EE 111L Lab 2

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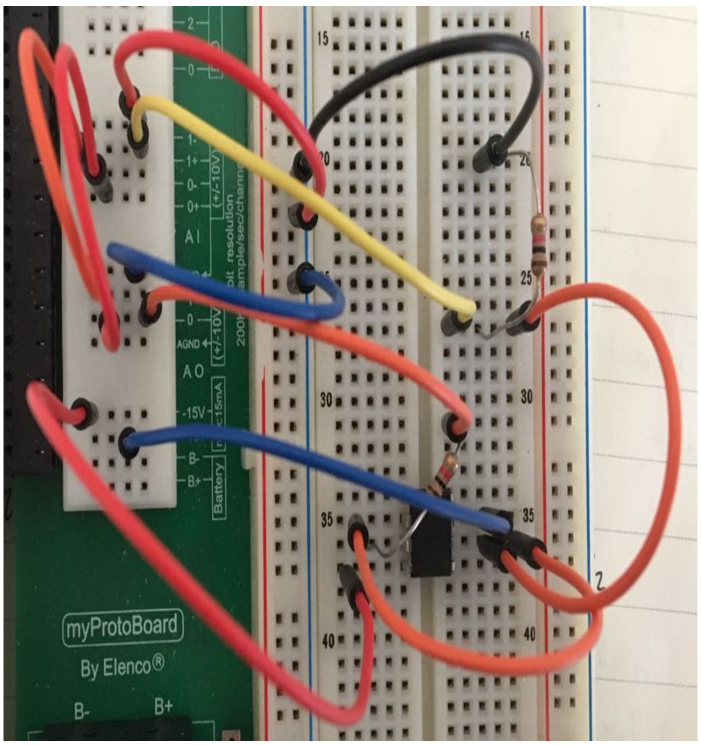
1.1 objective

Build a unity gain buffer and examine its effect on the load voltage.

1.2 theory

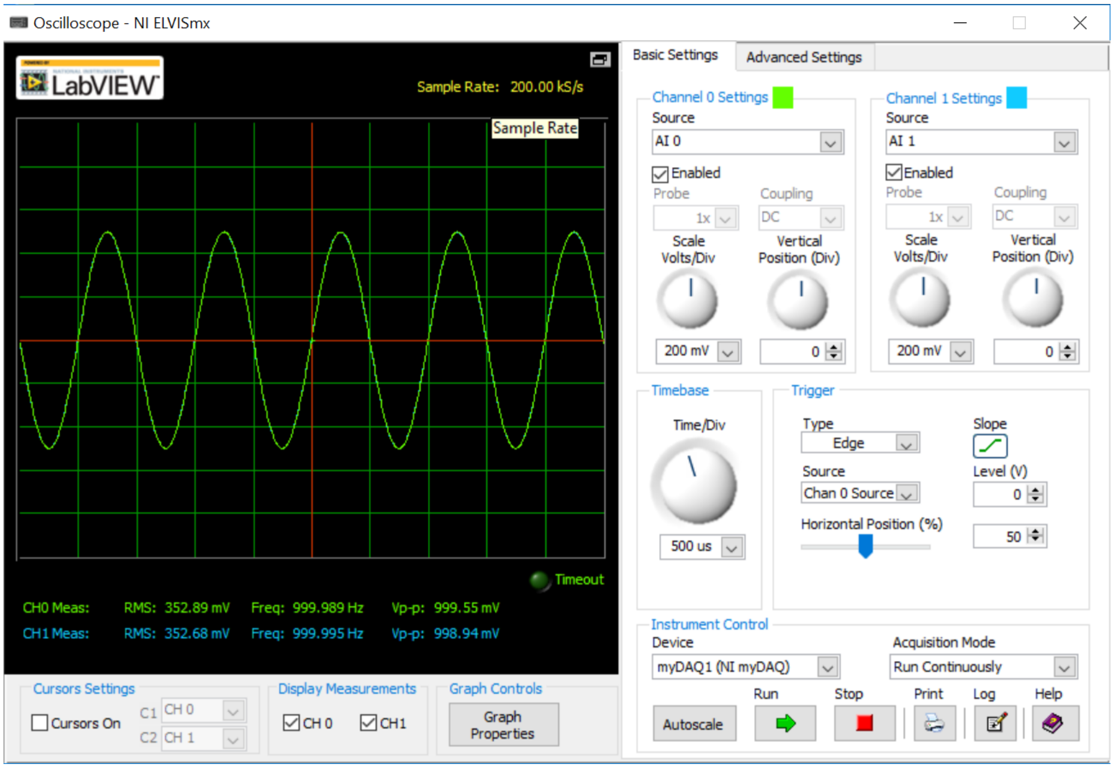
Since current $I_{\text{in}-}$ is almost 0, the voltage across source resistor is almost 0, and thus $V_{\text{in}+} = V_{\text{S}} = V_{\text{in}-} = V_{\text{L}}$. Thus with a unit gain buffer, the voltage across the load resistor should be the same as the supplied voltage $V_{\text{S}}$ .

1.3 Procedure



We connect the components as shown in the picture above, and measure the voltage across the load resistor.

1.4 Data




As we can see, the voltage across the load resistor is indeed the same as the source voltage. Source voltage is 999.55mV and voltage across load resistor is 998.94mV.

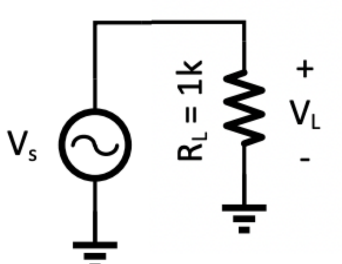
1.5 error analysis

The error is (998.94-999.55)/999.55=0.0006. The error is very small, and we can say that voltage across load is almost the same as source voltage.

