Lab Assignment 4

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1. Introduction

This lab report presents the design and construction of an oscillator. The main objective of this experiment was to design a 1 Hz oscillator capable of generating a stable signal at this frequency. However, we opted to construct a Voltage-to-Frequency Converter (VFC), also known as a Voltage Controlled Oscillator (VCO), instead of a fixed-frequency oscillator. This modification allows the output frequency to be dynamically controlled by an input voltage, offering greater flexibility and application in scenarios where the frequency needs to be adjusted based on varying conditions. The VFC circuit operates by converting a DC input voltage into a corresponding output frequency. In this report, we will discuss the design considerations for both fixed-frequency and variable-frequency circuits, the components used in constructing the VFC, and the experimental results that demonstrate the behavior of the circuit under different input conditions. The report will also explore the challenges faced during the construction and testing phases, as well as potential improvements to enhance the performance and accuracy of the oscillator.

2. Theory

2.1. What is an Oscillator?

An oscillator is a circuit that generates a repetitive waveform, like a sine wave, square wave, or triangular wave, with a DC input. They are sometimes characterised by their frequency. **LFO** is a Low Frequency Oscillator with oscillation frequency less than 20Hz. By contrast, an **RF oscillator** produces freqencies in the range 100kHz to 100GHz.

An oscillator can be linear or non-linear

- **Linear or Harmonic Oscillators** : Feedback Oscillator and Negative Resistance Oscillator. It consists of an amplifier in positive feedback or a current source-like-element.
- **Non - Linear or Relaxation Oscillator** : It generally consists of an energy-storing element and a switching device. This switching device is what causes the system to be non-linear.

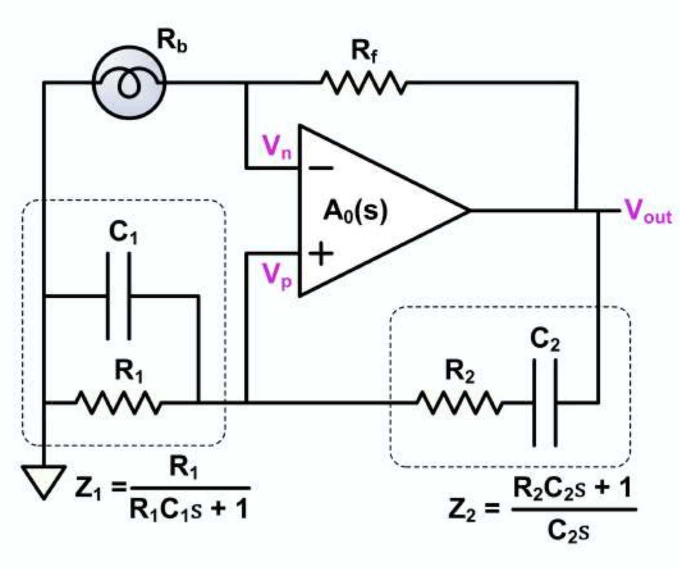

Figure 1. General Schematic of a Wien Bridge Oscillator

2.2. Example: Wien - Bridge Oscillator

The Wien bridge oscillator consists of an Op-Amp and a Wien bridge network made up of resistors and capacitors. A Wien Bridge Network is a bunch of resistors and capacitors, initially meant to help measure impedences of circuits. This network of R and C is used to provide positive feedback for oscillation, while a separate part of the circuit provides the necessary negative feedback to stabilize the amplitude.

2.2.1. *Working Of the Oscillator*

When the circuit in Figure 1 is powered, the inherently existent noise in the system is picked up by the Op Amp, and the frequency components of the noise that match the natural resonant frequency of the Wien bridge network will be amplified by positive feedback.

The feedback network consists of a frequency-selective bridge formed by resistors and capacitors. This network includes two arms: one arm consists of a resistor R_1 in series with a capacitor C_1, and the other arm consists of a resistor R_2 in parallel with a capacitor C_2. These components determine the frequency of oscillation based on the following relationship:

$$f_0 = \frac{1}{2\pi R_1 C_1}$$

At this frequency, the phase shift around the feedback loop is zero degrees, and the circuit satisfies the Barkhausen Criterion for sustained oscillation, which requires that the total phase shift around the loop is 0°, and the loop gain should be made equal to 1.

The ratio of R_f and R_b must be adjusted so that the gain of the op-amp is precisely 3, which compensates for the attenuation caused by the feedback network, producing a stable sine wave at the output.

