Lab Report

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Embedded Electronics IE1206

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DC Measurements (Lab 1)

1.1 KVL, KCL and Power in resistive net

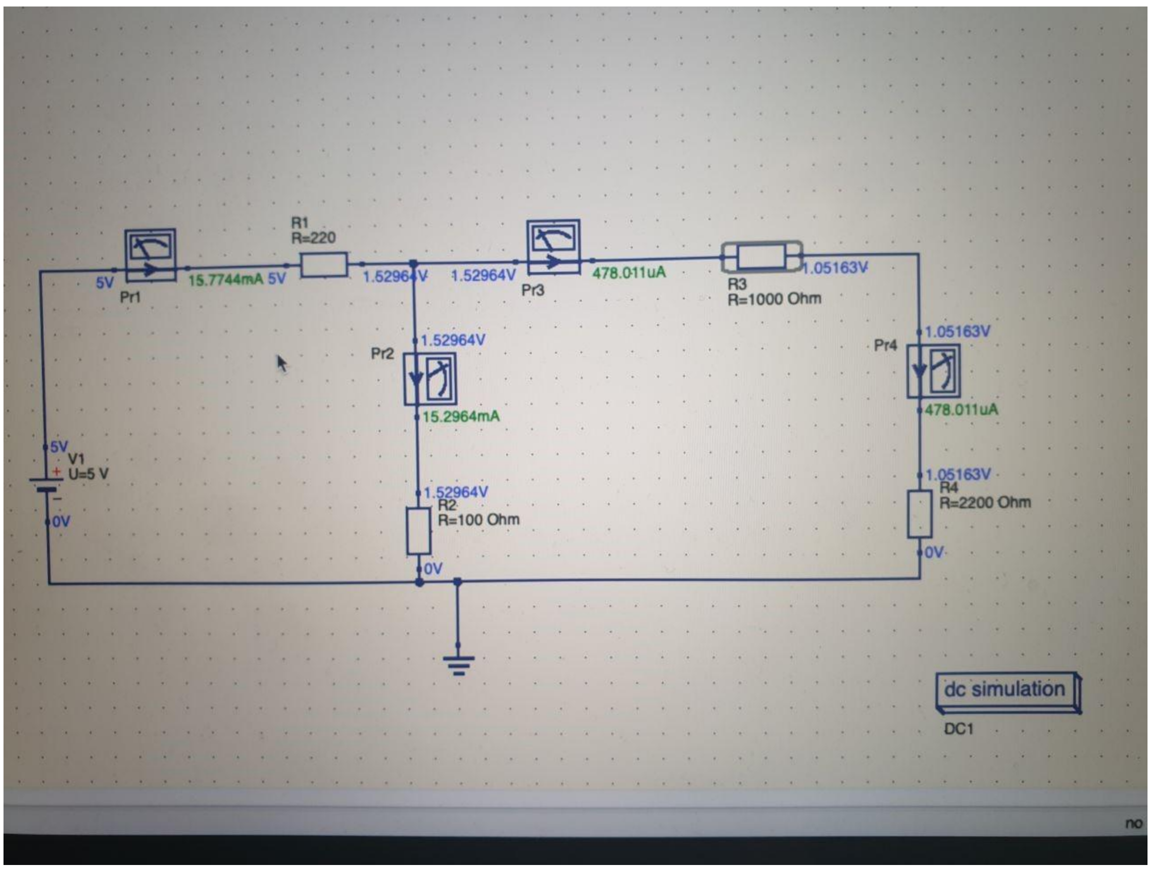


Figure 1: Circuit in Qucs

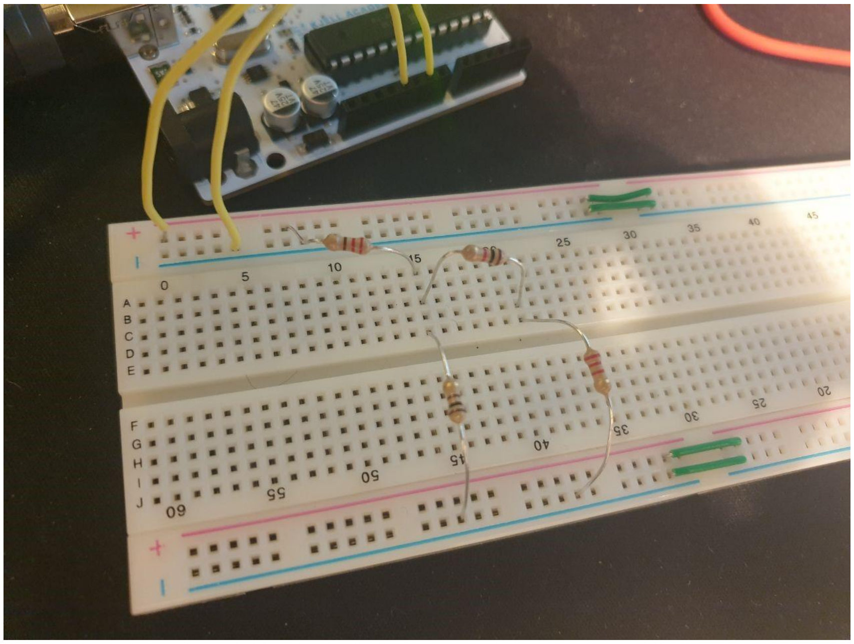


Figure 2: Built circuit on breadboard

The circuit in *Figure 1* is built and the measurements in the table below has been taken:

Comp.	Meas R Multim [kOhm]	Meas V Multim [V]	Meas I Multim [mA]	Calc R=V/I [Ohm]	Calc P=V*I [mW]	Sim V in Qucs [V]	Sim I in Qucs [mA]	Sim P Qucs [mW]
R1	0.22	3.48	15.6	0.22	54.3	3.47	15.8	54.8
R2	0.1	1.53	15	0.1	22.3	1.53	15.3	23.4
R3	1	0.47	0.48	0.98	0.226	0.478	0.478	0.229
R4	2.2	1.05	0.48	2.19	0.5	1.05	0.478	0.5
Arduino 5V Voltage source	Not applicable	5.06	15.6	Not Applicable	78.9	5	15.8	79

Table 1: Measurements from Qucs and the built circuit

Observations:

- **Are they the same within the measurement/simulation accuracy?**

They are almost the same with some slight differences which can be due to the multimeter not being accurate enough, human error with measurements or voltage source and resistors not having the quantity they should have (low quality resistors).

- **Confirm KVL in closed loop V - R1 - R2 and closed loop R2 - R3 -R4 within measurement accuracy:**

KVL (simulation):

V-R1-R2 = 5 – 3.47 - 1.53 = 0v

R2-R3-R4 = 1.53 - 0.478 - 1.05 = 0v

KVL (measured):

V-R1-R2 = 5.06 - 3.48 - 1.53 ≈ 0v

R2-R3-R4 = 1.53 - 0.47 - 1.05 ≈ 0v

The KVL in both simulation and on breadboard are 0v.

- **Confirm KCL in the node R1 - R2- R3 within measurement accuracy:**

  KCL (simulation):

  I1 = 15.8 mA

  I2 = 15.3 mA

  I3 = 0.478 mA

  => I1 = I2 + I3

  KCL (measured):

  I1 = 15.6 mA

  I2 = 15 mA

  I3 = 0.48 mA

  ≈> I1 = I2 + I3

  Both the simulation and breadboard circuit give the same KCL.

- **Is the power balanced in the circuit given the measurement accuracy?**

Yes, voltage Source delivers ca 79mW power to the circuit while all the other components consume around 79mW power combined (P1 + P2 + P3 + P4 =54.8+ 23.4 + 0.23 + 0.5 ≈ 79).

1.2 Determine Thevenin equivalent circuits

1.2.1 Thevenin Equivalent circuit for Arduino 5v Pin

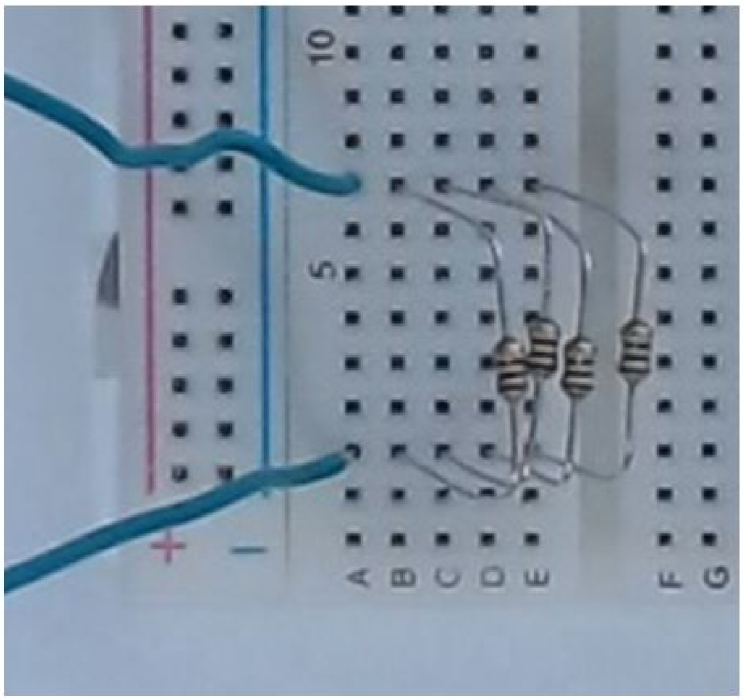


Figure 3: Four resistors in parallel on a breadboard powered by 5V supply from Arduino

4 resistors are connected in parallel as shown in *Figure 3*.

Observations:

- **Measure the equivalent resistance with the multimeter.**

  R = 25 Ω

- **Measure the voltage on the Arduino 5V supply when it is unloaded (i.e. not connected to anything).**

  V = 5.1 v

- **Connect the Arduino 5 V supply to the four parallel connected resistors on the breadboard and measure the voltage over the resistors.**

  V = 4.75 v

- **Calculate V_{TH} and R_{TH} of the Arduino 5V supply from the measurements.**

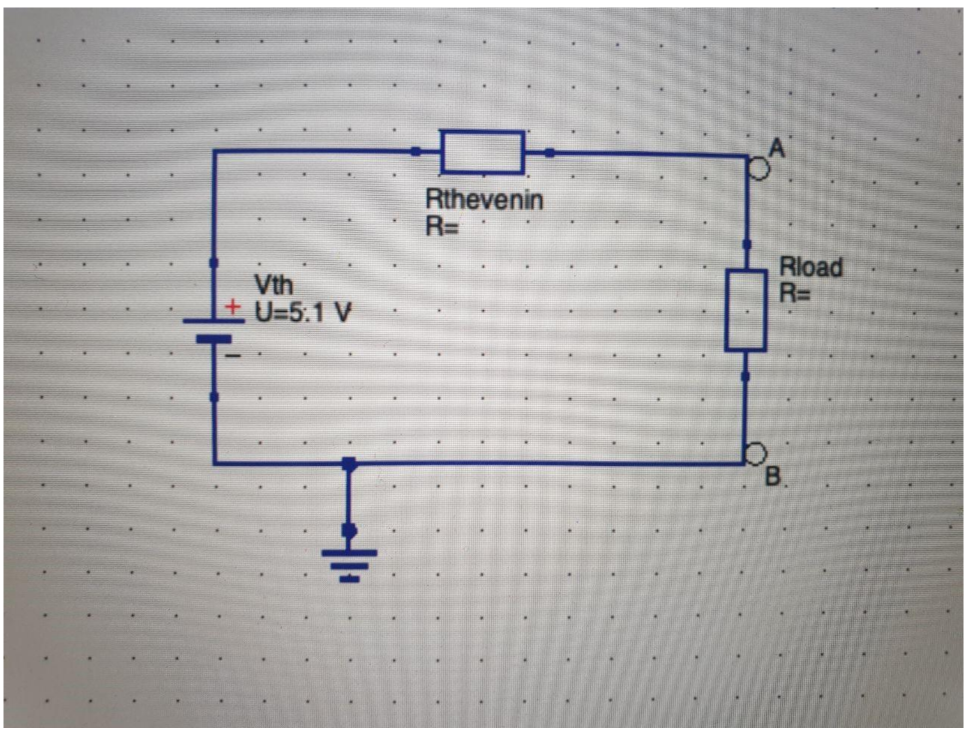


Figure 4: R(Thevenin) and V(Thevenin) for nodes A and B

V (Thevenin) = 5.1v

V (loaded) = 4.75v

R (loaded) = 25 Ω

We have:

$$V_L = R_L . I_L = R_L . \frac{V_{Th} - V_L}{R_{TH}}$$

Which gives us:

$$R_{th} = R_L (\frac{V_{th}}{V_L} - 1)$$

So:

R_{TH} = 25(5.1/4.75 - 1) = 1.84 Ω

V_{TH} = V (unloaded) = 5.1v

1.2.2 Thevenin Equivalent for Arduino output pin

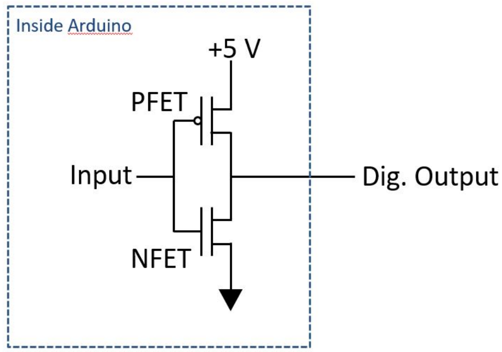


Figure 5: the inverter that is connected to the digital output pin that is accessible from the outside

We study the Thevenin Equivalent of the output pin from the Arduino that is shown in *Figure 5*.

Case 1: digital output pin is high

Pin 11 in Arduino is high. We use a 220Ω resistor.

Output voltage from the pin and GND: 5.06 V

Voltage over 220 Ω resistor connected to the pin and GND: 4.48v

Using the same concept as 1.2.1:

V (Thevenin) = 5.06v

V (loaded) = 4.48v

R (loaded) = 220 Ω

$$R_{th} = R_L\left(\frac{V_{th}}{V_L} - 1\right)$$

R_{TH} = 220(5.06/4.48 - 1) = 28 Ω

V_{TH} = V (unloaded) = 5.06v

Case 2: digital output pin is low

Pin 10 in Arduino is low. We use a 220Ω resistor.

