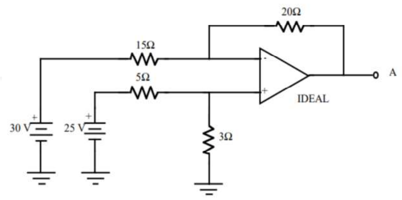
Op-Amp

Problem: For the difference amplifier circuit shown, determine the output voltage at terminal A.



By voltage division,

$$v_{in+} = 25V\left(\frac{3\Omega}{5\Omega + 3\Omega}\right) = 9.375V$$

By the virtual short circuit between the input terminals, v_{in-} = 9.375 V
Using **Ohm's** law, the current through the 15 Ω resistor is

$$I_{15} = \left(\frac{30V - 9.375V}{15\Omega}\right) = 1.375V$$

The input impedance is infinite; therefore, I_{in-}=0 and I_{15}=I_{20}.

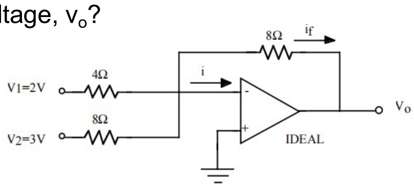
Use Kirchoff's voltage law to find the output voltage at A.

$v_A = v_{in-} - 20I_{20}$ = 9.375 V - (20Ω)(1.375 A) = -18.125 V

Problem

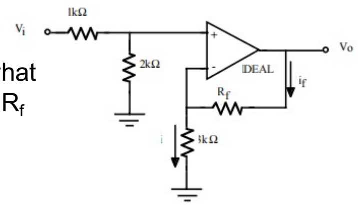
1. What's the value of current ***i***
2. What is the output voltage, v_o?

Answer:
1. 0
2. 7V (Current sum)

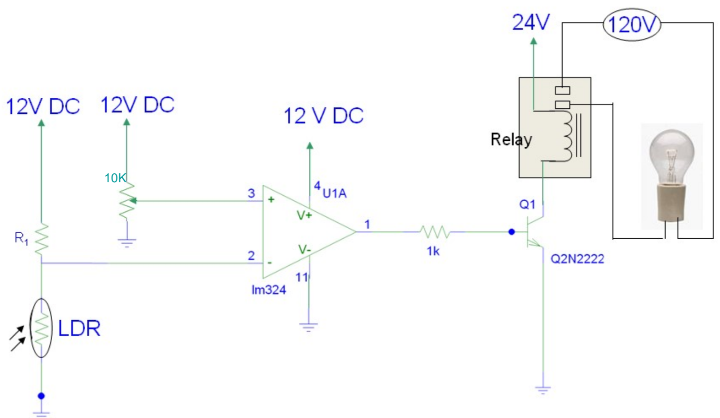


Assignment

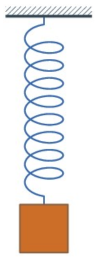
For the ideal op amp shown, what should be the value of resistor R_f to obtain a gain of 5?



A practical circuit using op amp



OSCILLATORS



Oscillators

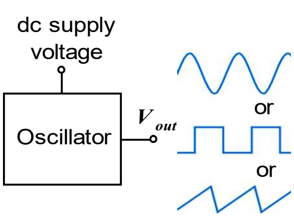
Introduction

Oscillators are circuits that produce a continuous signal of some type without the need of an input. These signals serve a variety of purposes. Communications systems, digital systems (including computers), and test equipment make use of oscillators.

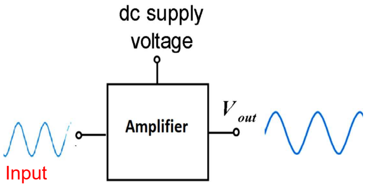
Oscillators

Oscillator is an electronic circuit that generates a periodic waveform on its output ***without an external signal source***. It is used to convert dc to ac.

The waveform can be sine wave, square wave, triangular wave, and sawtooth wave.



