Lecture Oscillator

- Introduction of Oscillator
- Linear Oscillator
  - Wien Bridge Oscillator
  - RC Phase-Shift Oscillator
  - LC Oscillator
- Stability

Oscillators

Oscillation: an effect that repeatedly and regularly fluctuates about the mean value

Oscillator: circuit that produces oscillation

Characteristics: wave-shape, frequency, amplitude, distortion, stability

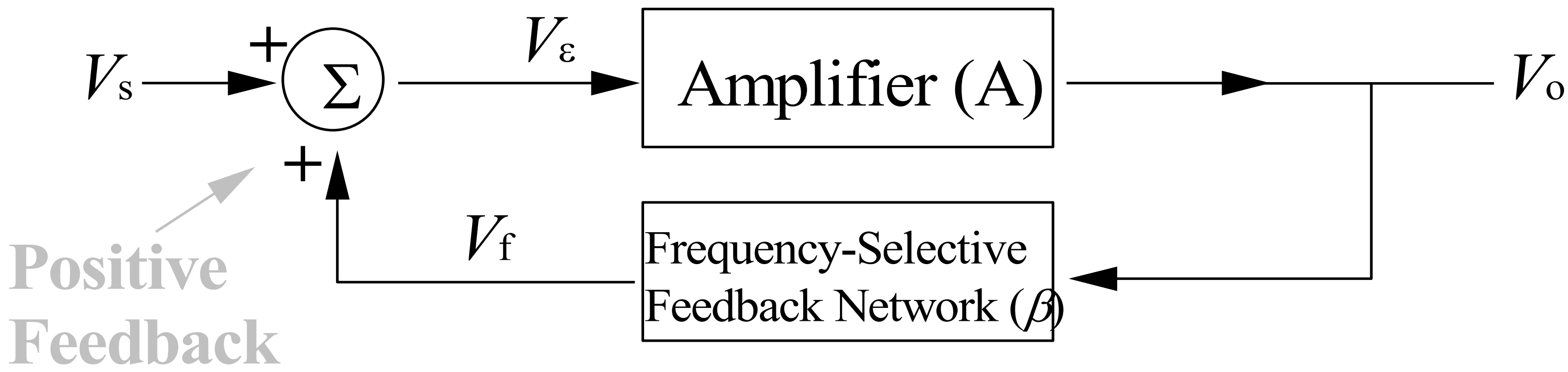
Application of Oscillators

- Oscillators are used to generate signals, e.g.
  - Used as a local oscillator to transform the RF signals to IF signals in a receiver;
  - Used to generate RF carrier in a transmitter
  - Used to generate clocks in digital systems;
  - Used as sweep circuits in TV sets and CRO.

Linear Oscillators

1. Wien Bridge Oscillators
2. RC Phase-Shift Oscillators
3. LC Oscillators
4. Stability

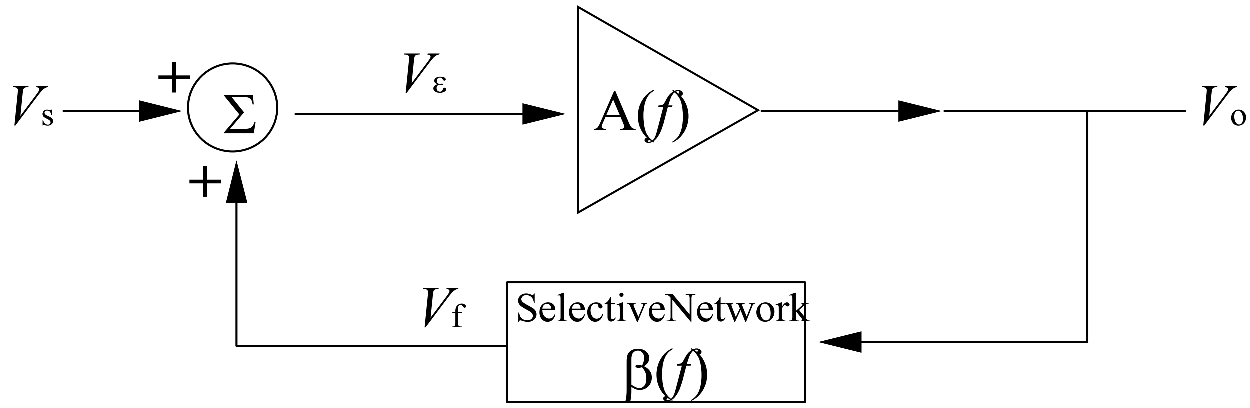
Integrant of Linear Oscillators



For sinusoidal input is connected
"Linear" because the output is approximately sinusoidal

A linear oscillator contains:
- a frequency selection feedback network
- an amplifier to maintain the loop gain at **unity**

Basic Linear Oscillator



$$V_o = AV_\varepsilon = A(V_s + V_f) \quad \text{and} \quad V_f = \beta V_o$$

$$\Rightarrow \frac{V_o}{V_s} = \frac{A}{1 - A\beta}$$

If $V_s = 0$, the only way that V_o can be nonzero is that loop gain $A\beta=1$ which implies that

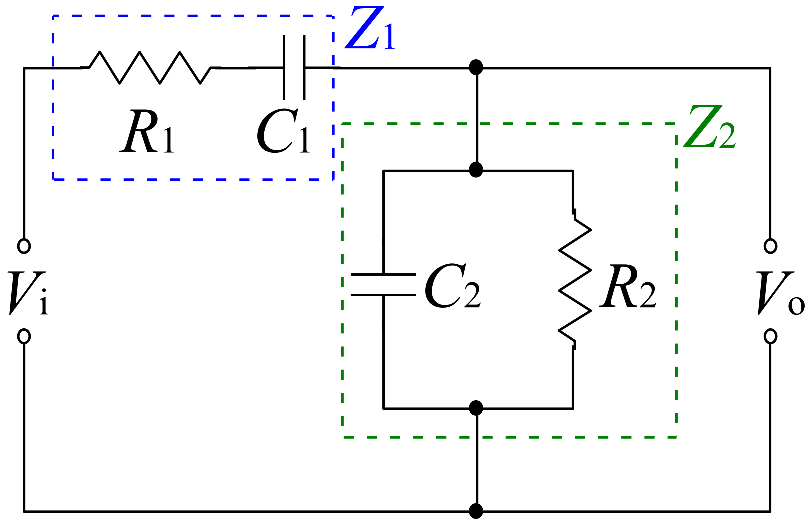
$$|A\beta| = 1$$
$$\angle A\beta = 0$$

(Barkhausen Criterion)

