Embedded electronics IE1206

LAB REPORT

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Lab 1: DC MEASUREMENTS

1.1 KVL, KCL and Power in resistive net

Comp.	Meas R Multimeter [kOhm]	Meas V Multimeter [V]	Meas I Multimeter [mA]	Calc R=V/I [Ohm]	Calc P=v*I [mW]	Simulated V QUICS [V]	Simulated I QUICS [mA]	Simulated P QUICS [mW]
R1	0.98	0.250	0.250	1000	0.0625	0.25	0.25	0.0625
R2	47.0	4.840	0.101	47920	0.4888	4.75	0.101	0.4798
R3	9.84	1.497	0.152	9848	0.2275	1.48	0.148	0.2190
R4	21.8	3.320	0.152	21842	0.5046	3.27	0.148	0.4840
Arduino 5V Voltage source	Not applicable	5.100	- 0.250	Not applic able	- 1.275	5	0.25	1.25

Table 1: Measured, simulated and calculated values according to the circuit values

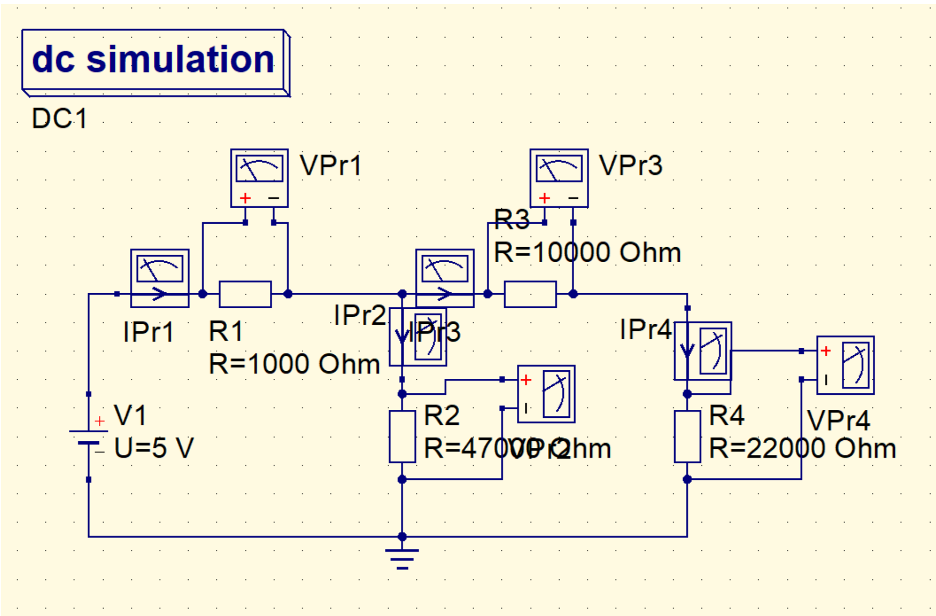

Figure 1: Circuit made in QUCS

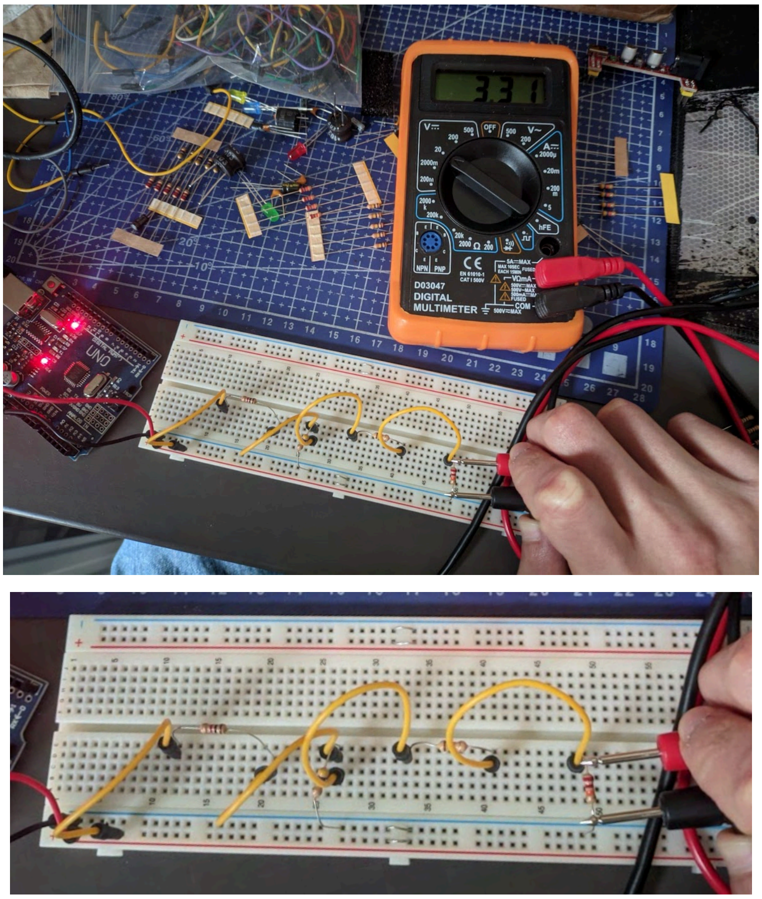

Figure 2: Photo of circuit on breadboard and measurement

Confirm KVL:

In closed loop V,R1, R2:

$$VA - V1 - V2 = 0$$

$$5.1 - 0.25 - 4.84 = 0.01 \approx 0$$

Therefore it holds true.

In closed loop R2, R3, R4:

$$V2 - V3 - V4 = 0$$

$$4.84 - 1.497 - 3.32 = 0.023 \approx 0$$

Therefore it holds true.

Confirm KCL:

In node R1, R2, R3:

$$I1 = I2 + I3$$

$$\Rightarrow I1 - I2 - I3 = 0$$

$$0{,}25 - 0{,}101 - 0{,}152 = -0{,}003 \approx 0$$

Therefore it holds true.

Check if the power is balanced:

P1 + P2 + P3 + P4 + PA = 0

0.0625 + 0.4888 + 0.2275 + 0.5046 - 1.275 = 0.0084 ≈ 0

Therefore the power is in fact balanced.

1.2 Determine Thevenin equivalent circuits

1.2.1 Thevenin equivalent circuit for Arduino 5 V pin.

Measured voltage over unloaded 5V pin: $V_{th} = 5.10\ V$
Chosen resistor with resistance value: $R_{res} = 0.100\ kOhm$
Measured voltage over the resistor: $V_{res} = 4.99V$
=> $I = V_{res} / R_{res} = 49.9\ mA$
And $R_{th} = Vth - Vres / I$
=> $R_{th} = 0.002\ kOhm$

Observation: 2 Ohm Thevenin resistance potentially dependent on the USB used as power source for the arduino.

1.2.2 Thevenin equivalent for Arduino digital output pin

Measured voltage over digital GPIO pin: $V_{th} = 5.09\ V$
Chosen resistor with resistance value: $R_{res} = 10\ kOhm$
Measured voltage over the resistor: $V_{res} = 5.08\ V$
=> $I = V_{res} / R_{res} = 0.508\ kOhm$
And $R_{th} = V_{th} - V_{res} / I$
=> $R_{th} = 0.020\ kOhm$

Observation: around 20 Ohm Thevenin resistance on the arduino digital GPIO pin.

1.3 Light Emitting Diode (LED) circuits

1.3.1 Resistor in series with yellow LED

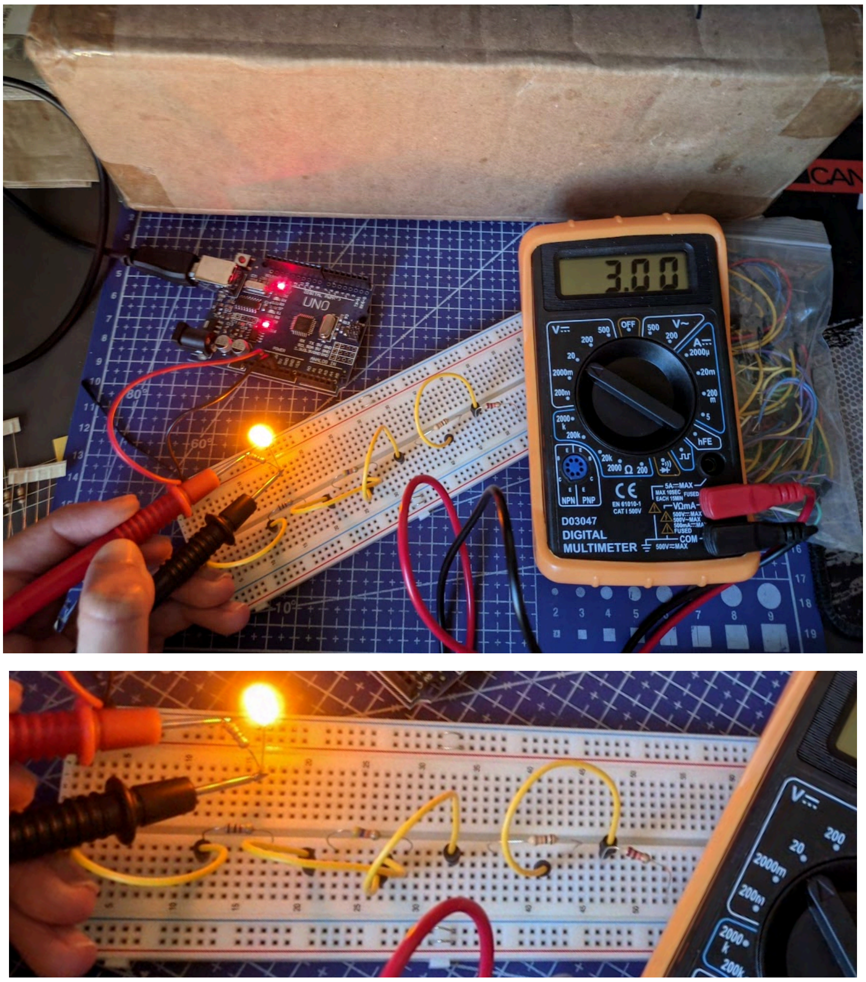

Figure 3: Photo of circuit on breadboard and measurement

Measurement of the voltage over the resistor: V_{res} = 3 V
Measurement of the voltage over the LED: V_{led} =2.07 V
Calculated current from the V_{res} and R(220 Ohm): I = 22.7 mA
=> $P = I * V_{led}$ = 46.989 mW

1.3.2 Resistor in series with blue LED

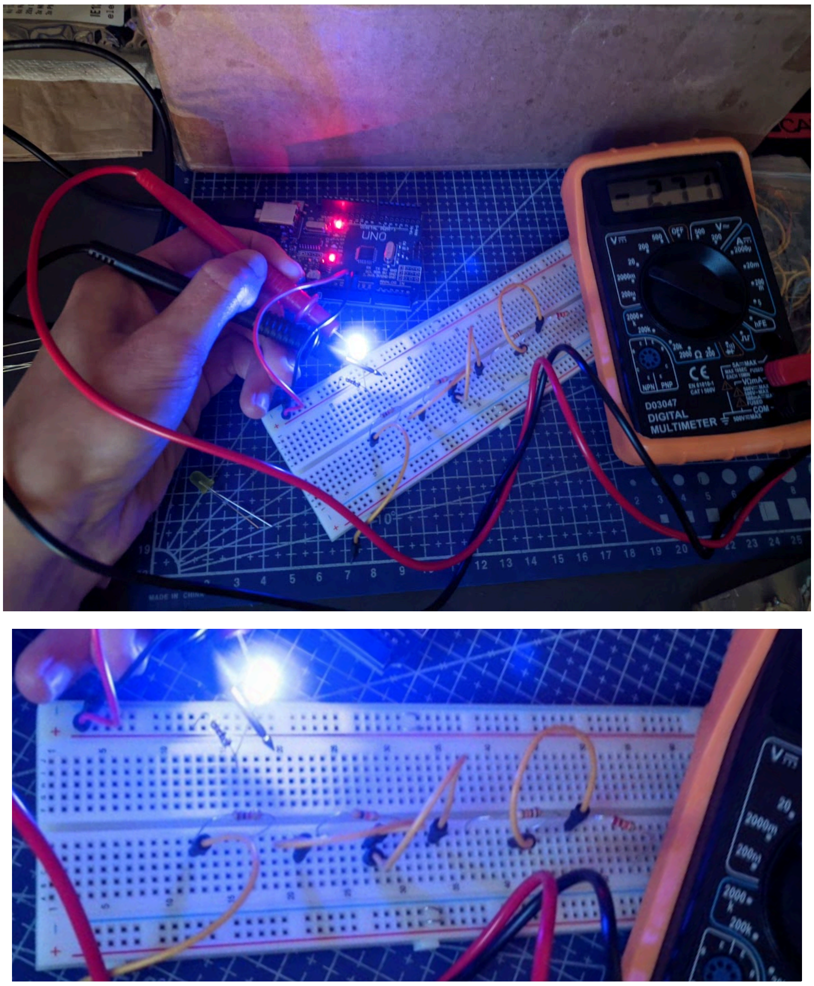

Figure 4: Photo of circuit on breadboard and measurement

Measurement of the voltage over the resistor: $V_{res} = 2.36\ V$
Measurement of the voltage over the LED: $V_{led} = 2.71\ V$
Calculated current from the $\mathrm{V_{res}}$ and R(220 Ohm): $I = 22.7\ mA$
$\Rightarrow P = I \star V_{led} = 61.591\ mW$

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

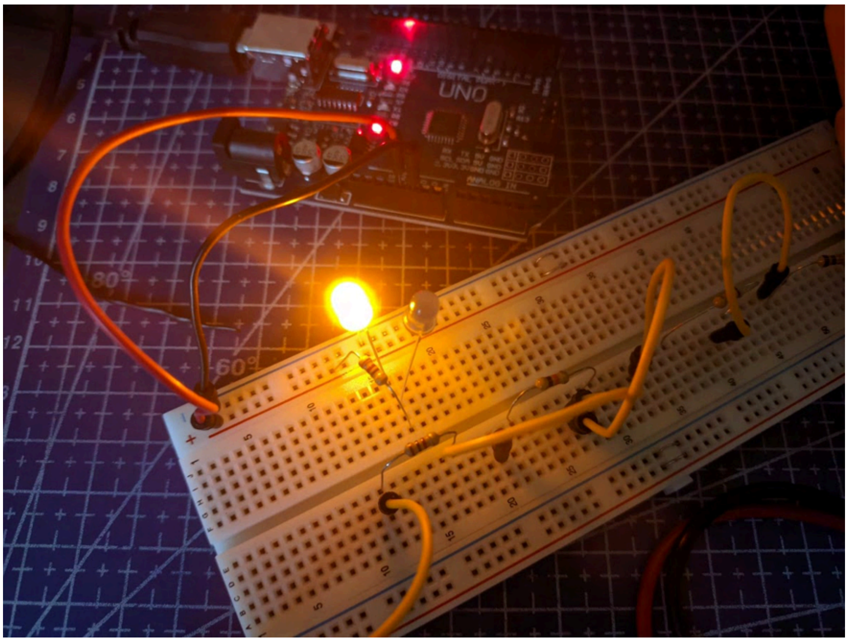

Figure 5: Photo of circuit on breadboard

Only the yellow LED lights up. This is due to the fact that the yellow LED has a lower voltage drop value compared to the blue one and so all the current passes through the yellow LED and none goes through the blue. This difference in forward voltage values (apparent even from the previous 2 tasks) is dependent on the wavelength of the light the diodes are emitting.