Output voltage from the pin and GND: 0 V

Voltage over 220 Ω resistor connected to the pin and VCC: 4.6v

Voltage from the pin to GND = 0.45v

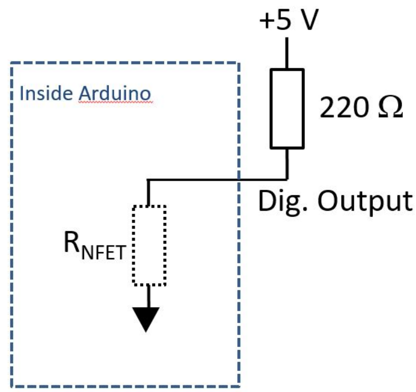


Figure 6: the output pin from the Arduino when it is set low

$I = V/R = 4.6 / 220 = 0.02$ mA

$R_{TH} = V/I = 0.45 / (4.6/220) = 21.5\ \Omega$

$V_{TH} = 0.45$v

1.3 Light Emitting Diode (LED) circuits

1.3.1 Resistor in series with yellow LED

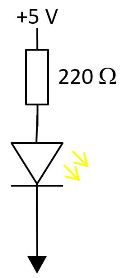


Figure 7: yellow LED with resistor

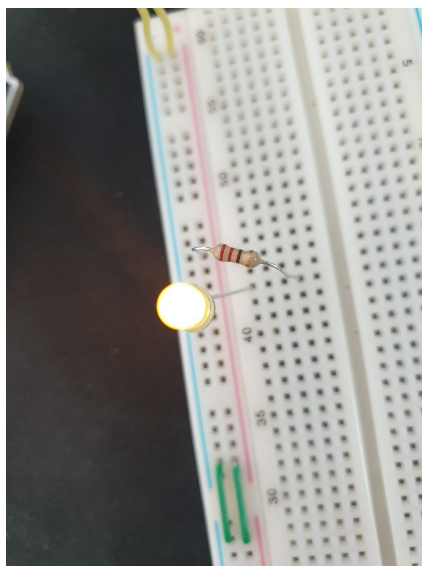


Figure 8: yellow LED on breadboard

Voltage over the 220-resistor: 3v

Forward voltage drop over the LED: 2v

Current in the LED = V/R = 3/220 = 13.6 mA

Consumed power by the LED = V*I = 2*13.6 = 27.2mW

1.3.2 Resistor in series with blue LED

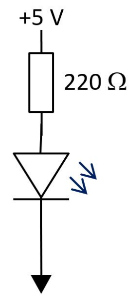


Figure 9: blue LED with resistor

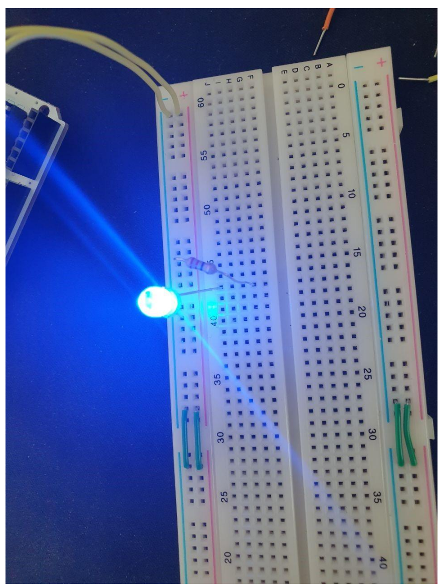


Figure 10: blue LED on breadboard

Voltage over the 220-resistor: 2.3v

Forward voltage drop over the LED: 2.75v

Current in the LED = V/R = 2.3/220 = 10.45 mA

Consumed power by the LED = V*I = 2.75*10.45 = 28.7mW

1.3.3 Resistor in series with a yellow and blue LED connected in parallel

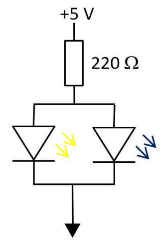


Figure 11: blue and yellow LED in parallel

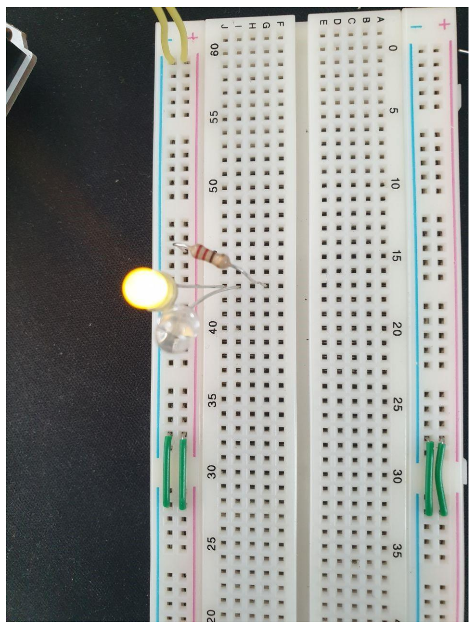


Figure 12: parallel blue and yellow LED on breadboard

Forward voltage drop over both LEDs: 2v

Observations:

The yellow LED only shines because the forward voltage over the blue LED is much higher (2.75v) than over the yellow (2v). Therefore, the yellow LED takes all the current and shines while the blue LED stays off.

1.3.4 Resistor in series with a yellow and blue LED connected in series

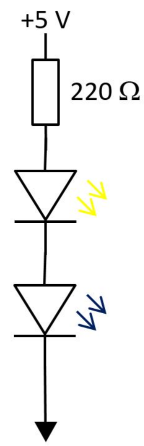


Figure 13: yellow and blue LED in series

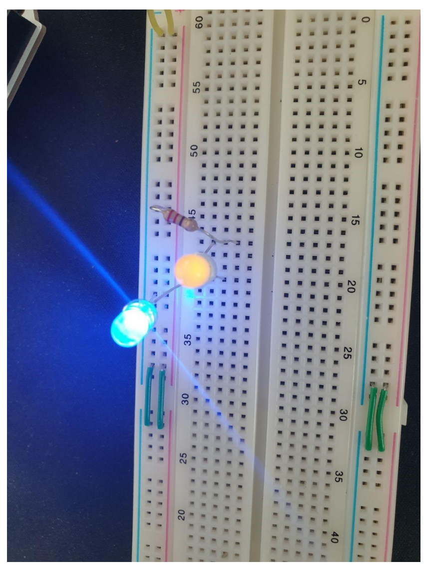


Figure 14: series yellow and blue LED on breadboard

Voltage over the 220-resistor: 0.65v

Forward voltage drop over yellow LED: 1.82v

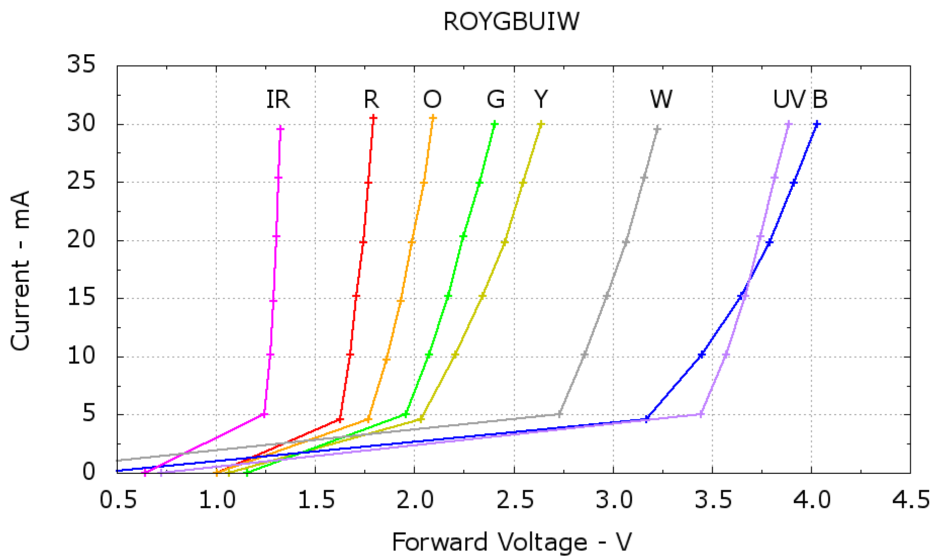
Forward voltage drop over blue LED: 2.6v

Current in the circuit = V/R = 0.65/220 = 2.95 mA

Observations:

The yellow LED shines a little bit while the blue LED shines a lot more.

We can see that the LED does not work like a switch, and it still passes current even if the voltage-drop over the LED is lower than Vf (forward voltage):



So, while the voltage-drop over the yellow LED is only 1.82v (lower than Vf=2v), it still lets 2.95 mA current pass through it and therefore it shines a little bit, but the blue LED has the voltage drop of 2.6v which is almost at its Vf-level.

Time Dependent Circuits (Lab 2)

2.1 Time Dependent Behavior of RL Circuit

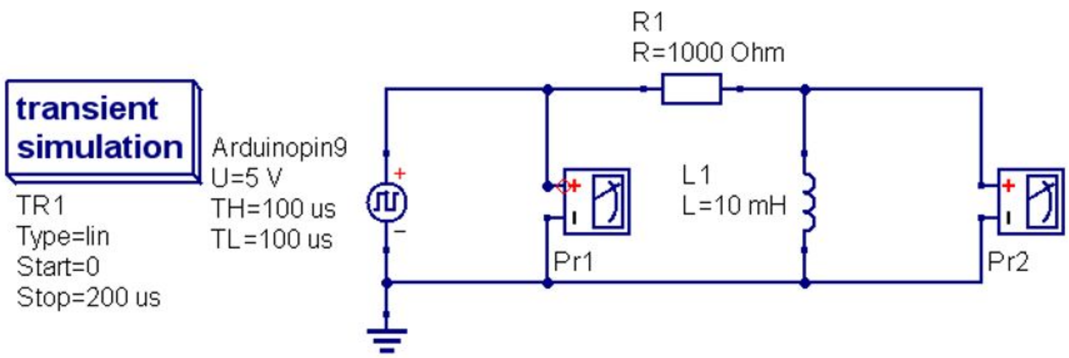


Figure 15: Simulation in Qucs

The circuit in *Figure 15* is simulated and built and the following results have been received.