Wien Bridge Oscillator

Let $X_{C1} = \frac{1}{\omega C_1}$ and $X_{C2} = \frac{1}{\omega C_2}$

Frequency Selection Network



$$Z_1 = R_1 - jX_{C1}$$

$$Z_2 = \left[\frac{1}{R_2} + \frac{1}{-jX_{C2}} \right]^{-1} = \frac{-jR_2 X_{C2}}{R_2 - jX_{C2}}$$

Therefore, the feedback factor,

$$\beta = \frac{V_o}{V_i} = \frac{Z_2}{Z_1 + Z_2} = \frac{(-jR_2 X_{C2} / R_2 - jX_{C2})}{(R_1 - jX_{C1}) + (-jR_2 X_{C2} / R_2 - jX_{C2})}$$

$$\beta = \frac{-jR_2 X_{C2}}{(R_1 - jX_{C1})(R_2 - jX_{C2}) - jR_2 X_{C2}}$$

β can be rewritten as:

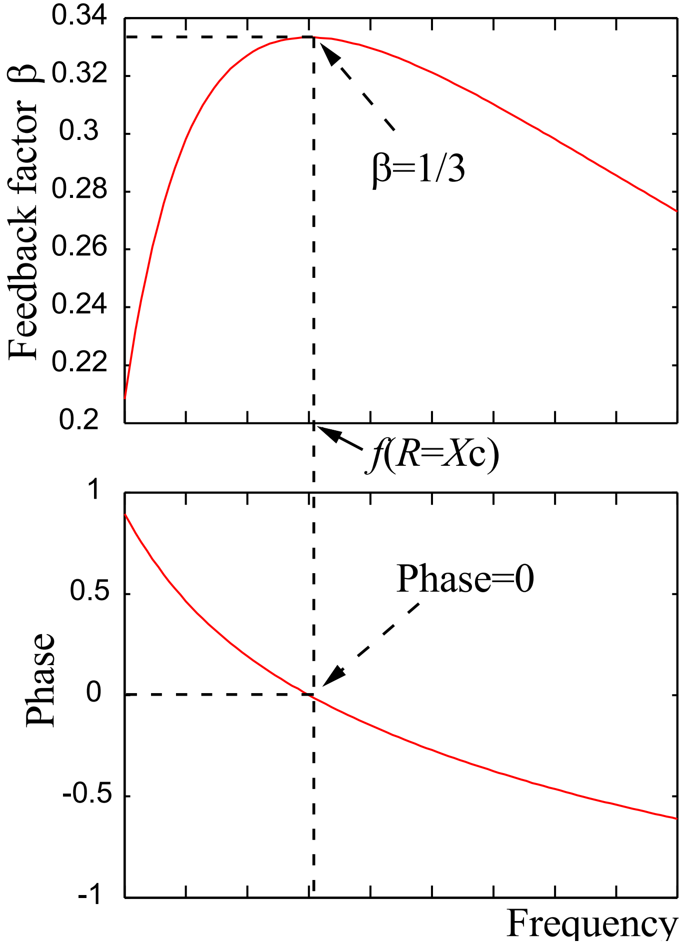
$$\beta = \frac{R_2 X_{C2}}{R_1 X_{C2} + R_2 X_{C1} + R_2 X_{C2} + j(R_1 R_2 - X_{C1} X_{C2})}$$

