# Lab rapport 1 - 3
# Embedded Electronics- IE1206
# KTH

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## 1.1 KVL, KCL and Power in resistive net

*Introduction:* The aim of this part of the lab was to build the given circuit, both in the simulation program QUCS and on the breadboard. (**See** Attachment 1 circuit 1.1 built on the breadboard)

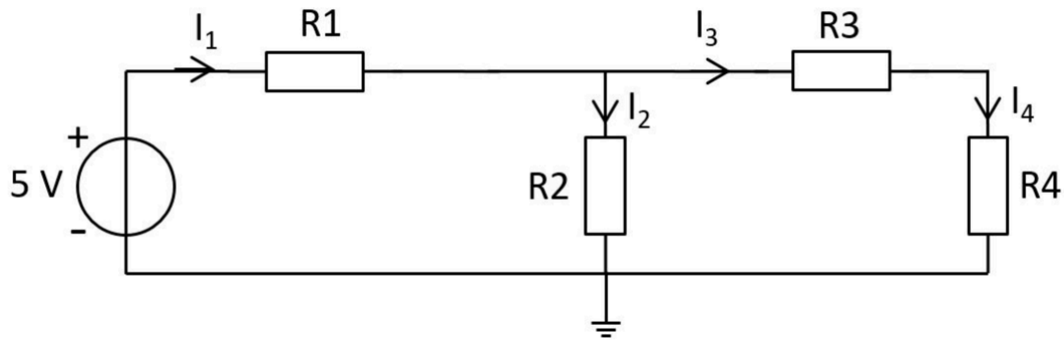



Figure 1: the circuit that was built, both in QUCS and on the breadboard.

The resistors chosen for this circuit:
$R_1$=1kΩ
$R_2$=47kΩ
$R_3$=10kΩ
$R_4$=4,7kΩ

*Method:* When the circuit was built on the breadboard, the voltage, resistance and current could be measured with a multimeter. The measurements were written down on a chart and then the power and resistance could be calculated. To get voltage over the circuit on the breadboard, an Arduino was connected through the 5V pin and ground.

| **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 QUCS [V]** | **Simulated I QUCS [mA]** | **Simulated P QUCS [mW]** |
|---|---|---|---|---|---|---|---|---|
| R1 | 0,98 | 0,40 | 0,44 | 0,91 | 0,18 | 0,41 | 0,41 | 0,17 |
| R2 | 46,6 | 4,63 | 0,099 | 46,77 | 0,46 | 4,59 | 0,097 | 0,45 |
| R3 | 9,9 | 3,15 | 0,317 | 9,94 | 0,99 | 3,13 | 0,31 | 0,97 |
| R4 | 4,6 | 1,46 | 0,315 | 4,63 | 0,46 | 1,47 | 0,31 | 0,46 |
| Arduino 5V Voltage source | Not applicable | 5,04 | 0,44 | Not applicable | 2,22 | 5,00 | 0,41 | 2,05 |

Chart 1: showing the measurements from lab 1.1

Confirming Kirchhoff's voltage law (KVL):
*KVL:* $V-V_1-V_2=0$
$V= V_1+V_2$
$5{,}04=V_1+V_2$
$V_1+V_2= 0{,}40+4{,}63=5{,}03V\approx5{,}04V=V$

*KVL:* $V_3+V_4-V_2=0$
$V_2=V_3+V_4$
$V_3+V_4=3{,}15+1{,}46=4{,}61V\approx4{,}63V=V_2$

Confirming Kirchhoff's current law (KCL):
$I_1=I_2+I_3$
$I_2+I_3=0{,}099+0{,}317=0{,}416mA\approx0{,}44mA=I_1$

*Discussion:* All the measurements from the circuit on the breadboard is similar to the values from the simulated circuit in QUCS, within reasonable measurement accuracy.
According to Kirchhoff's laws of currents and voltages, the circuit that was built are correct.
The measurements from the circuit on the breadboard are somewhat different from the calculated values.
As to the question if the power is balanced in the circuit above, the answer is yes as can be seen in chart 1. The calculated values from the circuit built on the breadboard is similar to the ones from the simulation program QUCS. The sum of the powers delivered and consumed by the voltage source from the breadboard and from QUCS is the same.

## 1.2 Determine Thevenin equivalent circuits

### 1.2.1 Thevenin equivalent circuit for Arduino 5 V pin

*Introduction:* In the next part of the lab, the Thevenin equivalent circuit for the Arduino 5V pin was calculated.
*Method:* The first step was to measure the voltage coming from the Arduino, giving the $V_{TH}$ value. (**See** Attachment 2 1.2.1 measuring the voltage in the arduino)
$V_{TH} = 5{,}04V$

To get the current that was going through the chosen resistor, the voltage over it was measured. **(See** Attachment 3 1.2.1 measuring the voltage over the resistor)
The resistor:
$R=220\Omega$
Voltage over resistor:
$V_R= 5{,}00V$

With Ohms law the current can be calculated.
Because of how the circuit was built, the assumption that the current over the wanted resistor $R_{TH}$ ($I_{RTH}$) are the same as the current used to calculate the resistor value $R_{TH}$, the following equations can be used.
The current going through the resistor $R_{TH}$:
$I_{RTH}=I_{SC}=V_R/R=5{,}00/220= 0{,}0227A$
$R_{TH} = V_{TH}/I_{SC}=5{,}04/0{,}0227= 221{,}76\Omega$

The Thevenin equivalent values:

$V_{TH} = 5{,}04V$
$R_{TH}= 221{,}76\Omega$

### 1.2.2 Thevenin equivalent for Arduino digital output pin

In this part of the lab, the Thevenin equivalent circuit for the Arduino from the digital output pin (pin 11) was calculated. The first step was to measure the voltage coming from the Arduino, giving the $V_{TH}$ value.
$V_{TH} = 5{,}04V$

To get the current that was going through the chosen resistor, the voltage over it is measured.
The resistor:
$R=220\Omega$
Voltage over resistor:
$V_R= 4{,}46V$

With Ohms law the current can be measured.
As well as in the part before, the following equations can be used to determine $R_{TH}$ because of the conclusion that the current ($I_{RTH}$) over the wanted resistor are the same as the current used to calculate the resistor value $R_{TH}$.
The current going through the resistor $R_{TH}$:
$I_{RTH}=I_{SC}=V_R/R=4{,}46/220= 0{,}020A$
$R_{TH} = V_{TH}/I_{SC}=5{,}04/0{,}020= 252\Omega$

The Thevenin equivalent values:
$V_{TH} = 5{,}04V$
$R_{TH}= 252\Omega$

## 1.3 Light Emitting Diode (LED) circuits

### 1.3.1 Resistor in series with yellow LED

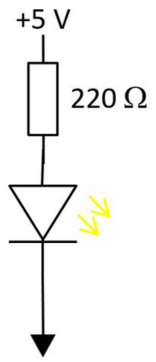



Figure 2: circuit with yellow LED

*Introduction:* In this part, a yellow LED was connected to a resistor in series as well as connected to the Arduino. The task was to calculate the power of the LED along with checking if the LED lit up or not.

When the yellow LED was connected to the resistor in the circuit, it did light up. **(See Attachment 4 1.3.2 built on the breadboard)**

In the case with the yellow LED, the current in the circuit was the same, thus coming to the conclusion that the resistance was low because of Ohms law.

The measurement values:
R=220Ω
$V_R$=3,02V
$V_{LED}$=1,99V
$I_R$=$I_{LED}$=$V_R$/R=13,7mA

The electrical power consumed by the yellow LED:
$P_{LED}$=$V_{LED}$*$I_{LED}$=27,3mW

**1.3.2 Resistor in series with blue LED**

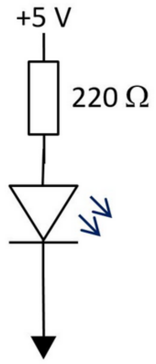



Figure 3: circuit with blue LED

*Introduction:* Here, a blue LED was connected to the same resistor in series as well as connected to the Arduino. The task was to calculate the power of the LED along with checking if the LED lit up or not.

In the case with the blue LED it had higher resistance for the same reason as mentioned before with the yellow LED, the current in the circuit was the same. When the LED was connected to a resistor it lit up. (**See** Attachment 5 circuit 1.3.2 built on the breadboard)

The measurement values:
R=220Ω
$V_R$=2,30V
$V_{LED}$=2,71V
$I_R$=$I_{LED}$=$V_R$/R=10,5mA

The electrical power consumed by the blue LED:
$P_{LED}$=$V_{LED}$*$I_{LED}$=28,3mW

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

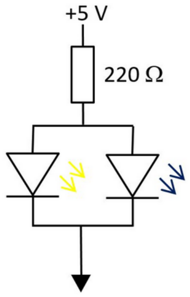


Figure 4: circuit with yellow and blue LED in parallel
In this part of the lab two LEDs was connected in parallel, one blue LED and one yellow. Also, a resistor with a resistance of 220Ω was connected to the LEDs in series. When the circuit was connected to a voltage source only one LED lit up. The blue one stayed turned off, while the yellow one started to shine. **(See** Attachment 6 circuit 1.3.4 built on the breadboard)

The reason for that is that the two LEDs have the same voltage over them, resulting in different current because of Ohm:s law and because their resistance is constant. LEDs with lower resistance will therefore be able to receive more current. While the LEDs with higher resistance will receive less current, not enough to shine. In this case, the blue LED had higher resistance which led to it not being able to be lit.

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

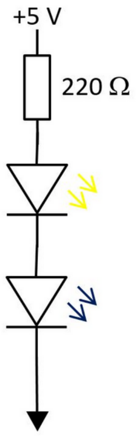


Figure 5: circuit with yellow and blue LED in series

Here, the two LEDs was connected in series instead of parallel with a resistor of 220Ω, also in series. When the voltage was applied to the circuit, both LEDs lit up. However, the blue LED was shining slightly brighter. **(See** Attachment 7 circuit 1.3.4 built on the breadboard)

The reason for that is the size of the resistance in the LEDs. The blue one has higher resistance, resulting in more light. As for the yellow LED, the light was lower because of the lower resistance. What happens is that more electrons must move through the LED with higher resistance (the blue LED) to be able to get through. More electrons and more current leads to more light.

## 2.1 Time dependent behavior of RL circuit

*Introduction and method:* The second lab contained circuits that generated square waves. This circuit was built with an inductor. These waves, generated from the circuit, were measured and plotted with a Picoscope that could simulate the waves in a program. The Picoscope was used on the circuit after it was built on the breadboard. The same type of circuit was simulated in QUCS so that the values from the breadboard could be compared to simulated values. When dealing with and measuring square waves it is important to make sure that the time constant tau ($\tau$) is calculated. When the value of tau is calculated it can then be used in equations.

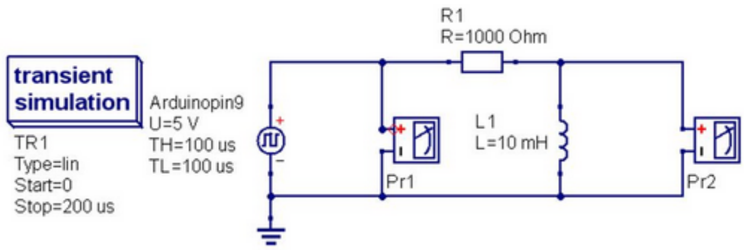



Figure 6: the circuit that was built on the breadboard as well as in QUCS.

The time constant calculated from the component values of the resistor and the inductor.
To determine the time constant in a circuit with an inductor the following equation is used:
$\tau$ = L/R= 1000/ 0,01=10$\mu$s

The decay constant for the circuit can be calculated with the following equation:
$V_L$/e= 5/e= 1,8393V.
The time constant is then determined when you take the difference between 5V and 1,8393V=>
$\tau$= 10,38$\mu$s

*Discussion:* When the circuit has a signal from low to high the current moves in the same direction, that direction is positive. When the signal goes from high to low instead, the current change direction and the voltage drops to negative. (**See** Attachment 8 circuit 2.1 simulated in QUCS)
The same behavior goes for inductors in parallel and in series only this time, the voltage change is somewhat faster in the circuit with the inductors in parallel and slower in the one with them in series. **See** Attachment 41 circuit from 2.1 with inductors in parallel **as well as** Attachment 42 circuit from 2.1 with inductors in series to see the circuits built on the breadboard, both with the inductors in parallel and in series.

The same behavior appears in the circuit that was built on the breadboard and for the same reason as explained above with the simulated circuit in QUCS. (**See** Attachment 9 picoscope measurements for inductor**,** Attachment 10 picscope measurements for inductors in parallel **as well as** Attachment 11 picoscope measurements for inductors in series)**.**

When two inductors are in parallel the total inductance is calculated with the equation:
$1/L= 1/L_1+1/L_2$

- ⇨ 1/10+1/10=1/5=1/L
- ⇨ L=5mH

$\tau$=L/R= 5m/1000=5µs

The time between 5V and 1,8393V in this circuit (with the two inductors in parallel) is in Picoscope 7: $\tau$=4,624µs

When two inductors are in series, the total inductance is calculated with:
L = L1 + L2
⇨ L = 10 + 10
⇨ L = 20mH
$\tau$ = L/R = 0,020/1000 = 20 $\mu$s VL/e = 5/e = 1,8393V

When the inductors are in parallel, the time constant between 5V and 1,8393V is in Picoscope: $\tau$ = 17,87 $\mu$s

## 2.2 Time dependent behavior of RC circuit

*Introduction and method:* This part of the lab also contained circuits that generated square waves. This time it contained a capacitor instead of an inductor. These waves were measured and plotted with a Picoscope that could simulate the waves in a program. The Picoscope was used on the circuit after it was built on the breadboard. The same type of circuit was simulated in QUCS so that the values from the breadboard could be compared to simulated values.

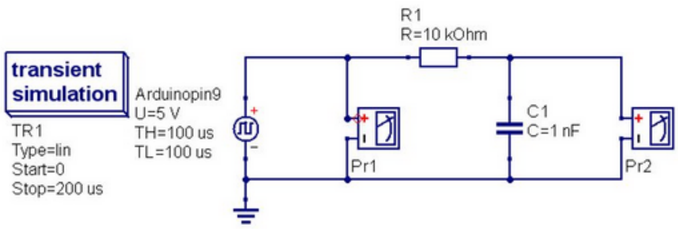



Figure 7: the circuit that was built in QUCS and on the breadboard.

The time constant calculated from the component values of the resistor and the inductor.
$\tau$ = R*C= 10 000*$10^{-9}$=10µs
The decay constant for the circuit can be calculated with the following equation:
$V_L/e$ = 5/e = 1,8393 V
The time constant between 5V and 1,8393V can then be calculated to:
$\tau$ = 9,935 $\mu$s

*Discussion:* When the signal goes from low to high it causes the capacitor to charge electrical energy making the voltage increase. When the signal later change and goes from high to low instead, the capacitor releases the energy which then will make the voltage drop in value.

The same behavior goes for capacitors in parallel and in series only this time, the voltage change is somewhat slower in the circuit with the capacitors in parallel and faster in the one with them in series. (**See** Attachment 13 picoscope measurements for capacitor**,** Attachment 14 picoscope measurements for capacitors in parallel **as well as** Attachment 15 picoscope measurements for capacitors in series)**. See** Attachment 39 circuit from 2.2 with capacitors in parallel **as well as** Attachment 40 circuit from 2.2 with capacitors in series to see the circuits built on the breadboard, both with the capacitors in parallel and in series.

When the capacitors are in parallel:

C = C1 + C2

⇨ C = 1 nF + 1 nF = 2 nF

$\tau = C*R = 2*10^{-9} *10000 = 20\ \mu s$

$V_L/e = 5/e = 1{,}8393$ V

The time constant between 5V and 1,8393V:

$\tau = 18{,}75\ \mu s$

When the capacitors are in series:

1/C = 1/C1 + 1/C2

⇨ $1/C = 2/10^{-9} = 50$ nF

$\tau = C*R = 5*10^{-10}*10000 = 5\ \mu s$

$V_L/e = 5/e = 1{,}8393$ V

The time constant between 5V and 1,8393V:

$\tau = 4{,}878\ \mu s$

## 2.3 Diode rectifier circuit with resistor and capacitor

*Introduction and method:* In this part of the lab, the voltage over the given circuit was measured. First without the capacitor and then with it. The task was then to explain why the voltage changed the way it did. This was done both in the simulation program QUCS and on the breadboard.

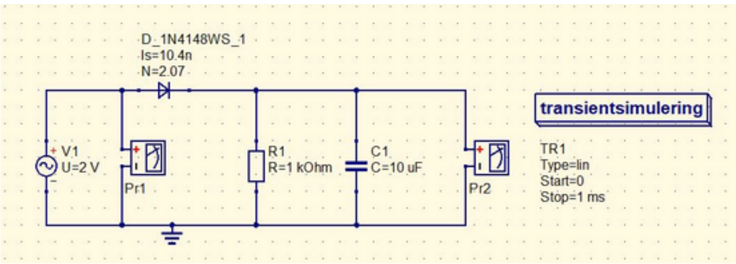



Figure 8: the circuit for both QUCS and breadboard.

*Discussion:* In the case where the capacitor was disconnected from the circuit, the only thing to look at was the resistor and the voltage value over only that. When the signal changed direction and the voltage over the voltage source was negative, the voltage over the resistor only dropped to 0V. The reason for that is the diode. Diodes does not allow voltage to flow from both directions, only one. (**See** Attachment 16 circuit 2.3 when the capacitor is disconnected)

In the other case, where the capacitor is connected to the circuit, the diode still affects the way the voltage can move in the circuit. Only this time, because of the capacitor, the voltage never drops because the capacitor does not discharge when the current stops. It will instead keep a constant voltage value. Because the circuit is bult the way it is, the voltage over the capacitor is the same as the voltage over the resistor. (**See** Attachment 17 circuit 2.3 when the capacitor is connected)

For the circuit built on the breadboard (**See** Attachment 38 circuit from 2.3), the voltage behavior is the same as for the one built in QUCS (**See** Attachment 18 picoscope measurements for circuit 2.3 when the capacitor is connected **as well as** Attachment 19 picoscope measurements for circuit 2.3 when the capacitor is disconnected)

The voltage of the circuit on the breadboard:
With the capacitor: 1,250V
Without the capacitor: 1,428V

Thevenin equivalent in circuit:
Over the resistor $R_R$=220Ω the voltage was $V_R$=0,64V

$$I = \frac{V_R}{R_R} = \frac{0{,}64}{220} \approx 0{,}0029A$$

I=2,9mA

$V_{TH}$= 1,115V

To calculate $R_{TH}$ the current I can be used together with the voltage over the resistor $R_{TH}$.
The voltage over the resistor $R_{TH}$ can be calculated as following:
$V_{TH}$- $V_R$= 1,115-0,64= 0,475V

$$R_{TH} = \frac{V_{TH} - V_R}{I} = \frac{0{,}475}{0{,}0029} \approx 163{,}793\Omega$$

The Thevenin values:
$V_{TH}$= 1,115V
$R_{TH}$=163,8Ω

The values on the Arduino:
$V_{TH}$=5,06V
$R_{TH}$=2,71Ω

For some reason the values from the calculation and from the Arduino are different. One explanation could be that there is resistance from other components on the breadboard that can affect the result.

