Circuits and Systems 2CJ4

Lab 3

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Set 3 Laboratory Experiment

1. Given the circuit in Figure 4, assume $R_3 = 10k\Omega$, $R_4 = 2.2M\Omega$, $C_3 = 100nF$ (104), $V_{CC+} = +5V$, $V_{CC-} = -5V$. Consider the two types of input: 1) a square wave, 2) a sine wave (both with a frequency of 1kHz and peak-to-peak amplitude of 2V). Determine the output voltage and plot the relationship between the input voltage and the output voltage.

Figure 1: Output Voltage Calculations for Square Wave Input

1. Square Wave

$R3 = 10k\Omega$, $R_4 = 2.2M\Omega$, $C_3 = 100nF$, $V_{cc+} = +5$, $V_{cc-} = -5V$

$$V_o(t) = -\frac{1}{RC}\int_0^t v(t)\,dt + V_o(0)$$

$$V_{in} = \begin{cases} 1V, & 0 \le t < 0.5ms \\ 1V, & 0.5 \le t < 1\ ms \end{cases}$$

@ $0 \le t < 0.5$ ms

$$V_o(t) = -\frac{1}{(10K)(100n)}\int_0^t 1\,dt + \cancel{V_o(0)}^{\,0}$$

$$= -10^3 \cdot t = -1000t$$

@ $t = 0.5ms \longrightarrow V_o(t) = -0.5$

@ $0.5 \le t < 1$ ms

$$V_o(t) = -\frac{1}{(10K)(100n)}\int_{0.5\times10^{-3}}^{t} -1\,dt - 0.5$$

$$= -10^3 \cdot (-t + 0.5\times10^{-3}) - 0.5$$

$$= 1000t - 0.5 - 0.5$$

$$= 1000t - 1$$

@ $t = 1ms \rightarrow V_o(t) = 0V$

$$V_o = \begin{cases} -1000t, & 0 \le t < 0.5ms \\ 1000t - 1, & 0.5 \le t < 1\ ms \end{cases}$$

Figure 2: Output Voltage Calculations for Sine Wave Input

2. Sin Wave

$R3 = 10k\Omega$, $R_4 = 2.2M\Omega$, $C_3 = 100nF$, $V_{cc+} = +5$, $V_{cc-} = -5V$

$$V_o(t) = -\frac{1}{RC}\int_0^t v(t)\,dt + V_o(0)$$

$$= -\frac{1}{(10k)(100n)}\int_0^t \sin(2000\pi t)\,dt$$

$$= -10^3 \times \frac{1}{2000\pi} \times \left(-\cos(2000\pi t)\right)\Big|_0^t$$

