ELEC ENG 2CJ4 Circuits and Systems Lab 2

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Section L01
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vi. Given the circuit in Figure 4, assume R_3 = 10Ω, R4 = 2.2MΩ, C3 = 100nF (104), V_{CC+}= +5V , and V_{CC-} = -5V. Consider two types of inputs: 1) a square wave, 2) a sine wave (both with frequency of 1 KHz and peak-to-peak amplitude of 2V). Determine the output voltage and plot the relationship between the input voltage and the output voltage.

1) R_3 = 10kΩ, R4 = 2.2MΩ, C3 = 100nF (104), V_{CC+}= +5V, and V_{CC-} = -5V and sine wave:

KCL at node V_1:

$i_{R3} = -i_{R4} - i_C$ (i_{R4} can be ignored as the resistance is 2.2MΩ and very large)

$$\frac{V_{in}}{R_3} = -C\frac{dV_o}{dt}$$

$$V_o = \frac{-1}{R_3 C}\int_0^t V_{in}(\tau)d\tau + V_o(0)$$

$V_o(0) = 0$ and $V_{in}(t) = \sin(2000\pi t)$

$$V_o = \frac{-1}{R_3 C}\int_0^t \sin(2000\pi\tau)d\tau$$

$$V_o = \frac{-1}{(10k)(100n)}\left[\frac{-1}{2000\pi}\cos(2000\pi t)\right]_0^t$$

$$V_o = \frac{-1}{(10k)(100n)} \times \frac{1}{2000\pi}[-\cos(2000\pi t) + 1]$$

$$V_o = \frac{-1}{2\pi}[-\cos(2000\pi t) + 1]$$

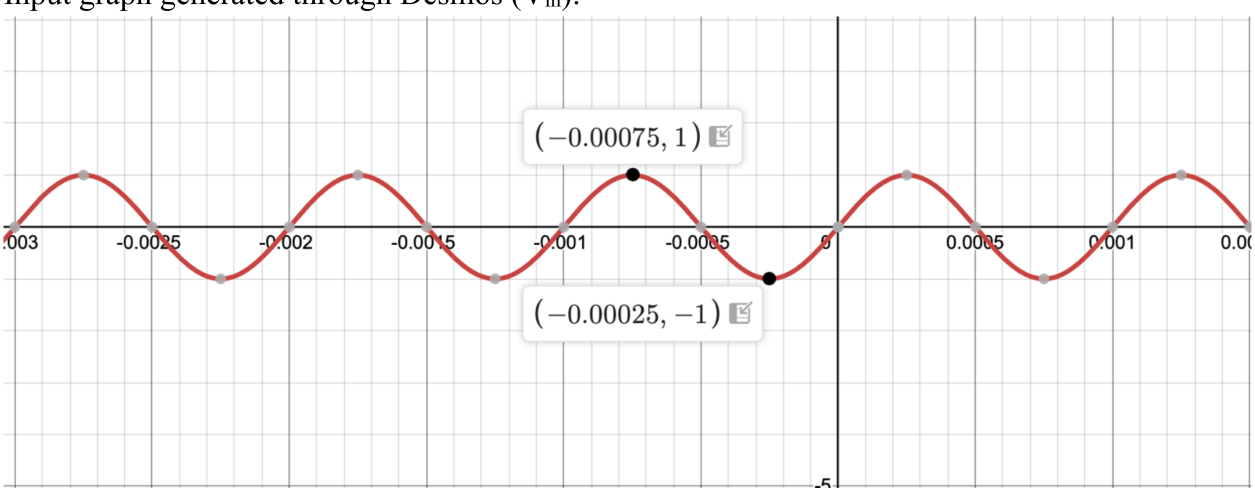
By inputting values of t, the value of V_o can be determined to create the output graph.

