Study of Phase Shift Oscillator using Op-Amps

Gayatri P
2nd year, Integrated M.Sc. Physics
Roll No.: 2211185
(Dated: February 8, 2024)

Oscillators are used in a wide range of applications in modern circuits to generate periodic signals. In this experiment, we construct and study the properties of an RC Phase Shift Oscillator.

I. OBJECTIVE

To construct and determine the resonant frequency of a phase shift oscillator.

II. THEORY

The basic principle of an oscillator is to generate continuous and periodic AC signal of desired frequencies. In its implementation, it is basically an amplifier circuit with positive feedback.

Working principle

Let's say some input sinusoidal signal is applied to the input. At the output, the input signal will get multiplied by the gain of this amplifier, $V_o = AV_i$. Now, this output signal is given as an input to the feedback circuit. The feedback circuit is typically a frequency selector or resonant circuit. Let β be the fraction of V_o that is feedback as input into the system, i.e. $V_f = \beta V_o$. Now the input voltage is removed from the circuit. After removing V_i, whether we will get sustained oscillations or not depends on the product $A\beta$, which is known as the **loop gain** of the oscillator.

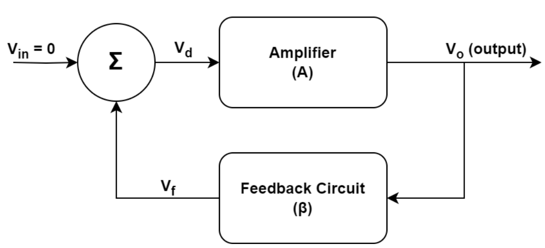

FIG. 1: Block diagram for a typical oscillator circuit

If $A\beta < 1$, the oscillator exhibits a decaying oscillation and the signal eventually decays to zero. If $A\beta > 1$, the output oscillation grows and becomes unbounded, eventually railing out the system. In other words, only when $A\beta = 1$ and when the phase difference is an integral multiple of 360° will the oscillator show stable oscillation.

These conditions are summarized in **Barkhausen's Criteria** for sustained oscillation,

1. The magnitude of the loop gain should be equal to 1, i.e. $A\beta = 1$
2. Phase Shift introduced by the amplifier and the feedback circuit should be 0 or 360°.

Without any input voltage, electronic oscillators use thermal noise to produce oscillations. When the circuit is turned on, all frequency components of the noise get amplified, which is given as the input to the feedback circuit. Since the feedback circuit is a frequency-selective circuit, only one particular frequency whose phase shift is 0 will get added back to the input. Hence, the noise signal of a desired frequency will show sustained oscillation.

From the block diagram (Fig. 1),

$$\begin{aligned} V_o &= A(V_f + V_i) \\ &= A(\beta V_o) + AV_i \\ \implies AV_i &= V_o(1 - A\beta) \\ \implies \frac{V_o}{V_i} &= \frac{A}{1 - A\beta} \end{aligned} \tag{1}$$

Since $V_i = 0$, $\frac{V_o}{V_i} = \infty$. This means that on the right-hand side, $1 - A\beta = 0$, or $A\beta = 1$, which is the Barkhausen condition.

RC Phase Shift Oscillator

RC phase shift oscillators produce stable sine waves and are used for low-frequency signal generation (typically in the range of audio frequencies).

Here, we use the op-amp as the amplifier and 3 cascaded networks as the frequency-selective feedback circuit. Since the op-amp is used in inverting mode, there is a 180° phase shift. So, to generate sustained oscillations, the additional 180° phase shift is achieved by the RC network.

Phase shift produced by a single RC stage is given by,

$$\phi = \tan^{-1} \frac{X_C}{R} \tag{2}$$

When $R = 0$, $\phi = 90°$. Thus by cascading two RC stages, we can achieve 180° phase shift. But practically since this requires R to be 0, it means there is no gain. Hence, practically we use 3 RC stages each with a phase shift of 60°.

