Electronic Circuits Analysis III

Oscillators

Principles

RC Phase-Shift Oscillator

Fall 2020

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.

Oscillators Classifications

- Oscillators are classified based on:
  - Output waveform
  - Circuit Components
  - Range of Operating Frequency

Oscillators Classifications

- Oscillators are classified based on:
  - Output waveform
    - Sinusoidal Oscillators, pure Sinusoidal output waveform
    - Non-sinusoidal Oscillators, triangular, square, sawtooth output waveforms

Oscillators Classifications

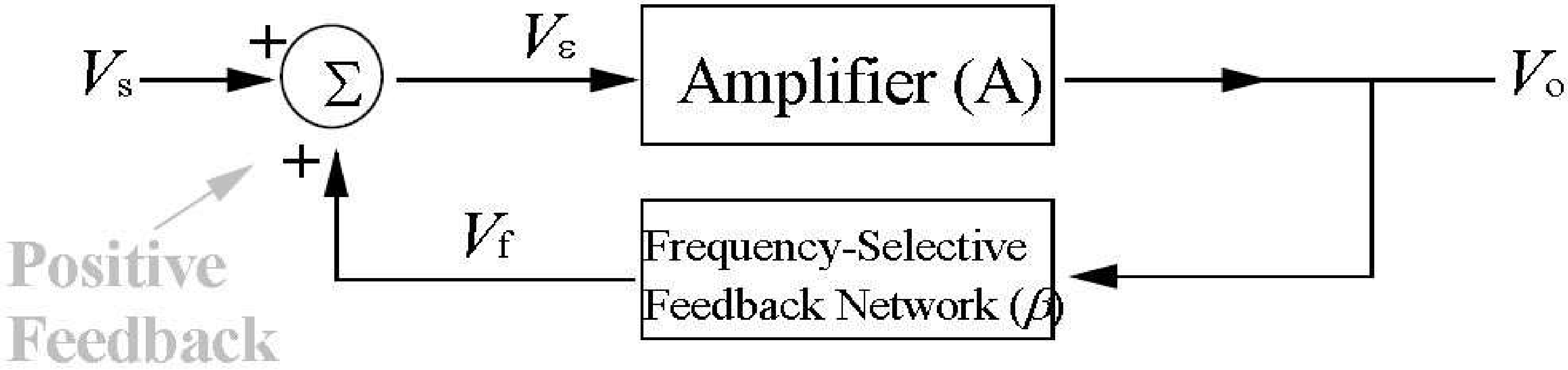
- Oscillators are classified based on:
  - Circuit Components
    - RC Oscillators, components Resistances and Capacitors
    - LC Oscillators, components Inductances and Capacitors

Oscillators Classifications

- Oscillators are classified based on:
  - Range of Operating Frequency
    - Audio Frequency (A.F.) Oscillators,
      - Range: 20Hz to100-200KHz
      - It's also called Low Frequency (L.F.) Oscillators
      - RC Oscillators
    - Radio Frequency (R.F.) Oscillators,
      - Range: More than 200-300KHz to xxxGHz
      - It's also called High Frequency (H.F.) Oscillators
      - LC Oscillators

