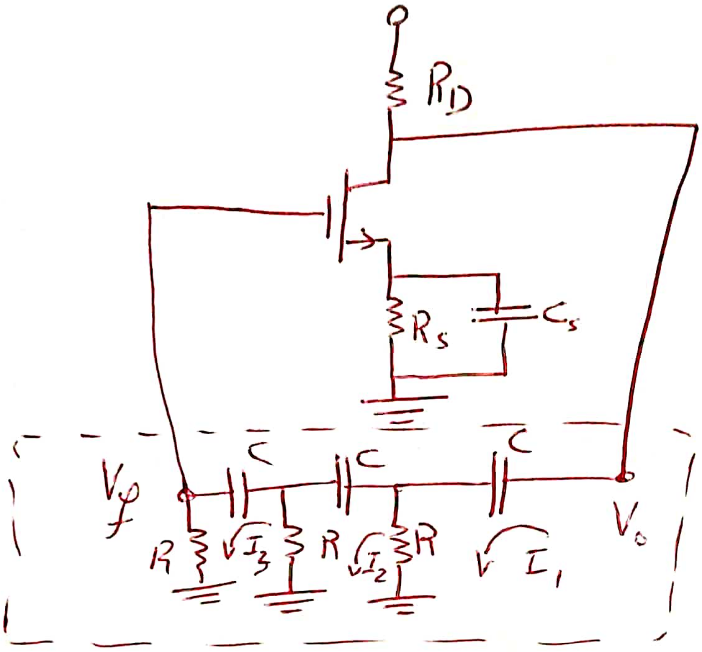
FET - Phase shift oscillator



$$\Rightarrow \quad V_o = I_1\left(R + \frac{1}{sC}\right) + I_2 R$$

$$0 = I_2\left(2R + \frac{1}{sC}\right) - I_1 R - I_3 R$$

$$0 = I_3\left(2R + \frac{1}{sC}\right) - I_2 R$$

$$\Rightarrow \quad V_f = I_3 R$$

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

$$= \left(R+\frac{1}{sC}\right)\left[4R^2 + \frac{4R}{sC} + \frac{1}{s^2C^2} - R^2\right] - R^2\left(2R+\frac{1}{sC}\right)$$

$$= 4R^3 + \frac{4R^2}{sC} + \frac{R}{s^2C^2} - R^3 + \frac{4R^2}{sC} + \frac{4R}{s^2C^2} + \frac{1}{s^3C^3} - \frac{R^2}{sC} - 2R^3 - \frac{R^2}{sC}$$

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

$$\Rightarrow \quad \Delta_3 = \begin{vmatrix} R+\frac{1}{sC} & -R & V_o \\ -R & 2R+\frac{1}{sC} & 0 \\ 0 & -R & 0 \end{vmatrix}$$

$$= V_o R^2$$

$$\Rightarrow I_3 = \frac{\Delta_3}{\Delta} = \frac{V_o R^2}{R^3 + \frac{6R^2}{sC} + \frac{5R}{s^2C^2} + \frac{1}{s^3C^3}}$$

$$\Rightarrow V_f = I_3 R = \frac{V_o R^3}{R^3 + \frac{6R^2}{sC} + \frac{5R}{s^2C^2} + \frac{1}{s^3C^3}}$$

$$\Rightarrow V_f = \frac{V_o R^3}{\left(R^3 - \frac{5R}{\omega^2C^2}\right) + j\left(-\frac{6R^2}{\omega C} + \frac{1}{\omega^3C^3}\right)}$$

at $\omega = \omega_o$:

$$\frac{6R^2}{\cancel{\omega_o C}} = \frac{1}{\omega_o^{\cancel{3}\,2} C^{\cancel{3}\,2}}$$

$$\Rightarrow \omega_o^2 = \frac{1}{6R^2C^2}$$

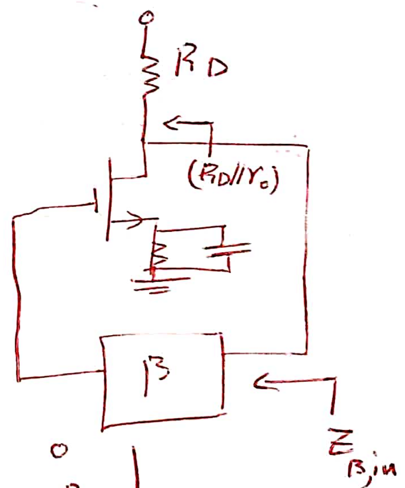
$$\omega_o = \frac{1}{\sqrt{6}\,RC}$$

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

* gain condition : at $\omega = \omega_o$

$$\Rightarrow \frac{V_f}{V_o} = \frac{R^3}{R^3 - \frac{5R(6R^2C^2)}{C^2}} = \frac{R^3}{R^3 - 30R^3} = -\frac{1}{29}$$

