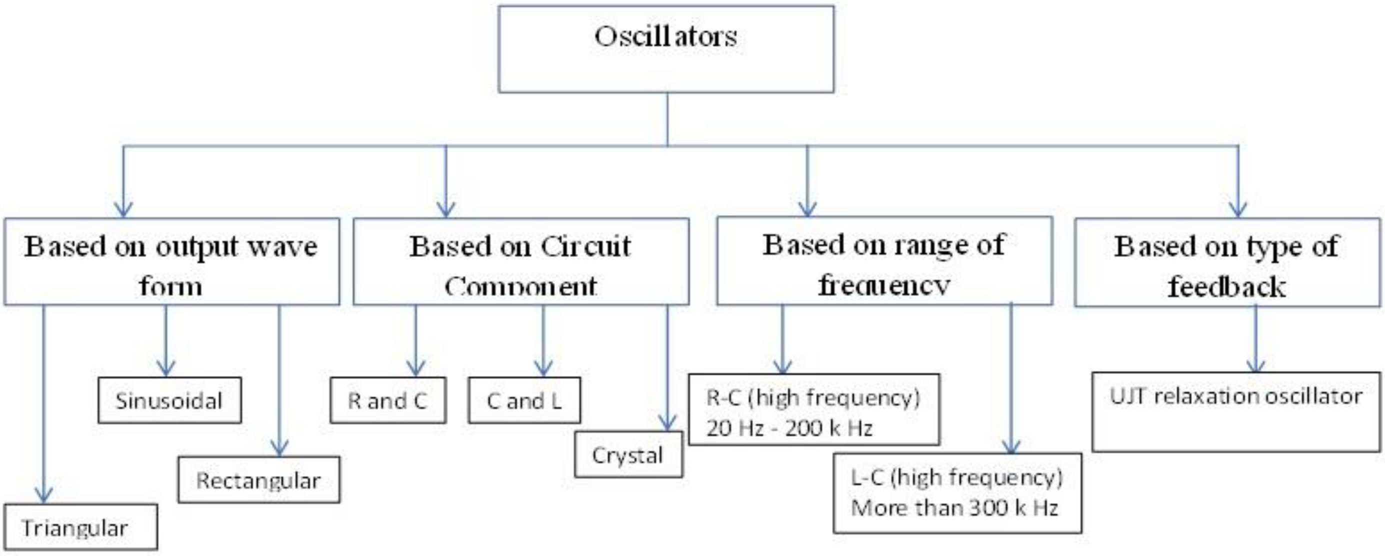
1.5 PHASE SHIFT OSCILLATOR

Classification of oscillator:



R-C Phase shift Oscillator:

- RC phase shift oscillator basically consists of an amplifier and a feedback network consisting of resistor and capacitors arranged in ladder fashion. Hence such an oscillator is also called ladder type RC phase shift oscillator.
- RC network is used in feedback path. In oscillator, feedback network must introduce a phase shift of 180^0 to obtain total phase shift around a loop as 360^0
- Thus if one RC network produces phase shift of $\varphi=60^0$ then to produce phase shift of 180^0 such three RC networks must be connected in cascade.
- Hence in RC phase shift oscillator, the feedback network consists of three RC sections each producing a phase shift of 60^0, thus total phase shift due to feedback is 180^0.
- Transistorized RC phase shift oscillator, a transistor is used as an active device element of the amplifier.

