Dr Satvir Singh

LINEAR INTEGRATED CIRCUITS

3-10

RC Phase Shift Oscillator

Oscillator Principle

Oscillator must satisfy following Barkhausen's criteria:

(1) Loop Gain must be unity ($\beta A = 1$)

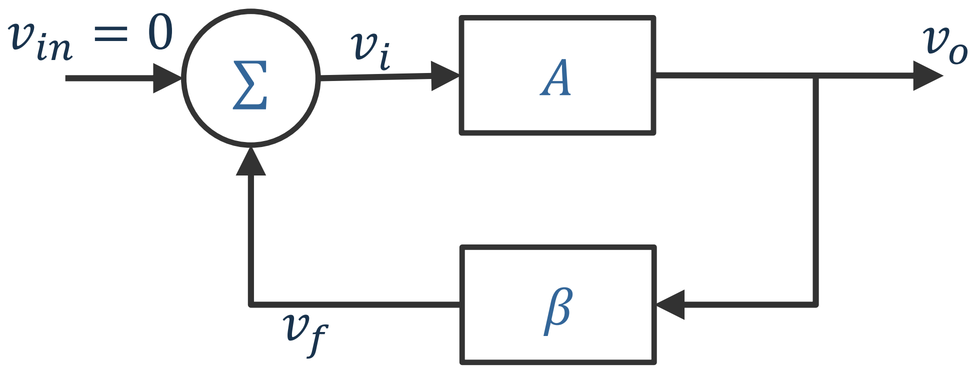
(2) Loop phase shift must be 0^o or 360^o

$$v_i = v_{in} + v_f$$

$$v_{in} = v_i - v_f$$

Since, $v_f = \beta v_o$ and $v_o = A v_i$

$$v_{in} = \frac{v_o}{A} - \beta v_o = v_o \left(\frac{1 - \beta A}{A} \right)$$

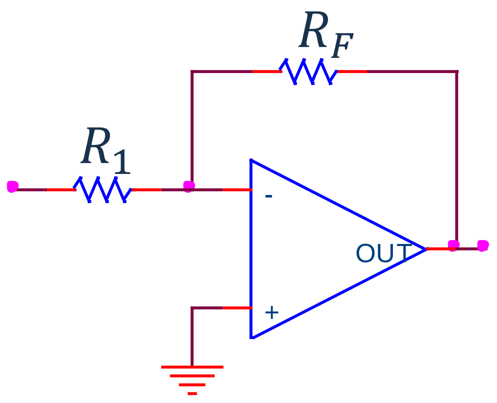


Overall gain after feedback is

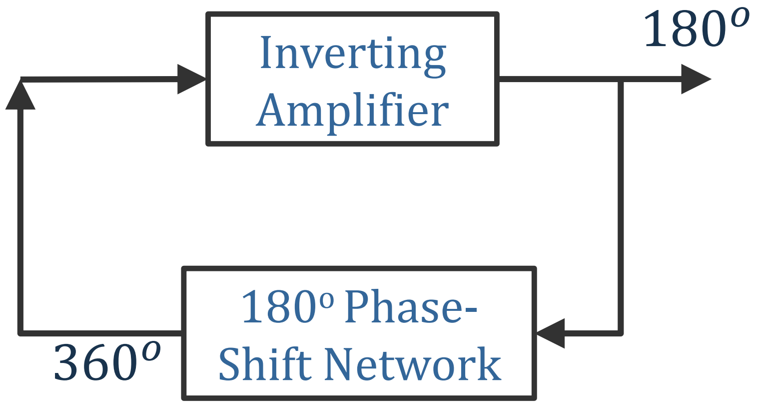
$$A_F = \frac{v_o}{v_{in}} = \frac{A}{1 - \beta A}$$