$$\Rightarrow |A_v| \geq 29$$



$$A_v = -g_m R_{out} \quad , \quad R_{out} = Z_{B,in} \,//\, (R_D // r_o)$$

$$Z_{Bin} = \frac{V_o}{I_1} = \frac{V_o \Delta}{\Delta_1} \quad , \quad \Delta_1 = \begin{vmatrix} V_o & -R & 0 \\ 0 & 2R+\frac{1}{sC} & -R \\ 0 & -R & 2R+\frac{1}{sC} \end{vmatrix}$$

$$= V_o\left(\frac{1}{s^2C^2} + \frac{4R}{sC} + 3R^2\right)$$

(sub. by Δ & Δ_1

$$\Rightarrow Z_{B,in} = R\,\frac{(s^3R^3C^3 + 6s^2R^2C^2 + 5sRC + 1)}{3s^3R^3C^3 + 4s^2R^2C^2 + sRC}$$

$$= R\,\frac{(1 - 6\omega^2R^2C^2) + j\omega RC(5 - \omega^2R^2C^2)}{-4\omega^2R^2C^2 + j\omega RC(1 - 3\omega^2R^2C^2)}$$

$$\Rightarrow A_v = -g_m \left(Z_{B,in} \,//\, R_D \,//\, r_o \right)$$

at $w = w_o$:

$$\Rightarrow Z = R \; \frac{\left(1 - \frac{6R^2C^2}{6R^2C^2}\right) + j \frac{-RC}{\sqrt{6}\,RC}\left(5 - \frac{R^2C^2}{6R^2C^2}\right)}{-4\left(\frac{1}{6R^2C^2}\right)R^2C^2 + j \frac{RC}{\sqrt{6}\,RC}\left(1 - 3\frac{R^2C^2}{6R^2C^2}\right)}$$

$$= R \; \frac{j \frac{5 - \frac{1}{6}}{\sqrt{6}}}{-\frac{4}{6} + j \frac{1}{\sqrt{6}}\left(1 - \frac{1}{2}\right)}$$

$$= R \; \frac{j \frac{29}{6\sqrt{6}}}{-\frac{4}{6} + j \frac{1}{\sqrt{6}}\left(\frac{1}{2}\right)} = R \; \frac{j29}{-4\sqrt{6} + j3} \;\Omega$$

$$= \left(2.82 \angle -72.9^\circ\right) R \;\Omega$$

* To avoid load the o/p of the Amplifier:

$$2.82R \gg \left(R_D // r_o\right)$$

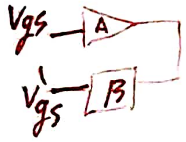
$$\Rightarrow A_v \simeq -g_m \left(R_D // r_o\right) > 29$$

<u>Note</u>: if the effect of loading is taken into consideration $\Rightarrow$ we can get to result similar to that of phase-shift BJT (By the same analysis)

BJT	MOS
$I_b R$	$\longrightarrow V_{gs}$
V_{be}	

* By analogy:

$$\frac{\overset{\text{I/P Voltage}}{V_{gs}}}{\underbrace{g_m V_{gs}'}_{\text{o/p current}}} = \frac{\overset{\text{I/P volt}}{I_b R}}{\underbrace{h_{fe} I_b'}_{\text{o/p current}}}$$



$$\because \frac{V_{gs}}{V_{gs}'} = \frac{I_b}{I_b'} = 1$$

$$\Rightarrow g_m \frac{1}{g_m} \Longrightarrow \frac{R}{h_{fe}} \Rightarrow g_m R \Rightarrow h_{fe}$$

$\because$ in BJT : $h_{fe} > 23 + 4\left(\frac{R_o}{R}\right) + 29\frac{R}{R_o}$

in MOS/FET $\Rightarrow g_m R > 23 + 4\frac{R_o}{R} + 29\frac{R}{R_o}$