Physics 3700 Lab 3

In the first part of this lab you will be putting together a few circuits and recording measurements. You can do this on paper and keep a log of what you're doing. It should be clear what you're doing and why you're doing it. Hand in your data and log with your lab. The instructions for the first part are not very detailed to give you some space to plan things on your own.

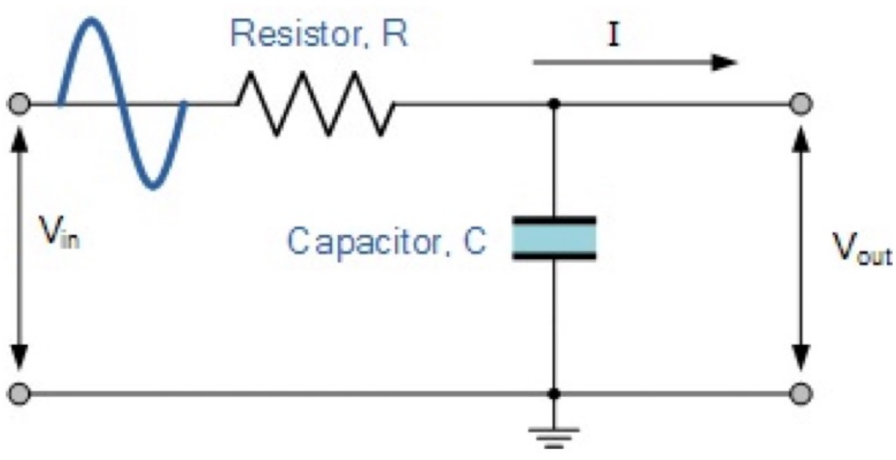
The second part of the lab will be completed in a Jupyter notebook (`P3700_Lab3_lastname.ipynb`). All requested plots need to be fully labelled. In addition to functional code, please fully explain what you're doing and declare variables either by commenting your code or using markdown cells. Submit it to our course Moodle site.

Part I Filtering with RC circuits. Here you will design 4 different filters using resistors and capacitors: a low-pass filter, a 2-stage cascade low-pass filter, a high-pass filter and a band-pass filter. The circuit diagrams are from www.electronics-tutorials.ws. The cutoff frequency is defined to be the frequency at which the signal is reduced to 70.7% and for RC filters is given by

