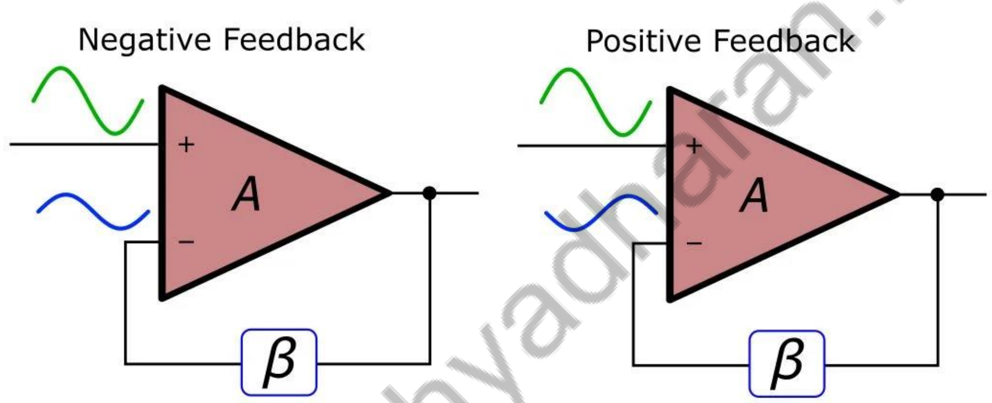
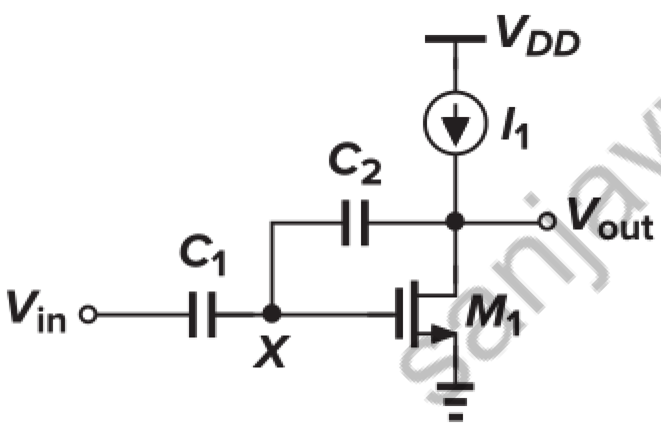
Analog IC Design : 2022-23
Lecture 12
Stability and Oscillators

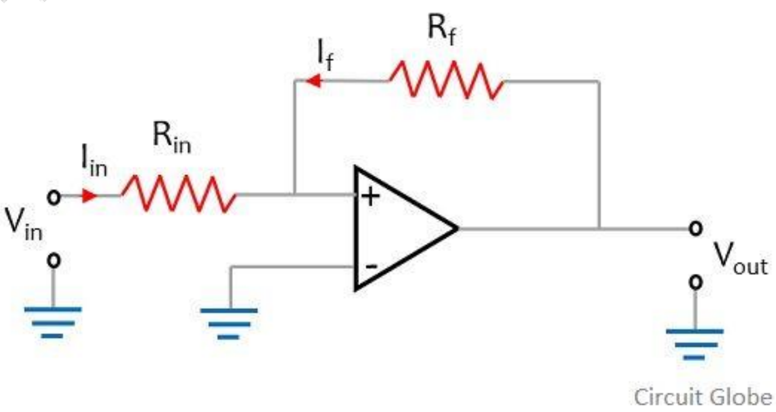
By Dr. Sanjay Vidhyadharan

Stability

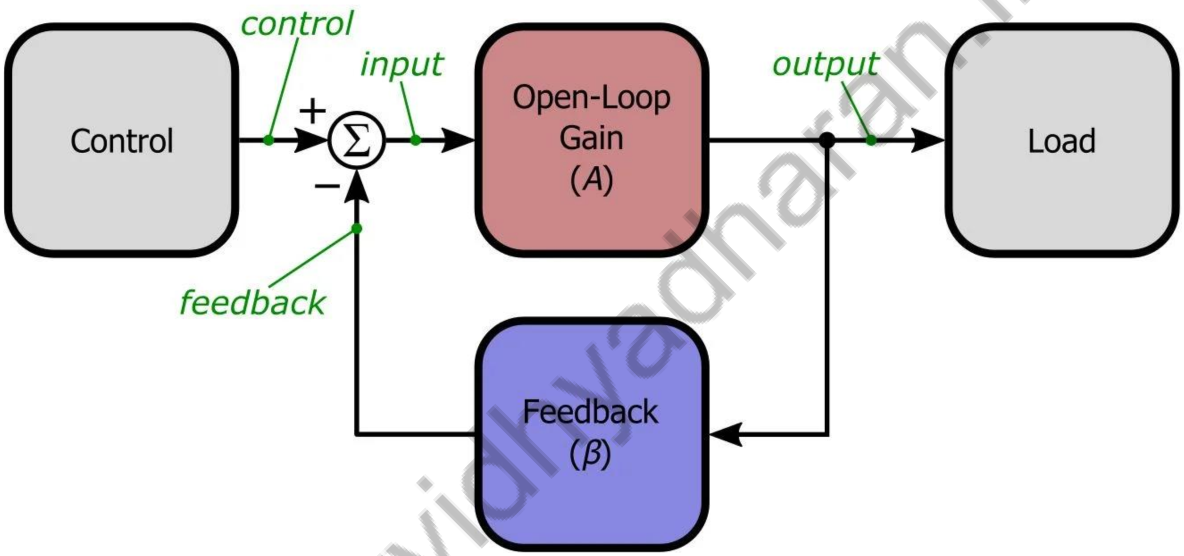

Negative Feedback
Positive Feedback
+
A
−
β
+
A
−
β


V_{DD}
I_1
C_2
V_{out}
C_1
V_{in}
X
M_1

(b)

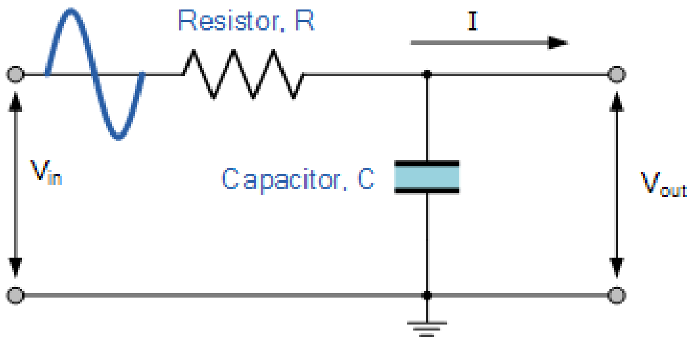

R_f
I_f
R_{in}
I_{in}
V_{in}
+
-
V_{out}
Circuit Globe

Stability



$$\textbf{Closed loop gain } A_f = \frac{A}{1 + A\beta}$$

Single Pole Response



For $\omega \ll \omega_0$ $A_v = 1$ $Power\ Gain = 0\ dB, \phi = 0$

For $\omega = \omega_0$ $A_v = \frac{1}{\sqrt{2}}$ $Power\ Gain = -3\ dB, \phi = -45^0$