Oscillator Circuit

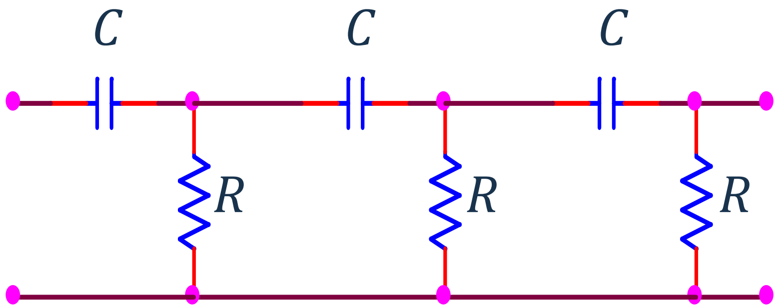
Inverting Amplifier



Gain $A = -\frac{R_F}{R_1}$

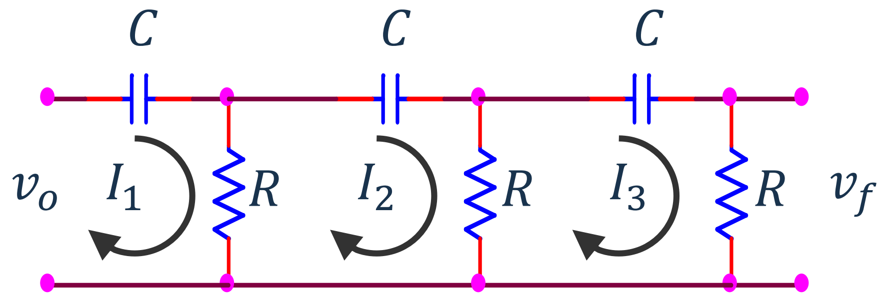


Feedback Network



Feedback Gain

Lets use Crammer's Rule to determine $\beta = \frac{v_o}{v_f}$

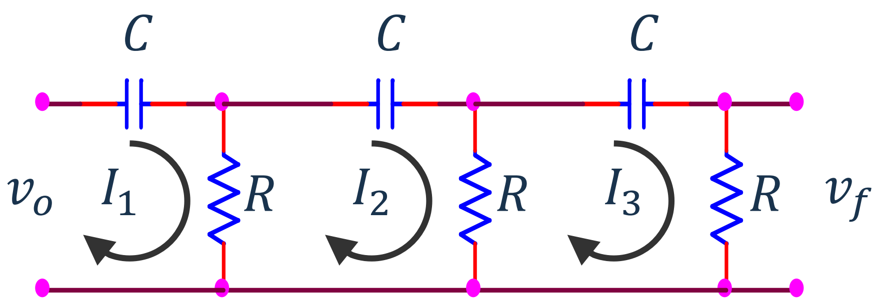


$$\begin{bmatrix} R + \frac{1}{sC} & -R & 0 \\ -R & 2R + \frac{1}{sC} & -R \\ 0 & -R & 2R + \frac{1}{sC} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} v_o \\ 0 \\ 0 \end{bmatrix}$$

$$D = \begin{vmatrix} R + \frac{1}{sC} & -R & 0 \\ -R & 2R + \frac{1}{sC} & -R \\ 0 & -R & 2R + \frac{1}{sC} \end{vmatrix} = \left(R + \frac{1}{sC}\right)\left[\left(2R + \frac{1}{sC}\right)\left(2R + \frac{1}{sC}\right) - R^2\right] + R\left(2R + \frac{1}{sC}\right) + 0$$

$$D = \frac{1 + 5sCR + 6s^2C^2R^2 + s^3C^3R^3}{s^3C^3}$$

Feedback Gain



$$D_3 = \begin{vmatrix} R + \frac{1}{sC} & -R & v_o \\ -R & 2R + \frac{1}{sC} & 0 \\ 0 & -R & 0 \end{vmatrix} = v_o R^2$$