Thus, the Wien bridge oscillator generates a stable, low-distortion sine wave with a frequency determined by the values of R_1, C_1, R_2, and C_2.

3. Design Of The VCO

We designed the VCO from scratch. The idea was quite simple.

1. Charge a capacitor to a particular voltage
2. Set a threshold voltage for the cap
3. Short the capacitor when it crosses the threshold voltage

3.1. Proof of Concept

Consider the following simulation of an integration coupled with switching using python.
Integrator: Rises, hits V_{cc}, and saturates.

```python
def integrator_output(R, C,  v_in, t):
    dt = t[1] - t[0]
     v = np.zeros_like(t)

    for i in range(1, len(t)):
         v[i] =  v[i-1] + (v_in[i-1] * dt) / (R * C)
         v[i] = min(v[i], 12)
    return  v

t = np.linspace(0, 2, 10000)
v_in = 2.35*np.heaviside(t , 1)
R = 5e5
C = 470e-9
v_out = integrator_output(R, C,  v_in, t)
```

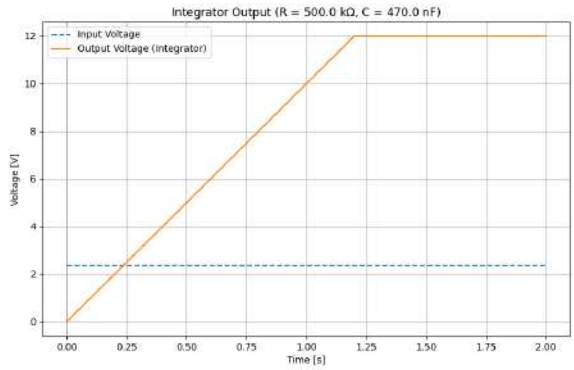

Figure 2. Output of the integrator simulation for a 2.35V CV in

Comparator

```python
def comparator(v_in) :
        if v_in < self.threshold :
            return -15
        return 0
```

Figure 3 shows the output of the comparator for an input sine wave and the theshold of -8V. Combining both, we have the following code.

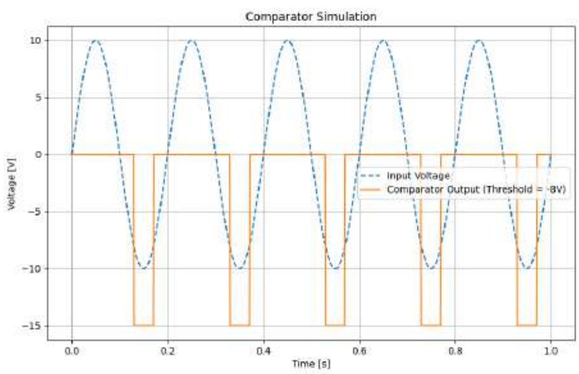

Figure 3. Output of the comparator simulation for an input sine wave

```python
class VCO:
    def __init__(self, R, C, v_t , t, cv_in, v_out):
        self.cv = cv_in
        self.R = R
        self.C = C
        self.threshold = v_t
        self.t = t
        self.dt = self.t[1] - self.t[0]
        self.v = v_out
        self.int_out = self.integrator(self.v, self.cv)


    def integrator(self, v, v_in) -> float :
        for i in range(len(self.t))[1:]:
            if self.comparator(v[i-1]) == -15:
                v[i] = v[i - 1] + v_in[i - 1]*dt/(R*C)
            else :
                v[i] = 0
        return v
    def comparator(self, v_in) -> int :
        if v_in < self.threshold :
            return -15
        return 0

if __name__ == "__main__":
    t = np.linspace(0, 5, 1000)
    cv = 2.35*np.heaviside(t, 1)
    # print(cv)
    v_out = np.zeros_like(t)
    v_out[0] = 0.1
    vco = VCO(5e5, 470e-9, 10, t, cv, v_out)
```

