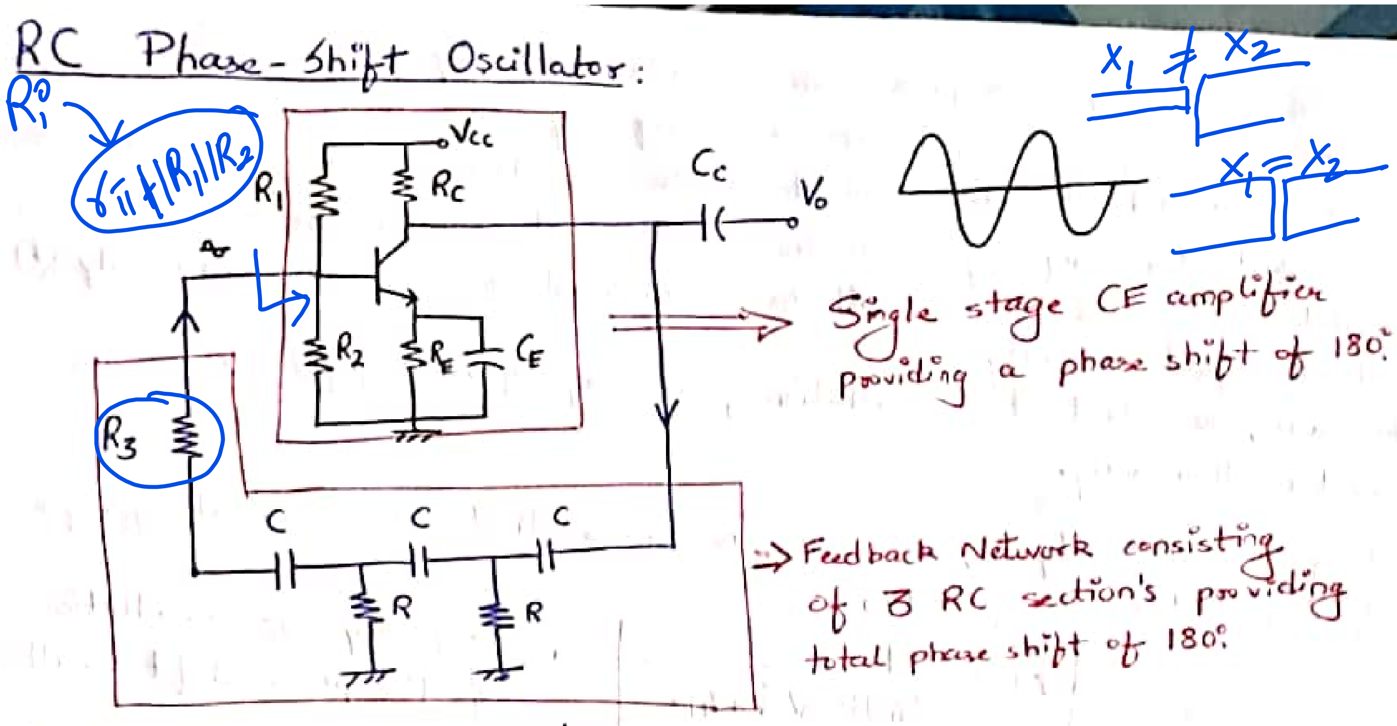
I] RC Phase-Shift Oscillator:



ckt ①: RC Phase-shift oscillator

- For producing oscillations, we must use a +ve feedback of sufficient magnitude. This occurs only when the fraction of o/p is f/b with the same phase as that of the I/p signal.
- In this ckt, a fraction of o/p of single-stage CE amplifier is passed through the RC phase-shift network, before feeding back to the I/P.
- The RC phase-shift n/w consists of 3 RC section's which provides a total phase shift of 180° in addition to the phase-shift of 180° introduced by the amplifier. Thus, there is a total phase shift around the loop between the I/p and o/p ckt is 0° or 360°.
- It has been found that by using a transistor (BJT) as an active element of the amplifier stage, the o/p of f/b network is loaded by relatively low I/P impedance of the transistor.
- In above ckt, the f/b signal is coupled through the f/b resistor (R_3) in series with the amplifier's I/P resistance's, that's why we have $\boxed{R_3 = R - R_i}$, where R is the value of resistor in phase-shift network, R_i is ampl's I/P resistance.

