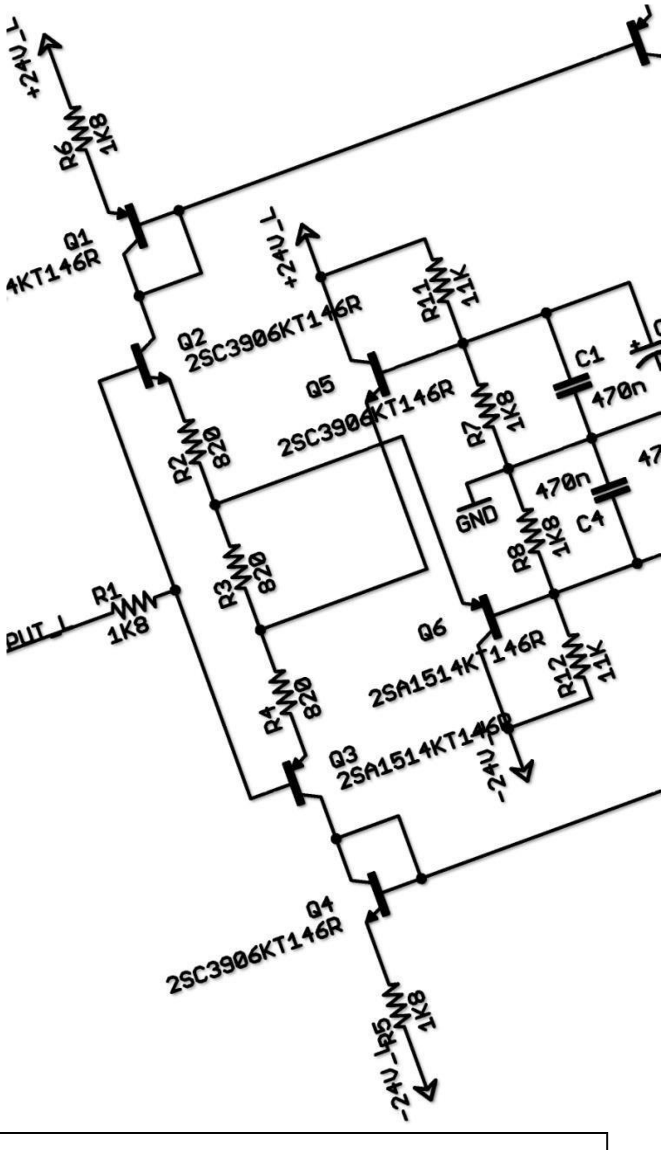
MONASH University
Engineering

ECE2131

Electrical Circuits

Laboratory Notes



2022 Edition

Name: Tan Jin Chun	Student ID: 32194471	Email: jtan0260@student.monash.edu

Electrical and Computer Systems Engineering, Monash University

2022

9 Operational Amplifier Applications II

9.1 Learning Objectives and Introduction

Another useful application of an opamp is as a source of oscillations. This laboratory explores two different sides of oscillation – hysteresis effects and the design of multivibrators.

The first part of this lab involves exploring the operation of a Schmitt trigger, a device which uses a positive feedback comparator to control the amount of certain types of noise (for example, from a switch bouncing) in a signal. It can also be used to generate a square wave from a sinusoidal input. This device relies on hysteresis to operate – the circuit has a sense of 'memory' of its state. This is a bi-stable multivibrator.

The second part of this lab involves the exploration of a relaxation oscillator, which is an astable multivibrator. This circuit has applications as a source of non-sinusoidal oscillations in electronic circuits (for example – making a turn light on a car flash).

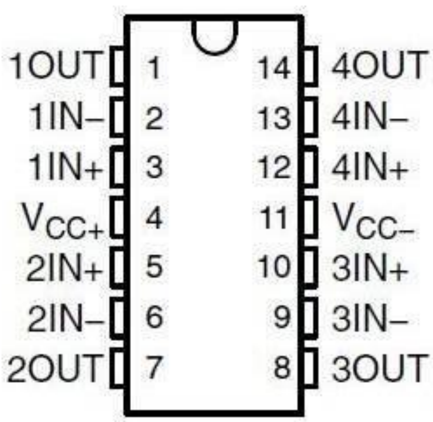
By the end of this lab you should:

- Build and characterise op-amp circuits with positive feedback.
- Understand the fundamental differences in operation for op-amp circuits in positive or negative feedback.
- Build a Schmitt trigger comparator, and understand the causes of differences between theory and lab outcomes
- Build an oscillator with a set frequency, based on knowledge of RC time constants and comparators.