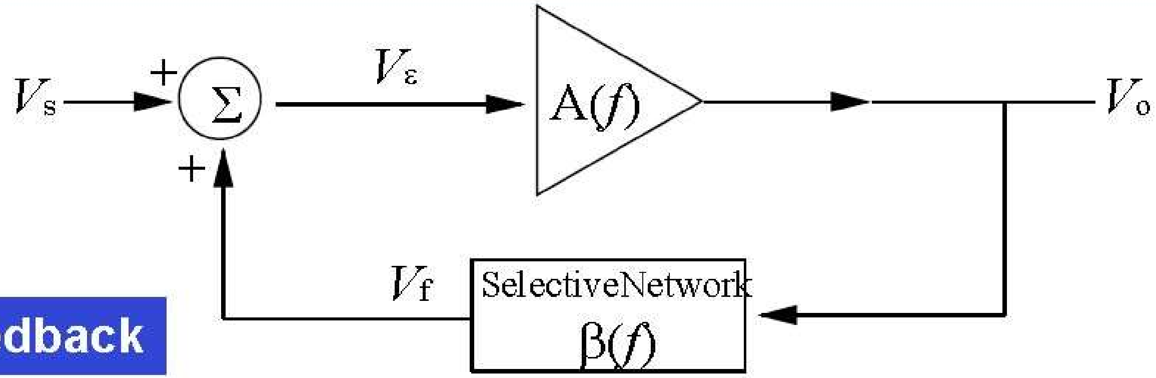
Sinusoidal Oscillators

- Basic Principles of Linear Oscillators



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

Basic Linear Oscillator



+ve feedback

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

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

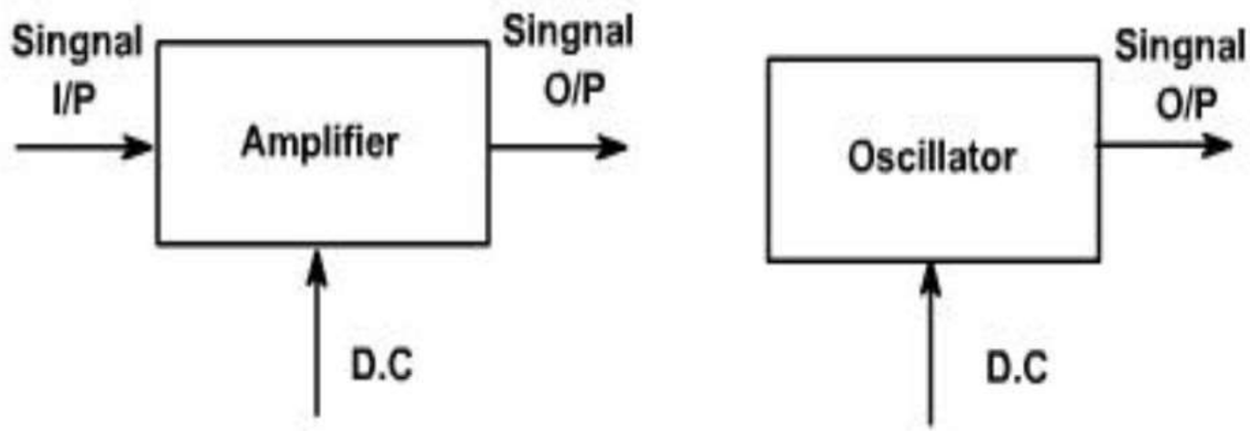
If V_s = 0, the only way that V_o can be nonzero is that loop gain $A\beta$=1 which implies that