→ Note: R_1, R_2 and R_E ⇒ [biasing resister to bias BJT in active region and does not play any role in getting oscillation's]

Operation:

- When the circuit is energized by switching on the dc power source, it starts oscillating. The oscillations may start due to minor variation in dc supply or inherent noise in the BJT.
- The variation in the base current is amplified and fedback through the RC phase-shift network and finally applied to the base.

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- At some frequency, the phase shift introduced by the 3 RC network will be precisely 180° and at this frequency the total phase shift from the base around the ckt and back to the base will be exactly zero.
- This particular frequency will be the one at which the circuit will oscillate. The oscillations will be maintained if the loop gain (ie $A_1 \cdot K$) is atleast equal to unity.
- However, to start the oscillations, the loop gain ($A_1 \cdot K$) must be greater than unity.

→ Using network analysis, it can be shown that the circuit frequency of oscillation is given by,

$$\boxed{f_o = \frac{1}{2\pi RC\sqrt{6+4k}}} \longrightarrow \text{Frequency of oscillation of RC phase-shift oscillator.}$$

where, $\boxed{k = \frac{R_C}{R}}$ $\boxed{k = \frac{R_C}{R}}$ $f_o = \frac{1}{2\pi RC\sqrt{6+4k}}$

- For the loop gain ($A.1$) to be greater than unity, the current current gain of the transistor must be,

$$\boxed{K > 23 + 4k + \frac{29}{k}}$$

- Variable-Frequency feature :-
  - RC phase-shift oscillator is particularly suited to the range of frequencies from several Hz to 100 KHz that includes the "audio range"
  - The frequency of oscillation may be varied by changing the 3 resistors (R) or capacitors (C) in the phase-shifting network simultaneously.

<u>Please Note:</u> The amplitude of oscillations should not be affected as the frequency is adjusted.

<u>Advantage:</u>
- Frequencies of oscillation's include audio range. (20Hz - 20kHz)
- Sinusoidal o/p can be obtained.
- Does not require the use of inductors (coils) making the ckt small & compact.

<u>Disadvantages:</u>
1) When required to provide a variable frequency ckt, it is difficult to adjust equally the capacitor values of the phase-shift n/w simultaneously.
2) <u>Frequency instability</u>: Frequency in RC phase-shift oscillator depends on the values of R and C elements in F/b network. The values of R and C can change due to temperature, aging, tolerance limit, etc
3) o/p sinusoidal sig is not perfect as it suffers from distortions due to loading effect of each RC network in the F/B stage.

Note: In a RC Phase Shift oscillator, in actual practise, it is difficult to get a Feedback network of 3 identical RC sections, which provides a total phase-shift of 180°. It is because of the fact, that each RC section in the Feedback network loads down the previous one.

• Derivation for frequency of oscillations f_0 (RC phase-shift oscillator)