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

1. RC Low-Pass Filter.

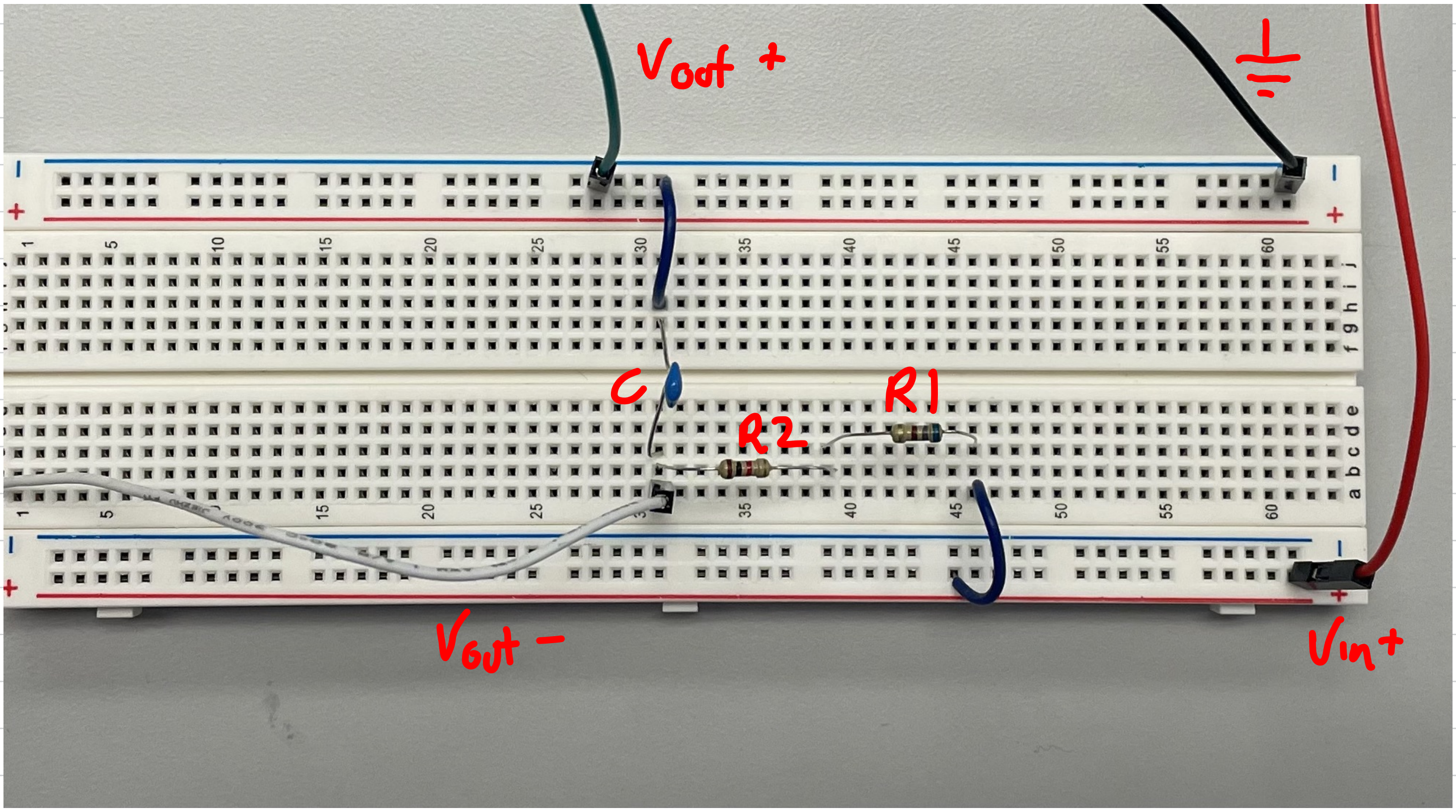
   (a) Using the signal generator as input and the oscilloscope to read the output put together the following circuit on a breadboard. This is your low-pass filter. Use a 47nF capacitor and a resistor that will give you a cutoff frequency of roughly 2000 Hz.



Calculate the resistance needed:

$$R = \frac{1}{2\pi f_c C} = \frac{1}{2\pi(2000)(47\times10^{-9})} = 1693\ \Omega$$

RC Low-Pass Filter Circuit Layout



$R_1 = 680\,\Omega$

$R_2 = 1000\,\Omega$

$C = 47\,nF$

$R = R_1 + R_2 = 680\,\Omega + 1000\,\Omega = 1680\,\Omega$

Recalcute for f_c:

$$f_c = \frac{1}{2\pi(1680\,\Omega)(47\times10^{-9}\,F)} = 2016\ Hz$$

(b) Before using this to filter, test the response of the filter. With a meter, measure and record the resistance and the capacitance. Calculate the expected cutoff frequency of your filter. If the internal resistance is not negligible include it in calculating your cutoff frequency.

$R = 1.6733\ k\Omega \qquad C = 46.7\ \mu F$

$$f_c = \frac{1}{(2\pi)(1.6733\times10^3\ \Omega)(46.7\times10^{-9}\ F)} = 2034\ Hz$$

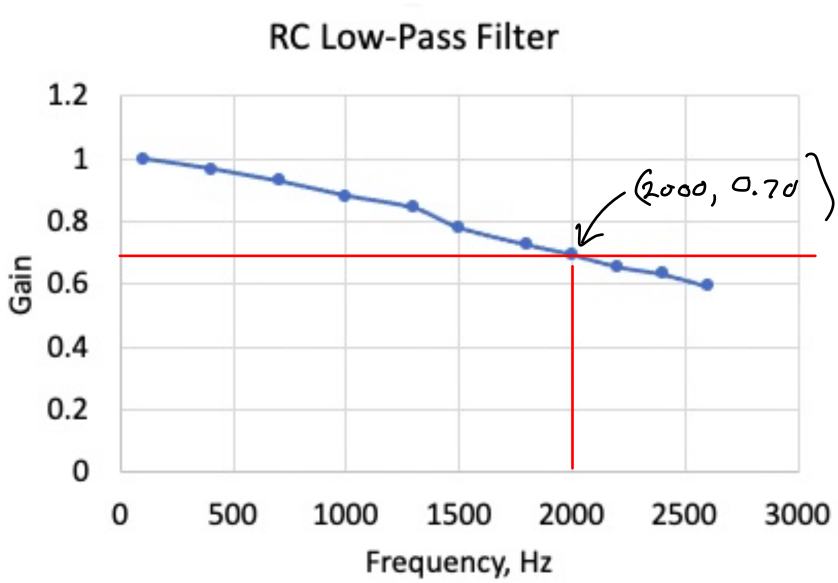
Internal Resistance of the oscilloscope
Internal Resistance of the function generator } negligible.