$$= \frac{1}{2\pi}\left(\cos(2000\pi t) - 1\right)$$

$$\therefore V_{out} = \frac{1}{2\pi}\left(\cos(2000\pi t) - 1\right)$$

Figure 3: Relationship Between Sine Wave Input and its Output

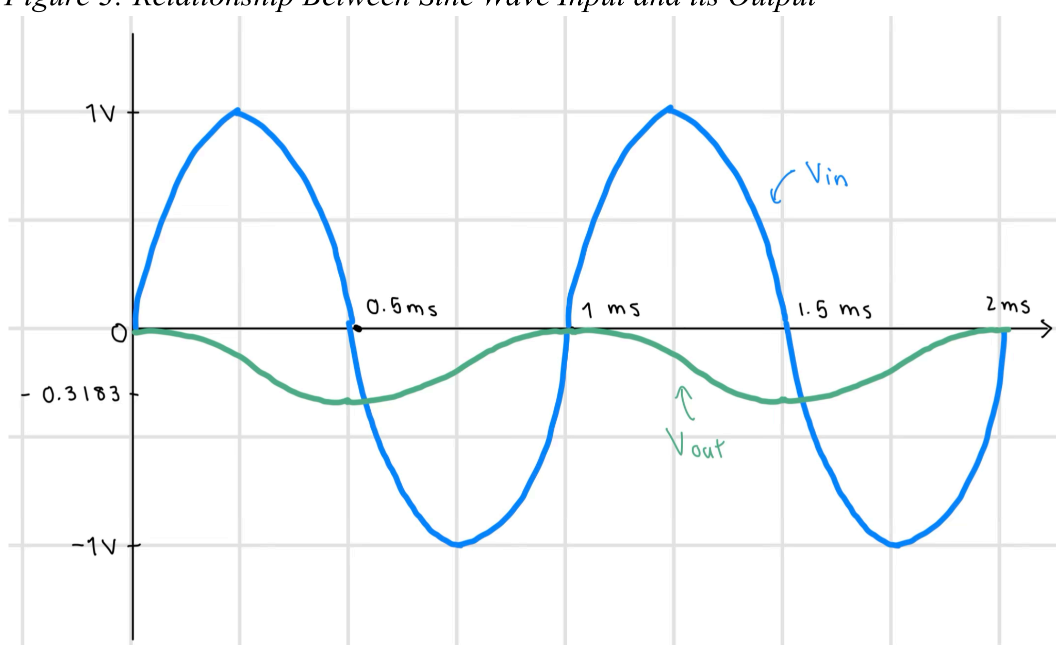
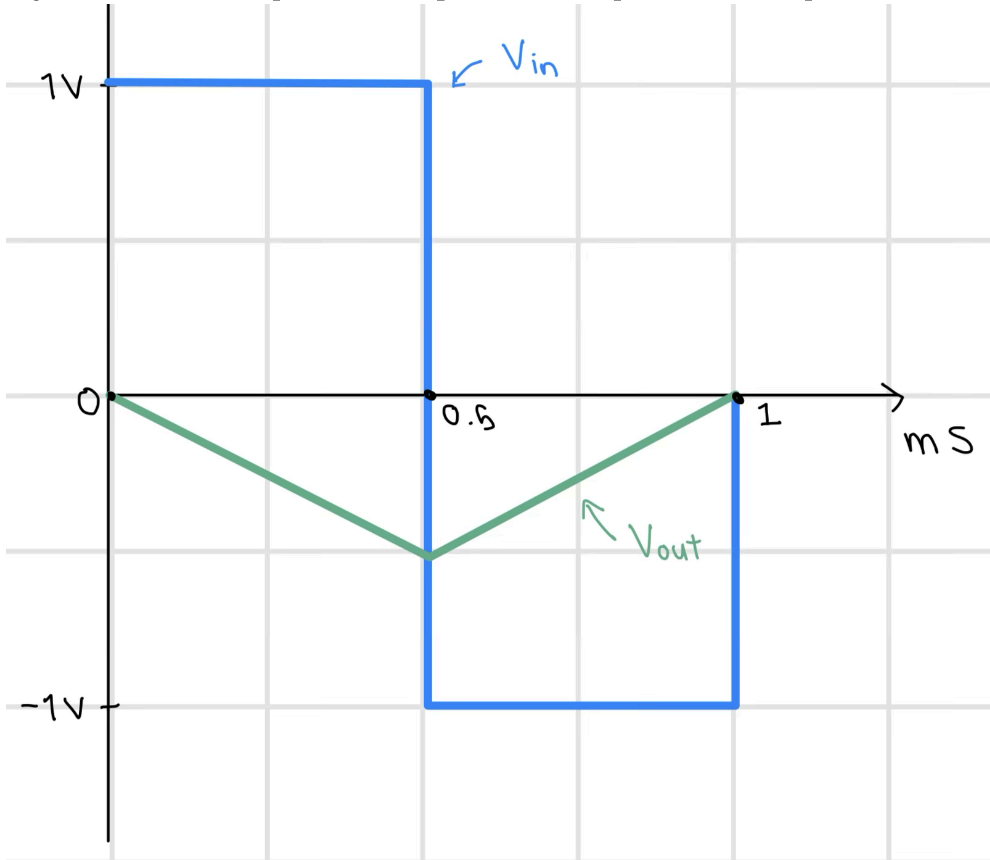


