2CJ4 – Lab 3 – Set 3 – Differentiator and Integrator Circuits Using Op-Amps

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Introduction

Operational amplifiers (Op-Amps) are essential components in analog circuits, especially in signal processing tasks like differentiation and integration. These circuits are often used in fields such as control systems, waveform shaping, and signal conditioning. In this experiment, we examine two essential circuits: the differentiator and the integrator and physically build an integrator circuit.

A differentiator circuit produces an output voltage that reflects the rate at which the input signal is changing over time. This makes it beneficial for uses such as edge detection and processing high-frequency signals. Conversely, an integrator circuit generates an output that sums the input signal over time, functioning as a smoothing filter or a waveform generator.

The primary aim of this experiment is to build and analyze the performance of these circuits when exposed to various input signals, including sine waves and square waves. In doing this, we intend to correlate theoretical predictions with actual circuit performance, while also uncovering practical issues like instability and sensitivity to noise.

Operational Principle of the Experimental Circuit

The circuits studied in this lab are designed to preform differentiation and integration on an input signal using op-amps. The differentiator circuit is designed to produce an output voltage that is proportional to the rate of change of the input signal. It has a capacitor at the input and a feedback resistor. The formula for V_{out} (t) can be expressed as:

$$V_{out}(t) = -RC * \frac{dV_{in}(t)}{dt}$$

R and C determine the circuits response. Since differentiators amplify high frequency signals, they tend to have lots of noise. To prevent this as much as possible, practical designs include an additional resistor in series with the capacitor to improve stability.

The integrator circuit accumulates the input signal over time, producing an output voltage that represents the integral of the input. This is accomplished by placing a resistor at the input and a capacitor in the feedback look, which leads to the equation:

$$V_{out}(t) = -\frac{1}{RC} * \int V_{in}(t)dt + V_{out}(0)$$

This circuit is often used in waveform generation and low-pass filtering. However, real integrators often have a parallel resistor across the feedback capacitor to contract drift and make sure the integrator can operate in the long term.

By testing these circuits with different input signals, this lab gives us some insight into the practical behaviour of differentiators and integrators. This includes how they respond at different frequencies, and how they are limited in real world applications.

Measurement Results

vi. Given the circuit in Figure 4, assume $R_3 = 10k\Omega$, $R_4 = 2.2M\Omega$., $C_3 = 100nF$ (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 1KHz and peak-to-peak amplitude of 2V). Determine the output voltage and plot the relationship between the input voltage and the output voltage.

Square wave:

$$R_3 = 10K\Omega, R_4 = 2.2M\Omega, C_3 = 100nF, V_{CC+} = 5V, V_{CC-} = -5V$$

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

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

For $0ms \le t < 0.5ms$:

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

$$V_o(t) = -10^3 t$$

$$V_o(t) = -1000t$$

$$@\, t = 0.5ms\, , V_o(t) = -0.5V$$

For $0.5ms \le t < 1ms$:

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

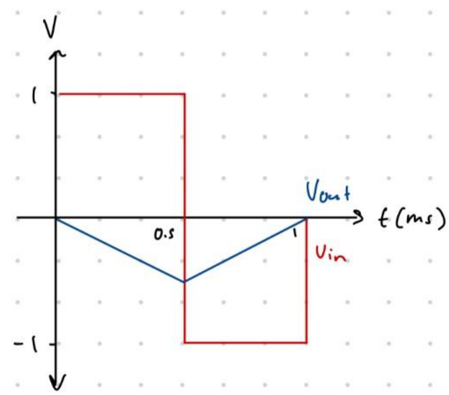
$$V_o(t) = -10^3\,(-t + 0.5 * 10^{-3}) - 0.5$$

$$V_o(t) = 1000t - 1$$

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

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

Relationship Between the Input and Output Voltage:



Sine Wave:

$$R_3 = 10K\Omega, R_4 = 2.2M\Omega, C_3 = 100nF, V_{CC+} = 5V, V_{CC-} = -5V$$

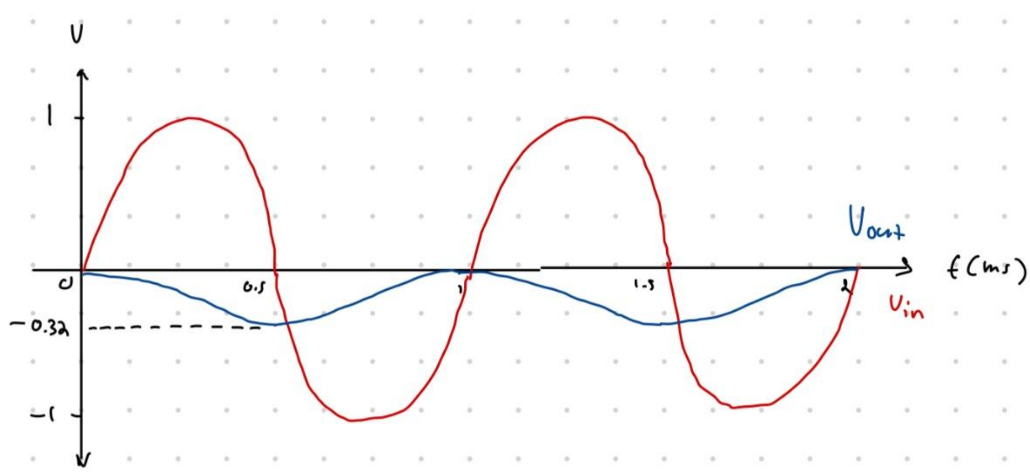
$$V_o(t) = -\frac{1}{RC}\int_0^t V(t)dt + V_o(0)$$

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

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

$$Therefore, V_o(t) = \frac{1}{2\pi} * (\cos(2000\pi t) - 1)$$

Relationship Between the Input and Output Voltage:



vii. Build the circuit in Figure 4 using the analog discovery 3 and measure the corresponding outputs. Compare your theoretical analysis with your measured responses.

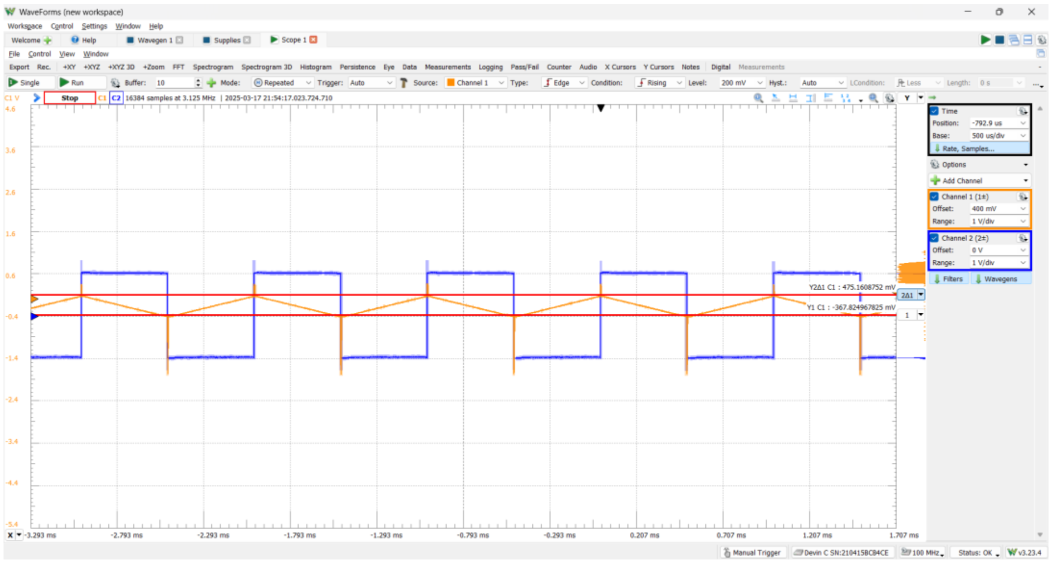


Figure 1: 1kHz 2VPP Square Wave, Integrator output

The output measured from this integrator matches our theoretical value, with some small differences. The theoretical output was expected to have a triangular shape, and the measured output also shows this triangular waveform. The measured amplitude was 524.01 mV, which is only 24.01 mV higher than the theoretical value, which is 500mv. Also, the measured output had a downward shift of around 140 mV compared to the theoretical value. Even though there is this small shift, the output is still consistent with the calculated values.

