Indian Institute of Technology Hyderabad

Course: Electronic Devices & Circuits Lab

Course Code : EE2301

Lab Assignment 4

1Hz Oscillator

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1 Introduction

In this experiment, we aim to create a 1 Hz oscillator circuit using an operational amplifier. The output is supposed to be a square waveform of frequency 1 Hz, varying between 0V (logic LOW) and 5V (logic HIGH). This type of circuit is called an Astable Multivibrator, because it has two states (high and low) and it switches constantly between them. The op-amp is set up to be a Schmitt Trigger so that it can eliminate noise from analog signal and produce a digital signal. Feedback in the op-amp ensures that the capacitor continuously charges and discharges, giving rise to oscillations in the square wave. This output can be used as a clock signal in digital circuits.

2 Aim of the Experiment

The aim of the experiment is to build a square-wave oscillator of frequency 1 Hz using op-amp.

3 Experimental Setup

The circuit is constructed as shown in the figure below (op-amp used is LM358):

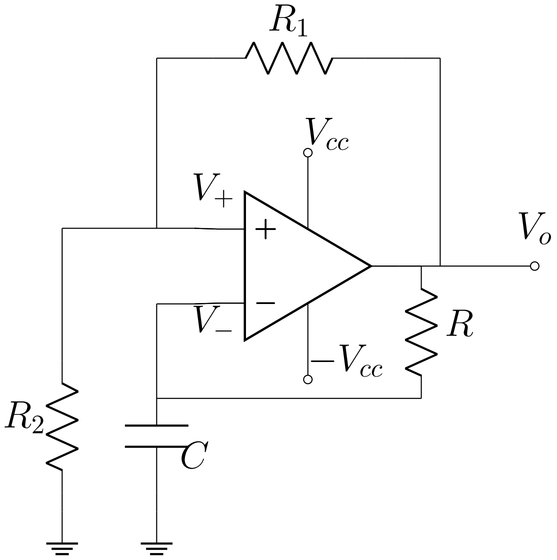


Figure 1: Oscillator Circuit Diagram

The op-amp is set to behave as a Schmitt Trigger. The Schimtt Trigger input is the voltage across the capacitor in a series RC Circuit. The working of the circuit is explained in the next section.

V_{cc} and $-V_{cc}$ are given $+11V$ and $-11V$ (available on the power supply). The output waveform is obtained at V_o shown in the circuit diagram and visualized using an oscilloscope.

4 Working Principle

The op-amp is set to behave as a Schmitt Trigger. A Schmitt Trigger is used to convert analog signals (magnitude of input signal may vary) to digital signals (output signal varies only between logic HIGH and logic LOW). The output signal switches only when the input signal "triggers" the change by varying sufficiently.

The output V_o is divided by a voltage divider (R_1 and R_2 in diagram) and this is connected to the non-inverting (+) input of the op-amp.

$$\therefore V_+ = \frac{R_2}{R_1 + R_2} V_o$$

When V_o is positive, V_+ is positive. If V_- remains less than V_o, the difference gets amplified and V_o shoots to V_{cc}. When V_- becomes larger than V_+, the negative difference is amplified and output shoots to $-V_{cc}$. This way, the output signal switches between V_{cc} and $-V_{cc}$ even if the input voltage fluctuates. This is how the Schmitt Trigger works.

The Schmitt Trigger's input is the voltage across the capacitor in a series RC Circuit. This voltage is provided to the inverting $(-)$ input of the op-amp.

At first, capacitor is uncharged so V_- is 0. Due to small voltage error between the input pins of the op-amp (because gain is large but finite practically so $V_+ - V_- = V_o/A$), the difference is amplified and output shoots to $+V_{cc}$.

This creates a voltage across the RC circuit and the capacitor begins charging as per the following equation ($\tau = RC$ (time constant)):

$$V_- = V_{cc}(1 - e^{\frac{-t}{\tau}})$$

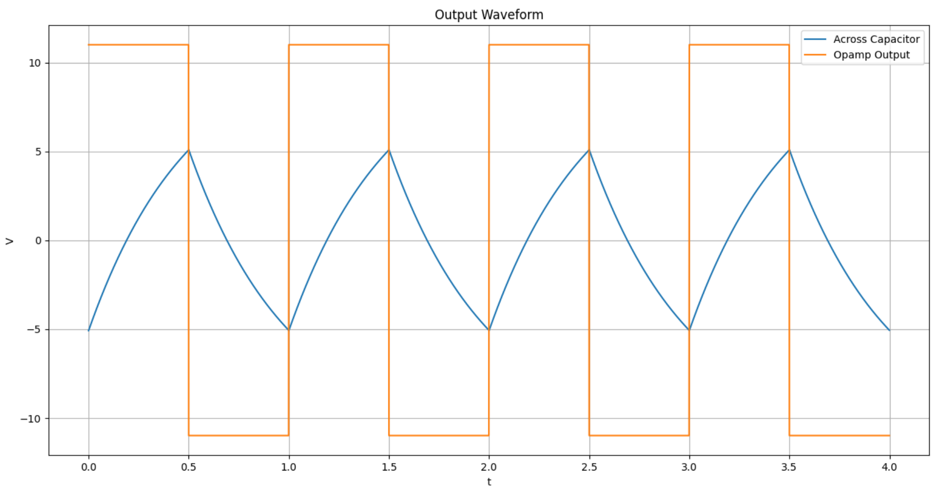
The voltage keeps increasing till it exceeds the non-inverting voltage $\left(V_+ = \dfrac{R_2}{R_1 + R_2} V_{cc}\right)$. Once this happens, the difference between inputs becomes negative and it is amplified causing the output to shoot to $-V_{cc}$. Then the capacitor begins discharging as per the equation:

$$
\begin{aligned}
&V_{-} = V_f + (V_i - V_f)e^{-\frac{t}{\tau}} \\
\implies &V_{-} = -V_{cc} + \left(\frac{R_2}{R_1 + R_2}V_{cc} + V_{cc}\right)e^{-\frac{t}{\tau}} \quad (\tau = RC)
\end{aligned} \tag{1}
$$

(V_f is taken $-V_{cc}$ because the capacitor would charge up to that value if given infinite time.) Similarly, now the capacitor has to discharge till it exceeds the new non-inverting input $\left(V_{+} = -\frac{R_2}{R_1 + R_2}V_{cc}\right)$. Then it begins charging again as per the equation:

$$
\begin{aligned}
&V_{-} = V_f + (V_i - V_f)e^{-\frac{t}{\tau}} \\
\implies &V_{-} = V_{cc} + \left(-\frac{R_2}{R_1 + R_2}V_{cc} - V_{cc}\right)e^{-\frac{t}{\tau}} \quad (\tau = RC)
\end{aligned} \tag{2}
$$

(V_f is taken V_{cc} because the capacitor would charge up to that value if given infinite time.) The charging and discharging cycles continue to produce a periodic waveform comprising of exponential charging and discharging portions. V_o accordingly fluctuates between $+V_{cc}$ and $-V_{cc}$. The equations (1) and (2) are combined and plotted below to simulate the output.



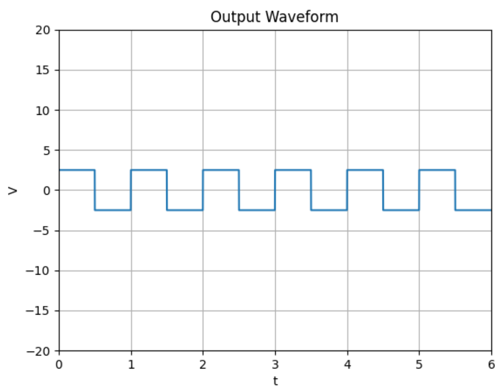
Note that the RHS of equations (1) and (2) are exactly negative of each other which means that the charging and discharging parts are just negative of each other. So if the Time Period of the output waveform is T, the charging/discharging time is $\frac{T}{2}$, i.e., the voltage across capacitor exceeds the corresponding V_+ at multiples of $\frac{T}{2}$.

$\therefore$ for one cycle, at $t = \frac{T}{2}$ (charging),

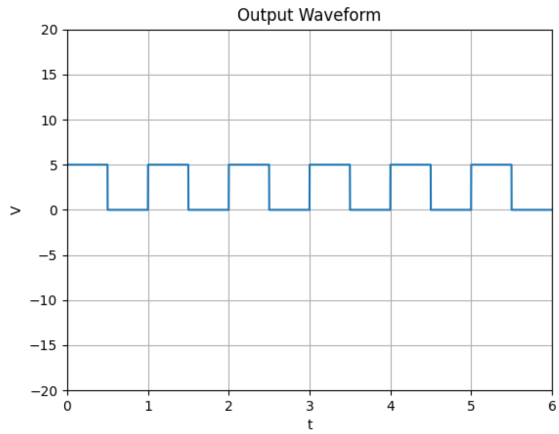
$$
\begin{aligned}
V_+ &= V_- \\
\implies \left(\frac{R_2}{R_1 + R_2}\right) V_{cc} &= V_{cc} + \left(-\frac{R_2}{R_1 + R_2} V_{cc} - V_{cc}\right) e^{-\frac{T}{2\tau}} \\
\implies \left(\frac{R_2}{R_1 + R_2} V_{cc} + V_{cc}\right) e^{-\frac{T}{2\tau}} &= \left(\frac{R_1}{R_1 + R_2}\right) V_{cc} \\
\implies e^{-\frac{T}{2\tau}} &= \frac{R_1}{R_1 + 2R_2} \\
\implies T &= 2RC \ln\left(\frac{R_1 + 2R_2}{R_1}\right) \\
\implies f &= \frac{1}{2RC \ln\left(\frac{R_1 + 2R_2}{R_1}\right)}
\end{aligned}
$$

The frequency of the capacitor cycle is same as that of the square waveform because the capacitor voltage will surpass V_+ during charging cycle at intervals of T.

