2CJ4 – Lab 4 – Set 4

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Introduction

First-order RC circuits are widely used in electrical engineering for filtering, signal processing, and timing applications. These circuits consist of a resistor and capacitor and follow a first-order differential equation that describes their voltage and current behavior.

In this experiment, we study how RC circuits respond to DC and AC sources, focusing on how capacitors charge and discharge over time. We examine both the transient and steady-state responses to understand the circuit's overall behavior. Additionally, we explore a relaxation oscillator, which uses a Schmitt trigger to generate repeated oscillations. These oscillators are useful for waveform generation and timing applications.

The goal of this lab is to build and analyze RC circuits and relaxation oscillators. We will compare theoretical predictions with experimental results to verify circuit equations and understand real-world effects like component tolerances. Additionally, we will explore how to modify the relaxation oscillator with an operational amplifier to generate a triangular waveform.

Operational Principle of the Experimental Circuit

The relaxation oscillator in this experiment alternates between charging and discharging a capacitor through a resistor. The Schmitt trigger controls the output voltage, switching it between two levels and creating stable oscillations.

At the start, V_{out} is at its positive saturation level V_{sat}. When the capacitor voltage is below the first threshold V_{th1}, the capacitor charges towards V_{sat}. Once V_c. reaches V_{th1}, the Schmitt trigger switches, and the output voltage drops to the negative saturation level $-V_{sat}$, This causes the capacitor to discharge. The capacitor continues to discharge until its voltage reaches the second threshold V_{th2}. When V_c reaches V_{th2}, the Schmitt trigger switches again, bringing the output back to V_{sat}, and the cycle repeats.

The frequency of oscillation depends on the values of the resistor, capacitor, and the Schmitt trigger's threshold voltages. The period of oscillation (T) is given by the equation:

$$T = R_3 C\left(ln\frac{V_{Sat}^{+} - V_{th2}}{V_{Sat}^{+} - V_{th1}} + ln\frac{V_{Sat}^{-} - V_{th1}}{V_{Sat}^{-} - V_{th2}}\right)$$

The frequency (*f*) is the reciprocal of the period:

$$f = \frac{1}{T}$$

In conclusion, the oscillation frequency is determined by how quickly the capacitor charges and discharges, which is influenced by the resistor and capacitor values, as well as the threshold voltages of the Schmitt trigger.

Experiment Results

i. Given the circuit in Fig. 9, calculate the period T and frequency f of the oscillator.

$$T = T_2 + T_1$$
$$T = 2R_1C \times \ln\left(\frac{1+\beta}{1-\beta}\right)$$

$$R_1 = 50k\Omega$$
$$R_2 = 22k\Omega$$
$$R_3 = 1k\Omega$$

$$\beta = \frac{R_3}{(R_2 + R_1)} = 0.04347$$
$$T = (2) \times (50000) \times (100 \times 10^{-9}) \times \ln\left(\frac{1 + 0.04347}{1 - 0.04347}\right)$$

$$T = 0.000869\ seconds$$

$$f = \frac{1}{T} = \frac{1}{0.000869} = 1150.7Hz$$

ii. Build the circuit in Fig. 9 and plot the voltage of the capacitor and the output voltage with respect to time (assuming Vsat = ± 5 F). Measure the time period T using the Analog Discovery 3 and compare it to the theoretical result.