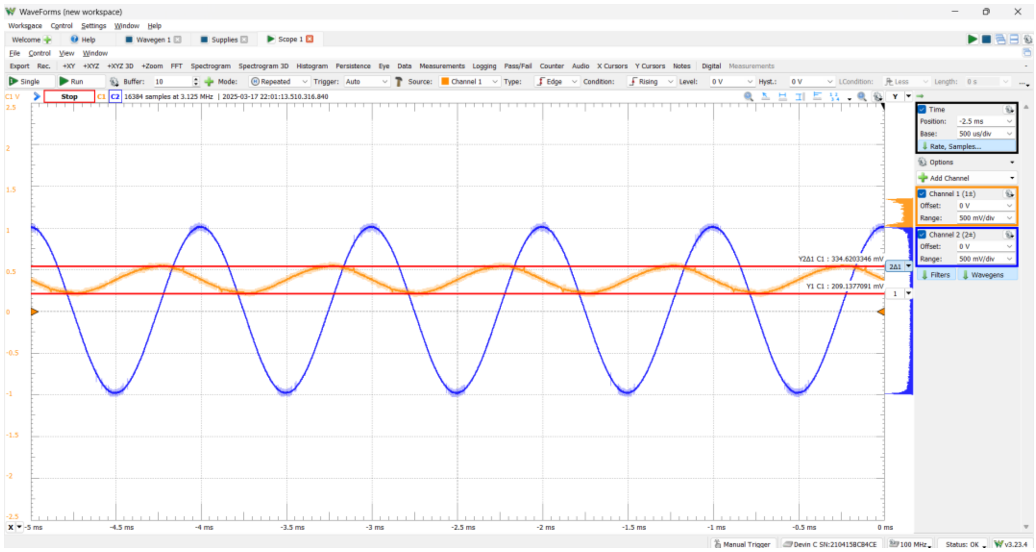


Figure 2: 1kHz 2VPP Sine Wave, Integrator output

The measured output for the sine input is also consistent with the theoretical value. The output voltage follows a sine wave shape, just as expected from the theoretical calculations. The measured amplitude was 344.25 mV, while the theoretical value was 318.31 mV. Similarly, the measured output is also shifted down by approximately 140 mV compared to the theoretical value.

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

At low frequencies like 10 Hz, the op-amp integrator saturates because the capacitor in the feedback loop keeps storing charge without discharging fast enough. This happens because the circuit continuously adds up the input voltage over time, causing the output voltage to rise more and more. Although a 2 MΩ resistor is included to help discharge the capacitor, it is too large to work effectively at such a low frequency. As a result, the capacitor keeps holding charge, and the output voltage eventually reaches the op-amp's power limits, getting stuck at the maximum or minimum voltage. This means the circuit can no longer function as an integrator. To prevent this, a smaller resistor could be used to help discharge the capacitor faster, or the input frequency could be increased so the capacitor has more chances to reset.

