Analog electronics

Ninth lecture

Oscillators

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Third stage

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2022- 2023

Outline

9.1. What is an Oscillator?

An oscillator is a circuit which produces a continuous, repeated, alternating waveform without any input. Oscillators basically convert unidirectional current flow from a DC source into an alternating waveform which is of the desired frequency, as decided by its circuit components.

This is because, if the energy supplied is more than the energy lost, then the amplitude of the oscillations will increase (Figure 1a) leading to a distorted output; while if the energy supplied is less than the energy lost, then the amplitude of the oscillations will decrease (Figure 1b) leading to unsustainable oscillations.

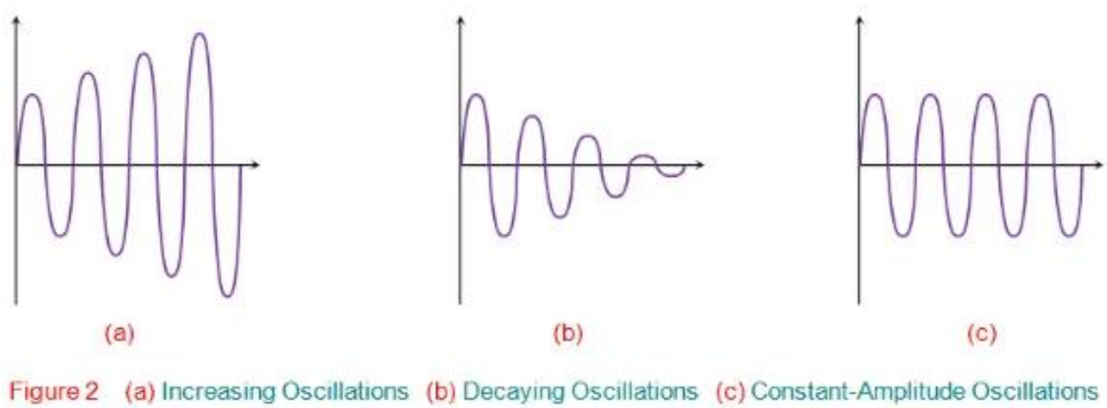

Figure 1: amplitude of the oscillations

Practically, the oscillators are nothing but the amplifier circuits which are provided with a positive regenerative feedback wherein a part of the output signal is fed back to the input (Figure 3). Here the **Oscillator** consists of an amplifying active element which can be a transistor or an Op-Amp. and the back-fed in-phase signal is held responsible to keep-up (sustain) the oscillations by making-up for the losses in the circuit.

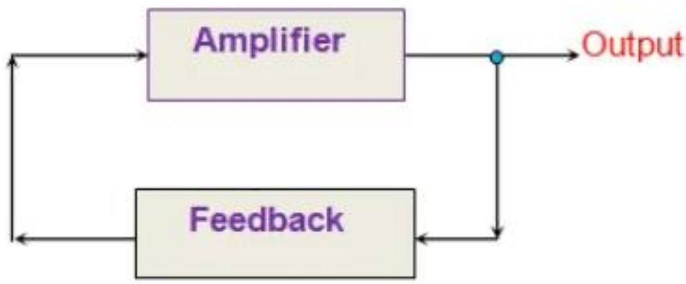

Figure 2: Typical Oscillator

The expression for the closed-loop gain of the oscillator shown in Figure 3 is given as:

$$G = \frac{A}{1 + A\beta}$$

Where A is the voltage gain of the amplifier and β is the gain of the feedback network.

Here, if $A\beta > 1$, then the oscillations will increase in amplitude (Figure 1a). while if $A\beta < 1$, then the oscillations will be damped (Figure 1b).

On the other hand, $A\beta = 1$ leads to the oscillations which are of constant amplitude (Figure 1c).