## 3.1 RL filter

*Introduction:* Lab 3 dealt with different types of filters and ac measurements. In part 3.1 specifically, it was a circuit built with an inductor. The circuit was built in the simulation program QUCS and on the breadboard. To get sinusoidal waves, a Picoscope was used on the board. When the cut off frequency was calculated and measured it could in the end be compared to the values from the simulation, the circuit on the breadboard and the calculated one with the component values given in the task.

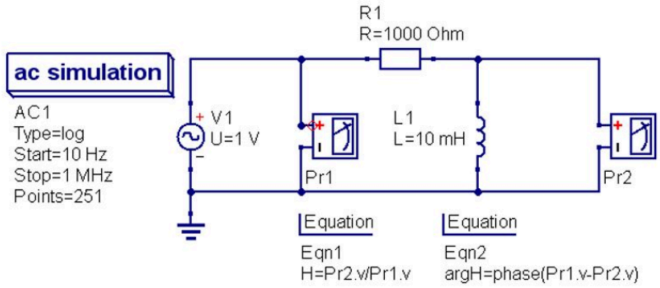



Figure 9: the circuit from 3.1 that was built in QUCS and on the breadboard

*Method:* When the circuit was built on the breadboard and the sinus signal from the Picoscope had an amplitude of 1V, the frequency could be variated so that the response from the filter could be checked.

The function to determine the cut off frequency in a RL high pass filter is:

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

$$f_c = \frac{1000}{2\pi 10 * 10^{-3}} \approx 16\,000\text{Hz}=16\text{kHz}$$

When the cut off frequency from the component values from the task was calculated, the same circuit was built in the simulation program QUCS and the requested values could be measured with graphs and charts (**See** Attachment 24 simulated circuit in QUCS with measurements).

After the simulation was done, the circuit could be built on the breadboard to get the cut off frequency from that (**See** Attachment 20 the circuit from 3.1 built on breadboard)
The steps to get the cut off frequency in the circuit on the breadboard was the following: First, the cut off frequency value was calculated with the help of the max value of the sinus signal (the blue sinusoid). To get the maximum value of the red curve (Pr 2) the equation $V_{\text{Pr}\,2} = V_{\text{Pr}\,1} * \frac{1}{\sqrt{2}}$ is used, where $V_{\text{Pr1}}$ is the maximum value of the blue curve seen in the circuit (Pr 1). This gives the equation $V_{\text{Pr}\,2} = 987{,}5 * 10^{-3} * \frac{1}{\sqrt{2}}$
$V_{\text{Pr}\,2} \approx 698{,}3\text{mV}$

After getting that value, the frequency on the red sinusoid was changed on the breadboard to match the calculated value 698,3mV. (**See** Attachment 21 measurements from Picoscope in part 3.1 with the cut off frequency ). This gave the cut off frequency 16kHz. That frequency matches the calculated frequency $f_c$ from before.

When the frequency of the circuit changed, the amplitude of the voltage over it got different values. To get an overall view of the voltage change, two different frequency values was used in Picoscope:
<u>At 80kHz (Breadboard):</u> 948,3mV (**See** Attachment 22 the voltage with a frequency of 80kHz)
<u>At 100Hz (Breadboard):</u> 39,61mV (**See** Attachment 23 the voltage with a frequency of 100Hz)

To get an overview of the values from the simulation, frequencies close to the ones from the breadboard is written down. This is also to help the discussion. (**See** Attachment 24 simulated circuit in QUCS with measurements)
<u>At 76kHz (QUCS):</u> 957,8mV
<u>At 100Hz (QUCS):</u> 0,0395mV

*Discussion:* When comparing the measurements from the breadboard with the ones from QUCS, some of them have a different value while others are more or less the same. When the frequency was at 80kHz the voltage amplitude was 948,3mV on the breadboard and 957,8mV in the simulation program, values that only differed with a few milli volt. When comparing the voltages with a frequency of 100Hz there is a similarity on the numbers, but the greatness of the voltage is a lot smaller from the simulation in QUCS. To decide whether the circuit was a low pass or a high pass filter, the graph from QUCS was analyzed. Because of the increase in voltage when the frequency got higher, an assumption can be made that the circuit is a high pass filter. The filter could with very low resistance let signals with low frequency pass through and at the same time let high frequency signals pass through at a higher resistance. This gave the graph that answered the question if it is a high pass or a low pass filter.

Going back to the comparing of the measurements from QUCS and the breadboard. As mentioned earlier, the voltage was much higher on the breadboard. This can be because of frequencies from other parts of the board affecting the circuit and the frequency from that. Because of the circuit being a high pass filter, the values should be near or almost exactly 0V as the component is an inductor, something that the simulation program gives out as values.

## 3.2 RC filter

*Introduction:* Lab 3 dealt with different types of filters and ac measurements. In part 3.2 it was a circuit built with a capacitor instead. The circuit was built in the simulation program QUCS and also on the breadboard. To get sinusoidal waves, Picoscope 7 was used on the board. When the cut off frequency was calculated and measured it could in the end be compared to the values from the simulation, the circuit on the breadboard and the calculated one with the component values given in the task.

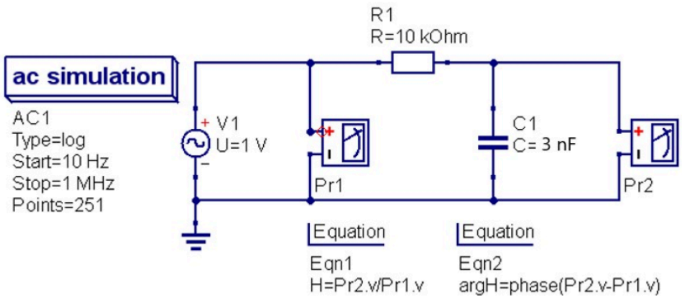



Figure 10: the circuit for 3.2 that was built in QUCS and on the breadboard

*Method:* Just as in the part before, the frequency of the sinus signal from the Picoscope was variated and the response from the filter got checked. This was done after the circuit was built on the breadboard.

The function to determine the cut off frequency in a RC high pass filter is:

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

$$f_c = \frac{1}{2\pi 10^4 * 3 * 10^{-9}}$$

$f_c \approx$ 5,3kHz

Just as in 3.1, the maximum value of the red curve (Pr 2) will be calculated with the following equation:

$V_{\text{Pr}\,2} = V_{\text{Pr}\,1} * \frac{1}{\sqrt{2}}$ is used, where $V_{Pr1}$ is the maximum value of the blue curve seen in the circuit (Pr 1). This gives the equation $V_{\text{Pr}\,2} = 987{,}5 * 10^{-3} * \frac{1}{\sqrt{2}}$

$V_{\text{Pr}\,2} \approx 698{,}3$mV

When this calculation was done, the circuit was built on the breadboard (**See** Attachment 37 the circuit from 3.2 built on breadboard**).**
After getting that value, the frequency on the red sinusoid was changed on the breadboard to match the calculated value 698,3mV. (**See** Attachment 27 the circuit from 3.2 with the cut off frequency) This gave the cut off frequency 5,3kHz. That frequency matched the calculated frequency $f_c$ from before.
When the frequency of the circuit changed, the amplitude of the voltage over it got different values. To get an overall view of the voltage change, two different frequency values was used in Picoscope:
<u>At 80kHz (breadboard):</u> 57,37mV (**See** Attachment 25circuit from 3.2 on breadboard with frequency of 80kHz)
<u>At 100Hz (breadboard):</u> 1,020V (**See** Attachment 28 the circuit from 3.2 with at frequency of 100Hz

When the circuit was built on the breadboard, the same circuit was also built in the simulation program QUCS and frequency values close to the ones from the breadboard was used in the simulation to se what voltage amplitude the signal had. (**See** Attachment 26 the circuit simulated in QUCS with simulated values). This is also to help the discussion.
<u>At 79,4kHz (QUCS):</u> 66,6mV
<u>At 100Hz (QUCS):</u> 0,999V

*Discussion:* This part of the lab gave a more satisfying values when the ones from the breadboard was compared to the ones from the simulation. The differences were small with just a few milli volt between them. When looking at the graph from the simulation it is easy to see that the circuit is a low pass filter because the voltage drops when the frequency increase in value (See Attachment 26 the circuit simulated in QUCS with simulated values). When the component is a capacitor instead of an inductor the frequency relative to the resistance is somewhat different. For capacitors, the resistance needs to be low for high frequency signals to be able to pass through the circuit. And when low frequency signals pass, the resistance is the opposite, very high.

## 3.3 RLC filter

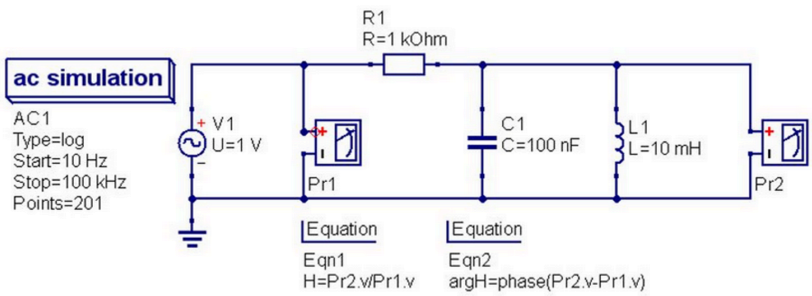



Figure 11: the circuit used for 3.3.1 and 3.3.2

### 3.3.1 Sinus input to the filter and viewing voltage versus time

*Introduction and method:* this lab had a circuit with both a capacitor and an inductor and the input to the filter was supposed to be a sinus signal. The circuit was built on the breadboard as well as in the simulation program QUCS and the center frequency was then determined from those circuits. Then the frequency on the sinus input was varied so that the voltage amplitudes could be checked to answer the question on how voltage change over time. Using equations, values from QUCS and Picoscope the wanted measurements could be checked. The values given from these different equipment's and equation could then help determine what type of filter the circuit was.

To calculate the center frequency of the circuit the following equation is used:

$$f_c = \frac{1}{2\pi\sqrt{L * C}} = \frac{1}{2\pi\sqrt{10^{-4} * 100 * 10^{-9}}} = \frac{1}{2\pi\sqrt{10^{-10}}} \approx 5kHz$$

When the circuit was built in the simulation program a graph could be plotted with the center frequency (**See** Attachment 43 circuit 3.3.1 graph and measurements)

*Discussion:* By looking at the graph and the values of the voltage, the center frequency could be determined. The center frequency that got calculated with the equation is the same as the value of the center frequency from the circuit on the breadboard. That indicated that the circuit was built right. (**See** Attachment 43 circuit 3.3.1 graph and measurements to get a clear view on both the values and the graph)

<u>The center frequency from the breadboard seen with Picoscope:</u>
5kHz (**See** Attachment 31 circuit from 3.3.1 measuring voltage with 5kHz)
The voltage over the inductor and the capacitor in parallel at center frequency can be measured to 841,4mV (**See** Attachment 31 circuit from 3.3.1 measuring voltage with 5kHz).
When the frequency of the circuit changed, the amplitude of the voltage over it got different values. To get an overall view of the voltage change, two different frequency values was used in Picoscope:
1kHz: 75,20mV (**See** Attachment 32 circuit from 3.3.1 measuring voltage with 1kHz)
10kHz: 253,4mV (**See** Attachment 30 circuit 3.3.1 measuring voltage with 10kHz)

When the type of filter is determined, the easiest way to do it is to look at the shape of the graph that the circuit makes after the input signals. According to the graph in QUCS the circuit is a band pass because of the positive peak (**See** Attachment 33 the graph of 3.3.1).
A band pass filter can reduce frequencies that do not match the center frequency by not letting most of it pass, although not frequency differing from the center frequency will be cast away.

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

<u>Sinus input</u>
*Method:* The first step of this lab was to have an input signal in the form of a sinus wave to the same circuit as in part 3.3.1. The frequency on the sinus input was supposed to be at 5kHz. The task was then to check the output- as well as the input wave and determine why they behaved the way they did.
After that, the Picoscope was changed to spectrum mode and for that part of the lab, different peaks of the graph were viewed. The interesting part was to see the amplitude of the peaks at different frequencies.

The voltage peaking on the output and input when there is a frequency of 5kHz on the sinus signal:
Channel A (input): amplitude peak at 636,9mV

Channel B (output): amplitude peak at 539,3mV (**See** Attachment 34 graph 3.3.2 sinus wave with peak)

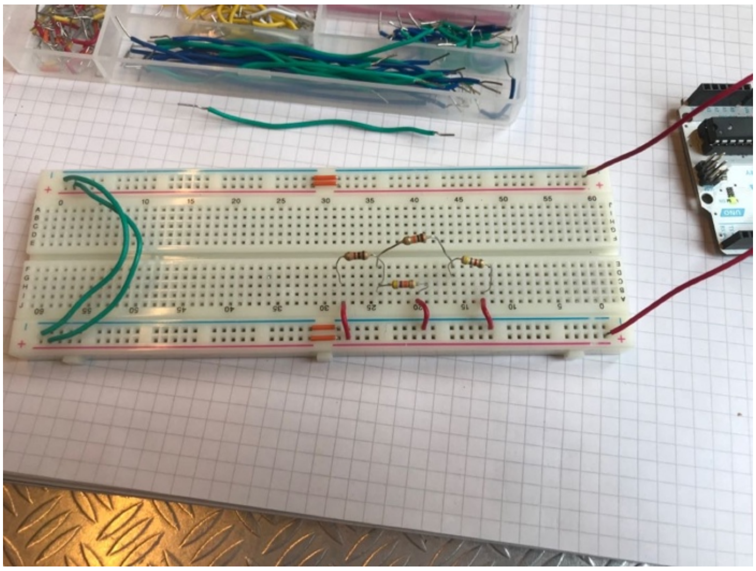
*Discussion:* This circuit had both a capacitor and an inductor making it a band pass filter, just as the circuit before. Because it includes both the components, specific frequencies will be passed through. This is because the high pass filter does not pass lower frequencies and the low pass filter does not let high frequencies pass, this leaves only a small space or band of frequencies to pass through the filter.

Square wave input
*Discussion:* The reason the wave behaves the way it does is simply because the inductor and capacitor charge up and load energy when the clock signal goes from low to high and when the signal then goes from high to low, the components release their energy, and the voltage drops to 0. This does not happen as soon as the clock cycle change, it builds up. Therefore, the wave is slightly curved (**See** Attachment 35 square wave input 3.3.2 with measurements).

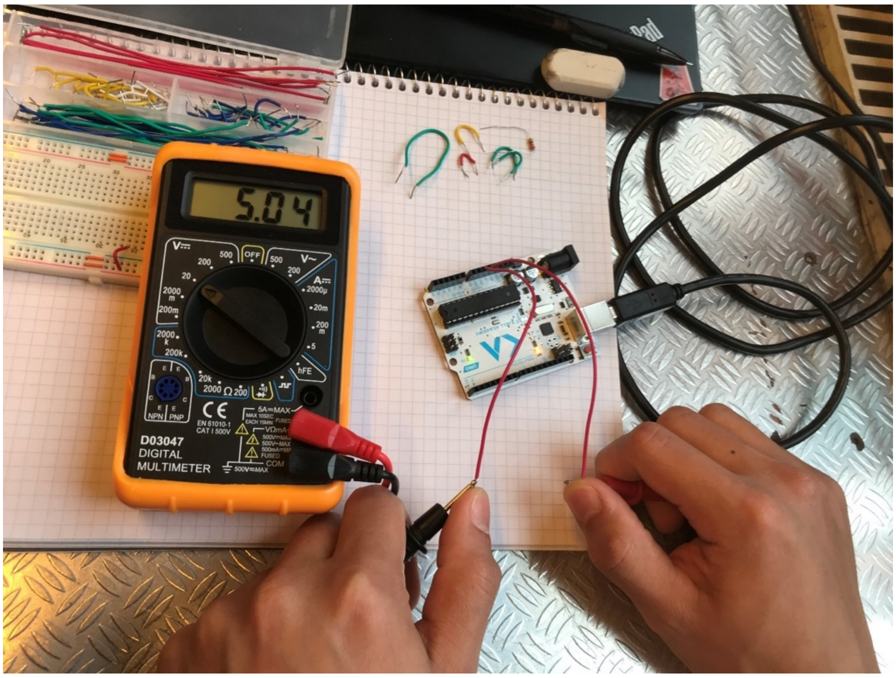
The next part of the lab was to look at the spectrometer and the amplitude of the voltage at different frequencies. At a frequency of 5kHz, the voltage amplitude was 0,74V (**See** Attachment 44 measurements from 3.3.2 square wave form 5kHz). However, other peaks were seen at frequencies such as:
15kHz (**See** Attachment 45 square wave form 3.3.2 15kHz)
25kHz (**See** Attachment 46 square wave form 3.3.2 25kHz)
35kHz (**See** Attachment 47 square wave form 3.3.2 35kHz)
45kHz (**See** Attachment 48 square wave form 3.3.2 45kHz)
The peaks were never higher than on a voltage of 36mV.