1.6 Discussion

a. They do not have same transfer function. The circuit without unit gain buffer has a transfer function $\frac{V_L}{V_S} = 0.5$. While the circuit with a unit gain buffer has a transfer function $\frac{V_L}{V_S} = 1$.

b.




Above is the equivalent circuit. The unity gain buffer helps eliminate the effect of source resistance, so it is as if the source voltage is directly connected to the load resistance.

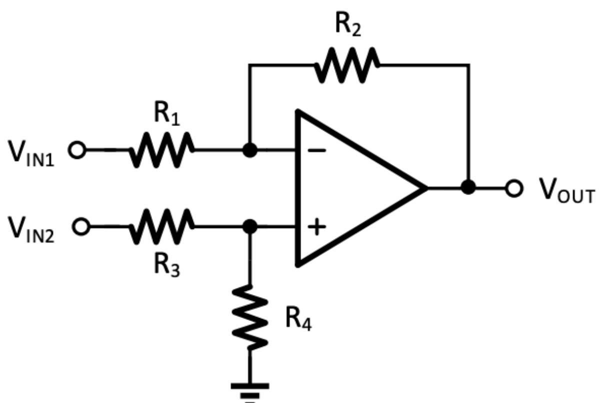
1.7 conclusion

We have verified that a unity gain buffer can eliminate the effect of source resistance, and make source voltage applied across the load resistance.

2.1 objective

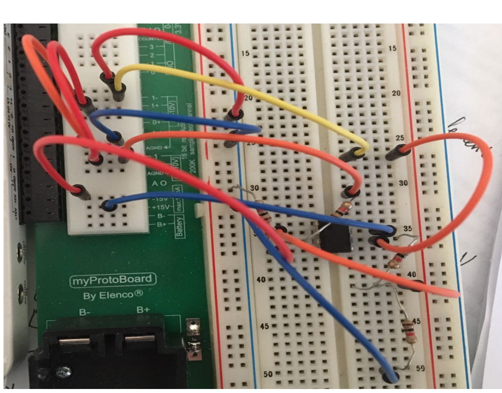
Explore the transfer functions of inverting amplifier and non-inverting amplifier.

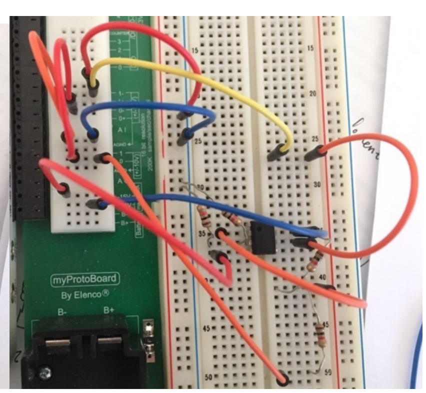
2.2 Theory

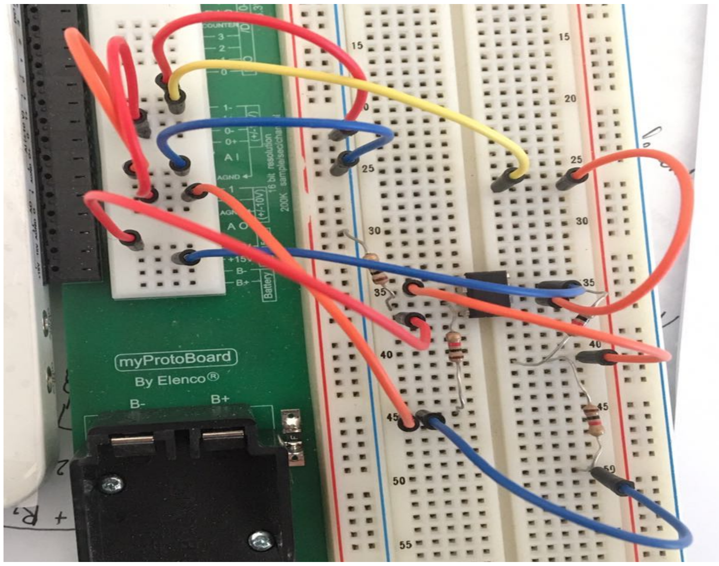



Let the current across $R_1$ be $I_1$, let the current across $R_2$ be $I_2$, let the current across $R_3$ be $I_3$, And let the current across $R_4$ be $I_4$. Now suppose $V_{in1}$ is disabled and $V_{in2}$ is supplied. From KCL, we get $I_1$ =$I_2$, $I_3$ = -$I_4$. And from KVLs, we get $V_{out}$=-($R_1 + R_2$ ) $I_1$, $I_3 = \frac{R_1}{R_4} I_1$, and $V_{in2}$=-($R_1 + \frac{R_3\, R_1}{R_4}$) $I_1$. From these equations, we get $\frac{V_{out}}{V_{in2}} = \frac{R_4}{R_3+R_4}(1+\frac{R_2}{R_1})$. Similarly, if $V_{in2}$ is disabled and $V_{in1}$ is supplied, we get $\frac{V_{out}}{V_{in1}} = -\frac{R_2}{R_1}$. By rules of superposition, we get $V_{out} = \frac{R_4}{R_3+R_4}(1+\frac{R_2}{R_1})\, V_{in2} - \frac{R_2}{R_1} V_{in1}$.