9.2. Classification of Oscillators

1. Inductor-Capacitor Oscillators (LC)
2. Resistor-Capacitor Oscillators (RC)
3. Quartz Oscillators
4. Crystal Oscillator Modules
5. MEMS Oscillators
6. Silicon Oscillators

1. LC Oscillator

LC or Inductor-Capacitor Oscillator is a type of oscillator which utilizes a tank circuit to produce positive feedback for sustaining oscillation. The schematic contains an inductor, capacitor, and also an amplifying component.

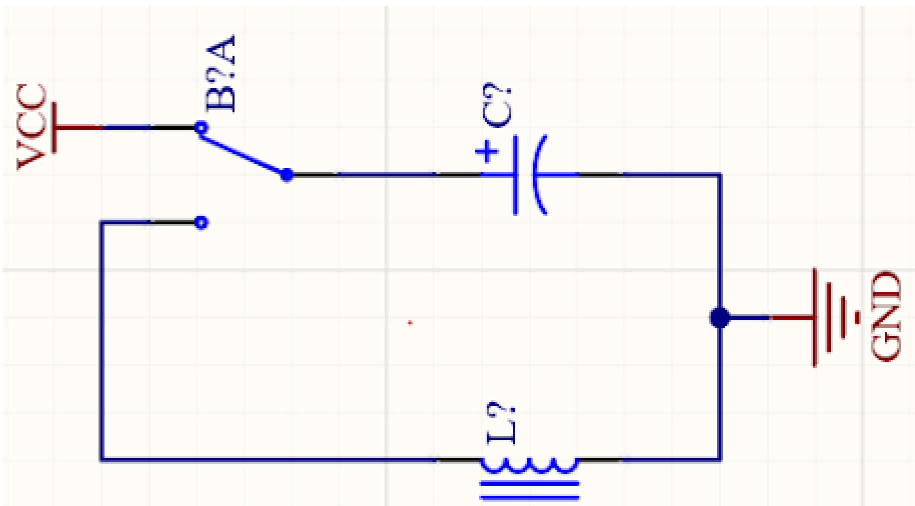

Figure 3: LC tank circuit

The tank circuit is a capacitor and inductor connected in parallel, the diagram above also includes the switch and voltage source for ease of demonstration of the working principle when the switch is connecting the capacitor to the voltage supply, the capacitor charges.

When the switch connects the capacitor and inductor, the capacitor discharges through the inductor. The increasing current through the inductor starts to store energy by inducing an electromagnetic field around the coil.

After discharging the capacitor, the energy from it has transferred into the inductor as an electromagnetic field. As the energy flow from the capacity decreases, current flow through the inductor decreases - this causes the inductor's electromagnetic field to fall as well. Due to electromagnetic induction, the inductor will create back EMF, which is equal to L(di/dt) in opposition to the change in current. This back EMF then begins to charge the capacitor. Once the capacitor has absorbed the energy from the inductor's magnetic field, the energy is stored once again as an electrostatic field within the capacitor.

If we had an ideal inductor and capacitor, this circuit could generate the oscillations forever. However, a capacitor has current leakage, and inductors have resistance.

In real life, however, the oscillations would look as below, as energy is lost. This loss is called damping.

