EXPERIMENT 4: OSCILLATORS

List of Components:

Transistors: 1x BC108
Resistors: 5x 10kΩ, 1x 3.3kΩ, 3x 5.6kΩ, 1x 6.8kΩ, 3x 10kΩ, 3x 560Ω, 1x 1kΩ POT, 1x 10kΩ POT.
Capacitors: 3x 10nF, 1x 47nF, 2x 100nF, 1x 1µF, 1x 10µF, 1x 47µF.
Integrated Circuits (ICs): LM324

Objective: To analyze various oscillator types and structures and to practice the phase shift oscillator and the Schmitt Trigger square wave oscillator.

4.1 General Information

Oscillator circuits convert a DC voltage to a desired AC frequency signals. Oscillators are powered by DC voltage sources. An oscillator circuit consists of a resonance circuit, a feedback layer and an amplifier layer. Basic oscillator circuits yield a sinusoidal output. But with some adjustments it is possible to obtain square and/or triangle wave oscillators. Oscillators can be designed using various topologies depending on the application area and desired specifications. The resonance circuits which provide the initial oscillation usually consist of passive RC or RL components. Some commonly used oscillator types are listed below:

- RC phase-shift oscillator
- Wien bridge oscillator
- Colpitts oscillator
- Hartley oscillator
- Crystal oscillator
- Schmitt trigger oscillator.

Oscillators are generally used in digital circuits, receiver-transmitter circuits and switch mode power supplies.

It is necessary to have a resonance (tank) circuit stage and an amplifier stage to obtain an oscillator circuit. In addition, it is required to have a positive feedback for the continuation of the oscillation. A common emitter amplifier circuit is shown in Figure 4.1. This amplifier circuit can be converted to an oscillator. It is known that the common emitter amplifier has 180 degrees phase shift between its input and output signals. To obtain the oscillation, it is necessary to apply a portion of the output signal to the input as a positive feedback. As stated above, it is necessary for the continuation of the oscillation.
5.1.1 Phase Shift RC Oscillator

To be able to obtain the oscillation by the positive feedback, it is necessary to shift the output signal by 180 degrees. The basic principle of the phase shift oscillator is originated from this condition. The RC phase shift oscillator circuit is given in Figure 4.2. It can be observed from the figure that a portion of the output signal is fed back to the input through those R and C components. Each RC block shifts the output 60 degrees. There are three RC blocks so the total phase shift equals 180 degrees, which in turn (along with the 180 phase shift from the amplifier stage) provides the positive feedback.

The necessary and sufficient conditions for a 60 degrees phase shift in each RC stage is

\[ R_1 = R_2 = R_m \quad \text{and} \quad C_1 = C_2 = C_3 \quad \text{.} \]

\[ R_m \] denotes the input impedance of the common emitter amplifier. The oscillation frequency of the phase shift oscillator can be obtained as

\[
 f = \frac{1}{2\pi C \sqrt{6R_m^2 + 4R_1R_C}} \quad \text{(4.1)}
\]

The amplitude of the oscillation depends on the feedback factor and the gain of the amplifier stage. The feedback factor is a function of the total impedance of the serial RC stages. The more the impedance, the lower the feedback factor and the amplitude of the oscillation it is.
4.1.2 Schmitt Trigger Square Wave Oscillator

It is preferred that the digital circuits work in a specified order because each block/subcircuit works in a predetermined time slot. In a complex system, it is necessary to have a proper timing circuitry between several circuit blocks. This synchronization is achieved using oscillator circuits. Oscillators provide synchronization by sending their square wave clock signal to all consisting blocks of the system.

There are several methods to obtain a square wave signal. One of these methods employs the Schmitt trigger inverter. Contrary to an ordinary inverter, the Schmitt trigger inverter has a hysteresis feature, thus it provides oscillation.

74HC14 is a Si-Gate CMOS integrated circuit with 6 Schmitt trigger inverting buffers. Hysteresis characteristic is shown in Figure 4.4.