9.2 Equipment and Components

- Breadboard.
- Opamp TL074.
- Resistors: 1 kOhm, 10 kOhm.
- Capacitors: 100 nF, 100 pF.

TL074 Connection Diagram



9.3 IMPORTANT NOTES

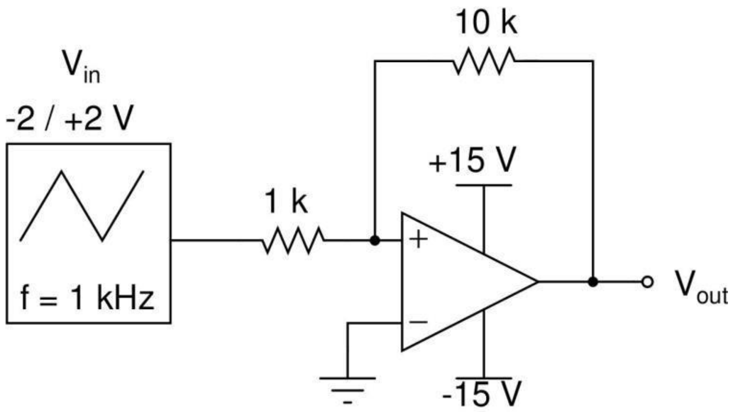
Remember that the components have tolerances (resistors 1%, ceramic and polyester capacitors 10%, electrolytic capacitors up to 40%). It is not critical that your circuit meet the required specifications exactly; but you should take account of component tolerances, their effect on your design and the performance variations that you can expect from the circuits as a consequence.
The operational amplifier used as a comparator in this experiment is the TL074. Note that the performance of this op amp as a comparator is poor, since the op amp slew rate limit significantly reduces the transition switching times.

Make sure you include 0.1uF ceramic decoupling capacitors between the supply voltages and ground close to the circuit/power supply pins of the op-amp. These capacitors provide transient high-frequency current to the circuit during switching transitions, and are critical for reliable operation.

9.4 EXPERIMENTAL WORK

9.4.1 PART A – SCHMITT TRIGGER (HYSTERESIS) COMPARATOR

Construct the following comparator circuit on the prototype board.



9.4.1.1 Set the signal generator to a 1 kHz $4V_{p\text{-}p}$ (+2V and -2V peaks) triangular waveform, with zero DC offset. If you are using ADAML2000, you can reduce the power supply to +5V and -5V respectively.

Using this arrangement, measure and record the circuit hysteresis offset (i.e. the input voltage difference between the comparator output switching high and switching low), $V_{hys} = V_{PH} - V_{PL}$

Compare each of these experimental values to the theorical values. Explain any discrepancies/similarities.

Experimental (Measured) Values

From the graph above, we can see that the circuit hysteresis offset is 897.010 mV

Theoretical Calculations

Assuming ideal op-amp, the output voltage will change when the non inverting input terminal voltage exceeds the inverting input terminal voltage.We can assume that the non-inverting input voltage is 0V. The theoretical circuit offset then can be obtained by applying KCL at V_+.

When triggering from low output voltage to high output voltage, V_{out} will be -5V and V_+ will be 0V.

$$\frac{V_+ - V_{in}}{1k} + \frac{V_+ - V_{out}}{10k} = 0$$

$$\frac{0 - V_{in}}{1k} + \frac{0 + 5}{10k} = 0$$

$$V_{input} = 0.5V$$

When triggering from high output voltage to low output voltage, V_{out} will be 5V and V_+ will be 0V.