(c) Your input should be a sine wave with an amplitude of 5.0V. You will need to make a gain versus frequency plot. Gain is your output voltage divided by your input voltage. You should decide what frequencies to measure the output voltage at. Using your plot, find the cutoff frequency and check that it matches with the value from the previous question.

$Gain = \frac{V_{out}}{V_{in}}$ Looking for the Gain = 70.7%

$V_{out} = V_{in}(Gain) = (5.0V)(0.707) = 3.535\ V$ target

frequency (Hz)	Vout (V)
100	5.12
400	4.96
700	4.76
1000	4.52
1300	4.32
1500	4.00
1800	3.72
2000	3.56
2200	3.36
2400	3.24
2600	3.04



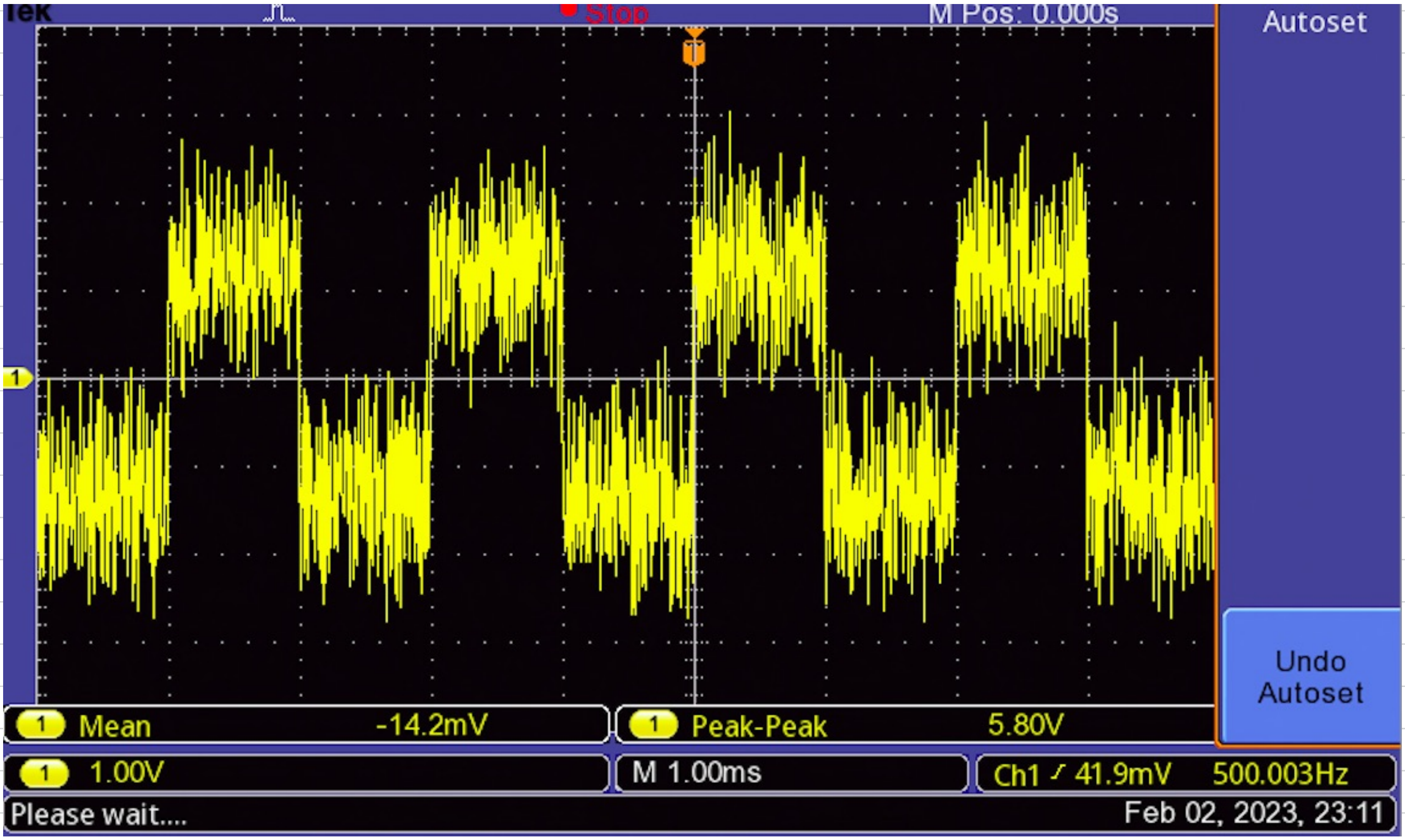
from the graph, signal reaches 70.7% at 2000 Hz which is approximately what the Low filter was set at.