Figure 4: Relationship Between Square Wave Input and its Output



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

Figure 5: Practical Integrator Circuit

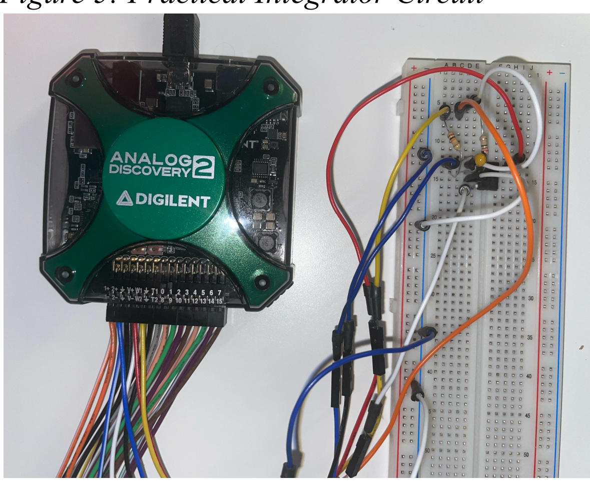


Figure 6: AD2 Measurements on the Sine Input and its Output Voltage

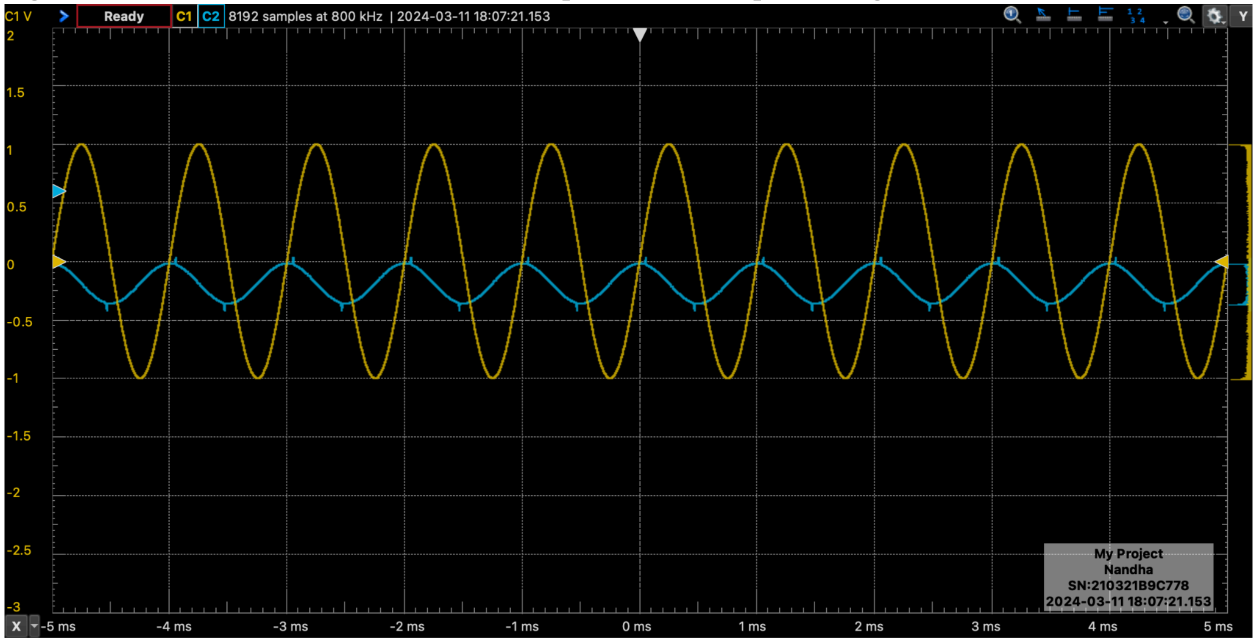
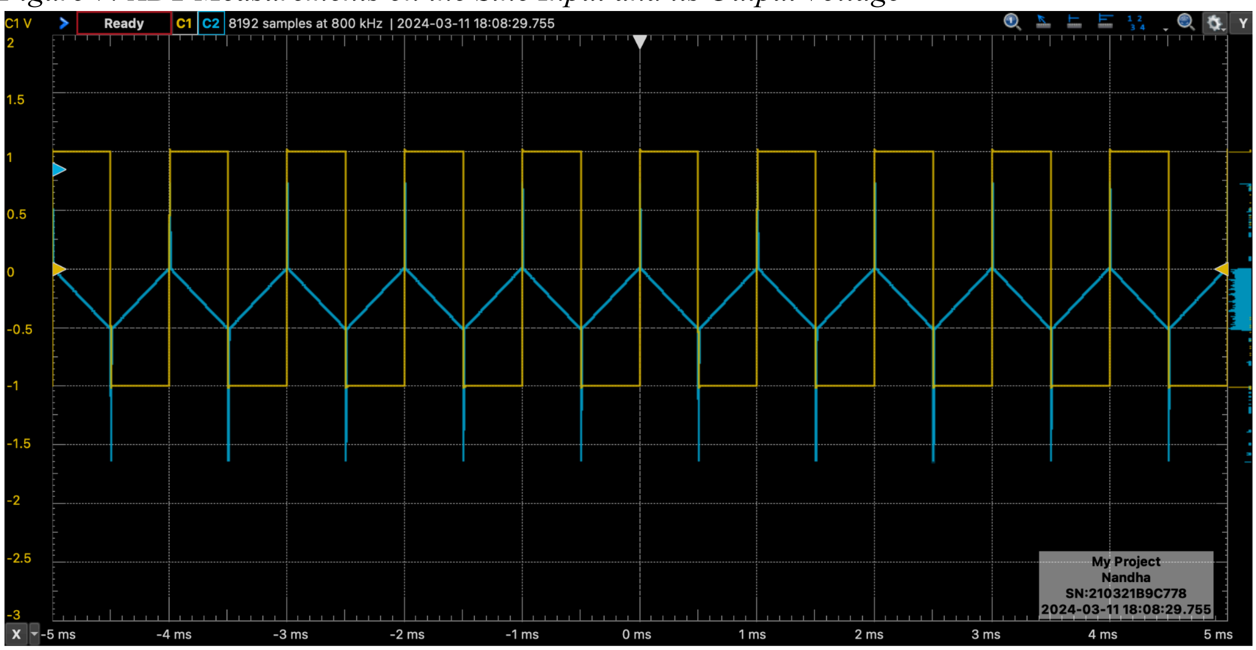