For $\omega > \omega_0$ $Slope\ 20\ dB$/decade $for\omega \gg \omega_0$ $\phi = -90^0$

$$V_{out} = V_{in}\frac{-jXc}{R - jXc} \qquad \omega_0 = \frac{1}{RC}$$

$$Gain = \frac{V_{out}}{V_{in}} = \frac{-jXc}{R - jXc} = \frac{1}{1 + jRC\omega} = \frac{1}{1 + j\frac{\omega}{\omega_0}}$$

$$Gain(j\omega) = \frac{1}{\sqrt{1 + (\frac{\omega}{\omega_0})^2}} \angle -\tan^{-1}(\frac{\omega}{\omega_0})$$

$$Power\ Gain\ in\ dB = 20\log(Av)$$

$$Half\ Power\ Gain\ in\ dB = 20\log\frac{1}{\sqrt{2}} = -3\ dB$$

$$A_{v1} = \frac{1}{\sqrt{1 + (\frac{\omega_1}{\omega_0})^2}}$$

$$A_{v2} = \frac{1}{\sqrt{1 + (\frac{10\omega_1}{\omega 0})^2}} \simeq A_{v1}/10$$

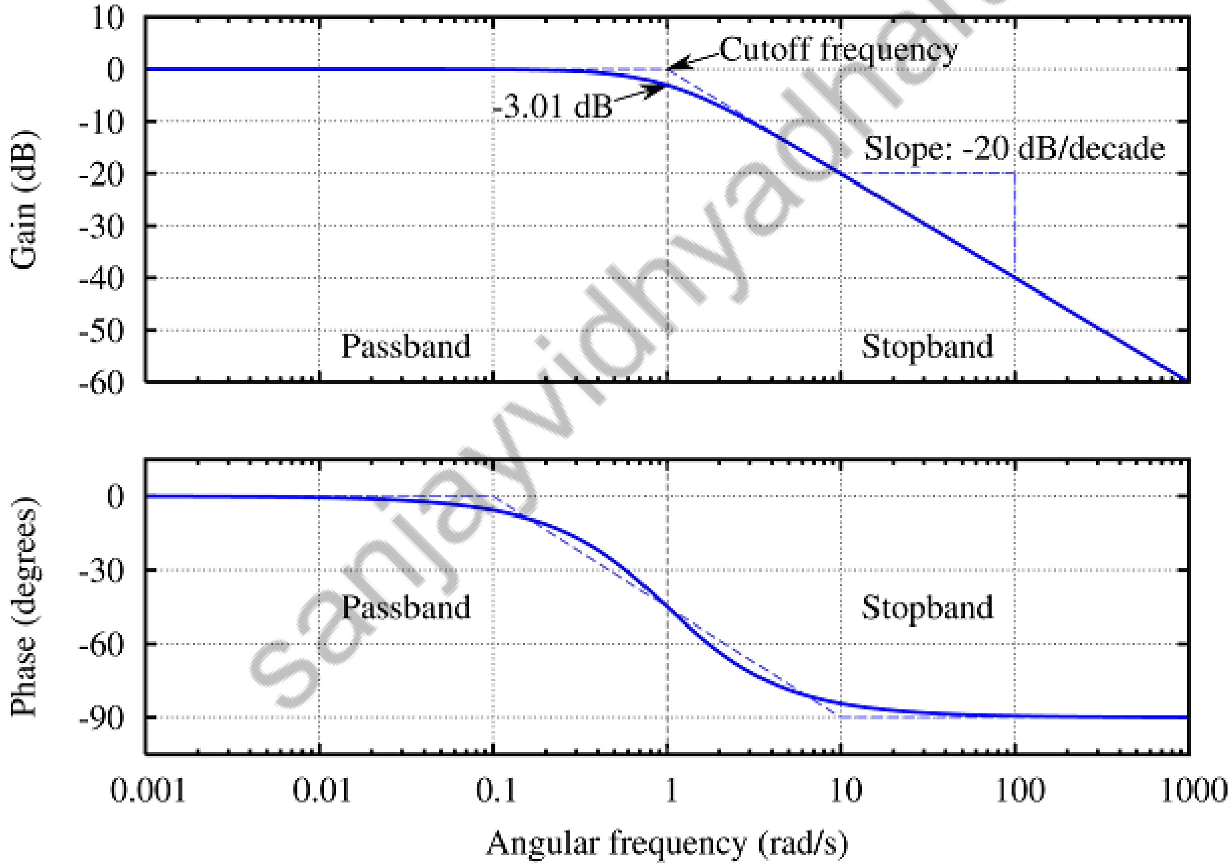
$$Gain\ in\ dB = 20\log\left(\frac{1}{10}\right) = -20\ dB$$

Single Pole Response

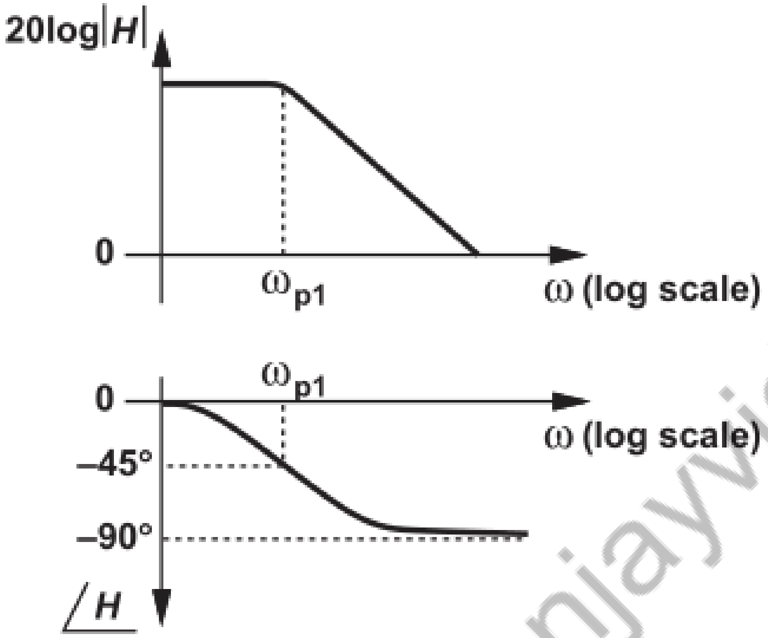
$For\ \omega \ll \omega_0 \ \ A_v = 1\ Power\ Gain = 0\ dB, \phi = 0$