$$\frac{V_+ - V_{in}}{1k} + \frac{V_+ - V_{out}}{10k} = 0$$

$$\frac{0 - V_{in}}{1k} + \frac{0 - 5}{10k} = 0$$

$$V_{input} = -0.5V$$

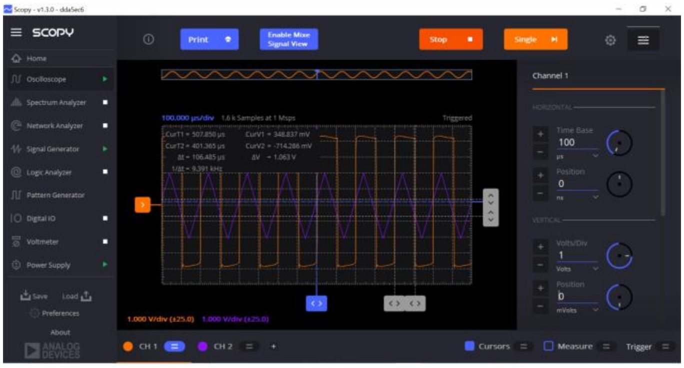
The circuit hysteresis offset would be 0.5 –(-0.5) = 1.0 V

The actual circuit hysteresis offset will be lower than the theoretical calculations. This is because a non-ideal op-amp is being used. There are voltage drop across the op-amp due to the presence of transistors and capacitors in the circuit. This will cause the output voltage to be unable to reach the supply rail voltage. This would result in the drop of the trigger voltage and the circuit hysteresis offset. This difference could also be due to the systematic error by humans during the reading of the graph and the inaccuraccies rising from Scopy itself.

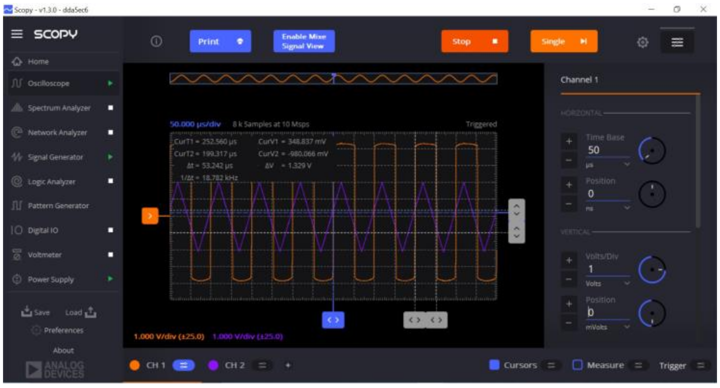
9.4.1.2 Increase the signal generator frequency to 2kHz, 5kHz, 10kHz, 50kHz, 100kHz, and then to 200 kHz. Explain any changes observed when frequency increases. Do not use a network analyzer for this question.

2kHz

5kHz



10kHz



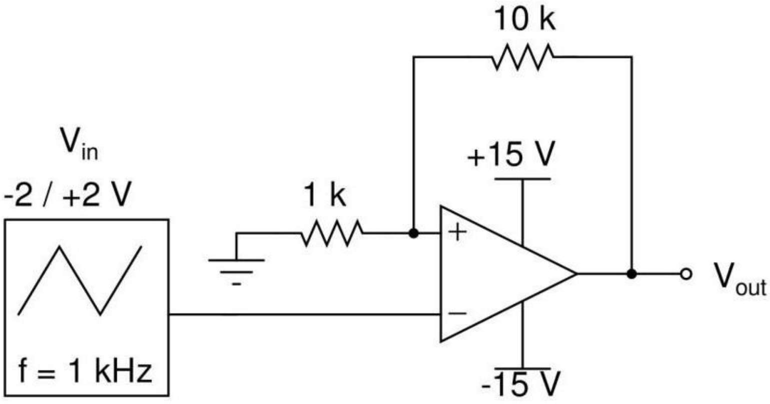
50 kHz

100 kHz

200 kHz

When the frequency of the signal generator increases, the time for the non-ideal op-amp to change its output will decrease as it can be seen in the sequence of graphs above. The circuit hysteresis offset will also increase with an increase in the frequency of the signal generator. As we can observe from the 4th graph (when the input frequency is 50kHz), the output voltage requires some time to move from high to low voltage and vice versa. We can also observe that the edge of the output voltage graph will become more slanted which is due to the limited slew rate of the op-amp.

9.4.1.3 Construct the following circuit. Measure the hysteresis levels and compare with the previous measurements in 9.4.1.1. Explain the differences to the previous circuit. Explain any comments/discrepancies against theoretical values also.