For ***Barkhausen Criterion***, imaginary part = 0, i.e.,

$$R_1 R_2 - X_{C1} X_{C2} = 0$$

$$\text{or} \quad R_1 R_2 = \frac{1}{\omega C_1}\frac{1}{\omega C_2}$$

$$\Rightarrow \omega = 1/\sqrt{R_1 R_2 C_1 C_2}$$



Supposing,

R_1=R_2=R and X_{C1}= X_{C2}=X_C,

$$\beta = \frac{R X_C}{3 R X_C + j(R^2 - X_C^2)}$$

Example

By setting $\omega = \dfrac{1}{RC}$, we get

Imaginary part = 0 and $\beta = \dfrac{1}{3}$

Due to ***Barkhausen Criterion***,

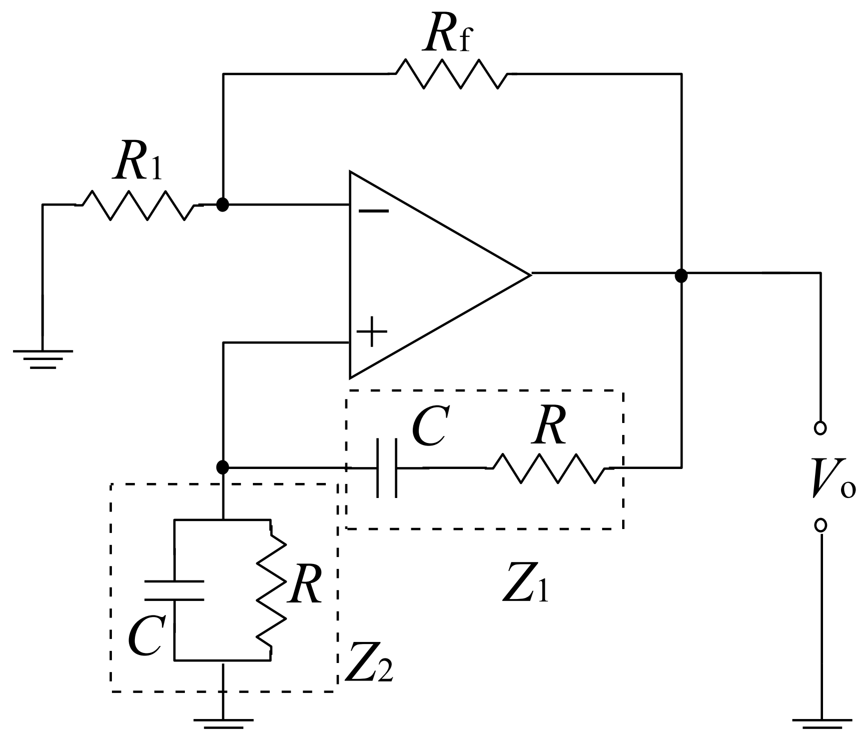
Loop gain $A_v\beta=1$

where

A_v : Gain of the amplifier

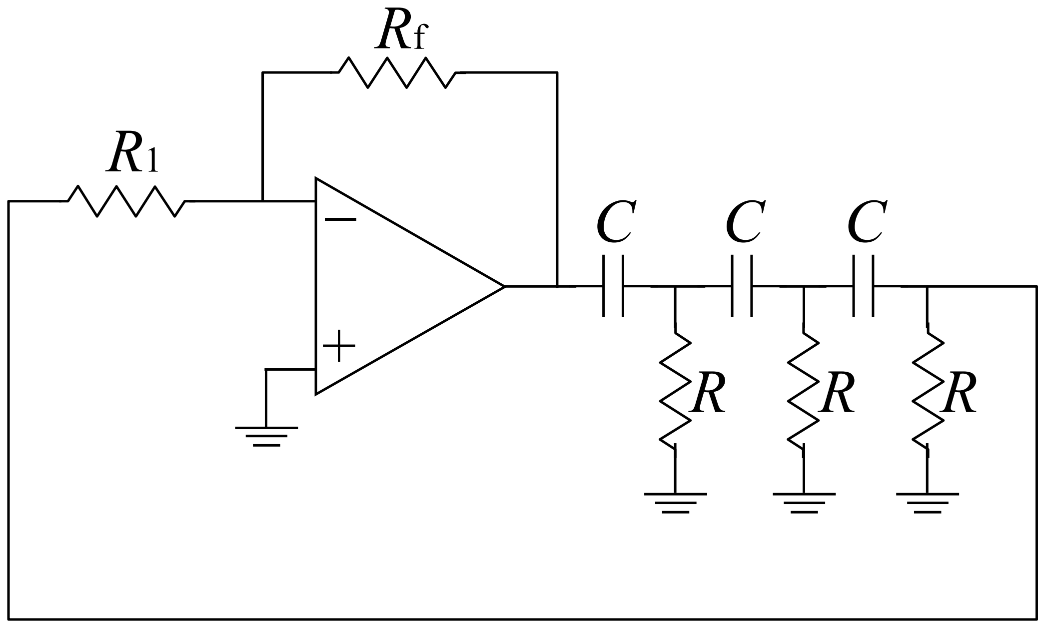
$$A_v\beta = 1 \Rightarrow A_v = 3 = 1 + \frac{R_f}{R_1}$$

Therefore, $\dfrac{R_f}{R_1} = 2$



Wien Bridge Oscillator

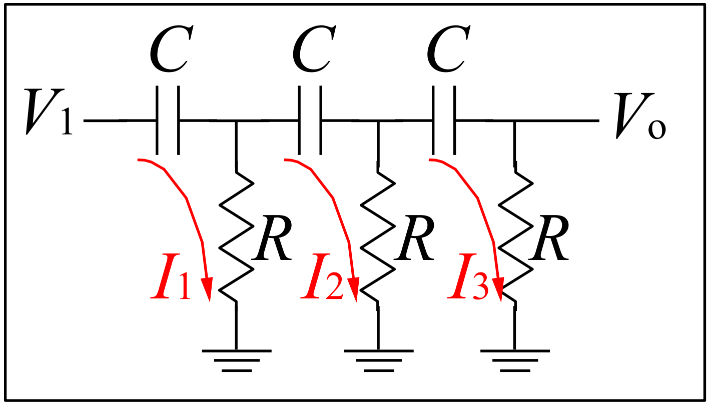
RC Phase-Shift Oscillator



- Using an inverting amplifier
- The additional 180° phase shift is provided by an RC phase-shift network

Applying KVL to the phase-shift network, we have

$$V_1 = I_1(R - jX_C) - I_2R$$
$$0 = -I_1R + I_2(2R - jX_C) - I_3R$$
$$0 = -I_2R + I_3(2R - jX_C)$$



Solve for I_3, we get

$$I_3 = \frac{\begin{vmatrix} R-jX_C & -R & V_1 \\ -R & 2R-jX_C & 0 \\ 0 & -R & 0 \end{vmatrix}}{\begin{vmatrix} R-jX_C & -R & 0 \\ -R & 2R-jX_C & -R \\ 0 & -R & 2R-jX_C \end{vmatrix}}$$

Or $$I_3 = \frac{V_1R^2}{(R-jX_C)[(2R-jX_C)^2 - R^2] - R^2(2R-jX_C)}$$

The output voltage,

$$V_o = I_3 R = \frac{V_1 R^3}{(R - jX_C)[(2R - jX_C)^2 - R^2] - R^2(2R - jX_C)}$$