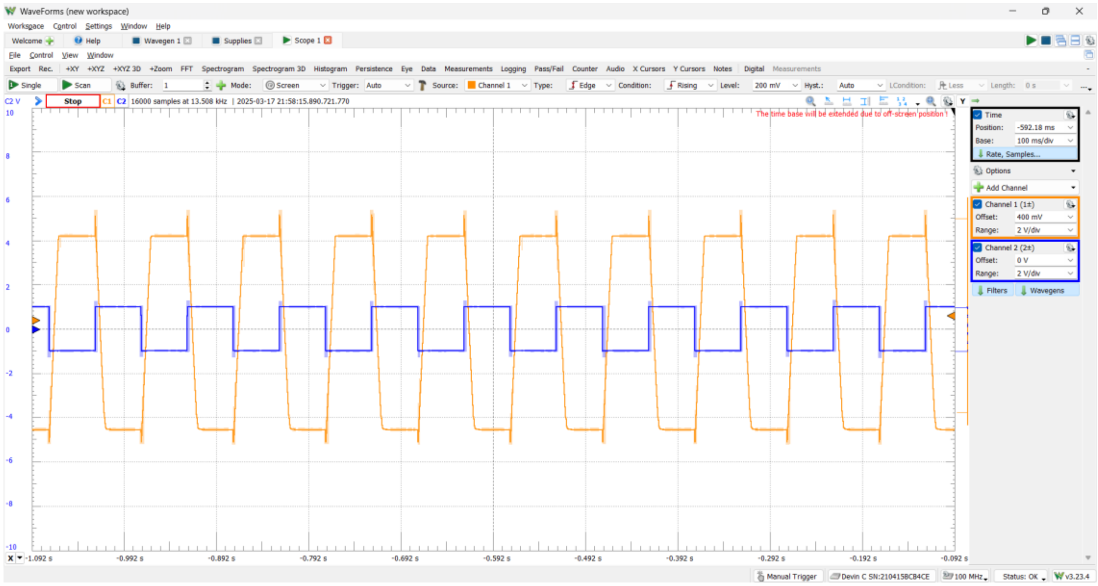


Figure 3: 10Hz 2VPP Square Wave, Integrator output

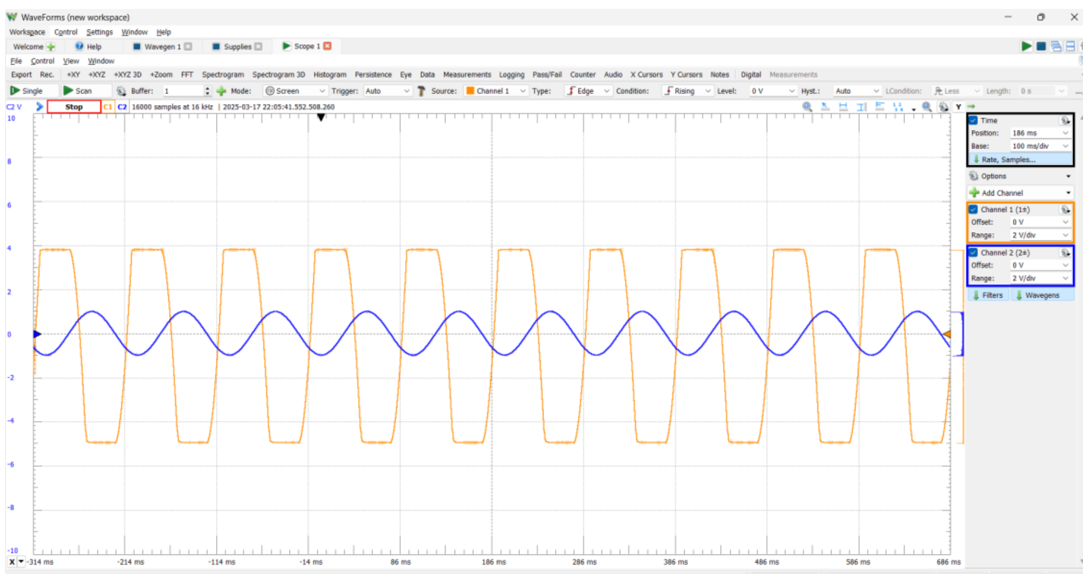


Figure 4: 10Hz 2VPP Sine Wave, Integrator output

Discussion:

This lab focuses on understanding how differentiator and integrator circuits work using Op-Amps. Our goal was to compare the theoretical output voltages with actual measurement output voltages to observe how it is affected by different inputs and frequencies.

The experimental results obtained were close to the theoretical values. For the square wave input, the output formed a triangular waveform, and the measured amplitude was only 24.01 mV higher than expected. For the sine wave input, the output followed the expected sine wave shape, with a measured amplitude of 344.25 mV, close to the theoretical 318.31 mV. Both outputs had a small downward shift of about 140 mV, which could be due to component tolerances or oscilloscope precision.

One challenge we encountered was the behavior of the integrator circuit at lower frequencies, like 10 Hz. At these frequencies, the output voltage becomes saturated, causing the circuit to stop functioning properly. This makes it difficult for us to measure the expected outputs, as the voltage will keep on increasing until it hits the op-amp's power limits.

In conclusion, the experiment showed how differentiator and integrator circuits behave in real life. While the results were mostly consistent with theory. the saturation issue at low frequencies demonstrated the importance of choosing the right components.