Measured Values

From the graph above, we can see that the circuit hysteresis offset is -863.787 mV

Theoretical Calculations

Assuming ideal op-amp, the output voltage will change when the non inverting input terminal voltage exceeds the inverting input terminal voltage.We can assume that the non-inverting input voltage is 0V. The theoretical circuit offset then can be obtained by applying KCL at V_+

When triggering from low output voltage to high output voltage, V_{out} will be -5V and V_+ will be 0V.

$$V_{PH} = \frac{R_1}{R_1 + R_2} * V_{cc}$$

$$V_{PH} = \frac{1000}{1000 + 10000} * (\text{-5V})$$

$$V_{PH} = \text{-0.455 V}$$

When triggering from high output voltage to low output voltage, V_{out} will be 5V and V_+ will be 0V.

$$V_{PH} = \frac{R_1}{R_1 + R_2} * V_{cc}$$

$$V_{PH} = \frac{1000}{1000 + 10000} * (5V)$$

$$V_{PH} = 0.455 \text{ V}$$

The theoretical circuit hysteresis would be -0.455 – 0.455 = -0.91 V

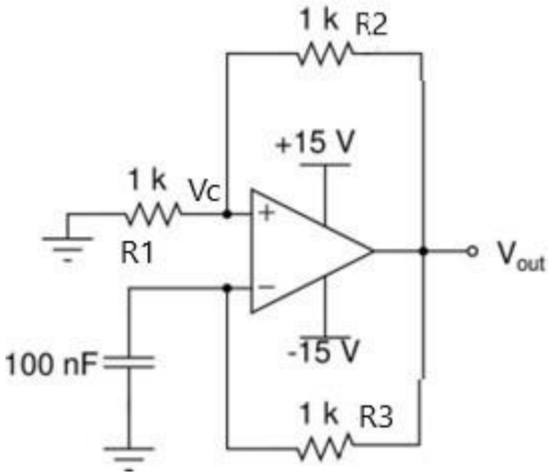
The actual circuit hysteresis offset will be lower than the theoretical calculations. This is because a non-ideal op-amp is being used. There are voltage drop across the op-amp due to the presence of transistors and capacitors in the circuit. This will cause the output voltage to be unable to reach the supply rail voltage. This would result in the drop of the trigger voltage and the circuit hysteresis offset.

The circuit configuration shown above is an inverting Schmitt Trigger Circuit. The measured hysteresis level for an inverting Schmitt Trigger Circuit is less than the hysteresis level for a non-inverting Schmitt Trigger. The voltage supplied to the inverting terminal and the output voltage is supplied to the non-inverting input terminal. Thus, the polarity of the output will be of the opposite when compared with the previous measured value in 9.4.1.1.

There are some slight difference between the theoretical and the measured value. This could be due to the systematic error by humans during the reading of the graph and the inaccuraccies rising from Scopy itself.

9.4.2 PART B – ASTABLE RELAXATION OSCILLATOR

Construct the following astable multivibrator circuit on the prototype breadboard.



9.4.2.1 Investigate the comparator output (V_{out}) and the voltage across the 100nF capacitor (V_C). Explain your observations. What is the measured frequency observed at V_C? Does the oscillation frequency match theoretical expectations? Explain.

Theoretical Calculations

We can use KCL to find the voltage then the frequency of the oscillation.

We will get

$$i_c + i_{R3} = 0$$

$$C\ \frac{dV_-}{dt} + \frac{V_{out} - V_-}{R_2} = 0$$

$$\frac{dV_-}{V_{out} - V_-} = \frac{1}{R_3 * C}$$

We would get

$$V_-(t) = V_{out} - (V_{out} - V_-(0))e^{-\frac{t}{R_3 C}}$$

The time to reach high threshold voltage would be

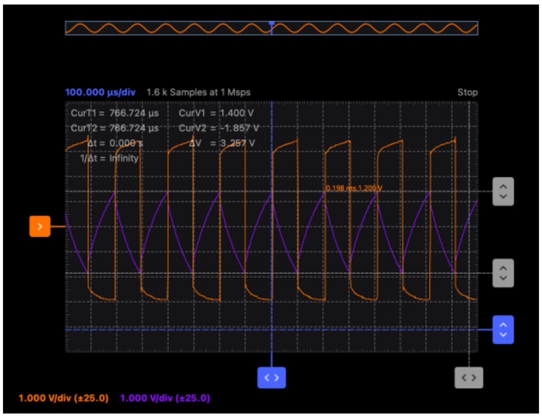
$$t = R_3 * C \ln\left(\frac{V_{CC} + \frac{V_{EE} * R_1}{R_1 + R_3}}{V_{CC}\left(1 - \frac{R_1}{R_1 + R_3}\right)}\right)$$