t = 0 seconds: V_o = 0V

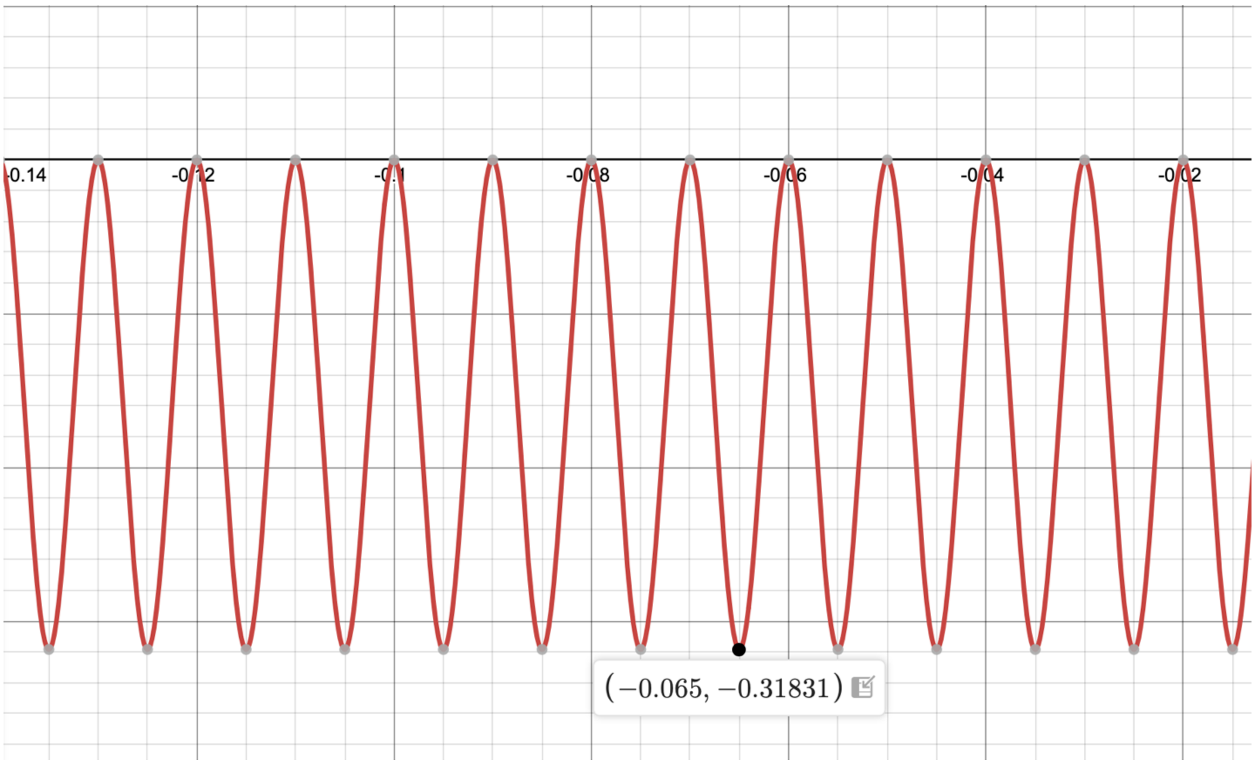
t = 0.5 seconds: V_o = -0.3183V

t = 1 seconds: V_o = 0V

Input graph generated through Desmos (V_{in}):



Output graph generated through Desmos (V_o):



With an input of sin(2000πt), the corresponding output generated is $\frac{-1}{2\pi}[-\cos(2000\pi t) + 1]$.

2) R_3 = 10kΩ, R4 = 2.2MΩ, C3 = 100nF (104), V_{CC+}= +5V, and V_{CC-} = -5V and square wave:

KCL at node V_1:

$i_{R3} = -i_{R4} - i_C$ (i_{R4} can be ignored as the resistance is 2.2MΩ and very large)

$$V_o = \frac{-1}{R_3 C}\int_0^t V_{in}(\tau)d\tau + V_o(0)$$

$V_o(0) = 0$ and $V_{in}(t)$ alternates between values of -1 and 1 every 0.5 ms

For V_{in} = 1V (0 < t < 0.5ms):

$$V_o = \frac{-1}{R_3 C}\int_0^t 1\, d\tau$$

$$V_o = \frac{-1}{(10k)(100n)}t = -1000t\ V$$

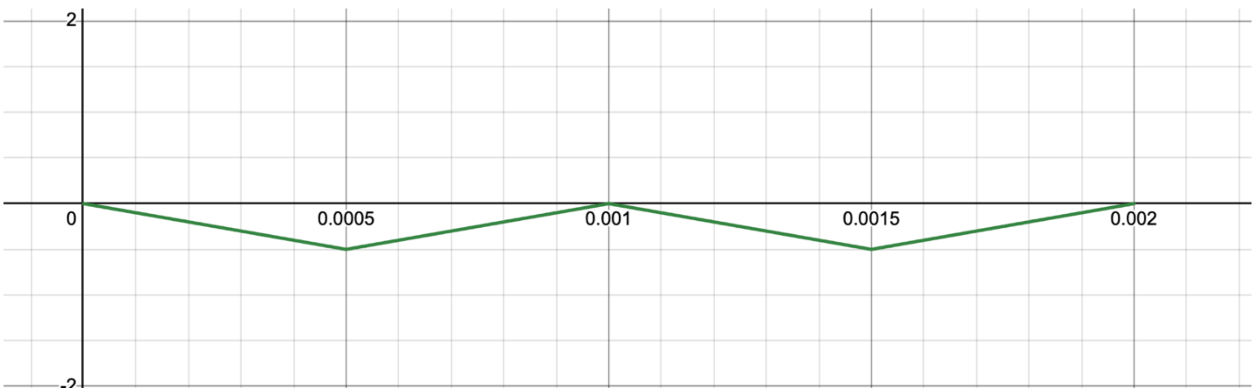
For V_{in} = -1V (0.5ms < t < 1ms):