What's the difference between an amplifier & an oscillator?



Oscillators

An oscillator is a circuit that produces a repetitive signal from a dc voltage. Two types of oscillator:

- **Feedback oscillator,** relies on a positive feedback of the output to maintain the oscillations.
- **Relaxation oscillator,** makes use of an RC timing circuit to generate a nonsinusoidal signal such as square wave.

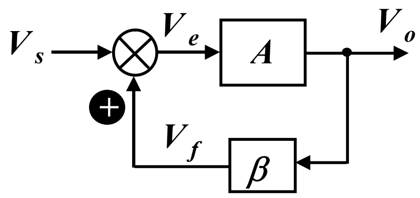
Oscillators

Types of oscillators

1. RC oscillators
   - Wien Bridge
   - Phase Shift
2. LC oscillators
   - Hartley
   - Colpitts
3. Relaxation oscillators

Basic principles for oscillation

➢ An oscillator is an amplifier with positive feedback.



$$V_e = V_s + V_f \quad (1)$$

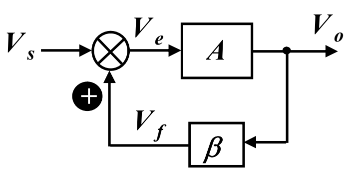
$$V_f = \beta V_o \quad (2)$$

$$V_o = AV_e = A(V_s + V_f) = A(V_s + \beta V_o) \quad (3)$$

Oscillators

The closed loop gain is;

$$A_f \equiv \frac{V_o}{V_s} = \frac{A}{(1 - A\beta)}$$



$A\beta$ is known as **loop gain.**

Oscillation Condition

The condition for sinusoidal oscillation of frequency f_0 is;

$$A\beta = 1$$

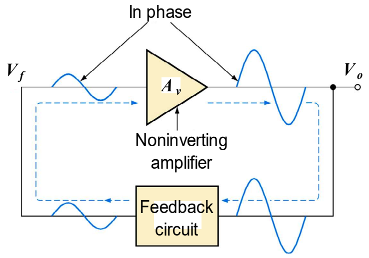
A and ***β*** both are frequency dependent

This is known as **Barkhausen criterion**.

Oscillators

The feedback oscillator is widely used for generation of sine wave signals. The positive (in phase) feedback arrangement maintains the oscillations. The feedback gain must be kept to unity to keep the output from distorting.

If the feedback circuit returns the signal out of phase, an inverting amplifier produces positive feedback.



Oscillators

Design Criteria for Oscillators

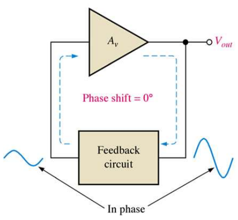
1. The magnitude of the loop gain must be unity or slightly larger i.e.

$$|A\beta| = 1$$ **– Barkhaussen criterion**

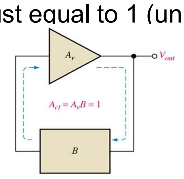
2. **Total phase shift, ϕ of the loop gain must be 0° or 360°.**

Conditions for oscillation:

1. The phase shift around the feedback loop must be 0°.

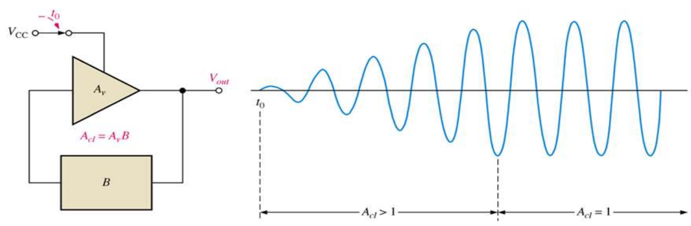


2. The voltage gain A_{CL}, around the closed feedback loop (loop gain) must equal to 1 (unity).



Feedback Oscillators: *Start-Up Conditions:*

- When oscillation starts at t_0, the condition $A_{CL} > 1$ causes the sinusoidal output voltage amplitude to build up to a desired level.
- Then A_{CL} decreases to 1 and maintains the desired amplitude.