Figure 7: AD2 Measurements on the Sine Input and its Output Voltage



Determining Output Voltage Value of Sine Wave Input with Y Cursor

At 0.5ms, V_{out} = –355.44 mV

At 1.0ms, V_{out} = 10.204 mV

Determining Output Voltage Value of Square Wave Input with Y Cursor

At 0.5ms, V_{out} = –508.5 mV

At 1ms, V_{out} = 1.7007 mV

Comparison between Output of Theoretical Sine Wave and Measured Sine Wave

Percent Error at 0.5ms = $\left|\frac{-0.3183-(-0.3554)}{-0.3183}\right| \times 100\% \;=\; 11.67\%$

Percent Error of Peak to Peak Amplitude = $\left|\frac{0.3183-(0.3656)}{0.3183}\right| \times 100\% \;=\; 14.86\%$

In the comparison between the theoretical sine wave and the measured sine wave outputs, the percentage error at 0.5 ms is 11.67%, while the percentage error for the peak-to-peak amplitude of the output voltage is 14.86%. These discrepancies may have arisen due to factors such as internal resistance within the breadboard and environmental conditions affecting the circuit. Despite these potential sources of error, the low percentage errors suggest that the experimental values closely align with the theoretical expectations. Furthermore, the plotted graphs exhibit similarities: both the theoretical and experimental graphs depict smaller output voltages that follow a cosine function, contrasting with the sine input waveform.

Comparison between Output of Theoretical Square Wave and Measured Sine Wave

Percent Error at 0.5ms = $\left|\frac{-0.5-(-0.5085)}{-0.5}\right| \times 100\% \;=\; 1.70\%$

Percent Error of Peak to Peak Amplitudes = $\left|\frac{0.5-(0.510)}{0.5}\right| \times 100\% \;=\; 2.0\%$

During the comparison of the theoretical square wave with the measured square wave outputs, a 1.7% percentage error at 0.5 ms and a 2.0% percentage error for the peak-to-peak amplitude of the output voltage were observed. These discrepancies might have been influenced by factors like internal resistance within the breadboard and environmental conditions affecting the circuit's performance. Nevertheless, despite these potential sources of error, the low percentage errors imply that the experimental values closely match the theoretical expectations. Additionally, both graphs display similarities, showcasing triangular output shapes when a square input is provided.

