

Chapter 12

Oscillators

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Electronics: Principles, Concepts and Practices

Table of contents

1. Introduction
2. Oscillatory Circuit
3. Theory of Oscillation
4. Classification of Oscillators
5. Sinusoidal Oscillators
6. Relaxation Oscillators
7. Multivibrators



Intro

Oscillators

- In this chapter, we will explore the fascinating world of oscillators. First we introduce the principles of oscillator operation, then explore feedback arrangements that sustain oscillation, and examine different practical oscillator circuits.
- Oscillators are essential electronic devices widely used in various applications, including ultrasonic and radio frequency systems.
- They play a crucial role in generating different types of signals, such as sine waves, square waves, saw-tooth waves, and triangular waves, which are vital in communication systems, control systems, computers, and more.
- An oscillator is a circuit that generates a repetitive, alternating signal waveform without any applied input signal. It achieves this by converting the direct current (DC) flow from a DC source into an alternating waveform of a specific frequency determined by the oscillator's circuit components.



Oscillatory Circuit

Oscillatory Circuit

A circuit that can generate electrical oscillations of a desired frequency is known as an oscillatory circuit.

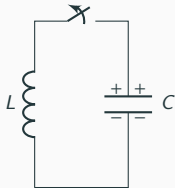
There are different types of oscillatory circuits, but two common ones are

1. the LC oscillator and
2. the crystal oscillator.

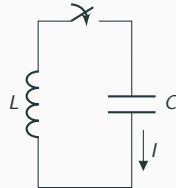
The circuit diagram of a simple LC oscillator is shown in Figure 1. It consists of a fully pre-charged capacitor (C) and an inductor (L).



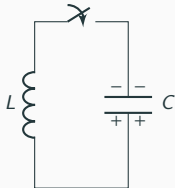
LC Oscillator



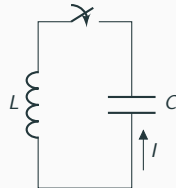
(a) Capacitor charged



(b) Capacitor discharges



(c) Inductor discharges



(d) Capacitor discharges

Figure 1: Simple LC oscillatory (tank) circuit



LC Oscillator

Initially, the pre-charged capacitor is shown in Figure 1(a). On closing the switch, the capacitor starts to discharge through the inductor, converting the stored electrical energy into electromagnetic energy, which is then stored in the inductor (Figure 1(b)).

Next the inductor's electromagnetic field continues until the magnetic field collapses. However, during this time, the capacitor charges in the opposite direction (Figure 1(c)), causing the cycle to repeat itself but in the opposite direction.

This discharge and charge process results in oscillation, where the energy alternates between the capacitor and the inductor. Note that this oscillation is damped due to energy lost in the circuit.

The frequency at resonance:

$$f = \frac{1}{2\pi\sqrt{LC}}$$



Crystal oscillator

To improve stability, a quartz crystal is used instead of the capacitor and inductor. The circuit symbol for a quartz crystal oscillator is shown in Figure 2(a), and an electrical circuit equivalent is shown in Figure 2(b).

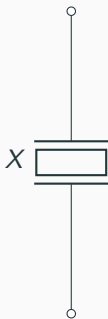
The quartz crystal operates based on the principle of the inverse piezoelectric effect.

To eliminate the effect of temperature variation, the crystal is mounted in a temperature-controlled oven.

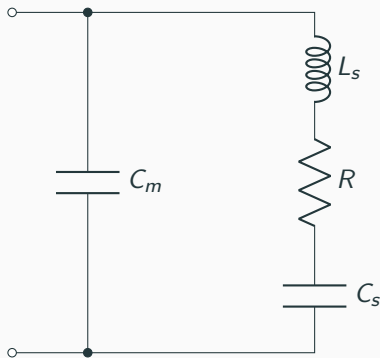
The crystal's resonance action can be represented by an equivalent electrical circuit, as shown in Figure 2(b). The series RLC branch represents the mechanical vibration of the crystal, and the parallel branch with capacitance C_m represents the electrical connection to the crystal between the parallel mounting plates.



Crystal oscillator continued ...



(a) Quartz crystal symbol



(b) Equivalent electrical circuit

Figure 2: Crystal oscillator symbol and equivalent circuit



Crystal oscillator continued . . .

It is interesting to note that the crystal oscillator has two resonance frequencies: the series resonance frequency f_s and the parallel resonance frequency f_p expressed mathematically as

$$f_s = \frac{1}{2\pi\sqrt{L_s C_s}} \quad (2)$$

$$f_p = \frac{1}{2\pi\sqrt{L_s \left(\frac{C_m C_s}{C_m + C_s} \right)}} \quad (3)$$

The series resonance occurs when the series capacitance C_s resonates with the series inductance L_s at the crystal's operating frequency, given by Equation 2. However, the parallel resonance occurs when the reactance of the series "arm" resonates with the reactance of the parallel capacitor plate C_m , resulting in the frequency given by Equation 3.