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

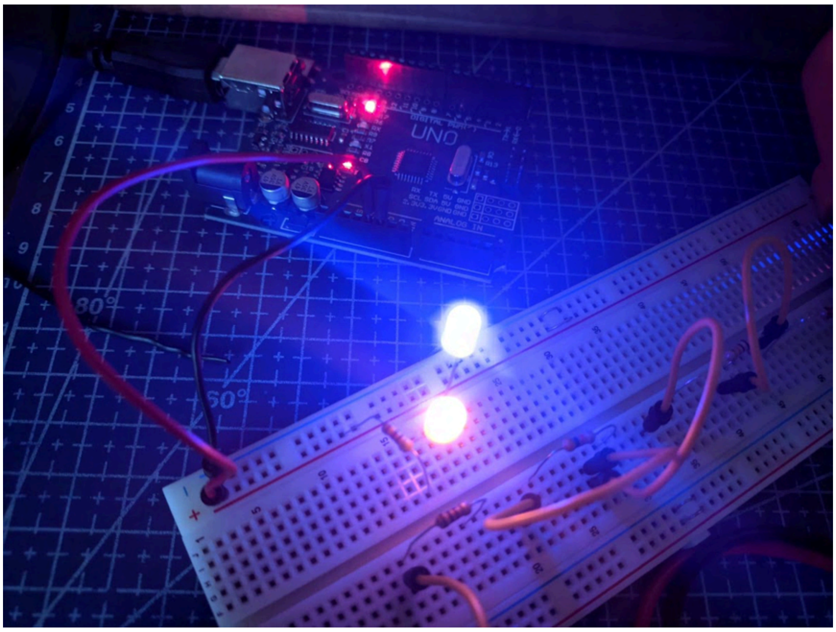

Figure 6: Photo of circuit on breadboard

Both of them light up. Because the LEDs are connected in series, sufficient current passes through both of them and thus reaches their required voltage drop values.

Lab 2: Time dependent circuits

2.1 Time dependent behaviour of RL circuit

By calculating using the given values we get:

$\tau = L / R_{th} = (10 * 10^{(-3)}) / (10^{3}) = 10 * 10^{(-6)} =$ ***10 us***

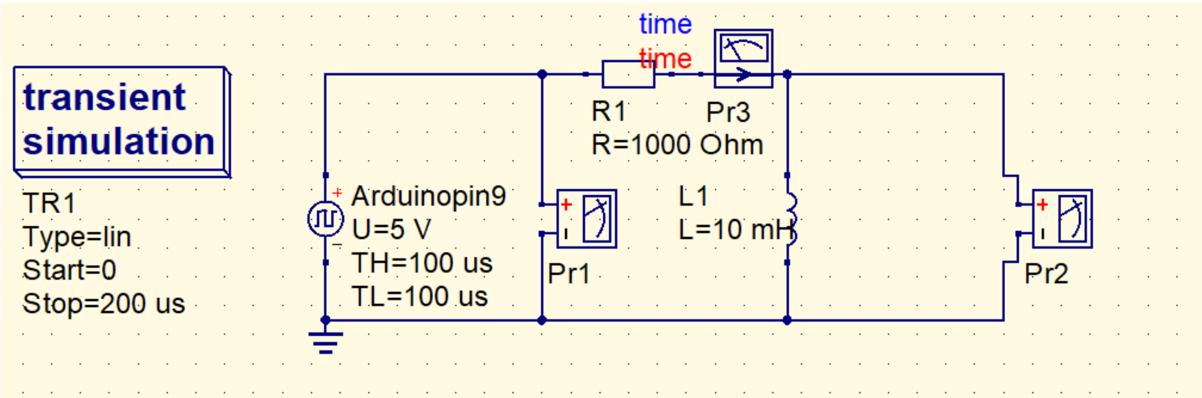

Figure 7: Circuit made in QUCS

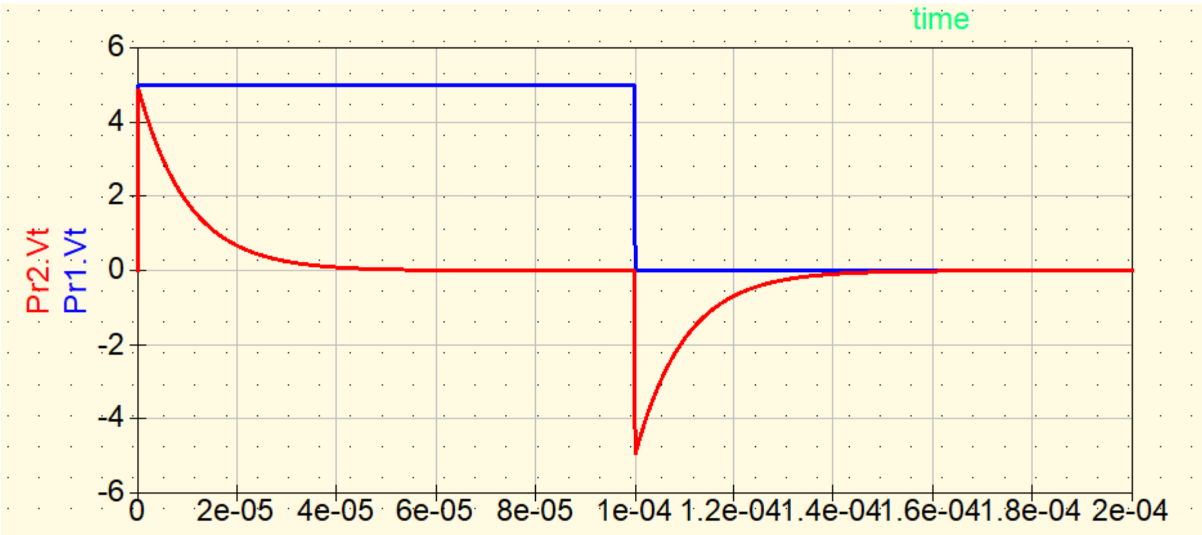

Figure 8: Simulation graph of the voltage probes

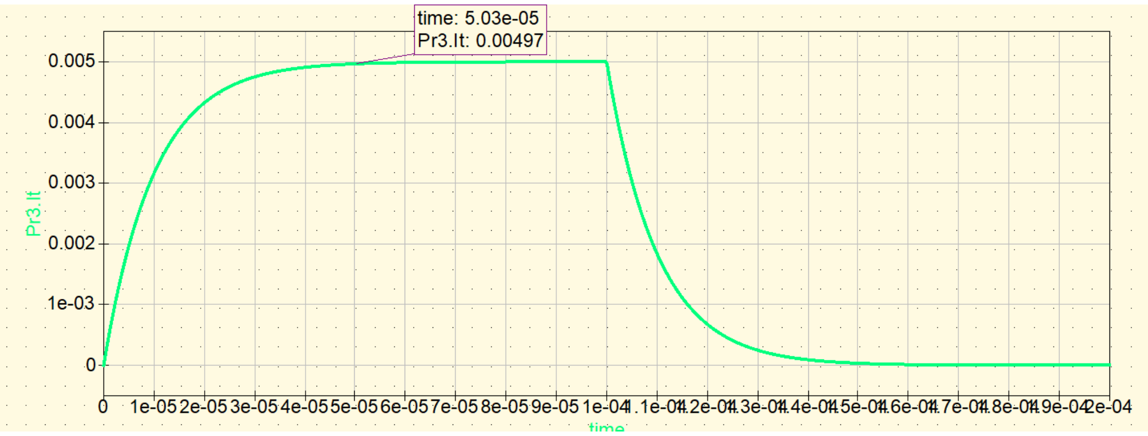

Figure 9: Simulation graph of the current probe

To calculate **τ** from the simulation graphs we can take I_c(50us) = 4,97 mA, we can also see that I_c(0) = 0 A and I_c(inf) = 5mA therefore in the formula:

*I_c(t) = I_c(inf) + (I_c(0) - I_c(inf))*e^(-t/ **τ**)*

We get: *4,97 = (-5) * e^(-50/ **τ**)*

*-0.03 / (-5) = e^(-50/ **τ**)*

τ ≈ 10 us

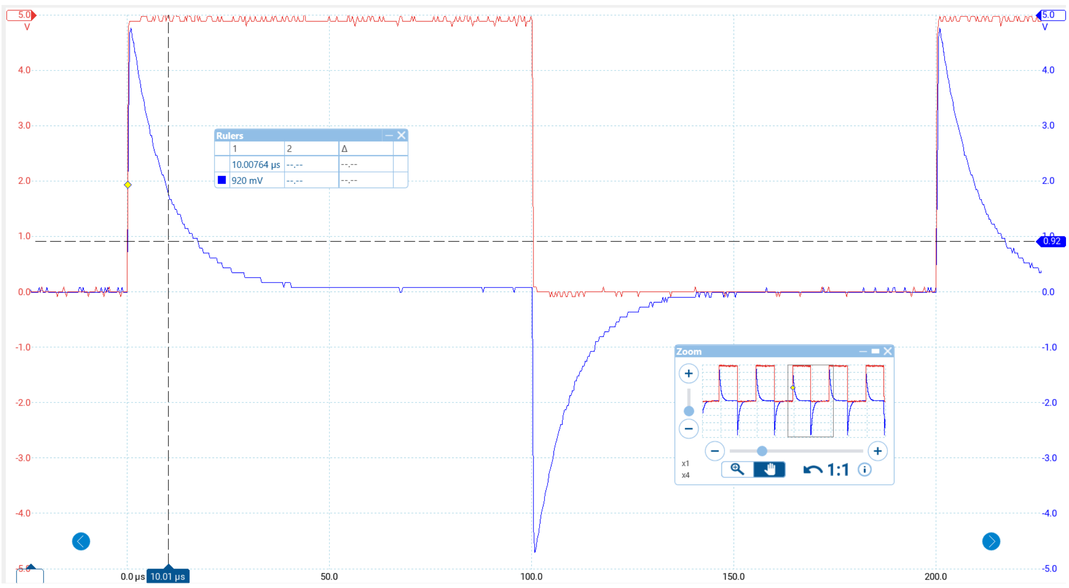

Figure 10: Oscilloscope graph

To determine the time constant from the oscilloscope measurement we can observe the period it takes to reach 63.2% of the amplitude voltage because we know that is equal to about a one time constant period. So at point *(100-63.2)% * 5V = 1.84V* we get **10.01us** which is our time constant.

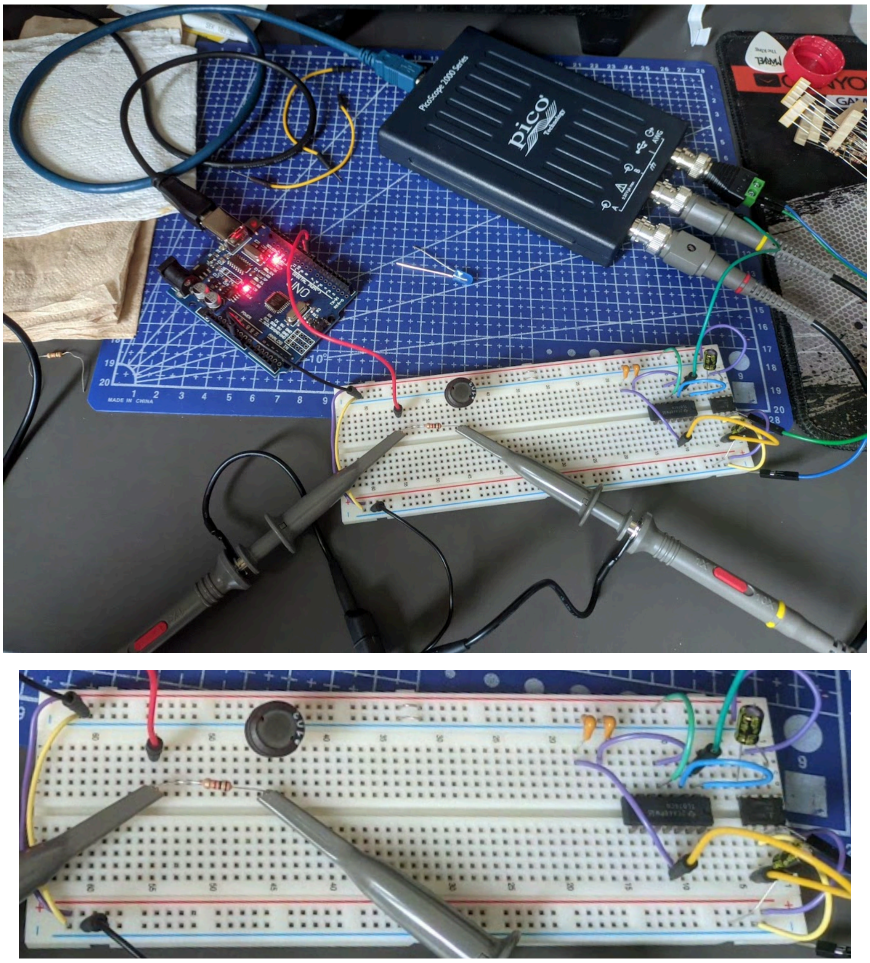

Figure 11: Circuit on breadboard

When we have two inductors in parallel we get a time constant of about **5.5us** (in the same way as we did before). This is explained due to fact that the equivalent inductance for two inductors in parallel is equal to
$(L1 * L2) / (L1 + L2) = 100/20 = 5mH$
And since $\boldsymbol{\tau}$ is proportional to L as L(equivalent) is two times less so is $\boldsymbol{\tau}$.