Hence the transfer function of the phase-shift network is given by,

$$\beta = \frac{V_o}{V_1} = \frac{R^3}{(R^3 - 5RX_C^2) + j(X_C^3 - 6R^2 X_C)}$$

For 180° phase shift, the imaginary part = 0, i.e.,

$$X_C^3 - 6R^2 X_C = 0 \quad \text{or} \quad X_C = 0 \text{ (Rejected)}$$

$$\Rightarrow \mathrm{X}_\mathrm{C}^2 = 6R^2$$

$$\omega = \frac{1}{\sqrt{6}RC}$$

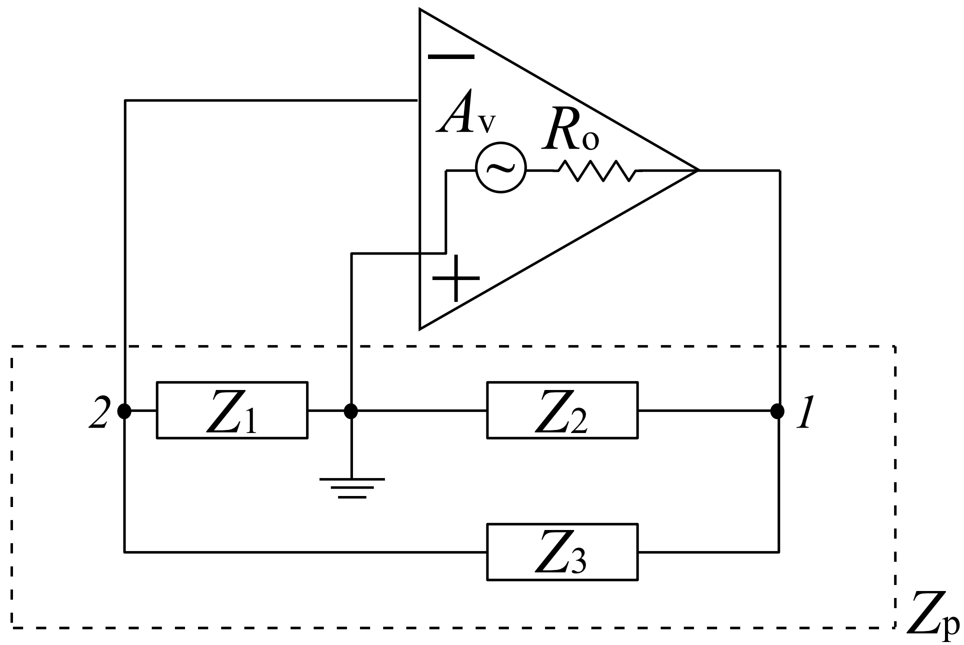
and,

$$\beta = -\frac{1}{29}$$

Note: The –ve sign mean the phase inversion from the voltage

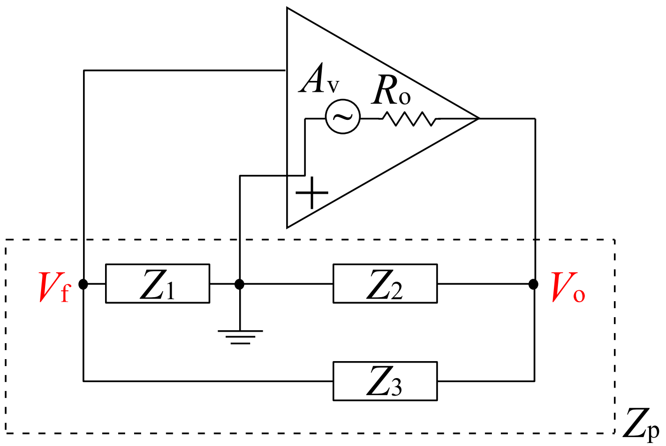
LC Oscillators

- The frequency selection network (Z_1, Z_2 and Z_3) provides a phase shift of 180^o
- The amplifier provides an addition shift of 180^o



Two well-known Oscillators:

- Colpitts Oscillator
- Harley Oscillator

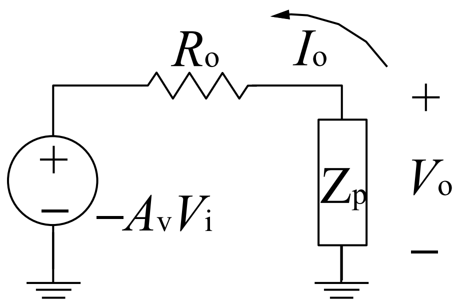


$$V_f = \beta V_o = \frac{Z_1}{Z_1 + Z_3} V_o$$

$$Z_p = Z_2 // (Z_1 + Z_3)$$

$$= \frac{Z_2(Z_1 + Z_3)}{Z_1 + Z_2 + Z_3}$$

For the equivalent circuit from the output



$$\frac{-A_v V_i}{R_o + Z_p} = \frac{V_o}{Z_p} \quad \text{or} \quad \frac{V_o}{V_i} = \frac{-A_v Z_p}{R_o + Z_p}$$

Therefore, the amplifier gain is obtained,

$$A = \frac{V_o}{V_i} = \frac{-A_v Z_2 (Z_1 + Z_3)}{R_o(Z_1 + Z_2 + Z_3) + Z_2(Z_1 + Z_3)}$$

The loop gain,

$$A\beta = \frac{-A_v Z_1 Z_2}{R_o(Z_1 + Z_2 + Z_3) + Z_2(Z_1 + Z_3)}$$

If the impedance are all pure reactances, i.e.,

$$Z_1 = jX_1, \quad Z_2 = jX_2 \text{ and } \quad Z_3 = jX_3$$

The loop gain becomes, $$A\beta = \frac{A_v X_1 X_2}{jR_o(X_1 + X_2 + X_3) - X_2(X_1 + X_3)}$$

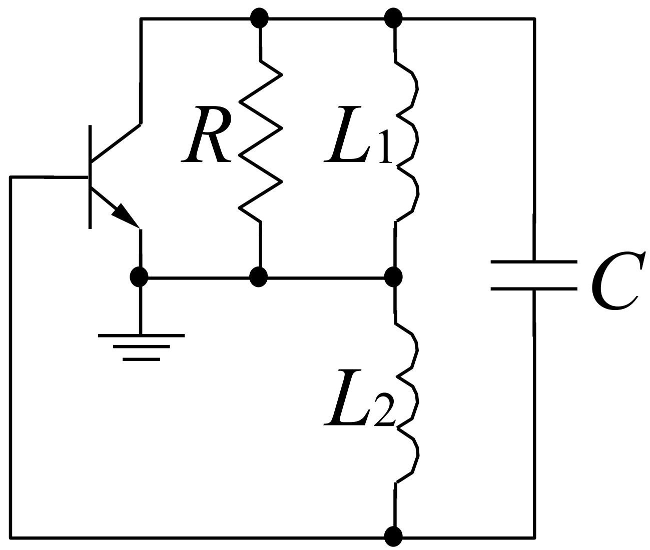
The imaginary part = 0 only when $X_1 + X_2 + X_3 = 0$