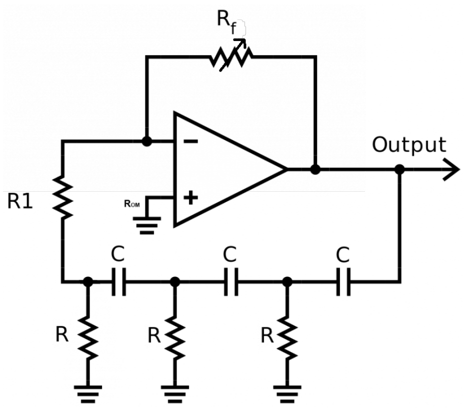

FIG. 2: Circuit diagram for the experimental setup

The frequency of oscillation of the RC network is given by,

$$f = \frac{1}{2\pi\sqrt{2N}RC} = \frac{1}{2\pi\sqrt{6}RC} \quad [\because N = 3] \tag{3}$$

Similarly, one can derive the gain of the RC network to be $\beta = 1/29$. Therefore to fulfill the Barkhausen criteria, we require the op-amp gain to be at least 29. Or,

$$\left|\frac{R_f}{R_1}\right| = 29 \tag{4}$$

One can also use **Lisssajous curves** to study the behavior of oscillator circuits. Lisssajous curves describe the family of curves which are formed by the superposition of two perpendicular oscillations in x and y directions of different angular frequencies. By using a secondary sinusoidal input source (a function generator) with variable frequency, we can observe these curves (using the X-Y mode of the oscilloscope).

These patterns form closed shapes if the frequencies are whole number ratios, i.e. at certain harmonics.

III. APPARATUS

1. OPAMP 741 Chip
2. Resistors
3. Oscilloscope
4. DC Power Supply
5. Function Generator
6. Potentiometer
7. Breadboard
8. Connecting Wires
9. Multimeters

IV. OBSERVATIONS

Refer Fig. 2,

- $R_1 = 2.152$ kΩ
- $R = 0.988$ kΩ, $R' = 0.987$ kΩ, $R'' = 0.995$ kΩ
- $C = 97.8$ nF, $C' = 93.2$ nF, $C'' = 98.6$ nF

$\therefore$ average value of $R = 0.990$ kΩ, $C = 96.53$ nF

$\implies$ From Eqn. (3), theoretical value of oscillating frequency = 679.88 Hz.

Observed Values:

- R_f at oscillating frequency = 80.6 kΩ
- Minimum gain required to sustain oscillations = $|R_f/R_1| = 37.45$
- Experimental value of Oscillating frequency = 719.4 Hz
- Oscillating frequency obtained from the Lissajous figure = 720 Hz

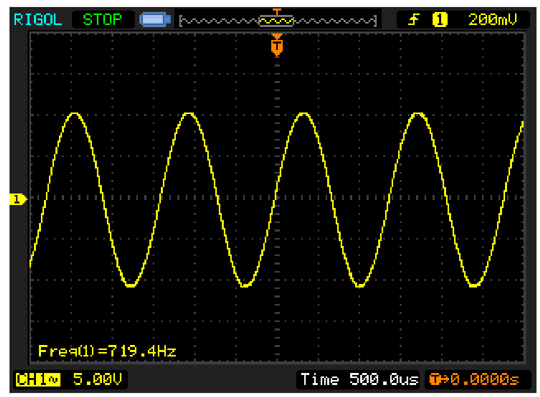

FIG. 3: Sinusoidal waveform obtained at $R_f = 80.6$ kΩ and oscillating frequency = 719.4 Hz

The variable resistor (R_f) value was increased until the sinusoidal waveform was obtained on the oscilloscope (Fig. 3). Furthermore, using a function generator a secondary signal was fed into the oscilloscope in X-Y mode and various kinds of Lissajous curves were obtained (Fig. 4 to 7).

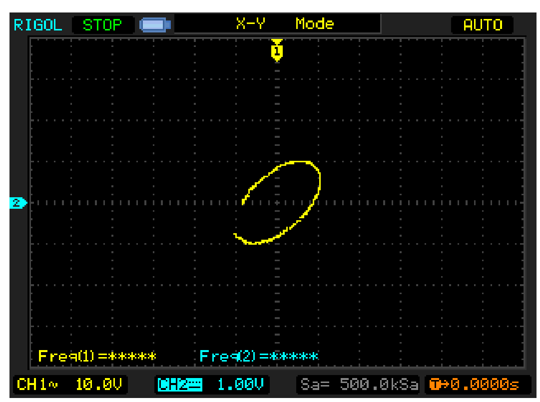

FIG. 4: Elliptical Lissajous figure obtained when the frequency of the function generator matched the oscillating frequency of the circuit ($\approx$ 720 Hz)