Building the circuit will produce a square waveform with amplitude $11V$ and frequency 1Hz when the appropriate R, R_1, R_2, C are used. However, $5V$ is sufficient to power the clock so we applied a voltage divider to reduce the peak-to-peak voltage to $5V$ to produce the following wave:



Then we applied offset of $2.5V$ to output to shift the wave and produce the following:



This can now be used as a good clock signal to use in digital circuits with Logic LOW as $0V$ and logic HIGH as $5V$.

5 Observations

The following values were used:

$$\begin{aligned} R &= 510\,k\Omega \\ C &= 1\,\mu F \\ R_1 &= 21\,k\Omega \\ R_2 &= 17.5\,k\Omega \end{aligned}$$

Then frequency:

$$\begin{aligned} f &= \frac{1}{2RC\ln\left(\dfrac{R_1+2R_2}{R_1}\right)} \\ &= \frac{1}{2\times 5.1\times 10^5\times 10^{-6}\times \ln\left(\dfrac{21k+35k}{21k}\right)} \\ &= 1.0045Hz \\ &\approx 1Hz \end{aligned}$$

The output of the op-amp is shown below:

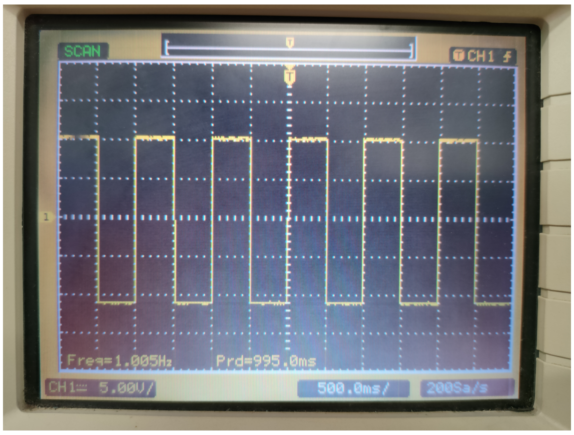


Figure 2: Output of Op-Amp with $V_{cc} = 11V$

Then the peak to peak voltage magnitude was reduced to $5V$ using voltage-divider and offset of $2.5V$ was applied to make the signal start from $0V$ (logic LOW). The DC power supply ($2.5V$) however introduced noise in the signal so we filtered that out by applying a $100\,pF$ capacitor across the load to remove the high frequency noise.

The circuit after the op-amp output is shown below:

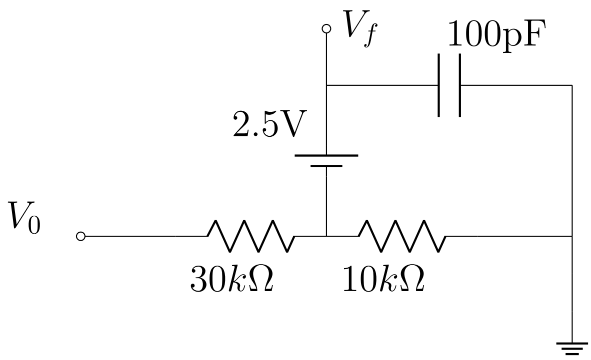


Figure 3: Circuit to Modify Amplitude and Offset Output

Note that we divided the amplitude ($11V$) by 4 to produce **approximately** $2.5V$ amplitude of the final signal.

This produced the following filtered square wave:

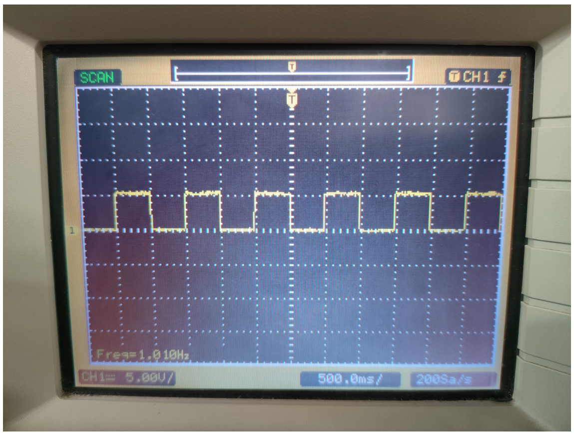


Figure 4: Output modified to act as clock signal

This signal can be used as a clock signal for the Digital Clock built in Lab Experiment 3 instead of the Arduino UNO.

6 Conclusion

The experiment successfully implemented an oscillator circuit using an astable multivibrator created using op-amp. A square wave of frequency 1 Hz and peak-to-peak voltage $5V$ was generated by the circuit. This circuit can now be used as a clock signal generator or an oscillator in digital circuits for timing applications.