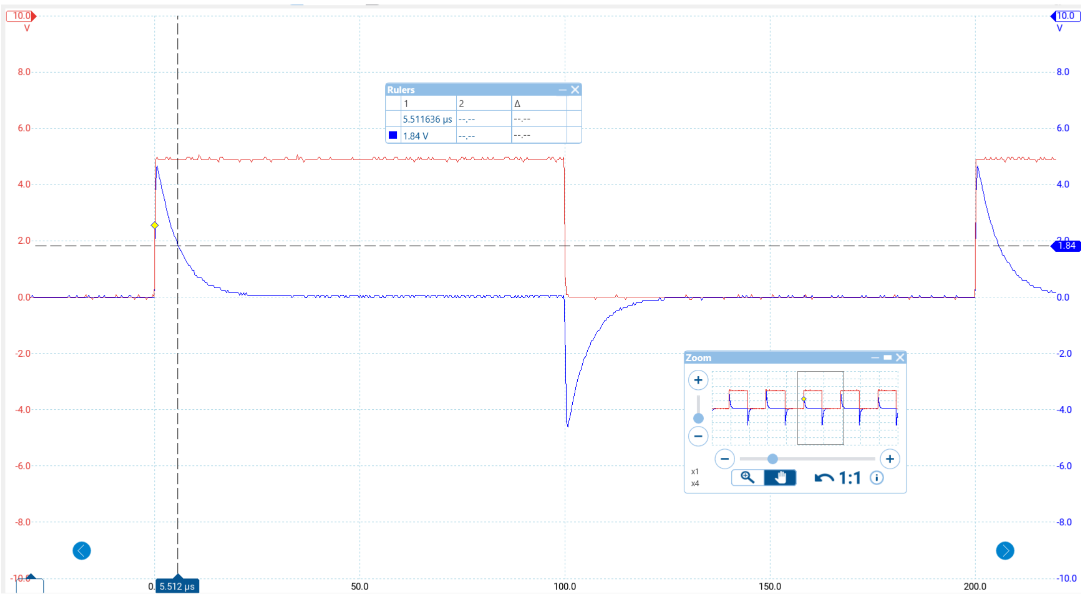

Figure 12: Oscilloscope graph with measurement at 1.84 V

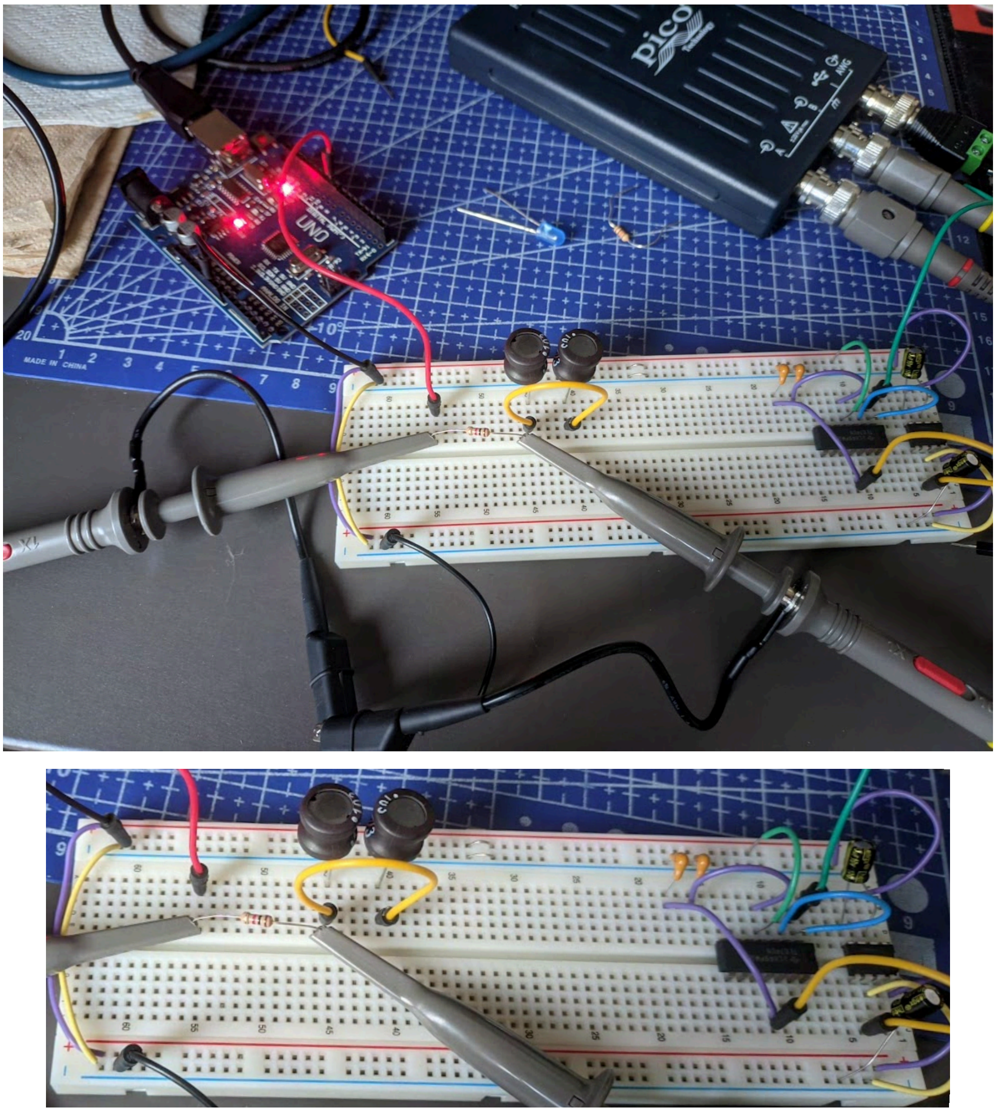

Figure 13: Parallel circuit on breadboard

When we have two inductors connected in series we get a time constant of about **20.4 us**. Again this is due to the equivalent inductance being L1 + L2 = 20mH and because **τ** is proportional to L as L(equivalent) doubles so does **τ**.

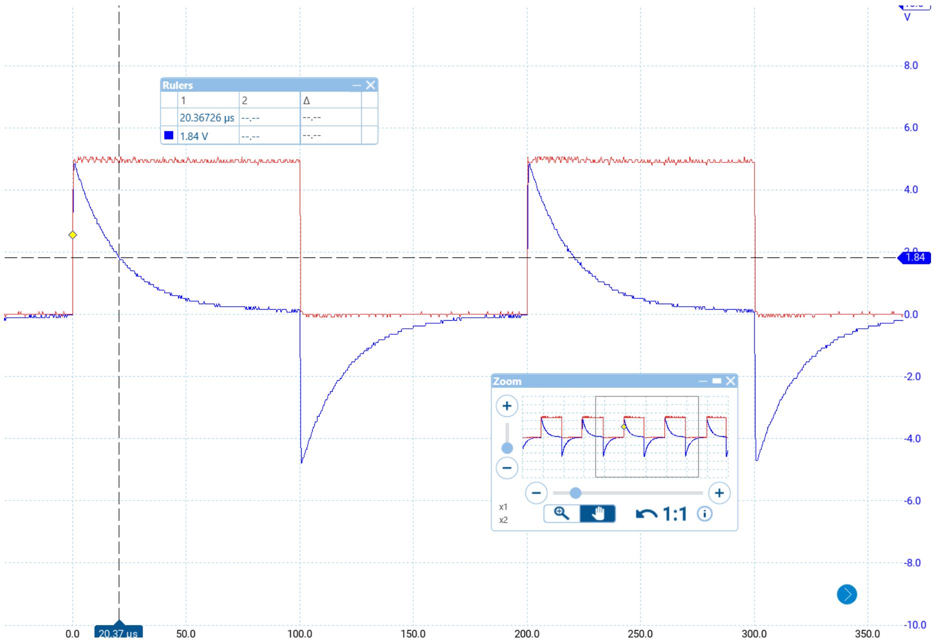

Figure 14: Oscilloscope graph with measurement at 1.84 V

2.2 Time dependent behaviour of RC circuit

By calculating using the given values we get:

$\tau = C * Rth = 1 * 10 ^ {(-9)} * 10 * 10 ^ {3} = 10 * 10 ^ {(-6)} = 10us$

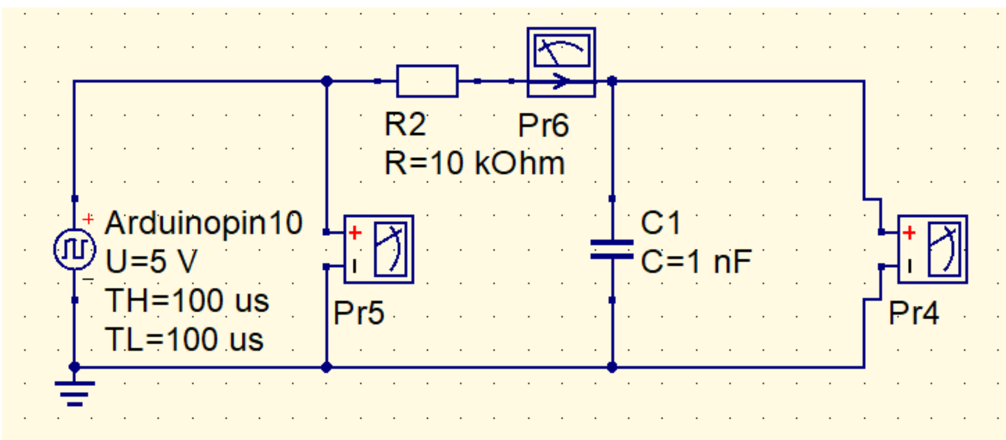

Figure 15: Circuit made in QUCS

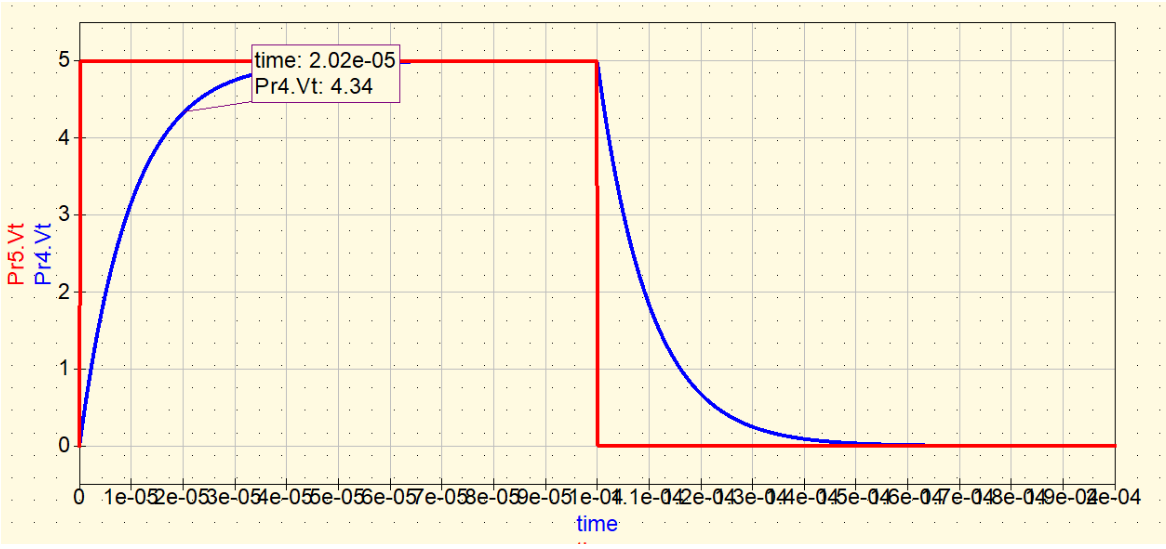

Figure 16: Simulation graph of the voltage probes

To calculate τ from the simulation graphs we can take $V_c(20us) = 4{,}34$ V, we can also see that $V_c(0) = 0$ V and $V_c(inf) = 5$ V
Therefore in the formula:

$V_c(t) = V_c(inf) + (V_c(0) - V_c(inf))*e\text{^}(-t/\tau)$

We get: $4{,}34 = (-5) * e\text{^}(-20/\tau)$

$-0.66 / (-5) = e\text{^}(-20/\tau)$

$-20/\tau = -2{,}02$

$\Rightarrow$ ***$\tau \approx$ 10 us***

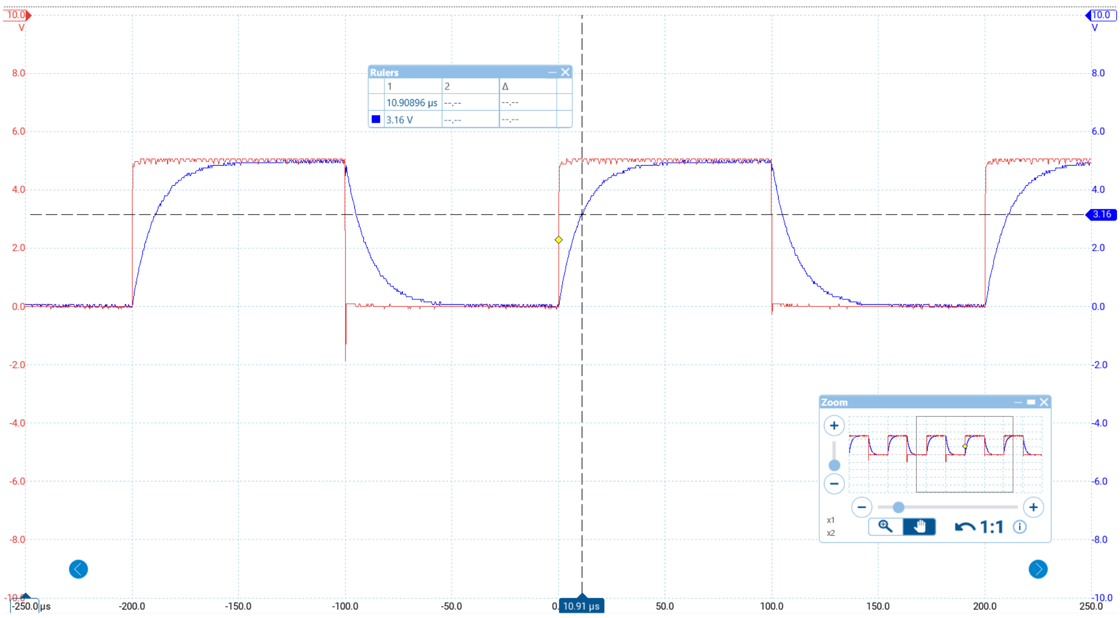

Figure 17: Oscilloscope graph with measurement at 3.16 V

To determine the time constant from the oscilloscope measurement we can observe the period it takes to reach 63.2% of the amplitude voltage because we know that is equal to about a one time constant period. So at point *63.2% * 5 V = 3.16 V* we get **10.9us** which is our time constant.

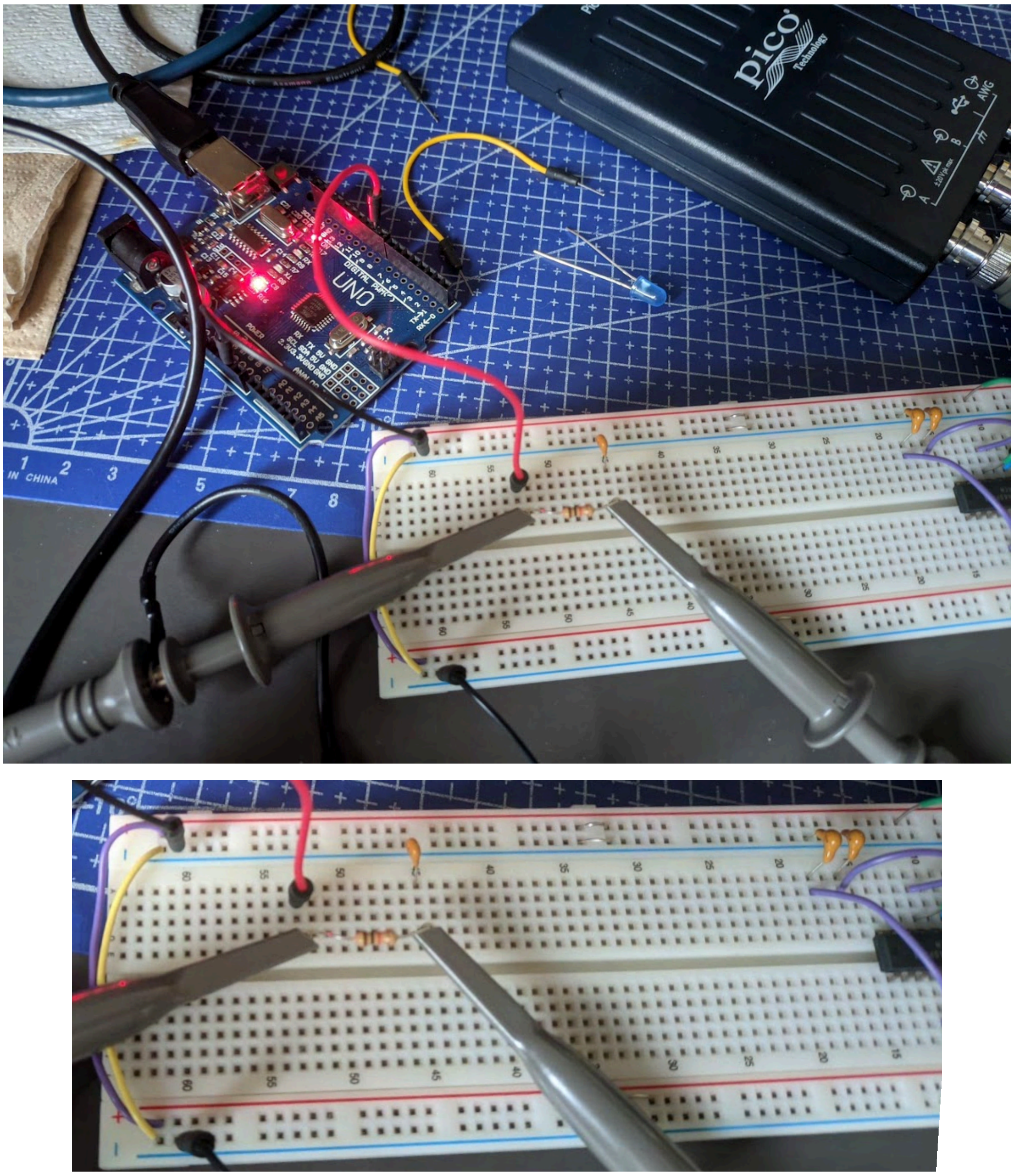

Figure 18: Circuit on breadboard

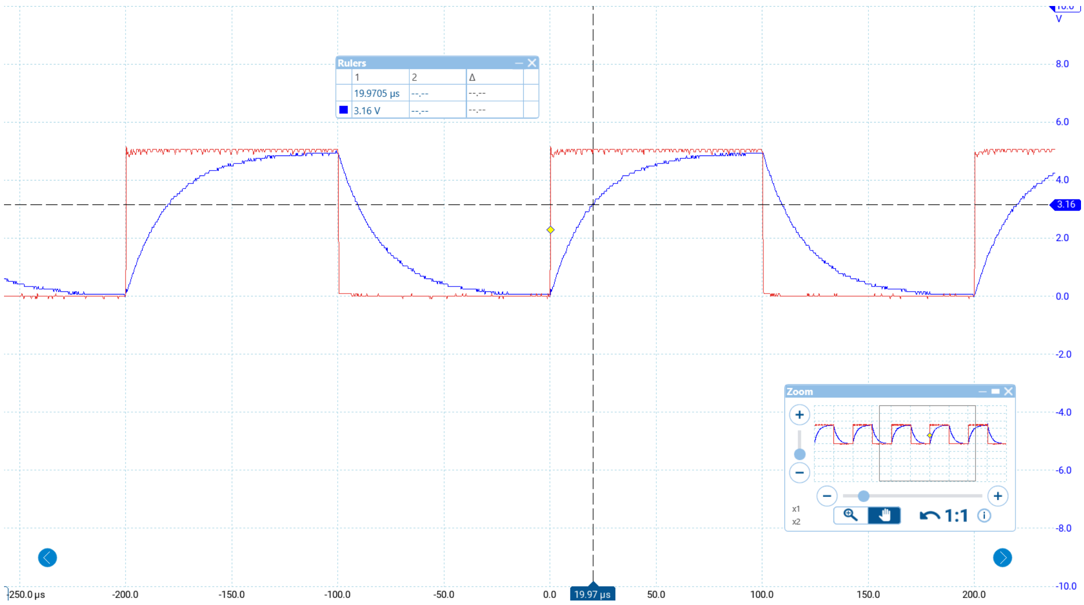

Figure 19: Oscilloscope graph with measurement at 3.16 V

When we have two capacitors in parallel we get a time constant of about **19.97us** (in the same way as we did before). This is explained due to fact that the equivalent capacitance for two capacitors in parallel is equal to *C1 + C2 = 10 + 10 = 20 uF*
And since **τ** is proportional to C as C(equivalent) is doubled so is **τ**.