$$\boxed{\begin{aligned} |A\beta| &= 1 \\ \angle A\beta &= 0 \end{aligned}}$$

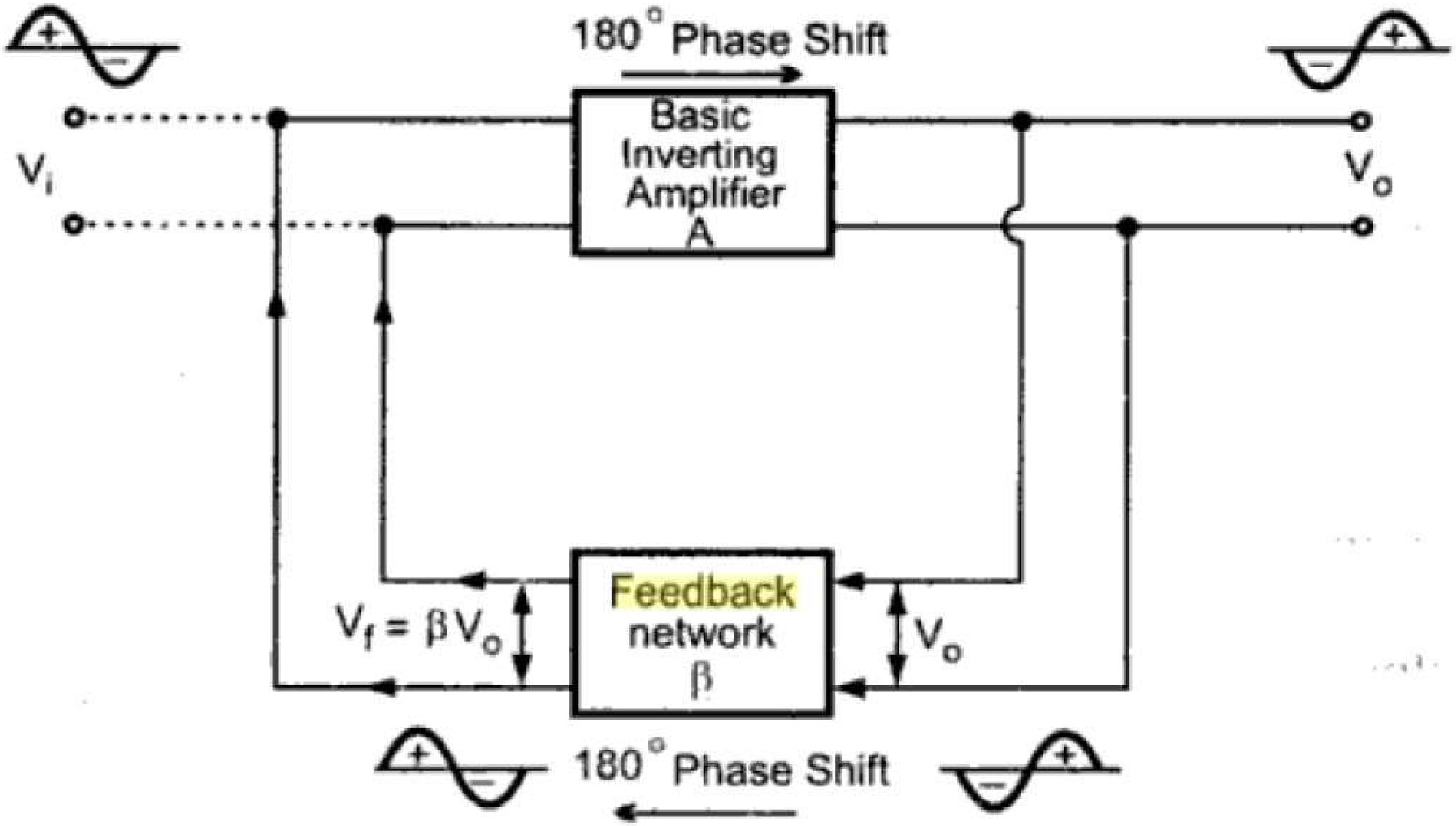
(Barkhausen Criterion)

Basic Linear Oscillator

- The oscillator, on the other hand, requires no external signal to initiate or maintain the energy conversion process.
- Instead an output signals is produced as long as source of DC power is connected.



Oscillators: Basic Block Diagram



Oscillators: Basic Block Diagram

(Barkhausen Criterion)

1. The total phase shift around a loop, as the signal proceeds from input through amplifier, feedback network back to input again, completing a loop, is precisely 0° or 360°.

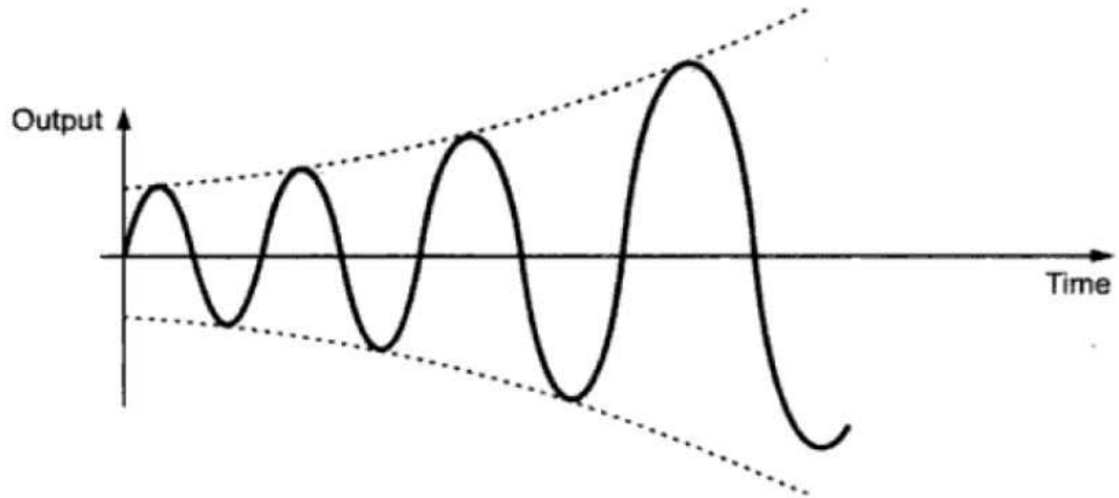
2. The magnitude of the product of the open loop gain of the amplifier (A) and the magnitude of the feedback factor β is unity i.e. | A β | = 1.