Oscillators

Factors determining the frequency of oscillation

- Oscillators can be classified into many types depending on the feedback components, amplifiers and circuit topologies used.
- RC components generate a sinusoidal waveform at a few Hz to kHz range.
- LC components generate a sine wave at frequencies of 100 kHz to 100 MHz.
- Crystals generate a square or sine wave over a wide range,i.e. about 10 kHz to 30 MHz.

Oscillators

1. RC Oscillators

RC feedback oscillators are generally limited to frequencies of 1 MHz or less.

The types of RC oscillators that we will discuss are the **phase-shift**.

Oscillators – Phase-shift

The three RC circuits combine to produce a phase shift of 180º.

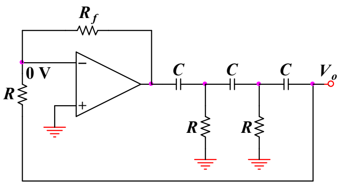


Fig. 3 shows a circuit containing three RC circuits in its feedback network called the **phase-shift oscillator**.

Oscillators – Phase-shift

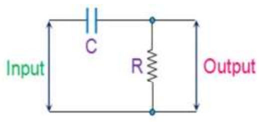


Figure 1 RC Phase-Shift Network

Ideally a simple RC network is expected to have an output which leads the input by 90°.

However, in reality, the phase-difference will be less than this as the capacitor used in the circuit cannot be ideal. Mathematically the phase angle of the RC network is expressed as

$$\varphi = tan^{-1}\frac{X_C}{R}$$

Where, $X_C = 1/(2\pi fC)$ is the reactance of C

In oscillators, these kind of ***RC*** phase-shift networks, each offering a definite phase-shift can be cascaded so as to satisfy the phase-shift condition led by the Barkhausen Criterion.

Oscillators – Phase-shift

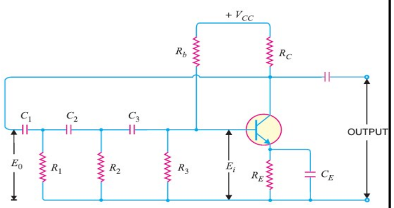
The phase shift oscillator utilizes **three RC circuits** to provide 180º phase shift that when coupled with the 180º of the op-amp itself provides the necessary feedback to sustain oscillations. The gain must be at least 29 to maintain the oscillations. The frequency of resonance for the this type is similar to any RC circuit oscillator.

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

Where, **N** is the number of **RC** stages formed by the resistors **R** and the capacitors **C**.

Phase-shift Oscillator: Problem

In the following phase shift oscillator R1 = R2 = R3 = 1MΩ and C1 = C2 = C3 = 68 pF. At what frequency does the circuit oscillate ?



Solution.

$$R_1 = R_2 = R_3 = R = 1\,M\Omega = 10^6\,\Omega$$
$$C_1 = C_2 = C_3 = C = 68\,pF = 68 \times 10^{-12}\,F$$

Frequency of oscillations is

$$f_o = \frac{1}{2\pi RC\sqrt{6}}$$
$$= \frac{1}{2\pi \times 10^6 \times 68 \times 10^{-12}\sqrt{6}}\ \text{Hz}$$
$$= \mathbf{954\ Hz}$$

Oscillators

2. LC Oscillators

Oscillators

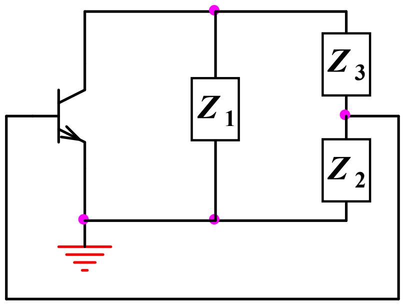
Oscillators With LC Feedback Circuits

For frequencies above 1 MHz, LC feedback oscillators are used.