## ATTACHMENTS

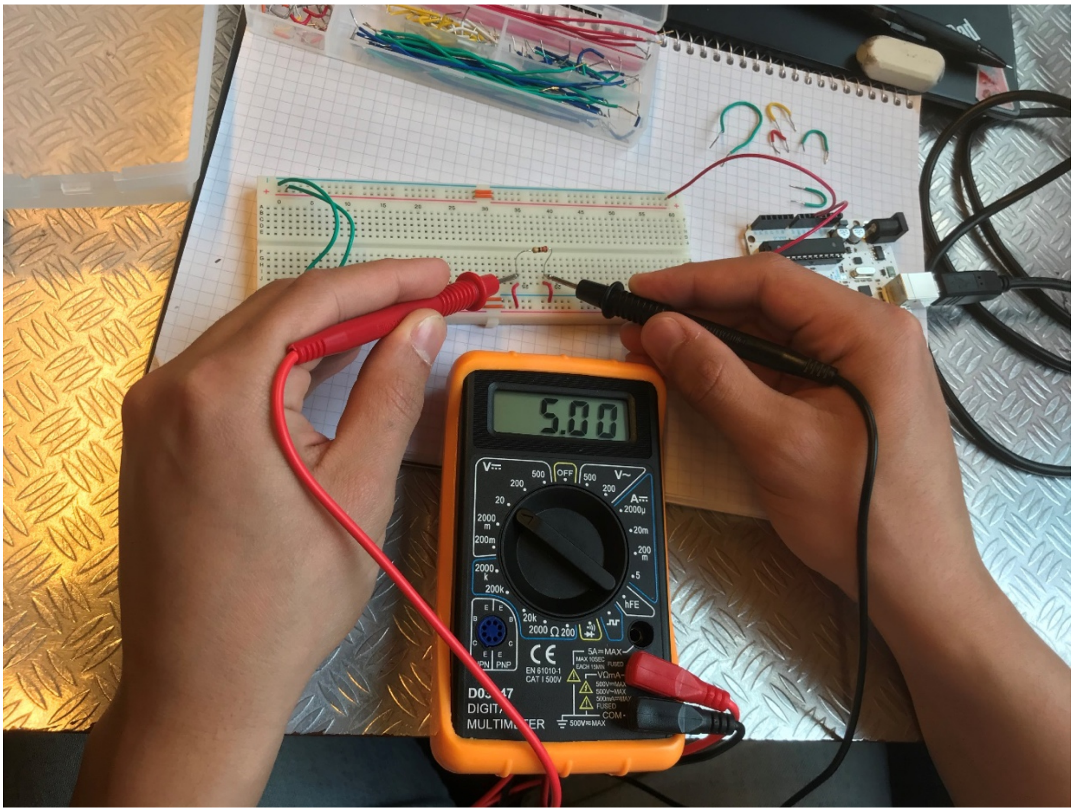
*Attachment 1 circuit 1.1 built on the breadboard*



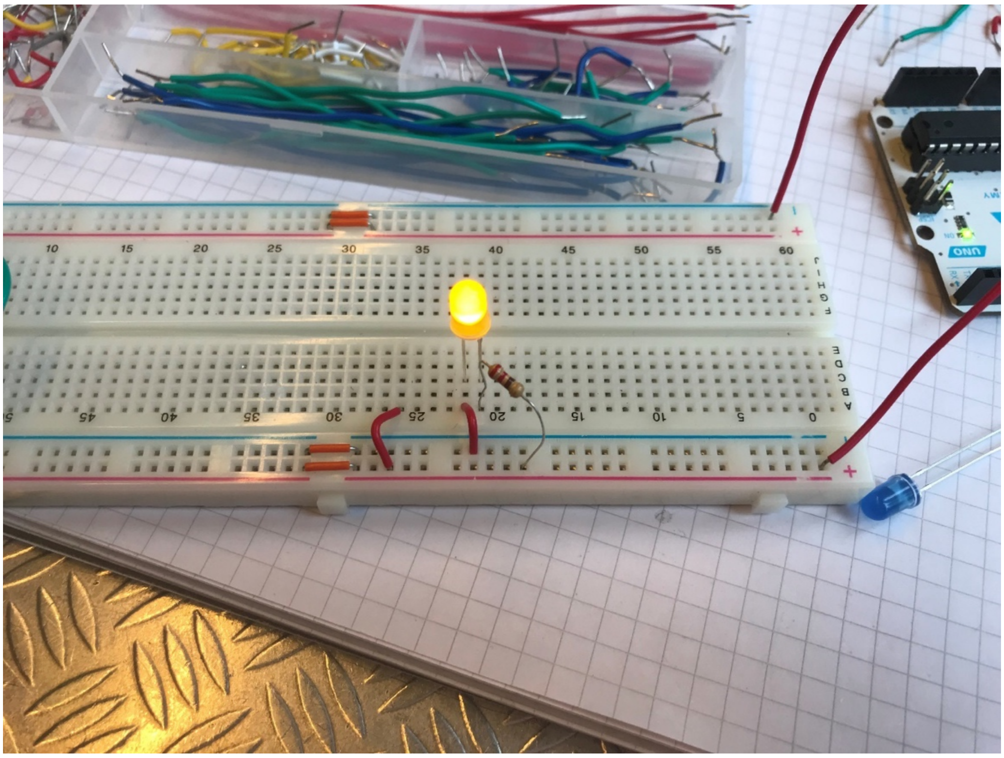
*Attachment 2 1.2.1 measuring the voltage in the arduino*



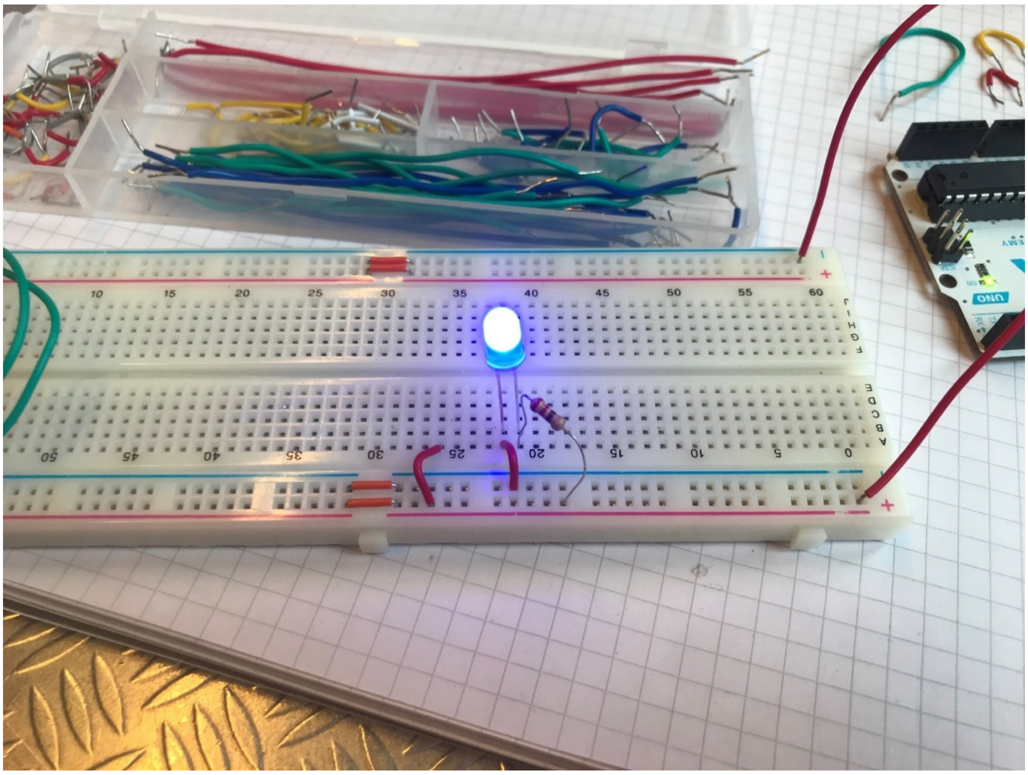
*Attachment 3 1.2.1 measuring the voltage over the resistor*



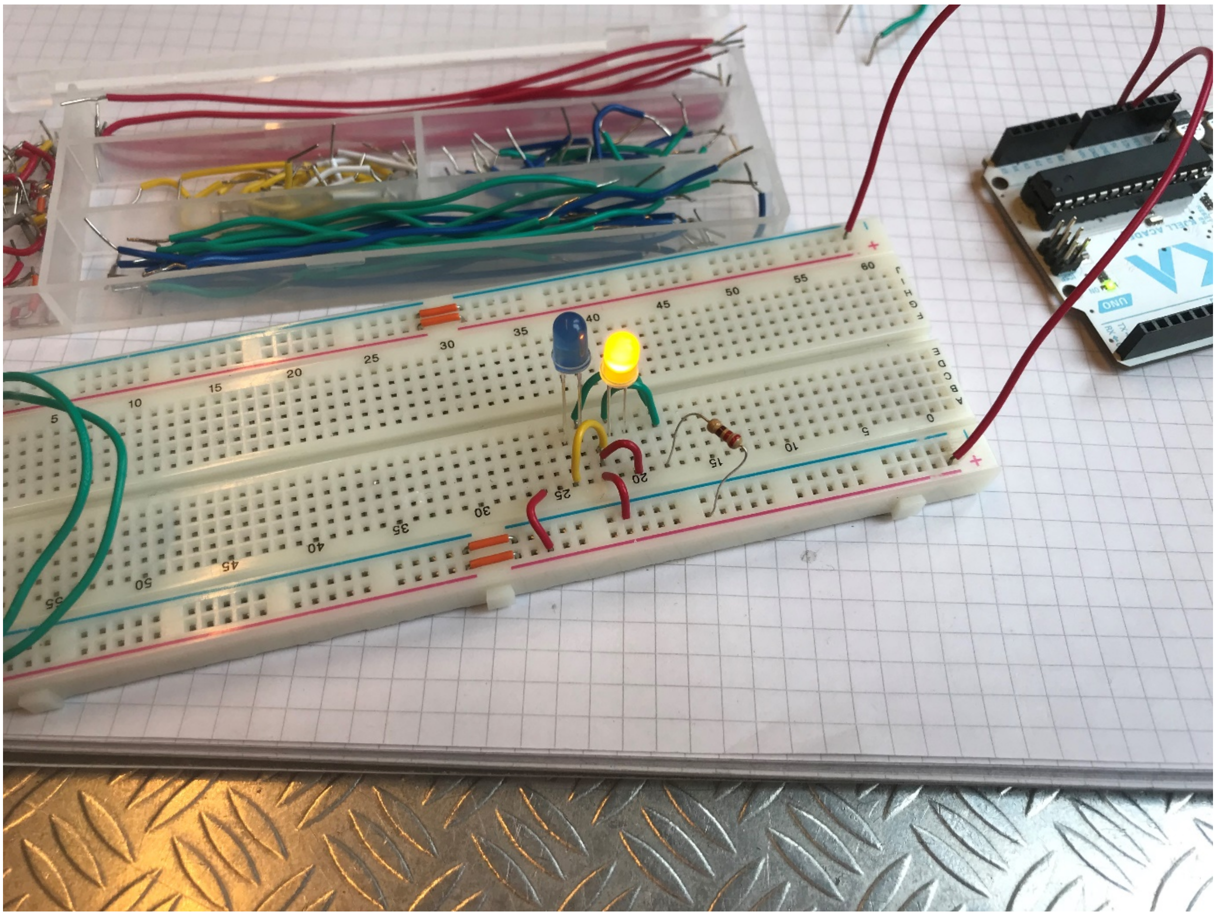

*Attachment 4 1.3.2 built on the breadboard*



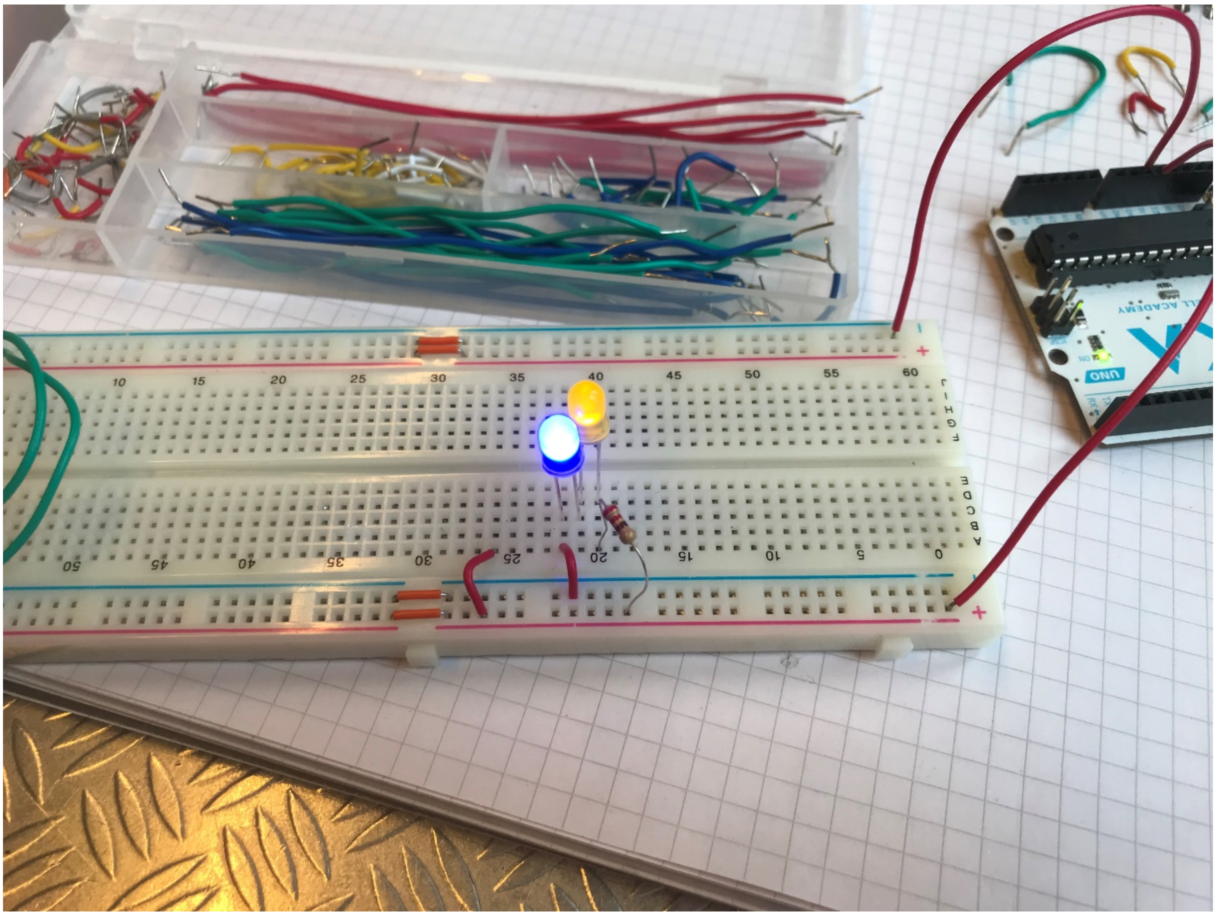
*Attachment 5 circuit 1.3.2 built on the breadboard*



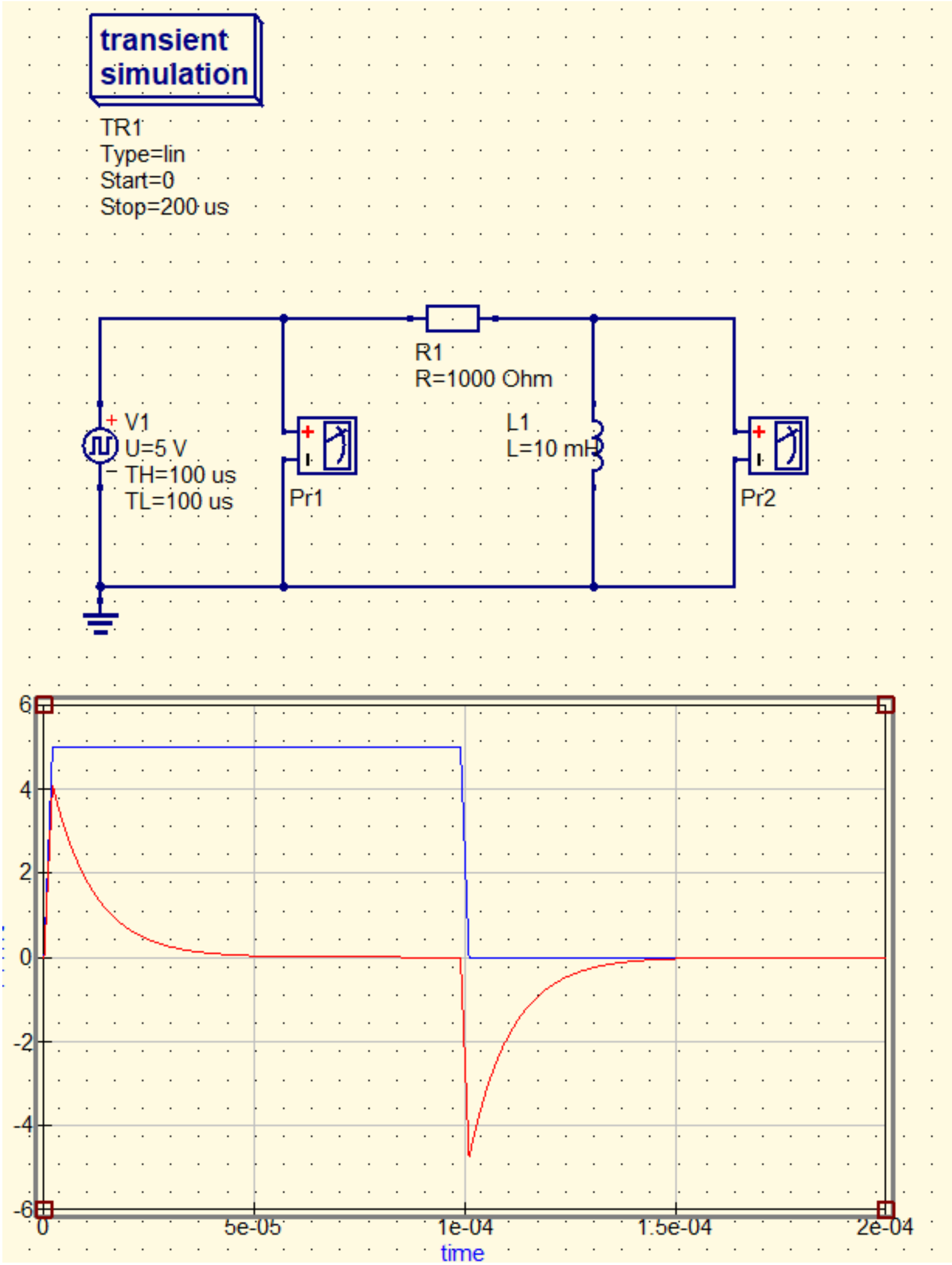
*Attachment 6 circuit 1.3.4 built on the breadboard*