$$|A\beta| = 1$$

$$\angle A\beta = 0 \quad or \quad 360$$

Sinusoidal Oscillators

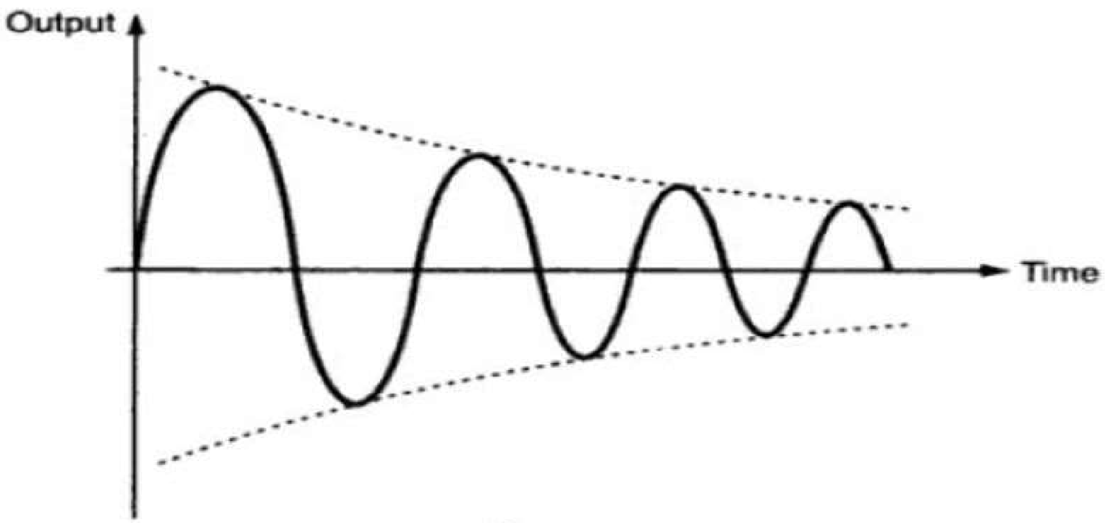
- Growing Type Oscillation



When the total phase shift around a loop is 0° or 360° and $|A\beta| > 1$, then the output oscillates but the oscillations are of growing type.