(d) Now generate a noisy square wave with a frequency of 500 Hz. Plot the input and the output after your filter.

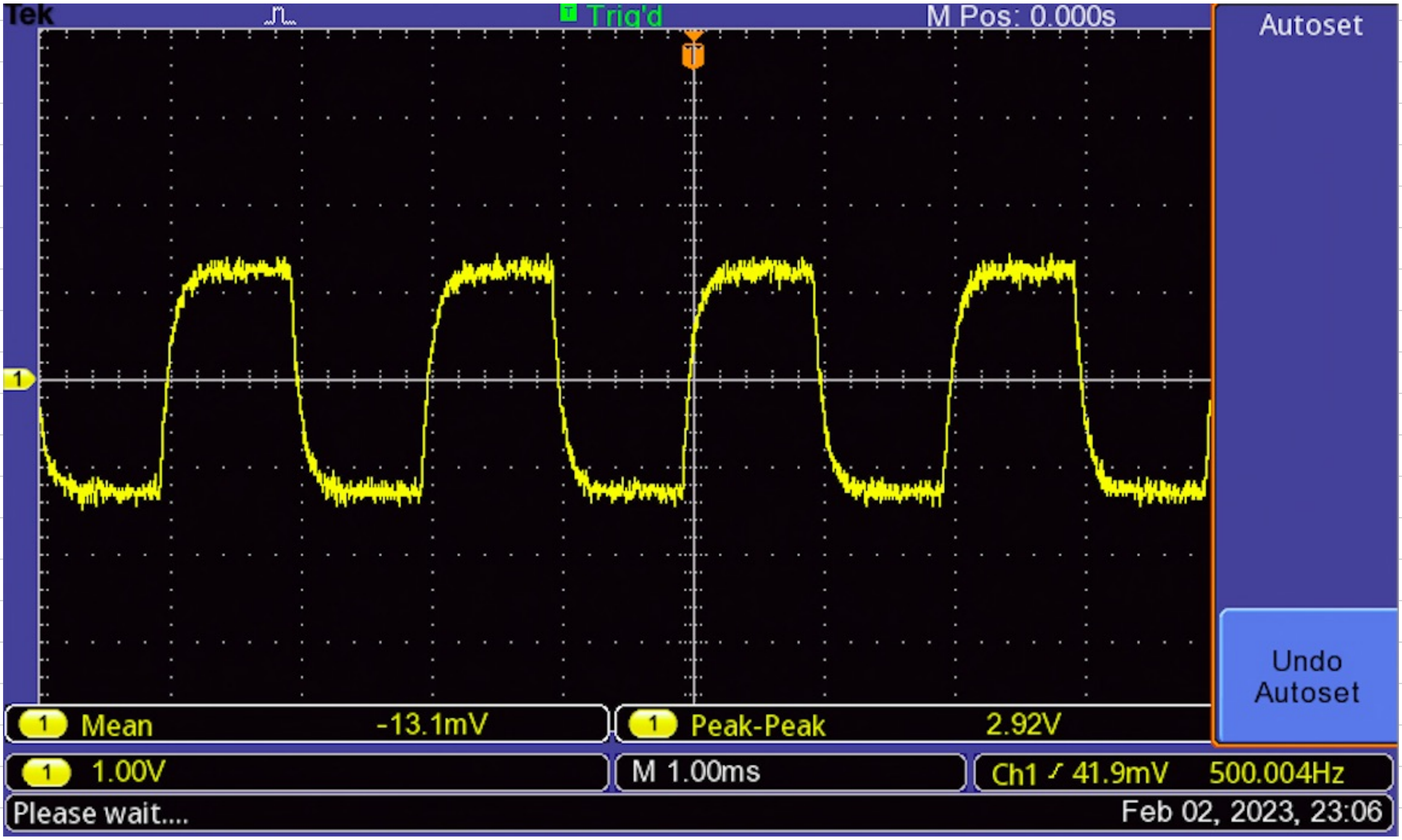
Function generator

Output 1 : Square wave 500 Hz
Output 2 : Noise
Input of filter