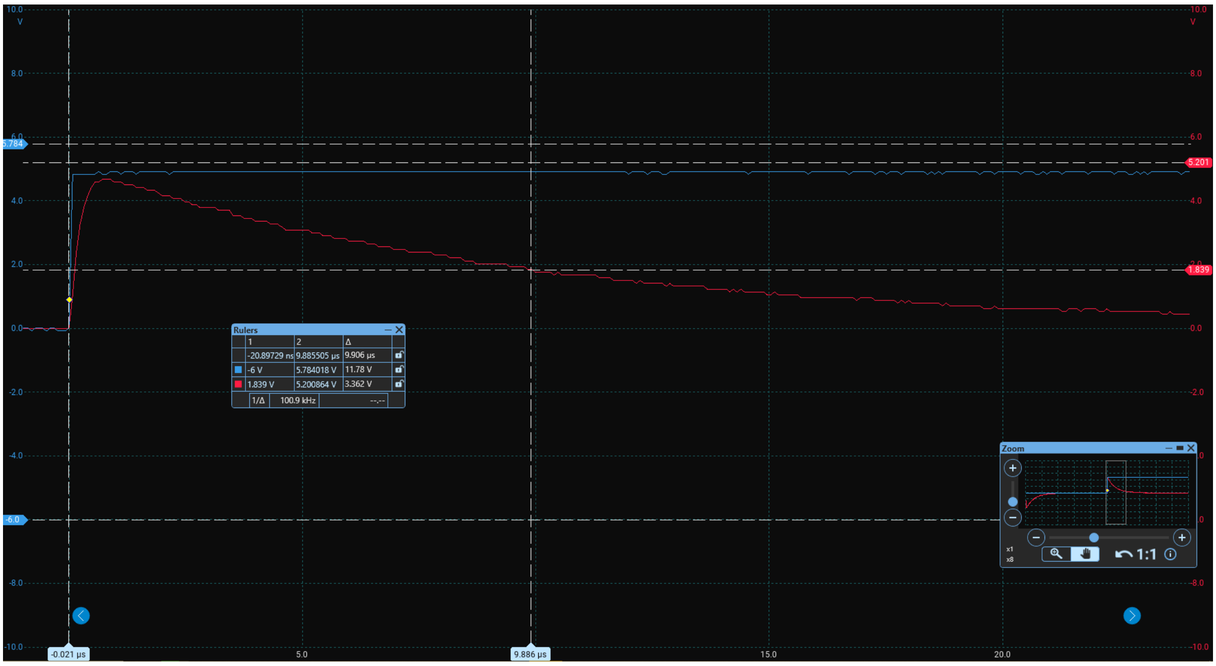
*Attachment 7 circuit 1.3.4 built on the breadboard*



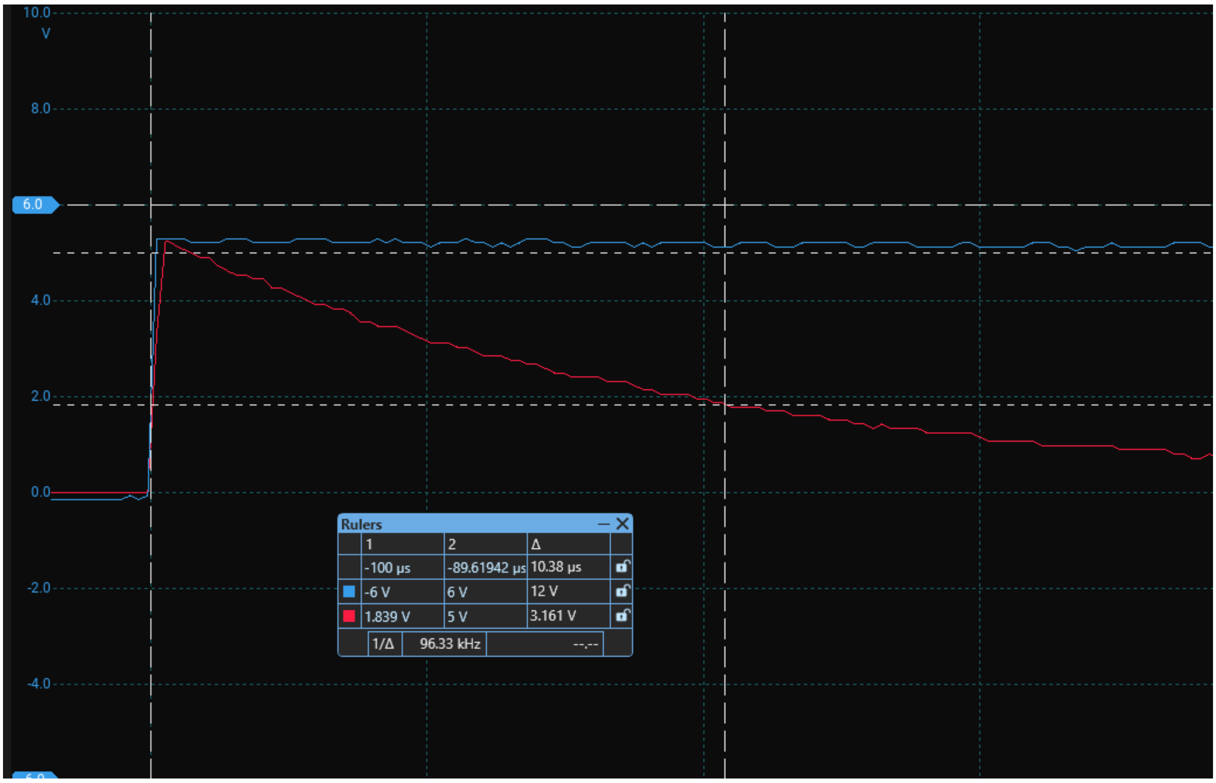
*Attachment 8 circuit 2.1 simulated in QUCS*



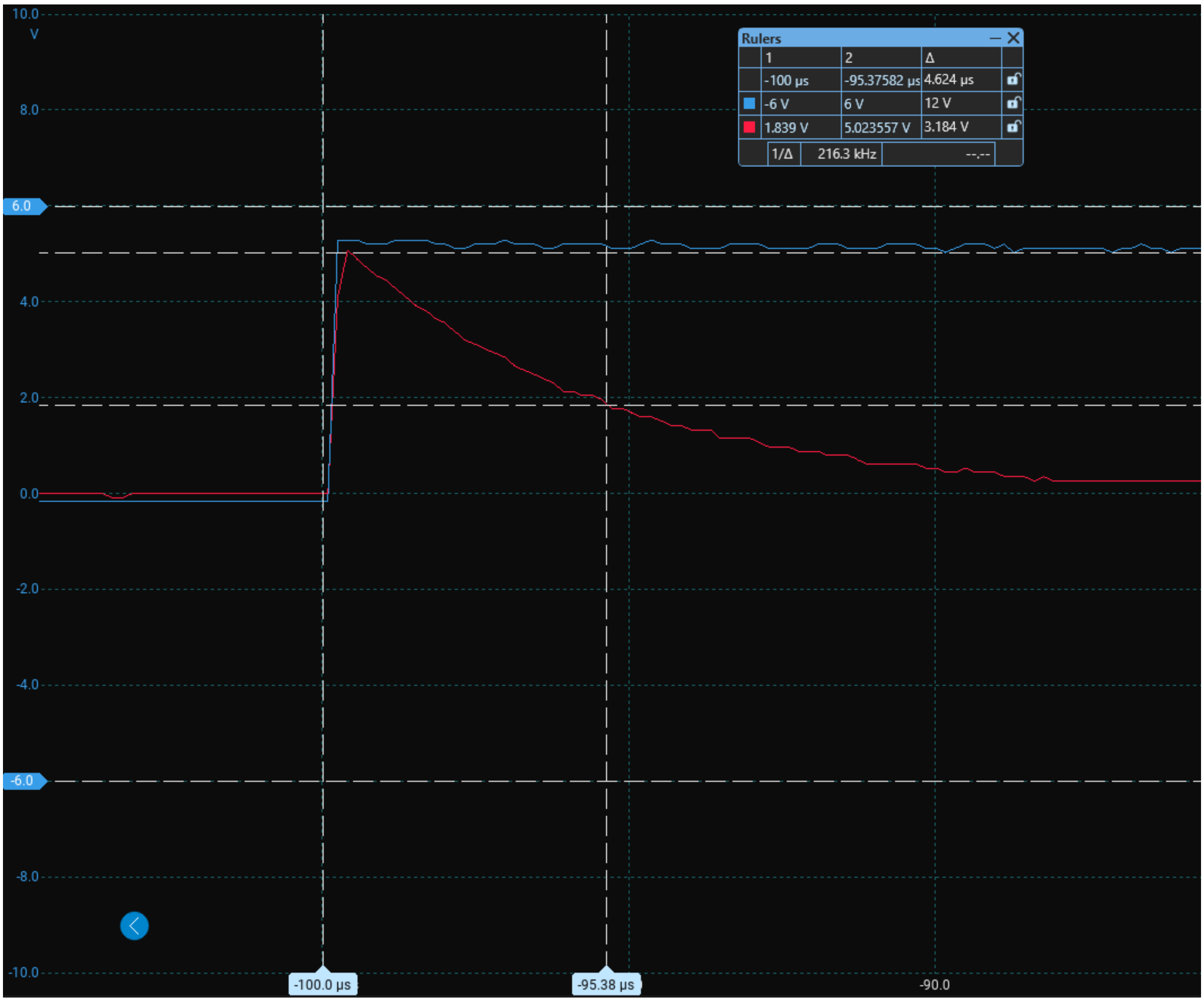
*Attachment 9 picoscope measurements for inductor*



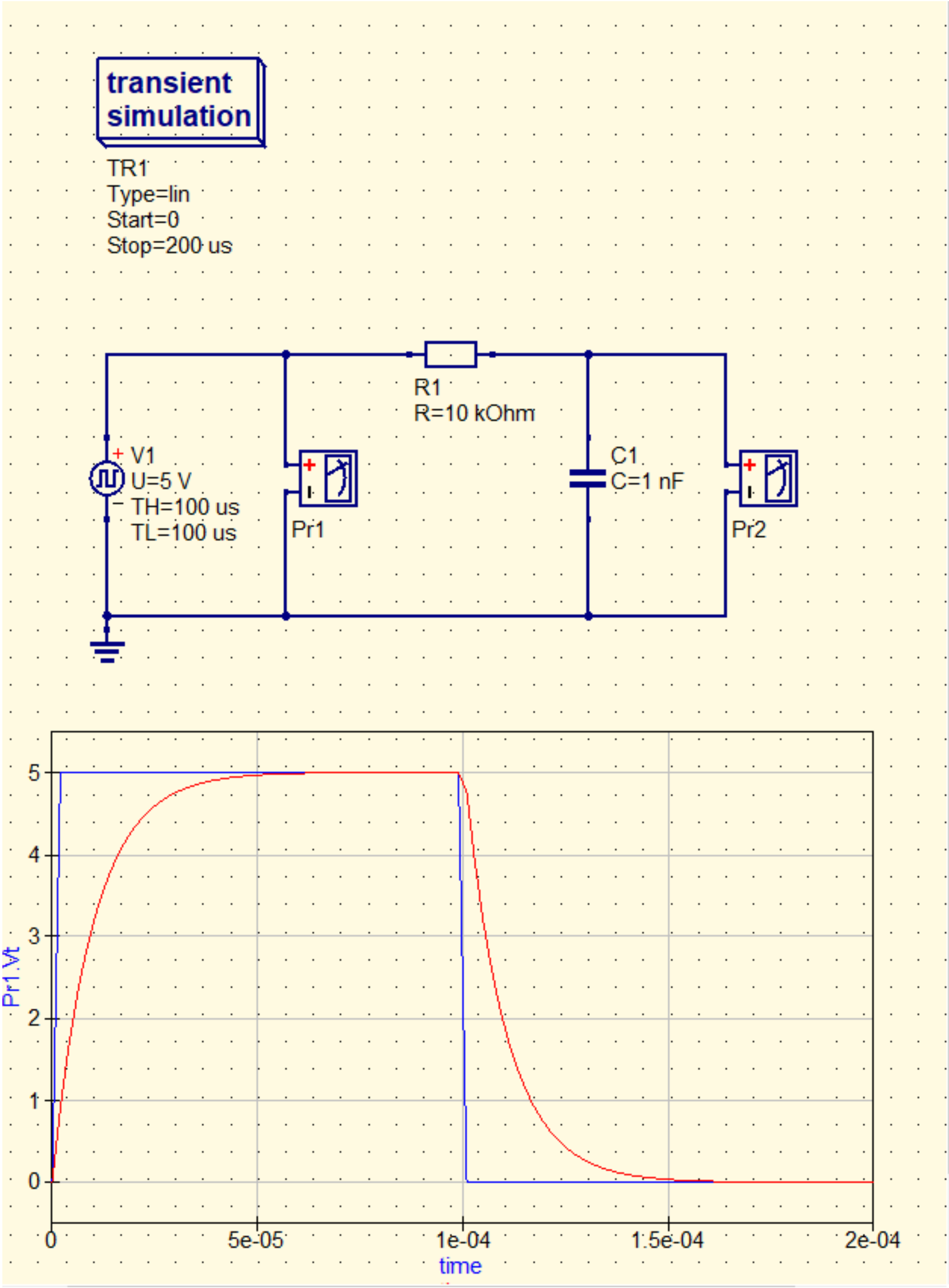

*Attachment 10 picscope measurements for inductors in parallel*



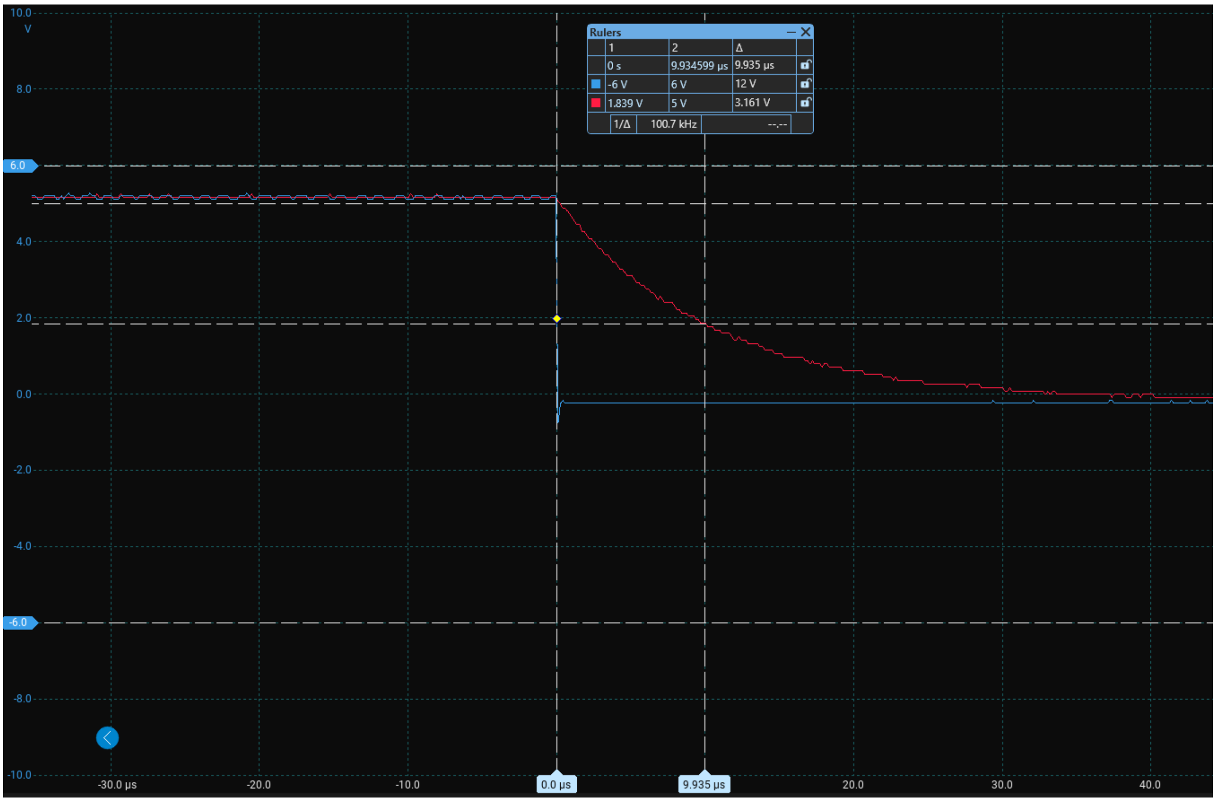
*Attachment 11 picoscope measurements for inductors in series*



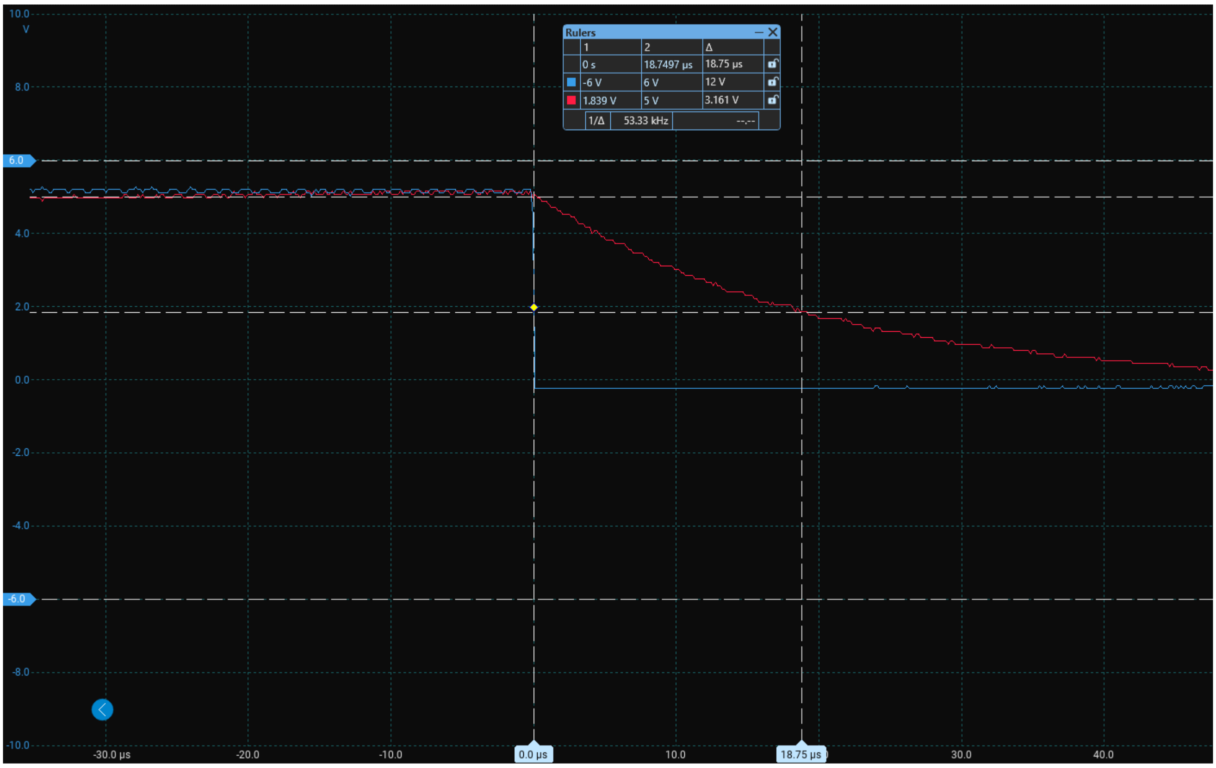
*Attachment 12 circuit 2.2 simulated in QUCS*