- It indicates that at least one reactance must be –ve (capacitor)
- X_1 and X_2 must be of same type and X_3 must be of opposite type

With imaginary part = 0, $$A\beta = \frac{-A_v X_1}{X_1 + X_3} = \frac{A_v X_1}{X_2}$$

For Unit Gain & 180° Phase-shift, $$A\beta = 1 \quad \Rightarrow \quad A_v = \frac{X_2}{X_1}$$

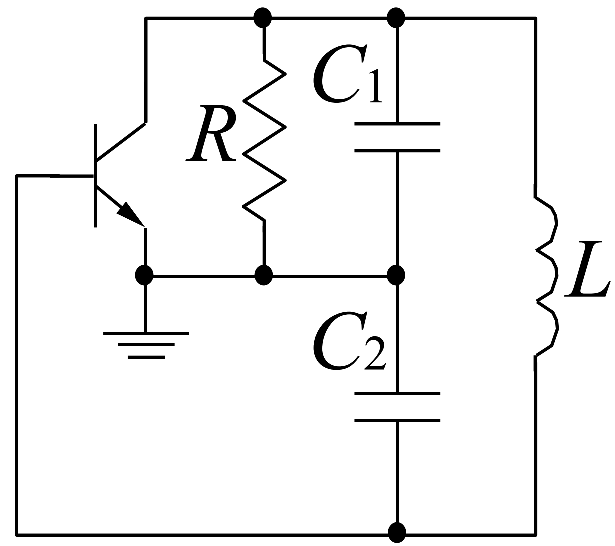
Hartley Oscillator



$$\omega_o = \frac{1}{\sqrt{(L_1 + L_2)C}}$$

$$g_m = \frac{L_1}{RL_2}$$

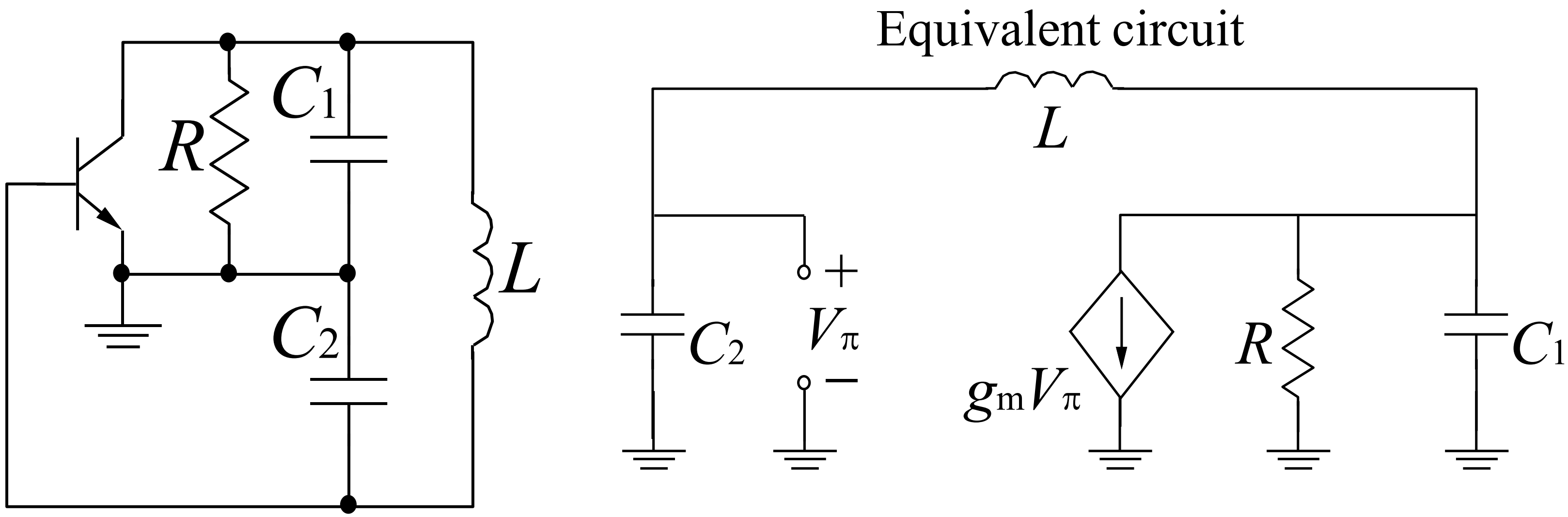
Colpitts Oscillator



$$\omega_o = \frac{1}{\sqrt{LC_T}} \qquad C_T = \frac{C_1 C_2}{C_1 + C_2}$$

$$g_m = \frac{C_2}{RC_1}$$

Colpitts Oscillator



In the equivalent circuit, it is assumed that:

- Linear small signal model of transistor is used
- The transistor capacitances are neglected
- Input resistance of the transistor is large enough