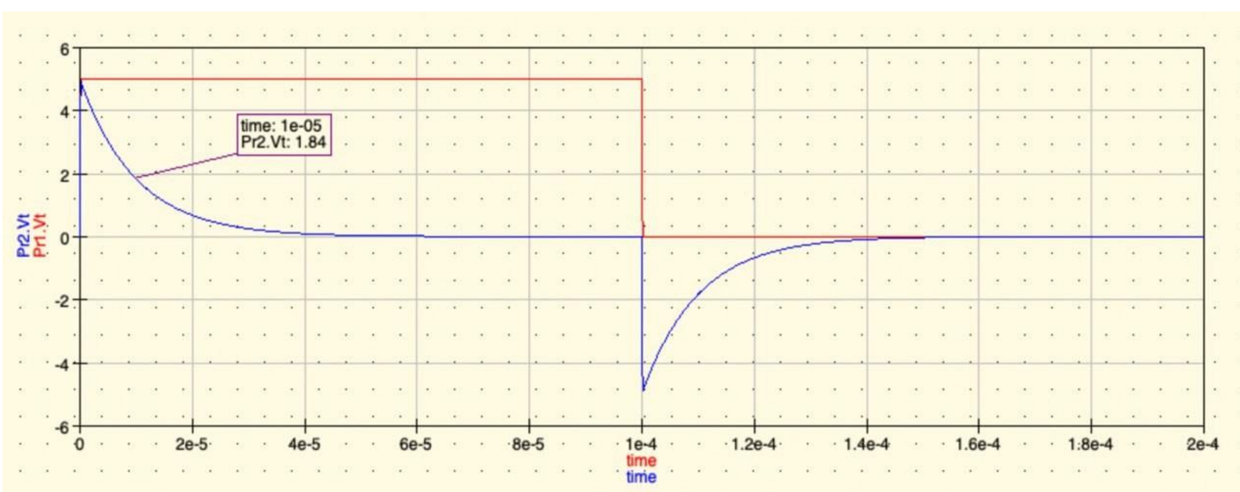


Figure 16: Graph of Pr1 and Pr2 in Qucs

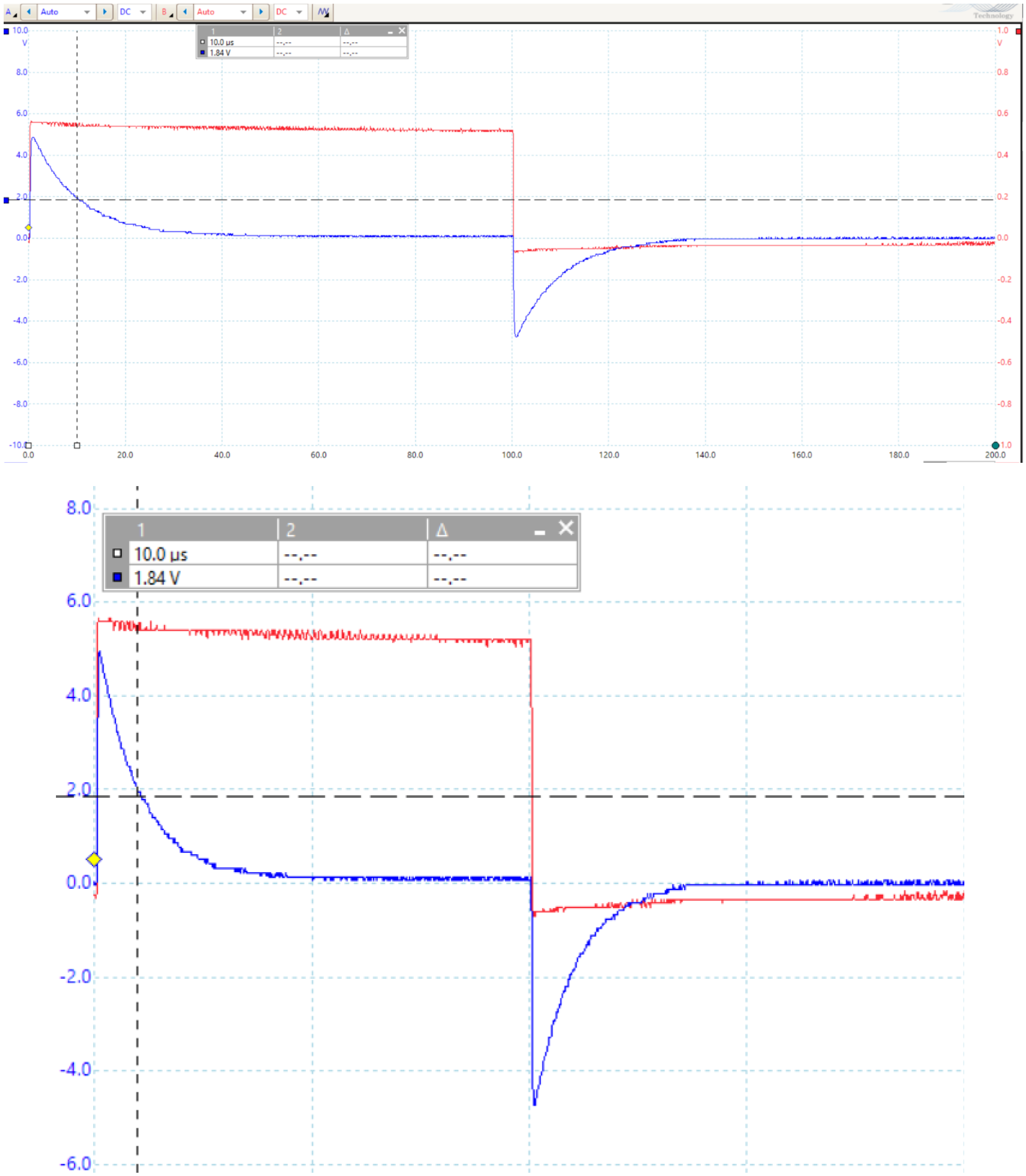


Figure 17: Graph of Pr1 and Pr2 measured by PicoScope

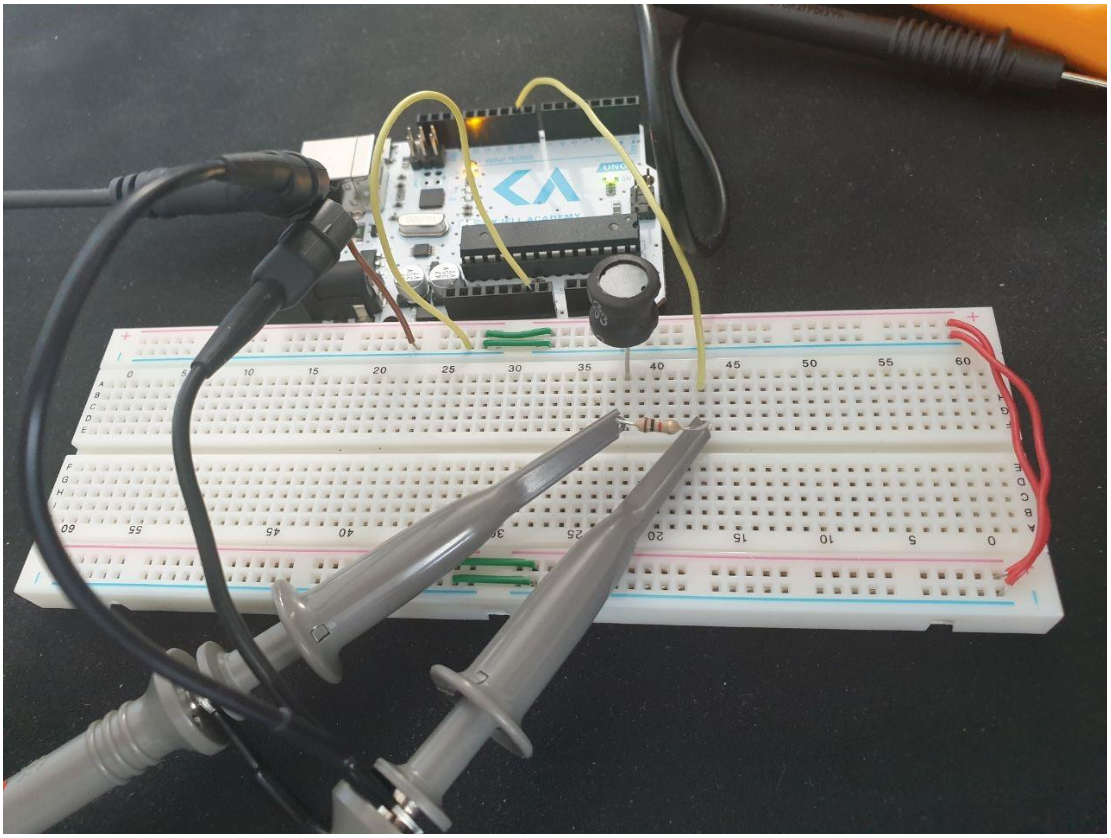


Figure 18: The built circuit on breadboard

Time constant τ (L/R):

- Calculated with formula L/R: 10mH/1000 Ω = 0.01 ms = 10 us
- Determined in Qucs: $\tau = t(\frac{V_0}{e})$= t(1.84v) = 10 us
- Measured in PicoScope: t(1.84v) = 10 us

Two inductors in parallel:

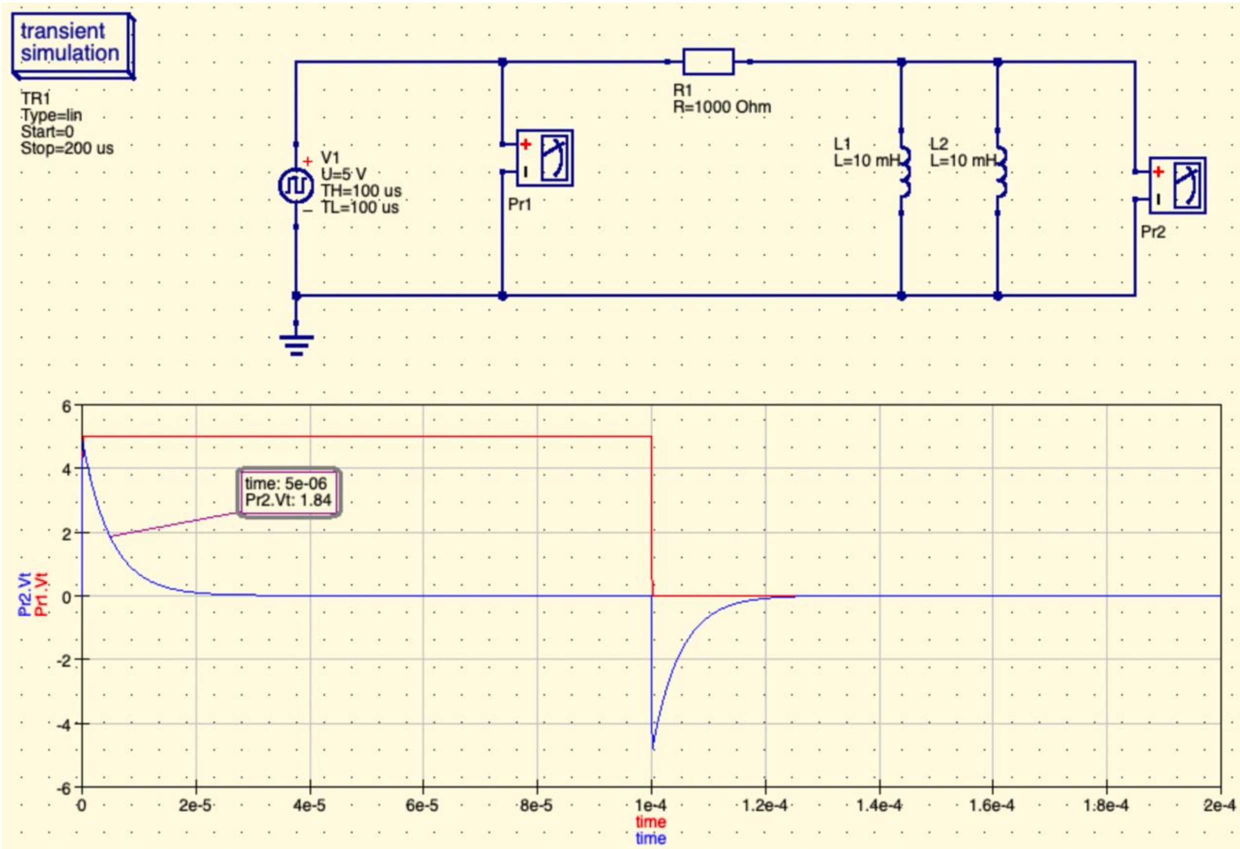


Figure 19: The circuit of two parallel inductors in Qucs and its graph of Pr1 and Pr2

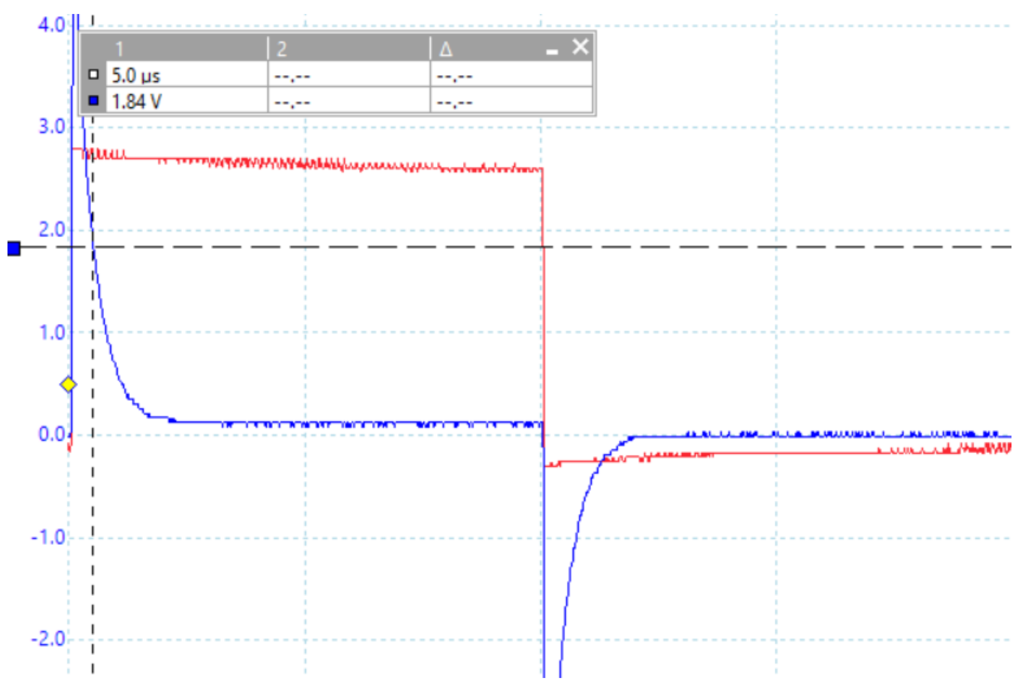


Figure 20: graph of Pr1 and Pr2 measured by PicoScope

We know that:

$$L_{parallel} = \frac{1}{\frac{1}{L1}+\frac{1}{L2}} = 5mH$$

So we can now calculate the time constant:

Time constant τ (L/R):

- Calculated with formula L/R: 5mH/1000 Ω = 0.005 ms = 5 us
- Determined in Qucs: = t(1.84v) = 5 us
- Measured in PicoScope: t(1.84v) = 5 us

Two inductors in series:

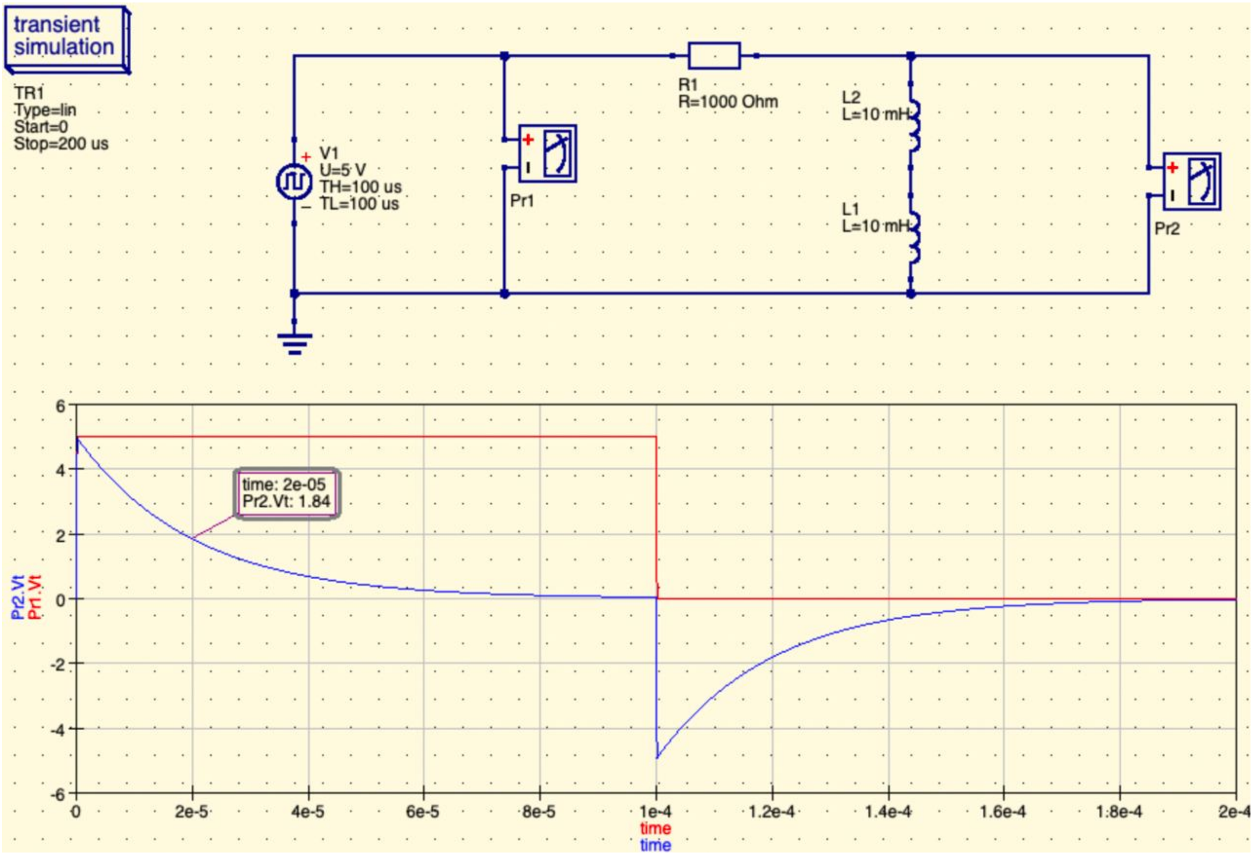


Figure 21: The circuit of two inductors in series in Qucs and its graph of Pr1 and Pr2

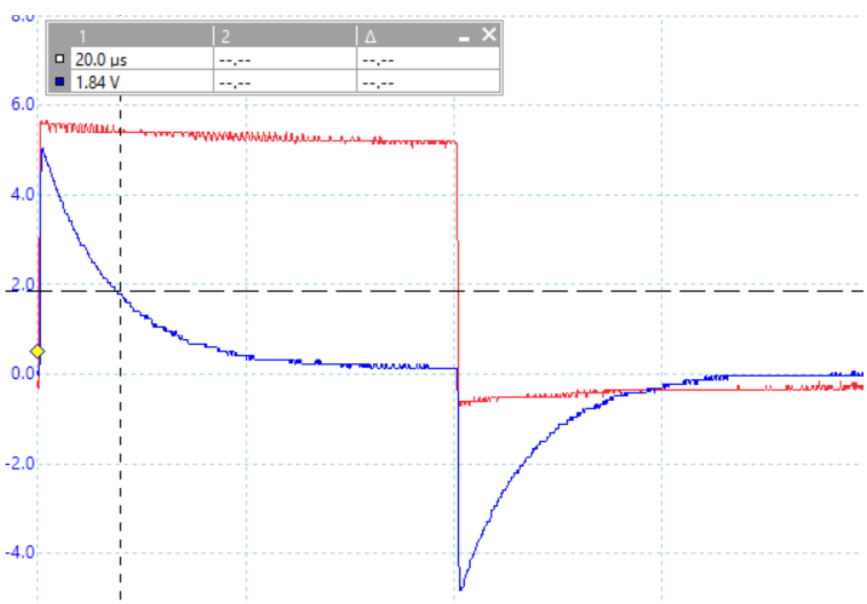


Figure 22: graph of Pr1 and Pr2 measured by PicoScope

We know that:

$$L = 10mH + 10mH = 20mH$$

So we can calculate the time constant:

Time constant τ (L/R):

- Calculated with formula L/R: 20mH/1000 Ω = 0.02 ms = 20 us
- Determined in Qucs: = t(1.84v) = 20 us
- Measured in PicoScope: t(1.84v) = 20 us

2.2 Time Dependent Behavior of RC Circuit

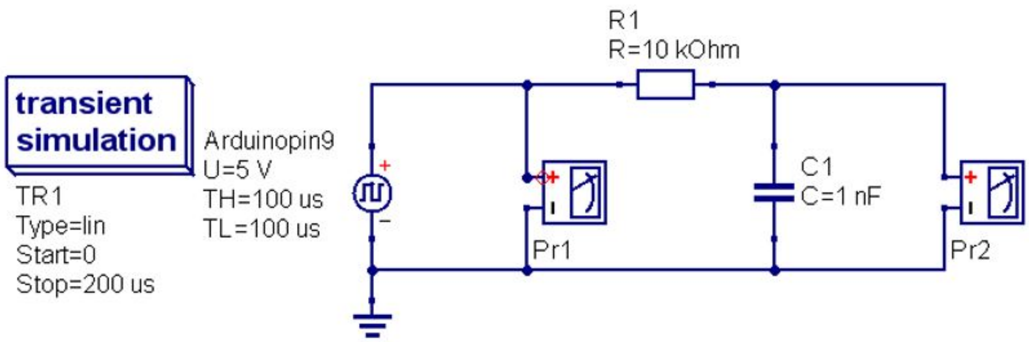


Figure 23: Simulation in Qucs

The circuit in *Figure 23* is simulated and built and the following results have been received.