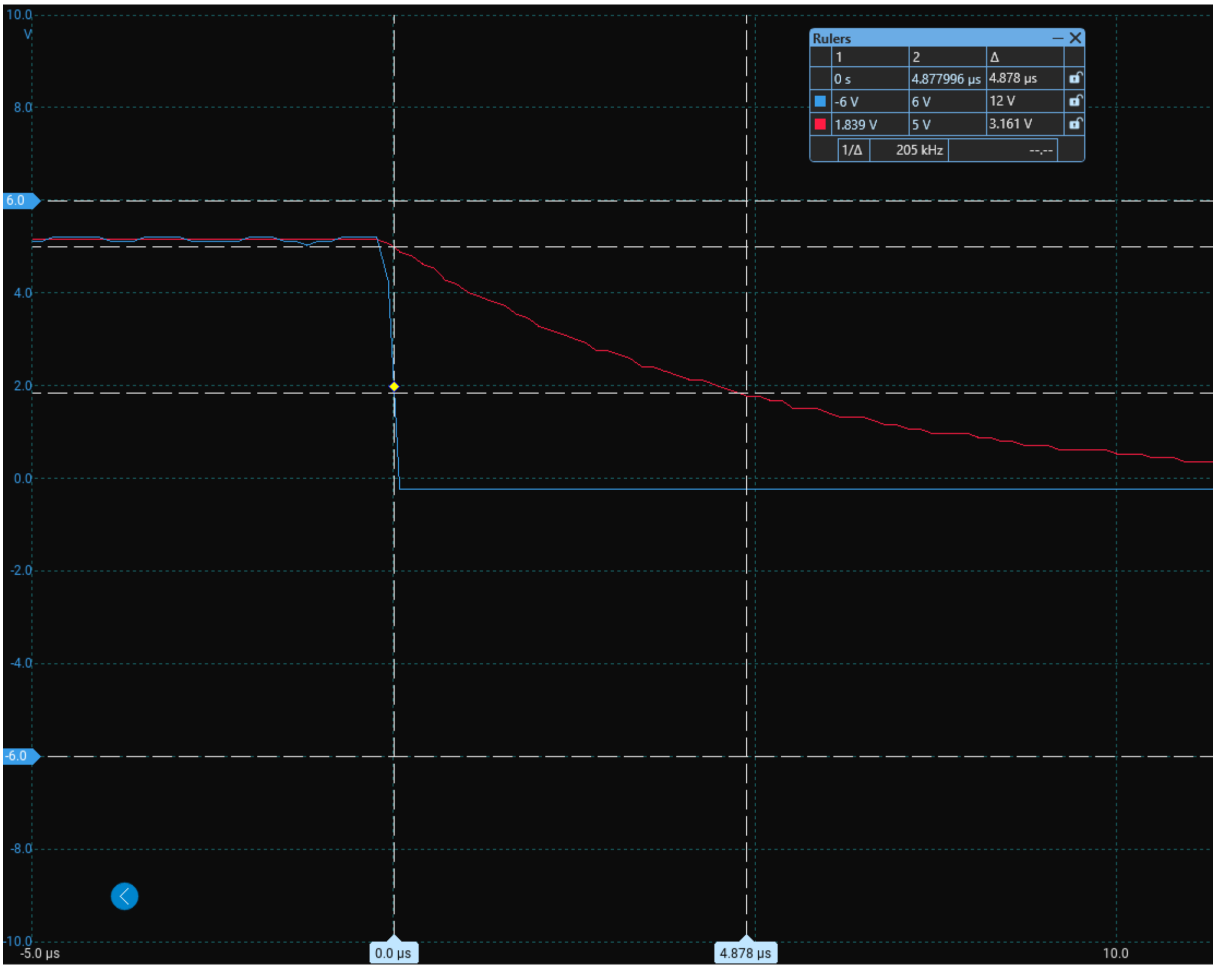
*Attachment 13 picoscope measurements for capacitor*



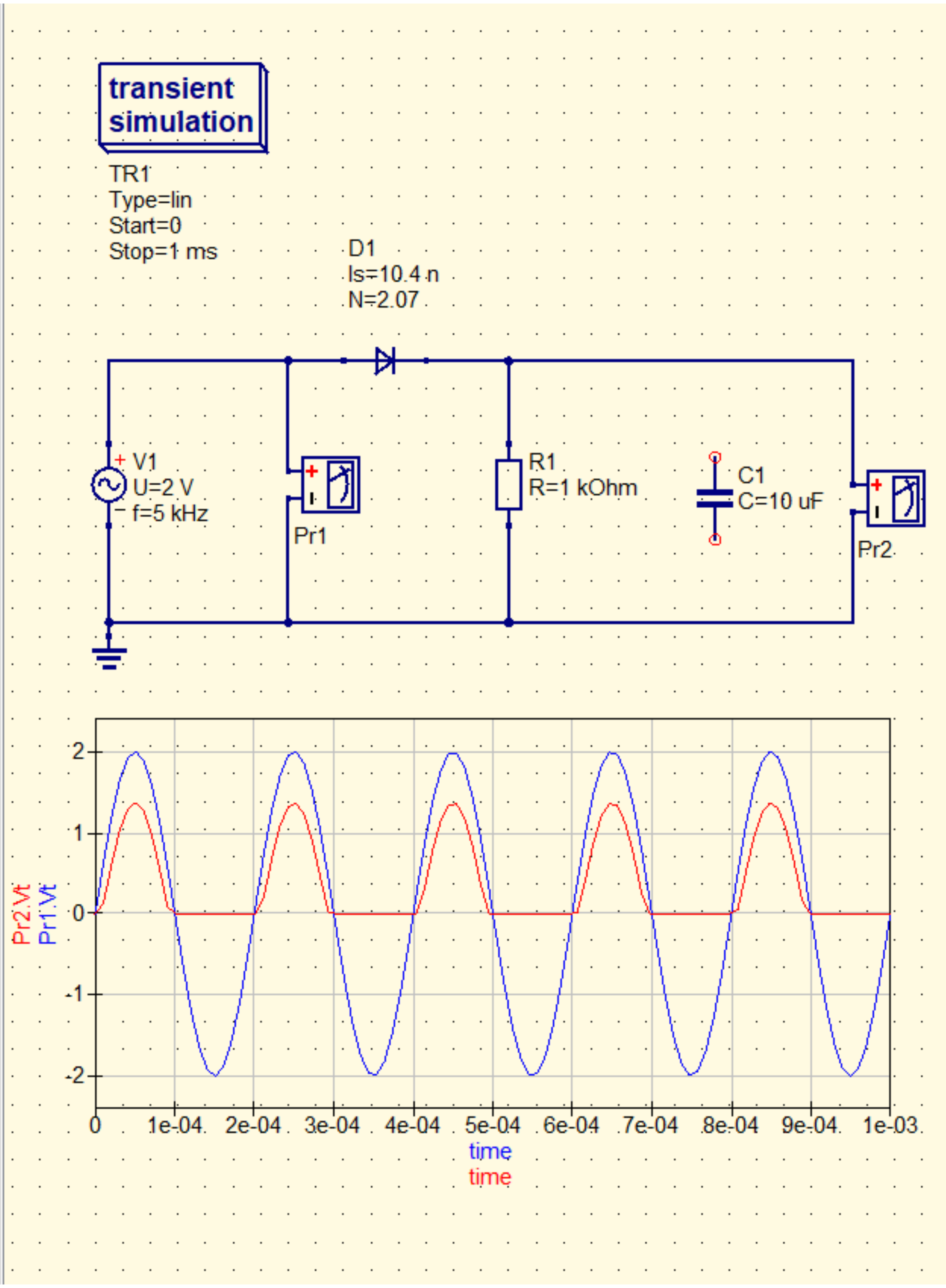

*Attachment 14 picoscope measurements for capacitors in parallel*



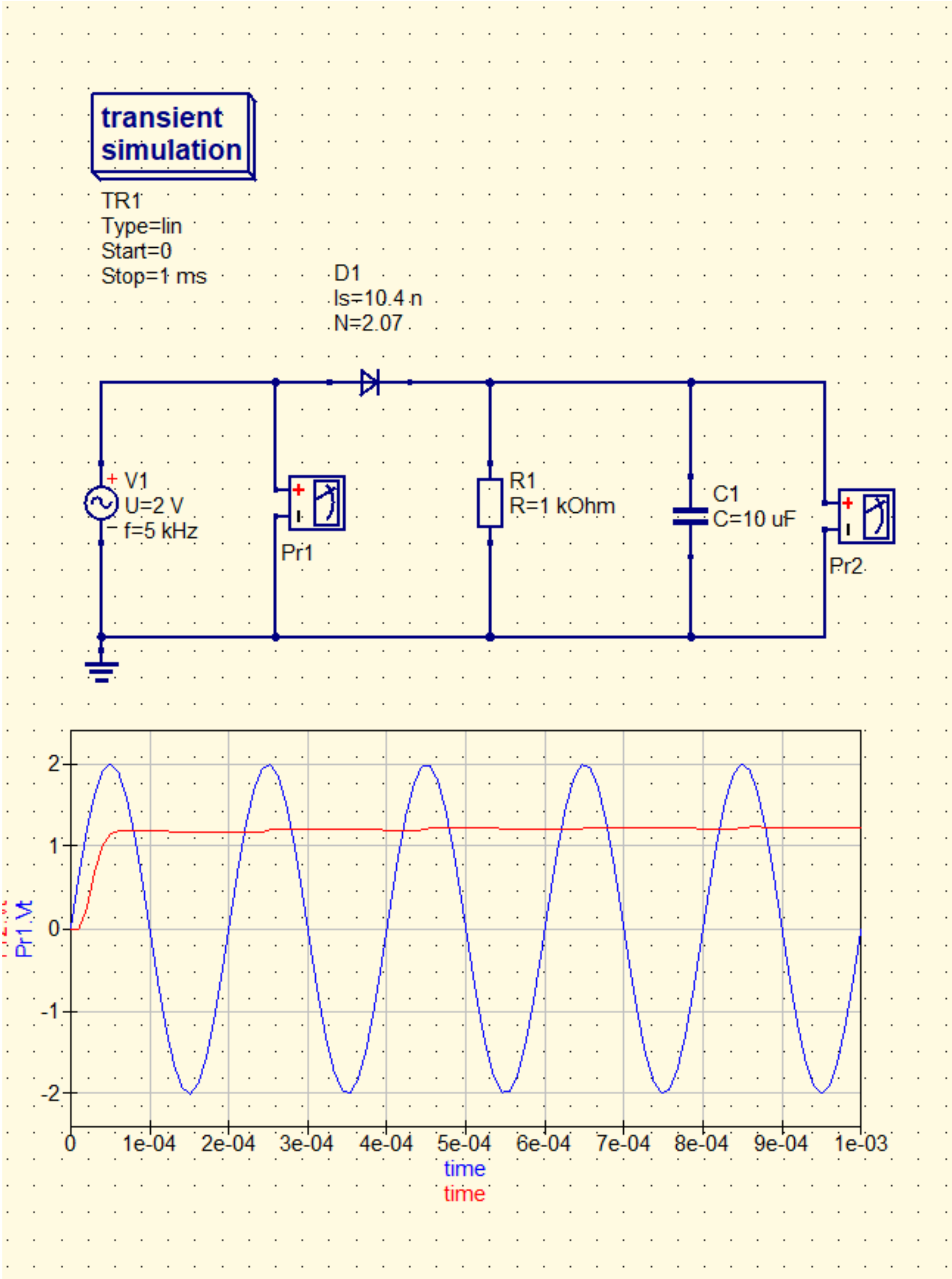
*Attachment 15 picoscope measurements for capacitors in series*



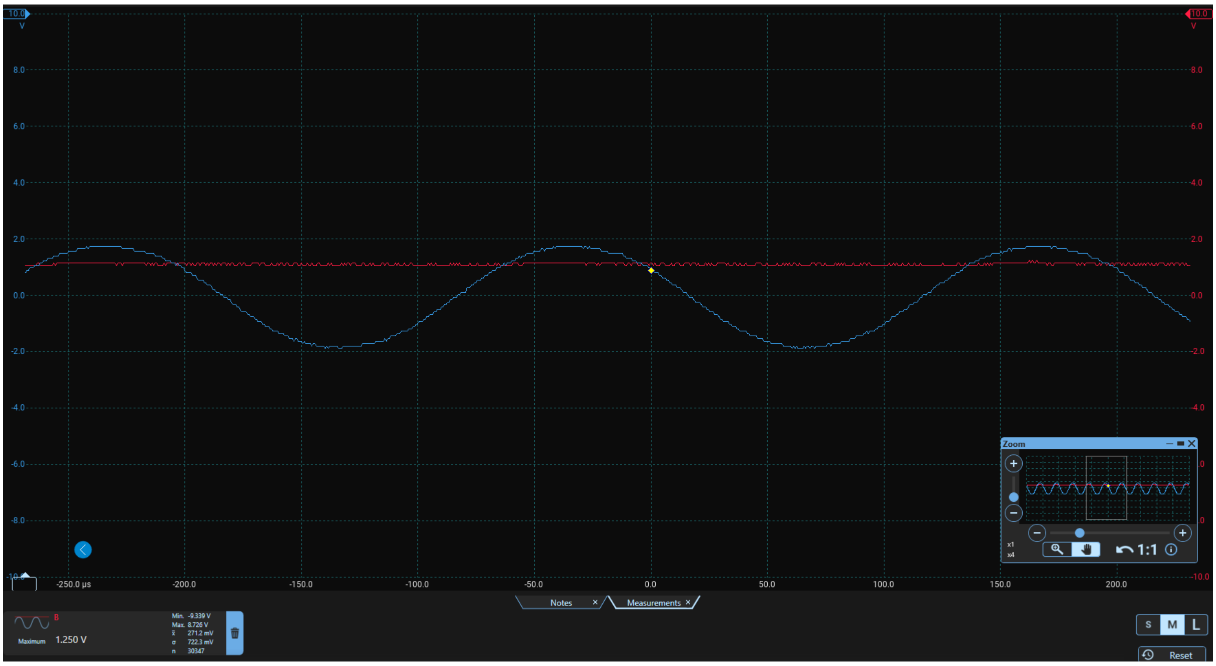
*Attachment 16 circuit 2.3 when the capacitor is disconnected*



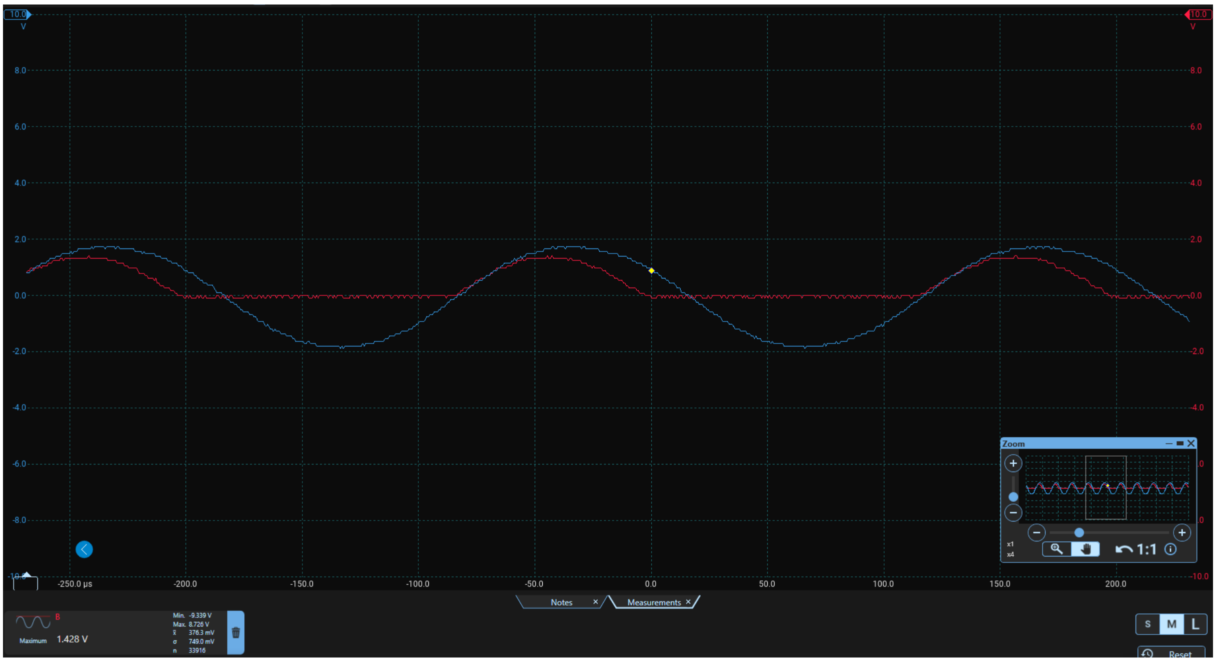
*Attachment 17 circuit 2.3 when the capacitor is connected*