We will discuss the **Colpitts, Hartley** and **crystal-controlled** oscillators.

Transistors are used as the active device in these types.

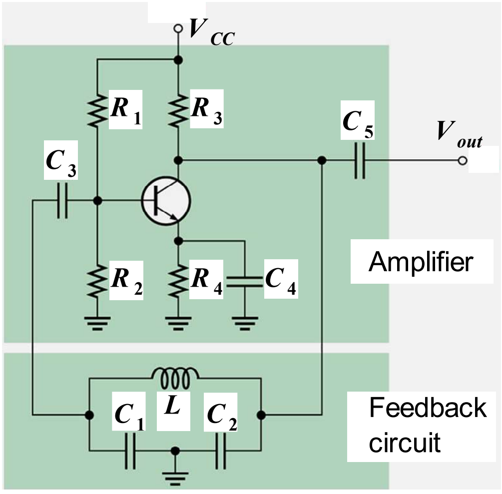
Oscillators With LC Feedback Circuits



Hartley Oscillators → Z_3 **is a capacitor**
Colpitts Oscillators → Z_3 **is an inductor**

Oscillators – Colpitts

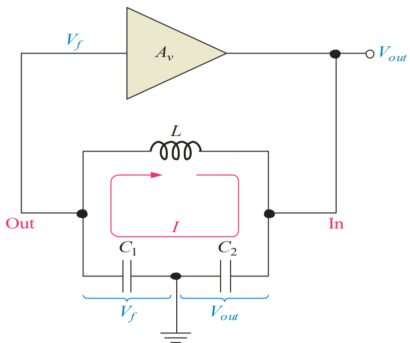
The Colpitts oscillator utilizes a tank circuit (LC) in the feedback loop as shown in the figure.



Oscillators – Colpitts

LC feedback oscillators use resonant circuits in the feedback path. A popular *LC* oscillator is the **Colpitts oscillator**. It uses two series capacitors in the resonant circuit. The feedback voltage is developed across C_1.

The effect is that the tank circuit is "tapped". Usually C_1 is the larger capacitor because it develops the smaller voltage.



Oscillators – Colpitts

Total capacitance (C_T) is ;

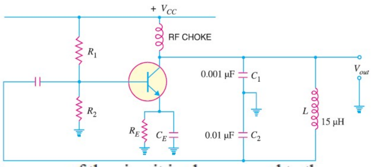
$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$C_T = \frac{C_1 C_2}{C_1 + C_2}$$

The resonant frequency can be determined by the formula below.

$$f_r = \frac{1}{2\pi\sqrt{LC_T}}$$

Determine the (i) operating frequency and (ii) feedback fraction for following Colpitt's oscillator



Solution.

(i) **Operating Frequency.** The operating frequency of the circuit is always equal to the resonant frequency of the feedback network. As noted previously, the capacitors C_1 and C_2 are in series.

$$\therefore \quad C_T = \frac{C_1 C_2}{C_1 + C_2} = \frac{0.001 \times 0.01}{0.001 + 0.01} = 9.09 \times 10^{-4}\ \mu\text{F}$$

$$= 909 \times 10^{-12}\ \text{F}$$

$$L = 15\ \mu\text{H} = 15 \times 10^{-6}\ \text{H}$$

$$\therefore \quad \text{Operating frequency, } f = \frac{1}{2\pi\sqrt{LC_T}}$$

$$= \frac{1}{2\pi\sqrt{15 \times 10^{-6} \times 909 \times 10^{-12}}}\ \text{Hz}$$

$$= 1361 \times 10^3\ \text{Hz} = \mathbf{1361\ kHz}$$

(ii) **Feedback fraction**

$$m_v = \frac{C_1}{C_2} = \frac{0.001}{0.01} = \mathbf{0.1}$$