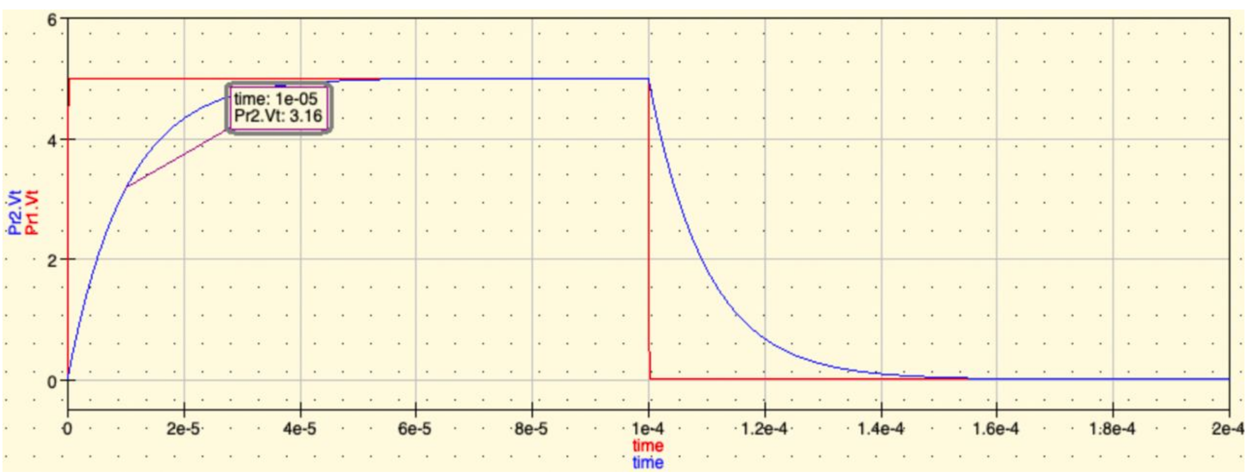


Figure 24: Graph of Pr1 and Pr2 in Qucs

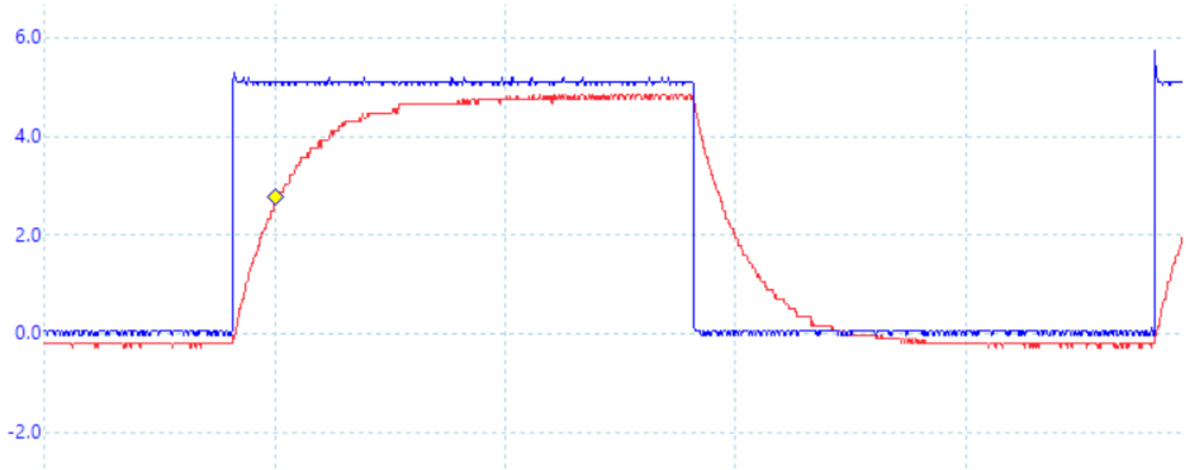


Figure 25: Graph of Pr1 and Pr2 measured by PicoScope

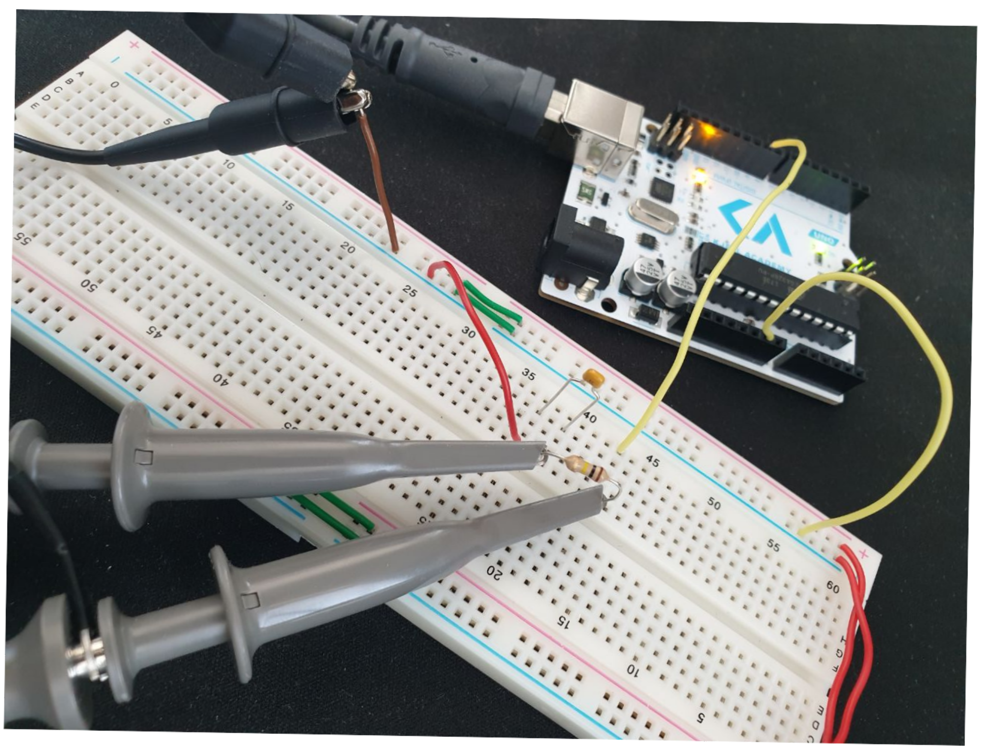


Figure 26: The built circuit on breadboard

Time constant τ (C*R):

- Calculated with formula C*R: 1nF*10000 Ω = 0.01 ms = 10 us
- Determined in Qucs: $\tau = t(V_0 - \frac{V_0}{e})$= t(5 - 1.84v) = t(3.16v) = 10 us
- Measured in PicoScope: t(3.16v) = 10 us

Two capacitors in parallel:

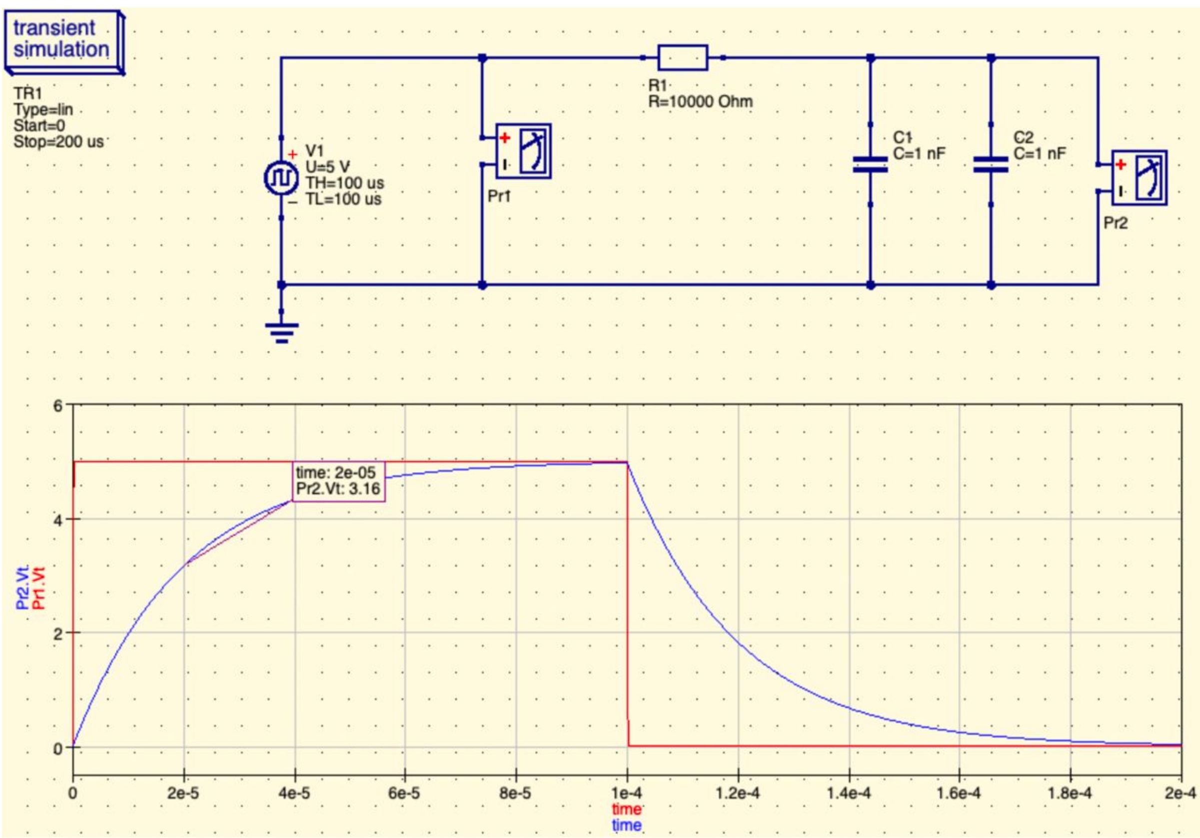


Figure 27: The circuit of two parallel inductors in Qucs and its graph of Pr1 and Pr2

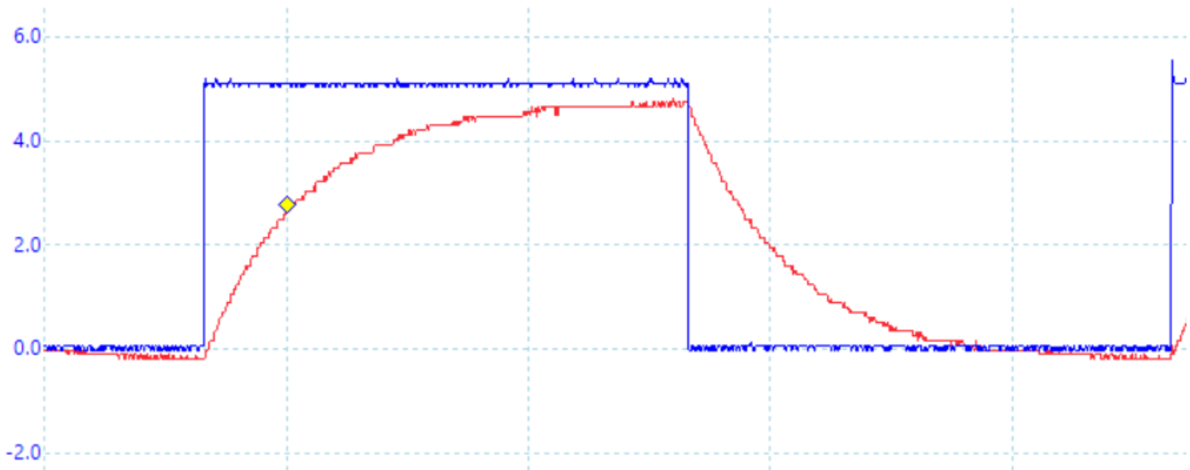


Figure 28: graph of Pr1 and Pr2 measured by PicoScope

We know that:

$$C = 1nF + 1nF = 2nF$$

So we can now calculated the time constant:

Time constant τ (C*R):

- Calculated with formula C*R: 2nF*10000 Ω = 0.02 ms = 20 us
- Determined in Qucs: == t(5 - 1.84v) = t(3.16v) = 20 us
- Measured in PicoScope: t(3.16v) = 20 us

Two capacitors in series:

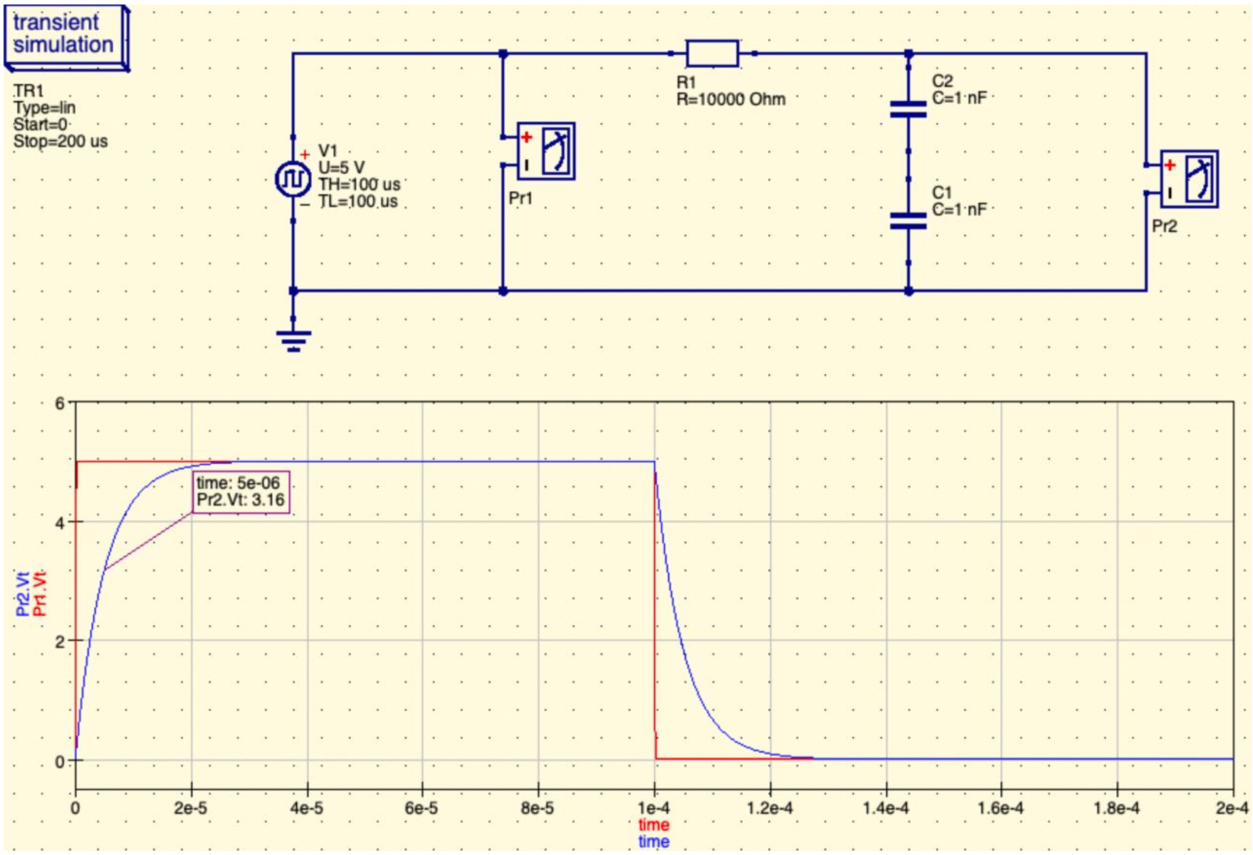


Figure 29: The circuit of two inductors in series in Qucs and its graph of Pr1 and Pr2