The Schmitt trigger has constant High and Low voltage values and also High ($V_T^+$) and Low ($V_T^-$) threshold values (Figure 4.4). When the input signal is Low, the output signal is High. When the input signal exceeds the High threshold value the output signal drops to the Low voltage value. If then the input voltage start to decrease, the output signal will not change to the High before the input decreases below the Low threshold value. This is the hysteresis property that separates the Schmitt trigger from the ordinary inverter.
Let us suppose the initial state of the capacitor is zero at the beginning. When the trigger input A is “0”V, the output B of the trigger is “5”V. Since the output is high, this value starts to charge the capacitor. When the voltage of the capacitor reaches the \( V_T^+ \) value, the output drops to the Low voltage level. Now since the output is “0”V, the current flows from the capacitor to the output node and the capacitor starts to discharge through the resistor. When the voltage of A drops below \( V_T^- \), the output changes again to the High value. The continual charge and discharge of the capacitor between \( V_T^+ \) and \( V_T^- \) values provide the square wave oscillation.

5.4 Schmitt Trigger using Opamp

The Schmitt trigger square wave oscillator using Opamp is given in Figure 4.6.

\[
V_A = \frac{V_0}{R_i + R_f} R_i 
\]  

(4.2)
Since the Opamp output “V₀” can take the maximum V⁺ and minimum V⁻ values, the hysteresis characteristic of the Opamp Schmitt trigger is obtained as in Figure 4.7.

![Figure 4.7 Hysteresis Characteristics of the Schmitt Trigger with Opamp](image)

Assume that the initial value of the capacitor is zero. Then V₀ = V⁺ and V_A > 0, and the V_A voltage is at the positive threshold value Vₐ⁺. The capacitor charges through the V₀ and resistor R. When V_C > V_A, the output changes to V₀ = V⁻. Now V_A < 0 and its value is V_A = Vₐ⁻. So the capacitor discharges through the resistor. When V_C < V_A, the output voltage reaches to V₀ = V⁺ and the cycle repeats. Thus the square wave oscillation is obtained. The frequency of the oscillation can be adjusted using the time constant of the RC circuit ( \( \tau = RC \) ).

4.1.4 Integrator Circuit using Opamp

Integrator circuit provides the time integral of its input signal. Therefore if the input is the square wave, the output should be the triangle wave, if the input is the triangle wave, the output should be the sinusoidal wave. The integrator circuit is given in Figure 4.8.

![Figure 4.8 Integrator Circuit using Opamp](image)

Let us obtain the current and voltage equations of integrator circuit given in Figure 4.8

\[
I_t = \frac{V_i - V_A}{R_t} = \frac{V_i}{R_t} \quad (4.3)
\]

\[
V_0 = \frac{1}{C_f} \int_0^T I_f dt , \quad I_f = -I_t \quad (4.4)
\]
\[ V_0 = -\frac{1}{C_f} \int_0^T I_t \, dt \]  
\[ (4.5) \]

\[ V_0 = -\frac{1}{C_f} \int_0^T V_i \, dt \]  
\[ (4.6) \]

\[ V_0 = -\frac{1}{R_i C_f} \int_0^T V_i \, dt \]  
\[ (4.7) \]

It can be seen from (4.7) that the circuit computes the integral of the input signal \( V_i \).

The resistor \( R_i \) is added in parallel to \( C_f \) to prevent the Opamp from saturating. The resistor \( R_2 \) is added to cancel the input offset voltage of the Opamp and its effects. \( R_2 \) is chosen as \( R_2 = R_i / R_f \).

The following two conditions should be met for the integrator to operate:

- \( f_{\text{input}} \geq \frac{1}{2\pi R_f C_f} \) (the input frequency should be equal to or larger than the critical frequency)
- The time constant \( \tau = R.C \) of the circuit should be equal or close to the time constant of the input signal.