The theoretical oscillation frequency would be

$$f = \frac{1}{2t}$$

which equates to 4551.196 Hz

Measured Value



The measured value across the capacitor will be 3.591 kHz

From the graph above, we can see that the voltage across the capacitor would charge up to the high threshold voltage. The output voltage would then drop to -Vsaturation, which would cause the capacitor to discharge. When the capacitor discharge from the high threshold voltage to low threshold voltage, the output voltage of the op-amp would increase to +Vsaturation.

There are some slight difference between the theoretical and the measured value. This could be due to the systematic error by humans during the reading of the graph and the inaccuraccies rising from Scopy itself. There would also be some drop in voltage across the op-amp as the transistors and the capacitors requires some current bias. The output swing of the output voltage is also not up to the supply rail voltage which would result in the decrease of the magnitude of the saturation voltage. This combined reason would result in the differences between the theoretical and measured frequency.

9.4.2.2 Comment on the magnitude limits of the capacitor peak voltages and the comparator switched output compared to ideal theory. What is the theoretical peak voltages across the capacitor?

Theoretical Calculations

Theoretical Trigger Points (High Threshold Voltage)

$$V_{ht} = \frac{R1}{R1 + R3} * Vcc$$

$$V_{ht} = \frac{1000}{1000 + 1000} * 5$$

$$V_{ht} = 2.5\ V$$

Theoretical Trigger Points (Low Threshold Voltage)

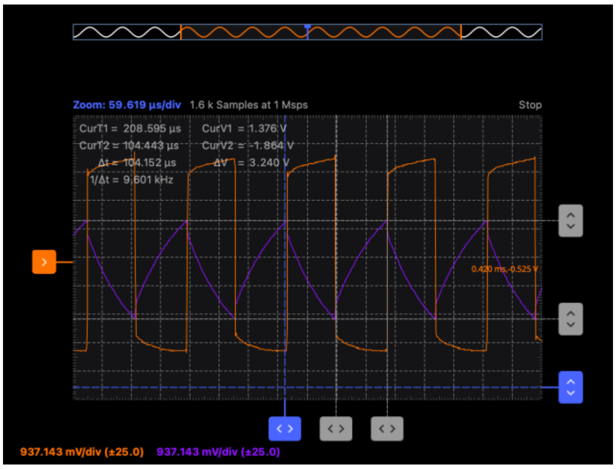
$$V_{ht} = \frac{R1}{R1 + R3} * Vcc$$

$$V_{ht} = \frac{1000}{1000 + 1000} * -5$$

$$V_{ht} = -2.5\ V$$

Measured Value

The Measured Trigger Points



The measured magnitude limits of the capacitor peak voltages are 1.376 V and -1.864 V respectively.

The measured magnitude limits of the capacitor peak voltages will be lower than the theoretical value. There is a difference between the theoretical and the measured value of the peak voltages which is caused by the maximum output swing of the non-ideal op-amp. The output is unable to reach to the supply rail voltage. The output would then decrease the trigger voltages and the hysteresis offset. This could also be due to the systematic error by humans during the reading of the graph and the inaccuraccies rising from Scopy itself.

9.4.2.3 Change the capacitor to 100pF. What is the oscillation frequency now? Does the circuit still operate correctly? If not, why not?