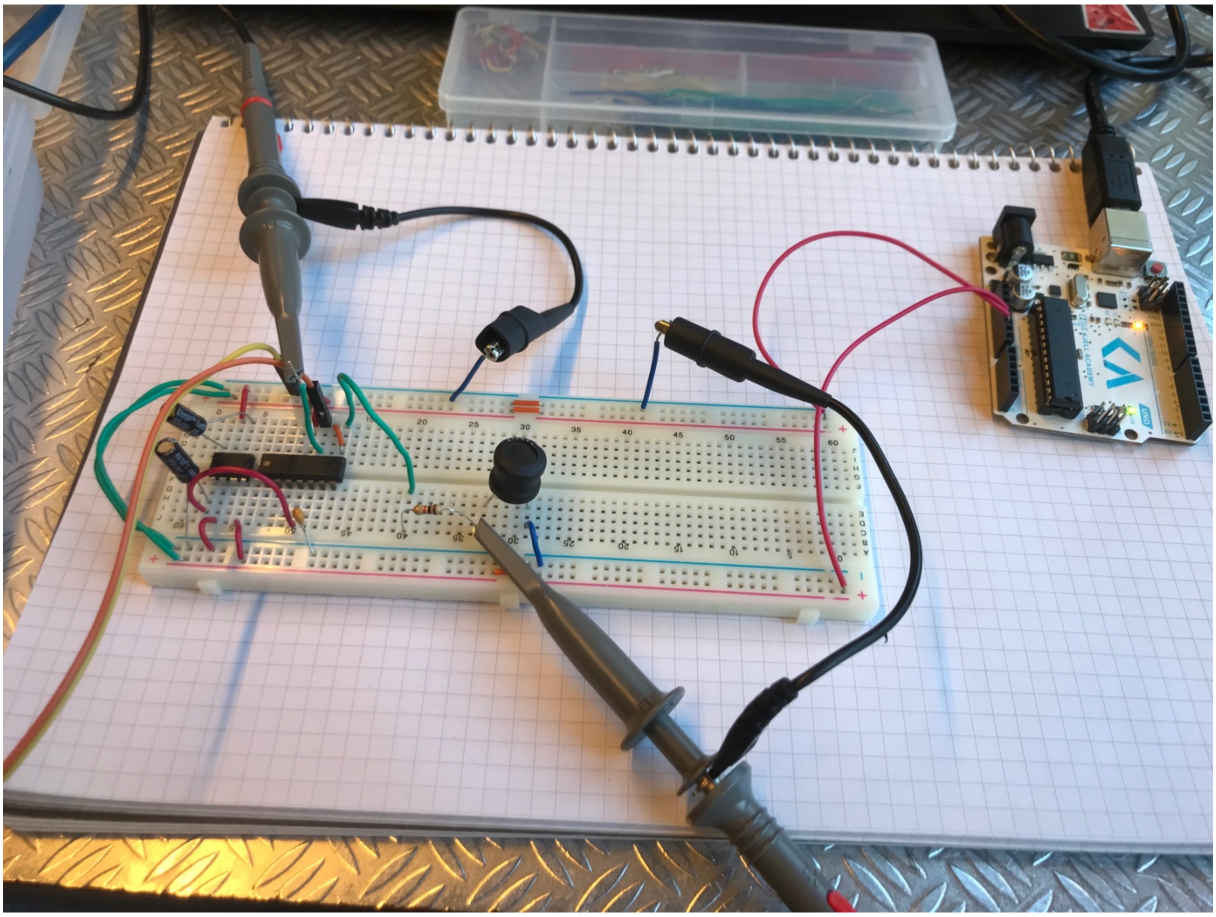


*Attachment 18 picoscope measurements for circuit 2.3 when the capacitor is connected*



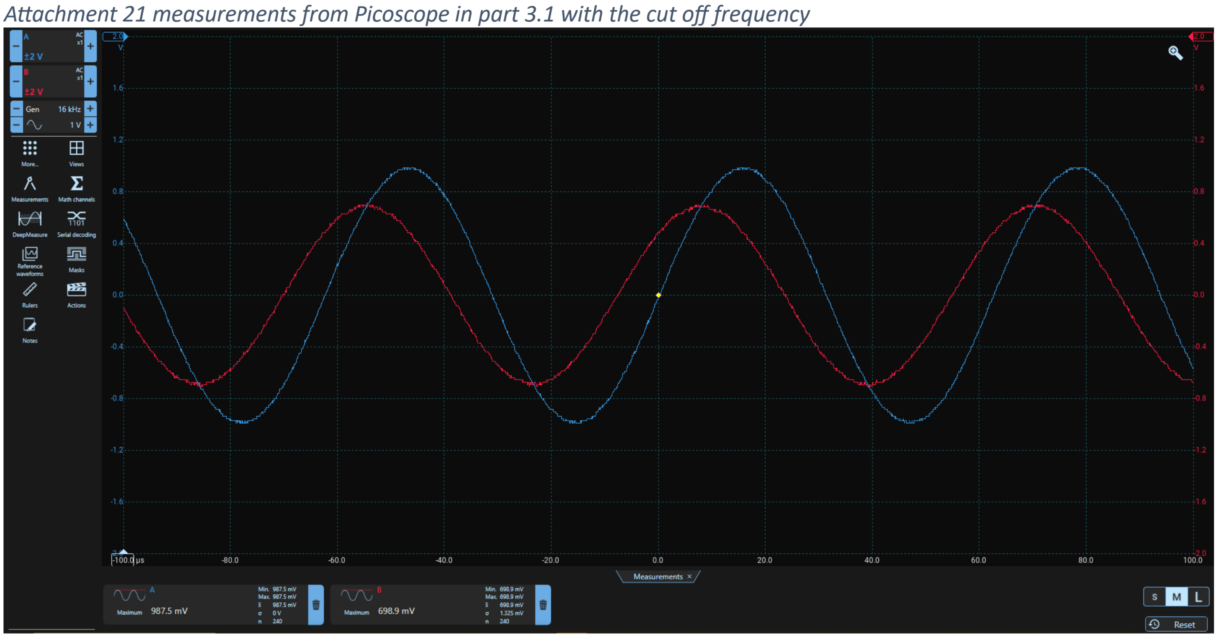

*Attachment 19 picoscope measurements for circuit 2.3 when the capacitor is disconnected*

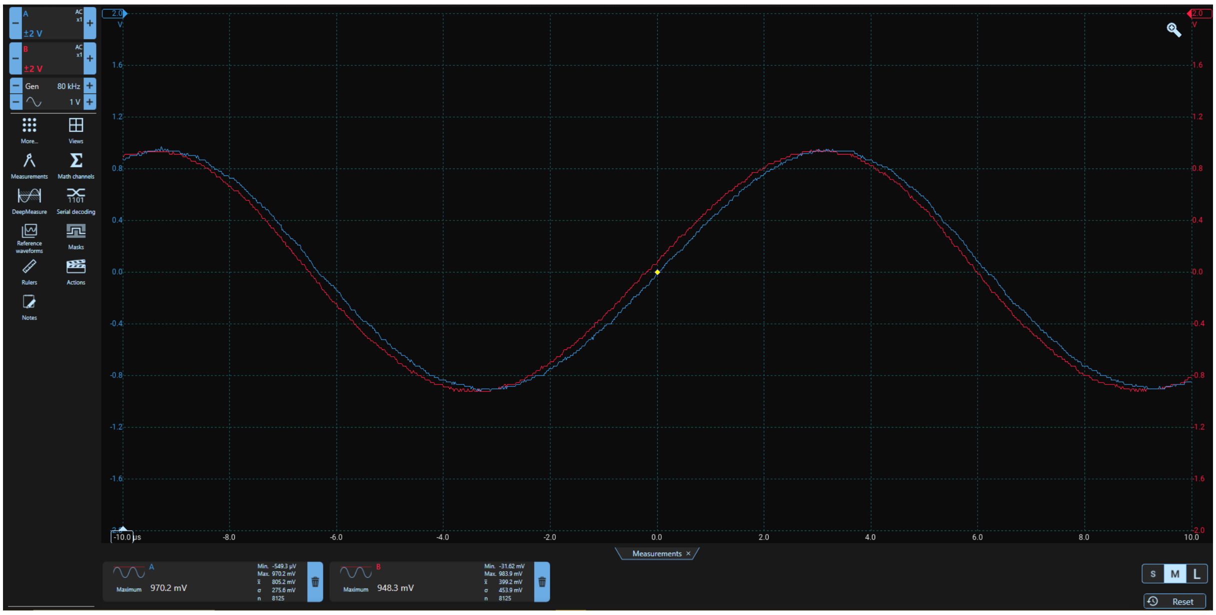




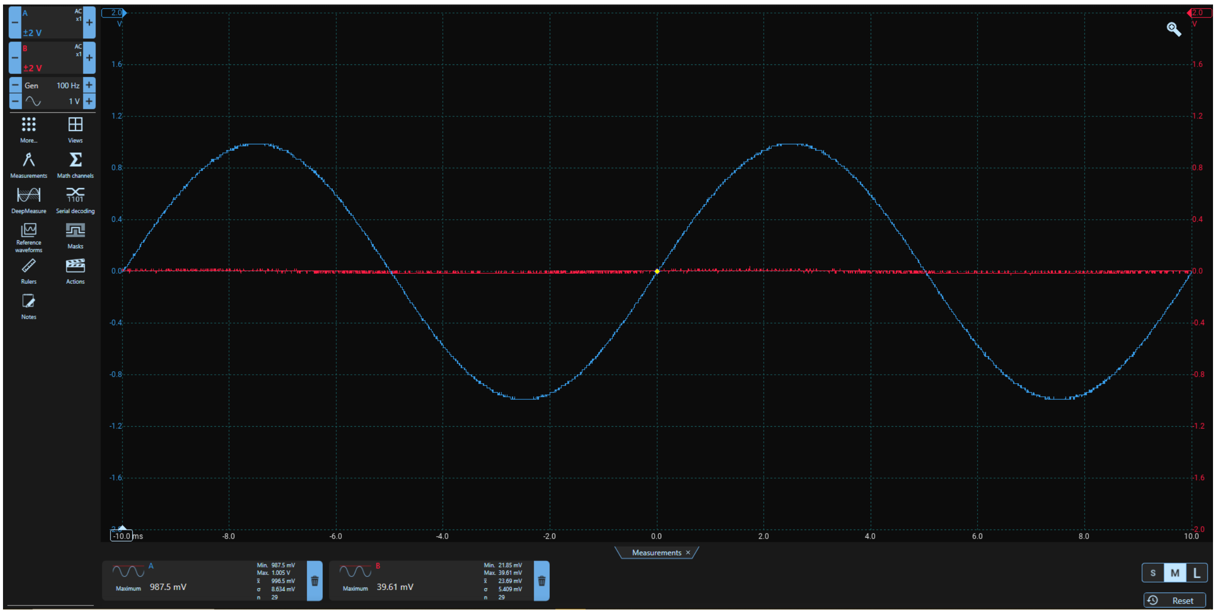
*Attachment 20 the circuit from 3.1 built on breadboard*

*Attachment 21 measurements from Picoscope in part 3.1 with the cut off frequency*

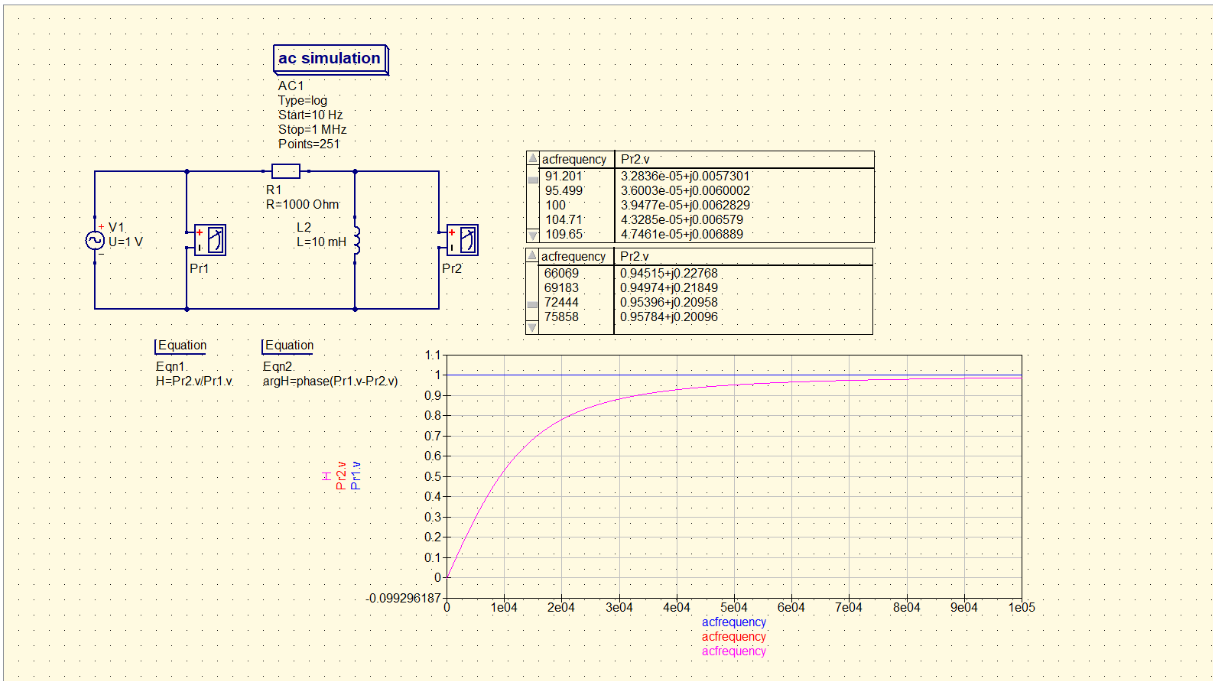




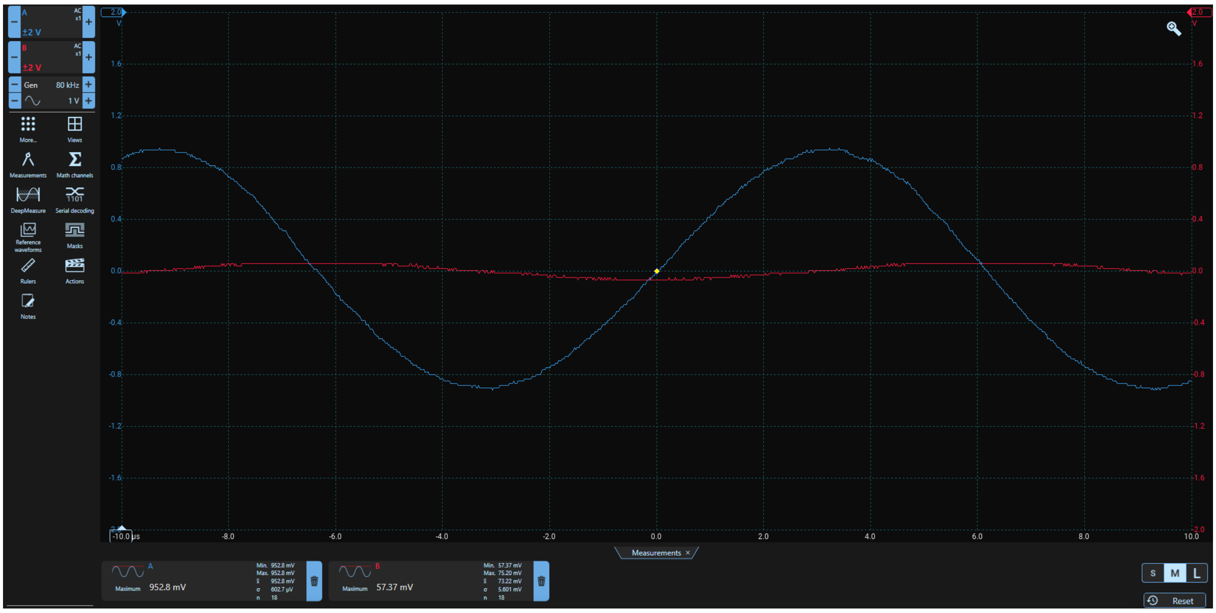
*Attachment 22 the voltage with a frequency of 80kHz*



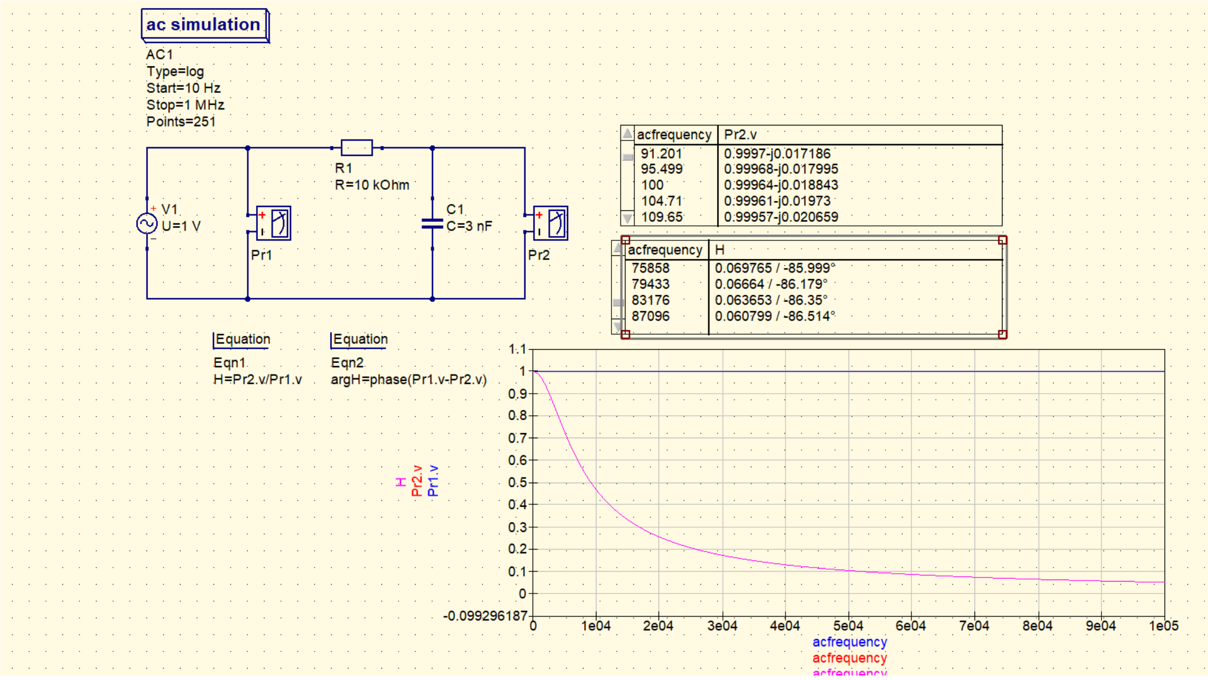
*Attachment 23 the voltage with a frequency of 100Hz*