2.3 procedure

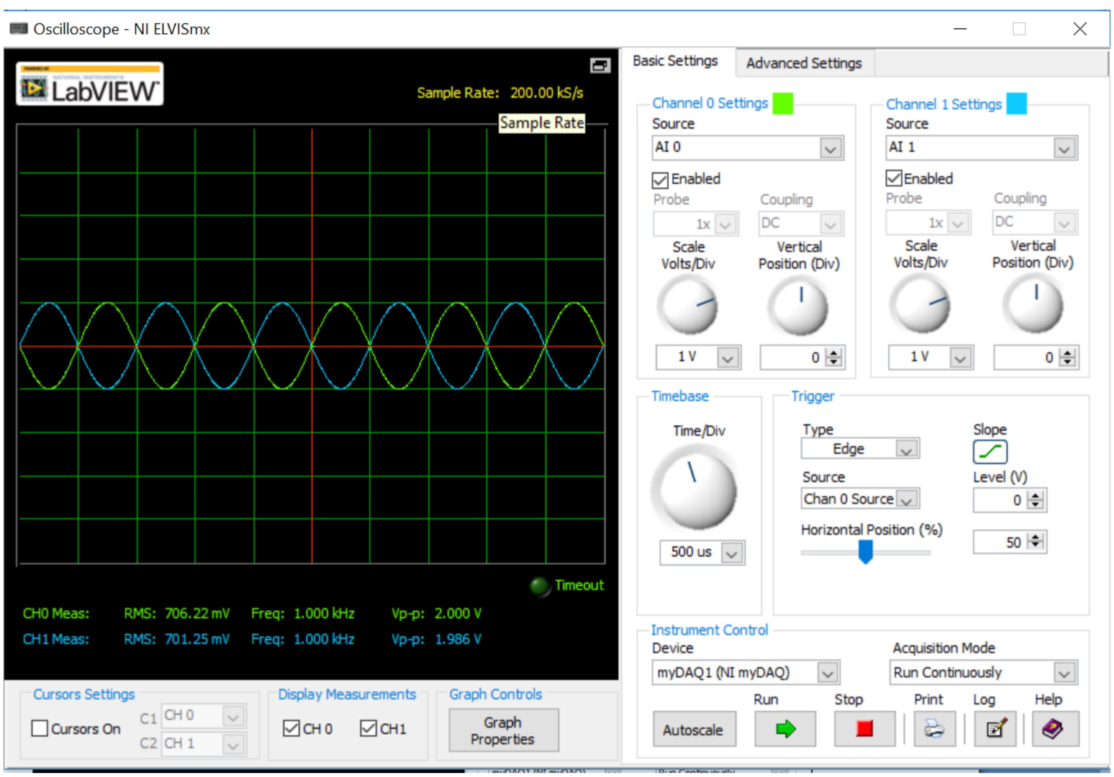




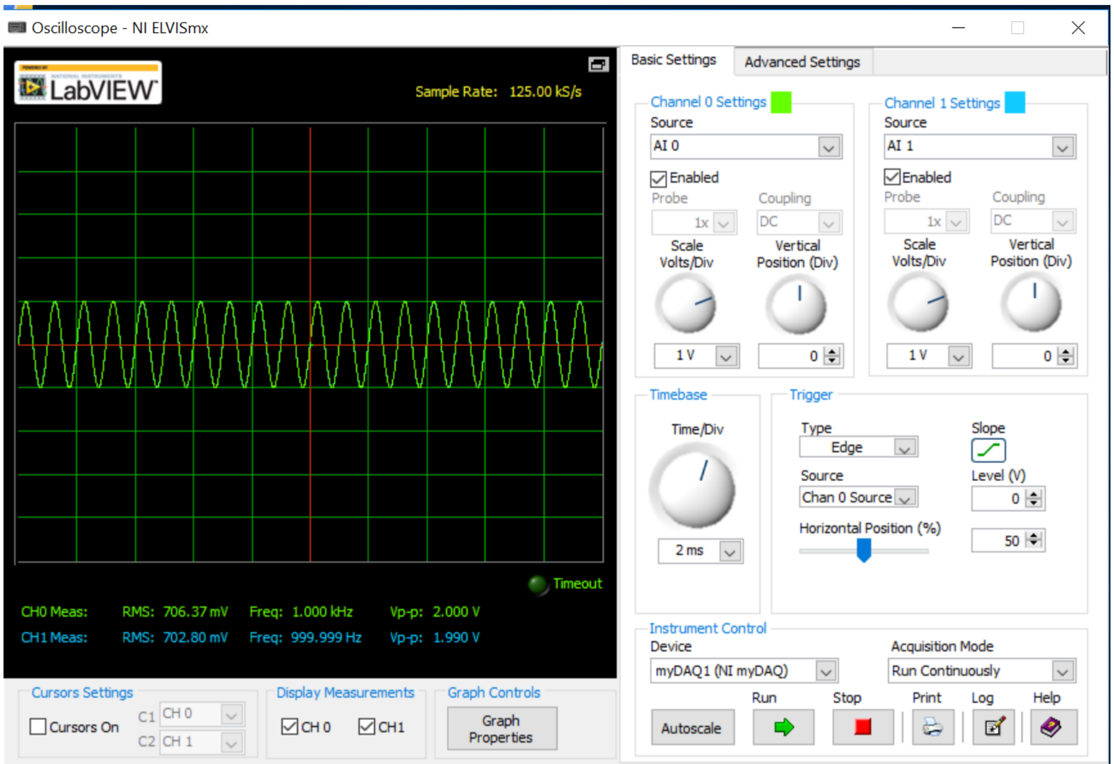



We build our circuits as shown in the above pictures. We first disable Vin1 and enable Vin2, and then we disable Vin2 and enable Vin1, and lastly we supply the same voltage to both Vin1 and Vin2.