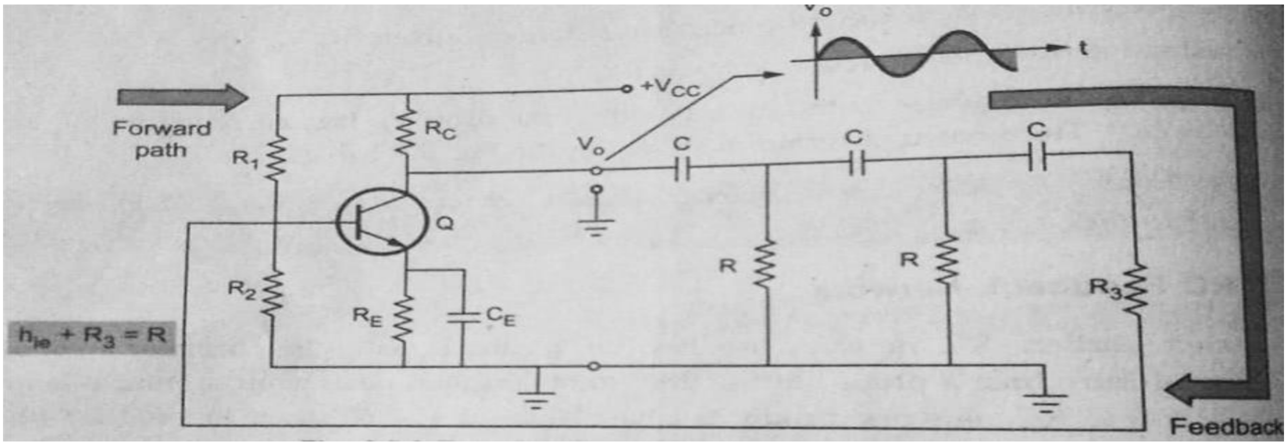


Figure: 2.2.1 RC phase shift oscillator

[Source: Microelectronics by J. Millman and A. Grabel, Page-386]

- Fig 2.2.1 shows a practical transistorized RC phase shift oscillator which uses a common emitter single stage amplifier and a phase shifting network consisting of three identical RC sections.
- The output of the feedback network gets loaded due to the low input impedance of a transistor. Hence an emitter follower input stage before the common emitter amplifier stage can be used, to avoid the problem of low input impedance.
- But if only single stage is to be used then the voltage shunt feedback, denoted by resistance R_3 in the figure 2.2.1 is used, connected in series with the amplifier input resistance.
- A phase shifting network is a feedback network, so output of the amplifier is given as an input to the feedback network.
- While the output of the feedback network is given as an input to the amplifier. Thus amplifier supplies its own input, through the feedback network.
- Neglecting R_1 and R_2 as these are sufficiently large,
  h_{ie}=input impedance of the amplifier stage

$$h_{ie} + R_3 = R$$

- This ensures that all the three sections of the phase shifting network are identical.

$$R_i' = R_1 || R_2 || h_{ie}$$

$$R_i' + R_3 = R$$

Derivation for the frequency of oscillations:

- Replacing the transistor by its approximate h-parameter model, we get the equivalent circuit as shown in the fig 2.2.2

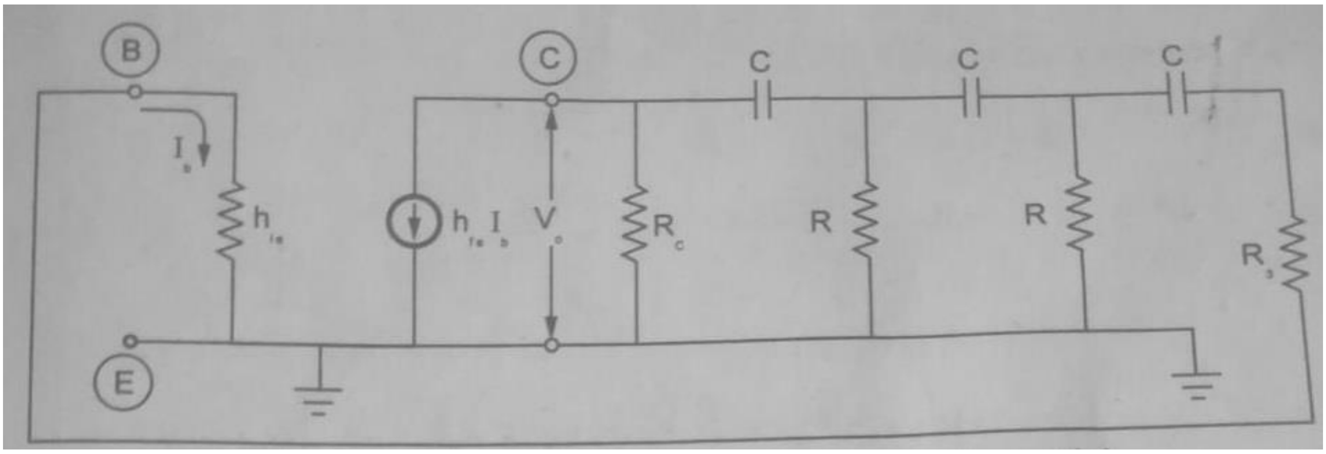


Figure: 2.2.2 RC phase shift oscillator-equivalent circuit using h-parameter

[Source: Microelectronics by J. Millman and A. Grabel, Page-386]