Signal Before filter

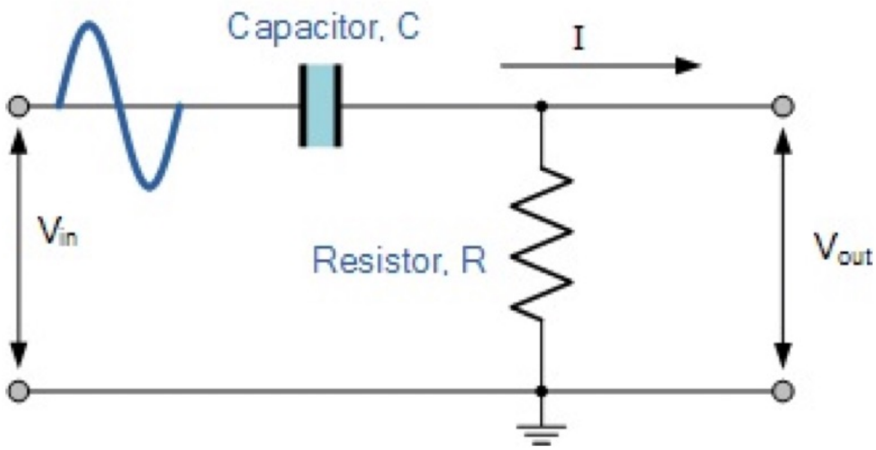


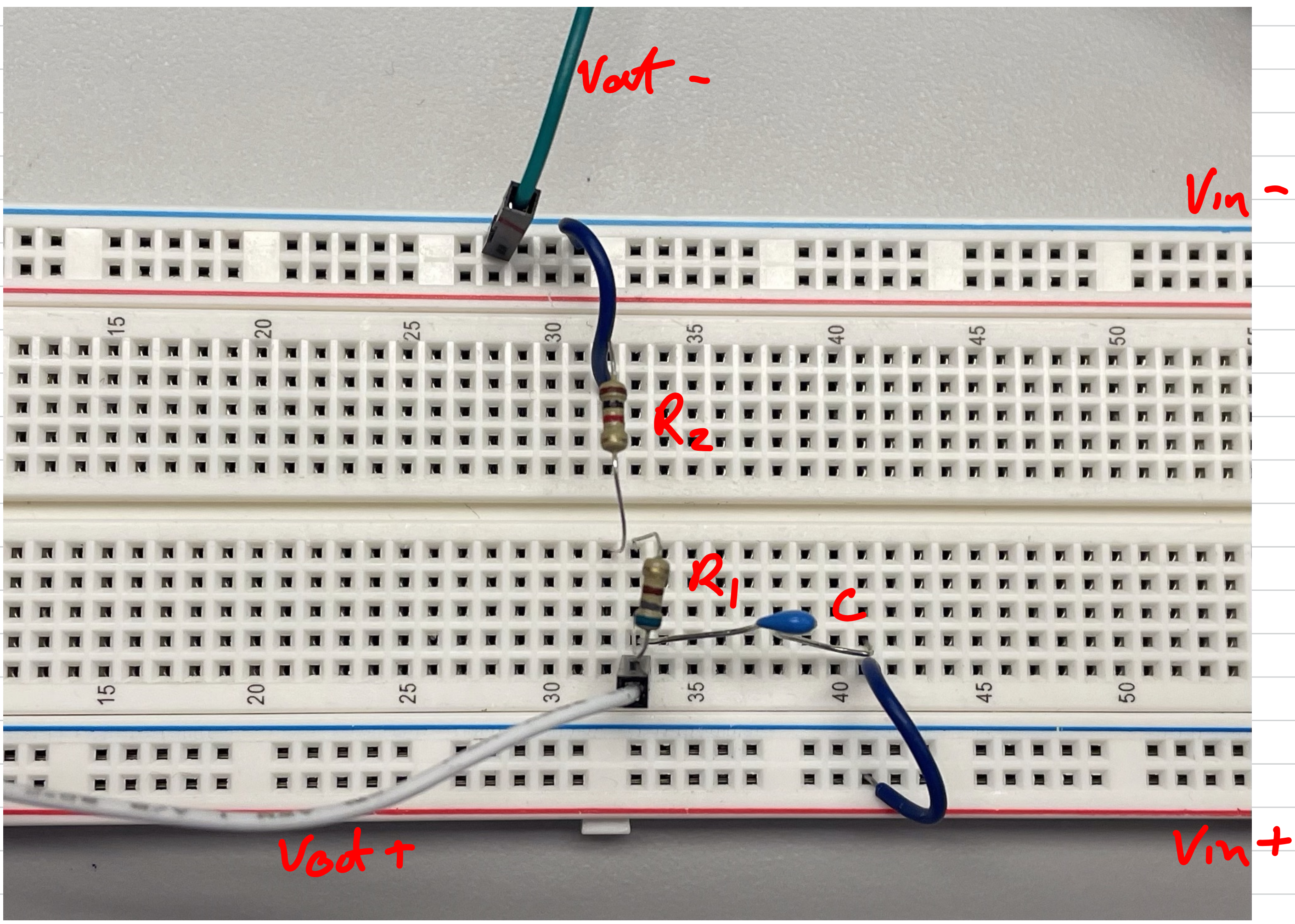
Signal Output After RC Low Pass Filter



2. RC High-Pass Filter.

(a) Convert your low-pass filter from the previous question