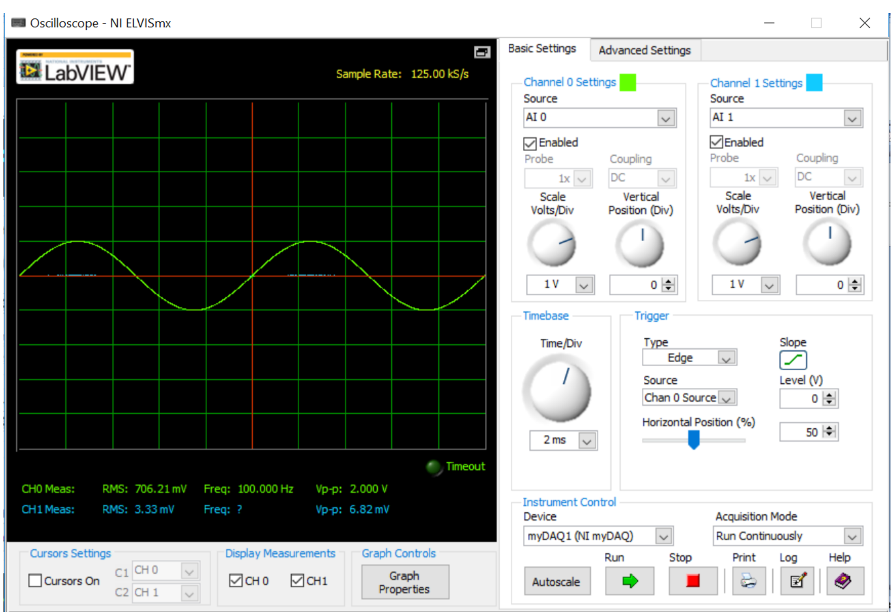
2.4 data



When we disable Vin2 and enable Vin1, the output voltage should be negative Vin1, and from oscilloscope, we get the waveform of $-1V \times \sin(2\pi \times 100Hz \times t)$. Peak to peak voltage of Vin2= 1.986 V.




When we disable Vin1 and enable Vin2, the output voltage should be Vin2, and from oscilloscope, we get the waveform of $1V \times \sin(2\pi \times 100Hz \times t)$. Peak to peak voltage of Vin1= 1.990 V.



When we enable both Vin2 and Vin1, the output voltage should be 0, and from oscilloscope, we get the waveform of $0V$. Peak to peak voltage is 6.82mV which is very close to 0.

2.5 error analysis

We use the equations we derived from theory section. We analyze the error between experimental peak to peak voltage and theoretical peak to peak voltage. In the first topology, error is (1.986-2)/2=0.007. In the second topology, error is (1.990-2)/2=0.005. In the third topology, since the theoretical output is 0, we could not divide by 0 to get relative error. Overall, the error is minimal, and we verified the equation $V_{out} = \frac{R_4}{R_3+R_4}(1+\frac{R_2}{R_1})\, V_{in2} - \frac{R_2}{R_1} V_{in1}$.

2.6 discussion

a. the transfer functions are derived in the theory section.

b. if we assume $R_3 = R_1$, $R_2 = R_4$, then $V_{out} = \frac{R_4}{R_3+R_4}(1+\frac{R_2}{R_1})\, V_{in2} - \frac{R_2}{R_1} V_{in1} = \frac{R_2}{R_1} V_{in2}$ - $\frac{R_2}{R_1} V_{in1}$

2.7 conclusion

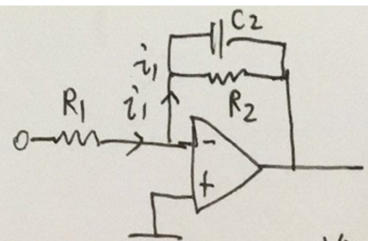
We applied the rule of superposition and verified the transfer function when two input voltages are supplied to the opamp.

3.1 objective

Use capacitor, resistor and opamp to build an active filter.

3.2. theory

The derivation is attached in the picture below.




KVL: $V_{in} - R_1 i_1 + V_x^- = 0$ $\quad i_1 \approx \frac{V_{in}}{R_1}$

KVL: $-\frac{R_2}{R_2 j w C_2} i_1 - V_{out} = 0$

thus $\frac{V_{out}}{V_{in}} = -\frac{\frac{R_2}{R_1}}{1 + jR_2 C_2 W}$

to have DC gain of 2,

$$\frac{Y(s)}{\frac{1}{s}} = \frac{-\frac{R_2}{R_1}}{1 + R_2 C_2 s}$$

$$\lim_{s \to 0} s \frac{-\frac{R_2}{R_1}}{s(1 + R_2 C_2 s)} = \frac{R_2}{R_1} = 2$$

thus $R_2 = 2K\Omega$

at 3dB, $\left| \frac{-\frac{R_2}{R_1}}{1 + jR_2 C_2 W} \right|^2 = \frac{1}{2} \left| \frac{P(0)}{Q(0)} \right|^2 = 2$

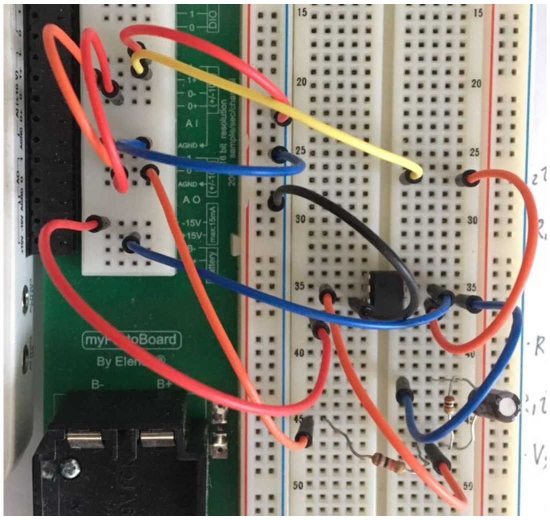
plug in $W = 2\pi \times 80\,Hz$ and $R_2 = 2K\Omega$,

we get $C_2 = 1\mu F$.