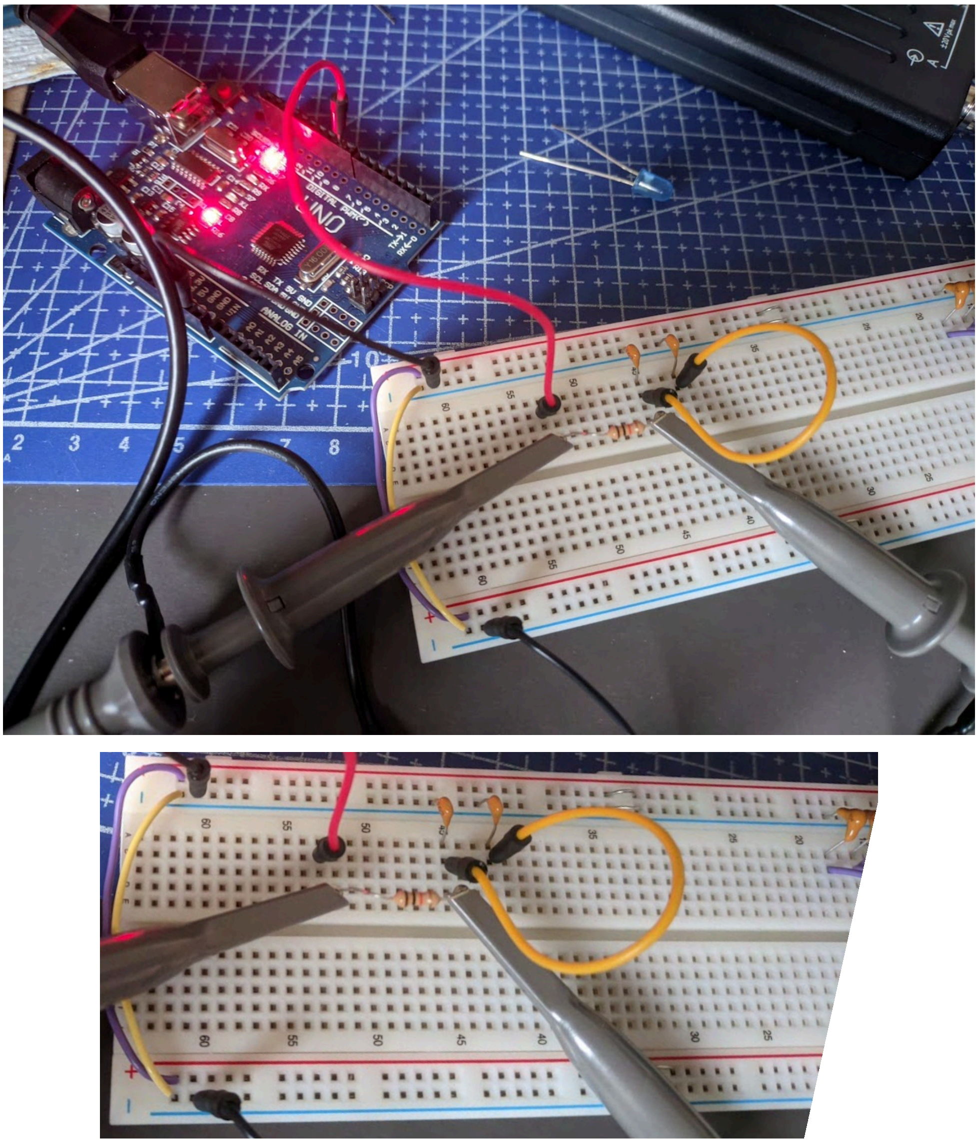

Figure 20: Parallel circuit on the breadboard

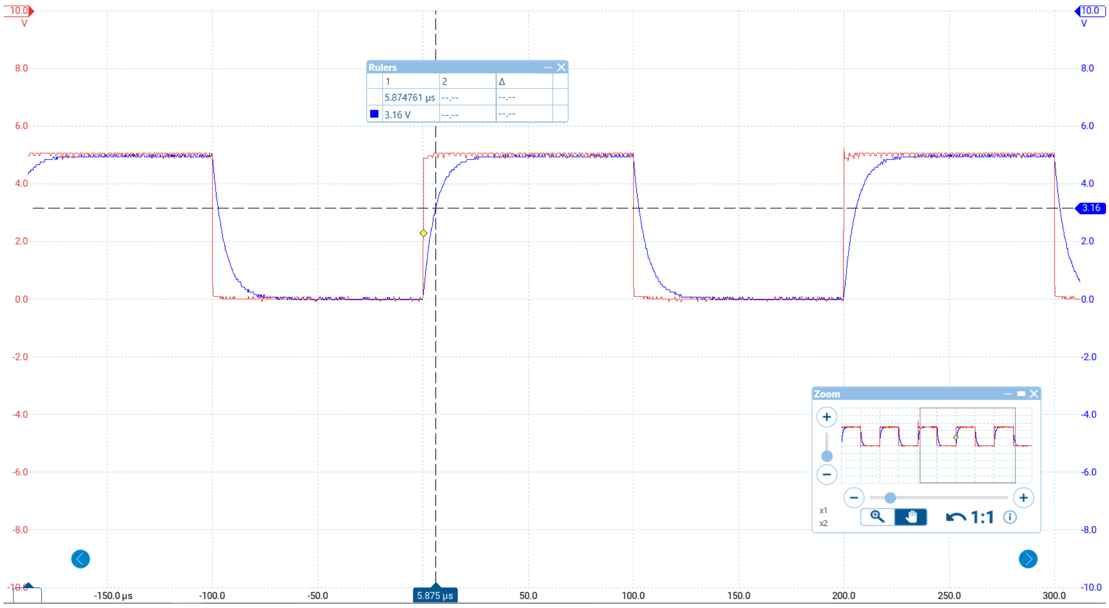

Figure 21: Oscilloscope graph with measurement at 3.16 V

When we have two inductors connected in series we get a time constant of about **5.87 us**. Again this is due to the equivalent capacitance in series being C1 * C2 / (C1 + C2) = 100/20 = 5 uF and because **τ** is proportional to C as C(equivalent) becomes two time less so does **τ**.

2.3 Diode rectifier circuit with resistor and capacitor

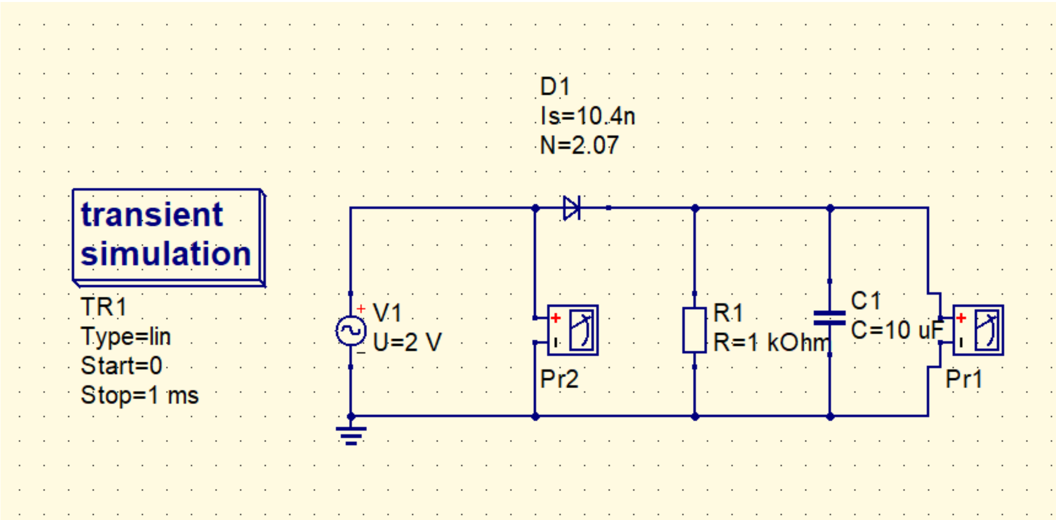

Figure 22: Circuit made in QUCS

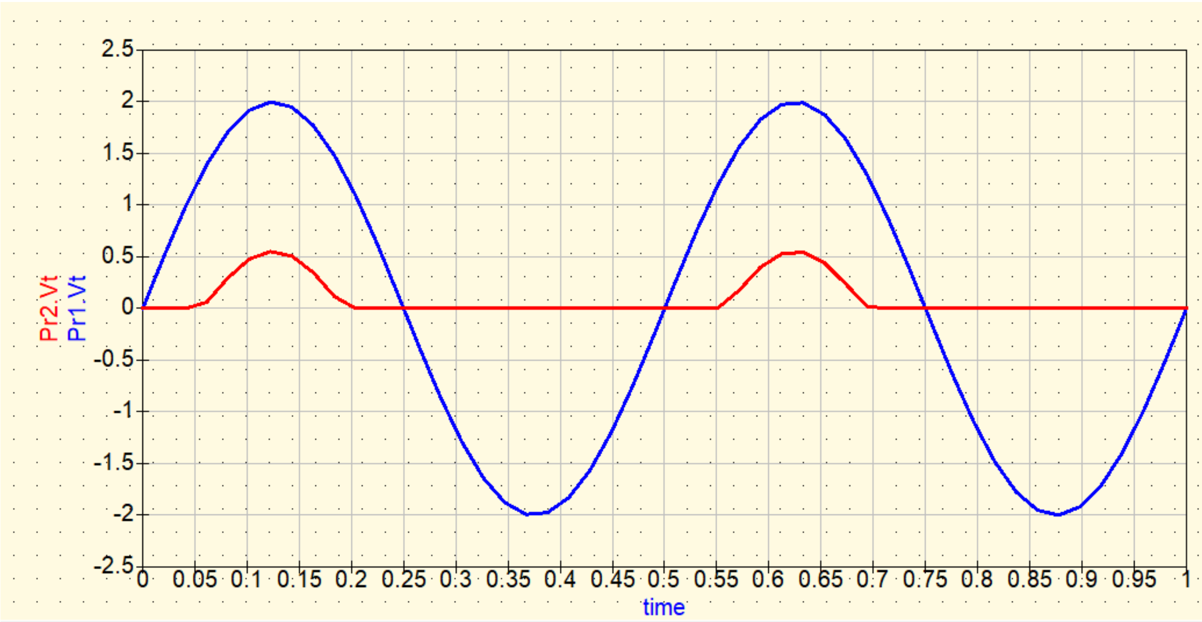

Figure 23: Simulation graph of the voltage probes on the circuit **without** a capacitor

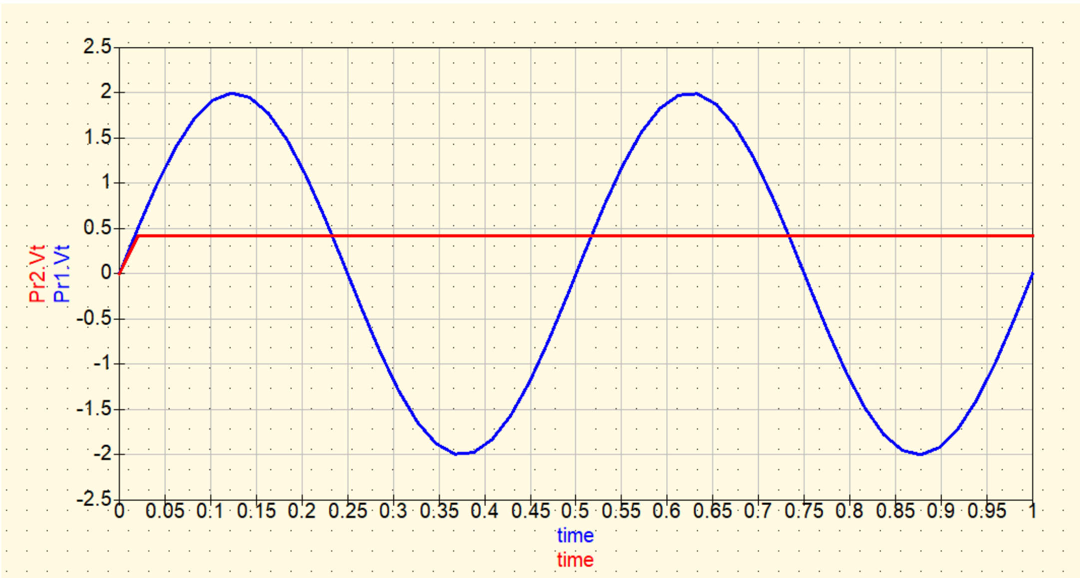

Figure 24: Simulation graph of the voltage probes on the circuit **with** a capacitor

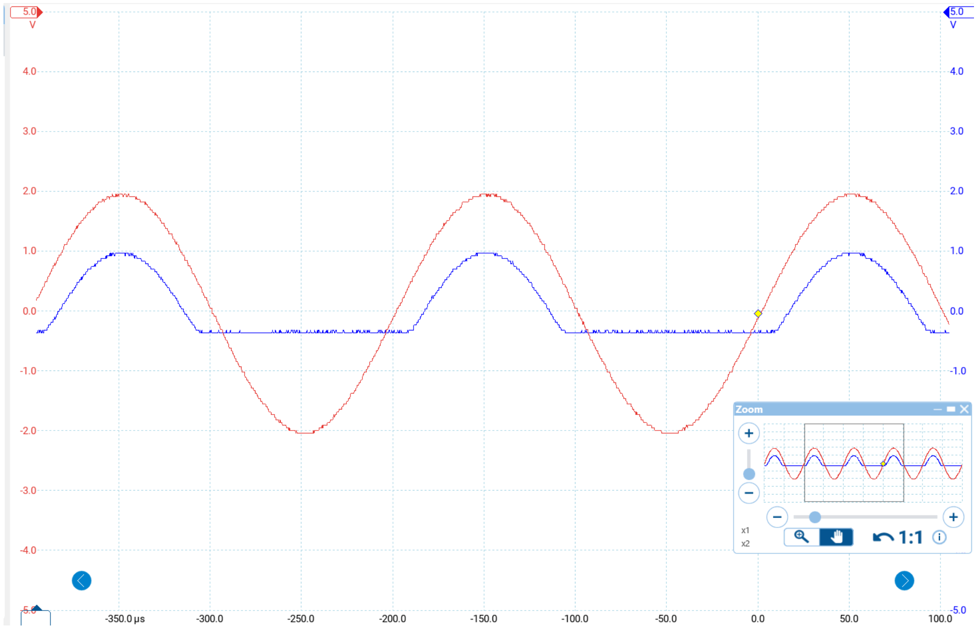

Figure 22: Oscilloscope graph of circuit without capacitor

The circuit without the capacitor acts like a half-wave rectifier, where only the positive part of the sine wave is preserved while when the voltage becomes negative it gets zero-ed.