into a high-pass filter as shown in the figure below. Use the same components.





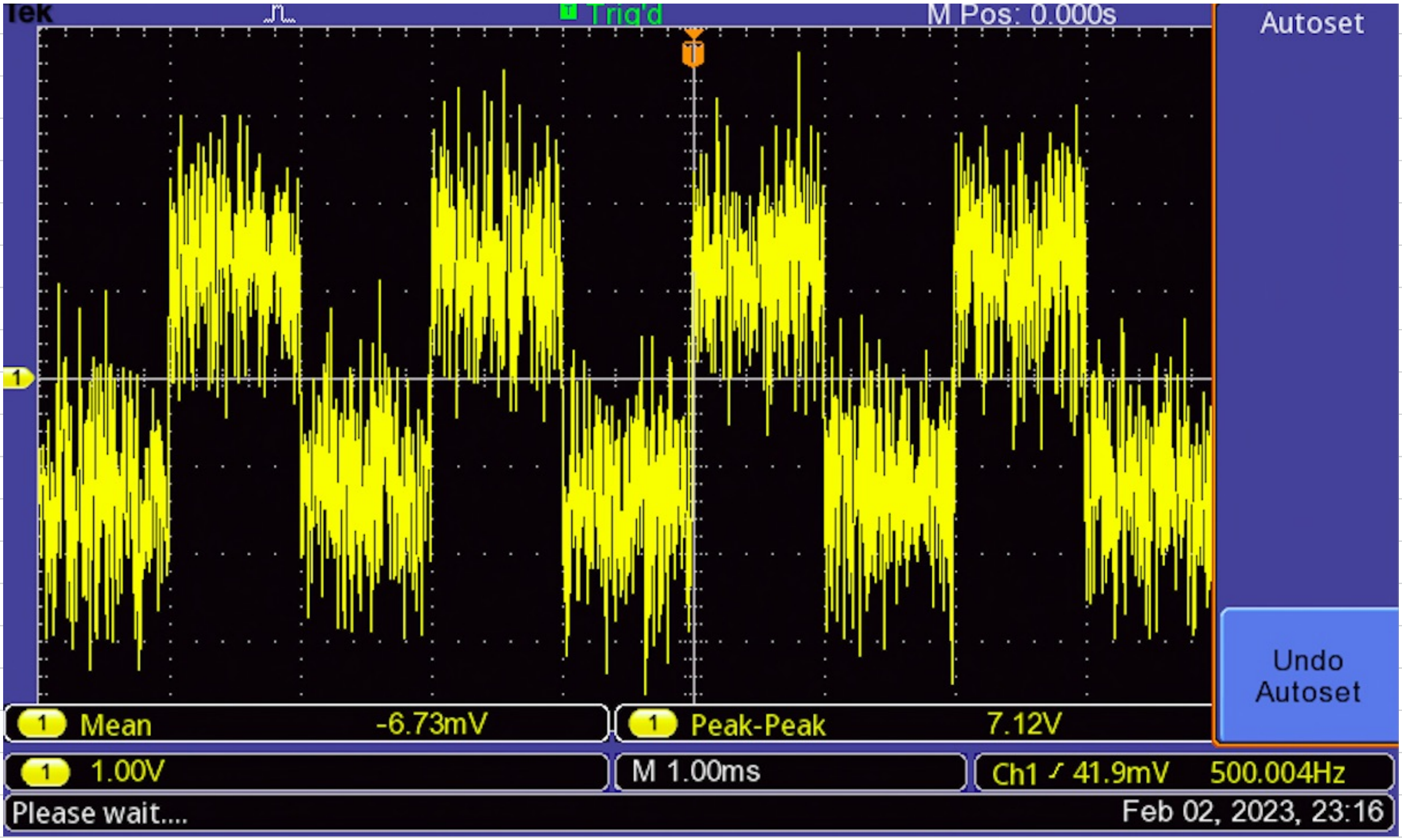
(b) Now generate a noisy square wave with a frequency of 500 Hz. Plot the input and the output after your filter.