$$I_3 = \frac{D_3}{D} = \frac{s^3C^3v_oR^2}{1 + 5sCR + 6s^2C^2R^2 + s^3C^3R^3}$$

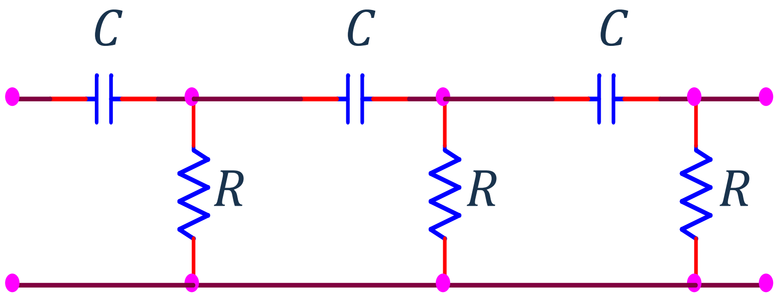
$$v_f = I_3 R = \frac{s^3C^3v_oR^3}{1 + 5sCR + 6s^2C^2R^2 + s^3C^3R^3}$$

Simplifying and putting $s = j\omega$

$$\beta = \frac{v_f}{v_o} = \frac{s^3C^3R^3}{1 + 5sCR + 6s^2C^2R^2 + s^3C^3R^3} = \frac{j^3\omega^3C^3R^3}{1 + 5j\omega CR + 6j^2\omega^2C^2R^2 + j^3\omega^3C^3R^3}$$

Feedback Gain

We get



$$\beta = \frac{-j\omega^3 C^3 R^3}{1 + 5j\omega CR - 6\omega^2 C^2 R^2 - j\omega^3 C^3 R^3}$$

Dividing by $-j\omega^3 C^3 R^3$ and assuming $\alpha = 1/\omega CR$

$$\beta = \frac{1}{j\alpha^3 - 5\alpha^2 - j6\alpha + 1} \qquad (1)$$

For 180° phase difference imaginary part in (1) must be zero, i.e.,

$\alpha^3 - 6\alpha = 0 \quad \Rightarrow \quad \alpha = \sqrt{6}$

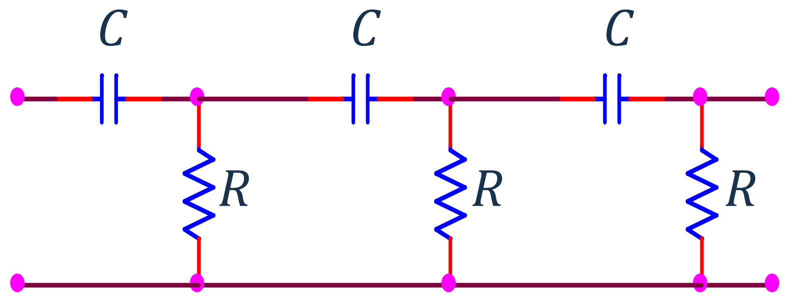
The frequency of oscillations is given by $\alpha = 1/\omega CR = \sqrt{6}$

$$f_o = \frac{1}{2\pi RC\sqrt{6}} = \frac{0.065}{RC}$$

Feedback Gain

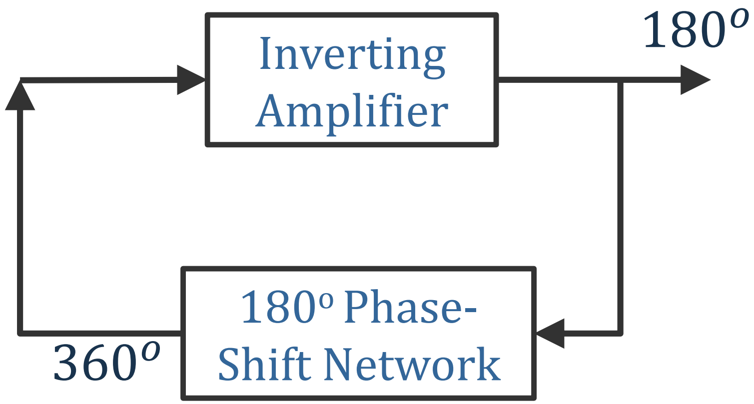
The β at frequency of oscillations from (1)

$$\beta = \frac{1}{-5\alpha^2 + 1} = \frac{1}{-5\left(\sqrt{6}\right)^2 + 1} = -\frac{1}{29}$$



Here, minus sign signifies 180º phase difference. Accordingly, for sustained oscillations the gain of the inverting amplifier must be

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



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Thank You