$For\ \omega = \omega_0 \ \ A_v = \frac{1}{\sqrt{2}}\ \ Power\ Gain = -3\ dB, \phi = -45^0$

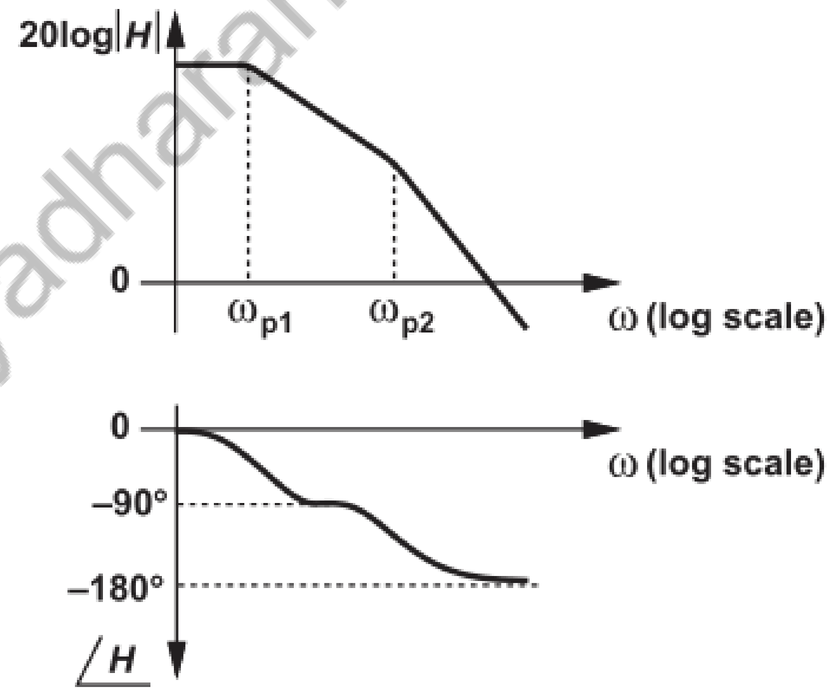
$For\ \omega > \omega_0\ Slope\ 20\ dB$/decade $\ \ for\omega \gg \omega_0\ \phi = -90^0$



Two Pole Response

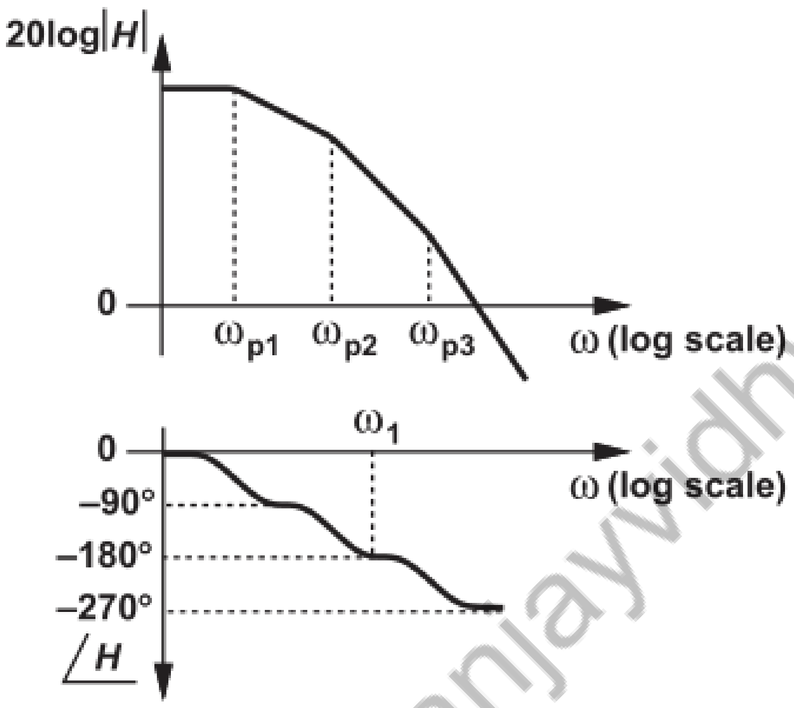


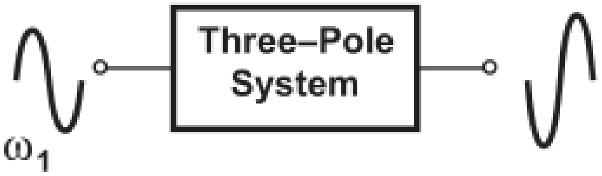
(a)



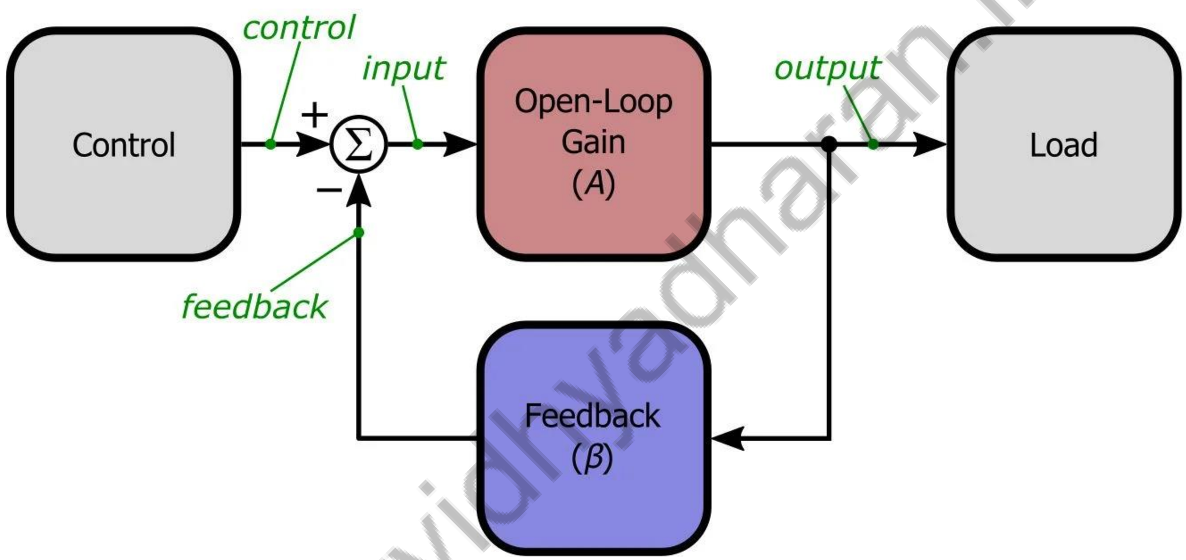
(b)