the magnitude transfer function is

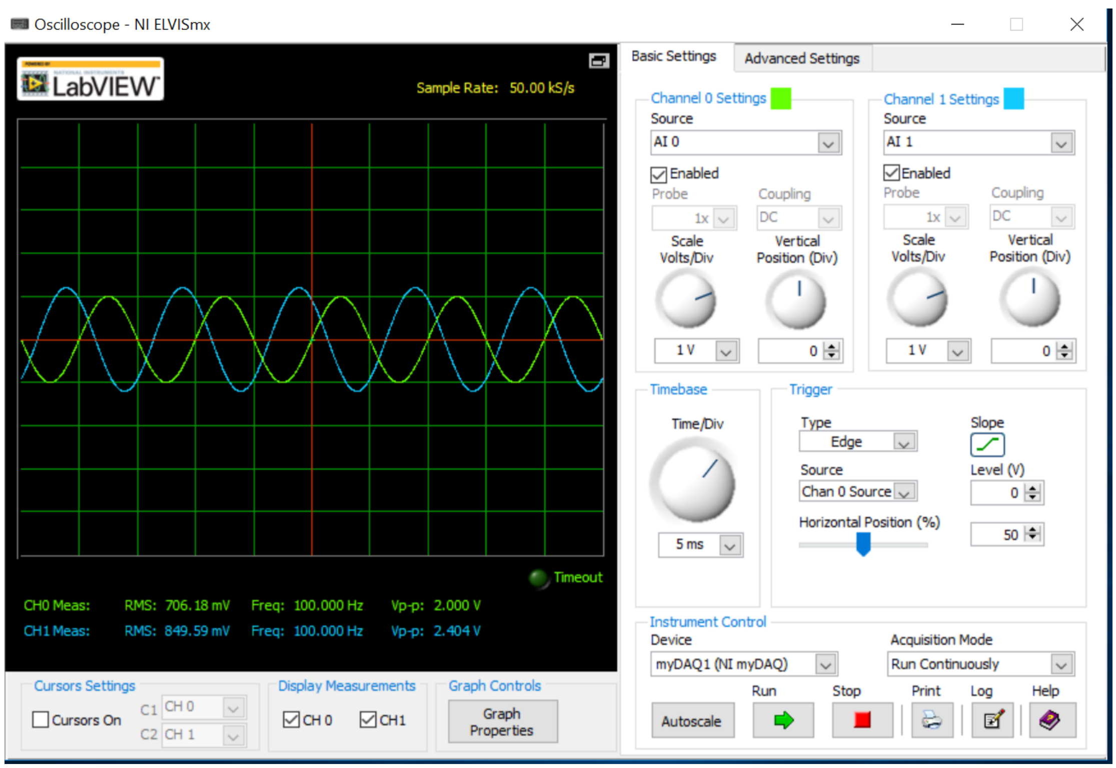
$$\frac{2}{\sqrt{1 + R_2^2 C_2^2 W^2}}$$