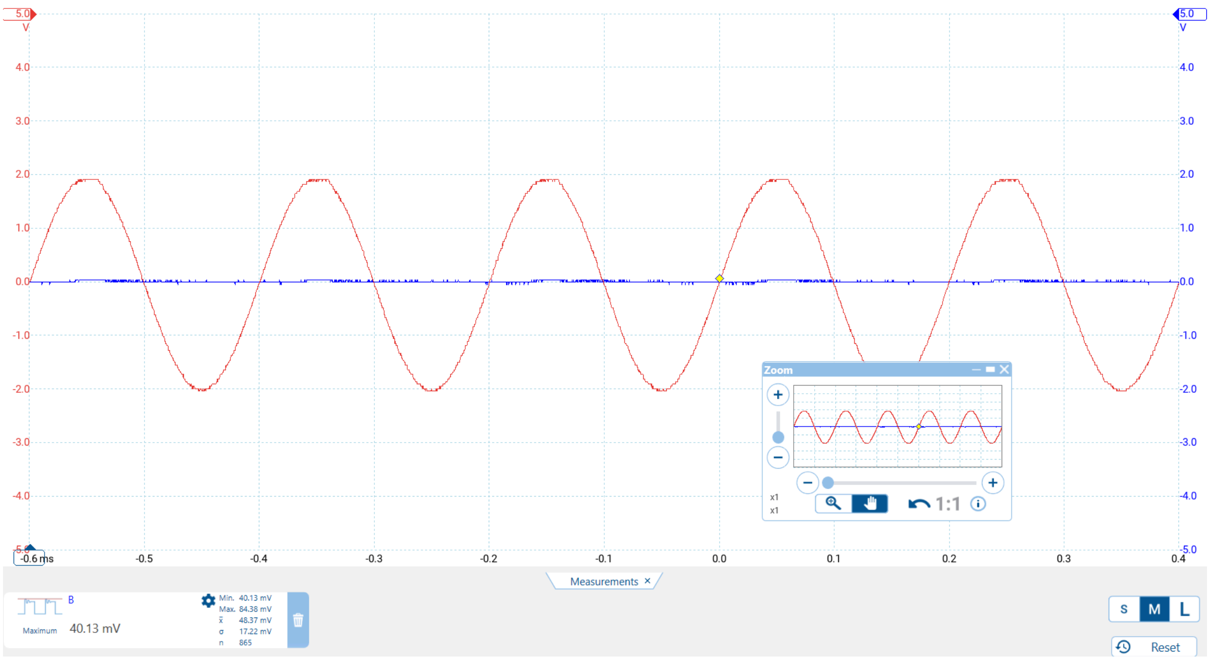

Figure 23: Oscilloscope graph of circuit with capacitor and measurement of rectified voltage

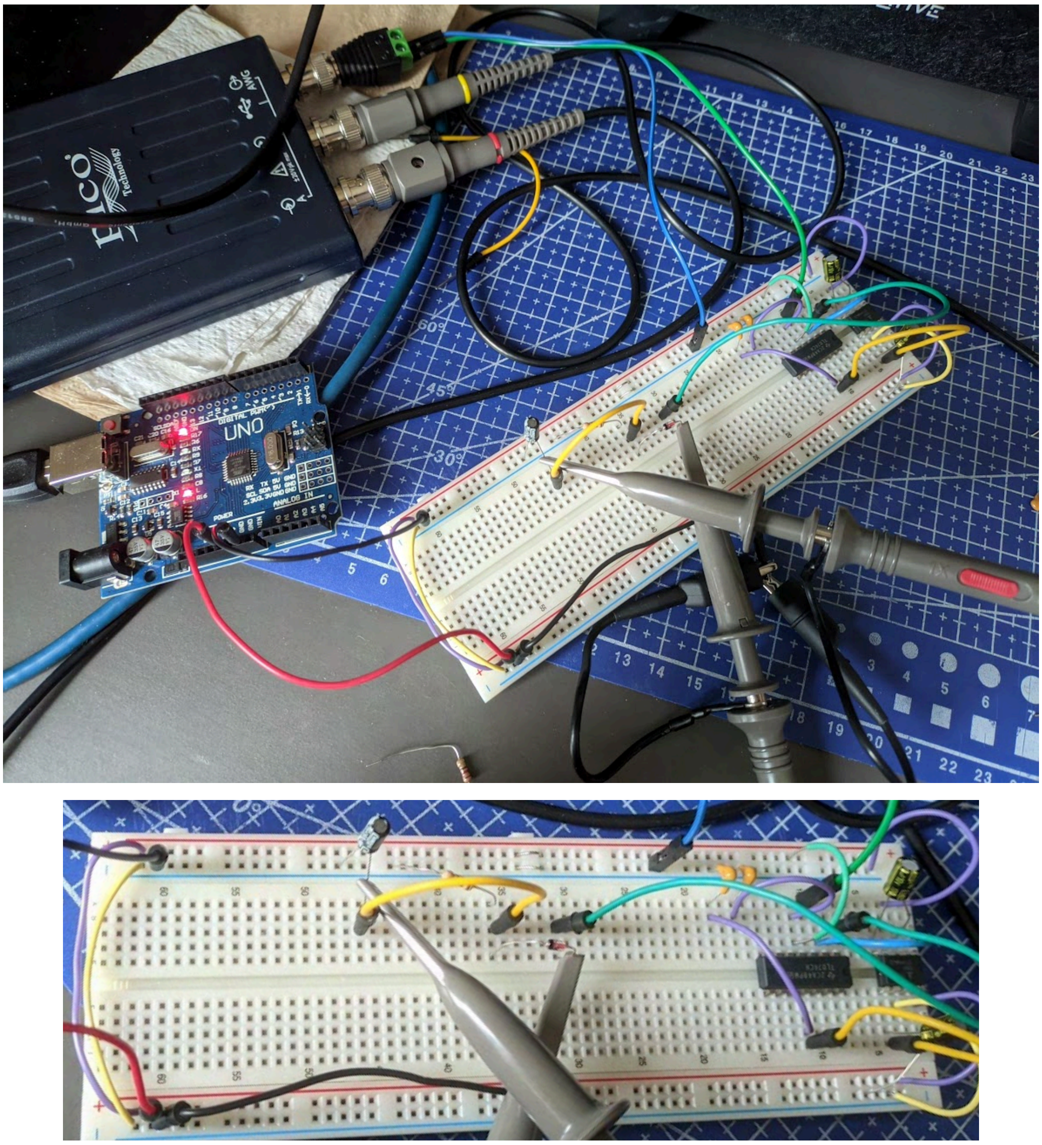

Figure 24: Circuit on breadboard

Observation: This rectifier circuit produces a constant voltage (i.e the voltage does not change as a function of time) from an input voltage that does fluctuate as a function of time. Converts AC voltage to DC voltage.
The voltage we get on probe B is about **40.13 mV**

Thevenin equivalent of the constant voltage at Probe B:

The voltage over the 220 Ohm resistor connected to the rectifier circuit gives 581 mV

=> Measured voltage over unloaded Pr2: V_{th} = *40.13 mV*
Chosen resistor with resistance value: R_{res} =*220 Ohm*
Measured voltage over the resistor: V_{res} = *581 mV*

=> $I = V_{res} / R_{res} = 2.64\ mA$
And $R_{th} = V_{th} - V_{res} / I$
=> $R_{th} = \mathbf{204.87\ Ohm}$

Observation: The value we got for the thevenin resistance of the 5 V power supply from the arduino was around 2 Ohms while here we get around a hundred times higher thevenin resistance of about 200 Ohms.

Lab 3: AC MEASUREMENTS

3.1 RL filter

To calculate f_c based on the component values of R1 and L1 we can use the formula (for RL filters):

$\omega_c = R/L$

from where we get that

$f_c = R/(L*2\pi)$

=> $f_c = 1000/(10^{-2}*2\pi) \approx$ ***15.9 kHz***

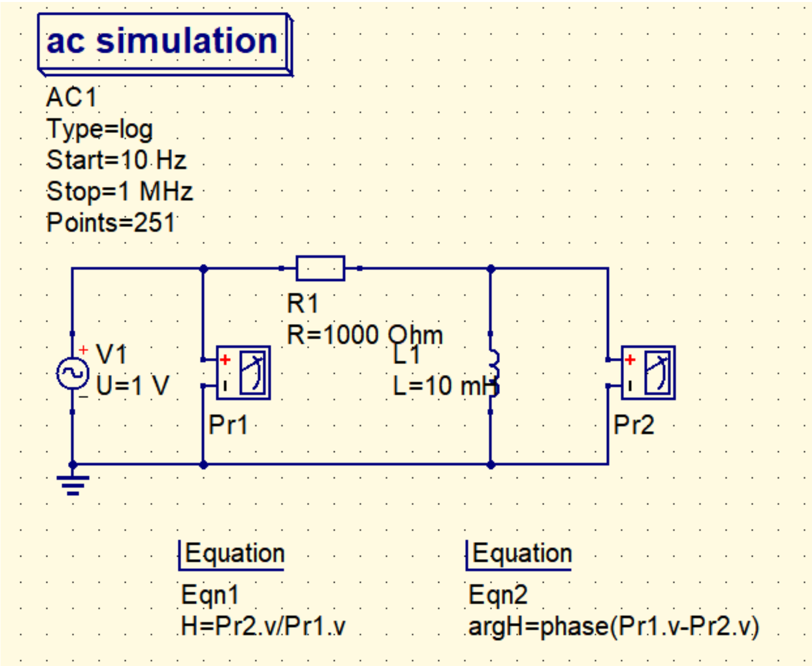

Figure 25: Circuit made in QUCS

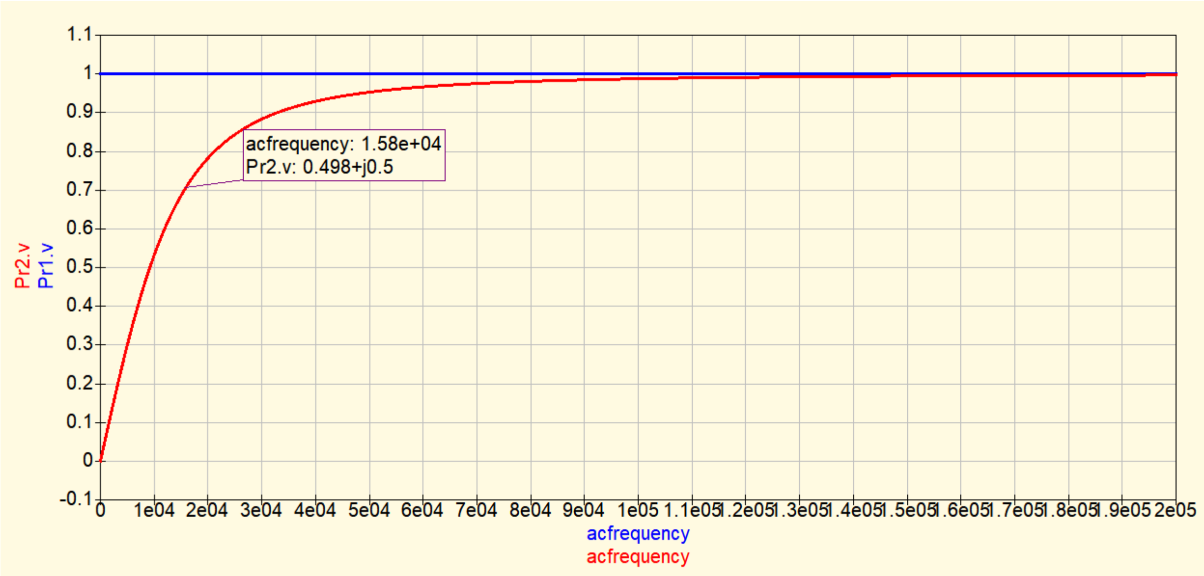

Figure 26: Simulation graph of the voltage probes with measurement at V≈0.707

On the simulation graph if we take a look at the frequency at which the voltage is $1/\sqrt{2}$ of its amplitude => 1V * $1/\sqrt{2}$ ≈ 0.707 V we will get the cut off frequency of the filter. The value $1/\sqrt{2}$ corresponds to the voltage at which the power delivered is half of its maximum (definition of cutoff frequency).

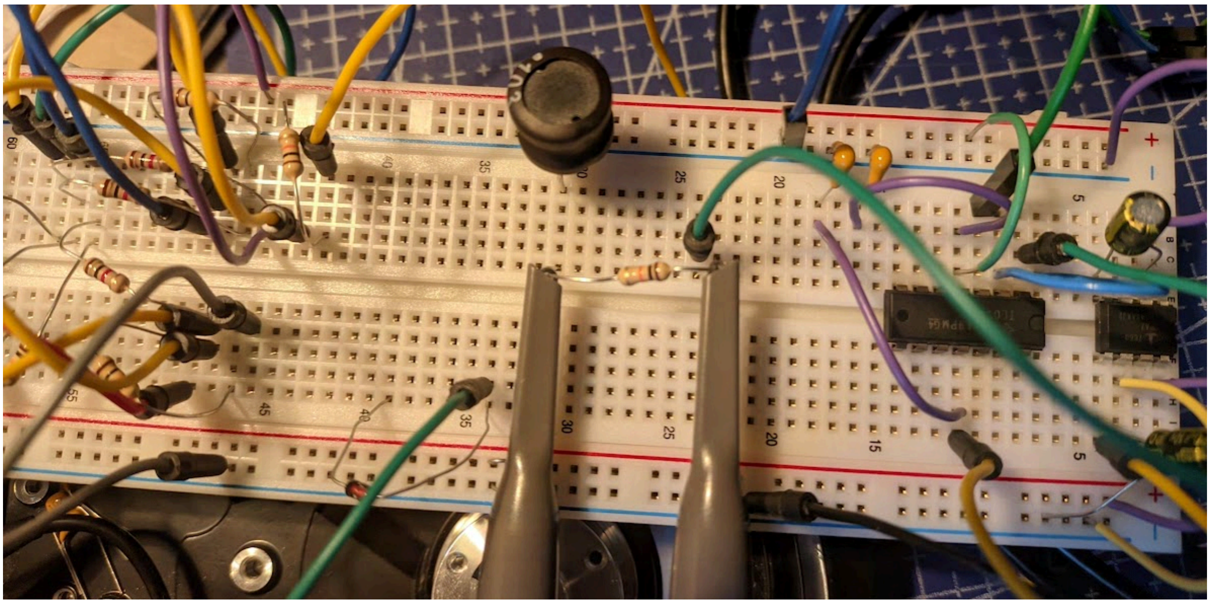

Figure 27: Photo of circuit on breadboard

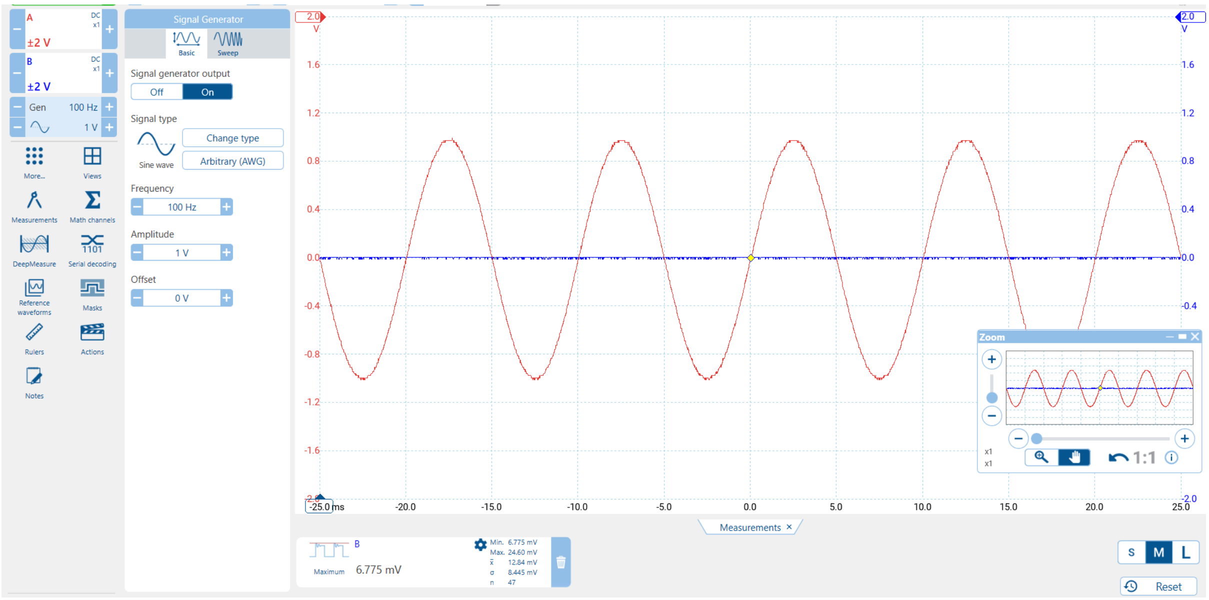

Figure 28: Oscilloscope graph of circuit at low frequency(100hz)