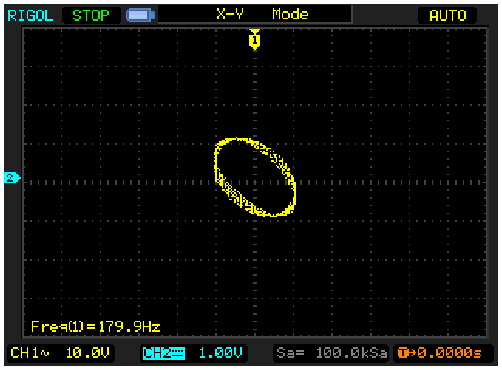

FIG. 5: Lissajous figure obtained at a frequency lower than the resonant frequency

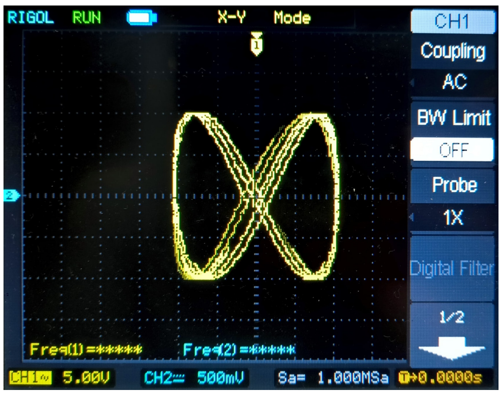

FIG. 6: Lissajous figure obtained at a frequency close to the second harmonic of the resonant frequency ($\approx$ 1.5 kHz)

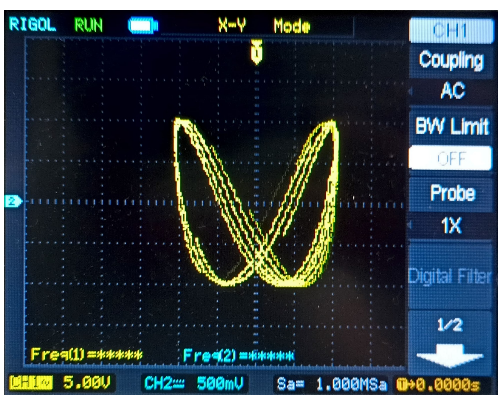

FIG. 7: Lissajous figure obtained at a higher frequency

V. DISCUSSION AND CONCLUSION

We have successfully constructed and demonstrated a phase shift oscillator using an op-amp and an RC network. We found out that over a minimum gain of around $|A_V| = 37.45$, the oscillator started showing stable periodic sinusoidal oscillations.

The observed value of the cutoff frequency of the oscillator was found to be 719.4 Hz, which shows around 5.8% deviation from the theoretical value. A major reason for this could be the error in the calculation since the average values of R and C were used in the calculation of cutoff frequency.

Also by using a secondary input source (function generator), were able to observe Lisssajous figures on the oscilloscope, at and near the cutoff frequency as well as near its higher harmonics.

We can thus build an oscillator circuit using op-amps which can be used to produce very low frequencies. It does not require transformers or inductors, and the circuit provides good frequency stability. These factors make them ideal for small circuits that require precision.

VI. PRECAUTIONS & SOURCES OF ERROR

1. Make sure the connections are proper before switching on the circuit.
2. Change the value of the potentiometer very carefully.
3. Make sure that the R and C values in the RC network are close, to get accurate values of f_c.

VII. APPLICATIONS

Oscillators are used by all kinds of laptop or smartphone processors to generate clock signals. Radio and mobile receivers use them to generate local carrier frequency signal.

RC phase shift oscillators in particular can be used for low-frequency applications, such as devices that produce radio and audio frequencies.

[1] SPS, *Operational Amplifiers (Supplementary note)*, NISER (2023).
[2] R. A. Gayakwad, *Op-Amps and Linear Integrated Circuits* (Pearson, 2015).
[3] P. Horowitz and W. Hill, *The art of electronics* (Cambridge University Press, 2015).