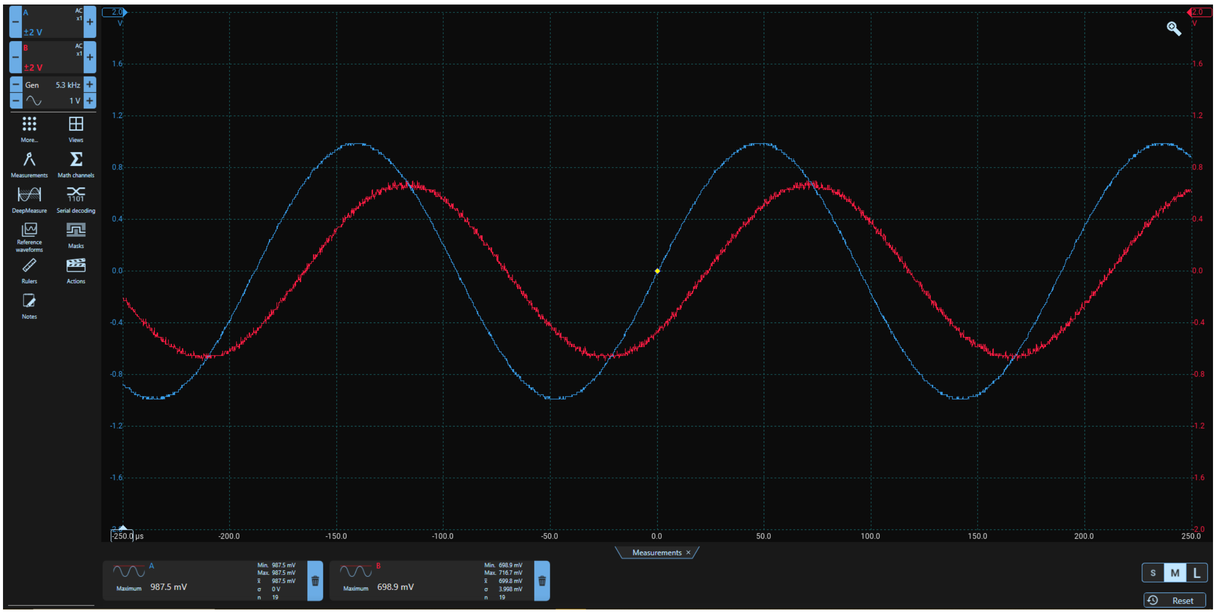
Attachment 24 simulated circuit in QUCS with measurements



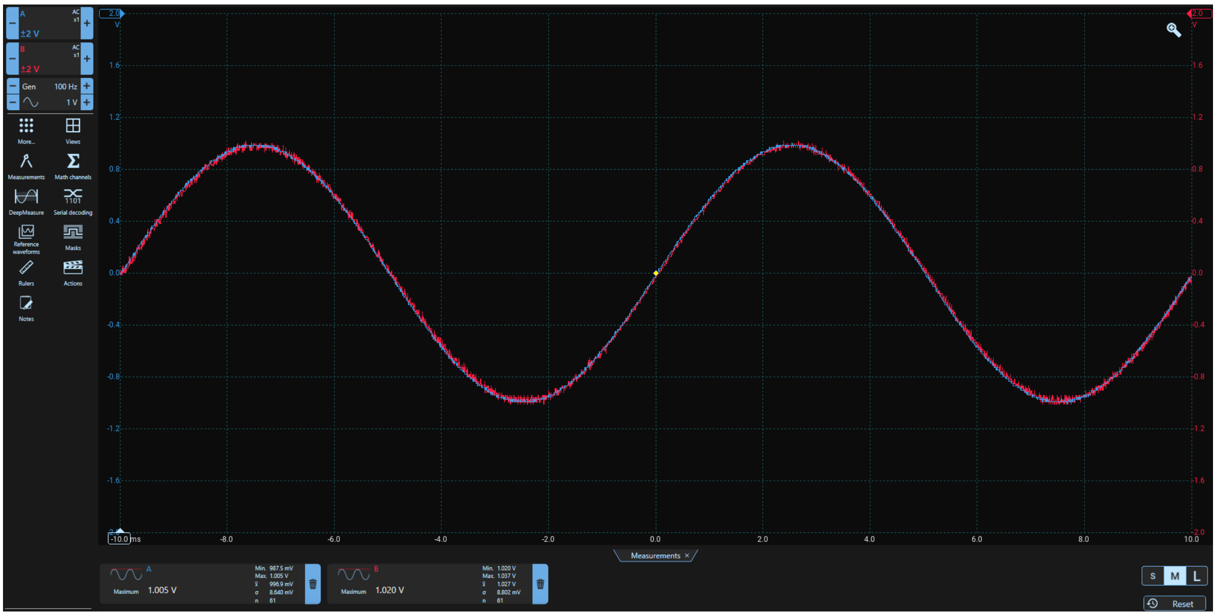
Attachment 25circuit from 3.2 on breadboard with frequency of 80kHz



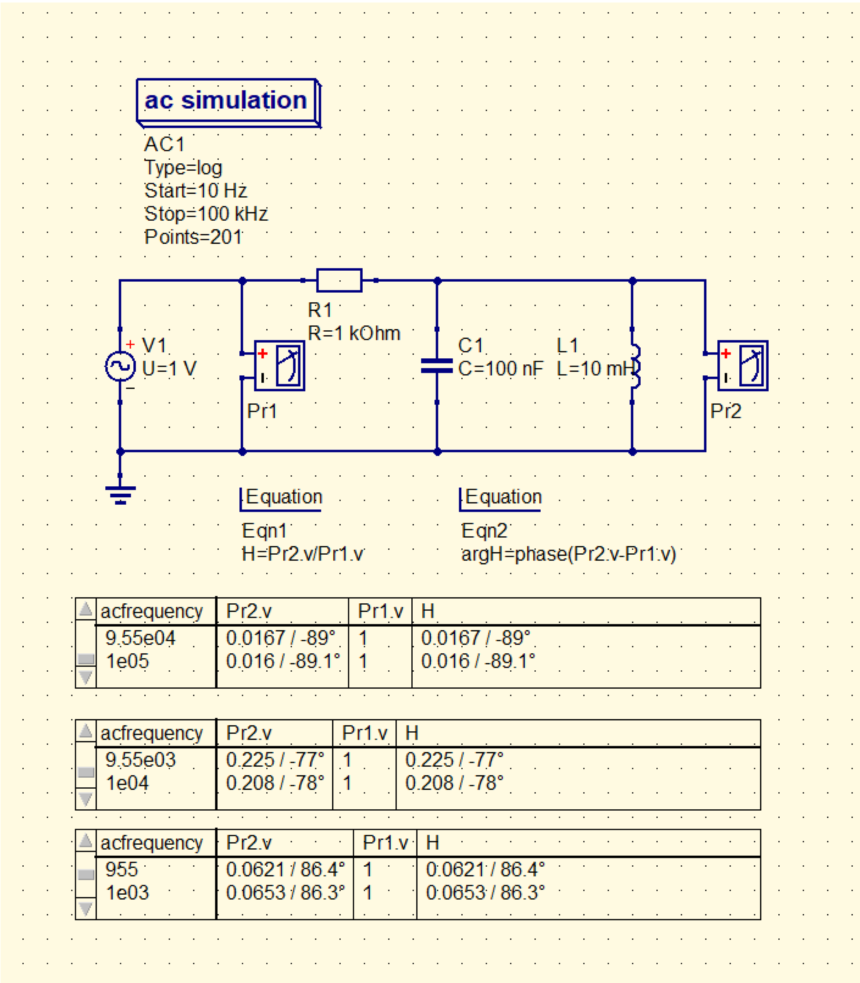
*Attachment 26 the circuit simulated in QUCS with simulated values*



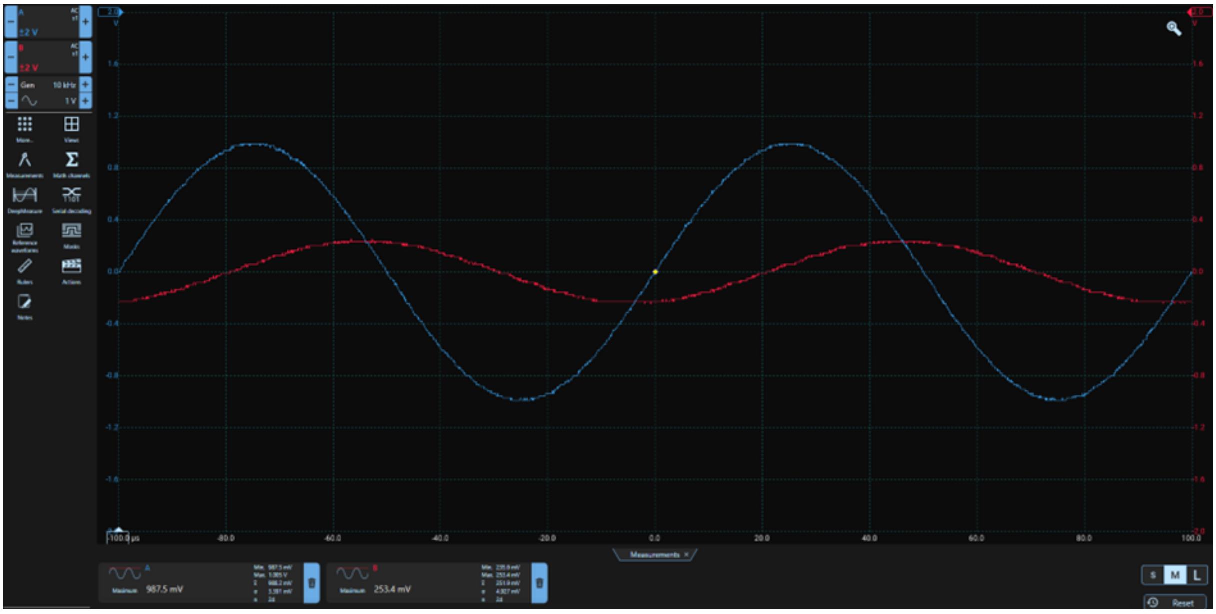
*Attachment 27 the circuit from 3.2 with the cut off frequency*



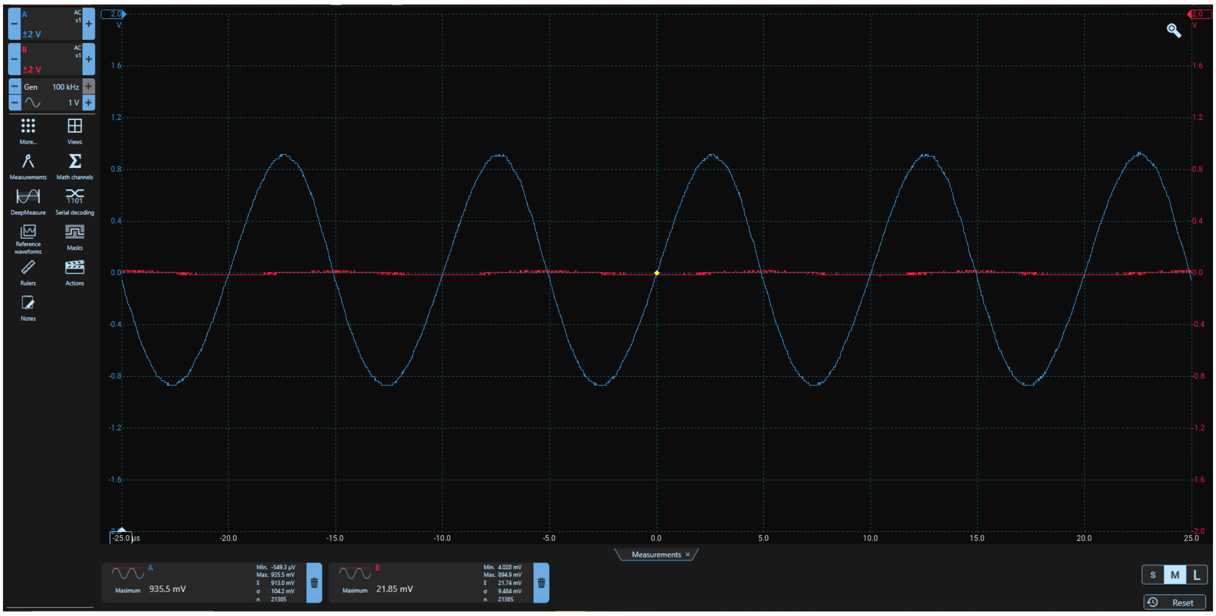

*Attachment 28 the circuit from 3.2 with at frequency of 100Hz*



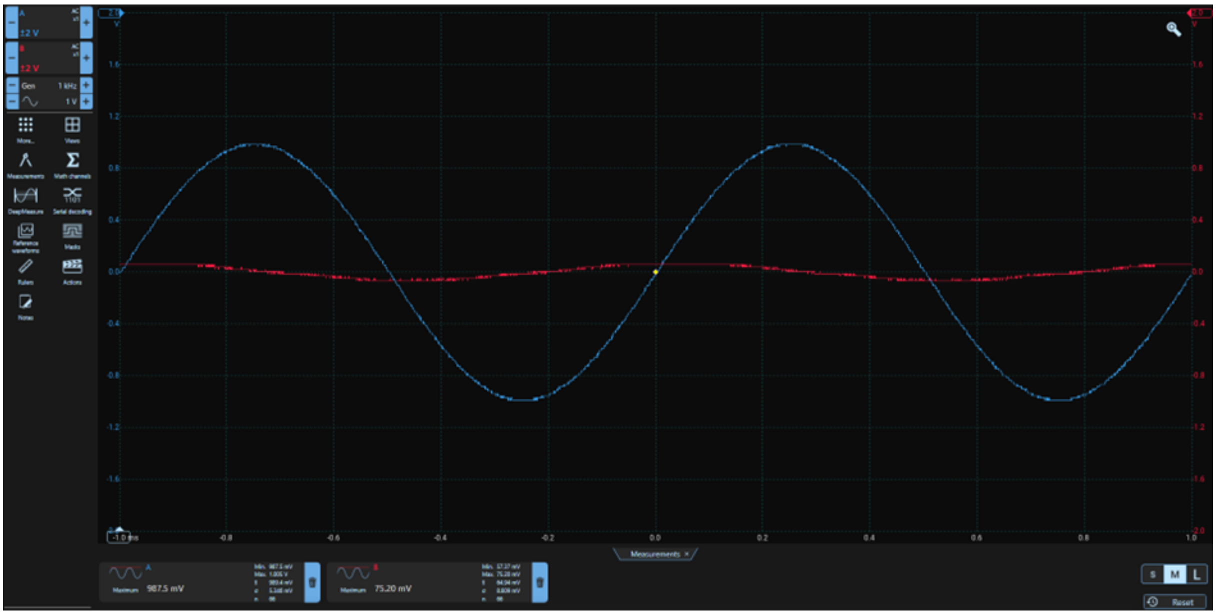

*Attachment 29 circuit from 3.3.1 simulated in QUCS with measurements*



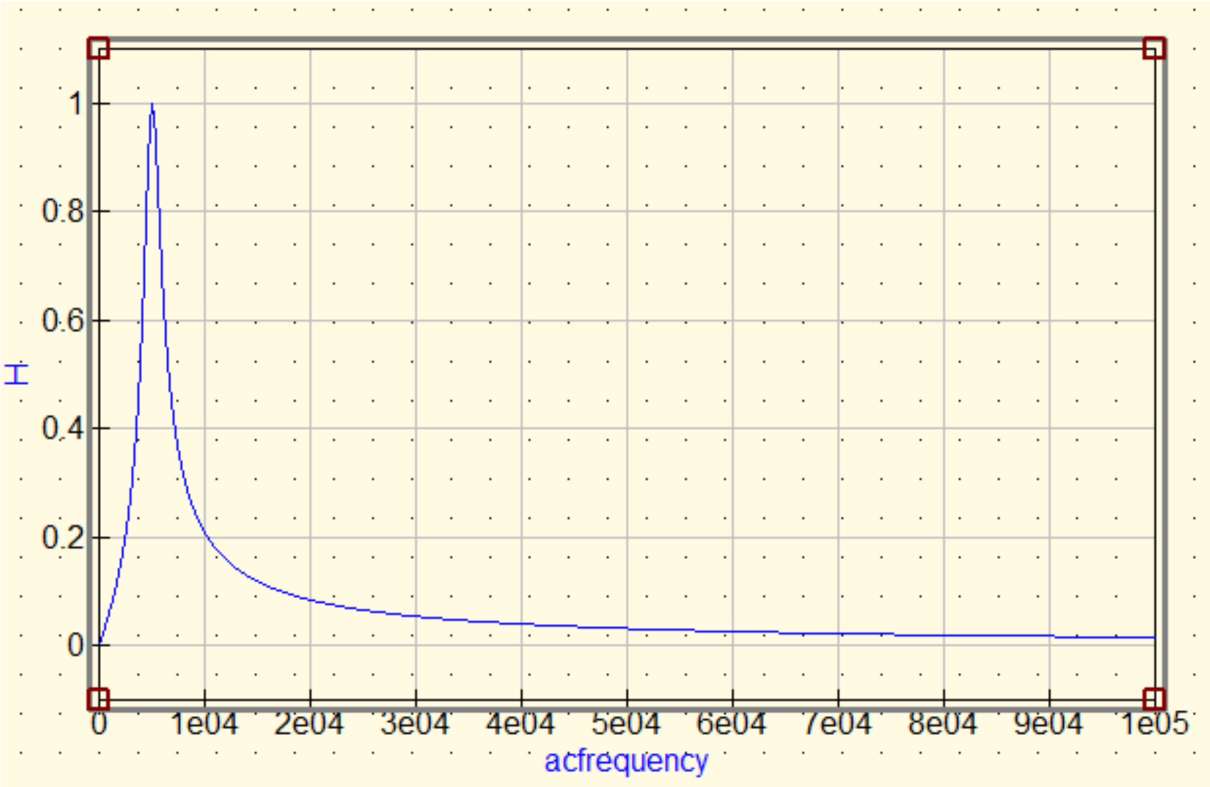
*Attachment 30 circuit 3.3.1 measuring voltage with 10kHz*