The crystal can be used as a series LC circuit or as a parallel LC circuit depending on the desired impedance.



Theory of Oscillation

Theory of Oscillation

Oscillators consist of two main parts: an amplifier with open-loop gain A_v and a frequency-selective positive feedback network, as shown in Figure 3.

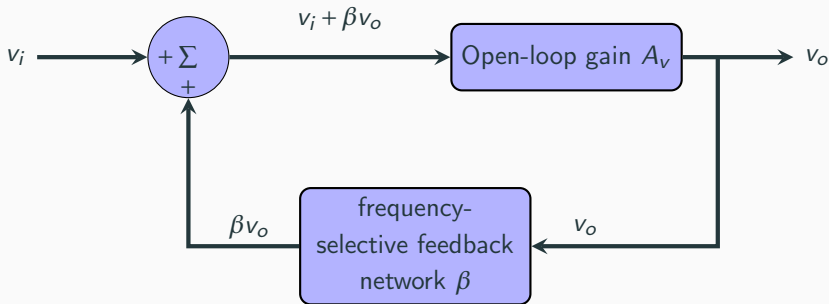


Figure 3: Feedback system in oscillator



Theory of Oscillation

The closed-loop phasor gain, obtained from Figure 3, is given by

$$A_{vC}(s) = \frac{A_v(s)}{1 - A_v(s)\beta(s)} \quad (4)$$

We can rewrite Equation (4) as

$$A_{vC}(j\omega) = \frac{A_v(j\omega)}{1 - A_v(j\omega)\beta(j\omega)} \quad (5)$$

The condition for infinite gain is again expressed as

$$1 - A_v(j\omega)\beta(j\omega) = 0 \quad (6)$$

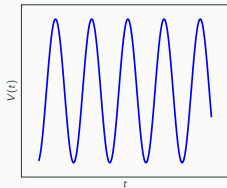
$$\therefore A_v(j\omega)\beta(j\omega) = 1 \quad (7)$$

The term $A_v(j\omega)\beta(j\omega)$ is known as the feedback loop gain and must have a magnitude of unity and a phase angle of zero for sustained oscillation. This condition is known as the **Barkhausen criterion**.

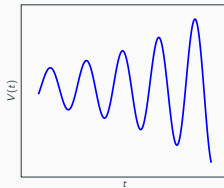


Theory of Oscillation

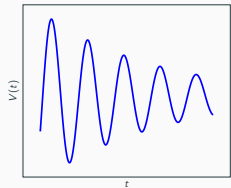
Fig. 4 is the impact of $A_v(s)\beta$ on the damping of the oscillation's amplitude.



(a) $A_v(s)\beta = 1$



(b) $A_v(s)\beta > 1$



(c) $A_v(s)\beta < 1$

Figure 4: Effect of feedback loop gain $A_v(s)\beta$



Classification of Oscillators

Classification of Oscillators

Oscillators can be classified based on these considerations.

1. **Feedback Mechanism:** Oscillators can be categorized into two types based on the feedback mechanism used e.g positive feedback and negative feedback oscillators.
2. **Frequency Control Components:** Oscillators can also be classified based on the frequency control components used e.g. RC oscillators, LC oscillators, and crystal oscillators.
3. **Output Waveform Shape:** The two main categories in this considerations are Sinusoidal oscillators and Relaxation oscillators.
4. **Frequency Nature:** Oscillators can be further classified based on the nature of the frequency of the output waveform. There are fixed frequency oscillators and variable or tunable frequency oscillators.

By considering these different classifications, we can gain a better understanding of the various types of oscillators and their characteristics.



Sinusoidal Oscillators

Sinusoidal Oscillators

The basic structure of sinusoidal oscillators, also known as harmonic oscillators, consists of an amplifier (such as Op-Amps, BJTs, or FETs) connected in a positive feedback loop arrangement with a frequency-selective network. These oscillators generate sinusoidal waveforms and examples are:

1. Wien bridge oscillator
2. Phase-shift oscillator
3. Twin-T oscillator
4. Colpitts oscillator
5. Hartley oscillator
6. Armstrong oscillator
7. Tuned oscillator

Each of these oscillators has its unique implementations and applications, and we will discuss them in the next slides.



Wien bridge oscillator

The Wien bridge oscillator is a sinusoidal or harmonic oscillator that utilizes positive feedback and a combination of resistors and capacitors in the frequency-selective network. Figure 5 presents an implementation of the Wien bridge oscillator.