Three Pole Response



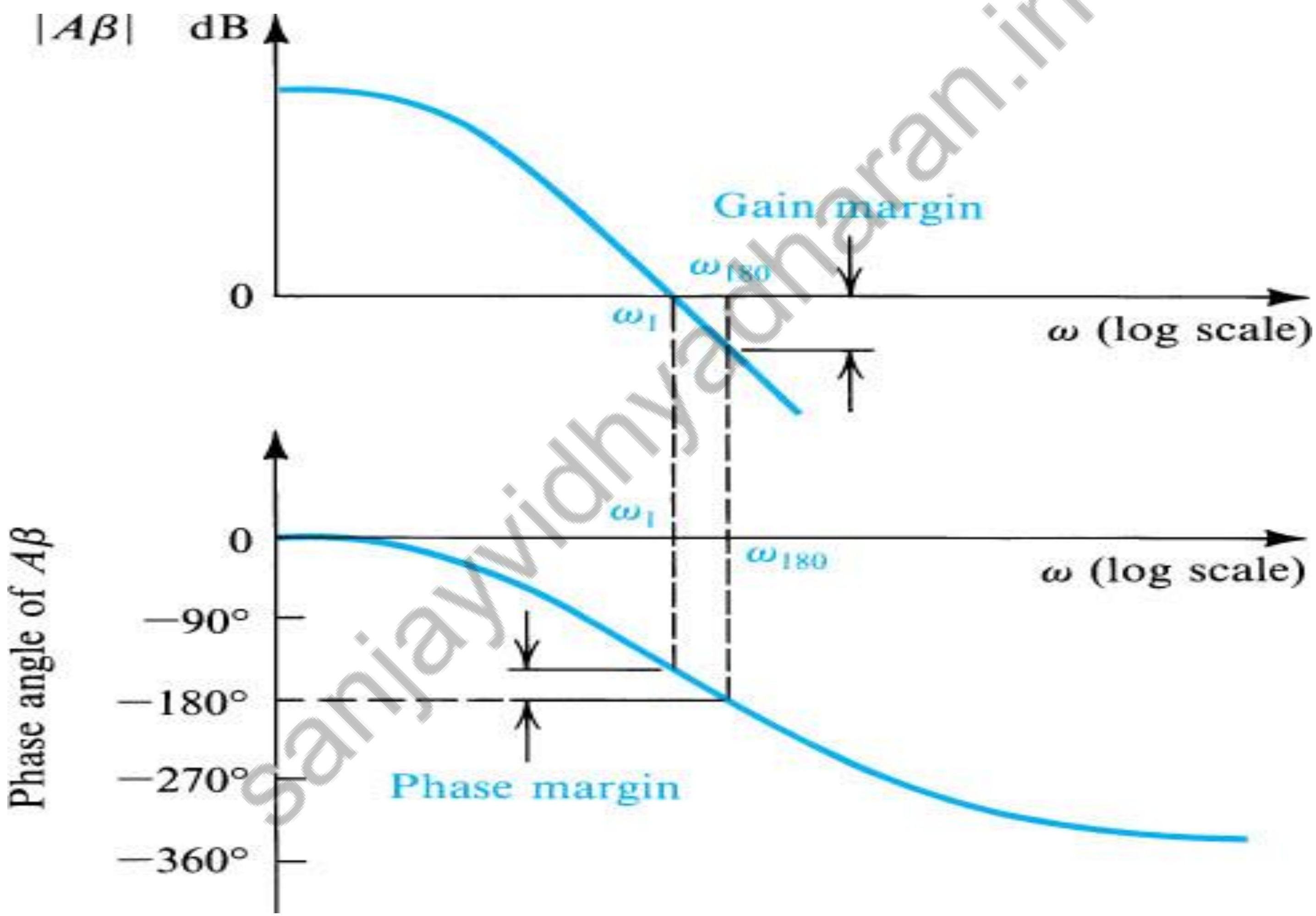


Stability

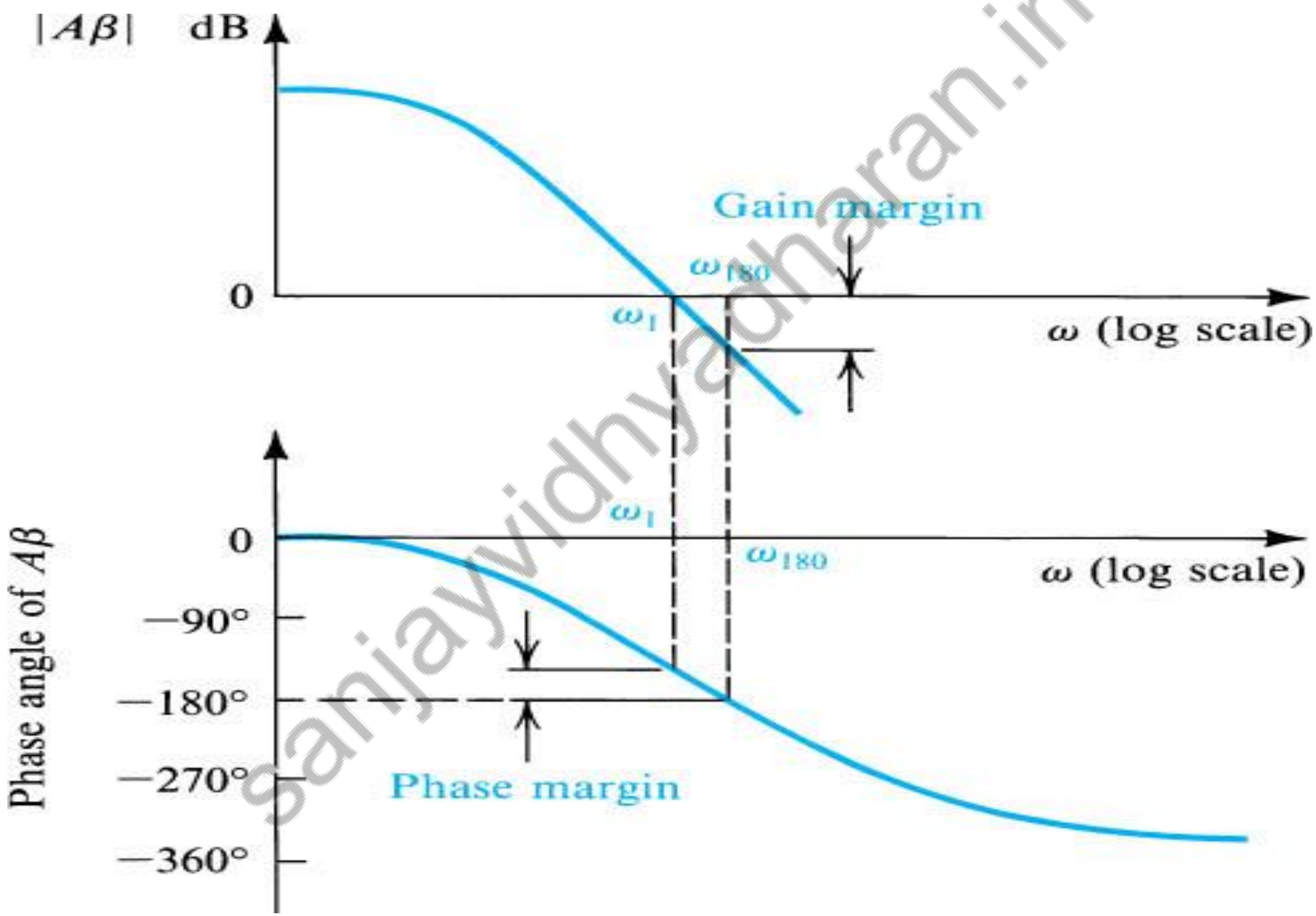


$$\textit{Closed loop gain } A_f = \frac{A}{1 + A\beta}$$

Stability


|Aβ| dB
0
Gain margin
ω180
ω1
ω (log scale)
Phase angle of Aβ
0
ω1
ω180
ω (log scale)
−90°
−180°
−270°
−360°
Phase margin

Stability



|Aβ| dB
Gain margin
ω180
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−90°
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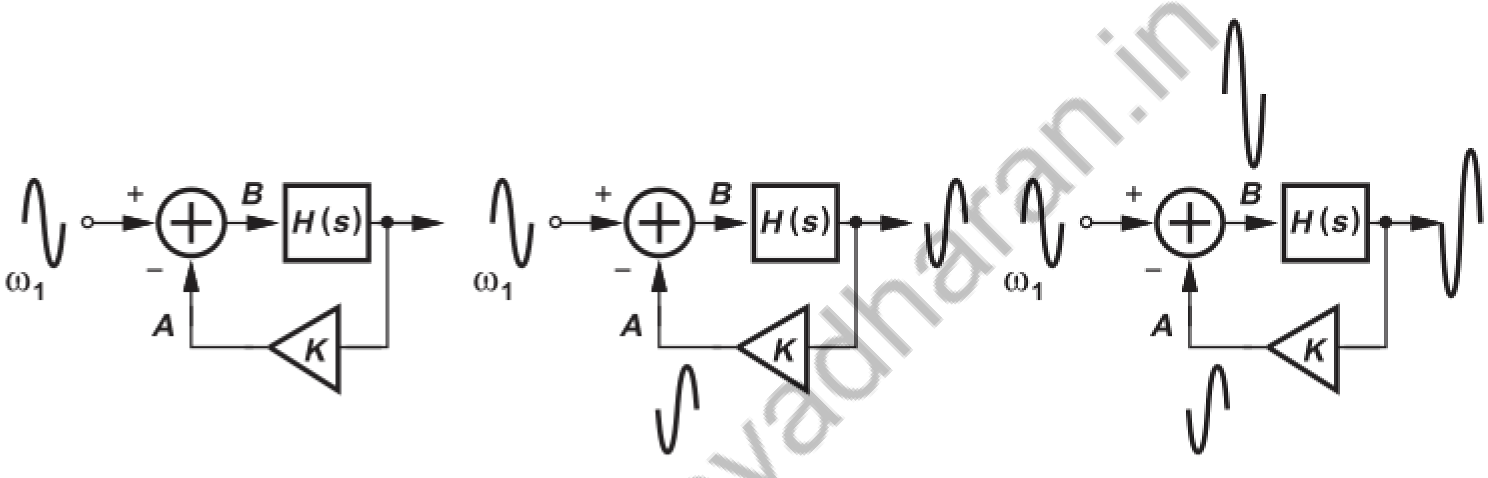
Phase margin

Stability



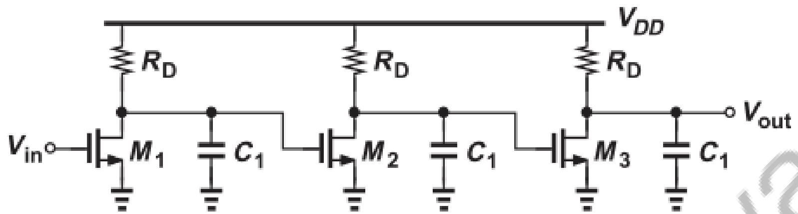
(a) (b) (c)

(a) a component at ω_1 is sensed at input, (b) the component returns to subtractor with a 180 ◦ phase shift, (c) the subtractor enhances the signal at node B.

A negative feedback system may become unstable if the forward amplifier introduces a phase shift of −180 ◦ at a finite frequency, ω_1 , and the loop transmission |KH| is equal to unity at that frequency