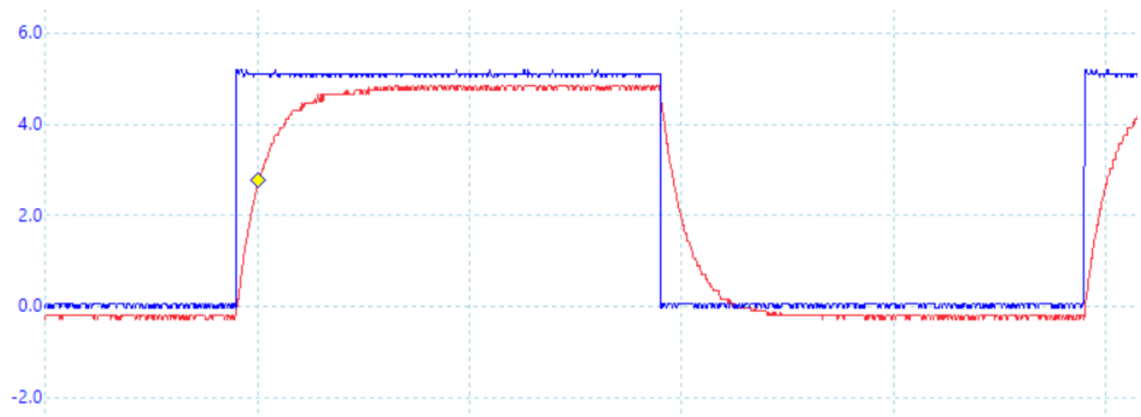


Figure 30: graph of Pr1 and Pr2 measured by PicoScope

We know that:

$$C_{series} = \frac{1}{\frac{1}{C1}+\frac{1}{C2}}$$ = 5*10^-10 F = 0.5 nF

So we can now calculate the time constant:

Time constant τ (C*R):

- Calculated with formula C*R: 0.5nF*10000 Ω = 5 us
- Determined in Qucs: == t(5 - 1.84v) = t(3.16v) = 5 us
- Measured in PicoScope: t(3.16v) = 5 us

2.3 Diode Rectifier Circuit with Resistor and Capacitor

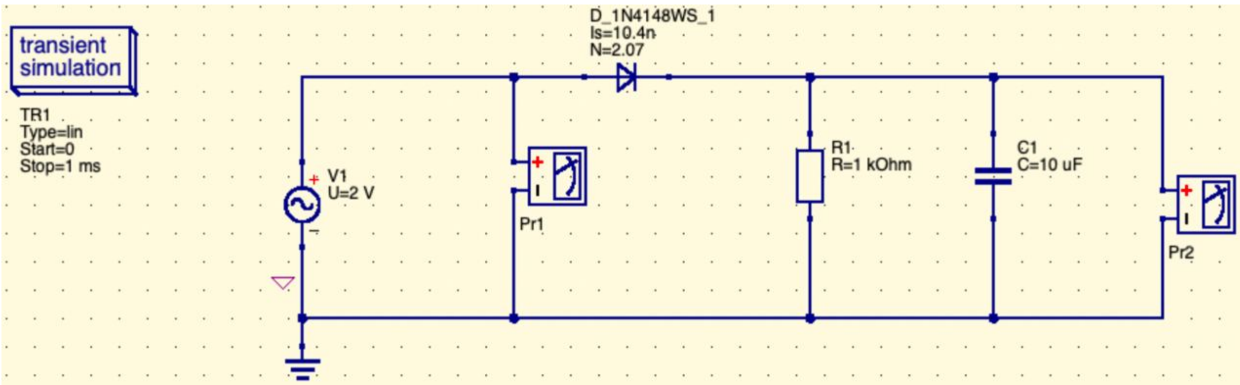


Figure 31: The circuit in Qucs

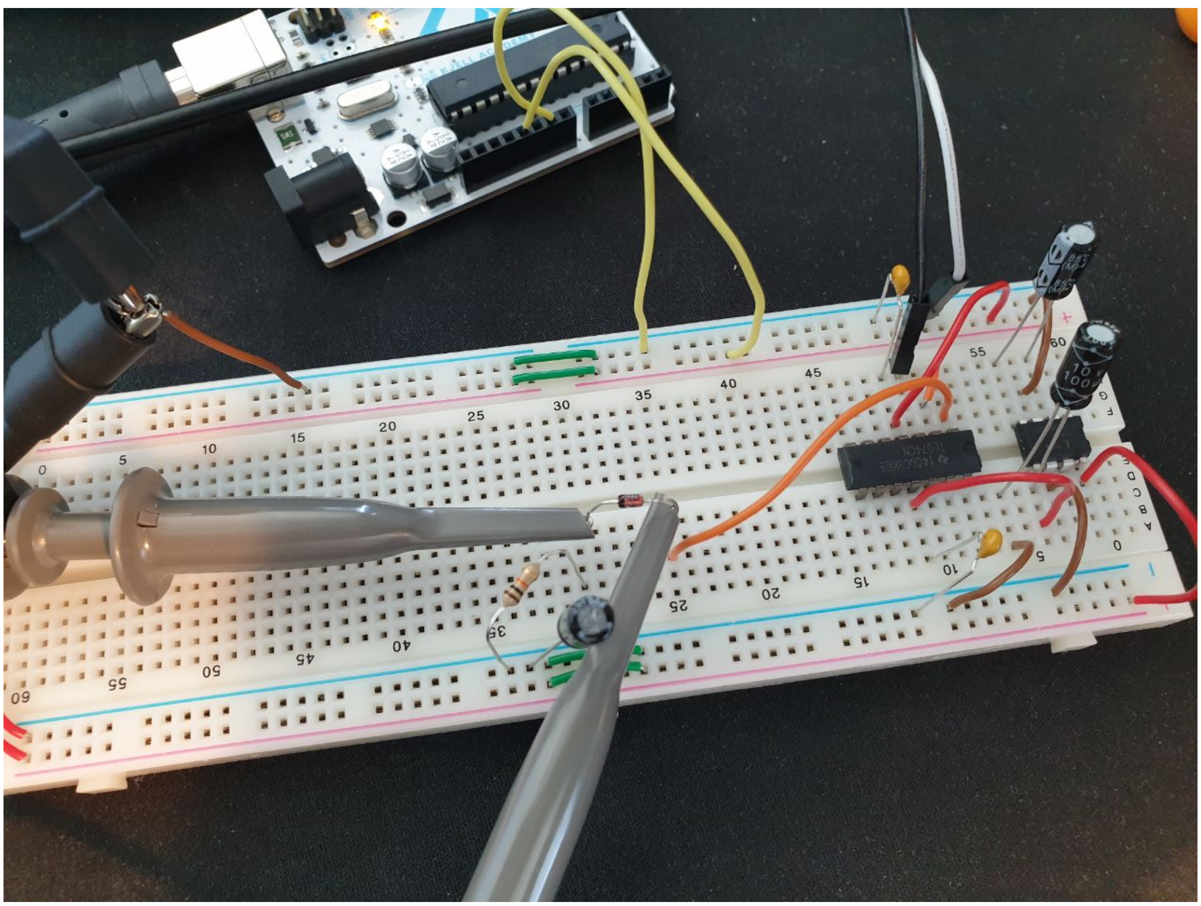


Figure 32: The built circuit on breadboard

Circuit simulation **without** the capacitor:

The results of the simulation are as below:

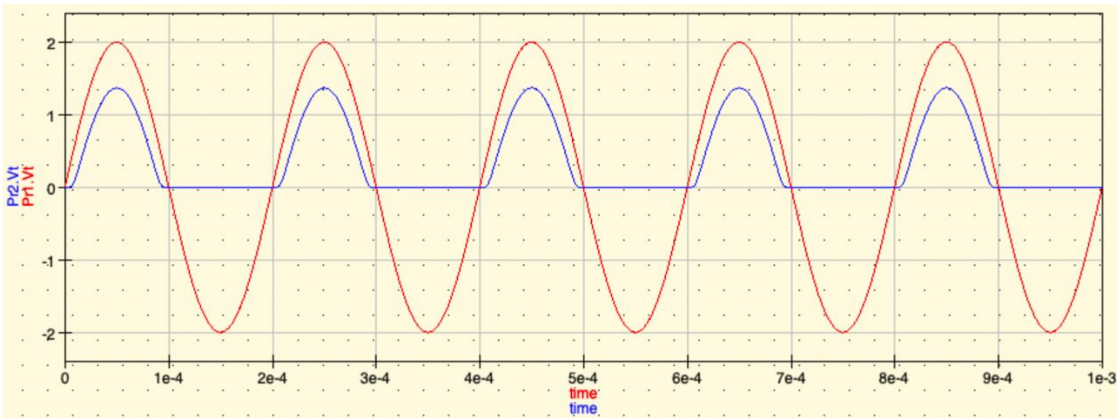


Figure 33: The graph of Pr1 and Pr2 in Qucs

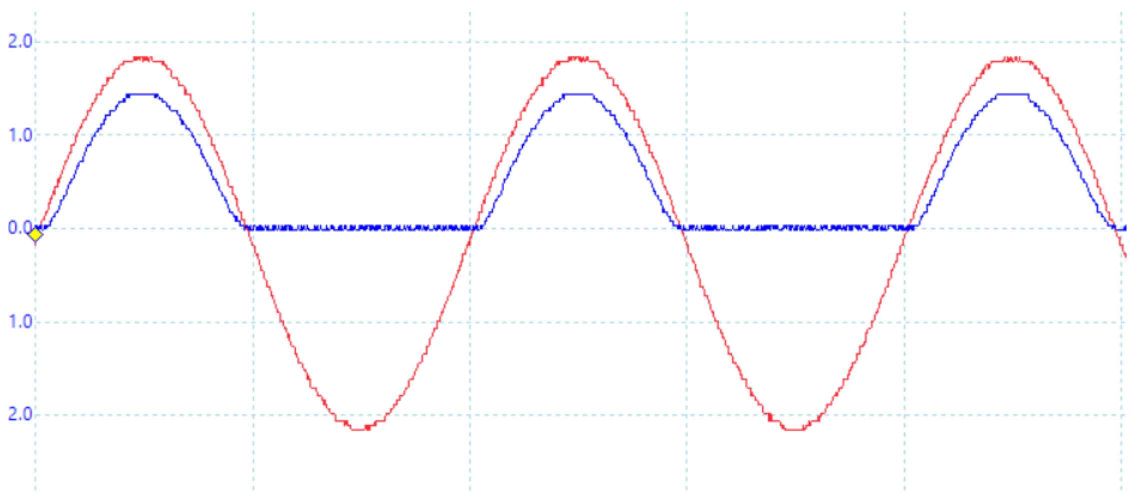


Figure 34: The graph of Pr1 and Pr2 measured by PicoScope

Observations:

This circuit omits the negative voltage part of the AC input. The output voltage is always positive in this case (or zero when AC input is negative)

Circuit simulation **with** the capacitor:

The results of the simulation are as below:

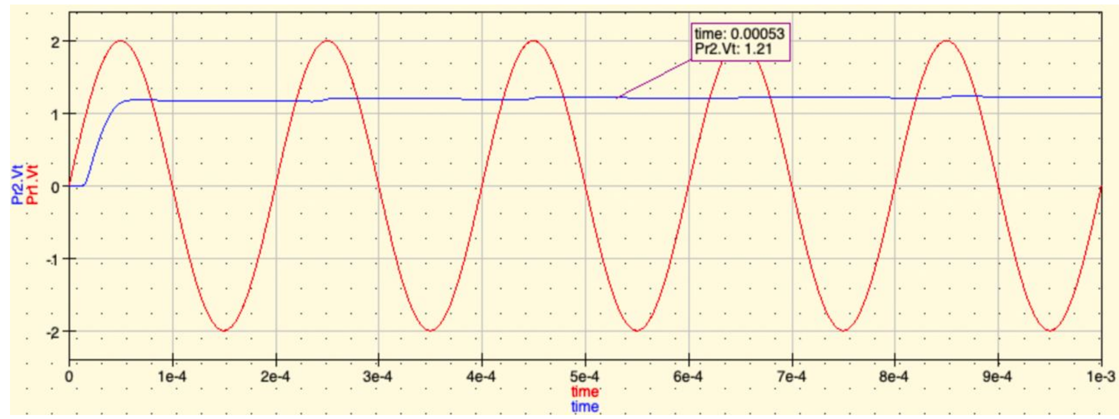


Figure 35: The graph of Pr1 and Pr2 in Qucs

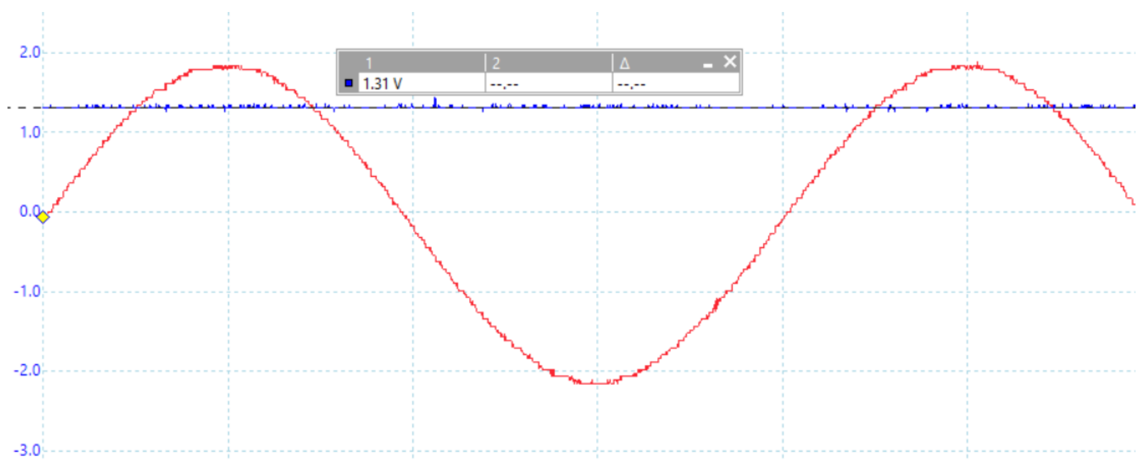


Figure 36: The graph of Pr1 and Pr2 measured by PicoScope

Observations:

This circuit acts like an AC to DC converter. It converts the sinus voltage coming from the AC input to a constant 1.2/1.3 v DC going to the output.

