IE1206 Embedded Electronics Lab

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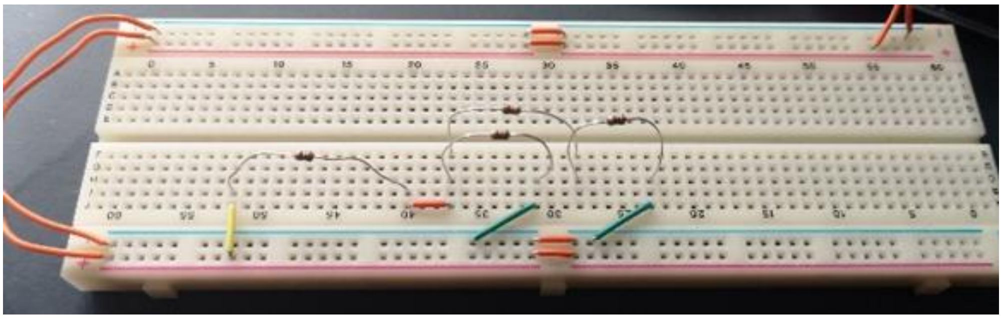
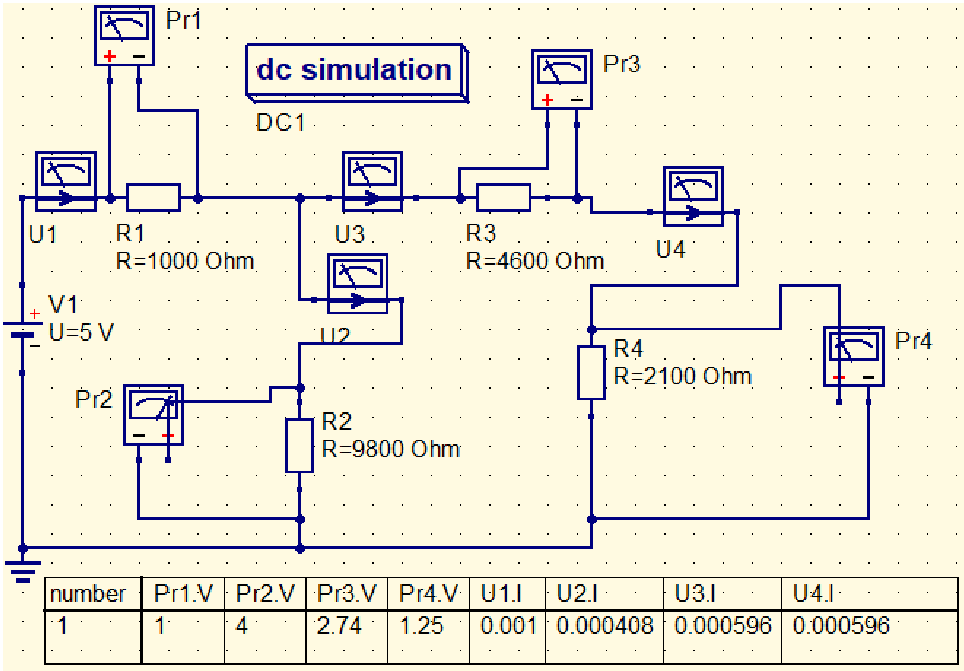
Lab 1 – DC Measurements

1.1 Resistive network with Arduino

Comp	Meas. (kΩ)	Meas. U(V)	Meas. I (mA)	Calc (kΩ) R = U/I	Calc (mW) P = U I	Calc (mW) P = U²/R	Calc (mW) P = I²R
R1	1	0.99	1.0	0.99	0.99	0.9801	1
R2	9.8	4.03	0.4	10.1	1.612	1.65723	1.568
R3	4.6	2.72	0.6	4.53	1.632	1.60835	1.656
R4	2.1	1.29	0.6	2.15	0.774	0.79243	0.756

The built and the simulated circuits:





The measured values of R, U and I compared to the simulated values of R, U and I were the same, with small margins of differences. The calculated resistances from the measured voltages and currents also agrees.

KVL can be confirmed in a loop if all the voltages in that loop equals zero. KVL in the first loop $U - IR1 - IR2$ is the same as $5V - 0.99 - 4.03 = -0.02 \approx 0$ V.

KVL in the second loop is $IR2 - IR3 - IR4 = 4.03 - 2.72 - 1.29 = 0.02 \approx 0$ V.

Therefore KVL is confirmed for both loops.

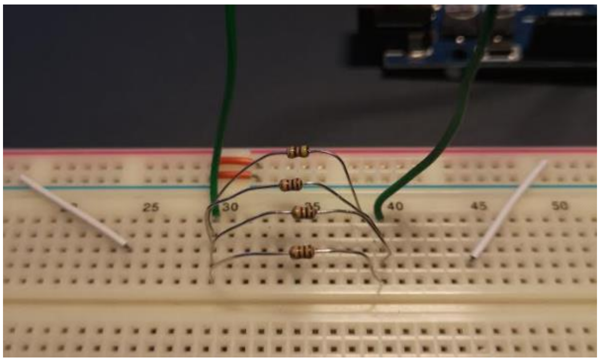
KCL can be confirmed if all the currents going out of a node equals all the currents going into the same node. For this circuit, the currents going in is R1 and the currents going out are R2 and R3, so $I1 = I2 + I3$. This gives the equation: $1 = 0.4 + 0.6$. Because $0.4 + 0.6 = 1.0$, KCL is confirmed for this node.

The power dissipation can be calculated by using the equation of power difference: $(P1 + P2 + P3 + P4) - P = 0.006$ mW.

Power balance means that the sum of the power from the load should equal the sum of the power loss in the circuit. The Arduino has a 5V output and a measured current of 1 mA, so its power is 5 mW, whilst the power of the circuit is:

$P1 + P2 + P3 + P4 = 5.006 \text{ mW} \approx 5 \text{ mW}$

1.2 Thevenin equivalent for Arduino 5V and 3.3V outputs



The total resistance of these 100Ω resistors in parallel is $\left(\frac{1}{100}+\frac{1}{100}+\frac{1}{100}+\frac{1}{100}\right)^{-1} = 25\Omega$

The power per resistor can be calculated using the equation $P = \frac{v^2}{R}$

We can then calculate the power in each resistor to be $P = \frac{5}{25} = 0.25\ W$

Results after measuring values using the multimeter for the following:

- 5V unloaded = 4.98V
- 5V loaded = 4.71V

Then, the internal resistance, Ri, can be calculated since $4.71 = \frac{4.98*25}{\mathrm{Ri}+25} \rightarrow \mathrm{Ri} = \frac{225}{157} = 1.43\Omega$

The measured current through this combined resistor load was: I = 0.18 A

The internal resistance as a voltage difference between the two measurements was:

Ri(5V) = $\frac{4.98-4.71}{0.18} = 1.5\Omega$

- 3.3V unloaded = 3.30V
- 3.3V loaded = 3.22V

And for 3.3V we have $3.22 = \frac{3.3*25}{\mathrm{Ri}+25} \rightarrow \mathrm{Ri} = \frac{100}{161} = 0.62\Omega$

The measured current through this combined resistor load was: I = 0.12 A

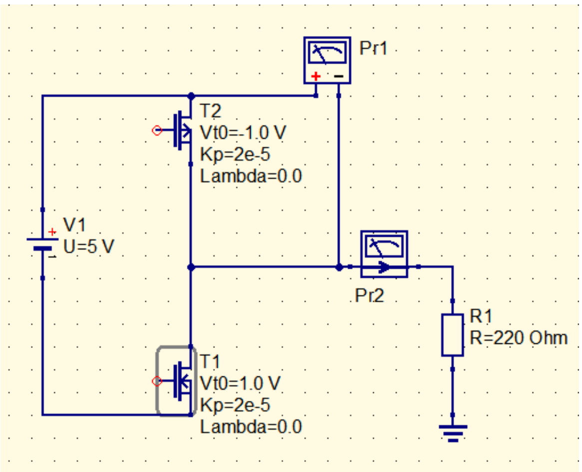
The internal resistance as a voltage difference between the two measurements was:

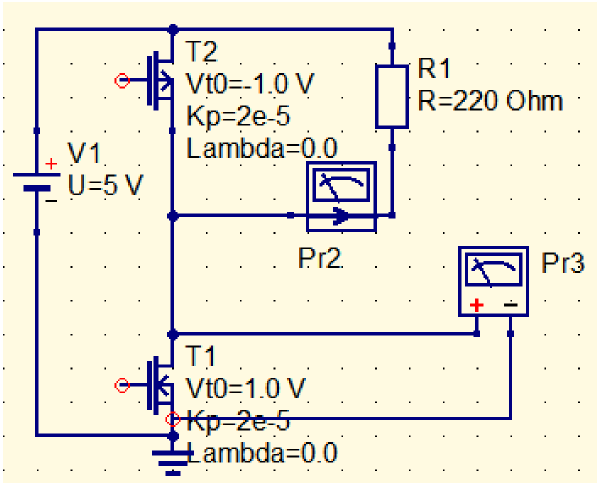
Ri(3V) = $\frac{3.3-3.22}{0.12} = 0.6\Omega$

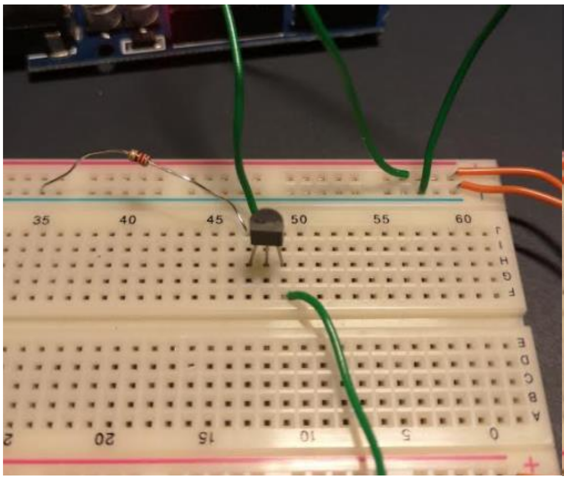
I believe that the internal resistance for the 3.3V source is low because the input voltage U is lower (5V and 3.3V). Because the resistance directly affects the input voltage through the equation V = IR, the internal resistance for 3.3V is also low.

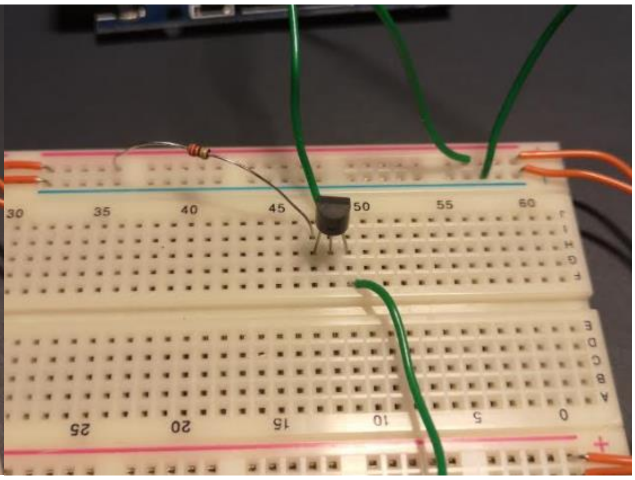
1.3 Resistance of MOSFETs on output pins

NMOS and PMOS in QUCS with the possibility to change the high and low actives to activate each one.









For these two measurements of finding the resistance of MOSFETs on output pins, I have decided to measure it by calculating the current as the divided voltage, through a voltage divider, over the known resistance.

The measured voltage of the PMOS was 0. Using voltage division of the following equation we can find the resistance:

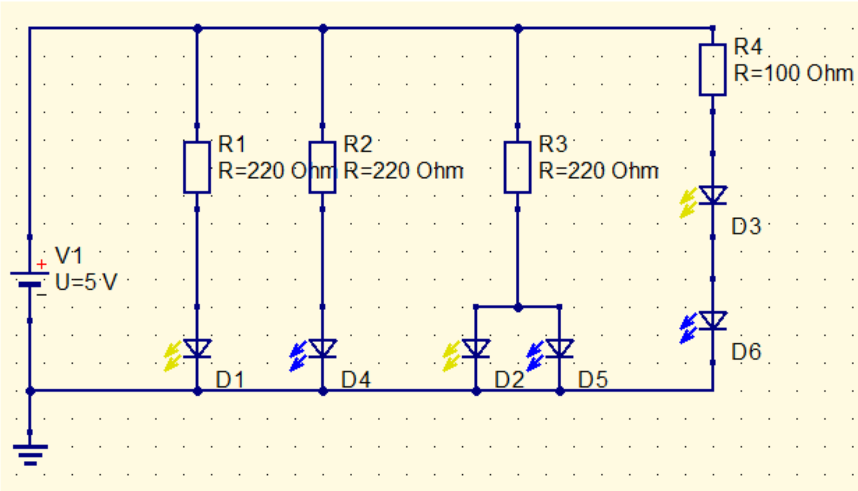
$$R(PMOS) = \frac{R * V}{V(Arduino) - V} = \frac{220 * 0.15}{5 - 0..15} = 6.8\Omega$$

Similarly, the measured voltage of the NMOS was 0.7V and by using the same method, we get:

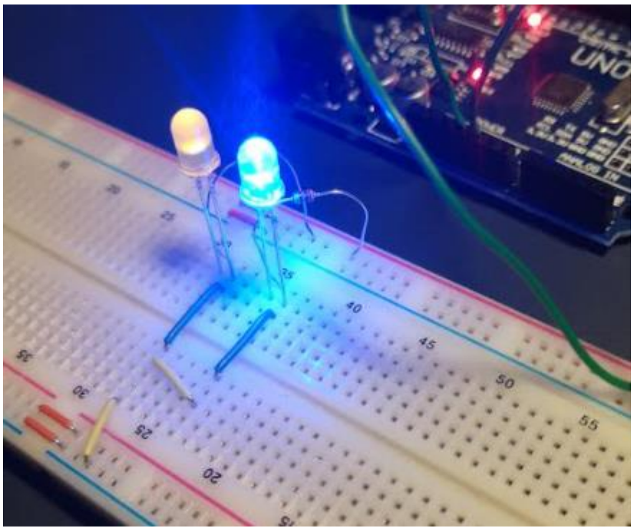
$$R(NMOS) = \frac{R * V}{V(Arduino) - V} = \frac{220 * 0.7}{5 - 0.7} = 35.8\Omega$$

1.4 LED Circuits

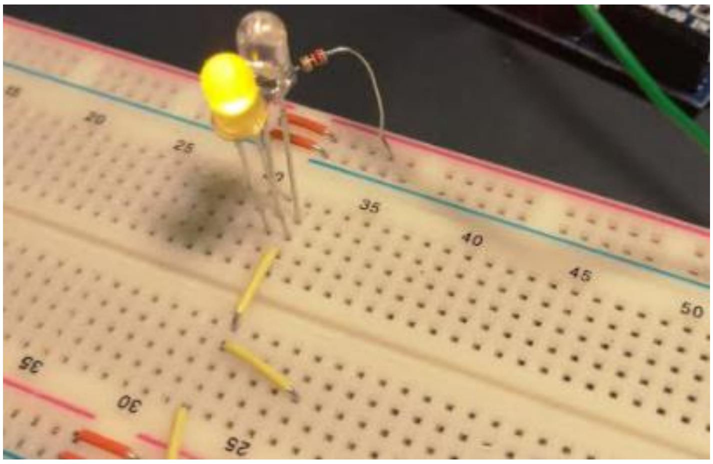
Simulated on QUCS:



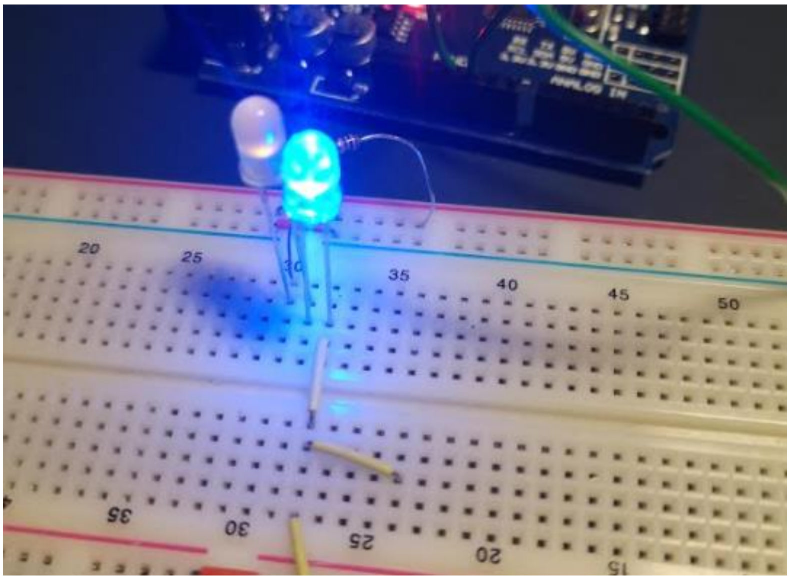
D1 and D2:



D1_ and D2_:



D1__ and D2__:



To find current, I will measure the voltages of the LEDs and divide by the known resistance.

R: 220Ω

D1: 2.06 V, R1: 3.03 V

I(D1) = $\frac{3.03}{220} = 13.8\ mA$

D2: 3.15 V, R2: 1.94 V

I(D2) = $\frac{1.94}{220} = 8.82\ mA$

R: 220Ω

D1_: 2.06 V, R3: 3.03 V

D2_: 2.06 V, R3: 3.03 V

I(D1_ & D2_) = $\frac{3.03}{220} = 13.8\ mA$

R: 100Ω

D1__: 1.87 V, R4: 0.36 V

D2__: 2.87 V, R4: 0.36 V

I(D1__ & D2__) = $\frac{0.36}{100} = 3.6\ mA$

Power Supply Voltage	LED Color	LED Vf	LEDs in series	Desired Current	Resistor (calculated)	Resistor (rounded)
3 V	Red, Yellow, or Yellow-Green	1.8	1	25 mA	48 Ω	51 Ω
4.5 V	Red, Yellow, or Yellow-Green	1.8	2	25 mA	36 Ω	39 Ω
4.5 V	Blue, Green, White, or UV	3.3	1	25 mA	48 Ω	51 Ω
5 V	Blue, Green, White, or UV	3.3	1	25 mA	68 Ω	68 Ω
5 V	Red, Yellow, or Yellow-Green	1.8	1	25 mA	128 Ω	150 Ω
5 V	Red, Yellow, or Yellow-Green	1.8	2	25 mA	56 Ω	56 Ω
9 V	Red, Yellow, or Yellow-Green	1.8	4	25 mA	72 Ω	75 Ω
9 V	Blue, Green, White, or UV	3.3	2	25 mA	96 Ω	100 Ω

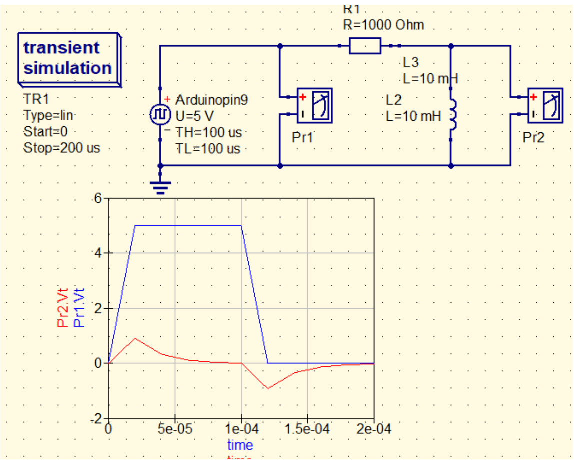
From these two images and the graph in the appendix of the lab instructions, we can infer that the yellow LED needs less voltage to power on (around 1.8 V – 2.5 V) whilst the blue LED requires more voltage. When the circuit is connected in parallel the voltage between the yellow and blue LED is the same, which would be at the voltage where the yellow LED turns on, therefore the blue LED will not power on as there is not enough power.

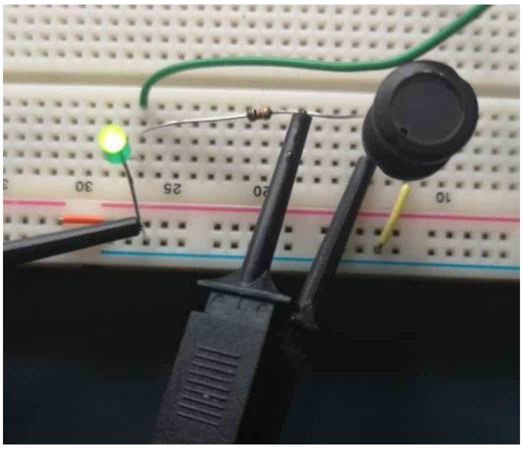
Lab 2 - Time-dependent Measurements

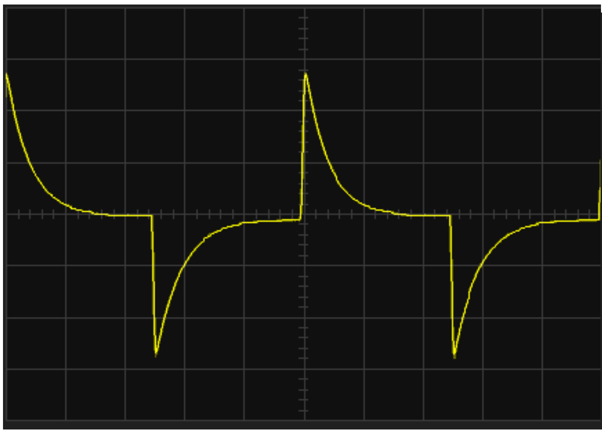
2.1 Time dependent behaviour of RL circuits

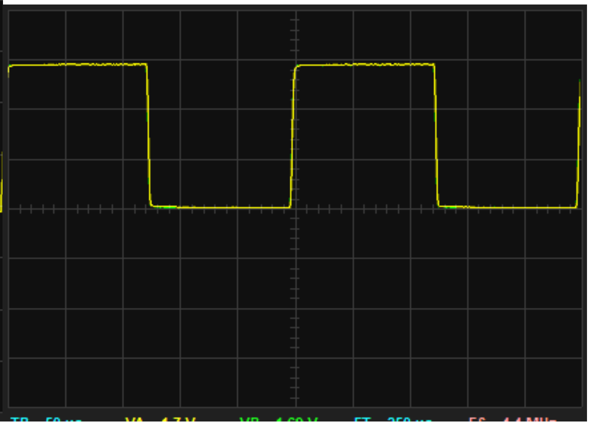
The time constant τ from R1 and L1 is $\tau = \frac{L1}{R1} = \frac{10*10^{-3}}{1000} = 10\mu s$

Build:



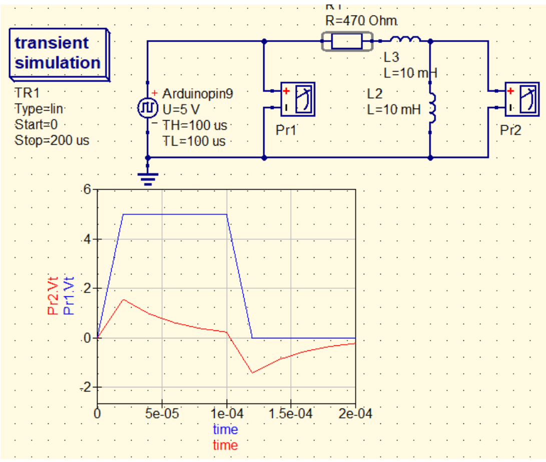


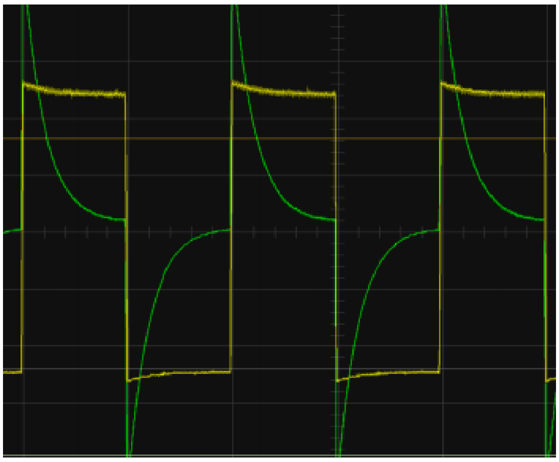




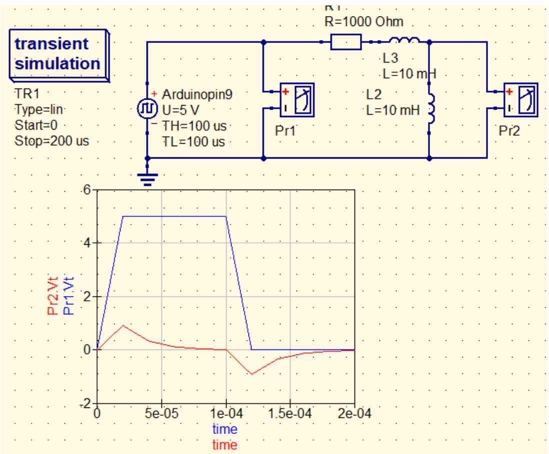
The measured time constant τ is also $10\mu s$.