Theoretical Value

The theoretical frequency would be

$$t = R_3 * C \ln\left(\frac{V_{CC} + \frac{V_{EE} * R_1}{R_1 + R_3}}{V_{CC}\left(1 - \frac{R_1}{R_1 + R_3}\right)}\right)$$

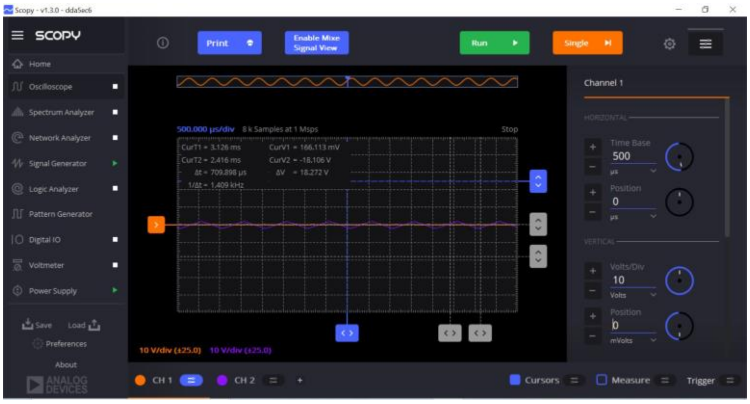
The theoretical oscillation frequency would be

$$f = \frac{1}{2t}$$

which equates to 4.6 MHz

Measured Value

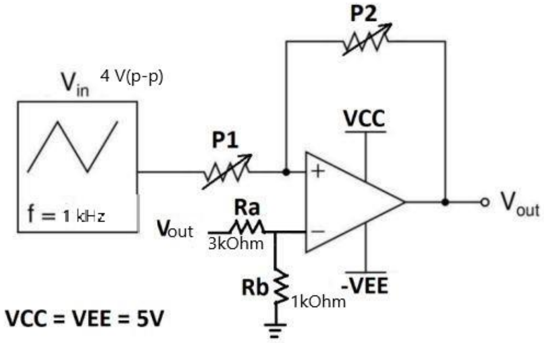
The measured frequency would be

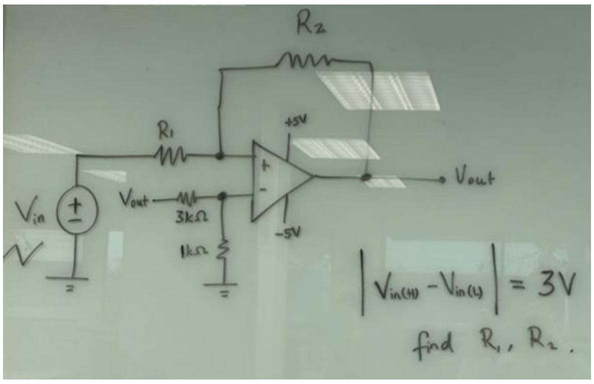


The measured frequency will be 0Hz as we can see in the graph above. The circuit will not operate properly. The given capacitor has a capacitance value that is too small, causing the oscillation frequency to be very high. The slew rate of the non-ideal op-amp would limit the rise and fall of the op-amp after reaching the trigger threshold voltage. The capacitor will not have enough time to charge and discharge as the oscillation frequency is too high.

LAB ASSESSMENT

Given Circuit





Design the circuit where $\left|V_{in(H)} - V_{in(L)}\right| = 3$.

Theoretical Value

We can find the ratio between R1 and R2 by using the voltage divider rule

$$v_+ = v_{in} + (v_{out} - v_{in}) \times \frac{R_1}{R_1 + R_2}$$

$$v_+ = v_{in} + v_{out}\left(\frac{R_1}{R_1 + R_2}\right) - v_{in}(\frac{R_1}{R_1 + R_2})$$

$$v_+ = v_{in} + (v_{out} - v_{in}) \times \frac{R_1}{R_1 + R_2}$$

$$v_{in} = \frac{v_+(R_1 + R_2) - v_{out}R_1}{R_2}$$

In order to obtain a symmetric threshold, we can separate 3V into two parts.

$$V_{in(H)} = \frac{V_{sys}}{2} = 1.5$$

$$V_{in(L)} = -\frac{V_{sys}}{2} = -1.5$$

where $v_{out} = -V_{EE} = -5V,\ v_{in} = V_{in(H)}$, $v_+ = v_-$ and given R1 = 1000 Ohms and R3 = 3000 Ohms

$$v_- = v_{out} \times \frac{1 \times 10^3}{3 \times 10^3 + 1 \times 10^3}$$

$$= -1.25 \text{ V}$$

$$V_{in(H)} = \frac{(-1.25)(R_1 + R_2) - (-5)R_1}{R_2} = 1.5$$

$$3.75R_1 - 1.25R_2 = 1.5R_2$$

$$\frac{R_1}{R_2} = \frac{2.75}{3.75} = 0.733$$

when $v_{out} = V_{CC} = 5V,\ v_{in} = V_{in(L)}$, $v_+ = v_-$ and given R1 = 1000 Ohms and R3 = 3000 Ohms