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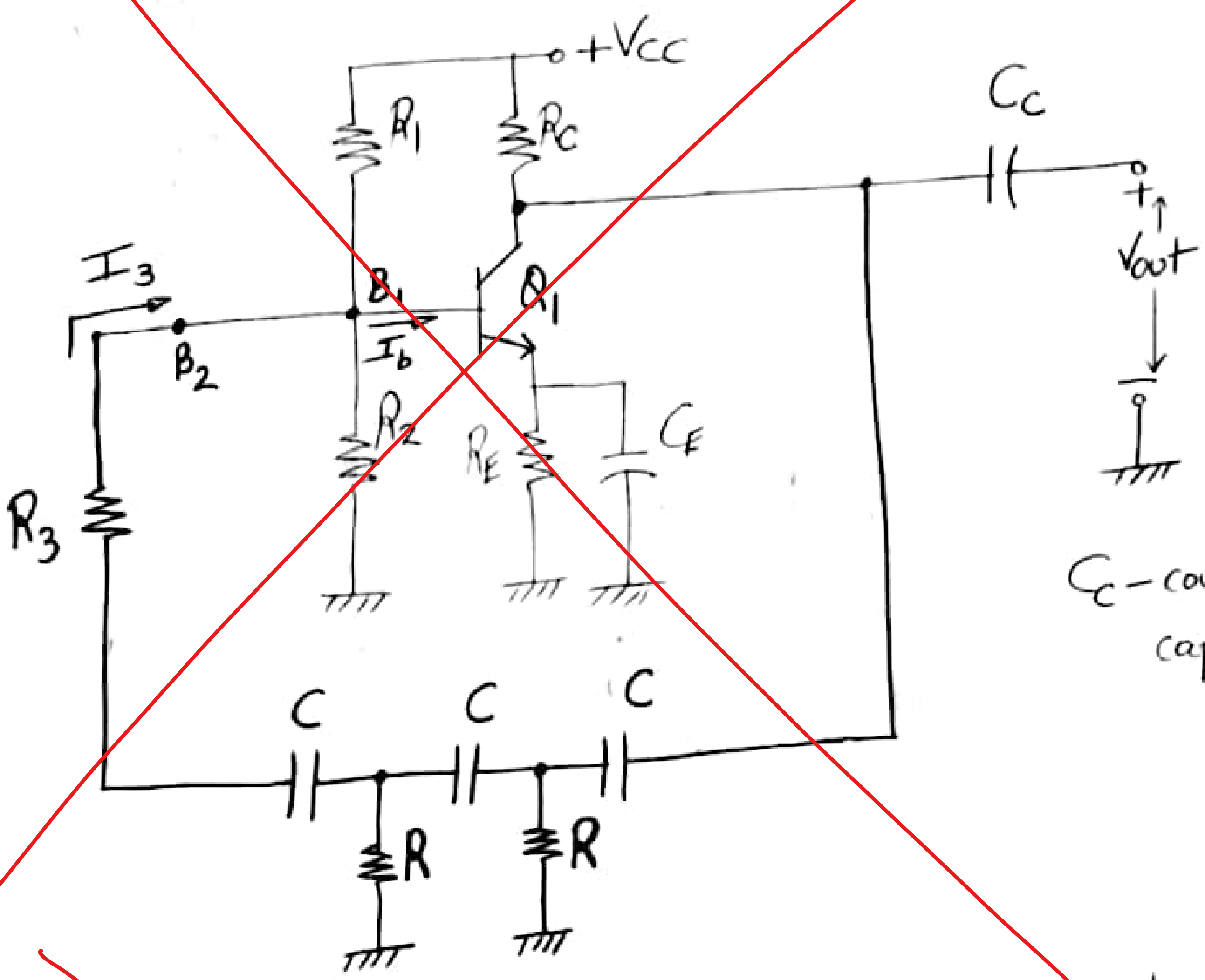
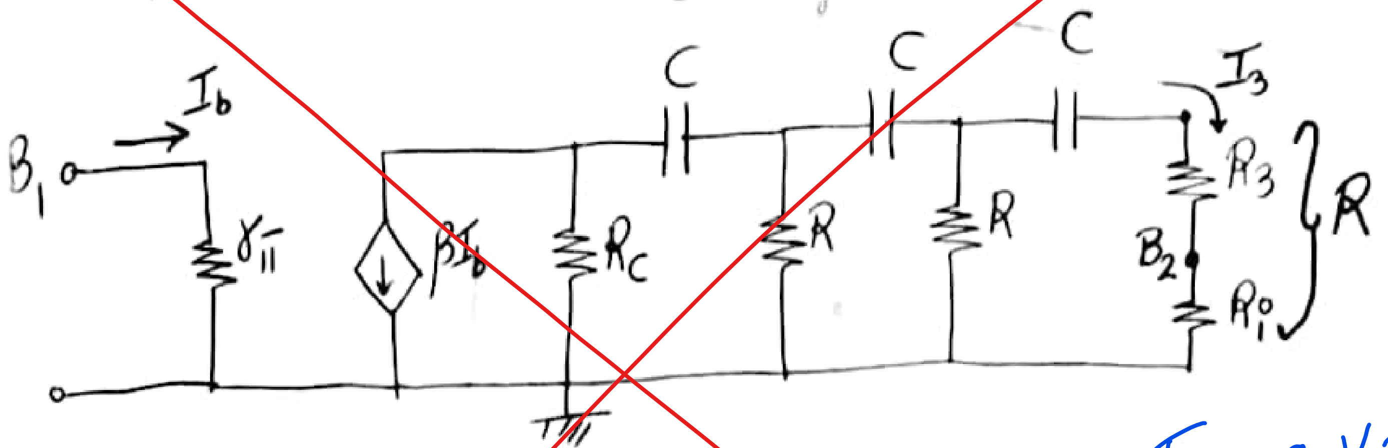