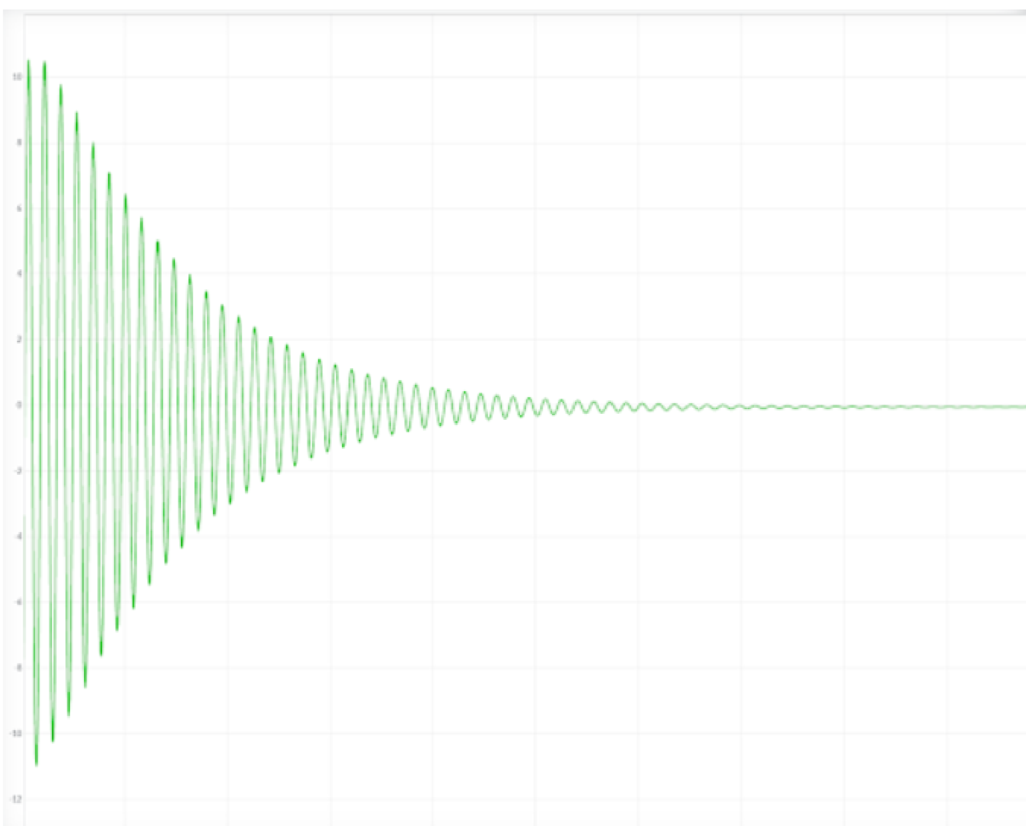

Figure 4: Oscillator Damping

If we want to sustain the oscillations, we need to compensate for the loss of energy from the tank circuit through the addition of active components to the circuit, such as bipolar junction transistors, field-effect transistors, or operational amplifiers. The primary function of the active components is to add the necessary gain, help generate positive feedback, and to compensate for the loss of energy.

2. RC Oscillators

An RC Oscillator (resistor-capacitor) is a type of feedback oscillator which is built using resistors and capacitors, along with an amplifying device such as a transistor or operational amplifier. The amplifying device feeds back into the RC network, which causes positive feedback and generates repeated oscillations.

Working Principle

The RC network of an RC oscillator shifts the phase of the signal by 180 degrees.

The positive feedback is needed to shift the phase of the signal to another 180 degrees. This phase shift then gives us 180 + 180 = 360 of phase shift, which is effectively the same as 0 degrees. Therefore, the total phase shift of the circuit needs to be 0, 360, or another multiple of 360 degrees.

For ideal RC networks, the maximum phase shift can be 90 degrees. Therefore, to create a 180-degree phase shift, oscillators require at least two RC networks. However, it is challenging to achieve precisely 90 degrees of phase shift with each RC network stage. We need to use more RC network stages cascaded together to produce the required value and the desired oscillation frequency.

By cascading several RC networks, we can obtain 180 degrees of phase shift at the chosen frequency. This cascade of networks forms the base for the RC oscillator, otherwise known as Phase Shift Oscillator. Adding an amplifying stage utilizing a bipolar junction transistor or inverting amplifier, we can produce a 180-degree phase shift between its input and output to provide the full 360-degree shift back to 0 degrees that we require, as mentioned above.

Basic RC Oscillator Schematic

The primary RC Oscillator circuit produces a sine wave output signal using regenerative feedback obtained from the RC ladder network. Regenerative feedback occurs due to the ability of the capacitor to store an electric charge.

The Resistor Capacitor feedback network can be connected to produce leading phase shift (phase advance network) or can be connected to create a lagging phase shift (phase retard network.) One or more resistors or capacitors from the RC phase shift circuitry can be changed to modify the frequency of the network. This change can be made by keeping resistors the same and using variable capacitors because capacitive reactance varies with frequency. However, for the new frequency, there could be a requirement to adjust the amplifier's voltage gain.