Sinusoidal Oscillators

- Exponentially Decaying Oscillation

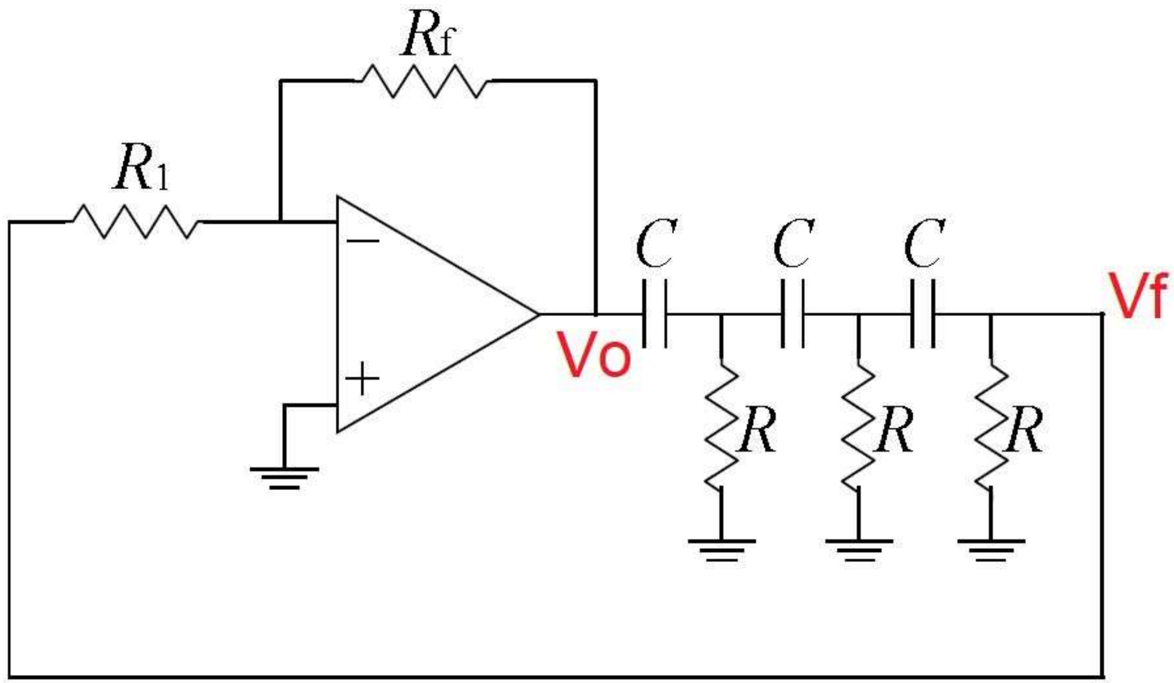


When total phase shift around a loop is 0° or 360° but $|A\beta| < 1$ then the oscillations are of decaying type i.e. such oscillation amplitude decreases exponentially and the oscillations finally cease. Thus circuit works as an amplifier without oscillations.

Linear Oscillators

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

1. RC Phase-Shift Oscillator

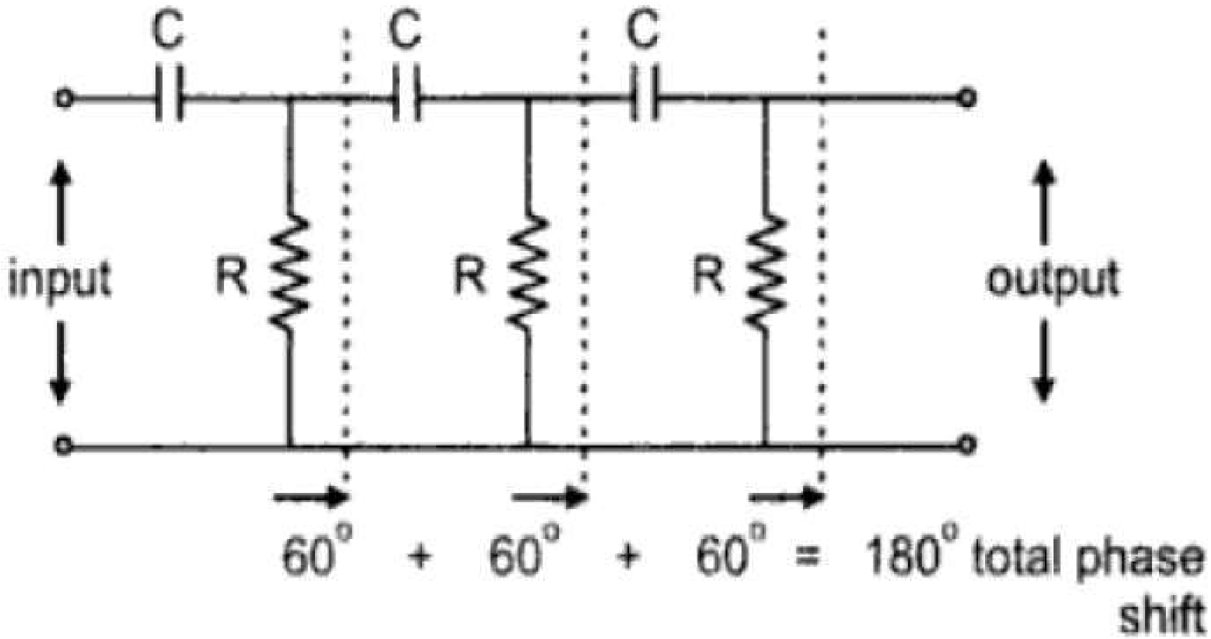


- **Using an inverting amplifier**
  180º phase shift Vi & Vo
- **The additional 180º phase shift is provided by an RC phase-shift network**

