6/(2*pulse);
  inductance = 1./(capacitance*frequency*frequency*4.*3.14159*3.14159);//one of my profs told me just do squares like this
  inductance *= 1E6; //note that this is the same as saying inductance = inductance*1E6
  inductance_mH = inductance / 1000; //note that this is the same as saying inductance = inductance*1E6

  //Serial print
  Serial.print("High for uS:");
  Serial.print( pulse );
  Serial.print("\tfrequency Hz:");
```

```
  //Serial print
  Serial.print("High for uS:");
  Serial.print( pulse );
  Serial.print("\tfrequency Hz:");
  Serial.print( frequency );
  Serial.print("\tinductance uH:");
  Serial.println( inductance );
  //delay(10);

  //LCD print
  lcd.clear();
  lcd.setCursor(0,0);
  lcd.print("uH Inductance mH");
  lcd.setCursor(0,1);
  lcd.print(inductance);
  lcd.setCursor(10,1);
  lcd.print(inductance_mH);
  delay(10);
  }
}
```