We can replace

$$h_{ie} + R_3 = R$$

And the current source h_{fe} I_b by its equivalent voltage source

Assume $k = \frac{R_c}{R}$

- The modified equivalent circuit is shown in fig 2.2.3

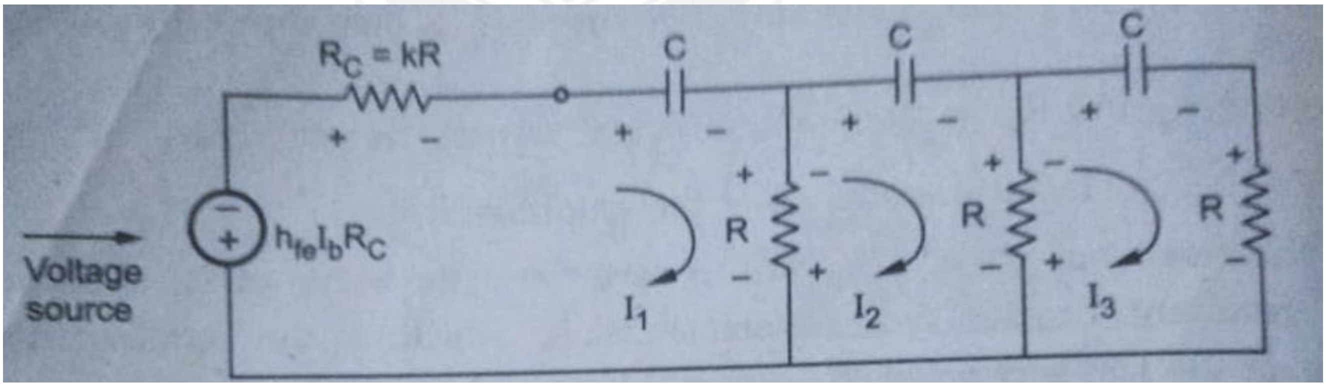


Figure: 2.2.3 RC phase shift oscillator-modified equivalent circuit

[Source: Microelectronics by J. Millman and A. Grabel, Page-386]

- Applying KVL for the various loops in the modified equivalent circuit we get,

For loop 1,

$$-I_1R_c - \frac{1}{j\omega C}I_1 - I_1R + I_2R - h_{fe}I_bR_c = 0$$

Replacing R_c by kR and jω by s

$$+I_1\left[(k+1)R+\frac{1}{sC}\right]-I_2R=-h_{fe}I_bkR--------(1)$$

For loop 2,

$$-I_1R+I_2\left[2R+\frac{1}{sC}\right]-I_3R=0--------(2)$$

For loop 3,

$$-I_2R+I_3\left[2R+\frac{1}{sC}\right]=0--------(3)$$

Using Cramer's rule to solve for I_3,

$$D=\begin{vmatrix}(k+1)R+\frac{1}{sC} & -R & 0\\ -R & 2R+\frac{1}{sC} & -R\\ 0 & -R & 2R+\frac{1}{sC}\end{vmatrix}$$

$$D=\frac{s^3C^3R^3[3k+1]+s^2C^2R^2[4k+6]+sRC[5+k]+1}{s^3C^3}----(4)$$

Now D_3,

$$D_3=\begin{vmatrix}(k+1)R+\frac{1}{sC} & -R & h_{fe}I_bkR\\ -R & 2R+\frac{1}{sC} & 0\\ 0 & -R & 0\end{vmatrix}$$

$$D_3=-kR^3h_{fe}I_b------(5)$$

$$I_3=\frac{D_3}{D}$$

$$I_3=\frac{-kR^3h_{fe}I_bs^3C^3}{s^3C^3R^3[3k+1]+s^2C^2R^2[4k+6]+sRC[5+k]+1}----(5)$$

$$I_3=output\ current\ of\ the\ feedback\ circuit$$

$$I_b=input\ current\ of\ the\ amplifier$$

$$I_c = h_{fe} I_b = input\ current\ of\ the\ feedback\ circuit.$$

$$\beta = \frac{output\ of\ feedback\ circuit}{input\ to\ feedback\ circuit} = \frac{I_3}{h_{fe} I_b}$$

And

$$A = \frac{output\ of amplifier\ circuit}{input\ to\ amplifier\ circuit} = \frac{I_c}{I_b} = h_{fe}$$

$$A\beta = \frac{I_3}{I_b} - - - - - - - - (6)$$

Using equation (6) we get

$$A\beta = \frac{-kR^3 h_{fe} s^3 C^3}{s^3C^3R^3[3k+1] + s^2C^2R^2[4k+6] + sRC[5+k] + 1} - - - (7)$$