C_C – coupling capacitor

→ Since a transistor is used as the active element, the Output across R of the feedback network is shunted by relatively low input resistance of the transistor.

→ Since O/P of oscillator is a voltage quantity and input going into loop is a current, a voltage shunt feedback is used.

AC equivalent circuit using r_π model,



$I_C = g_m V_\pi$
or $I_C = \beta I_b$

- Assume I_b to enter the base.
- We imagine the loop broken at the base between B_1 & B_2, but in order not to change the loading on the feedback network; we place R_i from B_2 to ground.
- The capacitor C offers some impedance at the frequency of oscillation and therefore it is kept as it is, while the coupling capacitors behaves like ac short.
- The input resistance of the transistor is $R_i \approx R_1 \| R_2 \| r_\pi \approx r_\pi$ ie $R_i \approx r_\pi$
- Therefore, the resistance R_3 is selected such that $R = R_3 + R_i = R_3 + r_\pi$
- This choice makes the three RC sections alike and simplifies the calculations.

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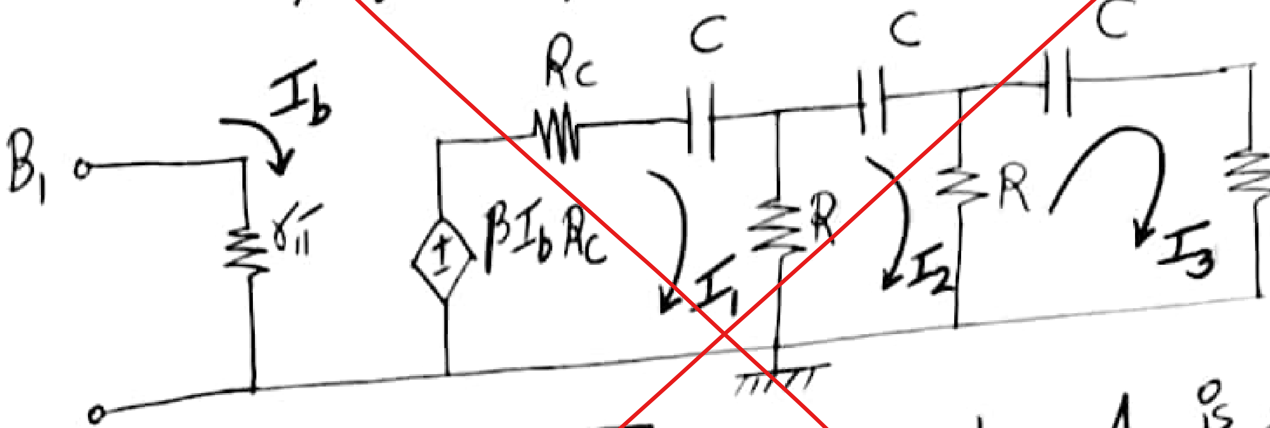
- We assume that the biasing resistors R_1, R_2 & R_E have no effect on the signal operation and neglect these in the following analysis.

- The simplified equivalent circuit is,



loop gain, $\boxed{KA_1 = \frac{I_3}{I_b}}$

where A_1 is gain of ampl^r
K is feedback factor.