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

Figure 8: Sine Input Voltage and its Output Voltage at Frequency of 10 Hz

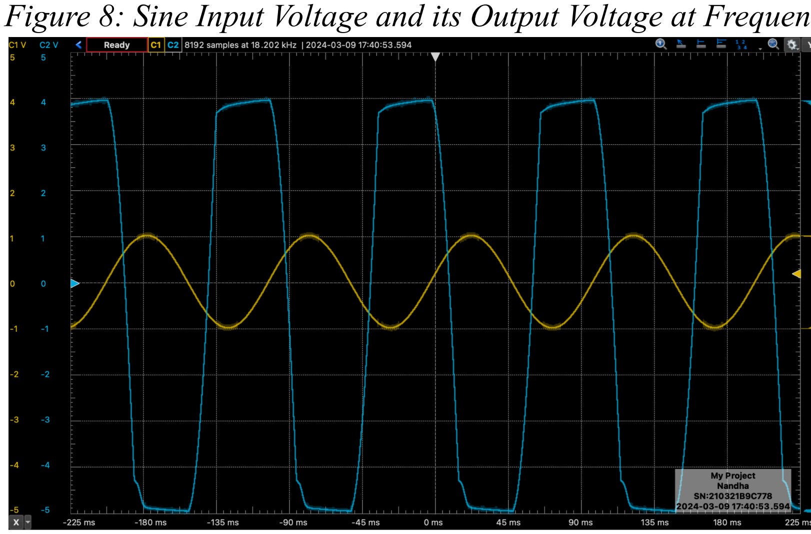
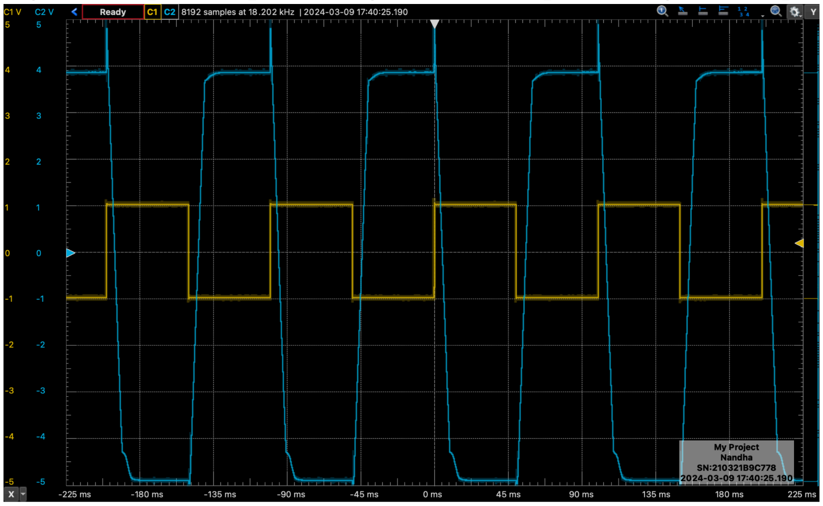


Figure 9: Square Input Voltage and its Output Voltage at Frequency of 10 Hz



Explanation

When the frequency is lowered to 10 Hz, it can be clearly seen that the integrator does not function properly. The output voltage is larger than the linear active region which is V_{EE} = -5V and V_{CC} = 5V, which indicates that it is in the saturated region and the gain is too high. This issue arises from the considerably large decrease in frequency, resulting in increased impedance of the capacitor. The heightened impedance restricts current flow, effectively creating an open circuit at the capacitor. Consequently, current solely flows through R3 and R4, yielding a gain equivalent to -R4/R3, as the input is $R3 \times I$. and the output is $-\ R4 \times I$.