Substituting s=jω, $s^2 = -\omega^2$, $s^3 = -j\omega^3$ in equation (7) and separating real and imaginary part in the denominator we get,

$$A\beta = \frac{+kR^3 h_{fe} j\omega^3 C^3}{[1 - 4k\omega^2C^2R^2 - 6\omega^2C^2R^2] - j\omega[3k\omega^2R^3C^3 + \omega^2R^3C^3 - 5RC - kRC]}$$

Dividing numerator and denominator by $j\omega^3C^3R^3$,

$$A\beta = \frac{+kh_{fe}}{\left[\frac{1-4k\omega^2C^2R^2-6\omega^2C^2R^2}{j\omega^3C^3R^3}\right] - \left\{\frac{j\omega[3k\omega^2R^3C^3+\omega^2R^3C^3-5RC-kRC]}{j\omega^3C^3R^3}\right\}}$$

Replacing -1/ j = j and replacing $\frac{1}{\omega RC} = \alpha$ for simplicity

$$A\beta = \frac{kh_{fe}}{[-3k - 1 + 5\alpha^2 + k\alpha^2] - j[\alpha^3 - 4k\alpha - 6\alpha]} - - - (8)$$

As per the Barkhausen criterion $< A\beta = 0^0$

Now the angle of numerator term $kh_{fe}$of the equation (8) is 0^0 hence to have angle of the Aβ term as 0^0, the imaginary part of the denominator term must be zero.

$$\alpha^3 - 4k\alpha - 6\alpha = 0$$

$$\alpha = \sqrt{4k+6}$$

$$\therefore \ \frac{1}{\omega RC} = \sqrt{4k+6}$$

$$\omega = \frac{1}{RC\sqrt{4k+6}}$$

$$f = \frac{1}{2\pi RC\sqrt{4k+6}}$$

This the frequency at which $< A\beta = 0^0$.at the same frequency |Aβ|=1

Substituting $\alpha = \sqrt{4k+6}$ in equation (8) we get

$$h_{fe} = 4k + 23 + \frac{29}{k}$$

This must be the value of $h_{fe}$for the oscillations.

To get minimum value of h_{fe}, $\frac{dh_{fe}}{dk} = 0$,

$$k = 2.6925 \ for\ minimum\ h_{fe}$$

$$(h_{fe})_{min} = 44.54$$

- Thus for the circuit to oscillate, we must select the transistor whose $(h_{fe})_{min}$should be greater than 44.54
- By changing the values of R and C, the frequency of the oscillator can be changed.
- But the value 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 oscillator, For all practical purpose.

RC phase shift oscillator using OP-amp

- It consists of a negative gain amplifier (-*K*) with a three-section (third-order) RC ladder network in the feedback.
- the circuit will oscillate at the frequency for which the phase shift of the RC network is 180^0

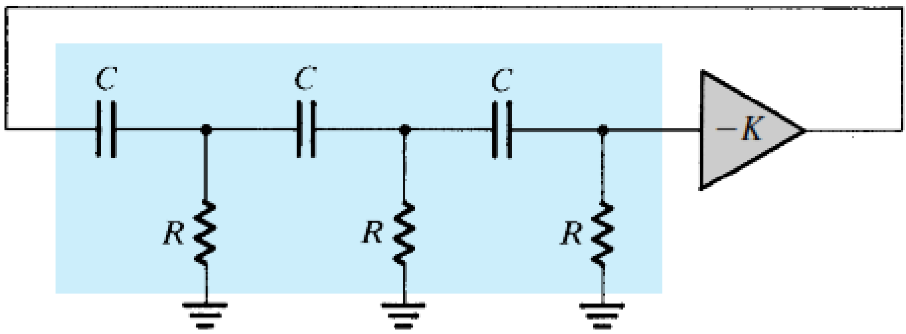


Figure: 2.2.2 RC phase shift oscillator using OP-amp

[Source: Microelectronic circuits by sedra and smith, Page-1345]

- The frequency of oscillation is given by

$$f = \frac{1}{2\pi RC\sqrt{6}}$$

- At this frequency

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

- To have oscillation

$$|A| \geq \frac{1}{\beta} \geq 29$$