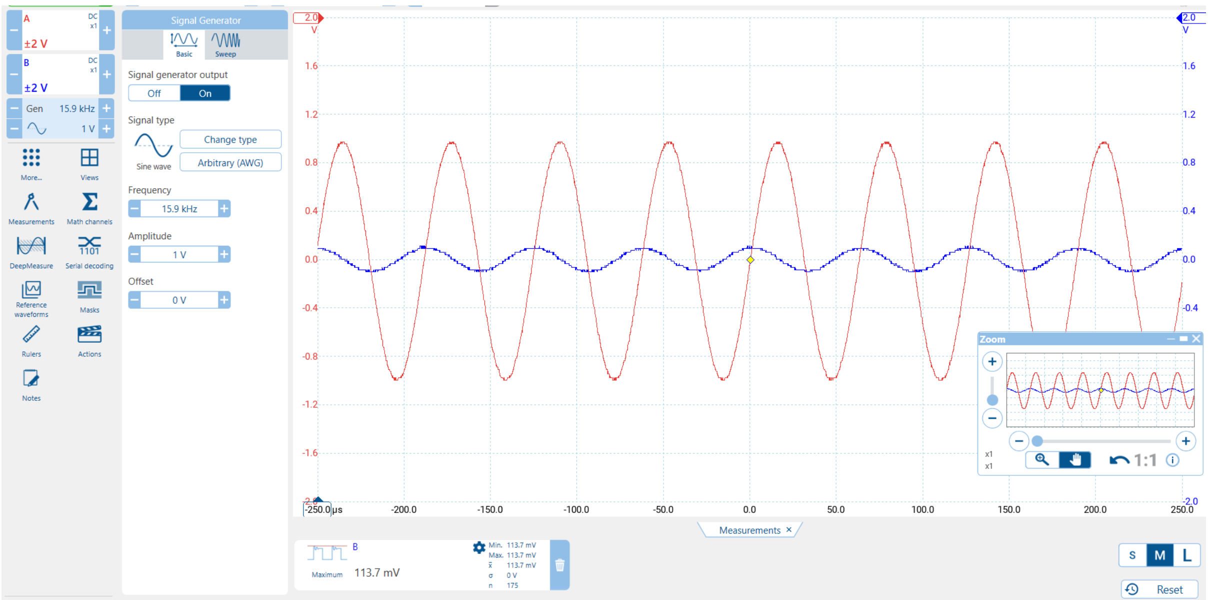

Figure 29: Oscilloscope graph of circuit at around cut-off frequency(15.9kHz)

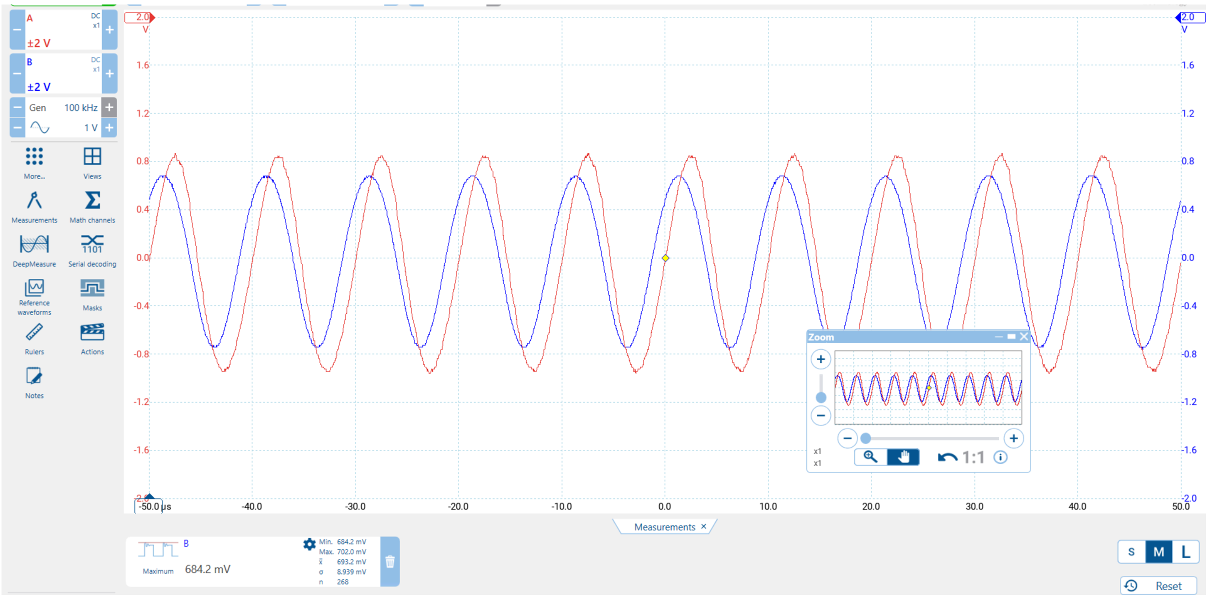

Figure 30: Oscilloscope graph of circuit at high frequency(100kHz)

Amplitude of V_{out} at 100 Hz is about **35.65 mV** (measured using the Amplitude measure mode in Picoscope).

Amplitude of V_{out} at 80 kHz is about **1.09 V** (measured using the Amplitude measure mode in Picoscope).

Observation: Since we get an amplitude comparable to V_{in} at high frequencies and almost negligible values at low frequencies we can safely assume that this circuit functions as a high-pass filter.

3.2 RC filter

To calculate f_c based on the component values of R1 and C1 we can use the formula (for RC filters):

$\omega_c = 1 / (R * C)$

from where we get that

$f_c = 1 / (R * C * 2\pi)$

=> $f_c = 1 / (10^4 * 3 * 10^{-9} * 2\pi) \approx \mathbf{5.3\ kHz}$

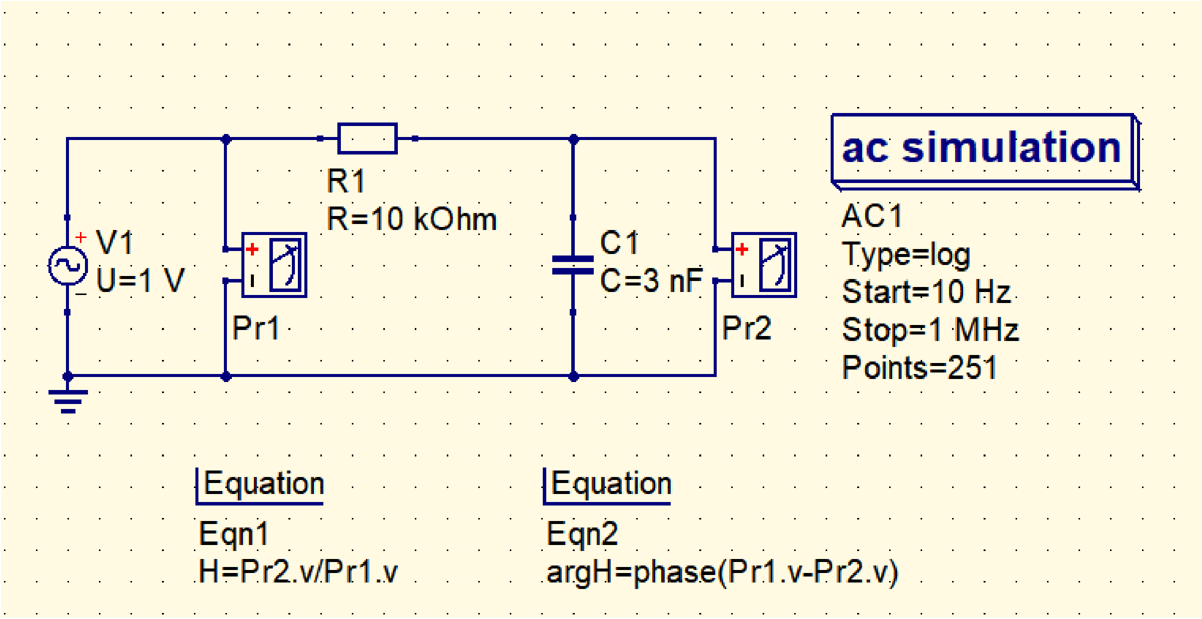

Figure 31: Circuit made in QUCS

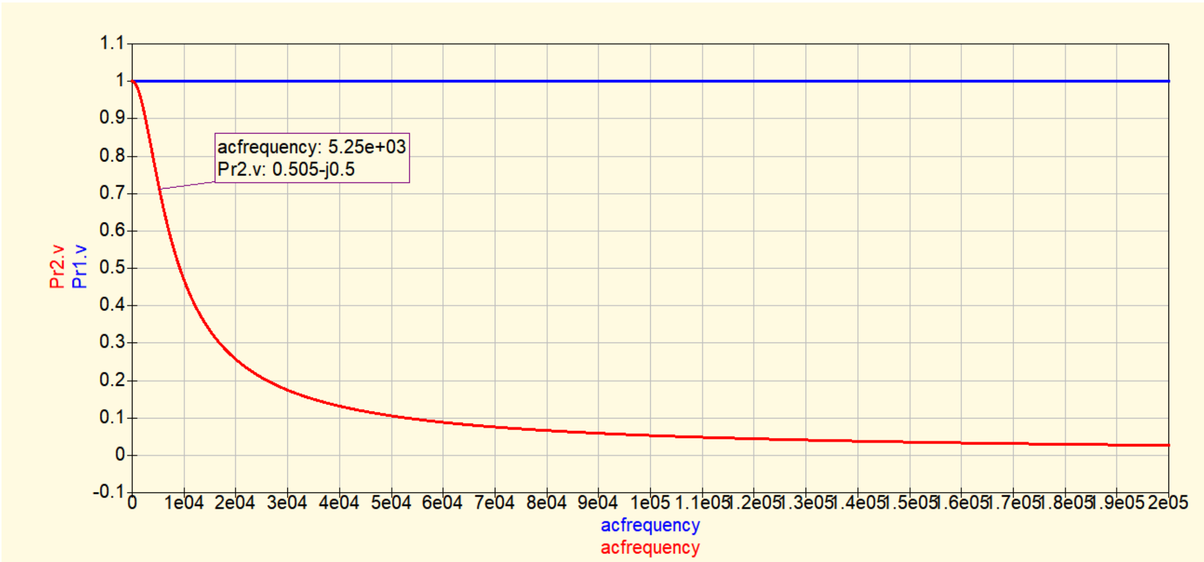

Figure 32: Simulation graph of the voltage probes with measurement at V≈0.707

On the simulation graph similar to the RL filter if we take a look at the frequency at which the voltage is $1/\sqrt{2}$ of its amplitude => $1V * 1/\sqrt{2} \approx 0.707$ V we will get the cut off frequency of the filter. The value $1/\sqrt{2}$ corresponds to the voltage at which the power delivered is half of its maximum (definition of cutoff frequency).

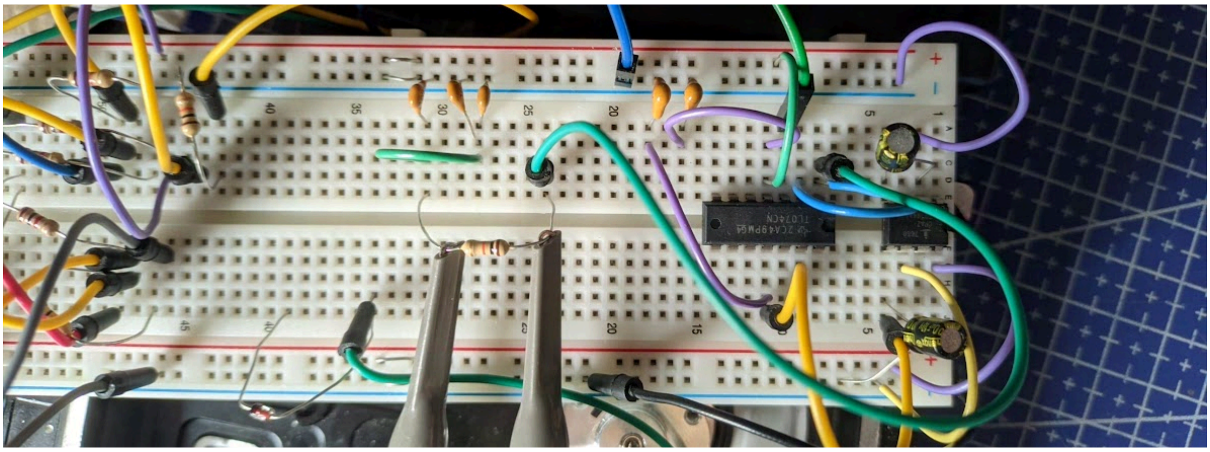

Figure 33: Photo of circuit on breadboard (we use three 1 nF capacitors in parallel to get an equivalent capacitance of 3 nF)