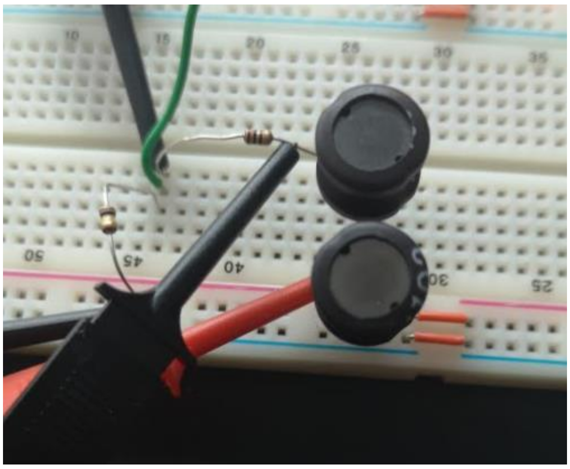
Using resistance R1 of 470Ω yields that $\tau = \frac{L1}{R1} = \frac{10*10^{-3}}{470} = 21\mu s$

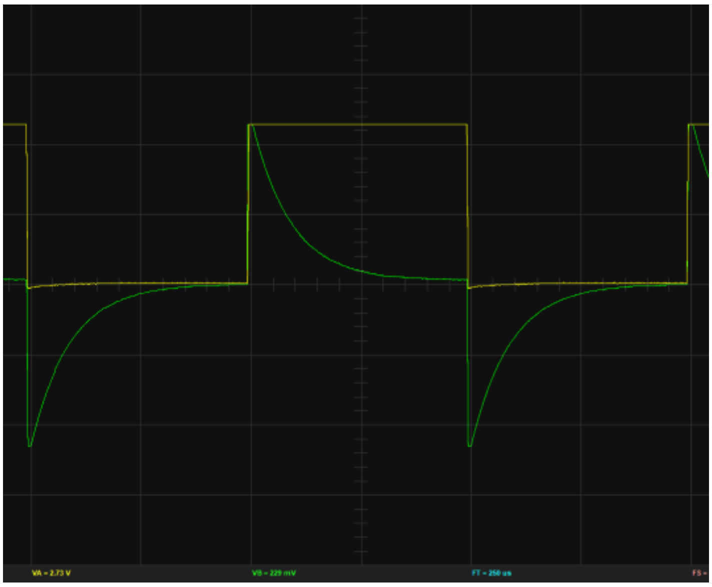




In series:

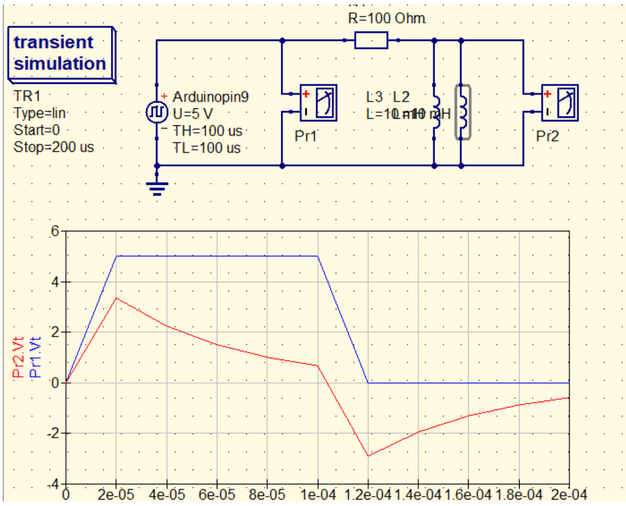


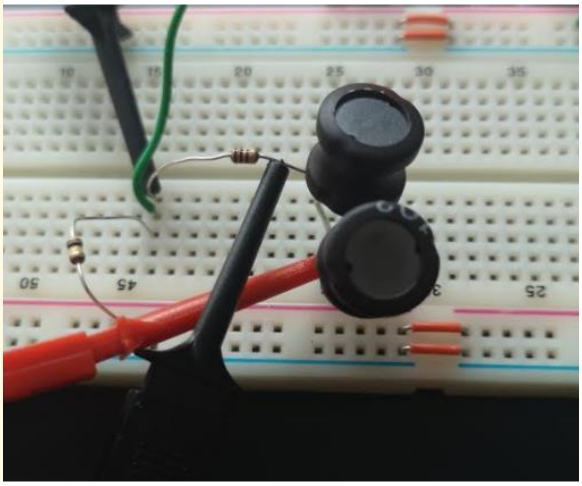


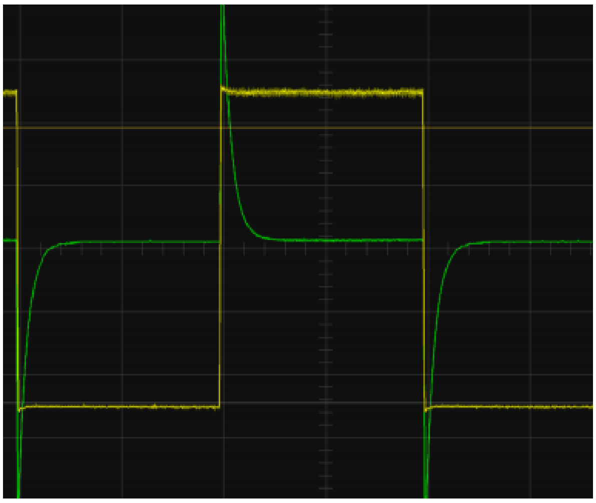


$$\tau = \frac{L1+L2}{R1} = \frac{20*10^{-3}}{1000} = 20\mu s$$

Parallel:





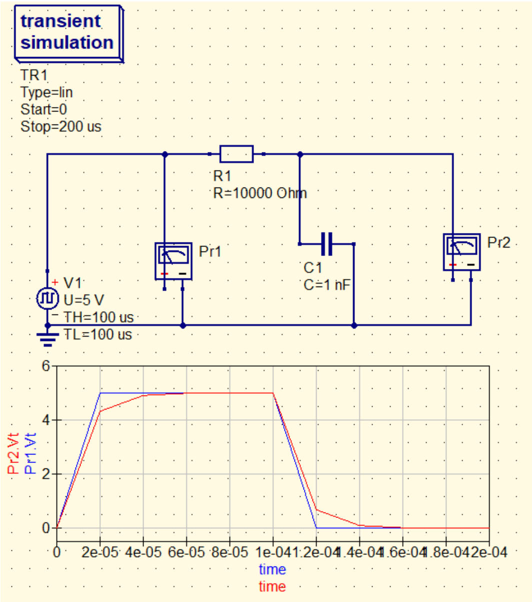


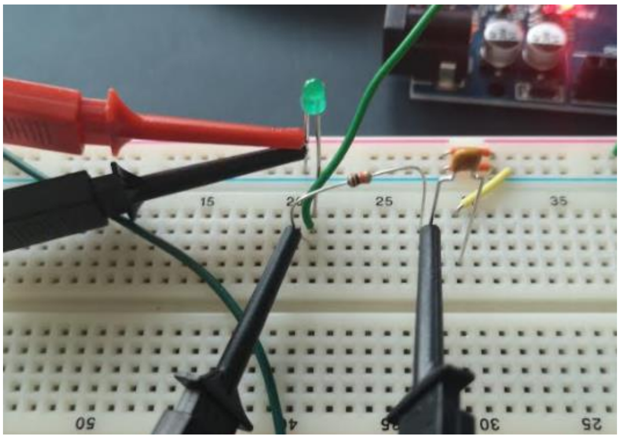
$$\tau = \frac{\frac{L1*L2}{L1+L2}}{R1} = \frac{5*10^{-3}}{1000} = 5\mu s$$

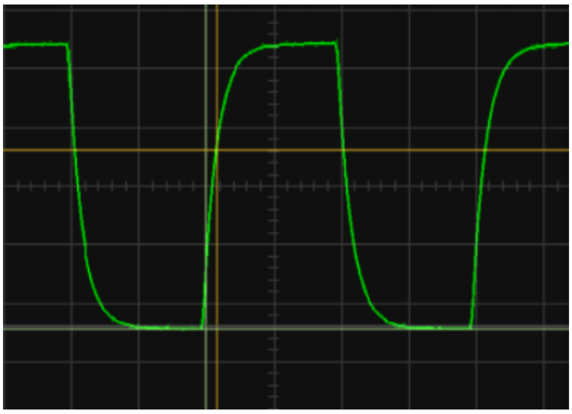
2.2 Time dependent behaviour of RC circuits

The time constant $\tau = C1 * R1 = 1 * 10^{-9} * 10{,}000 = 10\mu s$

Build:







The measured time constant τ is $\sim 8\mu s$.

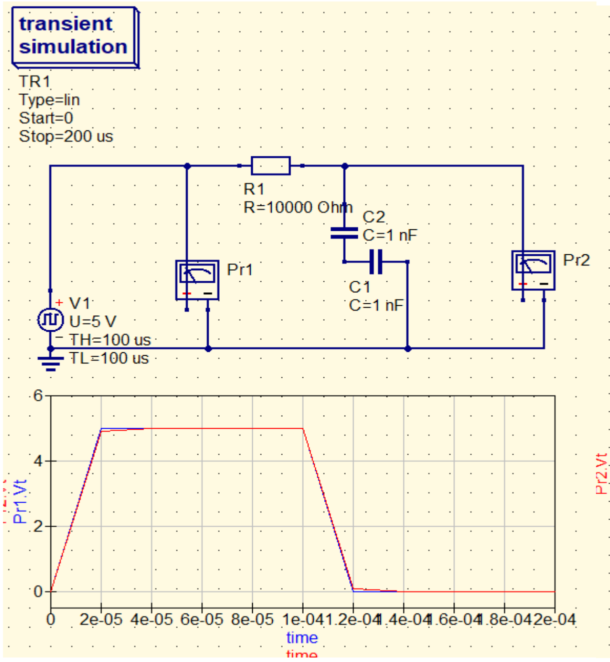
The time constant for R1 = 4.7 kΩ $\tau = C1 * R1 = 1 * 10^{-9} * 4{,}700 = 4.7\mu s$

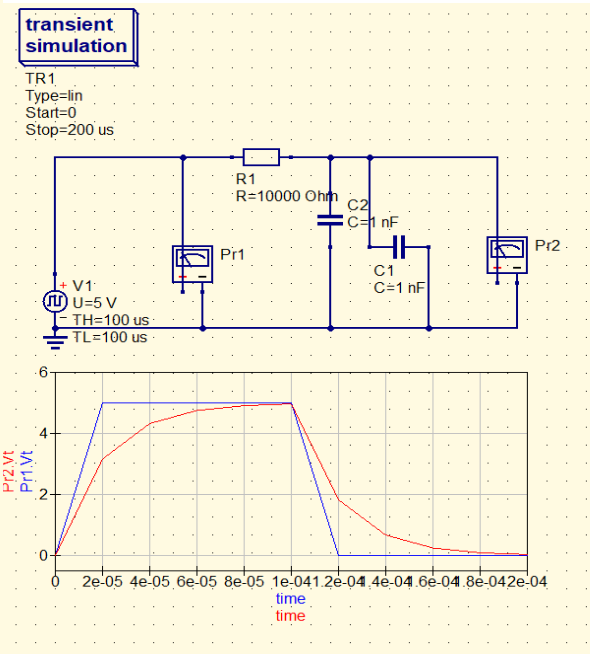
The time constant for R1 = 22 kΩ $\tau = C1 * R1 = 1 * 10^{-9} * 22{,}000 = 22\mu s$

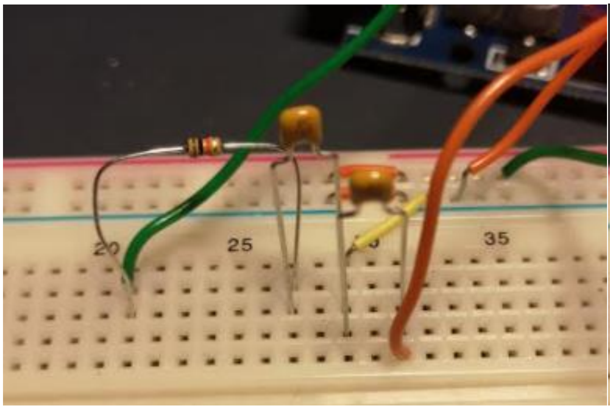
Serial and parallel:

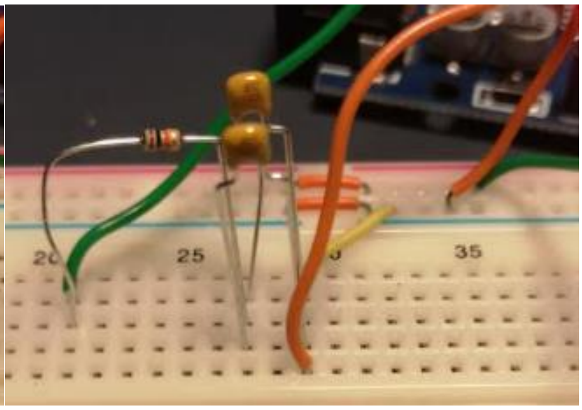
$$\tau_S = \frac{1}{\frac{1}{C1} + \frac{1}{C2}} * \mathrm{R1} = 5 * 10^{-10} * 10{,}000 = 5 * 10^{-6}$$

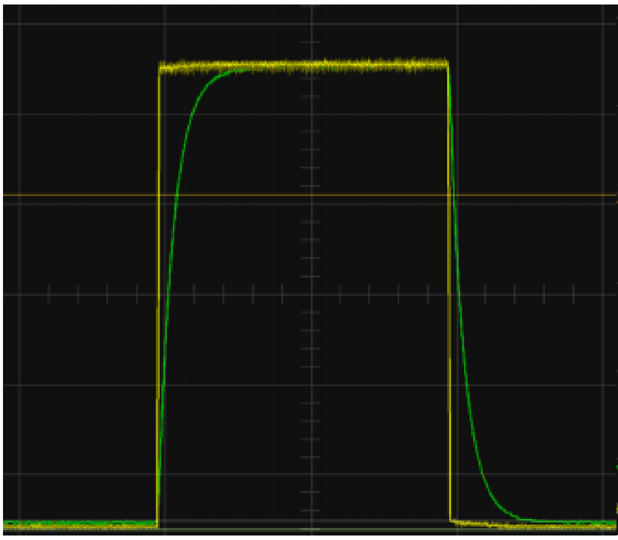
$$\tau_P = (C1 + C2) * \mathrm{R1} = 2 * 10^{-9} * 10{,}000 = 2 * 10^{-5}$$