Function generator

Output 1 : Square wave 500 Hz
Output 2 : Noise

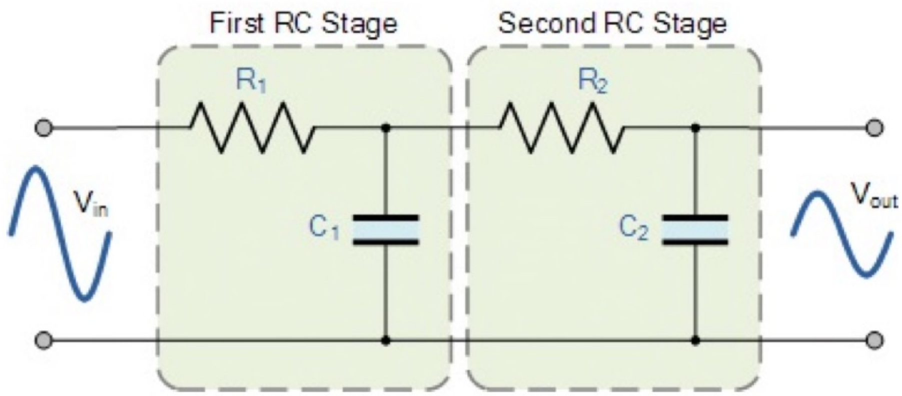
Input of filter

Output of RC High Pass Filter



3. RC 2-stage Low-Pass Filter.

(a) Now put together a 2-stage cascade low-pass filter with $R_2 \approx 10R_1$ and $C_2 \approx 0.1C_1$. The circuit diagram is as follows



Your new calculated cutoff frequency is

$$f_c = \frac{1}{2\pi\sqrt{R_1 C_1 R_2 C_2}}$$

An additional effect must be accounted for with the increased slope of the roll-off so the actual cutoff frequency is