The output of this code is shown in Figure 4

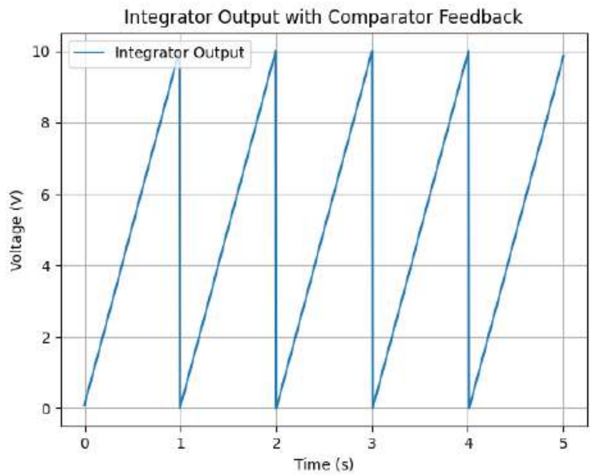

Figure 4. Output of the VCO simulation

3.2. The Integrator

The first part of the VCO is the integrator, whose output voltage V_{out} is related to V_{in}, by the following relation

$$V_{out} = \frac{1}{RC}\int_0^t V_{in}(t)dt$$

Here V_{in} is the DC input control voltage. Therefore

$$V_{out} = \frac{1}{RC}\int_0^t V_{in}dt = \frac{1}{RC}\left[V_{in}\cdot t\right]_0^t = \frac{V_{in}}{RC}t$$

If left unregulated, the output would linearly increase, and hit V_{cc}. The slope of this graph, and consequently the rise time of this circuit is determined by the input control voltage.
The next step in this process is to short the cap when it reaches some voltage. This means that voltage has to be sensed. We use a comparator for this purpose.

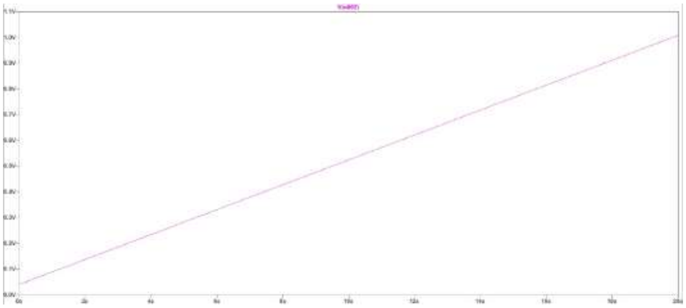

Figure 5. This is the output of our integrator for a 1V CV in

3.3. The Comparator

A comparator is an electronic device that compares two input voltages and provides a digital output indicating which input is higher. We use a Open-Collector Comparator for the purpose of this experiment.

3.3.1. An Open-Collector Comparator

An open-collector comparator is a type of comparator where the output is designed as an open-collector stage, meaning the output is an open transistor collector. This configuration requires an external pull-up resistor to properly function, as the output transistor can either sink current (pull the output low) or remain floating (allow the external resistor to pull the output high).

3.3.2. Operation

The comparator compares two input voltages: the inverting input (V_-) and the non-inverting input (V_+). The basic operation can be explained as follows:

- When $V_+ > V_-$, the output transistor is open (non-conducting). Since the transistor is not sinking current, it is in a floating state, unless combined with a resistor connected to some voltage greater than $-V_{cc}$, when the current flow is directed to the source.
- When $V_+ < V_-$, the output transistor is turned on (conducting). In this state, the transistor sinks current to $-V_{cc}$, pulling the output voltage to nearly $-V_{cc}$.

This open-collector design is particularly useful for making switching circuits. In this particular case, we need to control a transistor, to short a capacitor. If the voltage across the gate of a particular JFET is switched between -15V and 0V, the FET behaves as a switch (High resistance at -15V and virtually a short at 0V).
Now we need to connect a couple of things

- The Voltage across the capacitor as the input for the comparator.
- The output of the comparator to the gate of the JFET across the Capacitor.

The final circuit diagram looks something like this. The Op-Amp U2 in the schematic was swapped out with slight modifications for an LM741.