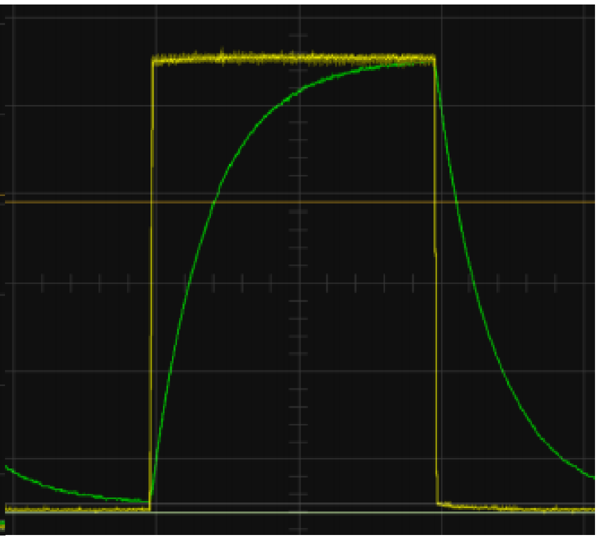




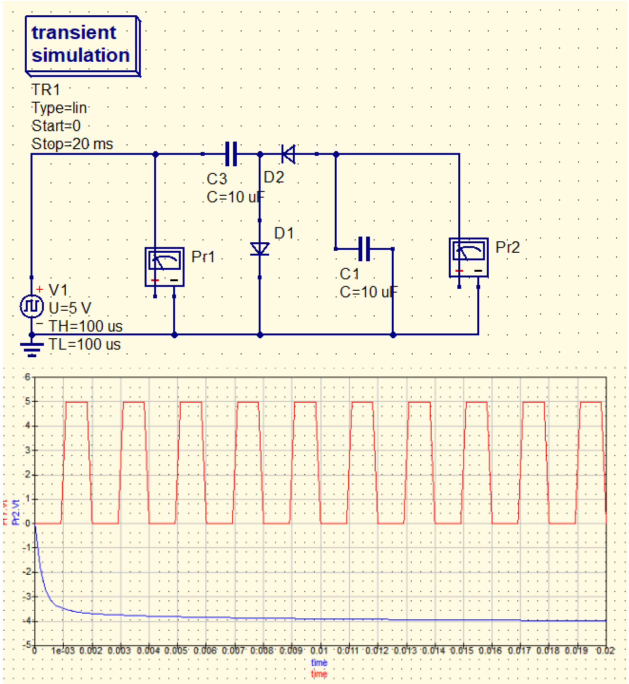


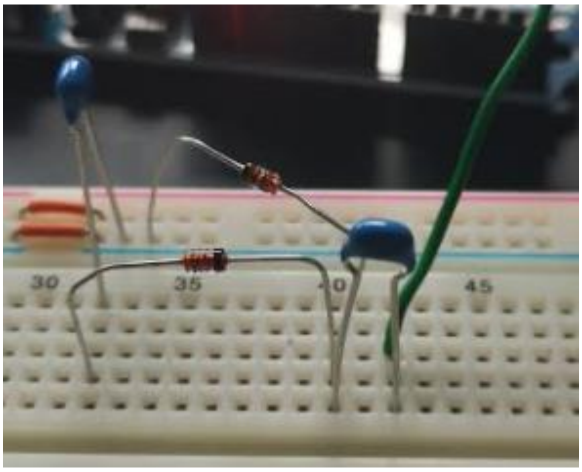






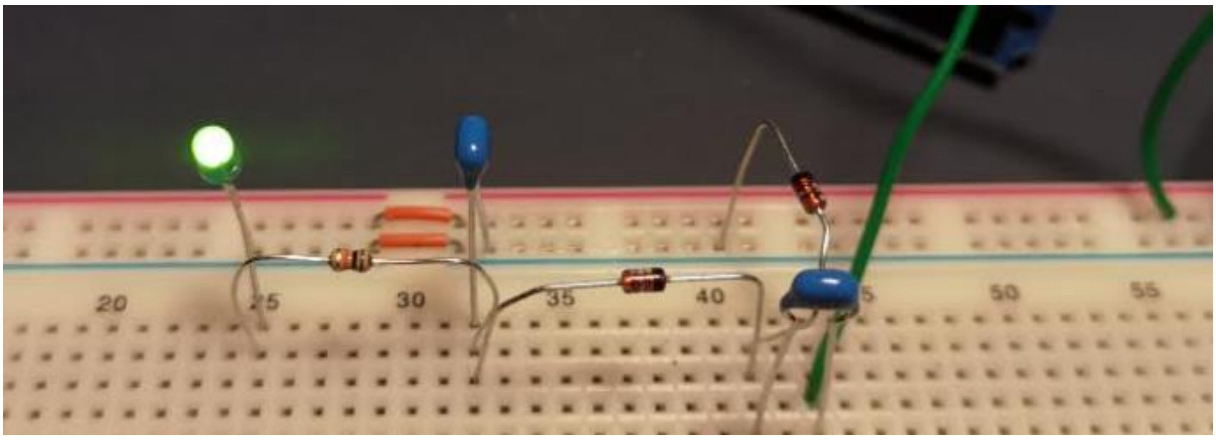
2.3 Negative power generator



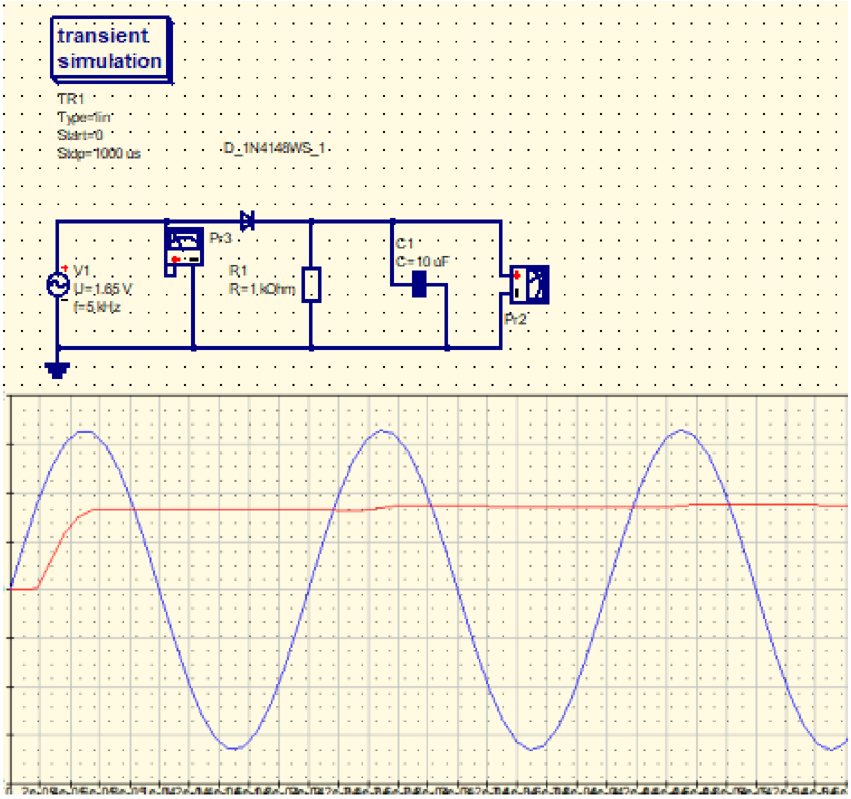


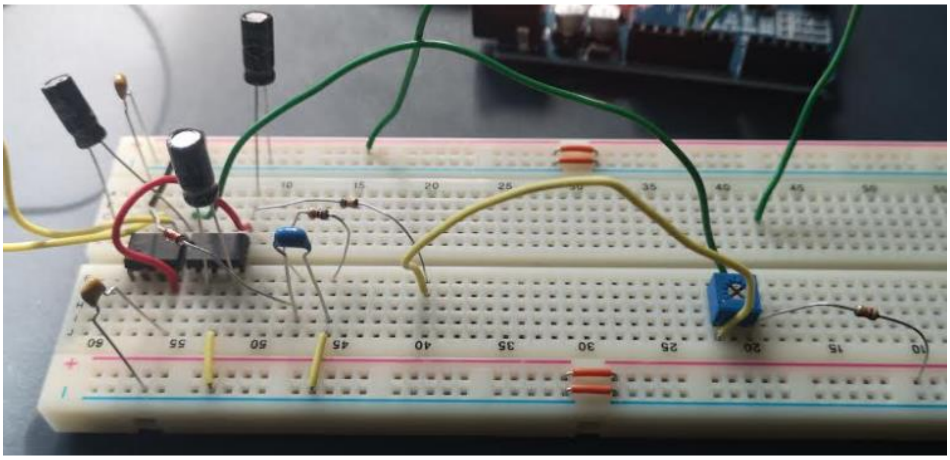
The voltage at C2 where it connects to the diode is -4.57 V, which is similar to the simulation but not exactly the same.

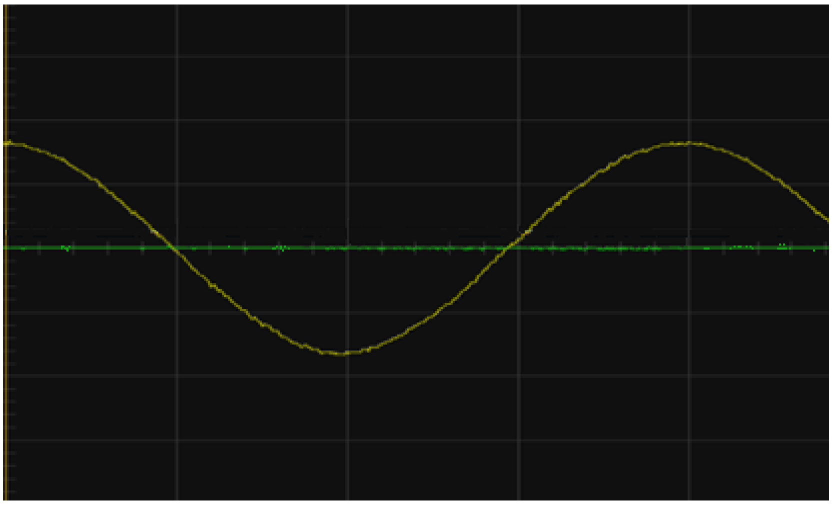
The value is not -5 V because the instruments used for measuring have many sources of errors. There is a possibility that the circuit built is wrong. There may also be small amounts of leaks in each part of the circuit leading to faulty readings.



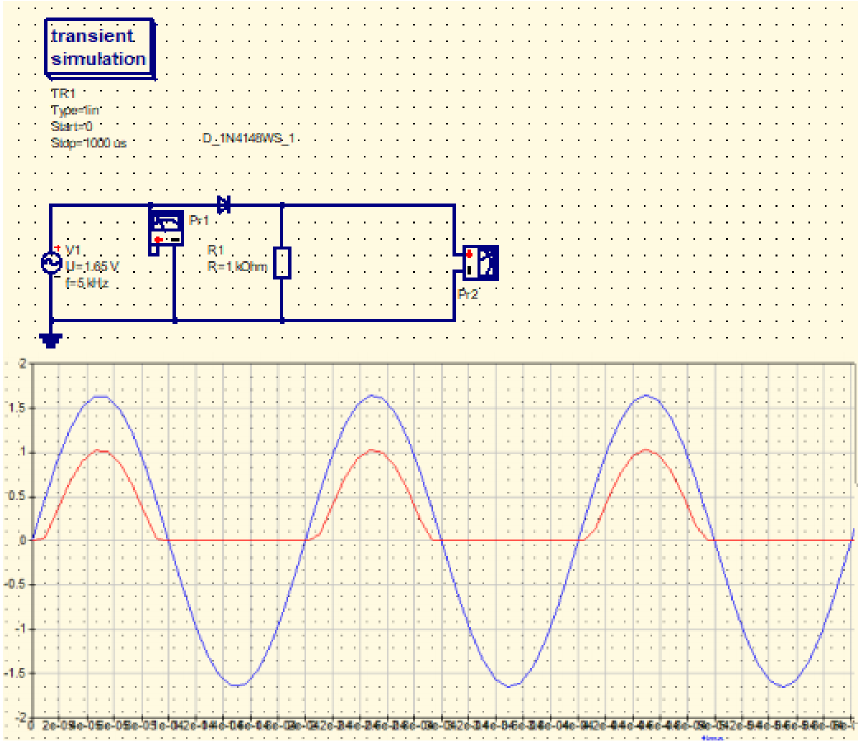
2.4 Rectifier circuit with capacitor and resistor

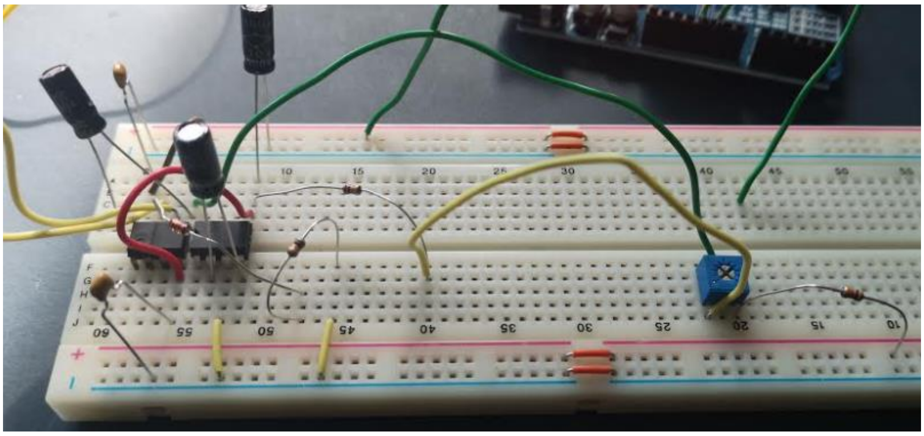


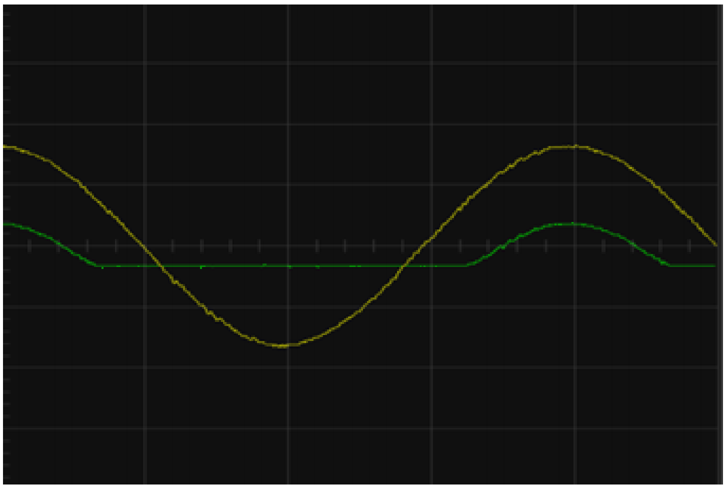




Without capacitor:

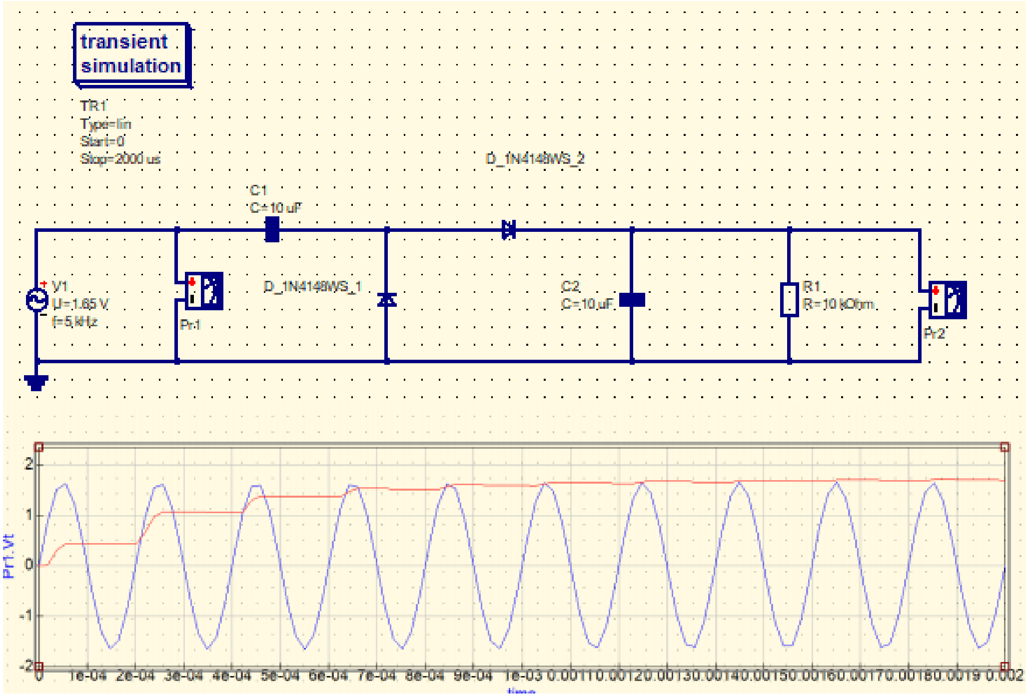


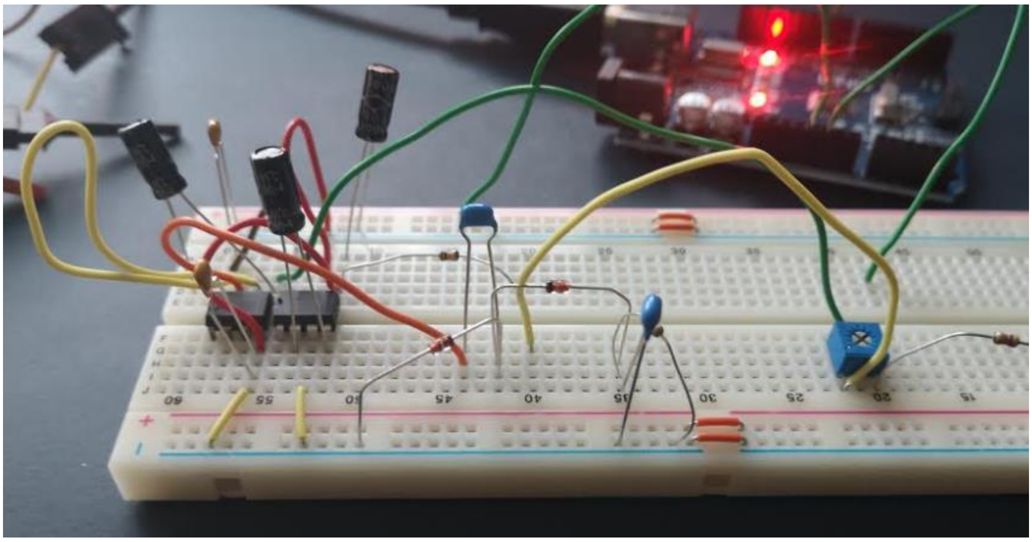


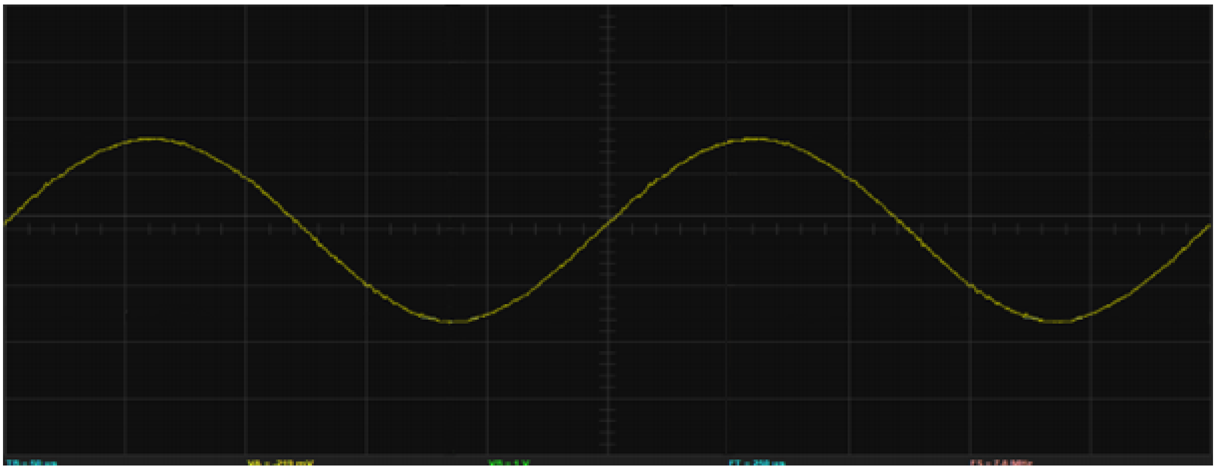


The behaviour with and without capacitors were different and so were their measured voltage values from the second probe (Pr2). The QUCs simulation was similar to the Bitscope result.

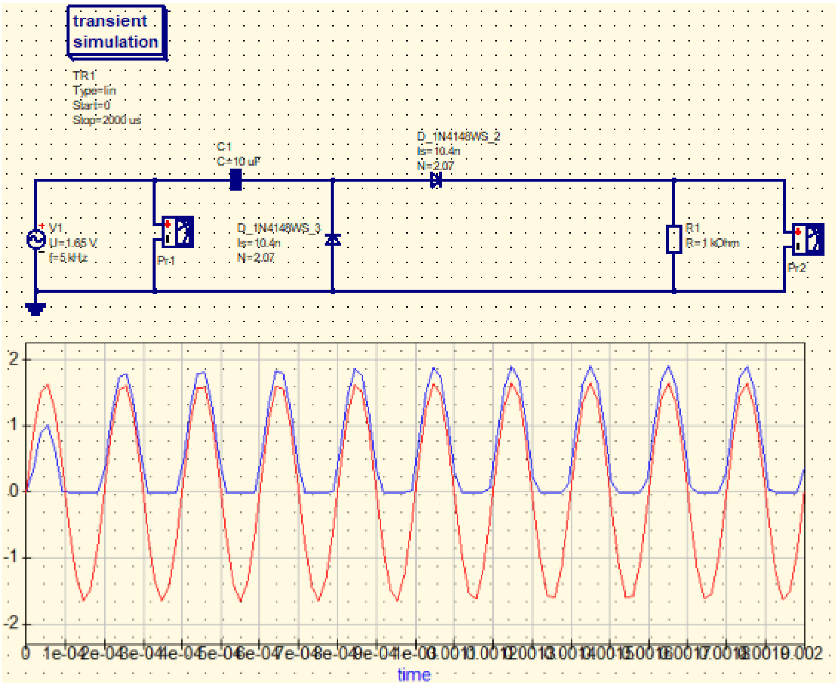
2.5 Voltage doubler

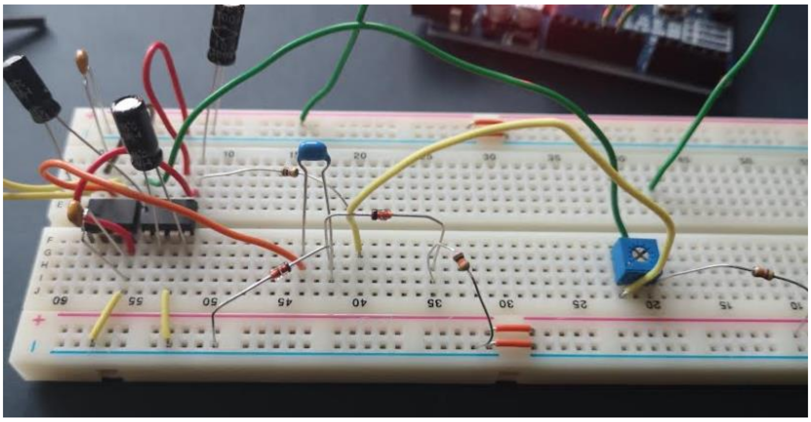


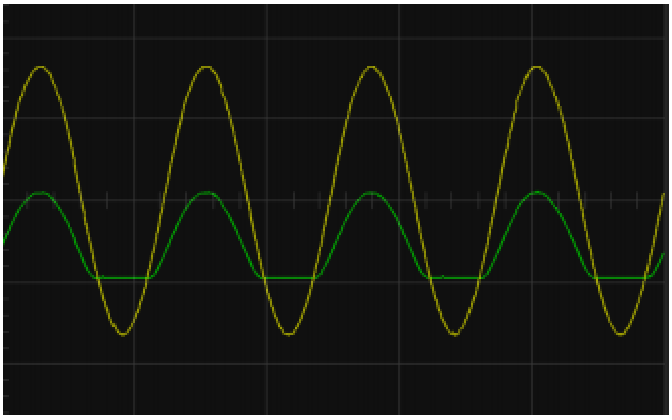




Without C2:







The behaviour of having the capacitor C2 and the behaviour of not having the capacitor C2 is somewhat different. Whilst they both have the sin wave function with the same peaks and troughs, the wavelength, or distance between each cycle is larger and the measured values from Pr2 follows the path of Pr1 instead of slowly diverging from it, which is the behaviour of the circuit with C2.

Lab 3 – AC Measurements

3.1 Internal resistance of BitScope waveform generator with Op amp buffer

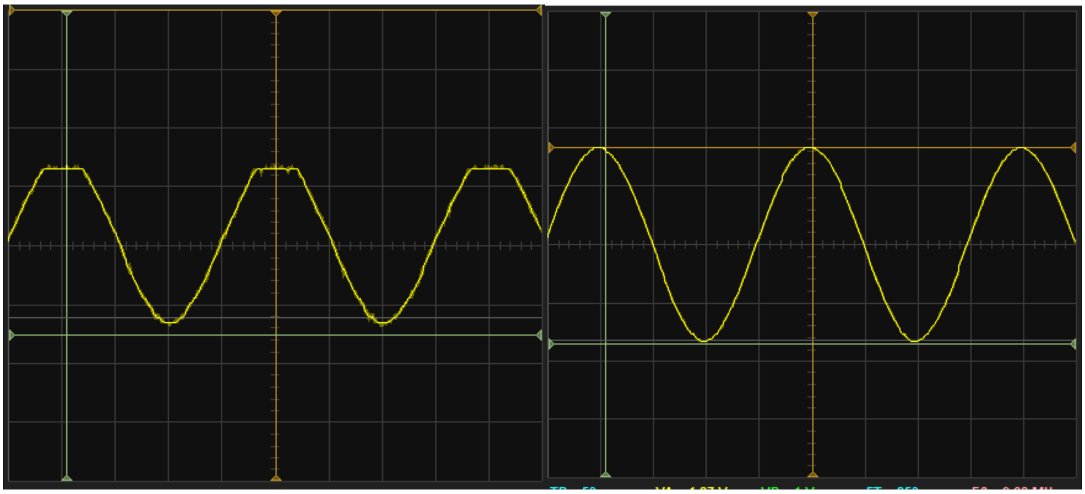
BitScope waveform generator with and without R_L

Load resistor R_L = 1000Ω

Voltage loaded $V_{pp.L}$= 2.2 V

Voltage unloaded $V_{pp.U}$= 3.35 V

From the equation $R_i = R_L \frac{V_{pp.U} - V_{pp.L}}{V_{pp.L}}$ we get: $1000 \frac{3.35-2.2}{2.2} = 523\ \text{m}\Omega$