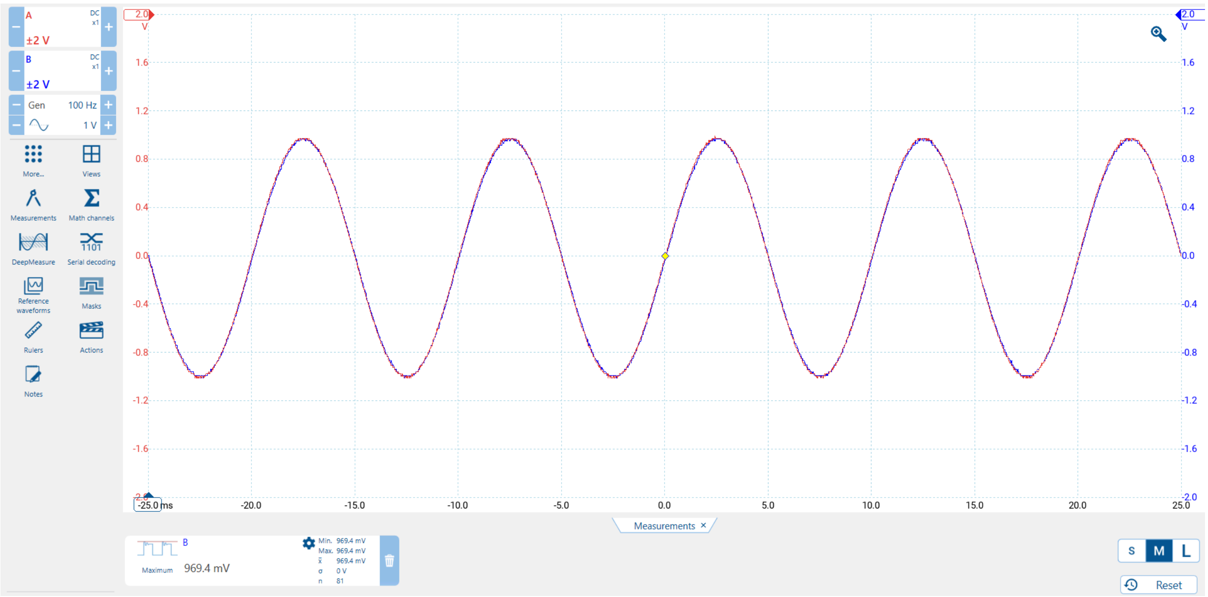

Figure 34: Oscilloscope graph of circuit at low frequency(100hz)

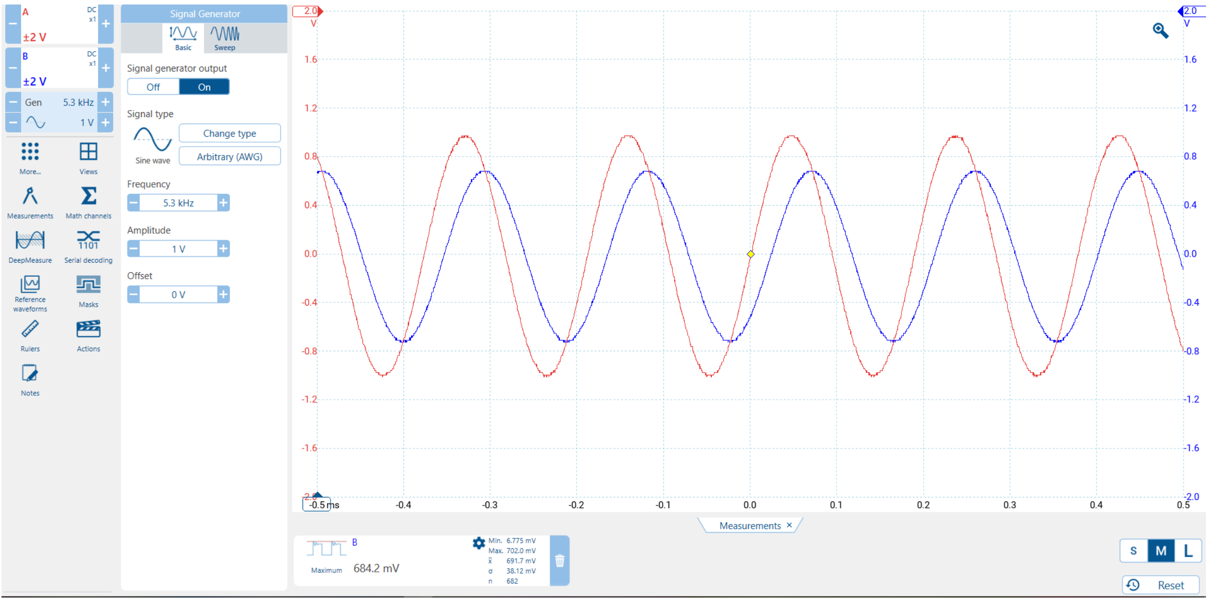

Figure 35: Oscilloscope graph of circuit at around cut-off frequency(5.3kHz)

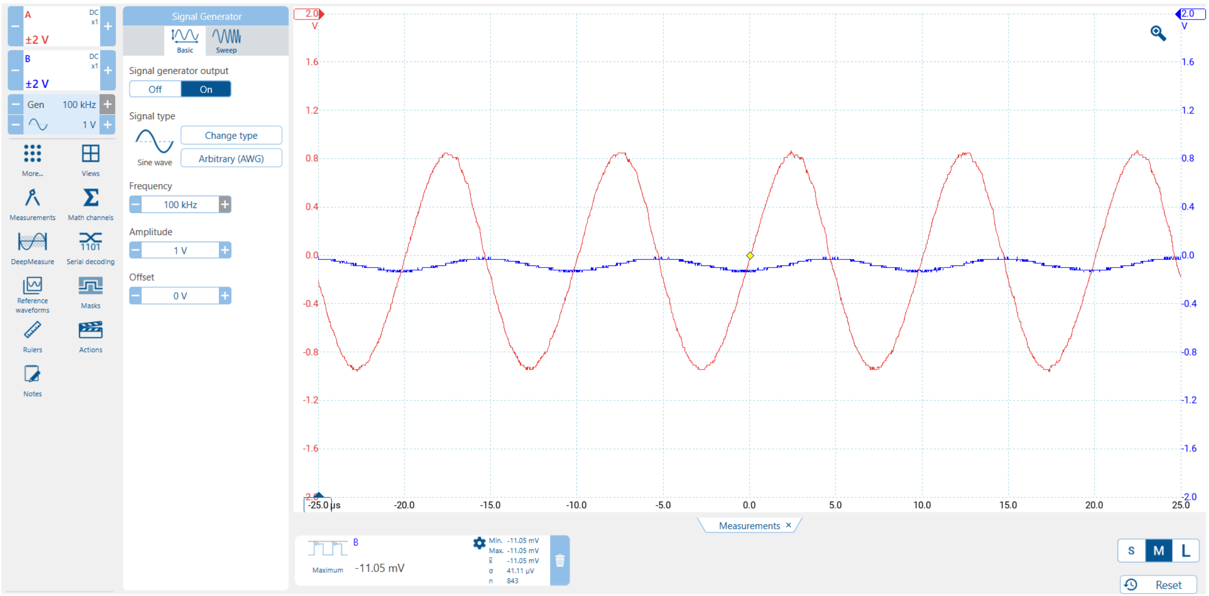

Figure 36: Oscilloscope graph of circuit at high frequency(100kHz)

Amplitude of V_{out} at 100 Hz is about **1.93 V** (measured using the Amplitude measure mode in Picoscope).

Amplitude of V_{out} at 80 kHz is about **109.9 mV** (measured using the Amplitude measure mode in Picoscope).

Observation: Since we get an amplitude comparable to V_{in} at low frequencies and almost negligible values at high frequencies we can therefore assume that this circuit functions as a low-pass filter.

3.3 RLC filter

3.3.1 Sinus input to the filter and viewing voltage versus time

To calculate the centre frequency f_0 based on the component values of R1, L1 and C1 first we need to calculate the two cutoff frequencies :

$$\omega_{c1} = -\frac{R}{2L} + \sqrt{(\frac{R}{2L})^2 + (\frac{1}{LC})}$$

$$\omega_{c2} = \frac{R}{2L} + \sqrt{(\frac{R}{2L})^2 + (\frac{1}{LC})}$$

which in turn are related to the centre frequency by the equation:

$$\omega_0 = \sqrt{\omega c1 \ * \ \omega c2}$$

from where we get that

$\omega_{c1} \approx$ 32.3 kHz

$\omega_{c2} \approx$ 1032.3 kHz

=> $\omega_0 \approx$ 182.6 kHz

And so as this is angular frequency in order to get our f_0 we divide by 2π and get:

$f_0 \approx$ **29.1 kHz**

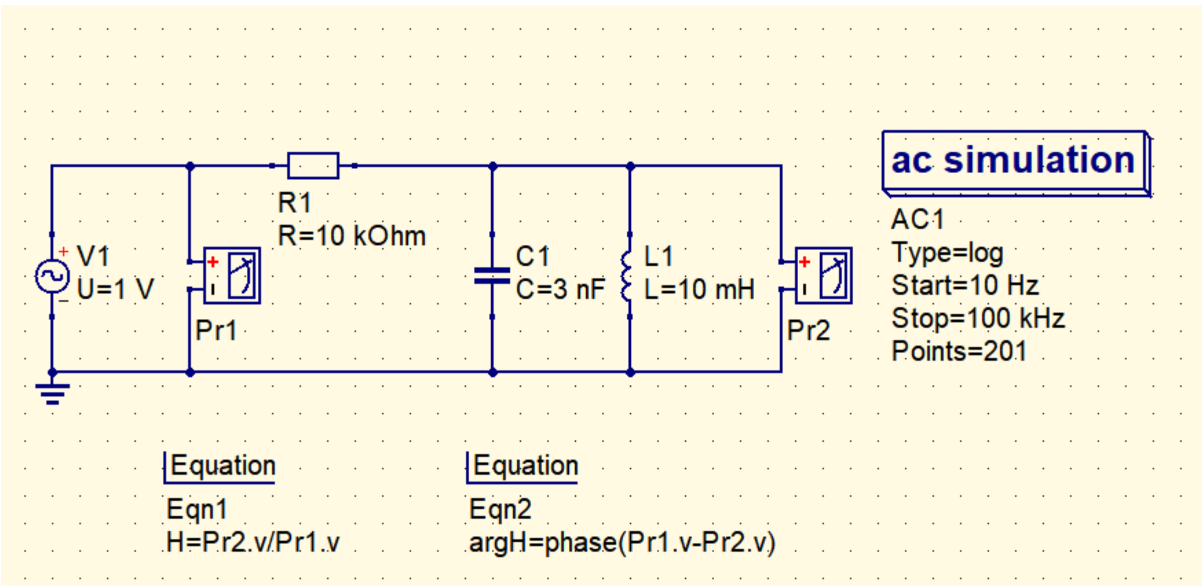

Figure 37: Circuit made in QUCS

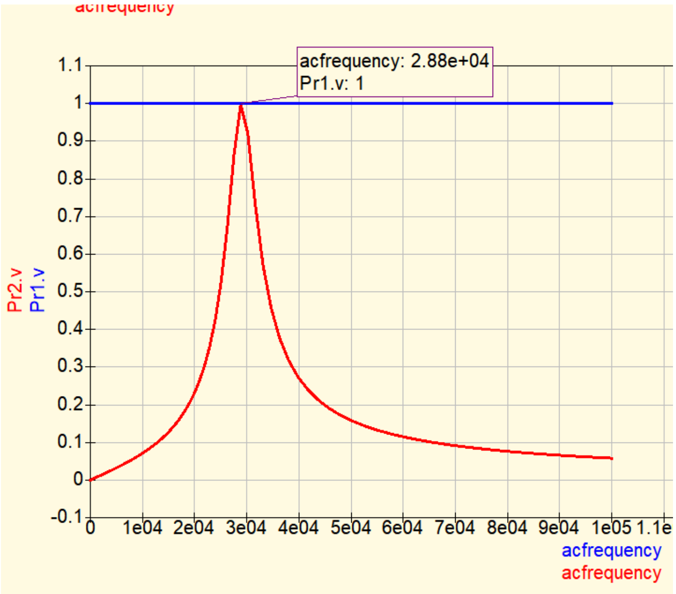

Figure 38: Simulation graph of the voltage probes with measurement at peak

Observation: We can see that at the centre frequency of about 29 kHz we get a voltage at V_{out} = 1 V i.e. equal to V_{in}.

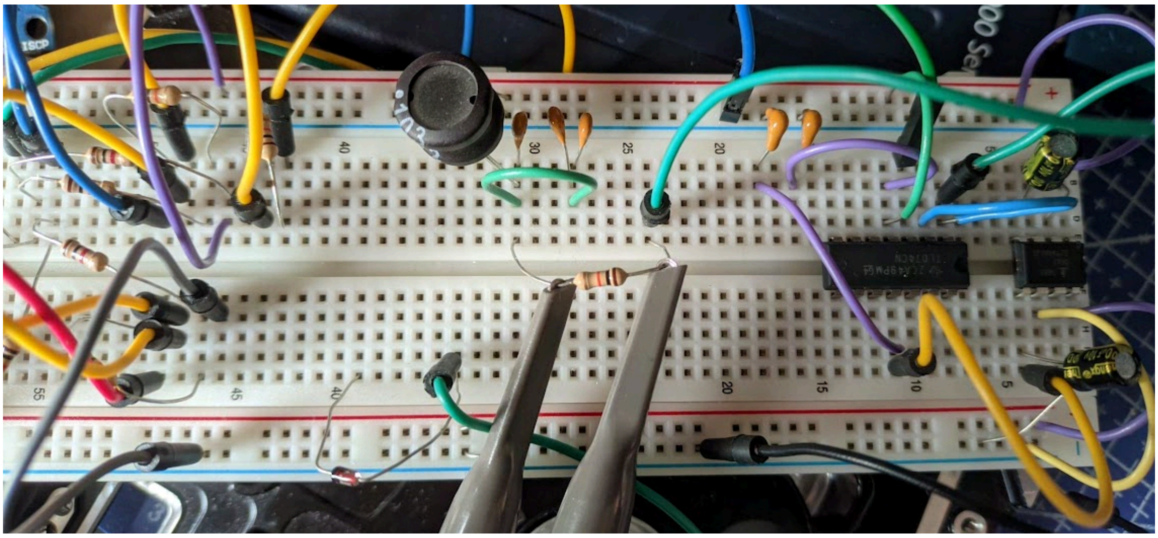

Figure 39: Photo of circuit on breadboard

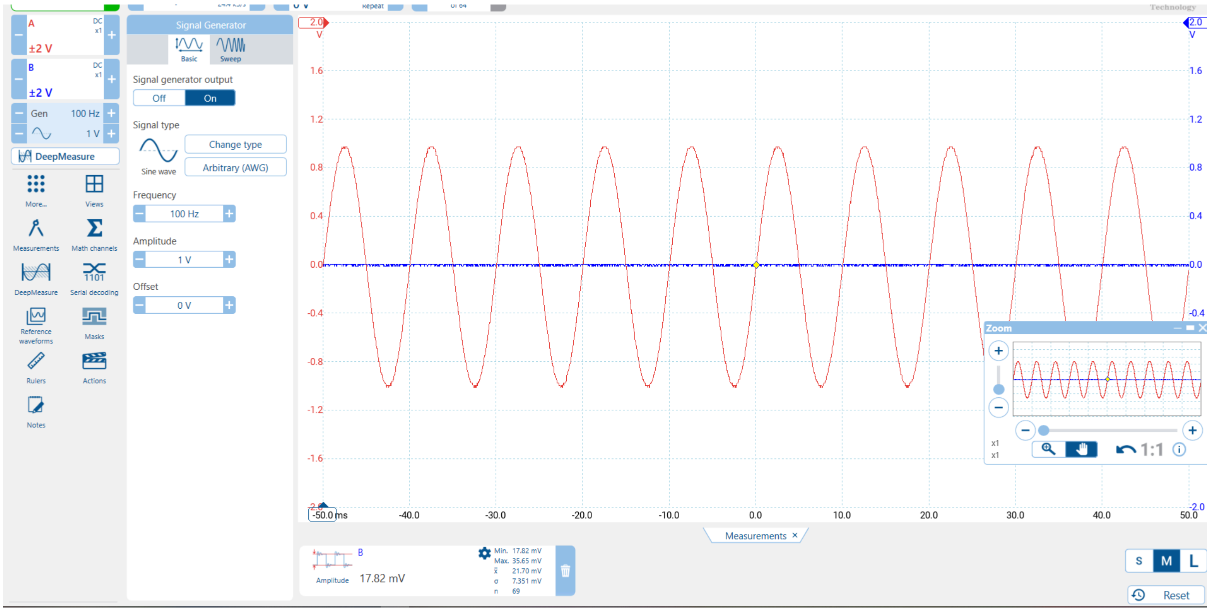

Figure 40: Oscilloscope graph of circuit at low frequency(100hz)