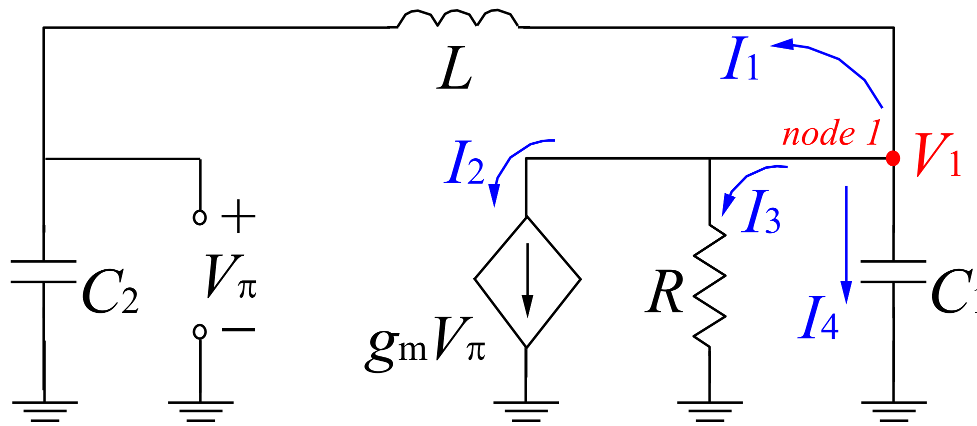
At node 1,

$$V_1 = V_\pi + i_1(j\omega L)$$

where,

$$i_1 = j\omega C_2 V_\pi$$

$$\Rightarrow \quad V_1 = V_\pi(1-\omega^2 LC_2)$$



Apply KCL at node 1, we have

$$j\omega C_2 V_\pi + g_m V_\pi + \frac{V_1}{R} + j\omega C_1 V_1 = 0$$

$$j\omega C_2 V_\pi + g_m V_\pi + V_\pi(1-\omega^2 LC_2)\left(\frac{1}{R} + j\omega C_1\right) = 0$$

For Oscillator V_π must not be zero, therefore it enforces,

$$\left(g_m + \frac{1}{R} - \frac{\omega^2 LC_2}{R}\right) + j\left[\omega(C_1 + C_2) - \omega^3 LC_1C_2\right] = 0$$

$$\left(g_m + \frac{1}{R} - \frac{\omega^2 L C_2}{R} \right) + j\left[\omega(C_1 + C_2) - \omega^3 L C_1 C_2\right] = 0$$

Imaginary part = 0, we have

$$\omega_o = \frac{1}{\sqrt{LC_T}} \qquad C_T = \frac{C_1 C_2}{C_1 + C_2}$$

Real part = 0, yields

$$g_m = \frac{C_2}{RC_1}$$

Frequency Stability

- The frequency stability of an oscillator is defined as

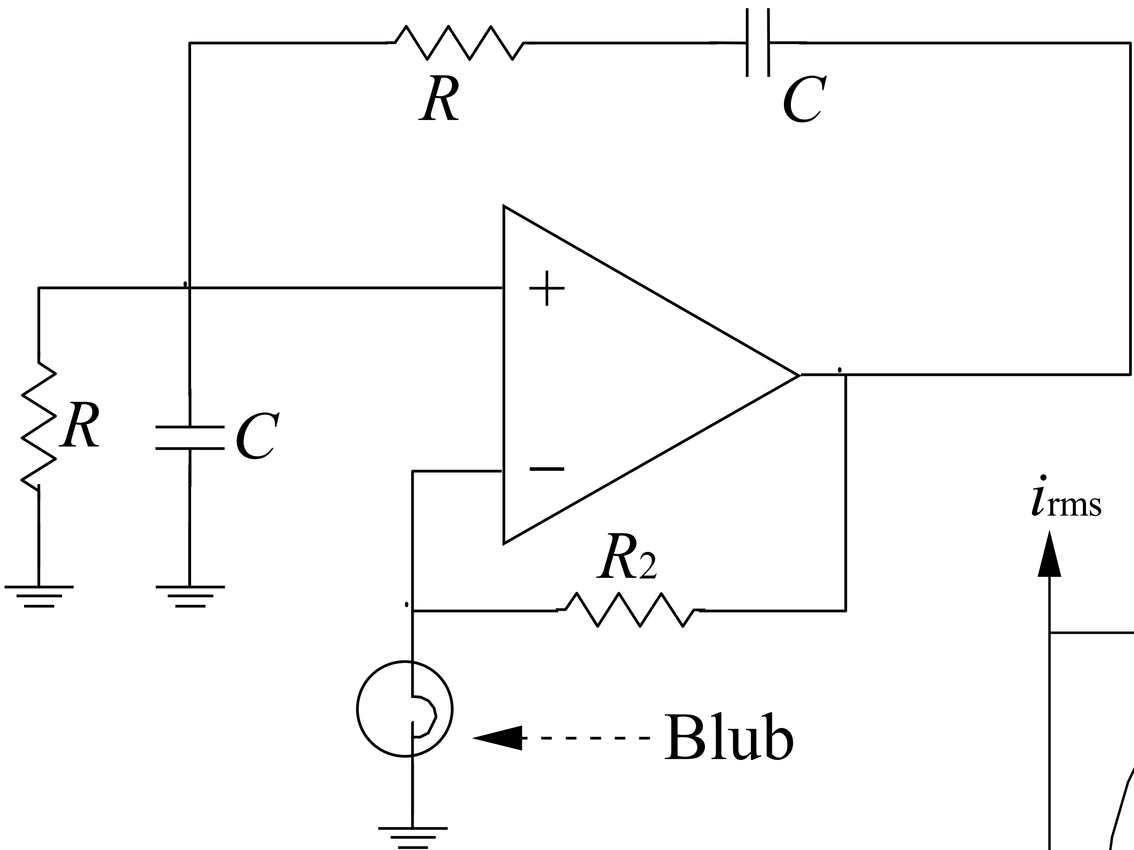
$$\frac{1}{\omega_o} \cdot \left(\frac{d\omega}{d\mathbf{T}} \right)_{\omega = \omega_o} \qquad \textbf{ppm/ }^{\mathbf{o}}\textbf{C}$$

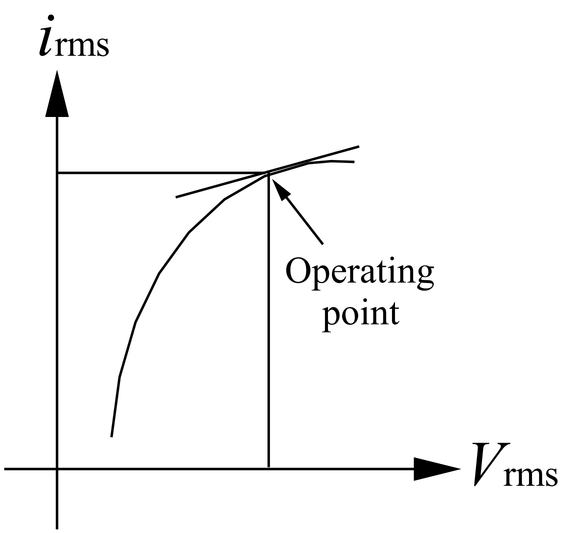
- Use high stability capacitors, e.g. silver mica, polystyrene, or teflon capacitors and low temperature coefficient inductors for high stable oscillators.