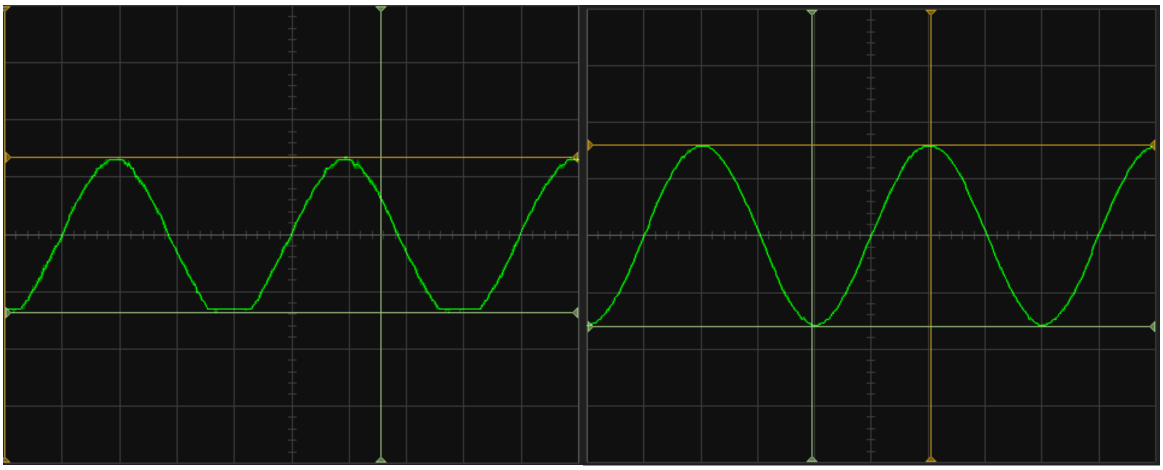
BitScope waveform generator and Op amp buffer with and without R_L

Load resistor R_L = 220Ω

Voltage loaded $V_{pp.L}$= 3.09 V

Voltage unloaded $V_{pp.U}$= 3.34 V

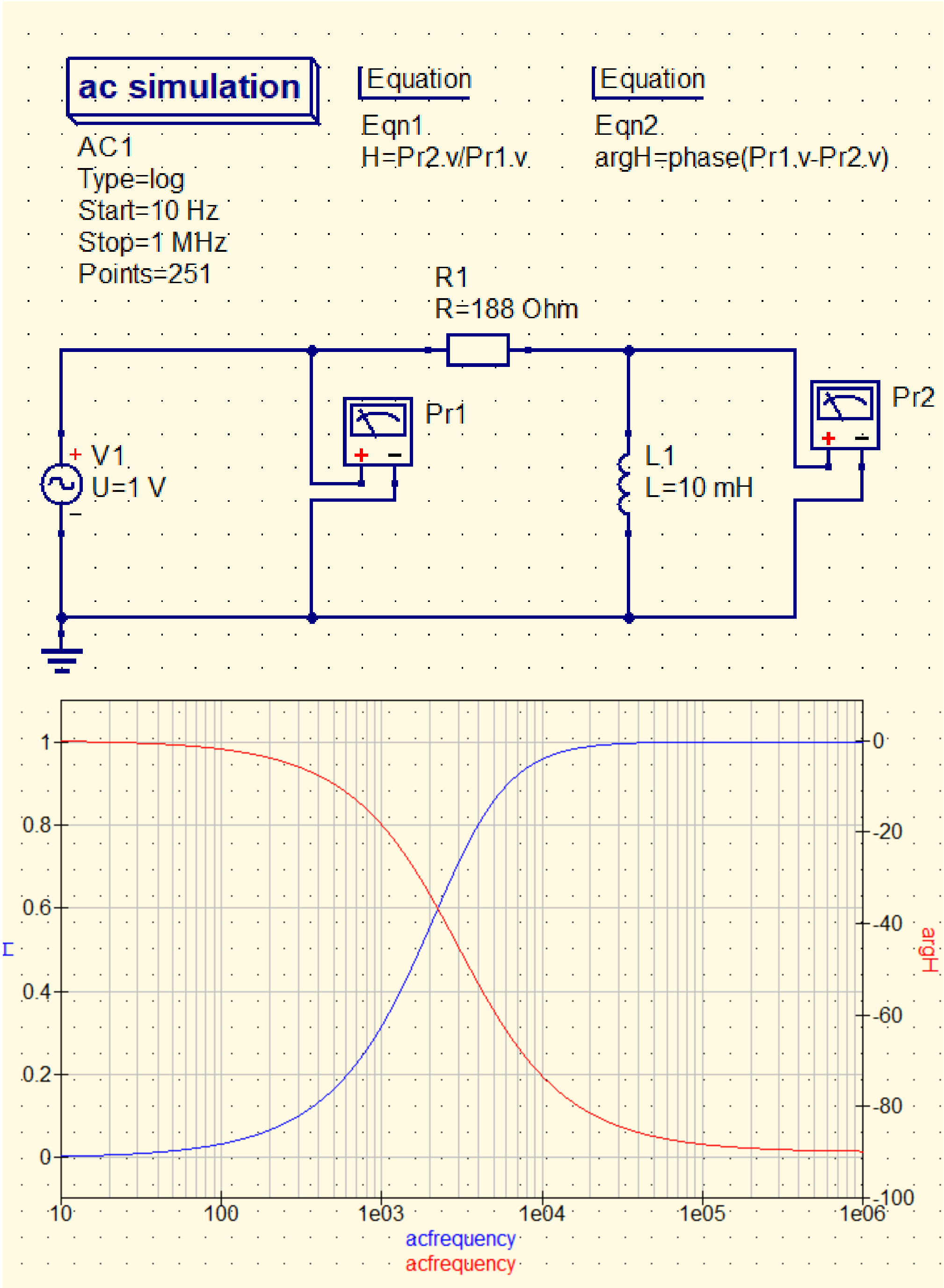
From the equation $R_i = R_L \frac{V_{pp.U} - V_{pp.L}}{V_{pp.L}}$ we get: $220 \frac{3.34-3.09}{3.09} = 17.8\ \Omega$



3.2 RL low pass and high pass

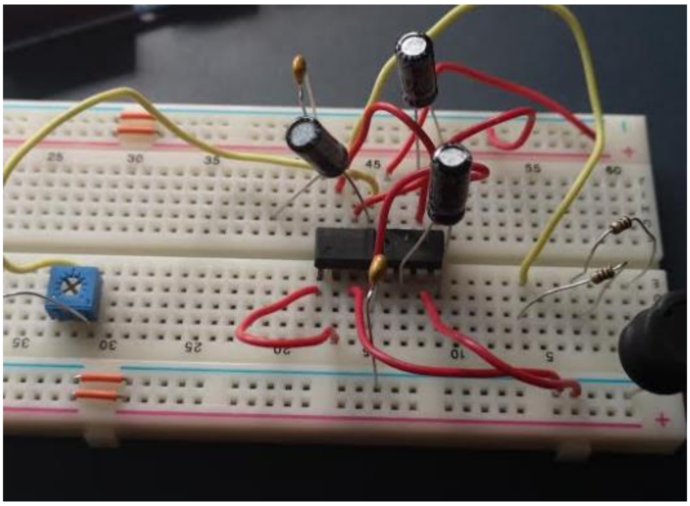
The cutoff frequency $f_c = \frac{1000}{2\pi 10 * 10^{-3}} = 15915 \text{ Hz} \approx 15.9 \text{ kHz}$

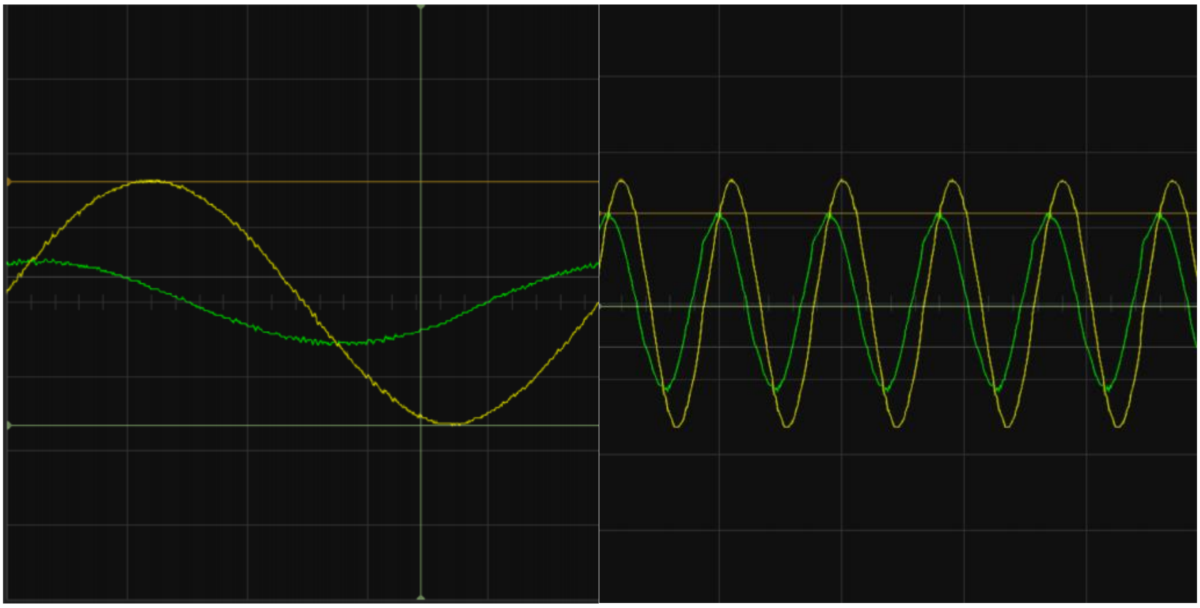
For March, $f_c = 3$ kHz which means that the resistance has to be 188Ω since R = $f_c * 2\pi L$



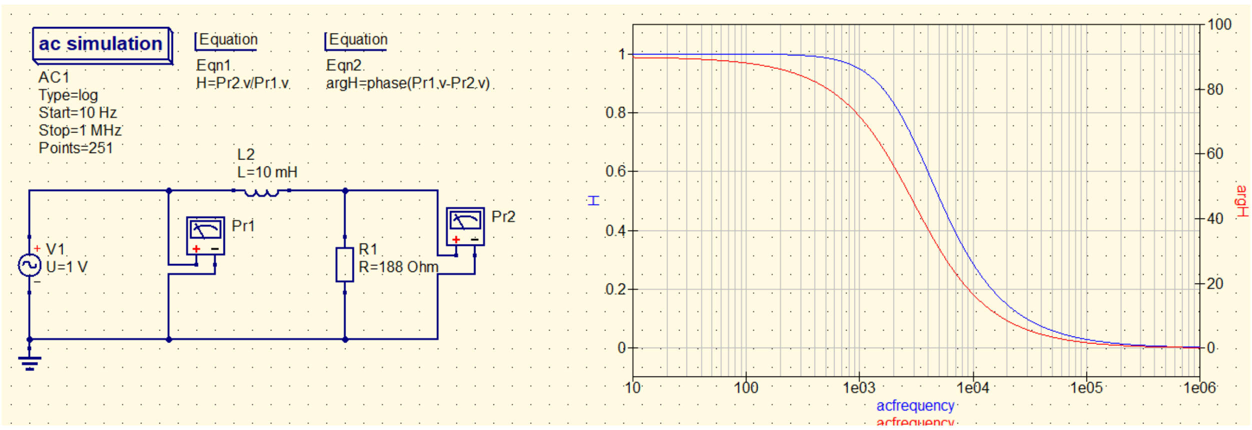
This would be a high pass filter.

Build with R = 200Ω and f_c = 3.2 kHz:





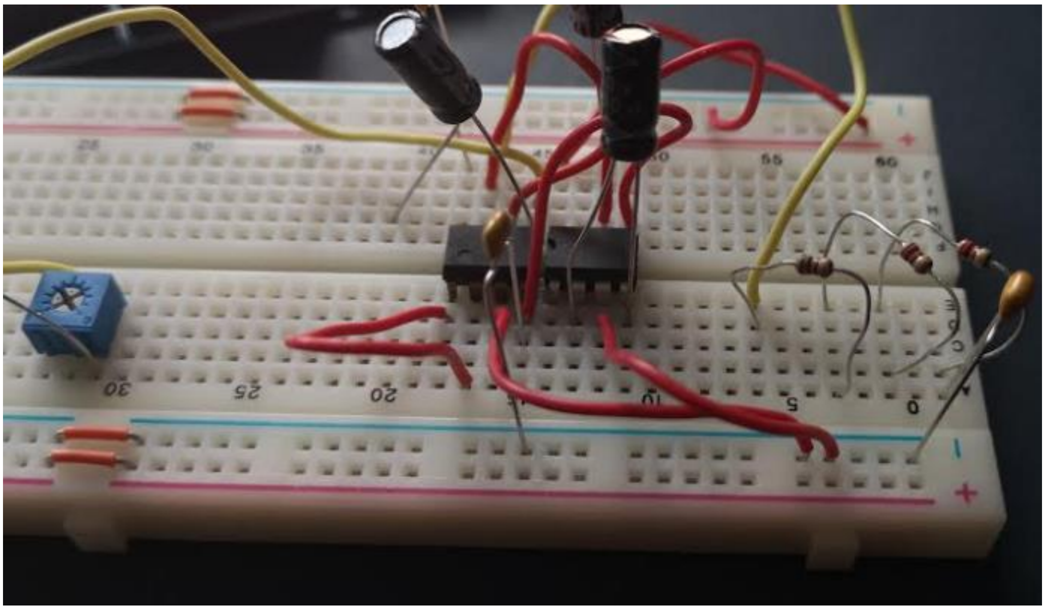
Reversed:

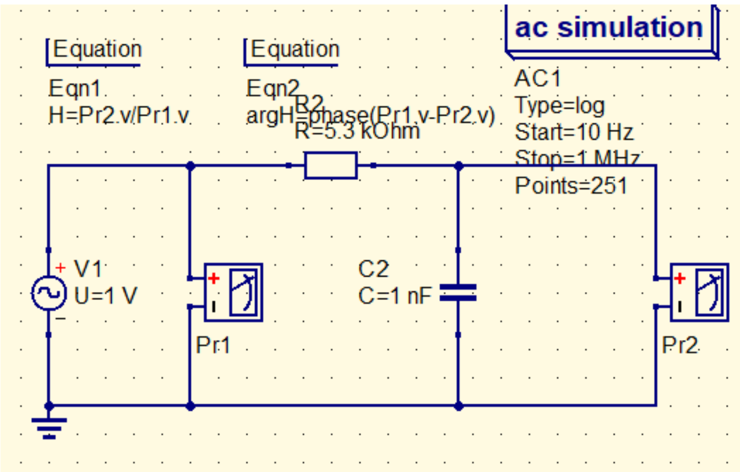

ac simulation
AC1
Type=log
Start=10 Hz
Stop=1 MHz
Points=251
Equation
Eqn1
H=Pr2.v/Pr1.v
Equation
Eqn2
argH=phase(Pr1.v-Pr2.v)
L2
L=10 mH
Pr1
Pr2
V1
U=1 V
R1
R=188 Ohm
H
argH
acfrequency
acfrequency

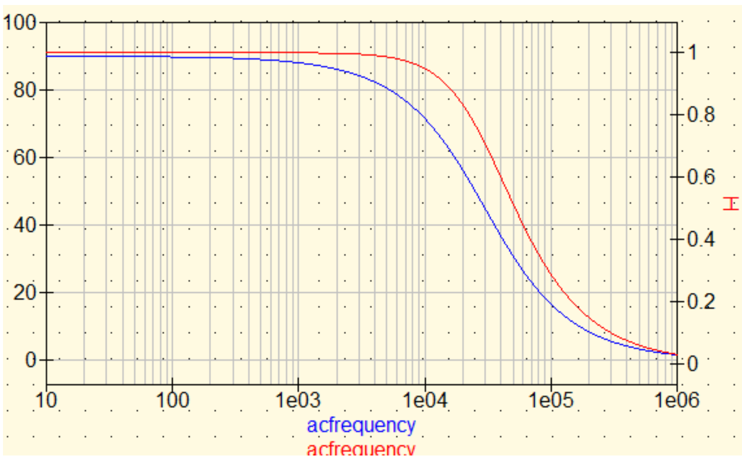
3.3 RC low pass and high pass

The cutoff frequency $f_c = \frac{1}{2\pi * 10000 * 10^{-9}} = 15.9$ kHz

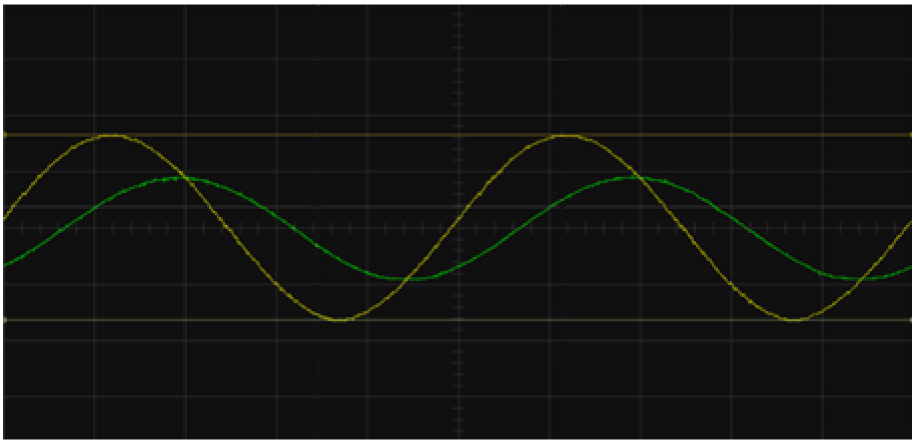
If $f_c = 30$ kHz, then R = 5.3 kΩ



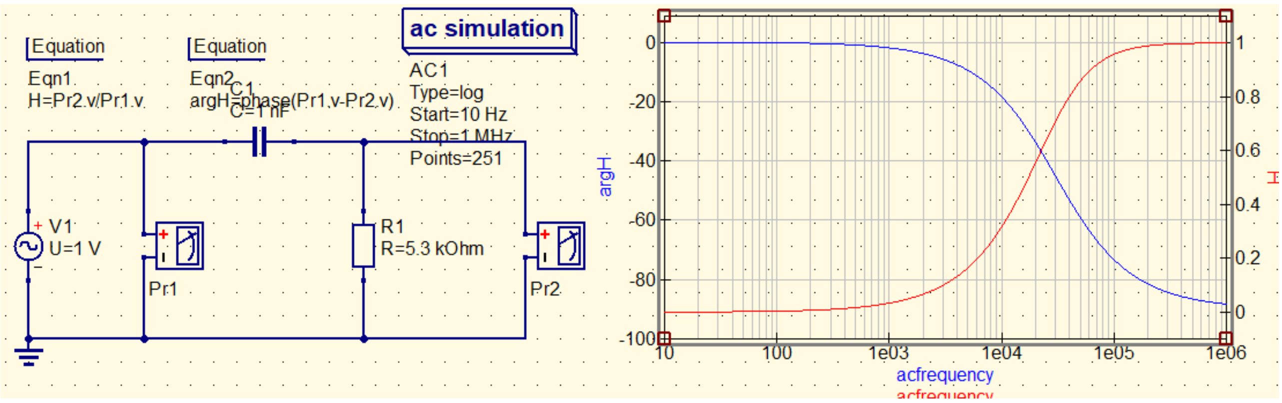




This would be a low pass filter.



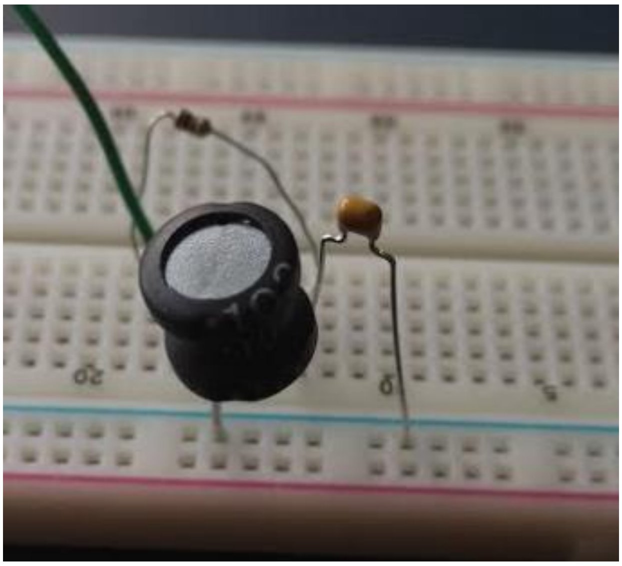
Reversed:

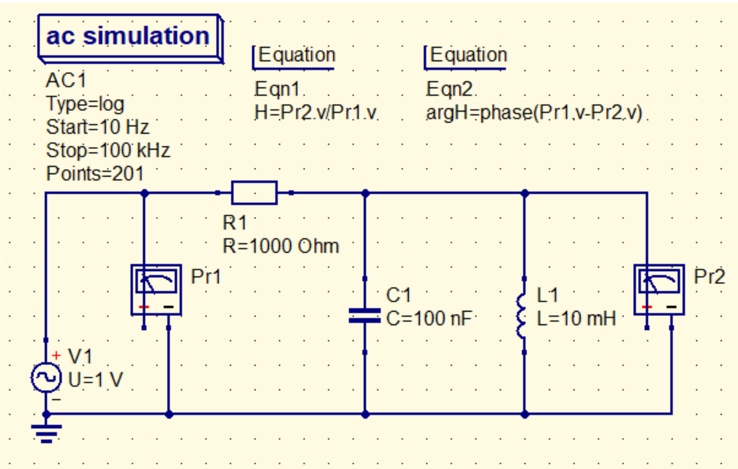

Equation
Eqn1
H=Pr2.v/Pr1.v
Equation
Eqn2
argH=phase(Pr1.v-Pr2.v)
C1
C=1 nF
ac simulation
AC1
Type=log
Start=10 Hz
Stop=1 MHz
Points=251
V1
U=1 V
Pr1
R1
R=5.3 kOhm
Pr2
argH
H
0
-20
-40
-60
-80
-100
1
0.8
0.6
0.4
0.2
0
10
100
1e03
1e04
1e05
1e06
acfrequency
acfrequency

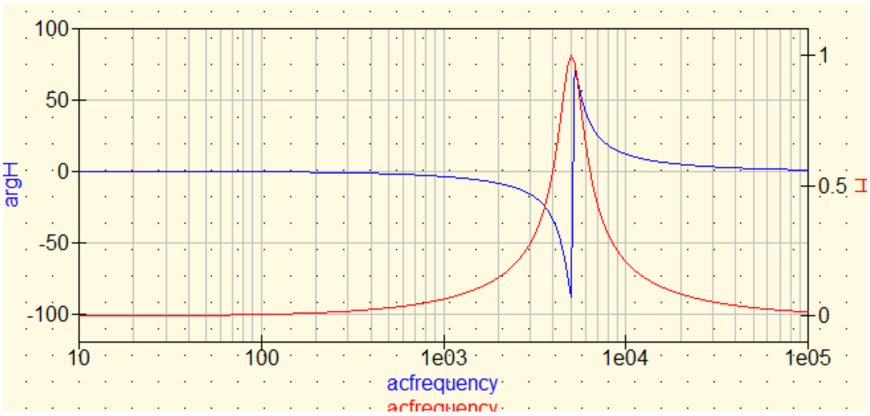
3.4 RLC band pass filter

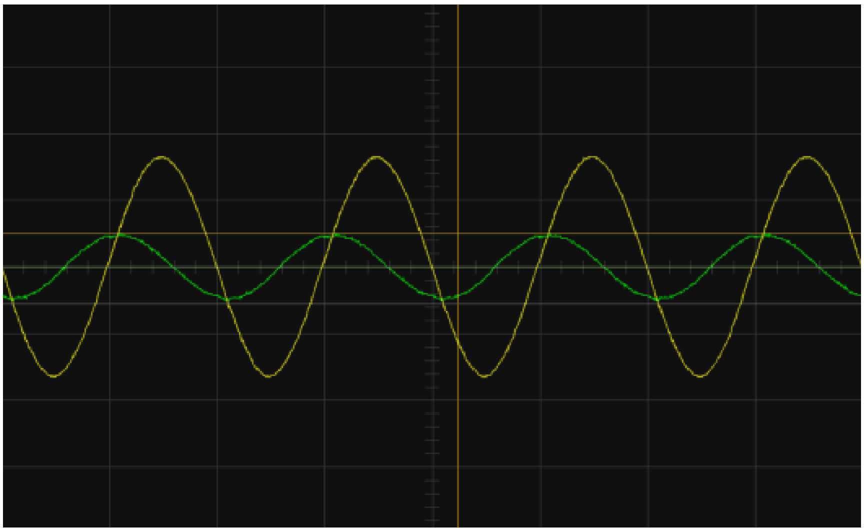
The cutoff frequency f_c based on L1 and C1 equals:

$$f_c = \frac{1}{2\pi * \sqrt{100 * 10^{-9} * 10 * 10^{-3}}} = 5000 \text{ Hz}$$



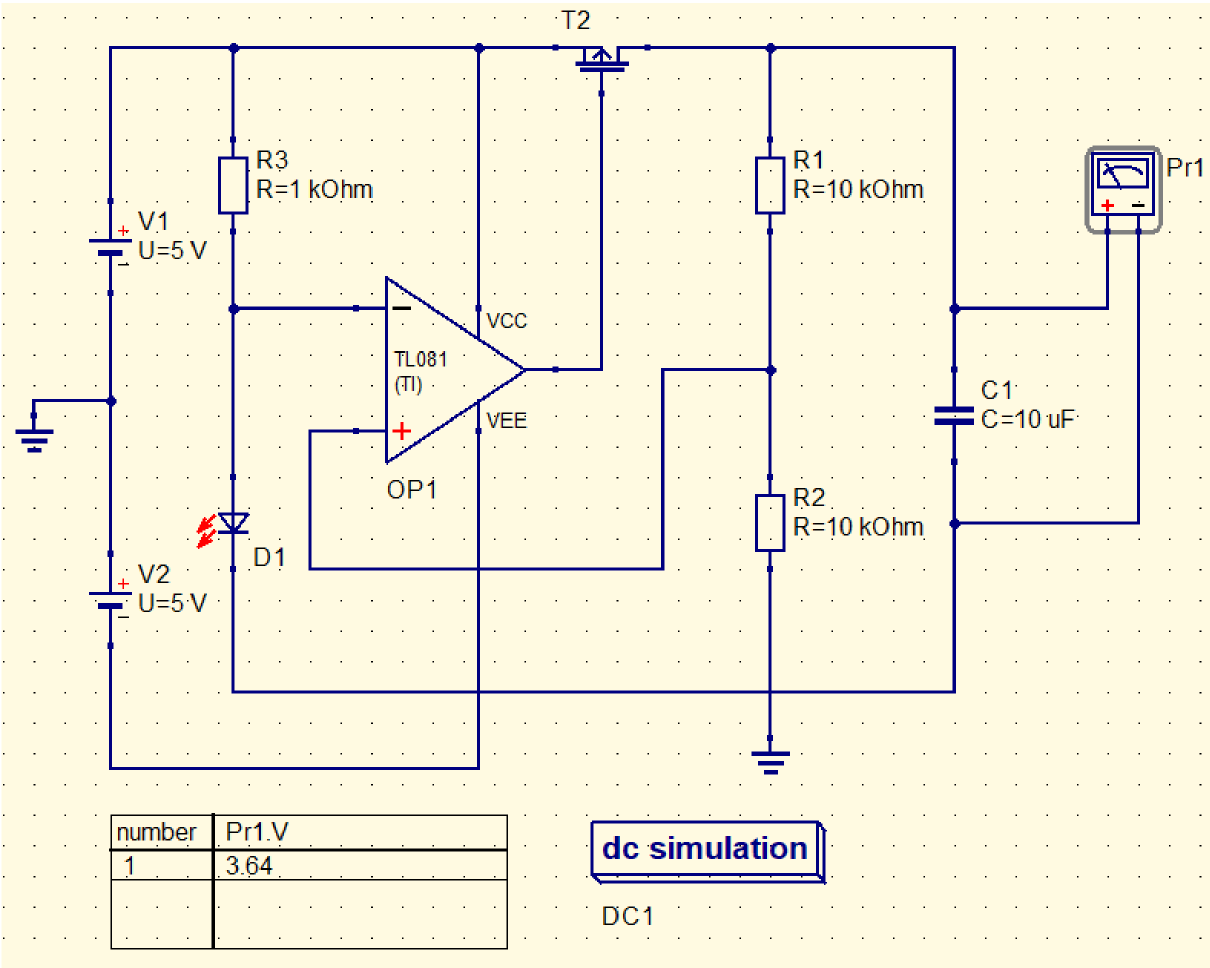






The measured bandwidth of the band pass filter is 1ms.