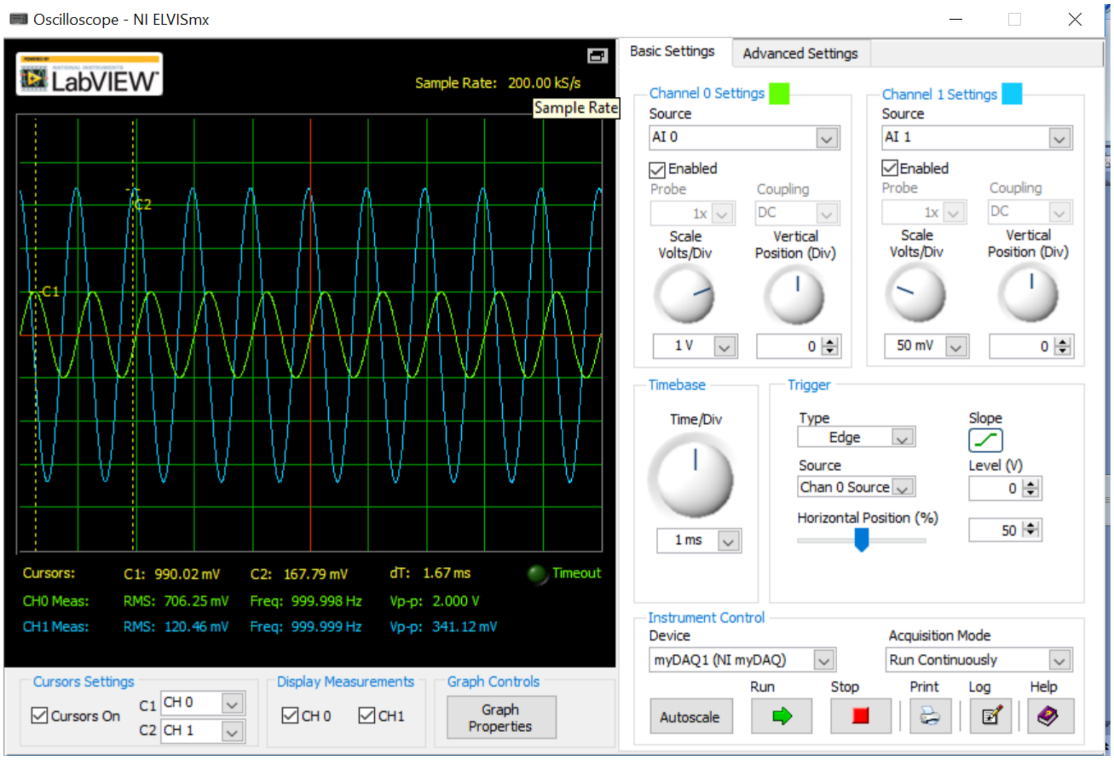
3.3 procedure



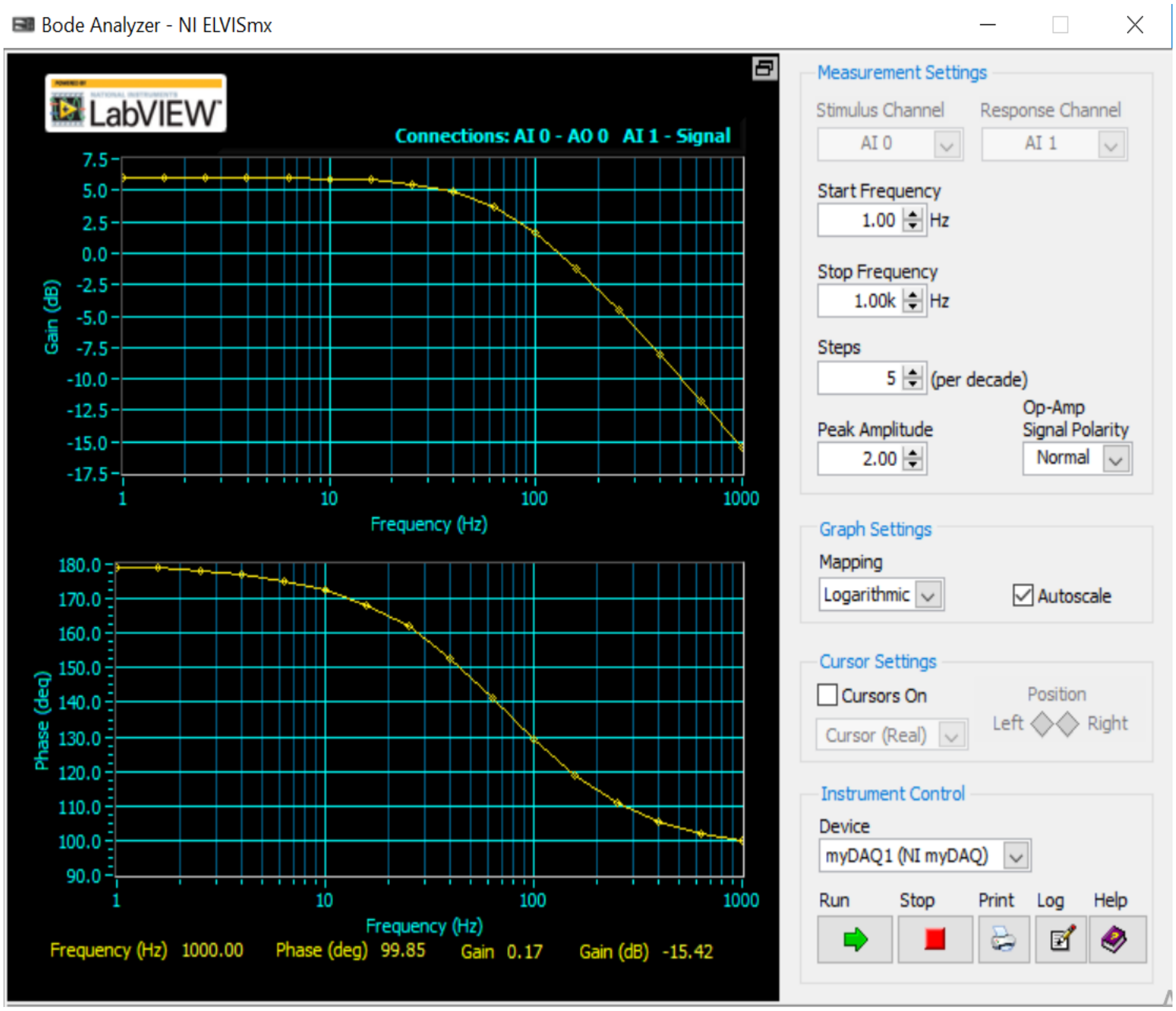
We connect the circuit as shown in the above picture and measure the output voltage.

3.4. data






As shown in the above pictures, when input is 100 Hz, output amplitude is 1.202 V. When input is 1000 Hz, output amplitude is 170.56mV. Using the amplitude transfer function we derived in the theory section, the theoretical amplitude when input is 100 Hz is 1.24535V, and the theoretical amplitude when input is 1000 Hz is 158.653mV.




The bode plot also gives an amplitude of 10^(0.1)=1.25V at 100Hz and 10^(-15.42/20)=0.169=169mV at 1000Hz, which are similar to the results we obtained individually.

3.5 error analysis

When input is 100 Hz, error is (1.202-1.24535)/1.24535=0.0348. When input is 1000 Hz, error is (170.56-158.653)/158.653=0.075. As we can see, the errors are minimal. And the results verify our transfer function is correct.

3.6 Discussion

Derivation and calculations are included in the theory section.

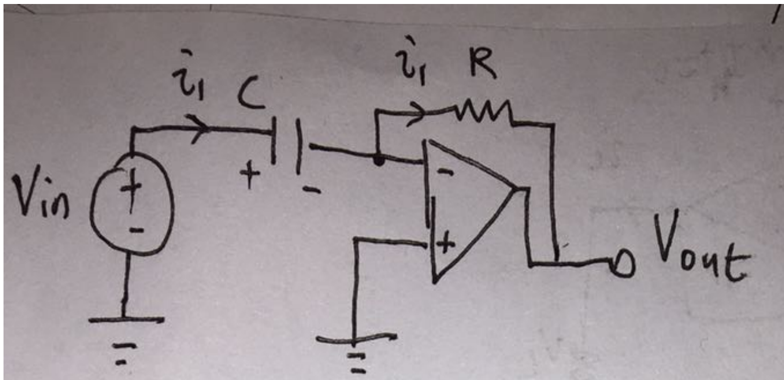
3.7 conclusion

As we can see, from the expression we derived in theory section, the numerator of the transfer function is fixed, and when input frequency is low, the denominator is small, and thus the output is big. When input frequency is big, the denominator in transfer function is large, and thus the output is small. Thus, the topology is low pass filter. Through the experiment, we have verified that our transfer function is correct.