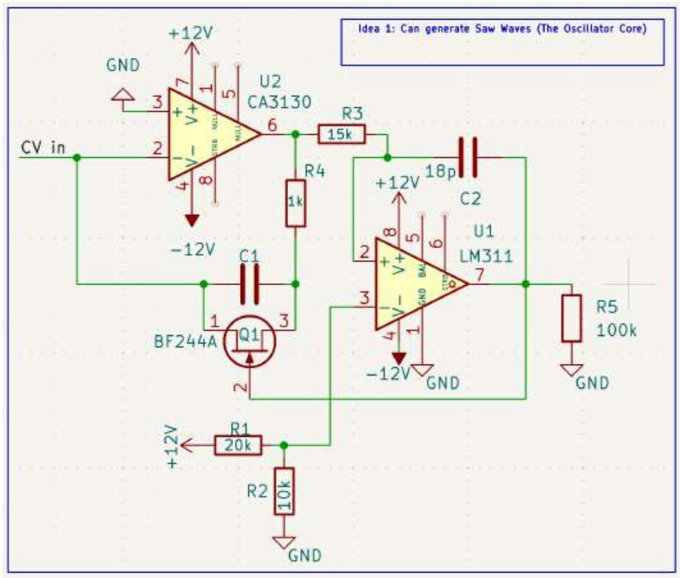

Figure 6. Schematic of the Oscillator

4. Challenges and Alternatives

The integrator and comparator functioned perfectly on their own, but when connected as shown, both outputs saturated at a value below the expected threshold. There are multiple reasons that this could have happened. We didn't have time to test why, or even fix the matter. So we decided to build the most unimaginative 1Hz Oscillator.

5. The Astable Multivibrator

An Astable Multivibrator is a circuit which oscillates continuously between 2 states, without any external triggering. It is termed "astable" because it has no stable states—both states of the output are unstable, causing the circuit to continually switch between high and low output levels.

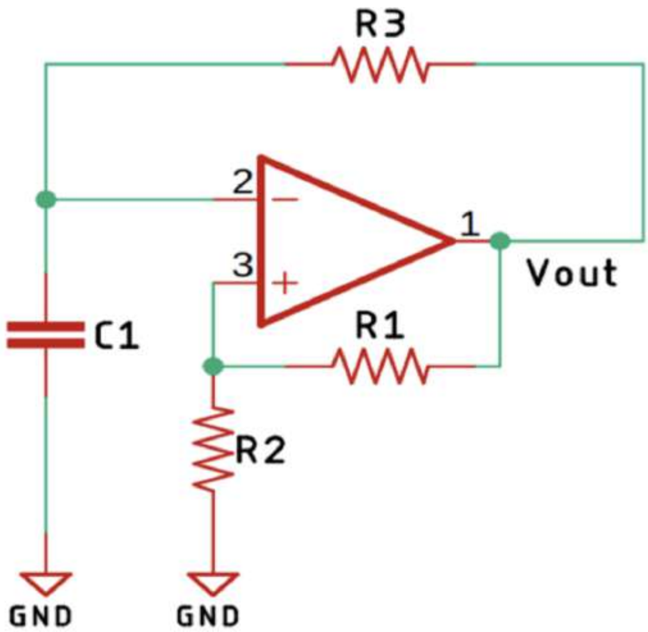

Figure 7. Schematic of the Astble Multivibrator Oscillator

5.1. Working Principle

This Oscillator has 2 "blocks". The RC circuit, which charges and discharges, and the reset circuit, The schmidt trigger. The voltage at the +ve terminal is

$$V_+ = \frac{R_2}{R_1} V_{out}$$

Let $\frac{R_2}{R_1} = k$. There is some noise in the circuit initially. The amplifier amplifies the signal and hits either V_{cc}, or $-V_{ee}$. Now the compare voltage V_+ is kV_{out}. Till the capacitor charges to kV_{out}. When it charges to kV_{out}, the output flips to the opposite polarity $-V_{out}$, and the discharge cycle starts, until it hits $-kV_{out}$, then the process repeats. The output swings between $+V_{out}$ and $-V_{out}$, where V_{out} is the Saturation voltage ($+V_{cc}$).