Determining Vth and Rth by connecting a 220Ω resistor to the DC output:

V (Thevenin) = 1.3v

V (loaded) = 0.66v

R (loaded) = 220 Ω

We know that:

$$R_{th} = R_L\left(\frac{V_{th}}{V_L} - 1\right)$$

So:

R_{th} = 220(1.3/0.66 -1) = 213 Ω

AC Measurements (Lab3)

3.1 RL Filter

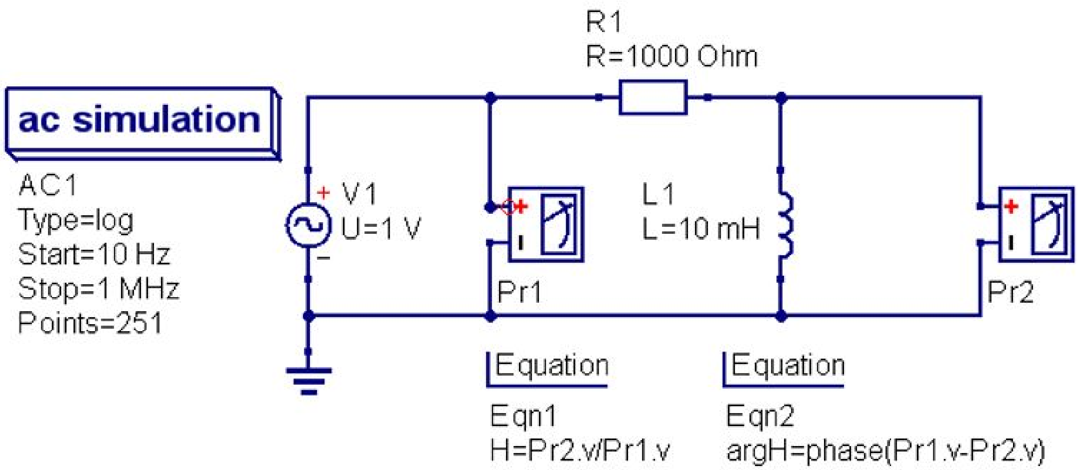


Figure 37: the RL circuit that has been examined

The circuit shown in *Figure 37* is built and simulated in Qucs to study cut-off frequency of the circuit:

Calculated cut-off frequency based on the components R1 and L1:

We know that:

R = 1000 Ω

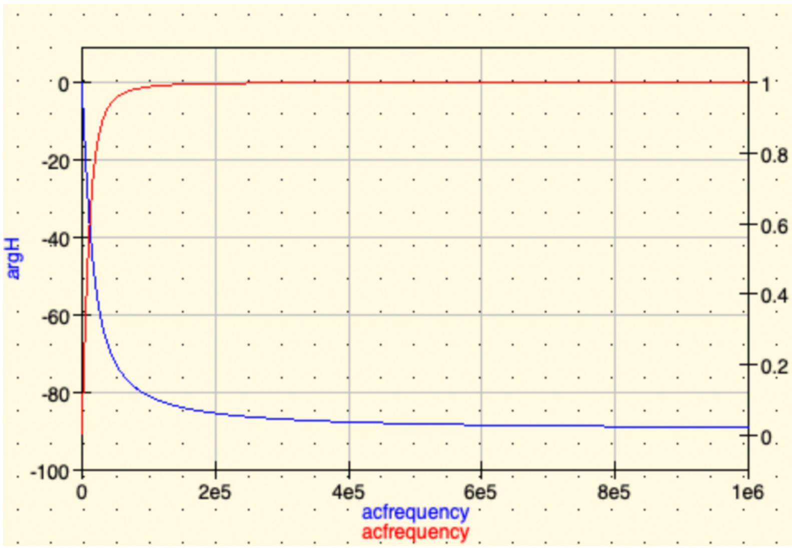
L = 10 mH

$$f_c = \frac{R}{2\pi L}$$

So:

$$f_c = \frac{1000}{2\pi 10^{-2}} = 15.9\ kHz$$

Determined cut-off frequency in Qucs:



acfrequency	argH	H
1.2e4	-37.1	0.603 / 52.9°
1.26e4	-38.3	0.62 / 51.7°
1.32e4	-39.6	0.638 / 50.4°
1.38e4	-40.9	0.655 / 49.1°
1.45e4	-42.2	0.672 / 47.8°
1.51e4	-43.6	0.689 / 46.4°
1.58e4	-44.9	0.706 / 45.1°
1.66e4	-46.2	0.722 / 43.8°
1.74e4	-47.5	0.737 / 42.5°
1.82e4	-48.8	0.753 / 41.2°
1.91e4	-50.1	0.767 / 39.9°
2e4	-51.4	0.782 / 38.6°
2.09e4	-52.7	0.795 / 37.3°
2.19e4	-54	0.809 / 36°
2.29e4	-55.2	0.821 / 34.8°
2.4e4	-56.4	0.833 / 33.6°
2.51e4	-57.6	0.845 / 32.4°
2.63e4	-58.8	0.856 / 31.2°
2.75e4	-60	0.866 / 30°
2.88e4	-61.1	0.876 / 28.9°
3.02e4	-62.2	0.885 / 27.8°
3.16e4	-63.3	0.893 / 26.7°
3.31e4	-64.3	0.901 / 25.7°
3.47e4	-65.3	0.909 / 24.7°

Figure 38: Simulation of RL filter on Qucs

We know that the cut-off frequency is the frequency when

$$H = \frac{V_{out}}{V_{in}} = \frac{1}{\sqrt{2}}$$

which means H should be around 0.7 v. By looking at the Qucs simulation we see that the frequency is around 15.8 kHz when H = 0.7 v.

Investigating the responses to different frequencies in Picoscope:

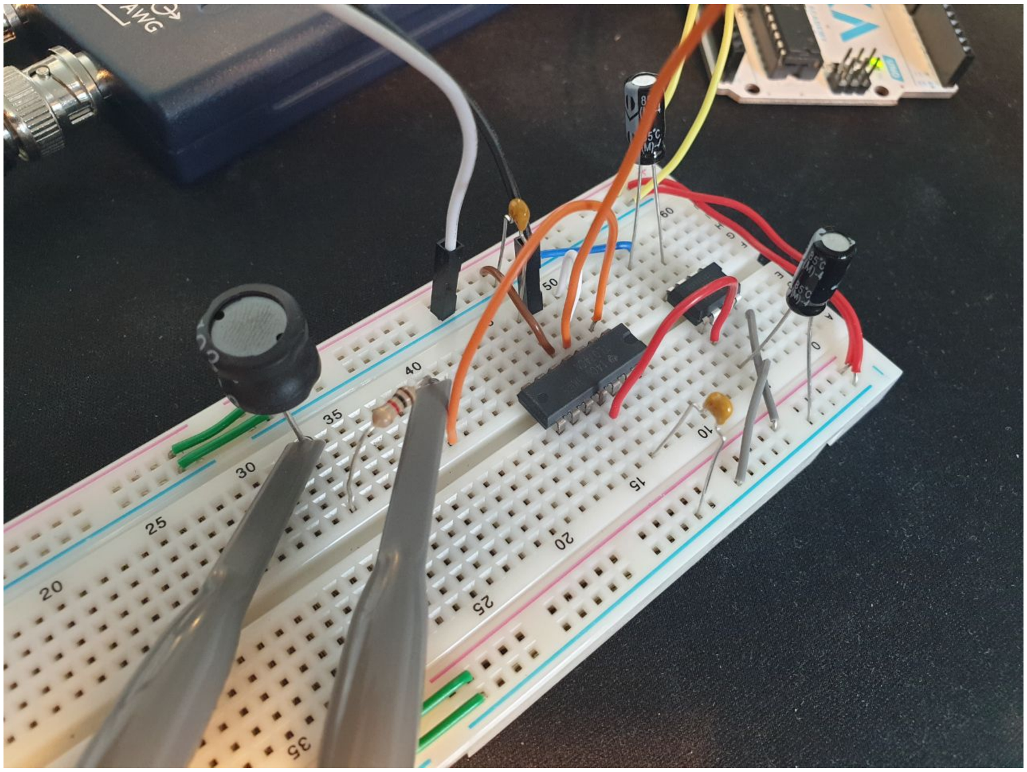


Figure 39: The built circuit on breadboard including Op-amp

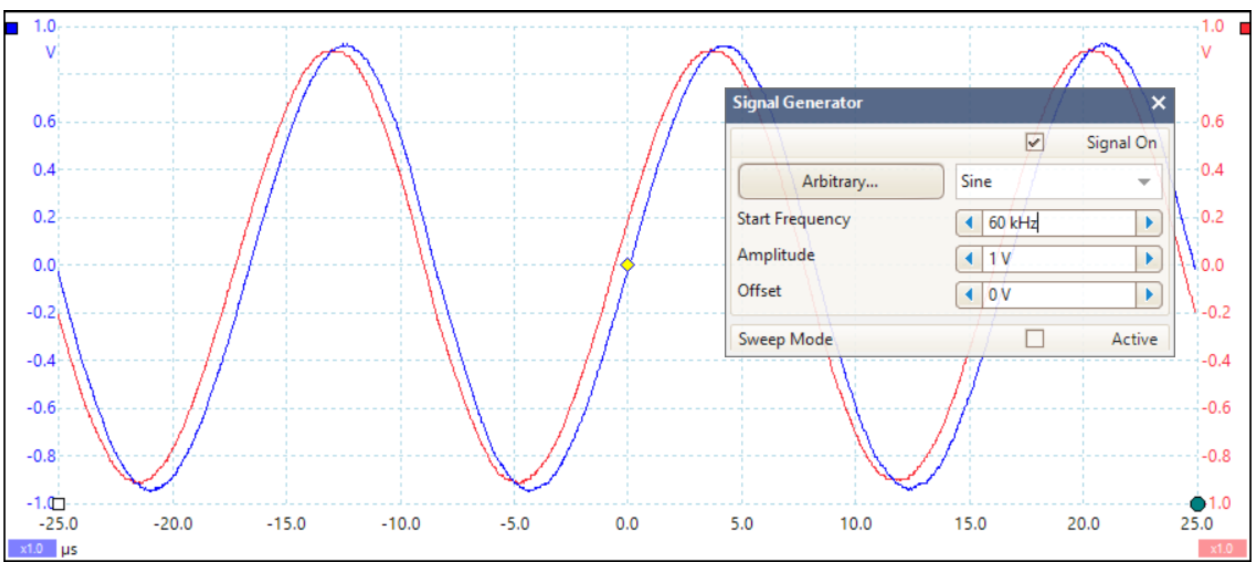


Figure 40: Vout and Vin measured in Picoscope with 60 kHz frequency

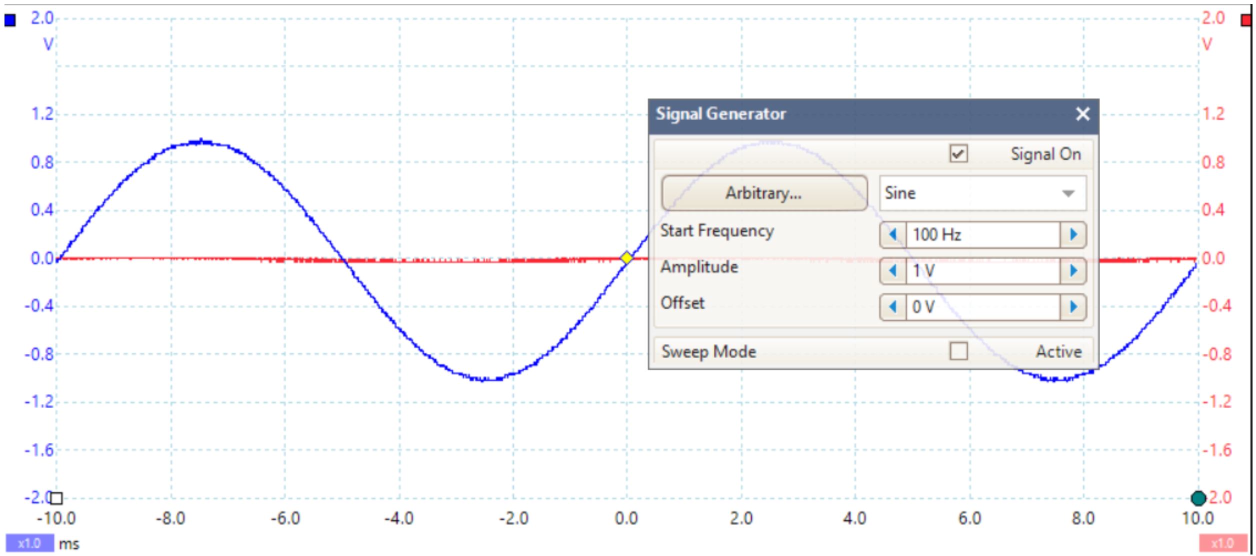


Figure 41: Vout and Vin measured in Picoscope with 100 Hz frequency

The measurements in Picoscope show that at lower frequencies (lower than Vf), the output voltage is almost 0v while at higher frequencies (higher than Vf) the output voltage is almost the same as input.

The amplitude of the voltage at the output of the filter at a frequency of 100 Hz is around 0v.
The amplitude of the voltage at the output of the filter at a frequency of 80 kHz is around Vin.
According to the calculations and measurements above, the filter is a high pass filter.

3.2 RC Filter

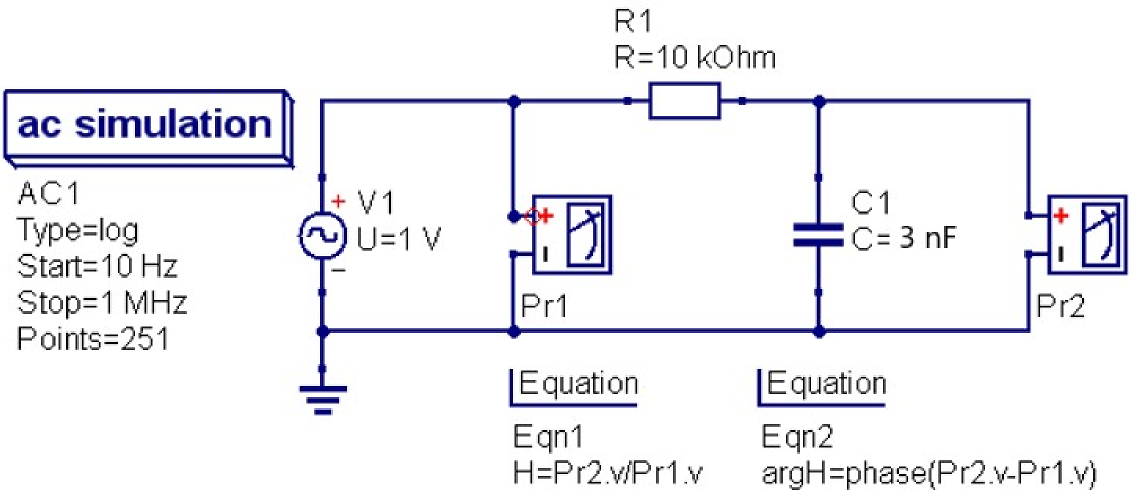


Figure 42: the RL circuit that has been examined

The circuit shown in *Figure 42* is built and simulated in Qucs to study cut-off frequency of the circuit:

Calculated cut-off frequency based on the components R1 and C1:

We know that:

$$R = 10000\ \Omega$$

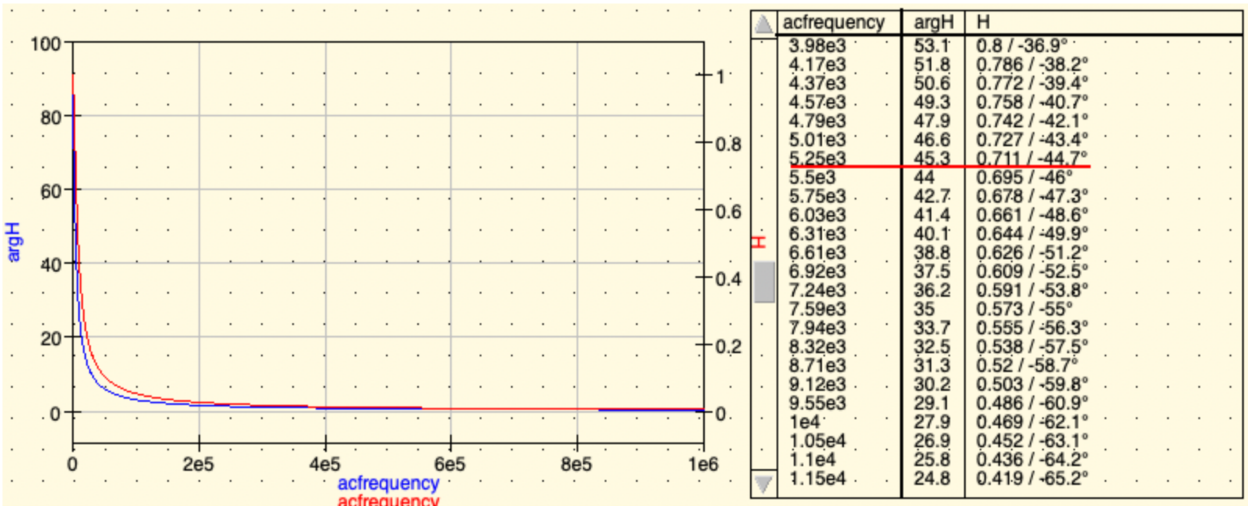
$$C = 3\ nF$$

$$f_c = \frac{1}{2\pi RC}$$

So:

$$f_c = \frac{1}{2\pi * 10000 * 3 * 10^{-9}} = 5.3\ kHz$$

Determined cut-off frequency in Qucs:



acfrequency	argH	H
3.98e3	53.1	0.8 / -36.9°
4.17e3	51.8	0.786 / -38.2°
4.37e3	50.6	0.772 / -39.4°
4.57e3	49.3	0.758 / -40.7°
4.79e3	47.9	0.742 / -42.1°
5.01e3	46.6	0.727 / -43.4°
5.25e3	45.3	0.711 / -44.7°
5.5e3	44	0.695 / -46°
5.75e3	42.7	0.678 / -47.3°
6.03e3	41.4	0.661 / -48.6°
6.31e3	40.1	0.644 / -49.9°
6.61e3	38.8	0.626 / -51.2°
6.92e3	37.5	0.609 / -52.5°
7.24e3	36.2	0.591 / -53.8°
7.59e3	35	0.573 / -55°
7.94e3	33.7	0.555 / -56.3°
8.32e3	32.5	0.538 / -57.5°
8.71e3	31.3	0.52 / -58.7°
9.12e3	30.2	0.503 / -59.8°
9.55e3	29.1	0.486 / -60.9°
1e4	27.9	0.469 / -62.1°
1.05e4	26.9	0.452 / -63.1°
1.1e4	25.8	0.436 / -64.2°
1.15e4	24.8	0.419 / -65.2°

Figure 43: Simulation of RL filter on Qucs

We know that the cut-off frequency is the frequency when

$$H = \frac{V_{out}}{V_{in}} = \frac{1}{\sqrt{2}}$$

which means H should be around 0.7 v. By looking at the Qucs simulation we see that the frequency is around 5.25 kHz when H = 0.711 v.

Investigating the responses to different frequencies in Picoscope:

In order to get a 3nf capacitor, three 10nf capacitors were connected in series which gave 3.3nf capacitance in total.

$$C_{tot} = \frac{1}{\frac{1}{10}+\frac{1}{10}+\frac{1}{10}} = 3.3nf$$

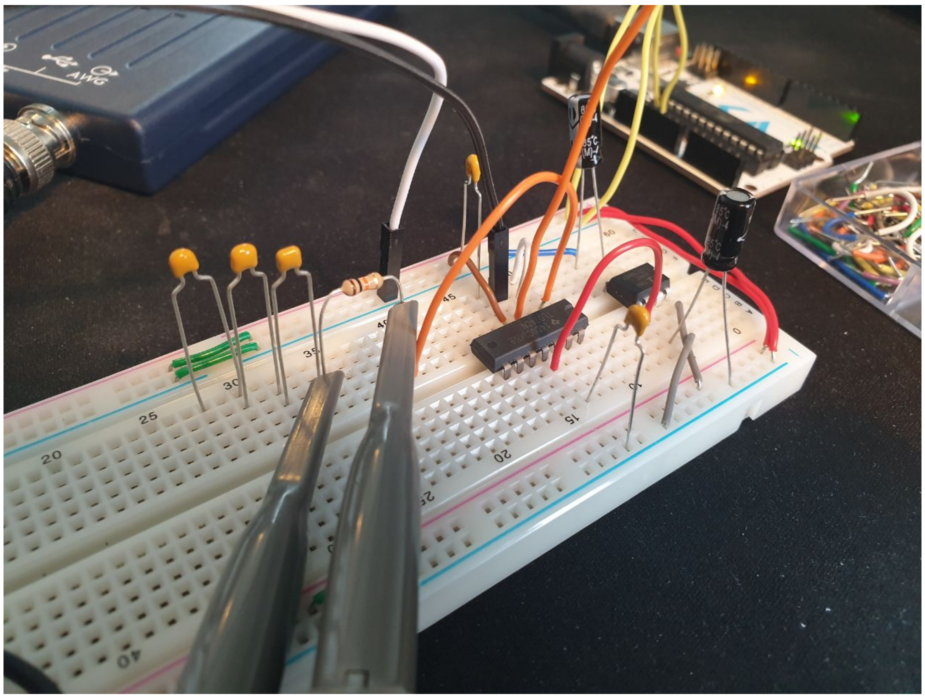


Figure 44: The built circuit on breadboard including Op-amp

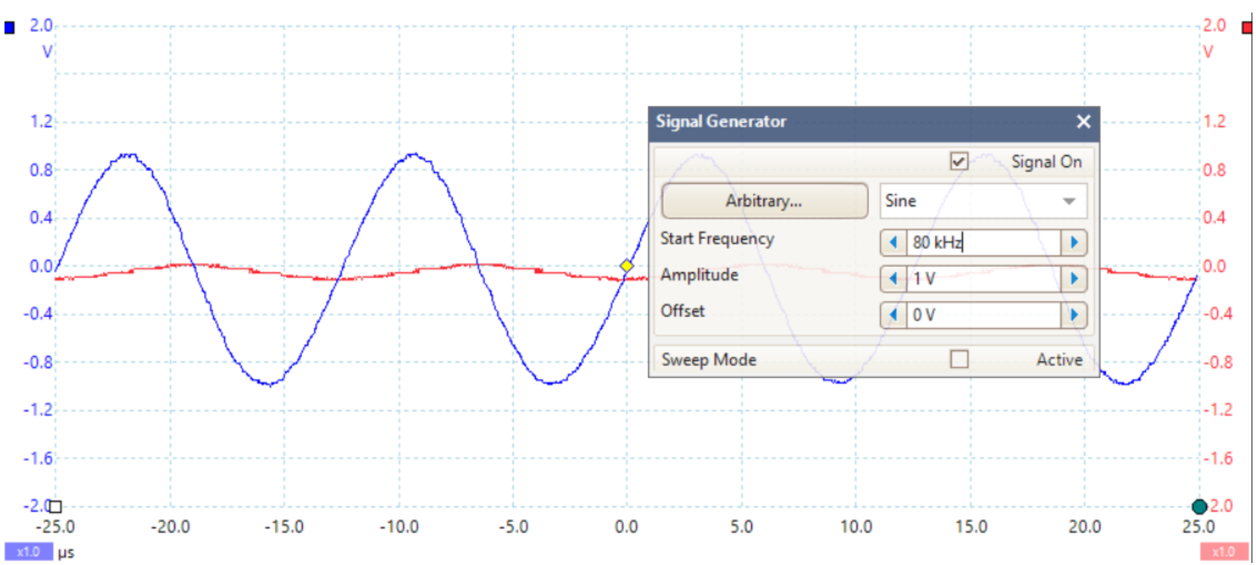


Figure 45: Vout and Vin measured in Picoscope with 80 kHz frequency

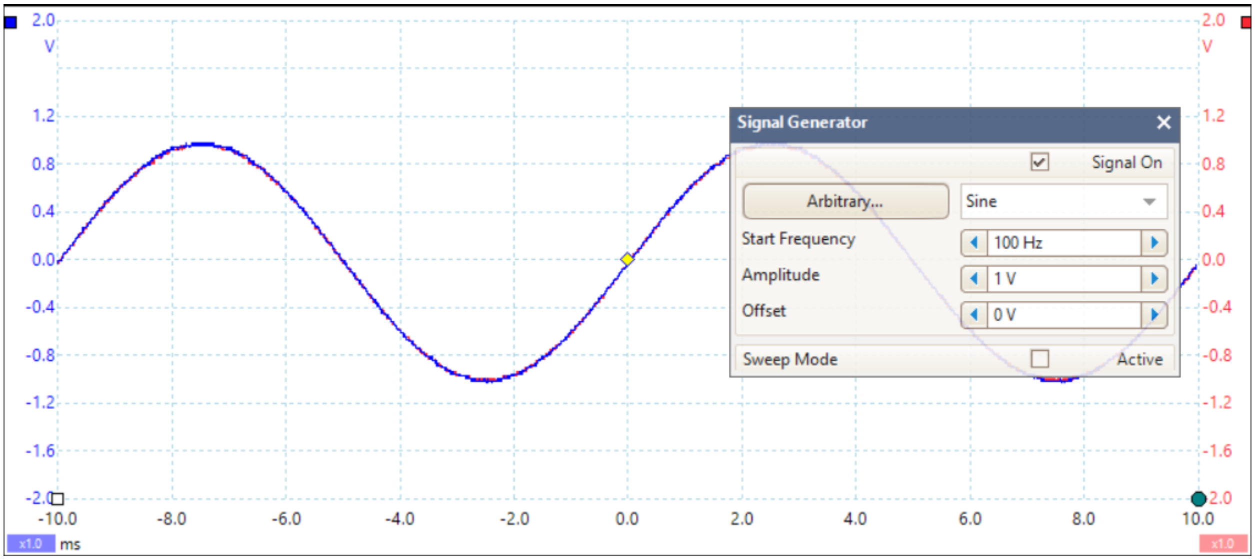


Figure 46: Vout and Vin measured in Picoscope with 100 Hz frequency

The measurements in Picoscope show that at lower frequencies (lower than Vf), the output voltage is almost exactly the same as input. While the output voltage on higher frequencies goes towards zero.

The amplitude of the voltage at the output of the filter at a frequency of 80 kHz is around 0v.
The amplitude of the voltage at the output of the filter at a frequency of 100 Hz is around Vin.
According to the calculations and measurements above, the filter is a low pass filter.

3.3 RLC Filter

3.3.1 Sinus input to the filter and viewing voltage versus time

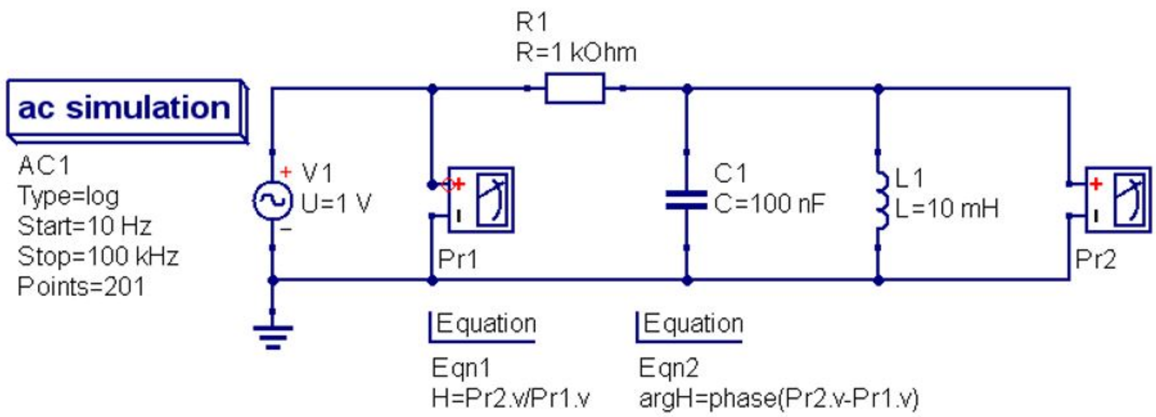


Figure 47: the RLC circuit that has been examined

The circuit shown in *Figure 47* is built and simulated in Qucs to study center frequency of the circuit:

Calculated center frequency based on the components R1, C1 and L1:

We know that:

R = 1000 Ω

L = 10 mH

C = 100 nF

$$f_c = \frac{1}{[2\boldsymbol{\pi} * \sqrt{(L*C)}]}$$

So:

$$f_c = \frac{1000}{[2\boldsymbol{\pi} * \sqrt{(10mH*100nF)}]} = 5.03\ kHz$$

Determined center frequency in Qucs:

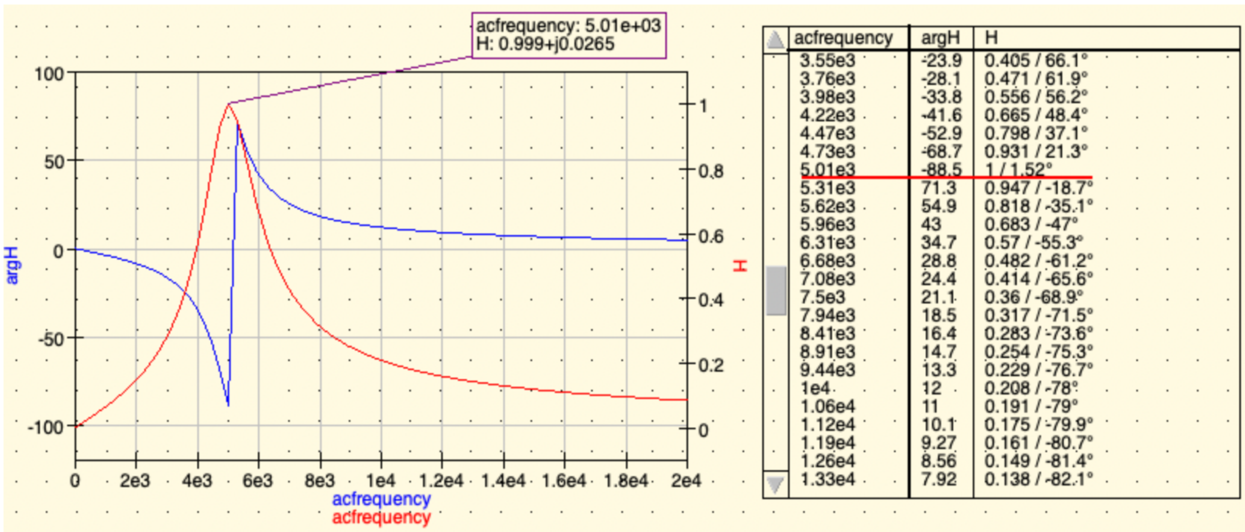


Figure 48: Simulation of RLC filter on Qucs

We know that the center frequency is the frequency when H is at its maximum.
We can see that the frequency is around 5.01 kHz when H is at its maximus which is almost equal to 1.