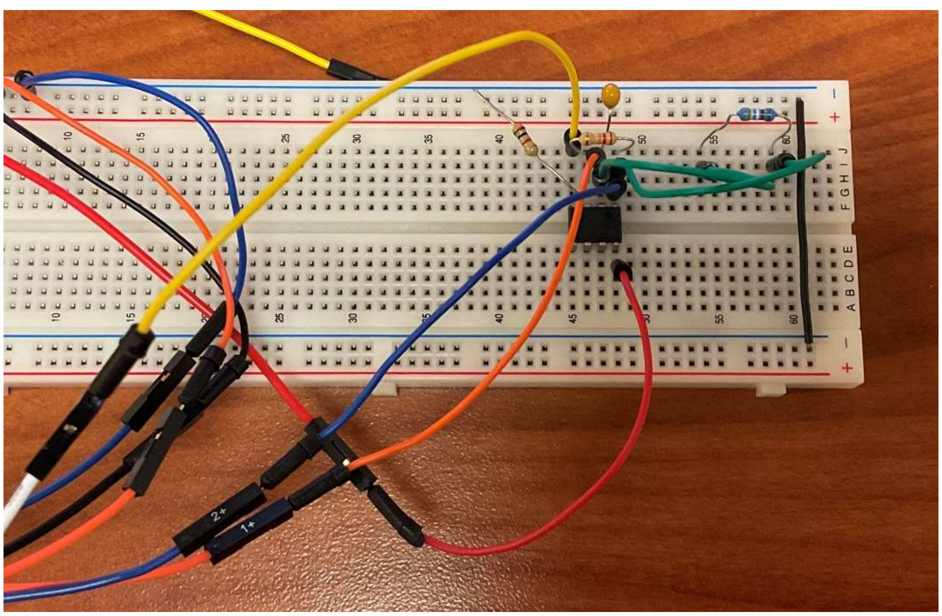

Figure 1: Relaxation Oscillator - Physical Circuit

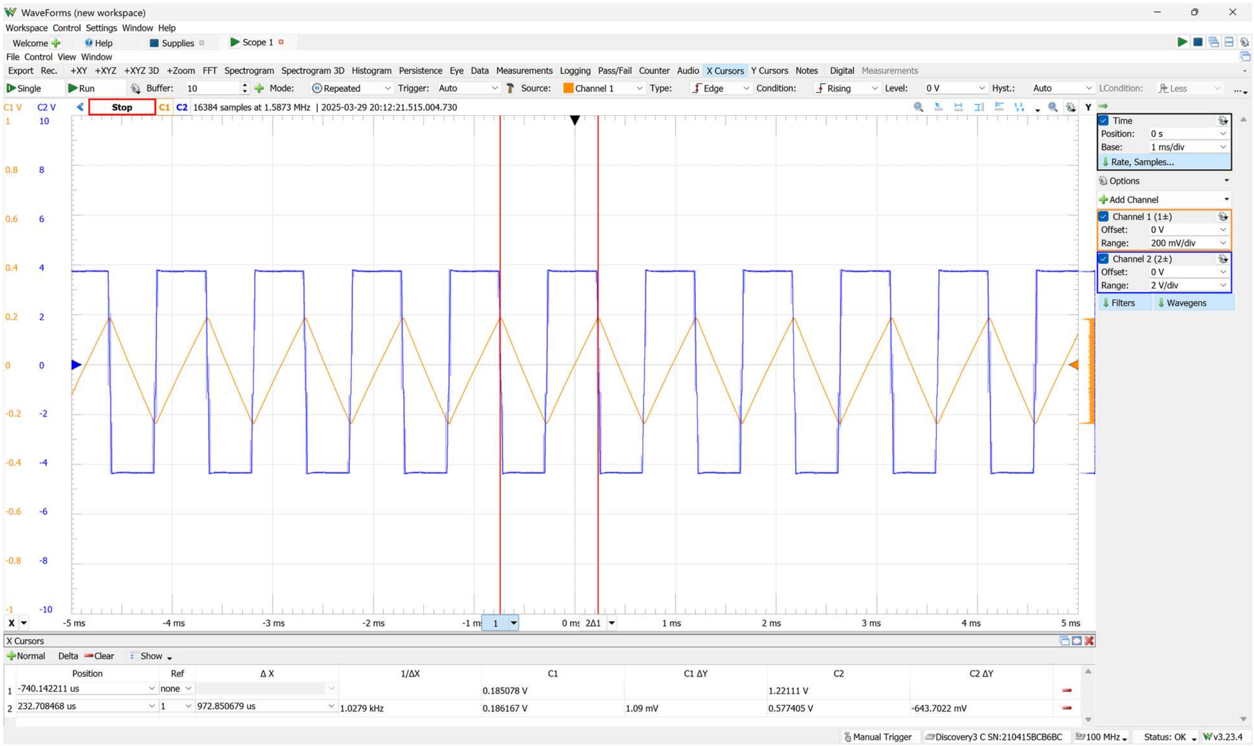

Figure 2: AD3 Measurement of V_C (t), V_{out}(t), and the Time Period

Measured Time Period: T = 0.000973 Seconds (difference if the two X cursors in Figure 2)

Theoretical Time Period: T = 0.000869 Seconds

% Error:

$$\% \, Error = \frac{Experimental - Theoretical}{Theoretical} * 100\%$$

$$\% \, Error = \frac{0.000973 - 0.000869}{0.000869} * 100\%$$

$$\% \, Error = 11.97\%$$

Therefore, the time period of the physical circuit was experimentally measured to be 973us, which is relatively close to the theoretical time period of 869us. We calculated the percent error to be 11.97%. This slight difference can be attributed to slight imperfections within the components used (resistors, capacitor, op-amp), internal resistance of the breadboard, and small calibration errors with the equipment.

The graph shows that VC forms a triangular wave and Vout forms a square wave, which confirms that the circuit is functioning as a relaxation oscillator.

iii. Can you build a circuit by using another Op-Amp LM358P to generate a triangular output? Explain.

Yes, it is possible to build a circuit that generates a triangular output using another op-amp LM358P. As we discussed in lab 3, an integrator circuit is a circuit that accepts a square wave input and produces a triangular wave output. The circuit we just build outputs a square wave, so we could feed the output of this circuit into the input of an integrator and receive a triangular wave output from the integrators output.

Discussion

This experiment successfully demonstrated how a relaxation oscillator works. It was built using an op-amp, a network of resistors and a capacitor. The goal was to measure and compare the theoretical and experimental results of the period and frequency of the oscillator output.

The theoretical period was calculated to be 860us, while it was measured to be 973us (11.97% error). This difference can be attributed to the imperfections of all real circuits which include imperfections in each individual component, internal resistances, and inaccuracies in the AD3.

The output waveform matched expectations, with the capacitor voltage displaying a triangular waveform and the output voltage forming a square wave. This confirms that the circuit was functioning as a relaxation oscillator, switching between positive and negative saturation levels as the capacitor charges and discharges.

The only minor challenge we faced was ensuring that connections were secure on the breadboard to prevent unstable oscillation or distorted waveforms. Apart from that the lab went very smoothly and everything worked on the first try.

Overall, the experiment validated the theoretical design principles of a relaxation oscillator, and the minor experimental error is consistent with what can be expected in real life circuits.