$$V_o = \frac{-1}{R_3 C}\int_{0.5ms}^t -1\, d\tau$$

$$V_o = \frac{1}{(10k)(100n)}(t - 0.5m) = 1000t - 0.5\ V$$

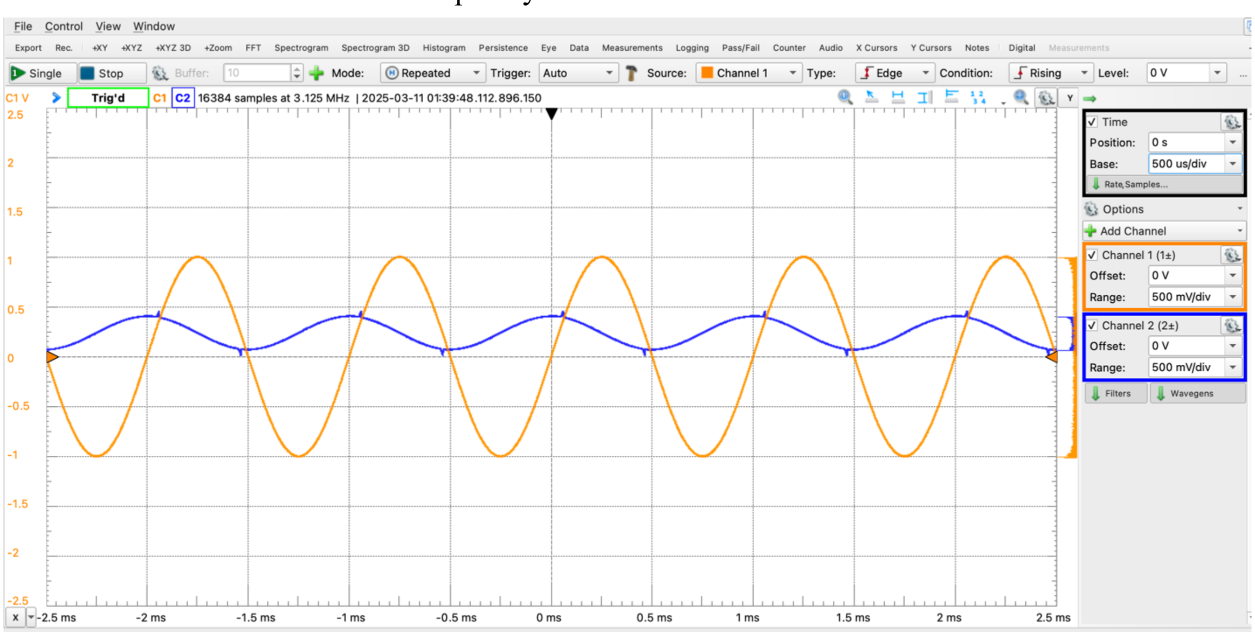
Input generated through Desmos (V_{in}):

Output generated through Desmos (V_o):