Amplitude Stability

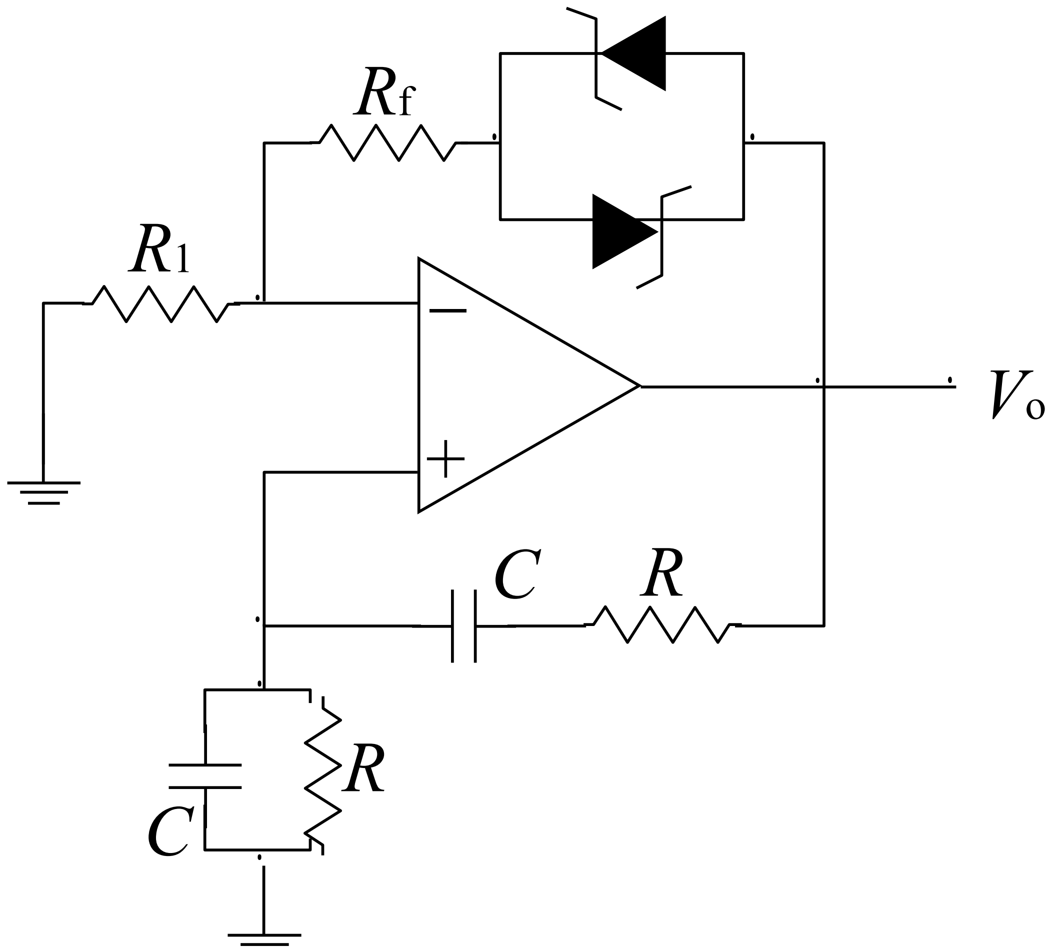
- In order to start the oscillation, the loop gain is usually slightly greater than unity.
- LC oscillators in general do not require amplitude stabilization circuits because of the selectivity of the LC circuits.
- In RC oscillators, some non-linear devices, e.g. NTC/PTC resistors, FET or zener diodes can be used to stabilized the amplitude