4.1 objective

Build a differentiator and compute its transfer function.

4.2 Theory




KVL: $V_{in} - V_c + V_x = 0 \quad V_c = V_{in}$

KVL: $-V_x - Ri_1 - V_{out} = 0 \quad V_{out} = Ri_1$

$$V_{out} = Ri_1 = R - C\frac{dV_c}{dt} = -RC\frac{dV_{in}}{dt}$$

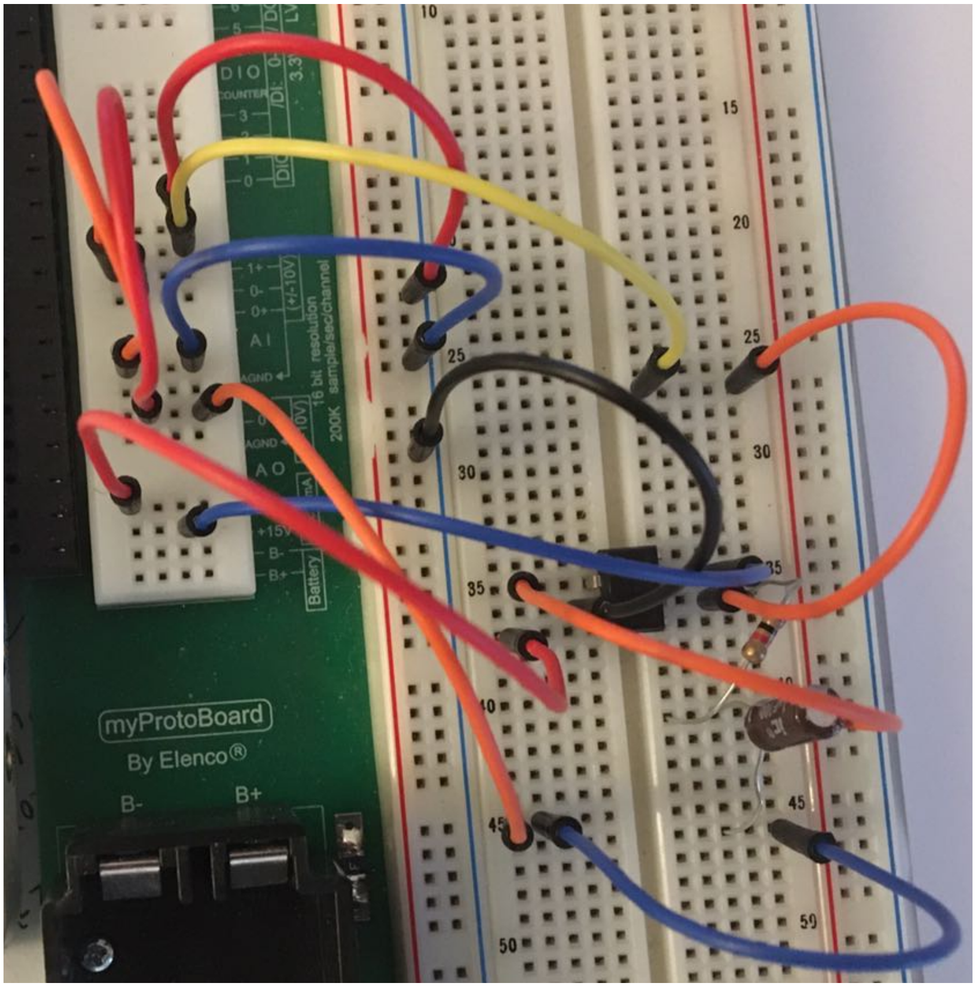
if $V_{in} = \sin(2\pi \cdot 100Hz \cdot t)$, $V_{out} = -RC\cos(2\pi \cdot 100t) \cdot 2\pi \cdot 100$. To get a gain of $0.2\pi$ at 100 Hz,