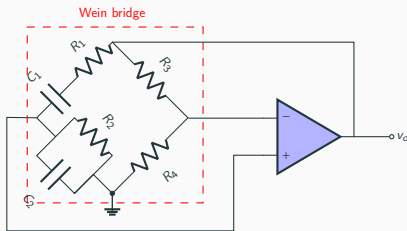


Figure 5: Wein bridge oscillator

The frequency of the Wien bridge oscillator can be derived as:

$$f_r = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}} \quad (8)$$



RC Phase-shift oscillator

A three-stage RC network is used in the RC phase-shift oscillator resulting in a total phase shift of 180 degrees (see Figure 6).

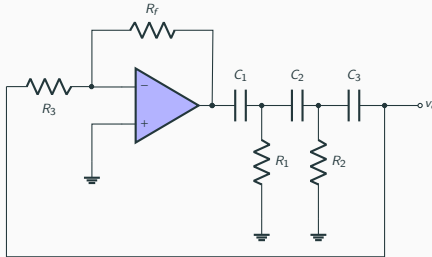


Figure 6: RC phase shift oscillator

For an N stage RC phase-shift oscillator, given that the resistors and capacitors in each stage have equal values, the resonant frequency is:

$$f_r = \frac{1}{2\pi RC\sqrt{2N}}$$



Twin-T oscillator

The Twin-T oscillator is an RC oscillator, which comprises two "T" branches connected in parallel to the negative input of an Op-Amp. Figure 7 illustrates this network.

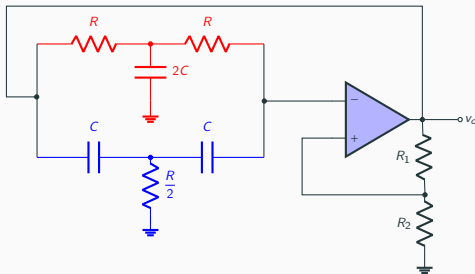


Figure 7: Twin-T oscillator circuit

The resonant frequency is:

$$f = \frac{1}{2\pi RC}.$$

(9)



Colpitts oscillator

Figure 8 illustrates an Op-Amp implementation of the Colpitts oscillator. The frequency of oscillation is:

$$f = \frac{1}{2\pi\sqrt{LC_T}} \quad (10)$$

where C_T is the equivalent capacitance of the frequency-selective network.

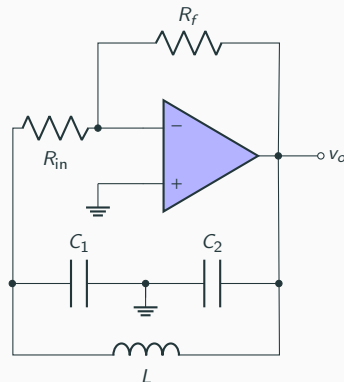


Figure 8: Op-Amp Colpitts oscillator



Hartley oscillator

Figure 9 illustrates an Op-Amp implementation of the Colpitts oscillator. The frequency of oscillation is:

$$f = \frac{1}{2\pi\sqrt{CL_T}} \quad (11)$$

where L_T is the equivalent inductor of the frequency-selective network given by

$$L_T = L_1 + L_2 + 2M \quad (12)$$

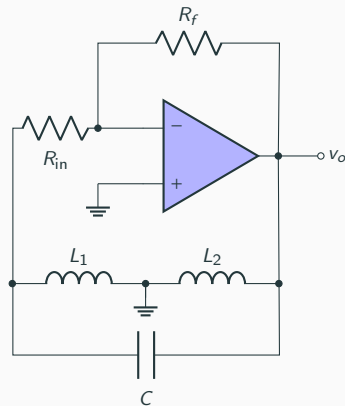


Figure 9: Op-Amp Hartley oscillator



Relaxation Oscillators

Relaxation Oscillators

The second major category of oscillators is the relaxation oscillator, which produces nonsinusoidal repetitive output signals.

Unlike the previous category, these oscillators utilize a combination of an RC timing circuit and an electronic component that switches states to generate a periodic waveform.

In this section, we will explore circuits that are specifically designed to produce nonsinusoidal waveforms. The following are examples of oscillators within this category:

1. Triangular wave oscillator
2. saw-tooth voltage-controlled oscillator
3. Square wave oscillator
4. Multivibrator
5. 555 Timer



Triangular wave oscillator

The triangular wave generator is a circuit that utilizes an Op-Amp integrator and a square wave generator, such as a comparator circuit, to produce a triangular waveform. The circuit consists of two Op-Amps, a capacitor, and three resistors, as illustrated in Figure 10.

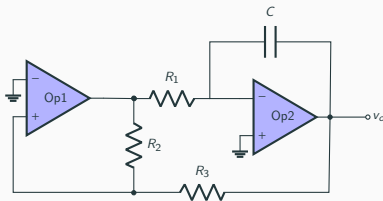


Figure 10: Triangular wave oscillator



Recommendation:
See worked examples in reference material!
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Multivibrators