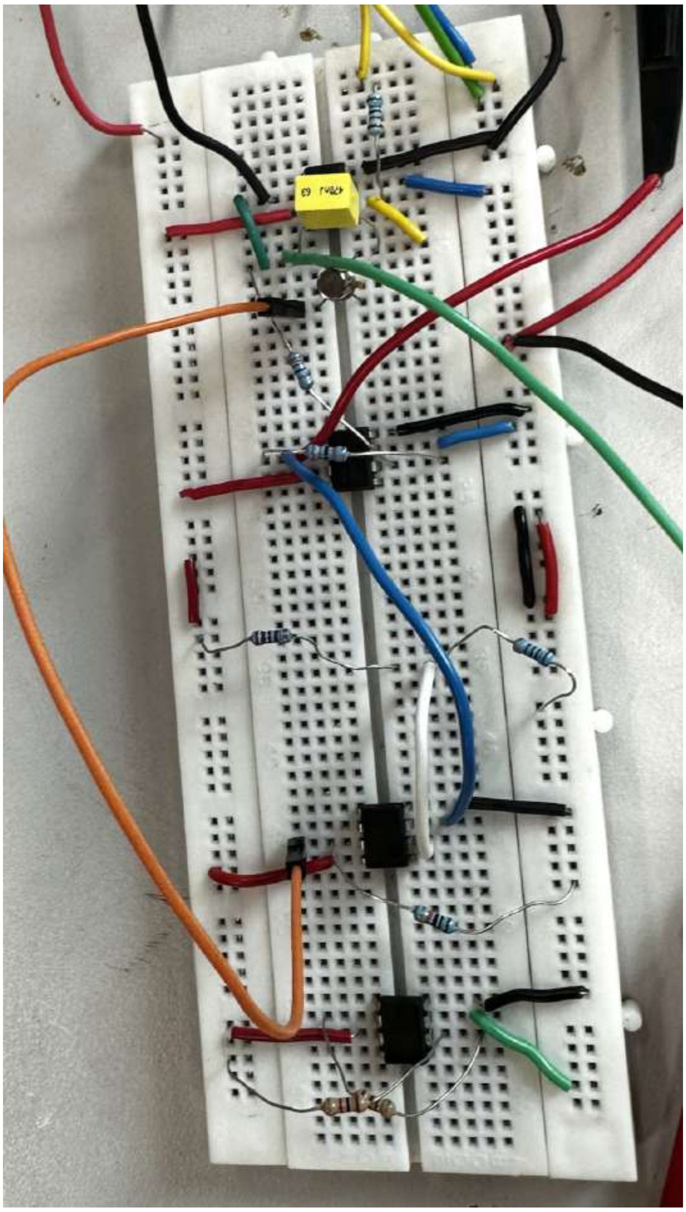

Figure 8. Failed Circuit

6. Final Result and Observations

6.1. Failed Circuit

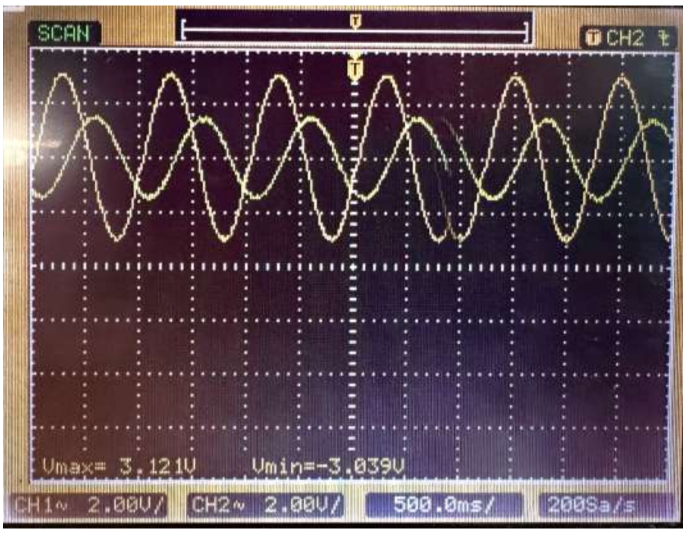

Figure 9. Output of Integrator

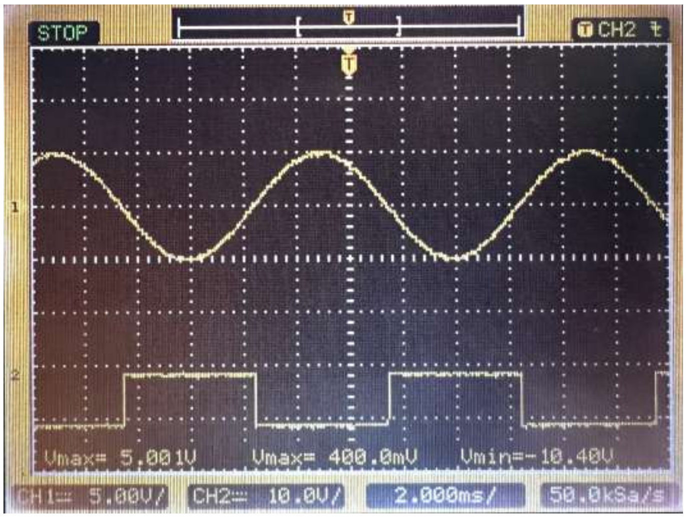

Figure 10. Output of Comparator

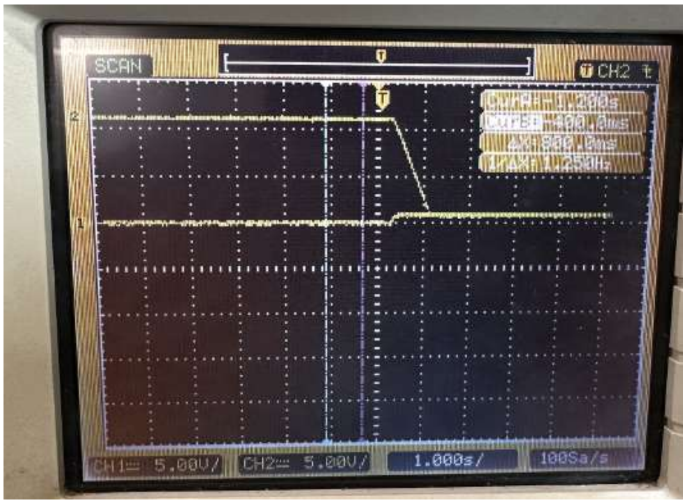

Figure 11. Failed Output

Figures 8, 9 and 10, are the circuit diagram, integrator output and comparator output respectively. When combined, it saturates at some voltage (Figure 11)

6.2. Working Outputs

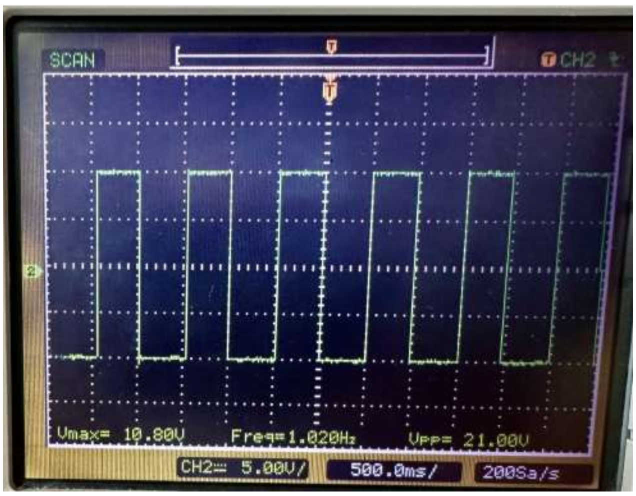

Figure 12. Output of Oscillator

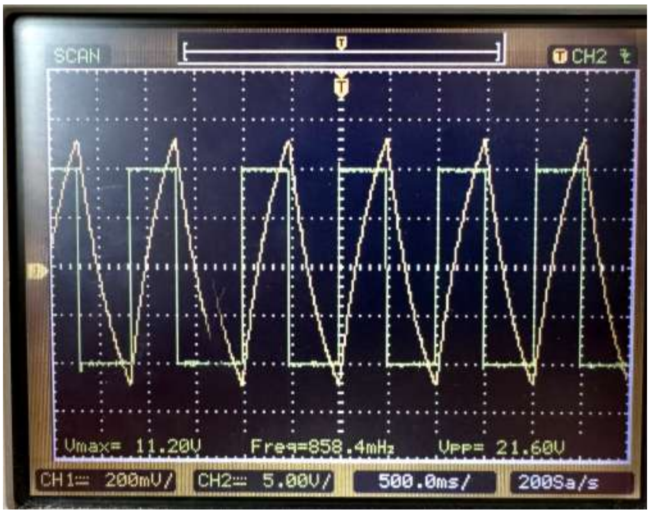

Figure 13. Output of Oscillator, and RC relaxation

7. Conclusion

In this lab assignment, we looked at the design and implementation of a 1 Hz oscillator by first attempting to construct a Voltage-to-Frequency Converter (VFC) and later switching to an astable multivibrator when initial designs failed. The primary goal was to achieve a stable 1 Hz oscillation, but the inclusion of variable frequency control in the VFC circuit introduced new challenges that could not be solved within the available time.

This exercise highlighted the complexities involved in oscillator design, especially when incorporating variable frequency control. Future improvements could focus on better debugging techniques, refining the comparator circuit, and exploring alternative oscillator configurations that offer both stability and frequency variability. Overall, this lab provided valuable insights into the practical challenges of analog circuit design and emphasized the importance of adaptability and troubleshooting in experimental electronics.