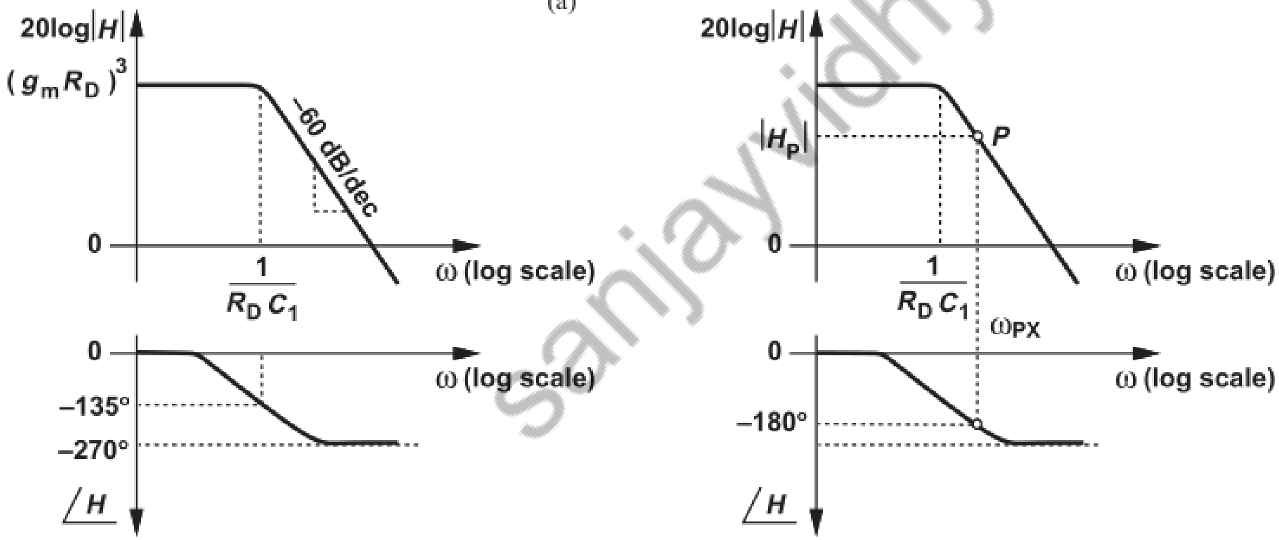
Example-1

We wish to apply negative feedback with K = 1 around the three-stage amplifier shown in Fig. 12.67(a). Neglecting other capacitances and assuming identical stages, plot the frequency response of the circuit and determine the condition for stability. Assume $\lambda = 0$.



(a)

The phase begins to change at one-tenth of this frequency, it reaches -135^0 at ω_p , and approaches -270^0 at $10\omega_p$.



Example-1

We wish to apply negative feedback with K = 1 around the three-stage amplifier shown in Fig. Neglecting other capacitances and assuming identical stages, plot the frequency response of the circuit and determine the condition for stability. Assume λ = 0.

$$H(s) = \frac{(g_m R_D)^3}{\left(1 + \frac{s}{\omega_p}\right)^3},$$

$$\angle H(j\omega) = -3\tan^{-1}\frac{\omega}{\omega_p},$$

The phase crossover occurs
if tan−1(ω/ω p) = 60 ◦ and hence

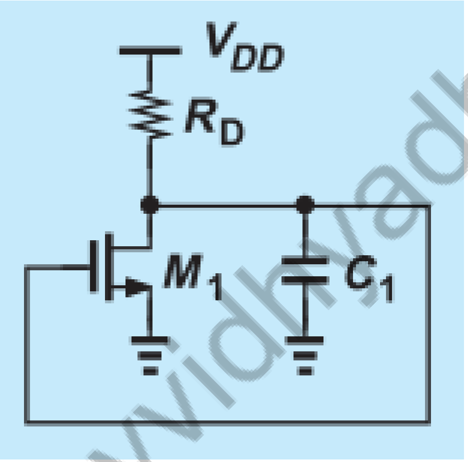
$$\omega_{PX} = \sqrt{3}\omega_p.$$

$$\frac{(g_m R_D)^3}{\left[\sqrt{1 + \left(\frac{\omega_{PX}}{\omega_p}\right)^2}\right]^3} < 1.$$

$$g_m R_D < 2.$$

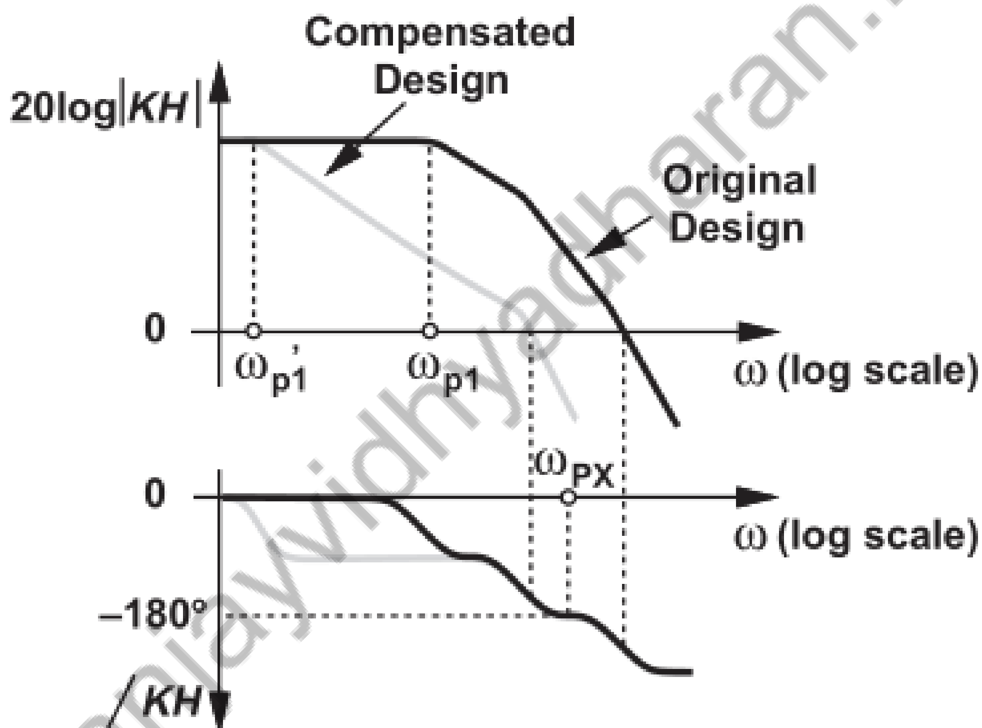
Example-2

A common-source stage is placed in a unity-gain feedback loop as shown in Fig. Explain why this circuit does not oscillate.

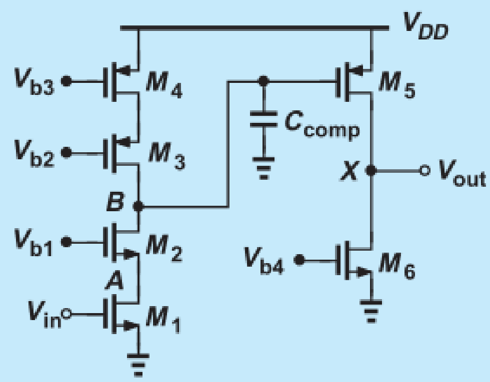


Since the circuit contains only one pole, the phase shift cannot reach 180 ◦ at any frequency. The circuit is thus stable.