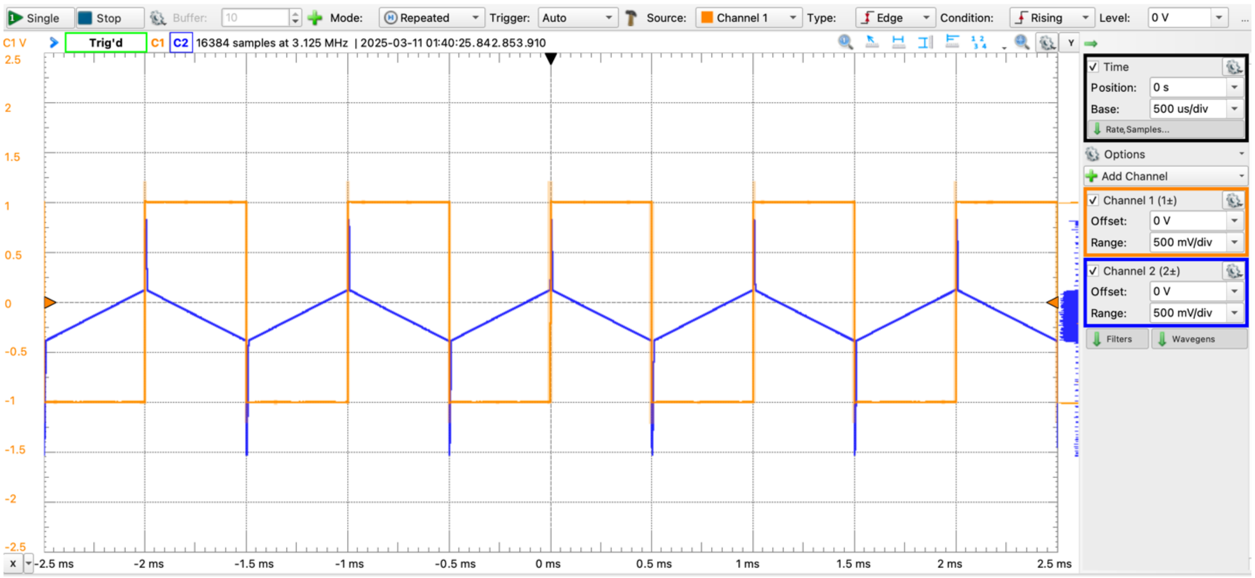
vii. Build the circuit in Figure 4 using the analog discovery 2 and measure the corresponding outputs. Compare your theoretical analysis with your measured responses.

AD3 results for sine wave with frequency of 1kHz:



Output sine wave peak-to-peak: 0.352V

AD3 results for square wave with frequency of 1 kHz:



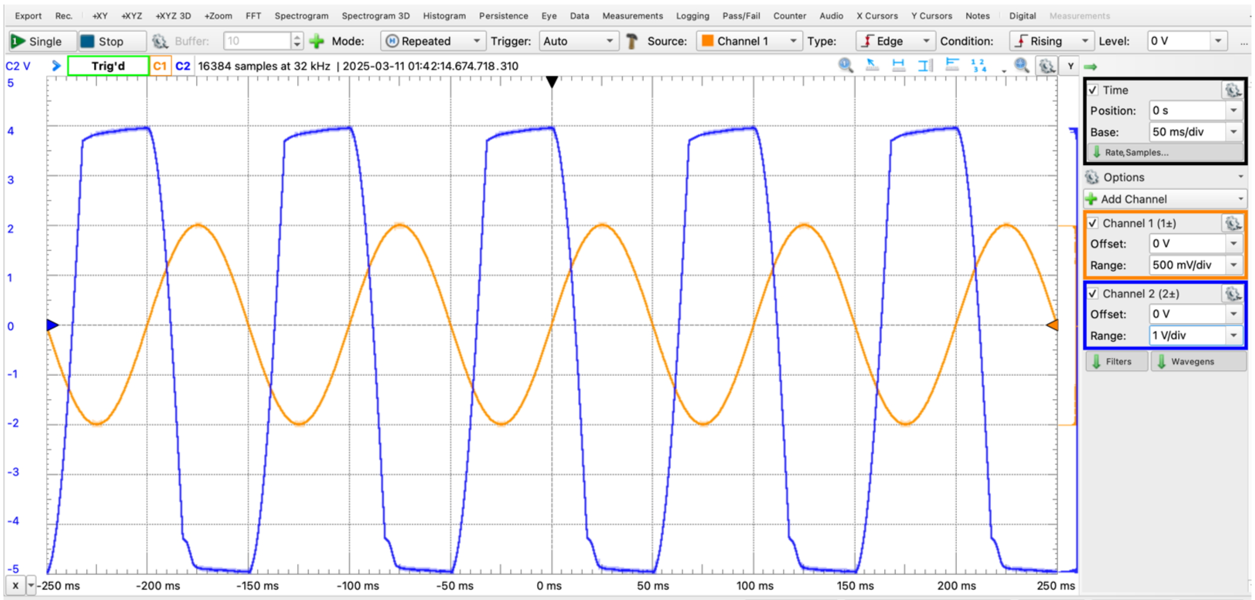
Output square wave peak-to-peak: 0.531mV

Discussion of Findings:

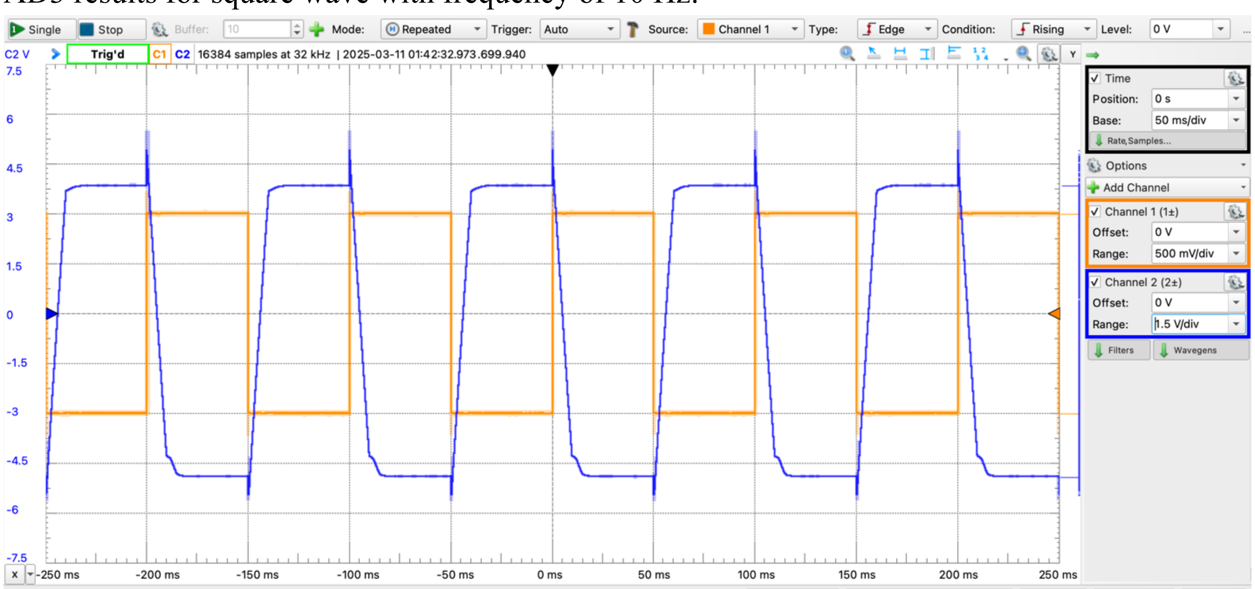
Looking at the graphs for the theoretical and measured responses, the theoretical and measured graph responses match. Looking at the theoretical graphs, the expected peak to peak for a sine wave is 0.3183V and the expected peak to peak for a square wave is 0.5V. The measured outputs of 0.352V and 0.531V are very close to the theoretical calculations with percentage errors of 10.59% and 6.2%, respectively. It can also be seen in the graph that there are slight deviations in the output for both square and sine wave. For the square wave, this can be attributed to discontinuities when switching between -1V and 1V which aligns with the recorded results as the deviations occur on the switching of the square wave. For the sine wave, leakage current may cause deviations at certain points in the sine wave.

viii. Set the frequency to 10 Hz or lower. Check whether the integrator functions properly and explain your findings.

AD3 results for sine wave with frequency of 10 Hz:



AD3 results for square wave with frequency of 10 Hz:



Explanation of findings:

When the frequency is reduced from 1 kHz to 10 Hz, both the input sine wave and its period undergo significant changes. Previously, the sine wave input followed the function $\sin(2\pi \times 1000t)$, corresponding to the general form $A \sin(\omega t)$. This resulted in an output voltage described by $-12\pi\,(-\cos(2000\pi t) + 1)$, with a voltage range spanning from 0V to 0.318V.

Unlike the square wave case—where time plays a crucial role in defining the output—the sine wave integration follows a different pattern. The earlier square wave integration produced an output oscillating between -0.5V and 0.5V but altering the input frequency impacts both sine and square wave responses. With the sine wave frequency decreased, the new output voltage equation becomes $-50\pi\,(-\cos(2000\pi t) + 1)$, leading to an output range of 0V to -31.8V over one period. Similarly, for the square wave input, the output now ranges from -50V to +50V.

Since lowering the frequency results in an output voltage exceeding the ±5V limits of the AD2 oscilloscope, these effects will not be observed in the actual measurement. Once the output voltage reaches the saturation threshold, it remains constrained within this range, meaning it will not continue to increase or decrease beyond ±5V, as shown in the graphs of the sine and square wave with a frequency of 10 Hz.