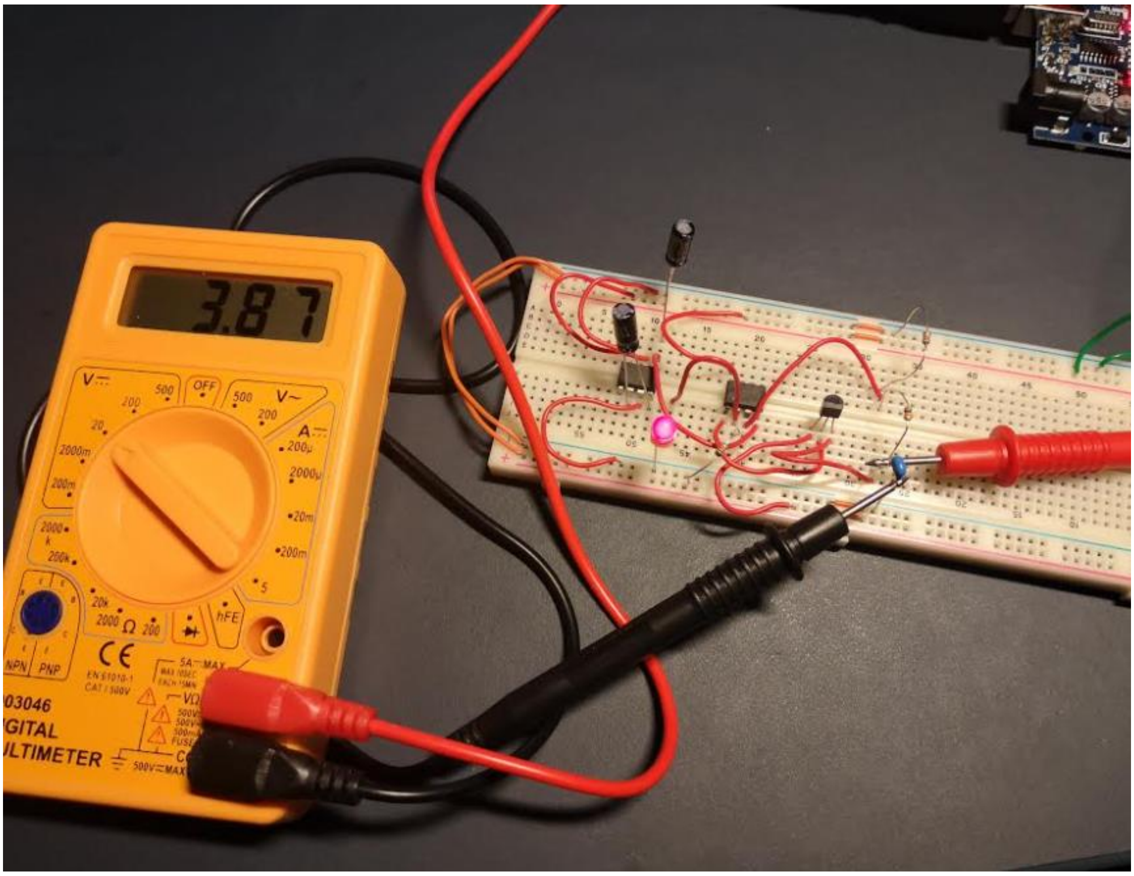
Lab 4.3 – Voltage Regulator



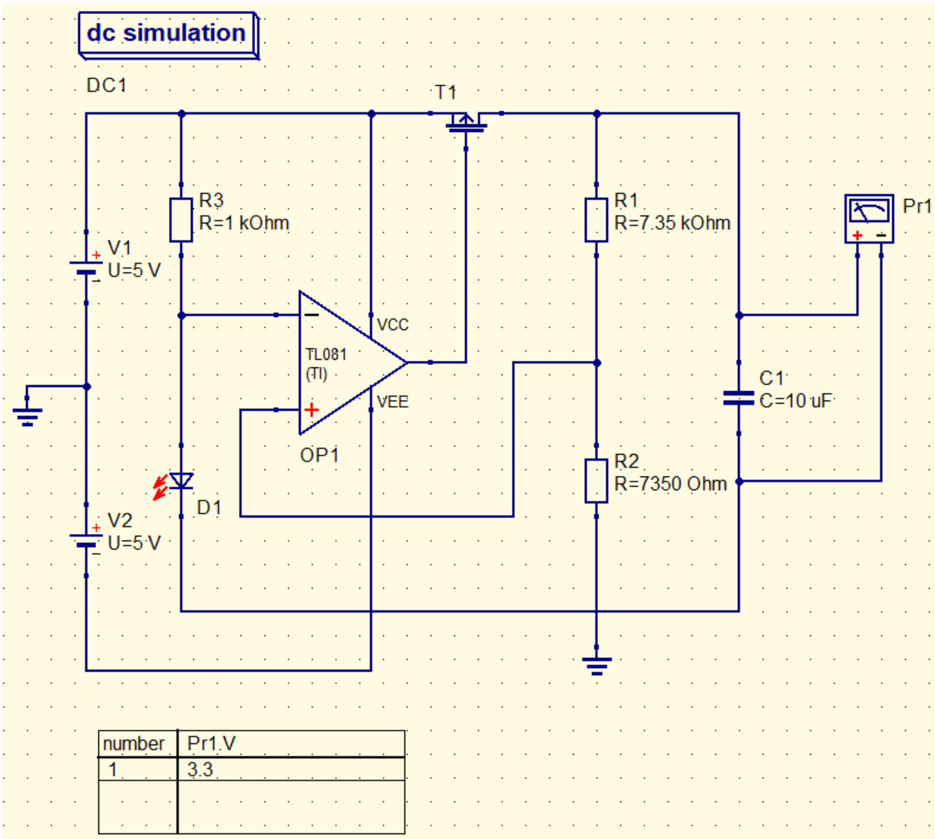
$V_{out} = 3.64$

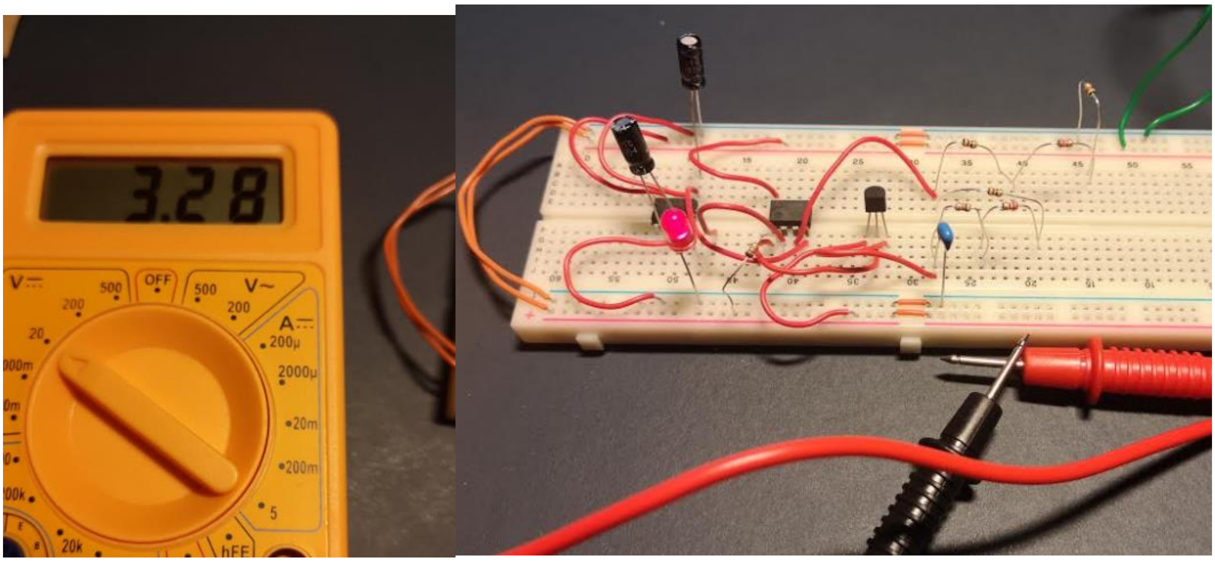
A voltage regulator can regulate voltage so that a constant output voltage V_{out} is generated even if there are changes in the load conditions or input voltage. In this lab we are using an Op Amp, a PMOSFET, resistors and an LED to create the voltage regulator. The resistors R1 and R2 create a voltage divider the goes into the Op Amp for a suitable voltage output which means that the Op Amp can take both voltage inputs and equal them for a suitable voltage output. After this, the Op Amp, through negative feedback, can supply the voltage into the PMOSFET so that the negative output voltage aligns with its positive input voltage (also known as the reference voltage). This means that the feedback loop will adjust the voltage to a constant value regardless of changes in load conditions or input voltages.

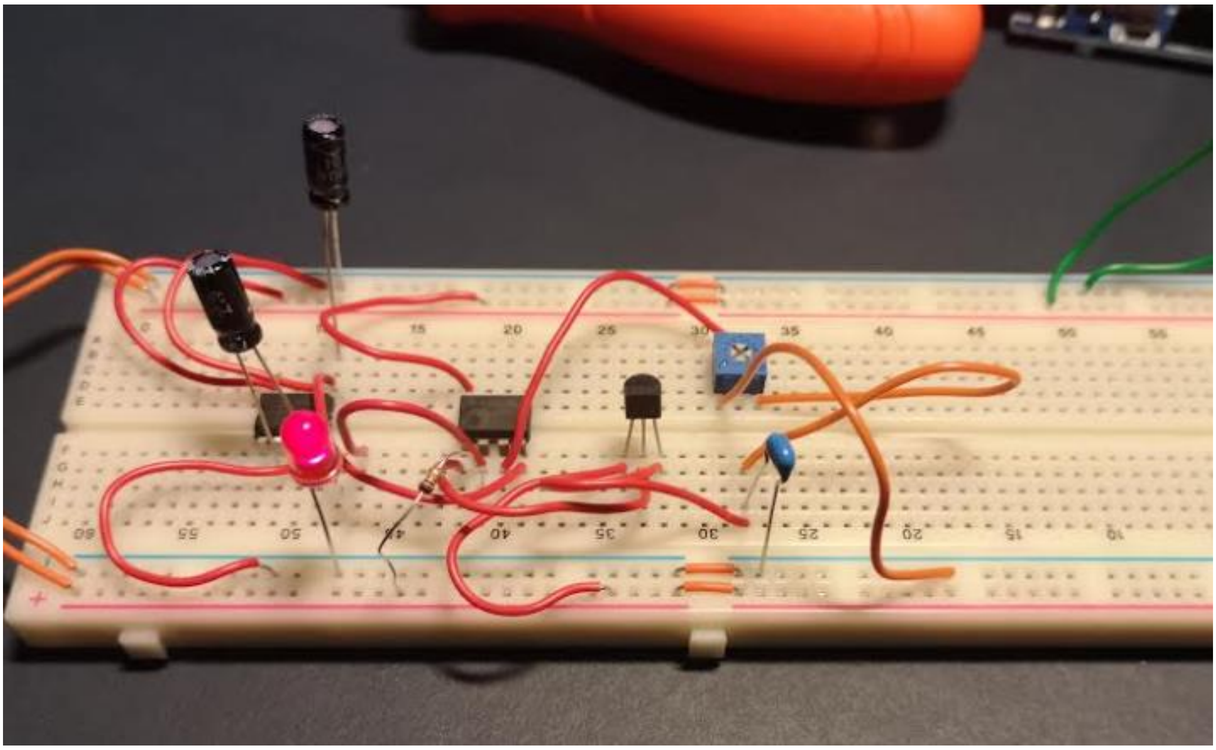
There is also an equation for this voltage which is $V_{out} = V_z\left(\frac{R1}{R2} + 1\right)$



As proven on QUCS, if R1 and R2 are changed from 10 kΩ to 7.35 kΩ the resulting output voltage will be $V_{out} \approx 3.3\ V$ instead.







The voltage range that was measured using the 10 kΩ trimmer was between 1.92 V – 5.07 V.