Investigating the responses to different frequencies in Picoscope:

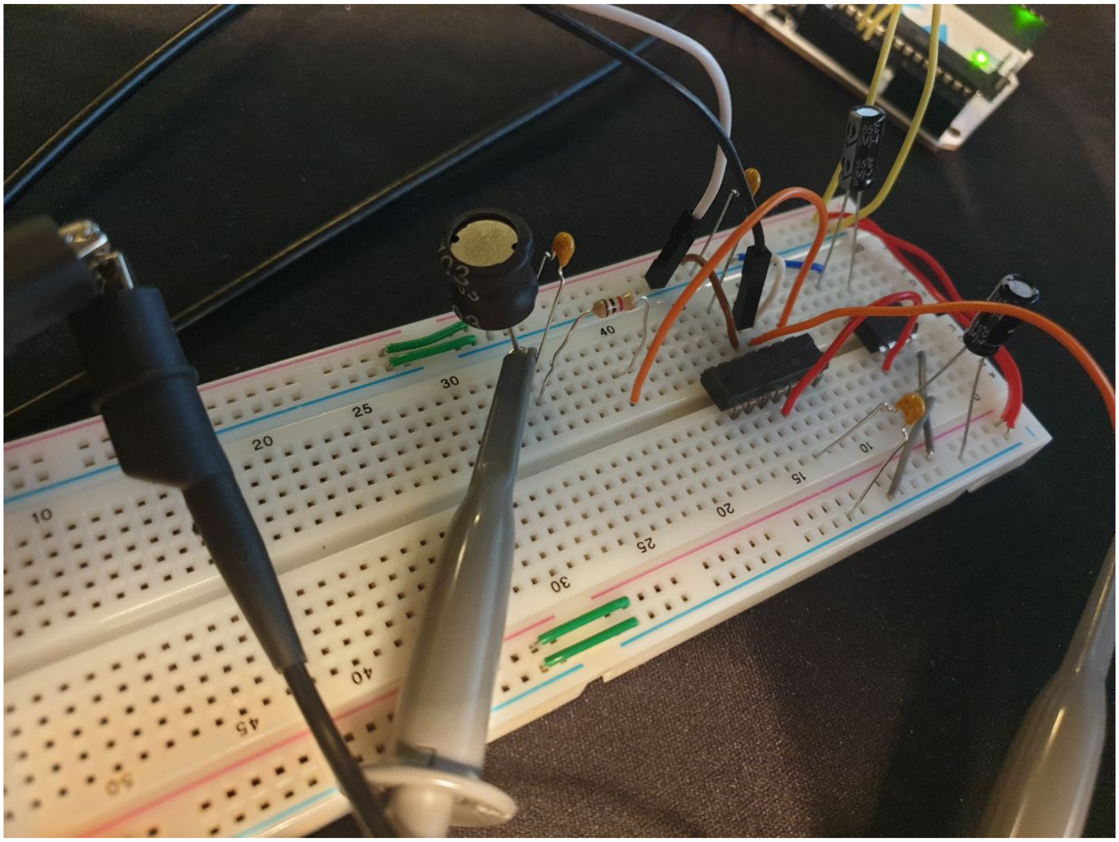


Figure 49: The built circuit on breadboard including Op-amp

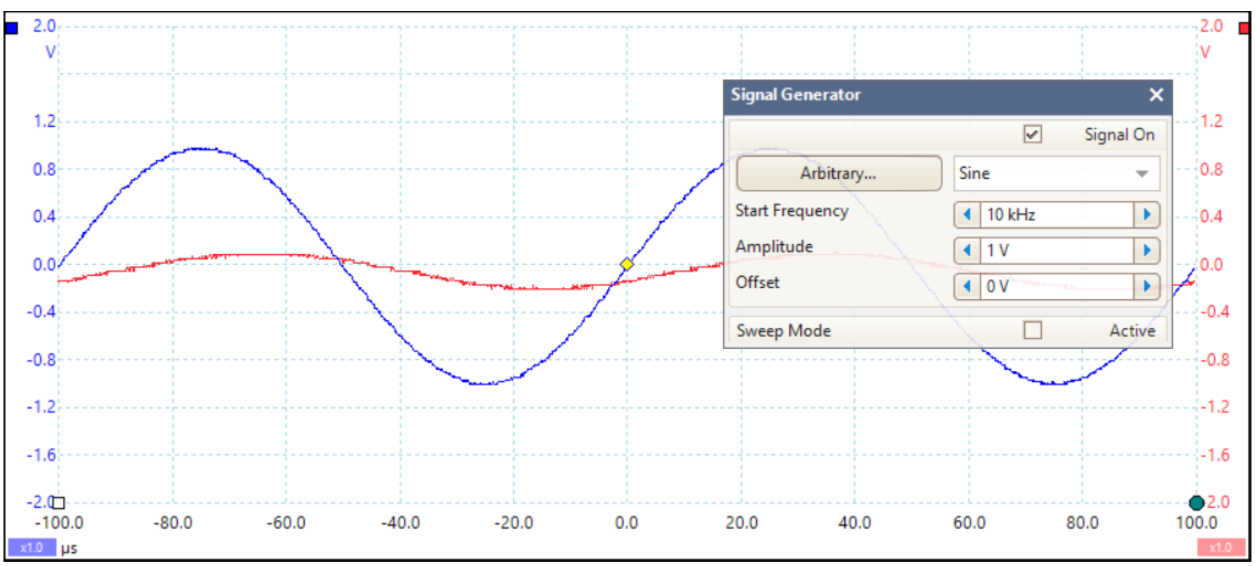


Figure 50: Vout and Vin measured in Picoscope with 10 kHz frequency

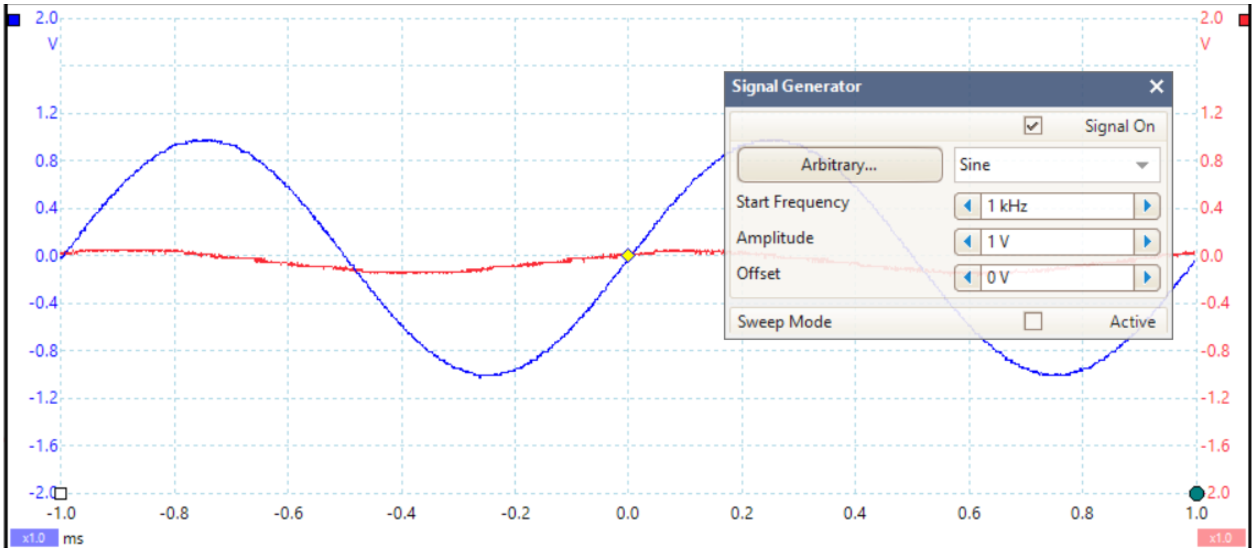


Figure 41: Vout and Vin measured in Picoscope with 1 kHz frequency

The measurements in Picoscope show that the output voltage is almost 0v at both 1 kHz and 10 kHz frequency which approves the center frequency of 5 kHz.

3.3.2 Sinus and square wave (5 kHz) input to the filter

Sinus input:

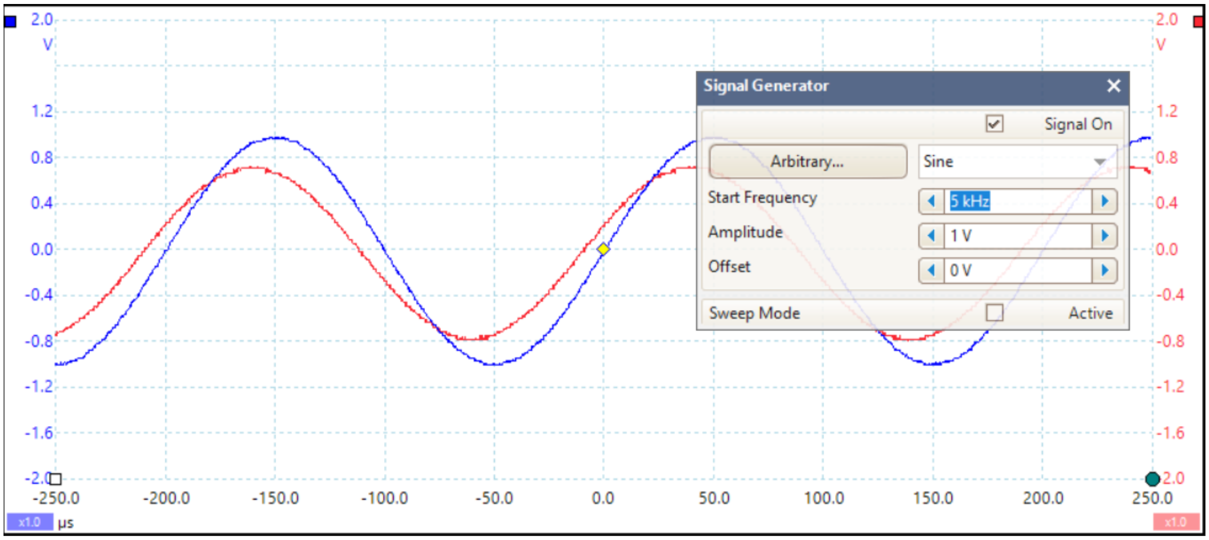


Figure 42: Vout and Vin measured in Picoscope with 5 kHz frequency

The output voltage is almost the same as input voltage which approves the calculated center frequency of 5 kHz. The filter lets waves around 5 kHz pass through and works as a band pass filter.
By changing the spectrum mode on the PicoScope and setting the rang to 49 kHz the following image is the result:

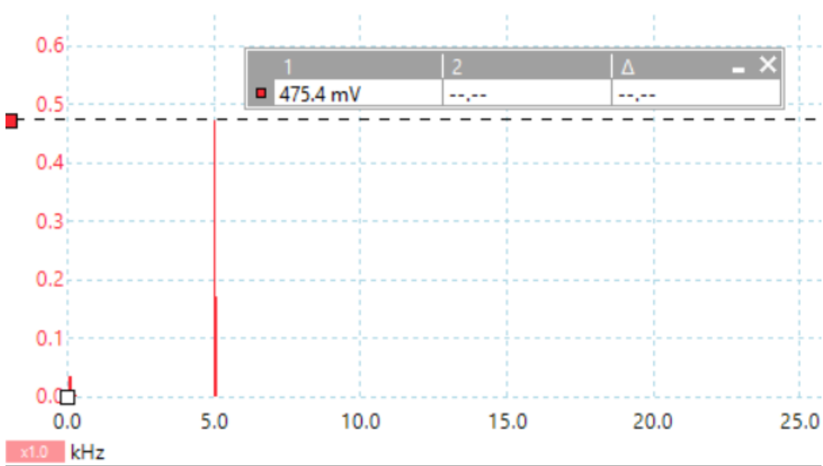


Figure 43: Vout measured in Picoscope with 5 kHz frequency

The Vout peaks at around 475 mV when the frequency is around 5 kHz.

Square wave input:

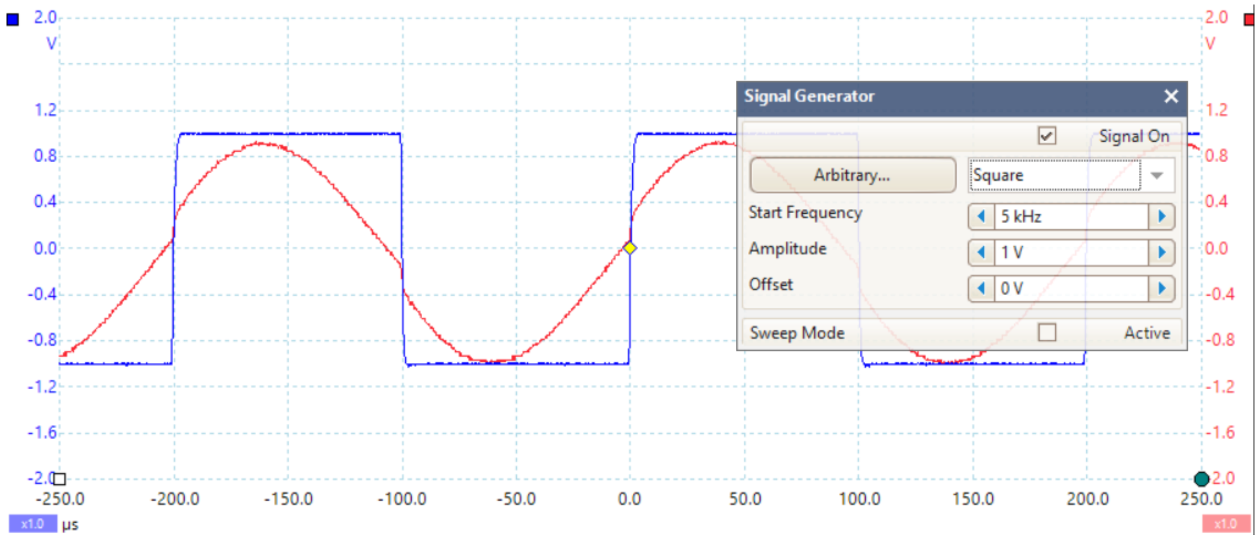


Figure 44: Vout and Vin measured in Picoscope with 5 kHz frequency

The output voltage has a sinusoidal shape although the input voltage has a square wave shape. It is because the square wave is a sum of different sin och cos with different amplitudes. But our filter only lets 5 kHz go through.

By changing the spectrum mode on the PicoScope the following image is the result:

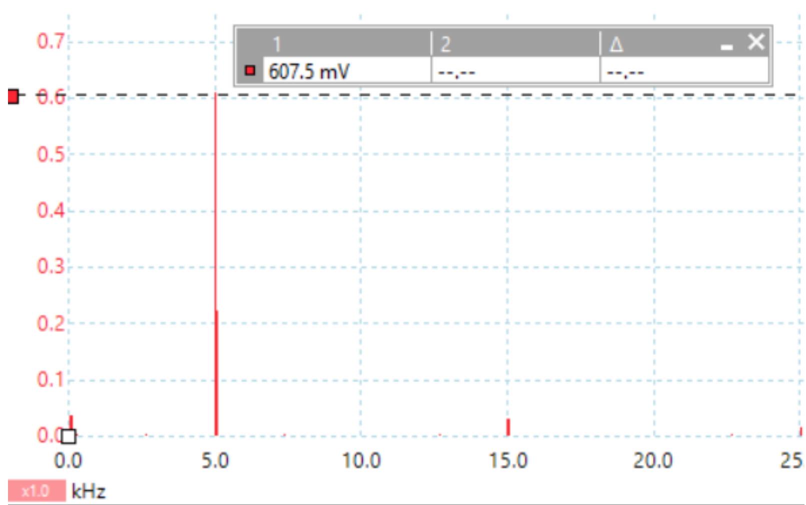


Figure 45: Vout measured in Picoscope with 5 kHz frequency

The Vout peaks at around 607.5 mV when the frequency is around 5 kHz.