Applying KVL, for the three meshes,

$$\beta I_b R_c + R_c I_1 + X_c I_1 + R(I_1 - I_2) = 0 \quad - (1)$$

$$R(I_2 - I_1) + X_c I_2 + R(I_2 - I_3) = 0 \quad - (2)$$

$$R(I_3 - I_2) + X_c I_3 + R I_3 = 0 \quad - (3)$$

ie $R I_2 = 2R I_3 + X_c I_3$

$$I_2 = \frac{1}{R}[2R + X_c] I_3 \quad - (4)$$

From ②,

$$R(I_2 - I_1) + X_C I_2 + R(I_2 - I_3) = 0$$

$$-I_1 R = -RI_2 - X_C I_2 - RI_2 + RI_3$$

$$I_1 R = (2R + X_C) I_2 - RI_3$$

From ④, $I_2 = \left(\frac{2R + X_C}{R}\right) I_3$

$$\therefore \quad I_1 R = (2R + X_C)\frac{(2R + X_C)}{R} I_3 - RI_3$$

$$I_1 = \frac{1}{R}\left[\frac{(2R + X_C)^2}{R} - R\right] I_3 \quad - ⑤$$

Put ⑤ in ①, we get

$$\therefore \quad \beta I_b R_C + (R_C + X_C + R) I_1 - RI_2 = 0$$

(From ④)

$$\beta I_b R_C + (R_C + X_C + R)\left[\frac{3R^2 + X_C^2 + 4RX_C}{R^2}\right] I_3$$

$$- \frac{\cancel{R} \times (2R + X_C)}{\cancel{R}} I_3 = 0$$

$$\therefore \beta R_C I_b R^2 = \left[-(R_C+R+X_C)(3R^2+X_C^2+4RX_C)+(2R+X_C)R^2\right] I_3$$

$$\frac{I_3}{I_b} = \frac{\beta R_C R^2}{\begin{array}{l} \underline{2R^3}+\underline{R^2X_C}-3R^2R_C-X_C^2R_C-4RX_CR_C \\ -\underline{3R^3}-X_C^2R-\underline{4R^2X_C} \\ -\underline{3R^2X_C}-X_C^3-4RX_C^2 \end{array}}$$

$$\frac{I_3}{I_b} = \frac{\beta R_C R^2}{\begin{array}{l} -R^3-6R^2X_C-5RX_C^2-3R_CR^2 \\ -4RR_CX_C-X_C^3-R_CX_C^2 \end{array}}$$

$$\frac{I_3}{I_b} = \frac{\beta R_C R^2}{\underbrace{\{-R^3-5RX_C^2-3R_CR^2-R_CX_C^2\}}_{\text{Real part}} + \underbrace{\{-6R^2X_C-4RR_CX_C-X_C^3\}}_{\text{Imaginary part}}}$$

— (X)

- To determine the frequency of oscillation, put imaginary part ≈ 0
- Since I_3 and I_b must be in phase to satisfy Barkhausen's criterion.

$\therefore$ Putting imaginary part ≈ 0

$$\text{ie} \; -6R^2X_C - 4RR_CX_C - X_C^3 = 0$$

$$-6R^2 - 4RR_C = X_C^2 \quad \text{---(i)} \qquad \left\{ \begin{array}{l} X_C = \frac{1}{j\omega C} \\ X_C^2 = \frac{-1}{\omega^2 C^2} \end{array} \right\}$$

$$-6R^2 - 4RR_C = -\frac{1}{\omega^2 C^2}$$

$$6R^2 + 4RR_C = \frac{1}{(2\pi f)^2 C^2}$$

$$f = \frac{1}{2\pi C\sqrt{6R^2 + 4RR_C}}$$

$$\boxed{f = \frac{1}{2\pi RC\sqrt{6 + 4\left(\frac{R_C}{R}\right)}}} \quad k = \frac{R_C}{R}$$

(A)

Frequency of oscillation for RC phase shift oscillator.