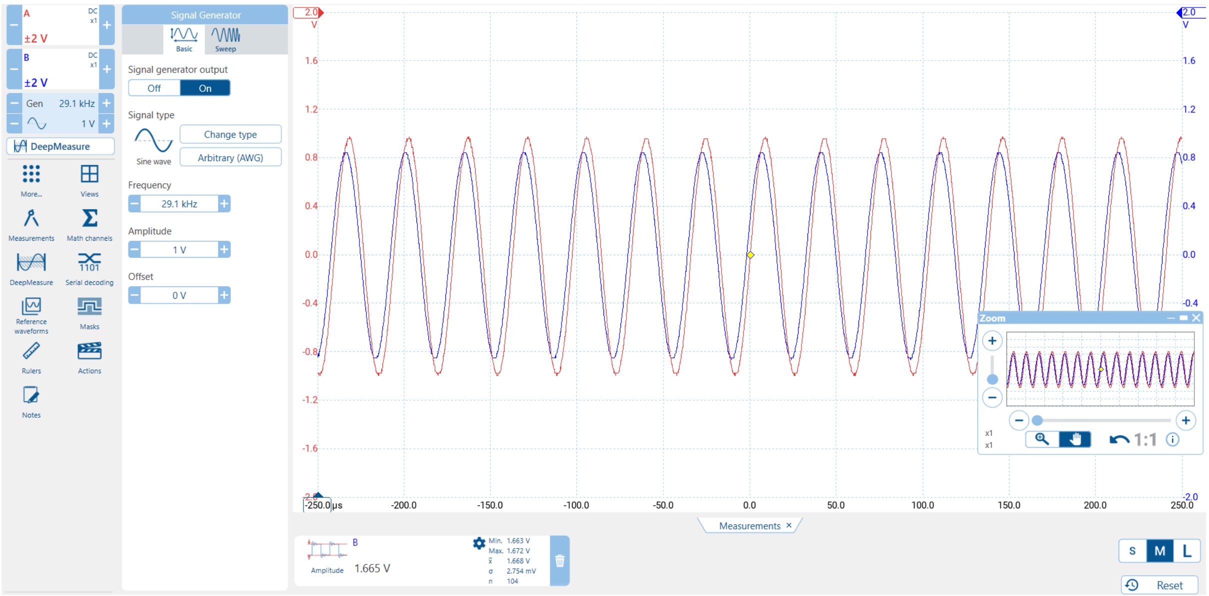

Figure 41: Oscilloscope graph of circuit at around centre frequency(29.1kHz)

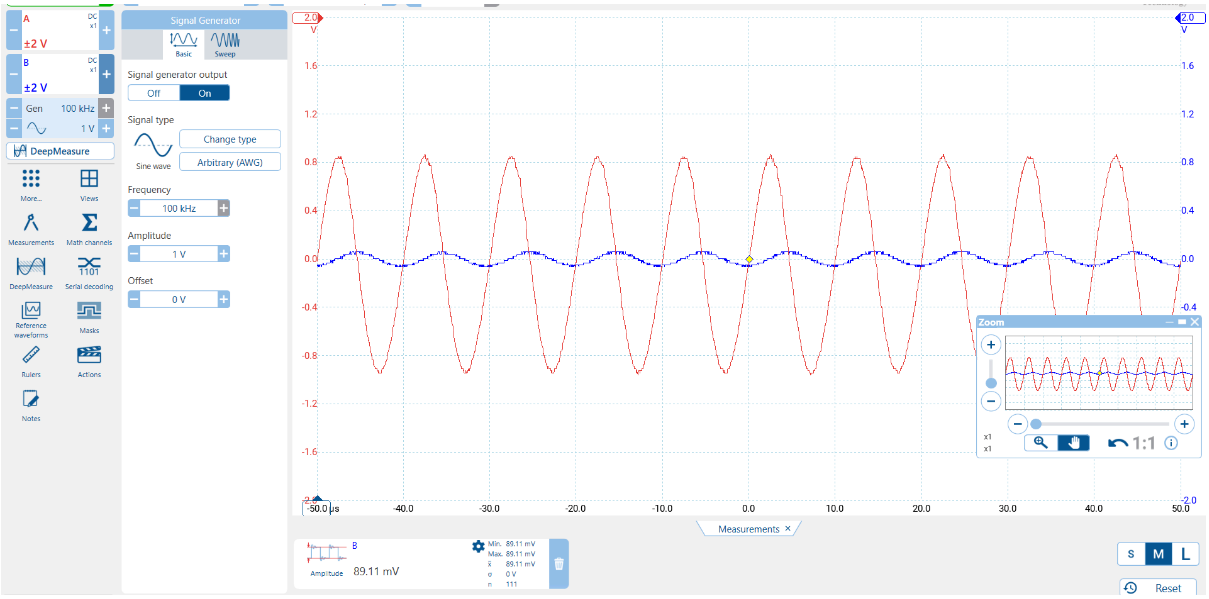

Figure 42: Oscilloscope graph of circuit at high frequency(100kHz)

Amplitude of V_{out} at 1 kHz is about **35.65 mV** (measured using the Amplitude measure mode in Picoscope).

Amplitude of V_{out} at 10 kHz is about **124.8 mV** (measured using the Amplitude measure mode in Picoscope).

Observation: Since we get an amplitude comparable to V_{in} only at about the centre frequency value and almost negligible numbers at any other frequencies we can deduce that this circuit functions as a band-pass filter for 29.1 kHz.

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

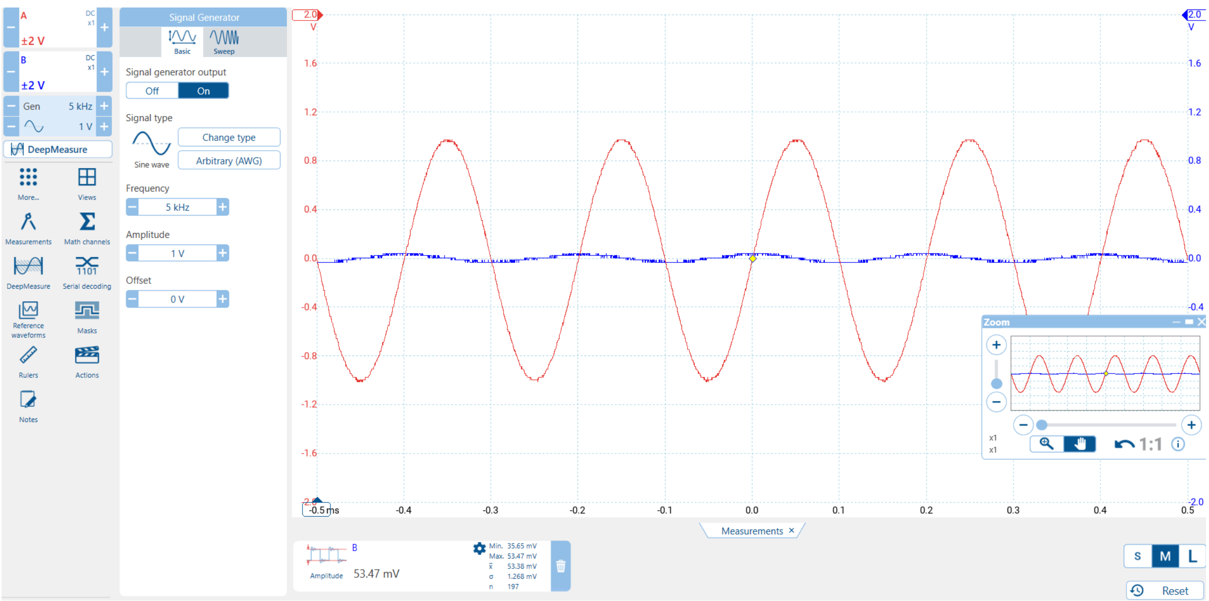

Figure 43: Oscilloscope graph of circuit at 5kHz

Observation: Since at 5 kHz we are not in the band which is passed by the filter circuit the voltage is suppressed and we get an amplitude at V_{out} = 53.5 mV

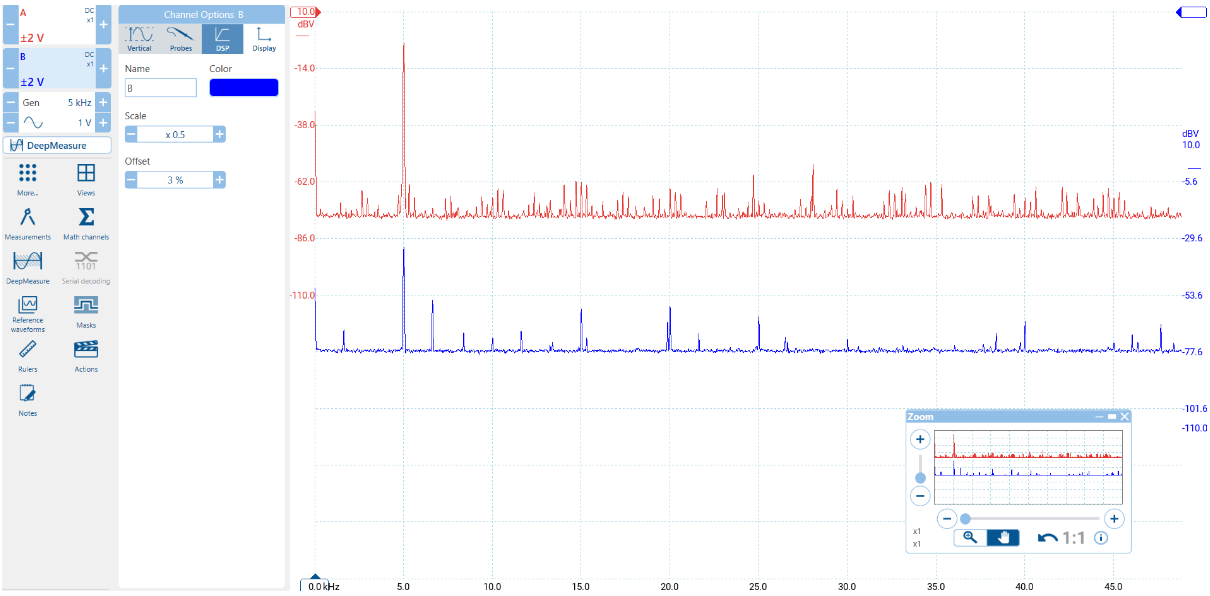

Figure 44: Oscilloscope spectrum graph of circuit(here I am using the average view option of the spectrum to more easily visualise the peaks)

Observation: We can see several peaks on the spectrum, the highest of which is the one at 5 kHz, the other noticeable ones appear at 6.66, 15, 20, 25 and 40 kHz. The peak at 5 kHz is about -57.6 dBv or around 1.3mV when utilising the definition of dBv

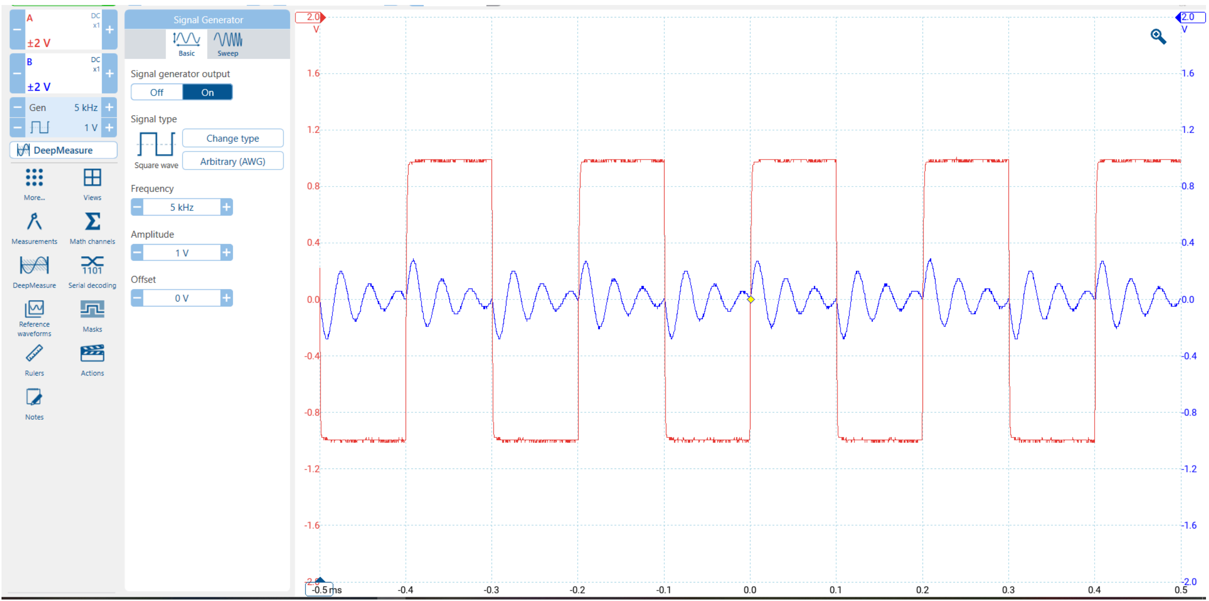

Figure 45: Oscilloscope graph of circuit with square wave V_{in} at 5 kHz

Observation: The input voltage of the square wave switches between the positive and negative values of the set amplitude at the frequency of 5 kHz. The output seems to follow a decaying sinusoidal shape which begins on every rising edge of the input.

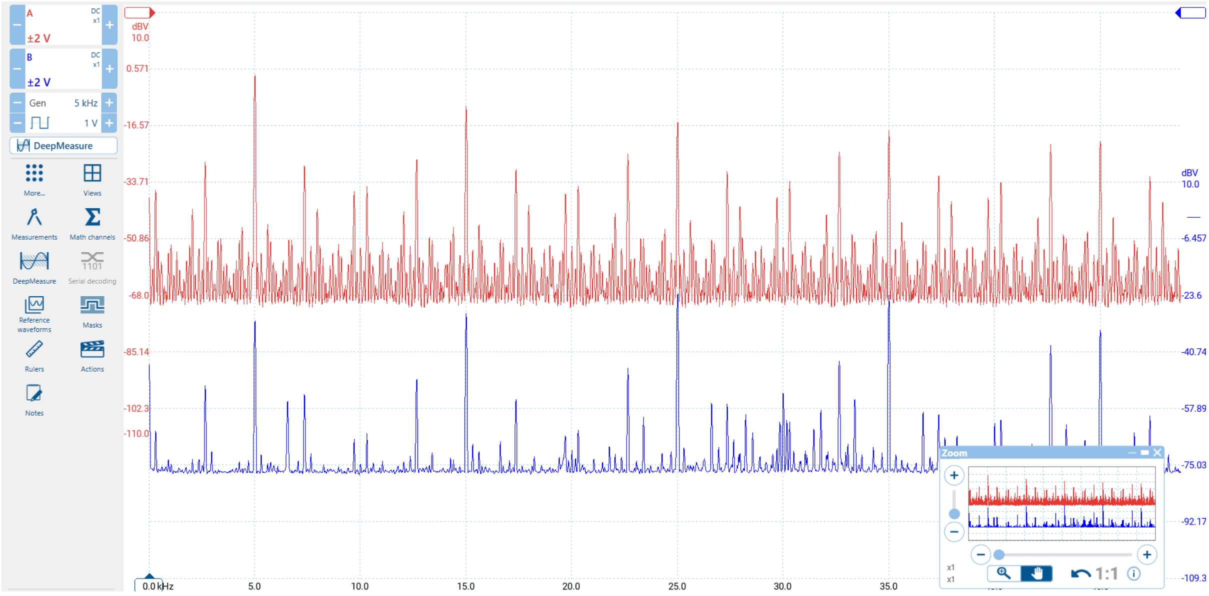

Figure 46: Oscilloscope spectrum graph of square wave input

Observation: We again see multiple peaks. The most significant ones appear at 5, 15, 25 and 35 kHz. The peak at 5 kHz is about -31.5 dBv using the provided definition:

$$dBV = 20\log\left(\frac{V}{Vref}\right)$$

We get that the amplitude is ≈ 26.6 mV