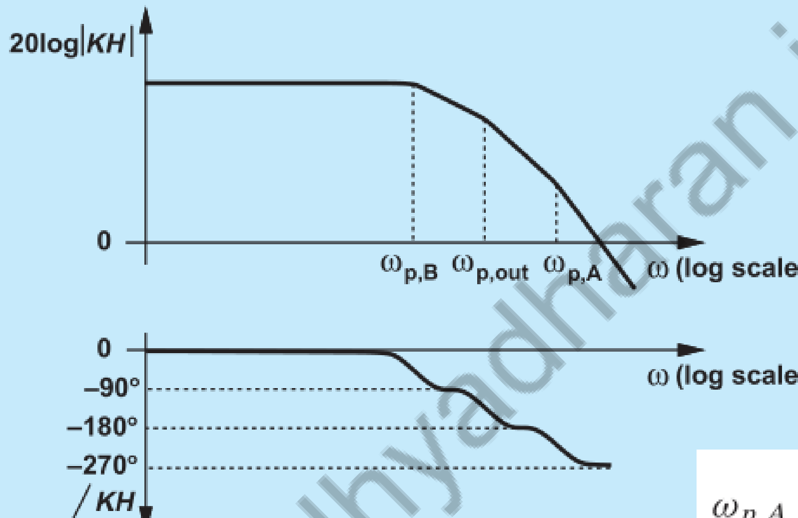
Frequency Compensation



Frequency Compensation



(a)

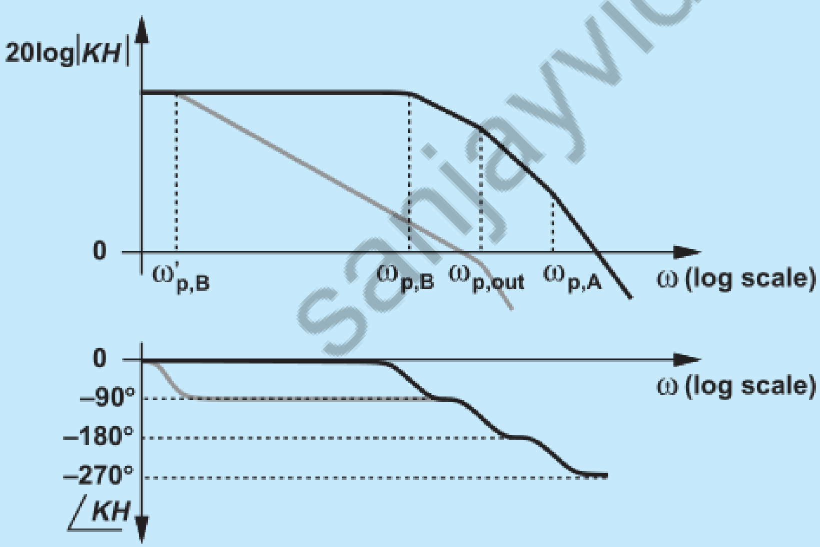


(b)

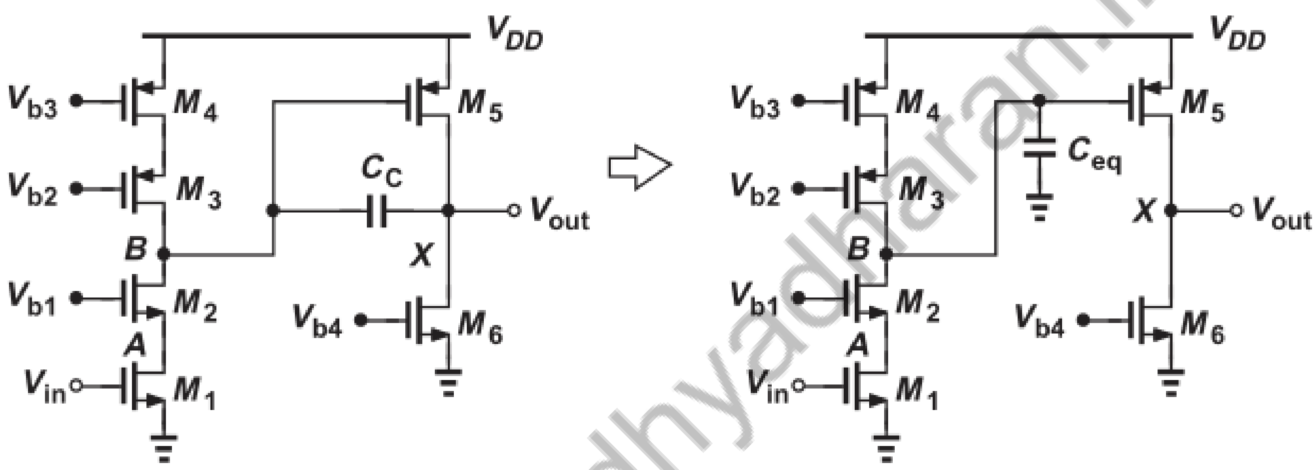
$$\omega_{p,A} \approx \frac{g_{m2}}{C_A}$$

$$\omega_{p,B} \approx \frac{1}{[(g_{m2}r_{O2}r_{O1})||(g_{m3}r_{O3}r_{O4})]C_B},$$

$$\omega_{p,out} = \frac{1}{(r_{O5}||r_{O6})C_{out}}$$



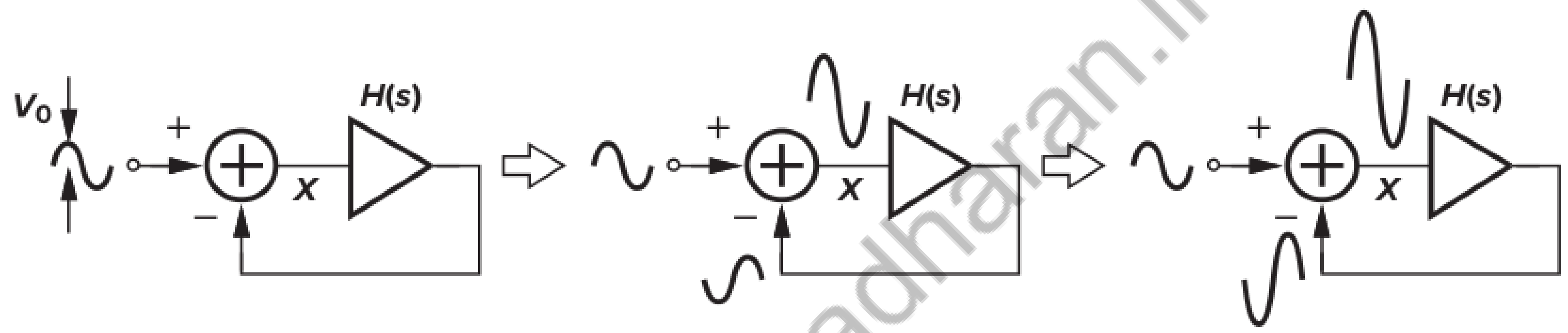
Miller Compensation



$$C_{eq} = (1 - A_v)C_c$$

$$= [1 + g_{m5}(r_{O5}||r_{O6})]C_c.$$

Oscillators



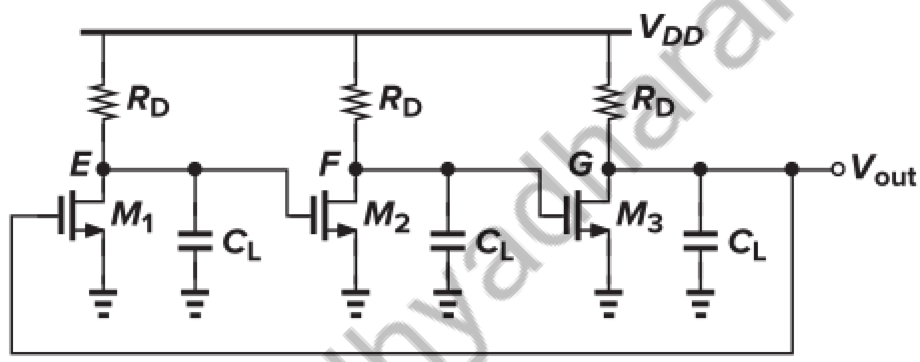
"Barkhausen criteria,"