$$f_c(\text{actual}) = f_c\sqrt{2^{(1/2)} - 1}$$

$C_1 = 46.7 \text{ nF}$ $\quad R_1 = 0.9991 \text{ k}\Omega$

$C_2 = 4.07 \text{ nF}$ $\quad R_2 = 9.900 \text{ k}\Omega$

$$f_c = \frac{1}{2\pi\sqrt{R_1 C_1 R_2 C_2}}$$

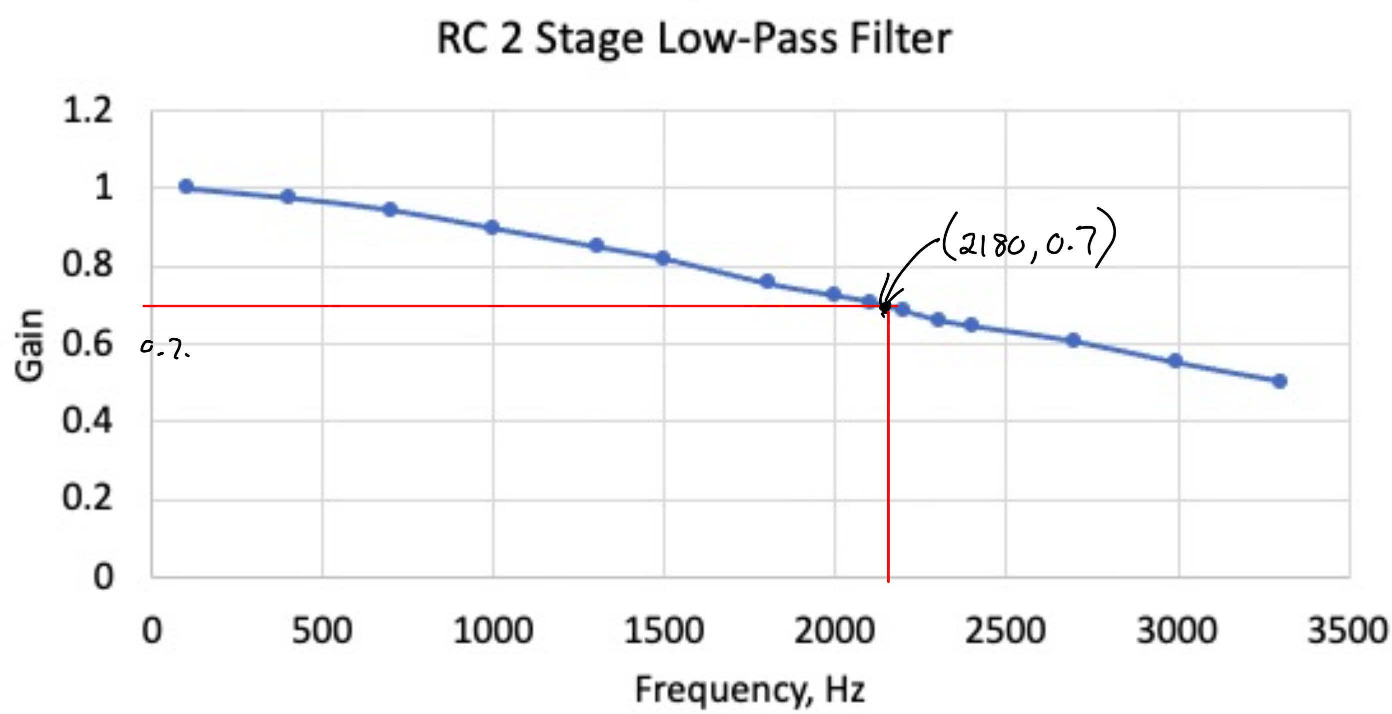
$$= \frac{1}{2\pi\sqrt{(999.1\ \Omega)(46.7\times10^{-9}\ F)(9900\ \Omega)(4.07\times10^{-9}\ F)}}$$

$$= 3670 \text{ Hz}$$

$$f_c(\text{actual}) = 3670\sqrt{2^{1/2} - 1} = 2362 \text{ Hz}$$

(b) Produce a gain vs frequency plot for your filter.

frequency (Hz)	Vout (V)
100	5.08
400	4.96
700	4.80
1000	4.56
1300	4.32
1500	4.16
1800	3.84
2020	3.68
2100	3.60
2200	3.48
2300	3.36
2400	3.28
2700	3.08
3000	2.80
3300	2.56



70% of the ~~the~~ gain was reached at around 2180 Hz

$\left(\frac{2362-2180}{2362}\right)\times 100\% = 7.72\%$ so the filter achieved the target frequency of 2362 within 10% error.

4. RC Band-Pass Filter. Nothing to do here, just look at this picture of how you would put together an RC band-pass filter