*Attachment 31 circuit from 3.3.1 measuring voltage with 5kHz*

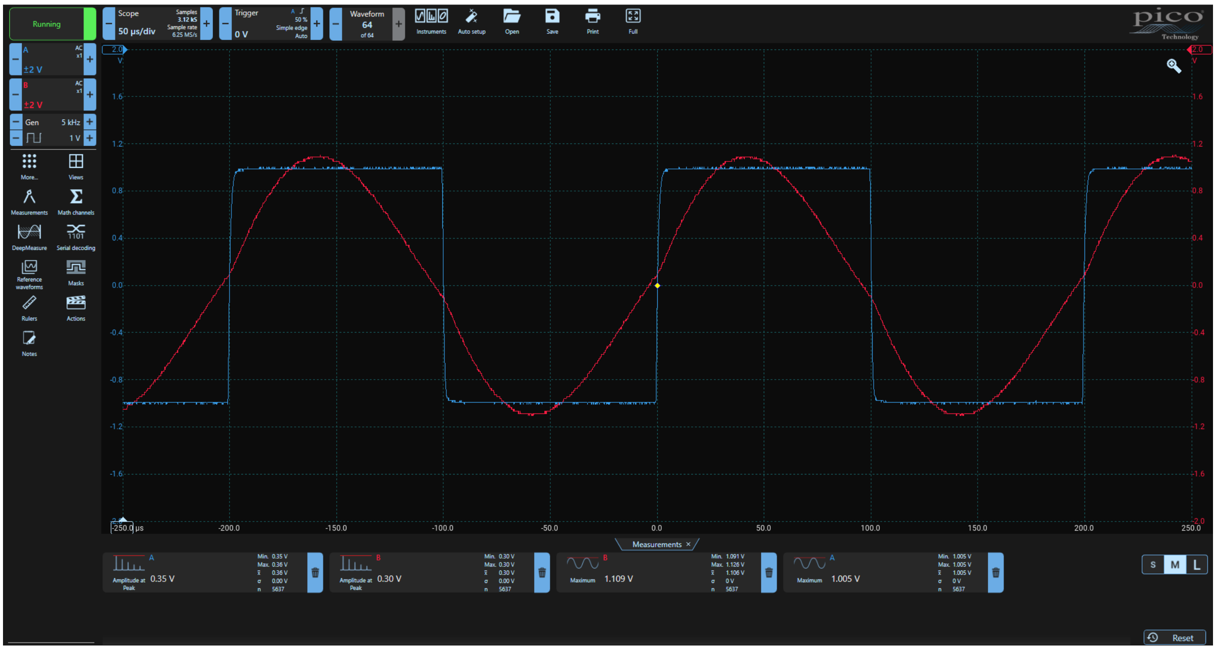


*Attachment 32 circuit from 3.3.1 measuring voltage with 1kHz*

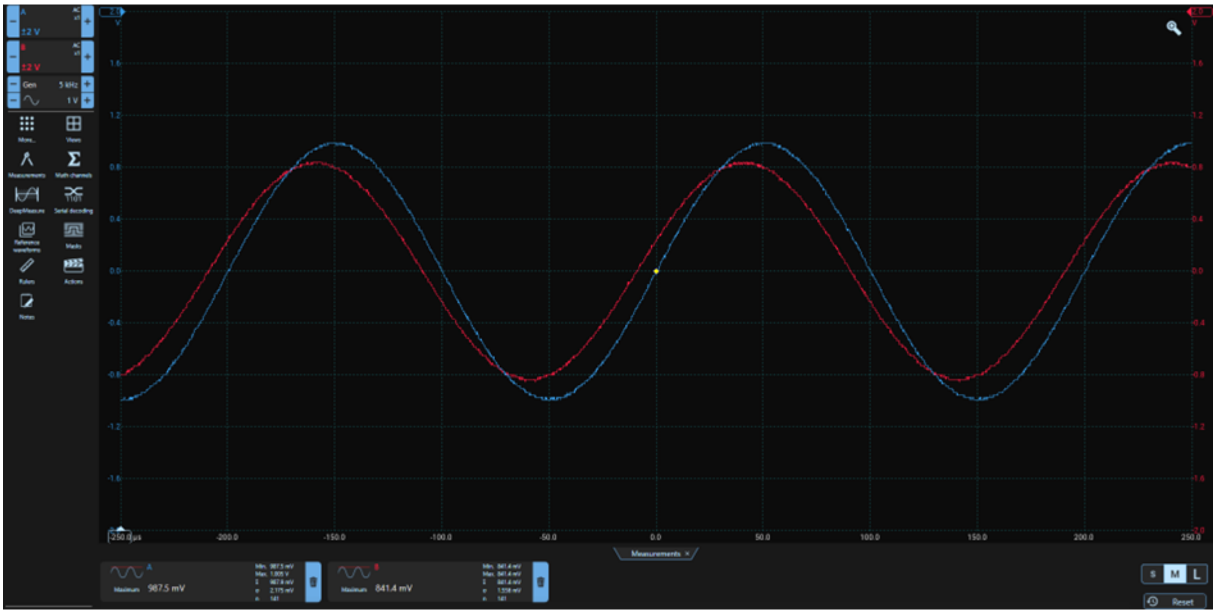


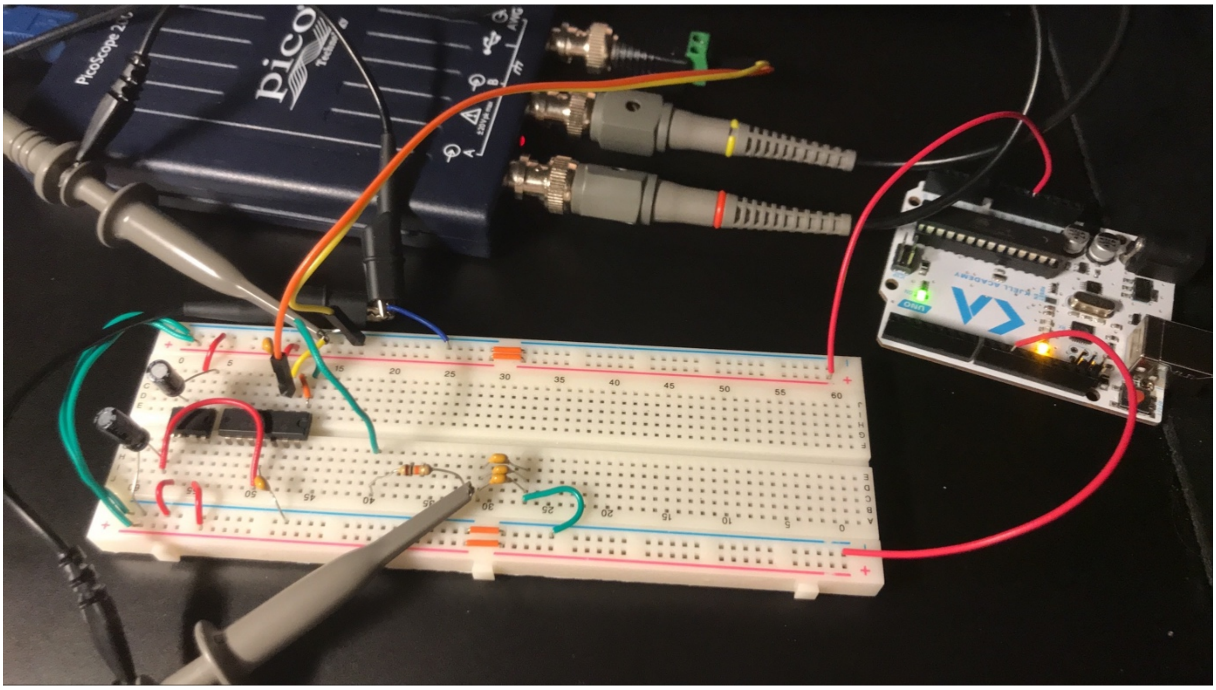

*Attachment 33 the graph of 3.3.1*

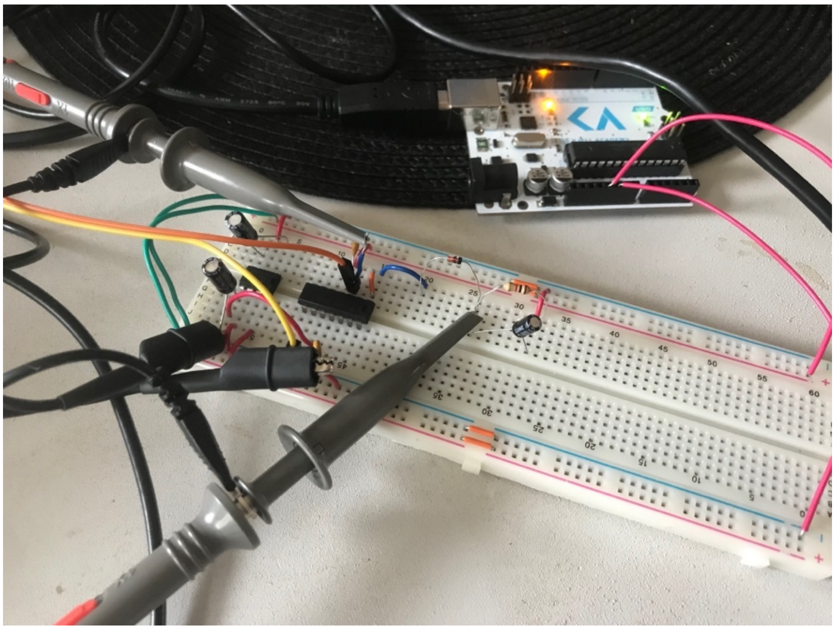
*Attachment 34 graph 3.3.2 sinus wave with peak*



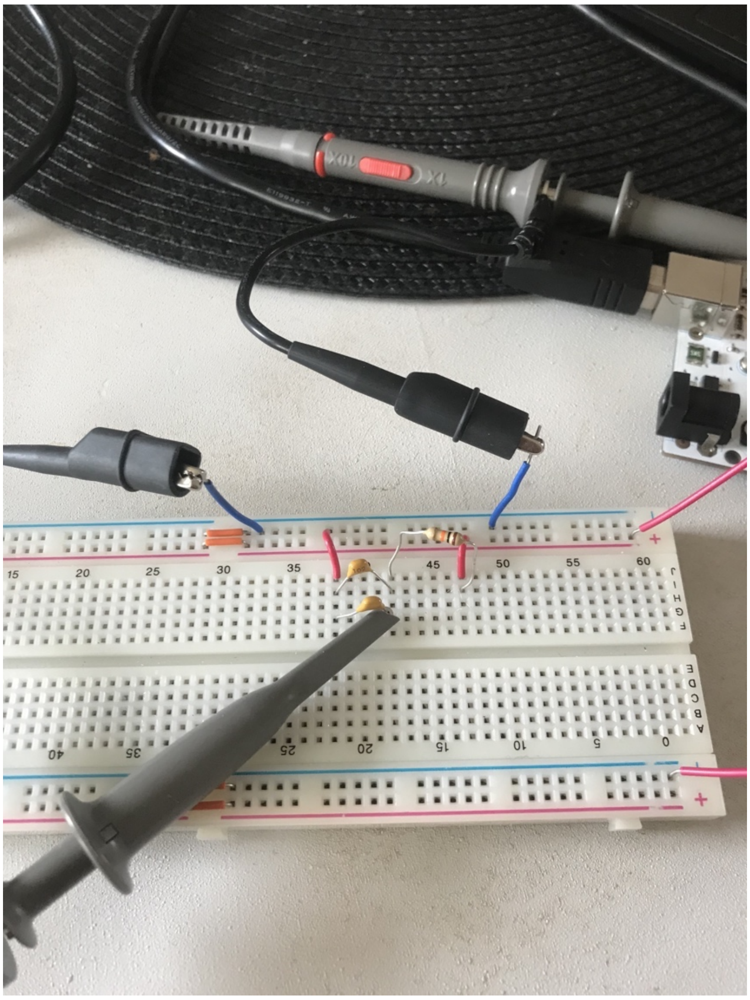
*Attachment 35 square wave input 3.3.2 with measurements*


Attachment 36 sinus input for 3.3.2 with frequency 5kHz

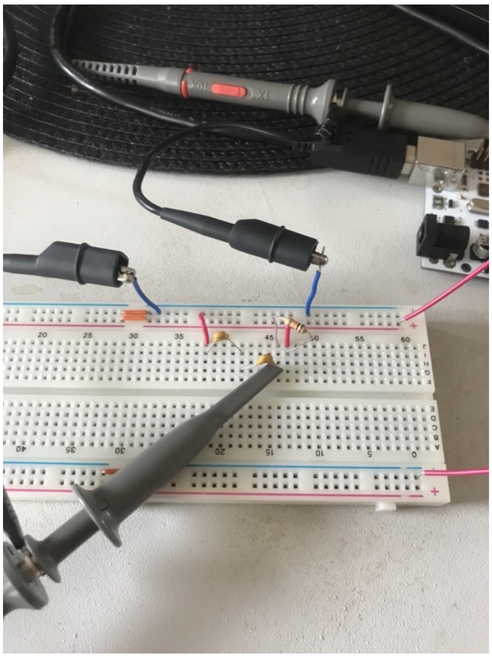

Attachment 37 the circuit from 3.2 built on breadboard



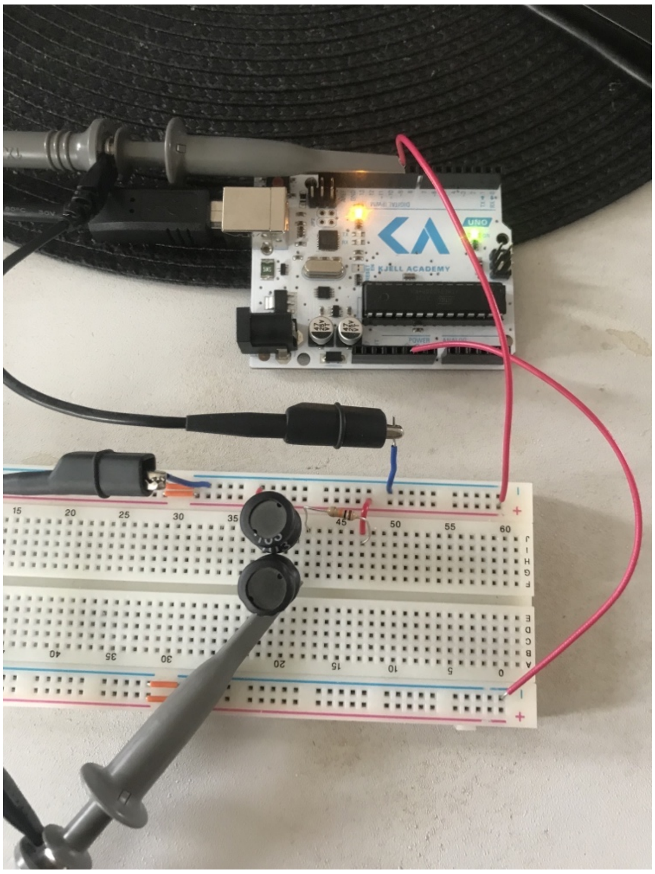
*Attachment 38 circuit from 2.3*



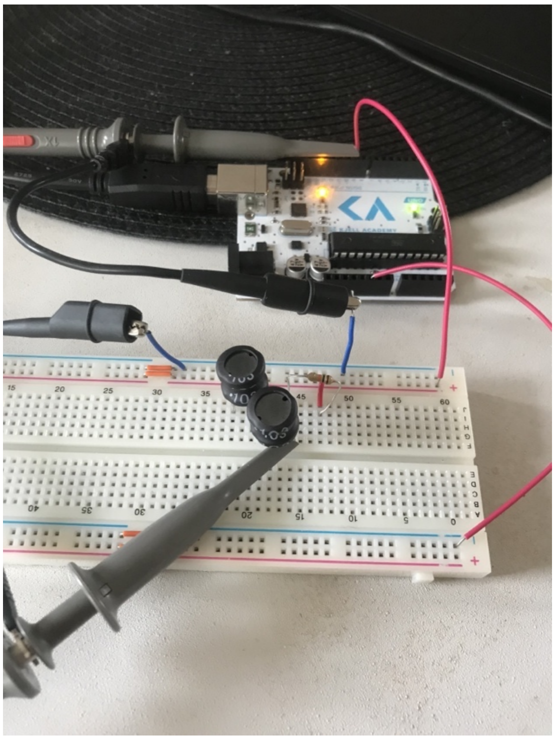
*Attachment 39 circuit from 2.2 with capacitors in parallel*



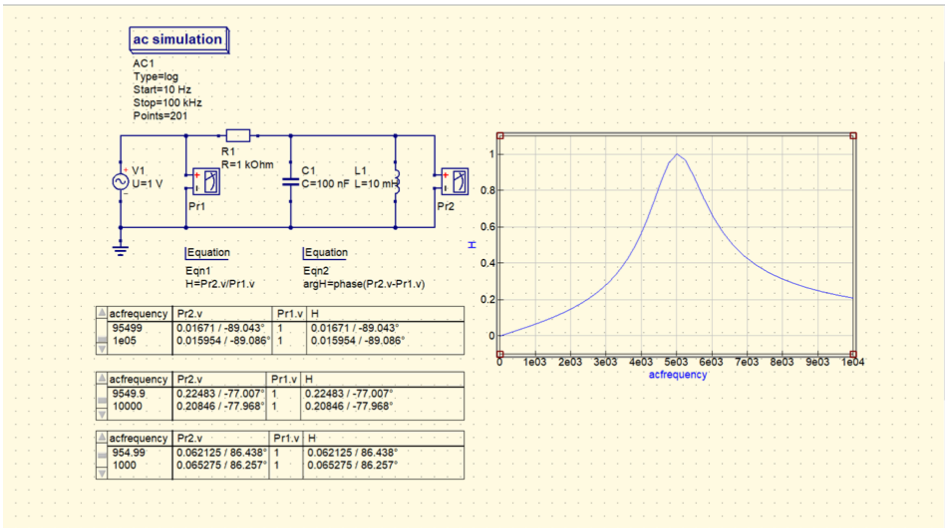
*Attachment 40 circuit from 2.2 with capacitors in series*



*Attachment 41 circuit from 2.1 with inductors in parallel*



*Attachment 42 circuit from 2.1 with inductors in series*




*Attachment 43 circuit 3.3.1 graph and measurements*

*Attachment 44 measurements from 3.3.2 square wave form 5kHz*

*Attachment 45 square wave form 3.3.2 15kHz*


*Attachment 46 square wave form 3.3.2 25kHz*


*Attachment 47 square wave form 3.3.2 35kHz*

*Attachment 48 square wave form 3.3.2 45kHz*