$200\pi RC = 0.2\pi$, $R = 1K\Omega$

since $-\cos(2\pi \cdot 100t) = \sin(2\pi \cdot 100t - \frac{\pi}{2})$,

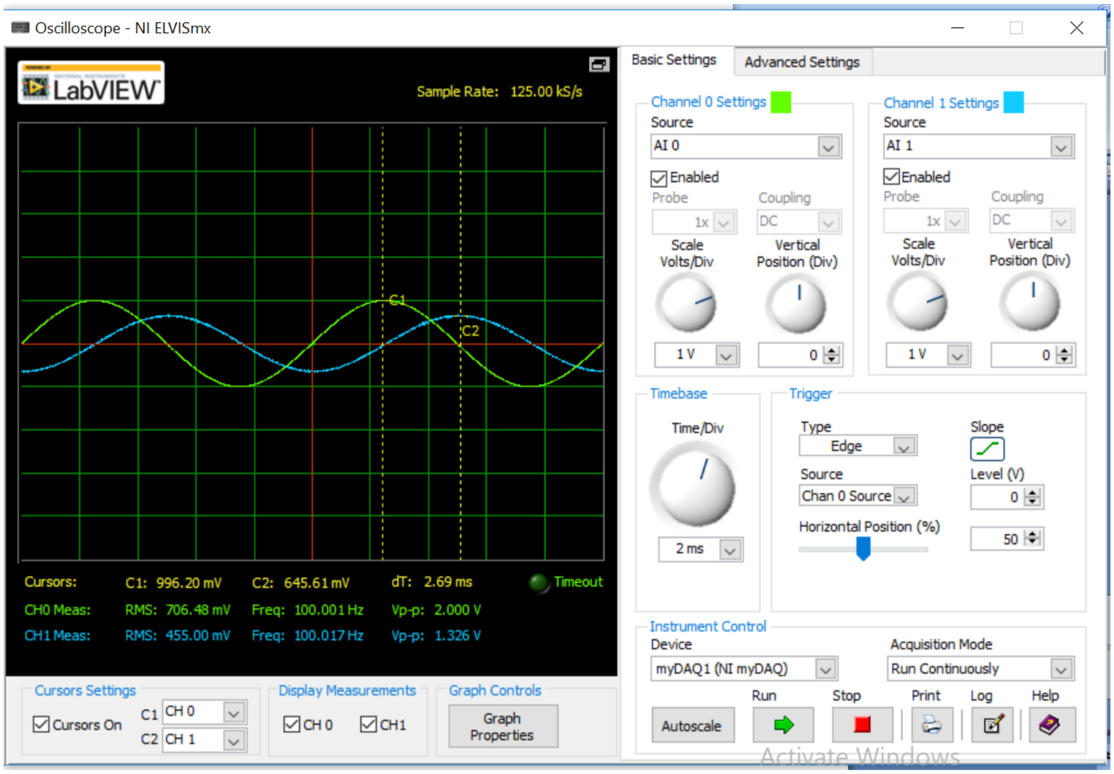
so the output phase lags input phase by $\frac{\pi}{2}$.

4.3 procedure

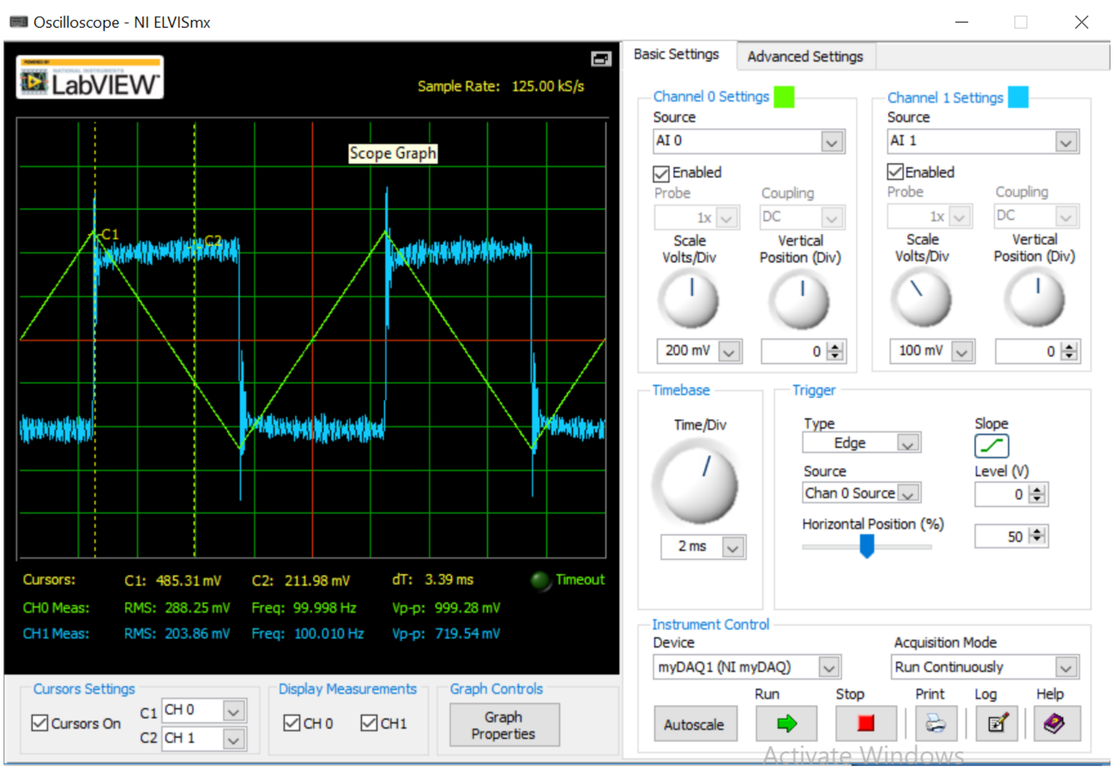



We connect the components as shown above and measure the output voltage.

4.4 data




As shown in the picture above. The peak to peak voltage of output is 1.326 V, which is 0.663 of the input voltage. And the phase of output is lagging the input by $2.69*0.1*2\pi=1.69$.



As shown in the picture above, when there is no sudden change in the input, the output voltage is 211.98 mV.

4.5 error analysis

Using the formula we derived from theory section, for the sinusoidal input, the theoretical magnitude is 0.2* $\pi$=628.319mV. Thus the error is (663-628.319)/628.319=0.0551. The theoretical phase is $\pi$ /2= 1.5708. The error of phase is (1.69-1.5708)/1.5708=0.075. For triangular input, the theoretical magnitude is -0.001*200V=200mV. The error of magnitude is thus (211.98-200)/200=0.0599.

4.6 Discussion

part and part b: as shown in the theory section.
Part c: if input is step, at t=0, the response is -0.001*infinity=infinity. At $t > 0$, response is 0.

4.7 conclusion

We have verified the transfer function of a differentiator, examined the magnitude response and phase response. The errors are minimal.