$$A_v = -\frac{R_f}{R_1} \Rightarrow \quad \angle A_v = 180$$

$$\Rightarrow \angle\beta = 180$$

Feedback Network



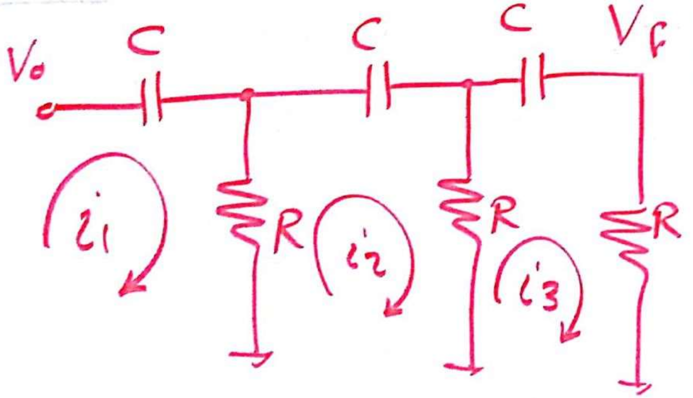
The network is also called the **ladder network**. All the resistance values and all the capacitance values are same, so that for a particular frequency, each section of R and C produces a phase shift of 60°.

Amplifier gain

$$A = \frac{V_o}{V_f} = -\frac{R_F}{R_1}$$

Feedback factor (β)

β – network



$$\boxed{\beta = \frac{V_f}{V_o}}$$

$C \longrightarrow -jX_c \, , \; X_c = \frac{1}{\omega c}$

$$\boxed{V_f = i_3 R} \quad ①$$

Loop ①

$$\boxed{(R - jX_c)\, i_1 - R\, i_2 = V_o} \quad ②$$

Loop ②

$$(2R - jX_c)\, i_2 - R\, i_1 - R\, i_3 = 0$$

$$\boxed{-R\, i_1 + (2R - jX_c)\, i_2 - R\, i_3 = 0} \quad ③$$

Loop ③

$$(2R - jX_c)\, i_3 - R\, i_2 = 0$$

$$\boxed{-R\, i_2 + (2R - jX_c)\, i_3 = 0} \quad ④$$

$$\Delta = \begin{array}{ccc} \oplus & \ominus & \\ \end{array}$$

$$\Delta = \begin{vmatrix} (R-jX_c) & -R & 0 \\ -R & (2R-jX_c) & -R \\ 0 & -R & (2R-jX_c) \end{vmatrix}$$

$$\Delta 3 = \begin{vmatrix} (R-jX_c) & -R & V_o \\ -R & (2R-jX_c) & 0 \\ 0 & -R & 0 \end{vmatrix}$$

$$\Delta = (R-jX_c)\left[(2R-jX_c)^2 - R^2\right]$$

$$+R\left[-R(2R-jX_c) - 0\right]$$

$$\Delta = \left[R^3 - 5RX_c^2\right] + j\left[X_c^3 - 6R^2X_c\right]$$

$$\Delta 3 = V_o\left[R^2 - 0\right]$$

$$\boxed{\Delta 3 = V_o R^2}$$

$$\therefore i_3 = \frac{\Delta 3}{\Delta} = \frac{V_o R^2}{\left[R^3 - 5RX_c^2\right] + j\left[X_c^3 - 6R^2X_c\right]}$$

$$\therefore V_f = i_3 \cdot R = \frac{V_o R^3}{\left[R^3 - 5RX_c^2\right] + j\left[X_c^3 - 6R^2X_c\right]}$$

$$\beta = \frac{V_f}{V_o} = \frac{R^3}{\left[R^3 - 5RX_c^2\right] + j\left[X_c^3 - 6R^2X_c\right]}$$