$$v_- = 5\ \times \frac{1 \times 10^3}{3 \times 10^3 + 1 \times 10^3}$$

$$= 1.25 \text{ V}$$

$$V_{in(L)} = \frac{(1.25)(R_1 + R_2) - 5R_1}{R_2} = -1.5$$

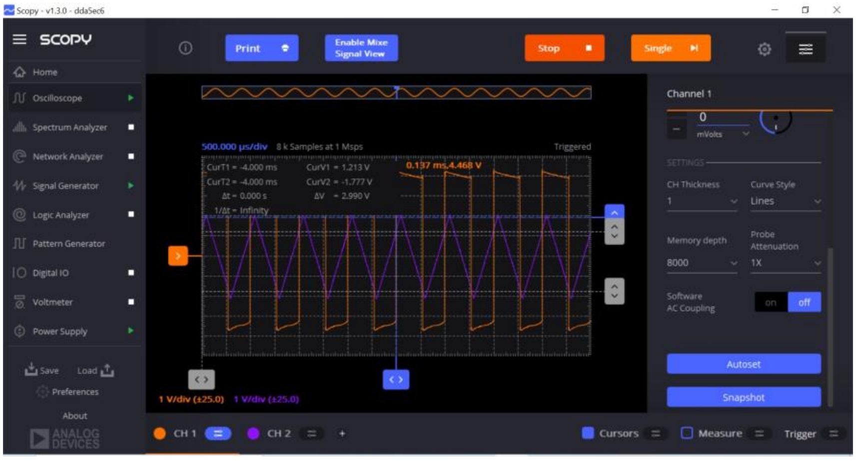
$$-3.75R_1 + 1.25R_2 = -1.5R_2$$

$$\frac{\mathrm{R}_1}{\mathrm{R}_2} = \frac{2.75}{3.75} = 0.733$$

Both ratios are the same, this means that we can freely choose any value of R_1 and R_2 that satisfies the ratio found above.

For our circuit, we have chosen 1000 Ohms to be R1. The theoretical value that we should get for R2 would be 1363.64 Ohms.

Measured Value



Based on the visual observation of the graph above, the value of v_{in} is 1.213 V while the value of $V_{in(L)}$ is -1.777 V. Our value for $|V_{in(H)} - V_{in(L)}|$ is equal to $|1.213\text{ V} - (-1.777\text{ })|$ which would equate to 2.990 V. The resistor value used for R1 is 1000 Ohm and the R2 (potentiometer) will have a value of 1480 Ohm (Measured using the multimeter) which would equate to a value for $\frac{\boldsymbol{R_1}}{\boldsymbol{R_2}} = \frac{1000}{1480}$ = 0.676. This value is close to the theoretical value of 0.733. There could be discrepancies between the measured and the theoretical value. This is due to the fact that there is a systematic error made by humans during the reading of the graph in Scopy or the difference could arise from the inaccuracies from Scopy itself. We can also observe that the measured lower threshold will be larger than the theoretical value while the measured upper threshold will be smaller than the theoretical value. This means that the V_{hys} ($V_{PH} - V_{PL}$) will have a smaller value than 3V. This observation could be explained as the maximum output swing of the op-amp output voltage is not rail-to-rail. The output voltage will be unable to reach to the supply rail voltage. Thus, this could explain the reason why the measured value is has a lower magnitude than the theoretical value.

ASSESSMENT

Student Statement:

I have read the university's statement on cheating and plagiarism, as described in the *Student Resource Guide*. This work is original and has not previously been submitted as part of another unit/subject/course. I have taken proper care safeguarding this work and made all reasonable effort to make sure it could not be copied. I understand the consequences for engaging in plagiarism as described in *Statue 4.1 Part III – Academic Misconduct*. **I certify that I have not plagiarized the work of others or engaged in collusion when preparing this submission.**

Student signature: Tan Jin Chun Date: 13 / 5 / 2022

TOTAL: ________(/7)

ASSESSOR: ________