If we choose the resistors and capacitors for RC networks, then the frequency of RC oscillations would be:

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

R - Feedback resistors resistance

C - Feedback capacitors capacitance

N - Number of RC networks cascaded

However, the combination of the RC Oscillator network works as an attenuator, and it reduces the signal by some amount as it passes through each RC stage. So voltage gain of the amplifier stage should be sufficient to restore lost signal.

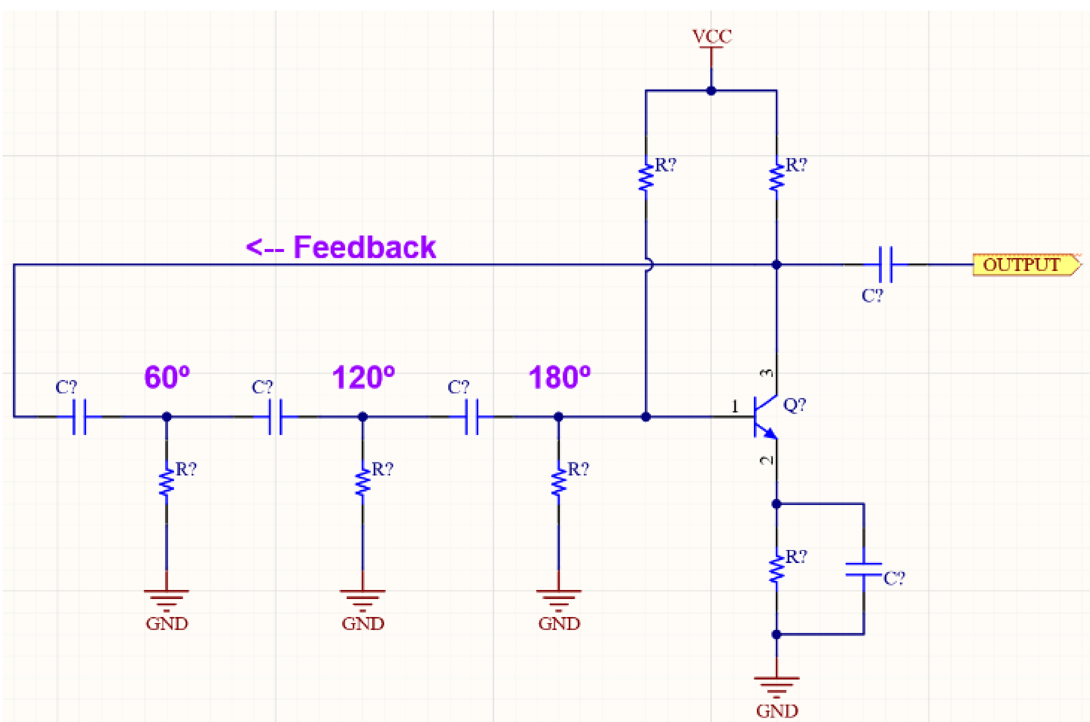

Figure 5: Basic RC Oscillator Schematic

9.3. Sinusoidal Oscillators

An electronic device that generates sinusoidal oscillations of desired frequency is known as a sinusoidal oscillator.

Although we speak of an oscillator as "generating" a frequency, it should be noted that it does not create energy, but merely acts as an energy converter. It receives d.c. energy and changes it into a.c. energy of desired frequency.

Advantages

Although oscillations can be produced by mechanical devices (e.g. alternators), but electronic oscillators have the following advantages :

1. An oscillator is a non-rotating device, there is longer life.
2. Due to the absence of moving parts, the operation of an oscillator is quite silent.
3. An oscillator can produce waves from small (20 Hz) to extremely high frequencies (> 100 MHz).
4. The frequency of oscillations can be easily changed when desired.
5. It has very high efficiency

9.4. References

Electronics principles (fourth edition) by Malvino.