$A \rightarrow$ Real $\therefore \beta \rightarrow$ Real

$\therefore X_c^3 - 6R^2 X_c = 0$

$X_c^2 = 6R^2 \rightarrow X_c = \sqrt{6}\, R$

$\frac{1}{\omega_o C} = \sqrt{6}\, R$

$\omega_o = \frac{1}{\sqrt{6}\, RC}$, $\omega_o = 2\pi f_o$

$\therefore f_o = \frac{1}{2\pi\sqrt{6}\, RC}$ oscillation frequency

$A\beta = 1$

$-\frac{R_F}{R_1}\left(-\frac{1}{29}\right) = 1$

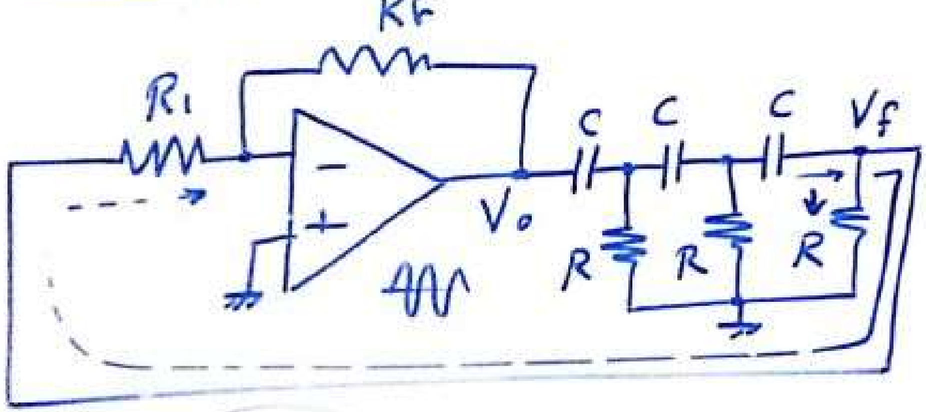
$\frac{R_F}{R_1} = 29$

<u>oscillation condition</u>

$\beta = \frac{R^3}{R^3 - 5RX_c^2} = \frac{R^3}{R^3 - 5R(6R^2)} = -\frac{1}{29}$

Summary

RC - phase - shift oscillator



* $f_o = \dfrac{1}{2\pi\sqrt{6}\,RC}$ → oscillation frequency

* Condition $\dfrac{R_F}{R_1} = 29$, $R_1 \gg R$

$\boxed{R_1 = 10R}$

Example

Design RC-phase shift oscillator that generates a signal of 10kHz frequency.

Sol.

$$* \; f_0 = \frac{1}{2\pi\sqrt{6}\,RC}$$

let $\boxed{C = 0.01\,\mu F}$

$$10\times10^{3} = \frac{1}{2\pi\sqrt{6}\,R\times0.01\times10^{-6}}$$

$$R = \frac{1}{10^{4}\times2\pi\times\sqrt{6}\times0.01\times10^{-6}}$$

$$R = 649.75\,\Omega$$

$$* \; R_1 = 10R$$

$$R_1 = 6497.5\,\Omega$$

$$\boxed{R_1 = 6.4975\,k\Omega}$$

$$\frac{R_F}{R_1} = 29$$

$$\therefore R_f = 29R_1$$

$$R_f = 29\times6.4975$$

$$R_f = 188.43\,k\Omega$$

RC Phase-Shift Oscillator

Advantages

The advantages of R-C phase shift oscillator are,

1. The circuit is simple to design.
2. Can produce output over audio frequency range.
3. Produces sinusoidal output waveform.
4. It is a fixed frequency oscillator.

Disadvantages

By changing the values of R and C, the frequency of the oscillator can be changed. But the values of R and C of all three sections must be changed simultaneously to satisfy the oscillating conditions. But this is practically impossible. Hence the phase shift oscillator is considered as a fixed frequency oscillator, for all practical purposes.

And the frequency stability is poor due to the changes in the values of various components, due to effect of temperature, aging etc.