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

where $k = \frac{R_C}{R_C}$

Also, initially $I_3 > I_b$, therefore, for oscillations to start, (ie $|A_1K| \geq 1$), 07

(I_3/I_b is a real quantity)

$$\beta R_C R^2 > \{-R^3 - 5RX_C^2 - 3R_C R^2 - R_C X_C^2\}$$

From (i) $\underline{X_C^2 = -6R^2 - 4RR_C}$ at freq^n of oscillations.

$$\text{ie}\quad \beta R_C R^2 > \{-R^3 - 5R(-6R^2 - 4RR_C) - 3R_C R^2 - R_C(-6R^2 - 4RR_C)\}$$

$$\beta R_C R^2 > \{-R^3 + 30R^3 + 20R^2 R_C - 3R_C R^2 + 6R_C R^2 + 4RR_C^2\}$$

$$\beta R_C R^2 > \{29R^3 + 23R^2 R_C + 4RR_C^2\}$$

$$\beta > \left\{29\frac{R}{R_C} + 23 + 4\frac{R_C}{R}\right\}$$

let $k = \dfrac{R_C}{R}$

$$\boxed{\beta > 4k + 23 + \frac{29}{k}} \quad \text{— (B)}$$

β → current gain of BJT

The requirement that the magnitude of $\frac{I_3}{I_b}$ must exceed unity in order for oscillations to start leads to inequality in eq^n (B)

- For the loop-gain to be greater than unity, the requirement on the current gain of the transistor is eqⁿ (B).

$\therefore$ The two conditions (A) & (B) must also be satisfied for oscillations to start & be sustained.

→ To determine the value of 'k' with minimum β

Consider eqⁿ (B), $\beta > 4k + 23 + \frac{29}{k}$

$$\frac{d\beta}{dk} = 4 - \frac{29}{k^2} = 0$$

$$\text{ie } 4 = \frac{29}{k^2} \Rightarrow k = \left(\frac{29}{4}\right)^{\frac{1}{2}} = 2.69$$

$$\text{ie } \boxed{k \simeq 2.7}$$

$$\therefore (\beta)_{min} \geq 4(2.7) + 23 + \frac{29}{2.7}$$

$$\underline{(\beta)_{min} \gtrsim 44.5}$$

- Hence the value of β for a transistor must be atleast 45 for the circuit to oscillate.

If $\beta < 44.5$, the circuit won't oscillate, since then $|A_1 K|$ would be < 1.

To find $A_1K = \frac{I_3}{I_b}$ $\boxed{\text{Loop gain} = A_1K}$ 09

Put imaginary part $= 0$ in eq^n ⓧ,

$$A_1K = \frac{\beta R_C R^2}{-R^3 - 5RX_c^2 - 3R_CR^2 - R_CX_c^2}$$

From (i), $X_c^2 = -6R^2 - 4RR_c$

$$A_1K = \frac{\beta R_C R^2}{-R^3 - 5R(-6R^2 - 4RR_c) - 3R_CR^2 - R_c(-6R^2 - 4RR_c)}$$

$$= \frac{\beta R_C R^2}{-R^3 + 30R^3 + 20R^2R_c - 3R_CR^2 + 6R^2R_c + 4RR_c^2}$$

$$= \frac{\beta R_C R^2}{29R^3 + 23R_CR^2 + 4RR_c^2}$$

Divide N^r and D^r by R^3

$$A_1K = \frac{\beta R_c/R}{29 + 23\frac{R_c}{R} + 4\left(\frac{R_c}{R}\right)^2}$$

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$$A_1K = \frac{\beta k}{29 + 4k^2 + 23k}$$

$$\boxed{k = \frac{R_c}{R}}$$ 10.

Substitute $\beta \simeq 45$, $k = 2.7$, we get

$$|A_1K| = \frac{45 \times 2.7}{29 + 4\underbrace{k^2}_{(2.7)^2} + 23\underbrace{k}_{2.7}}$$

$$\boxed{|A_1K| \simeq 1.01}$$ which is the desired BC condition.

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