4.2 Preliminary Studies

1. Study the BC108C transistor datasheet and learn the pin connections and the important DC parameters of the transistor.
2. Study the LM324 Opamp datasheet and find out max output voltage \( (V_{OH}) \), min output voltage \( (V_{OL}) \), high threshold voltage \( (V^+_{TH}) \) and low threshold voltage \( (V^-_{TH}) \) values of the Schmitt trigger circuit using Opamp.
3. Perform the SPICE simulation of the circuits of the experiment and obtain the output oscillation.

**Note:** The circuits will not oscillate at the beginning of the simulation, but start to oscillate after a while due to the effect of the positive feedback. Show these steps in your simulation.

4.3 Experiment

4.3.1 RC Oscillator

1. Set up the phase shift oscillator circuit given in Figure 4.3. Connect the oscilloscope probes required to observe the output signal accordingly.
2. Measure the output signal and draw it to the Figure 4.12. Measure the signal voltages at the points A, B and C and draw them to the Figure 4.13.
3. Measure the pick to pick output voltage and output frequency and fill in Table 4.1. Fill in table 4.2 with the calculated and measured oscillation frequency values and compare them.
4. Observe the output of the oscillator and the signal voltage at the base of the transistor simultaneously and measure the phase shift between them. Give the phase shift in Table 4.3 and comment on it.

4.3.2 Schmitt Trigger Oscillator Using Opamp

1. Use the first Opamp in LM324 IC to set up Schmitt Oscillator circuit given in Figure 4.9.

![Figure 4.9 Schmitt Trigger Oscillator Circuit](image)

2. Observe the signals at $V_0$ and $V_C$ at the dual mode of the oscilloscope and comment on them.
3. Change the value of the pot $R_3$ and observe the change in the output signal.
4. Draw the observed output signals for the minimum and the maximum values of the potentiometer in Figure 4.14.
5. Use the circuits given in Figs 4.9 and 4.10 to set up the square-triangle-sinusoidal oscillator circuit given in 4.11.

![Figure 4.10 Integrator Circuit Using Opamp](image)

![Figure 4.11 Square-triangle-sine Oscillator Circuit](image)
6. Measure the output signals of each stage separately and two at a time in dual mode and draw them in Figure 4.15.
7. Show that whether the two conditions for the integrator to operate is met by doing the necessary measurements and calculations.

4.4 Questions

1. Explain that how the phase difference between the output and the input signals is obtained in the RC oscillator circuit to start the oscillation.
2. How does $R_E$ resistor affect the operation of the RC oscillator? The changes in $R_E$ cause what kinds of changes in the oscillator output signal?
3. Why duty cycle of the output signal is not 50% in the Schmitt trigger square wave oscillator circuit?
4. Explain why it is not possible to obtain the oscillation if an ordinary inverter is used instead of Schmitt trigger in the Schmitt oscillator.
5. If one more integrator stage is added to the output of the circuit in Figure 4.14, what kind of an output signal is obtained?
6. Design a system to obtain a square and triangle wave at the end of the RC oscillator circuit. Give the block diagram (as in Figure 4.14) and the circuit schematic of the designed system.
5.5 EXPERIMENT 5 RESULTS PAGE

**Figure 4.12** Oscillator output signal

**Figure 4.13** Voltage signals of the points A, B and C.

**Table 4.1** Pick to pick value and frequency of the output signal

<table>
<thead>
<tr>
<th></th>
<th>$V_{pp} (V)$</th>
<th>$f$ (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC Oscillator</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 4.2** The measured and calculated oscillation frequencies

<table>
<thead>
<tr>
<th></th>
<th>Calculation</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC Oscillator</td>
<td>f(KHz)</td>
<td></td>
</tr>
</tbody>
</table>

**Table 4.3** The phase shift between the output signal and the base signal of transistor

<table>
<thead>
<tr>
<th></th>
<th>$\Phi$ (input-output)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC Oscillator</td>
<td></td>
</tr>
</tbody>
</table>
Figure 4.14 Minimum and maximum output signals of the Schmitt oscillator

\[ f_{\text{min}} = \ldots \quad f_{\text{max}} = \ldots \]

Figure 4.15 Outputs of the Schmitt oscillator and the square-triangle-sinus oscillator