Wien-bridge oscillator with bulb stabilization

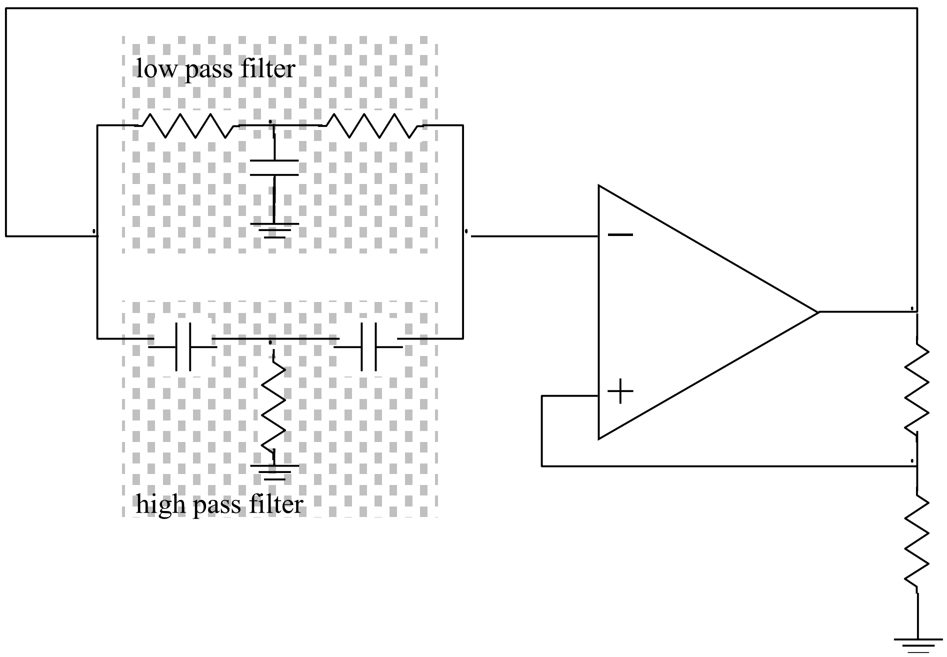


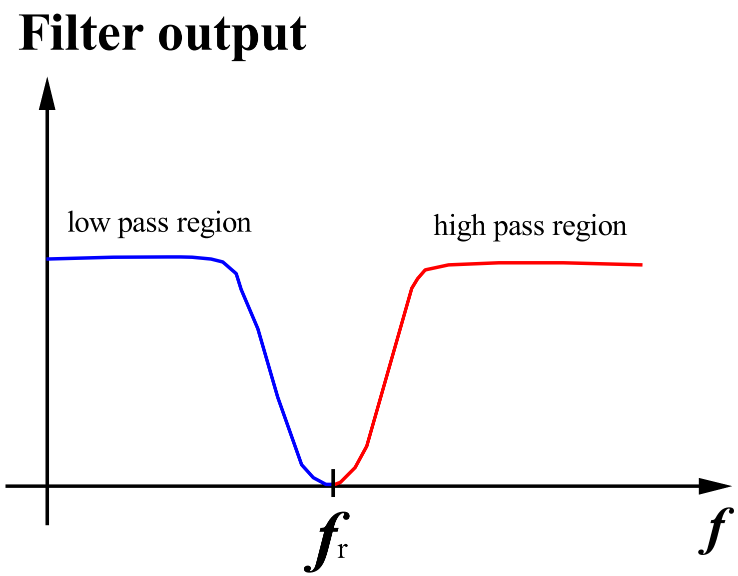


Wien-bridge oscillator with diode stabilization

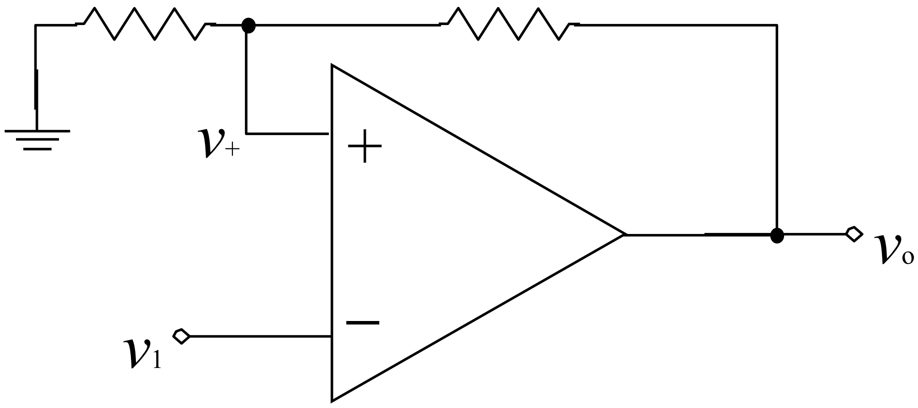


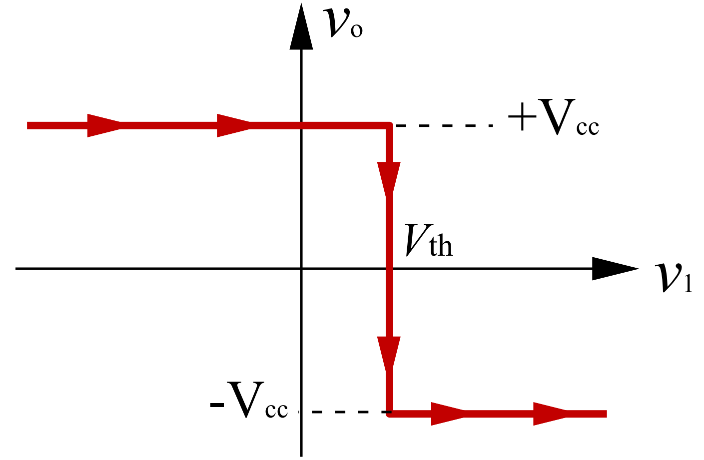
Twin-T Oscillator

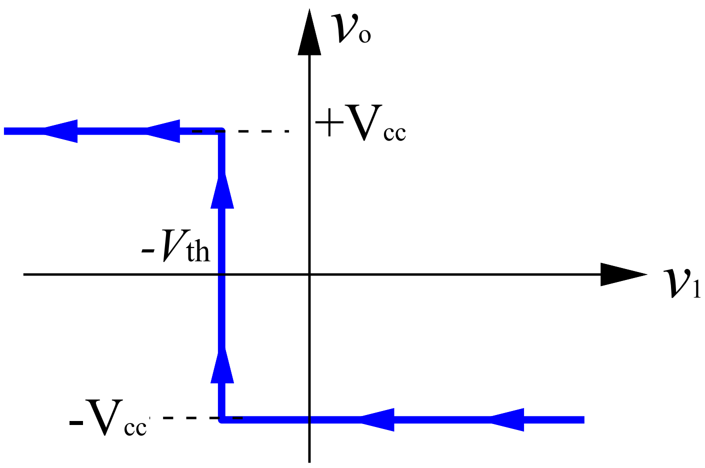


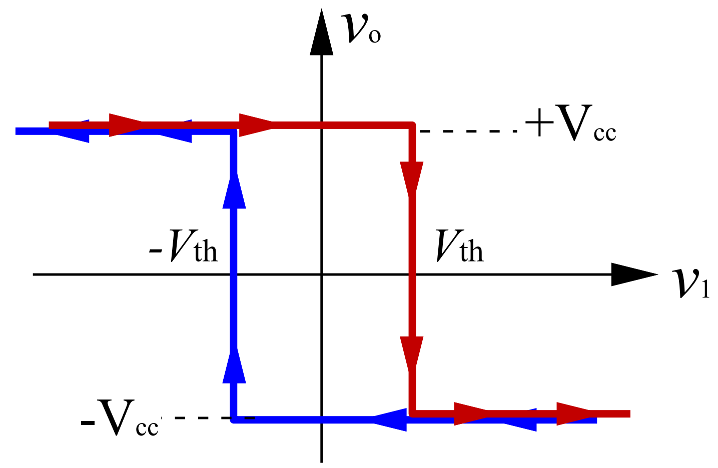


Bistable Circuit









A Square-wave Oscillator