$$|H(j\omega_0)| \geq 1$$

$$\angle H(j\omega_0) = 180^\circ$$

Oscillators

Three-stage ring oscillator.



$$\tan^{-1}\frac{\omega_{osc}}{\omega_0} = 60^\circ$$

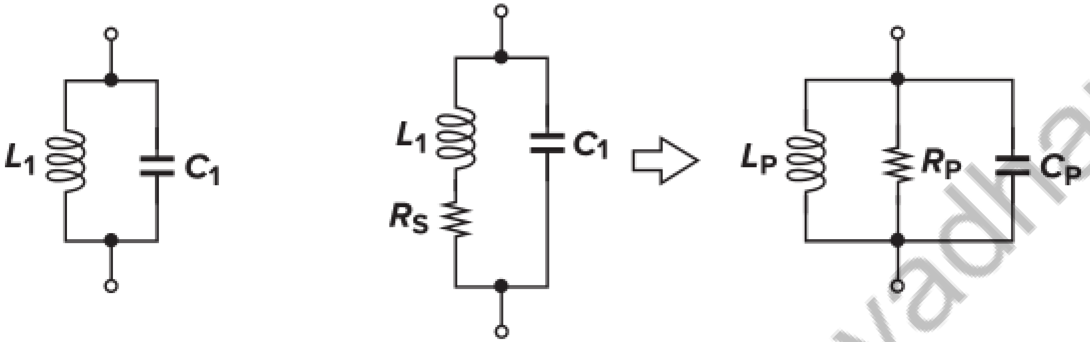
$$\omega_{osc} = \sqrt{3}\omega_0$$

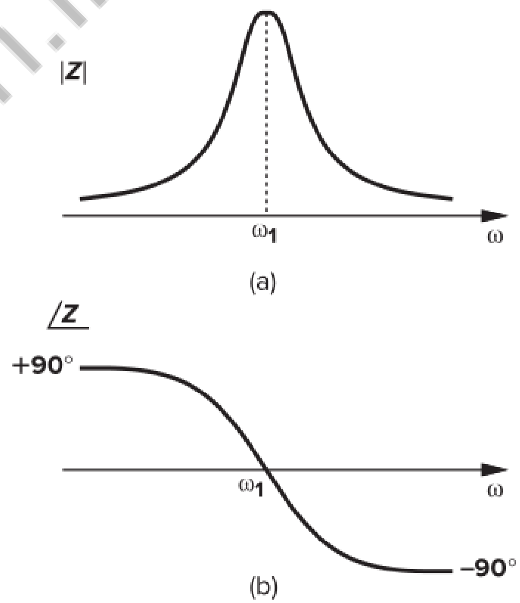
$$\frac{A_0^3}{\left[\sqrt{1+\left(\frac{\omega_{osc}}{\omega_0}\right)^2}\right]^3} = 1$$

$$A_0 = 2$$

Oscillators

LC oscillator.





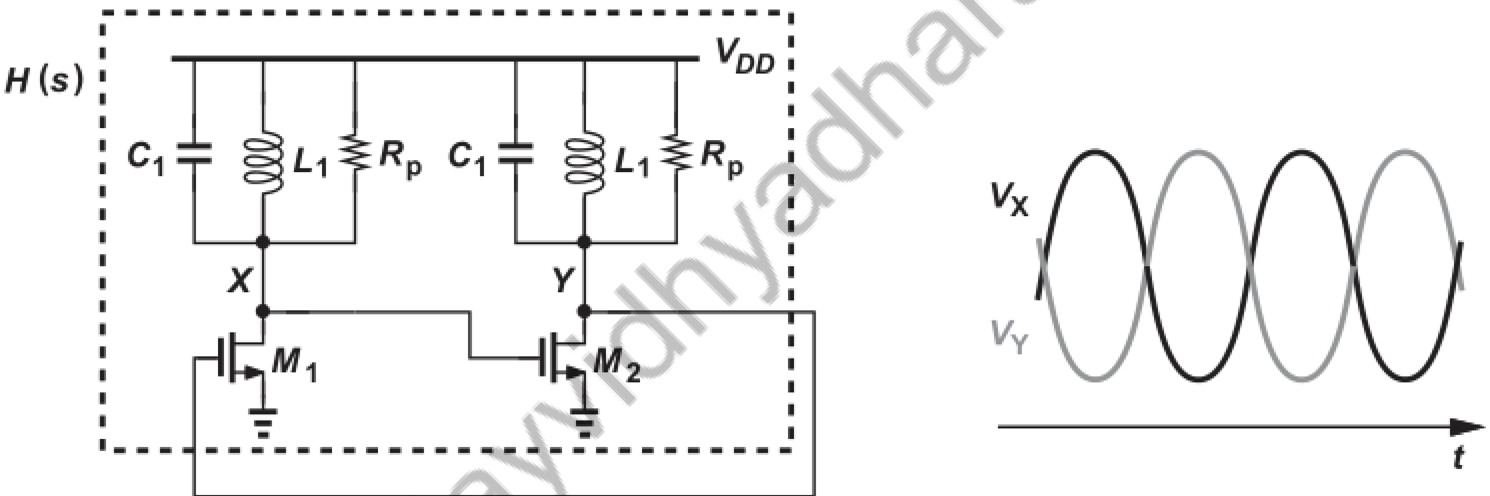
$$L_P \approx L_1 \qquad R_P \approx \frac{L_1^2\omega^2}{R_S}$$

$$R_P \approx \frac{L_1^2\omega^2}{R_S} \approx Q^2 R_S$$

Impedance: $\frac{1}{Z} \equiv \frac{I_{max}}{\mathcal{E}_{max}} = \sqrt{\frac{1}{R^2} + \left(\frac{1}{\omega L} - \omega C\right)^2}$

Oscillators

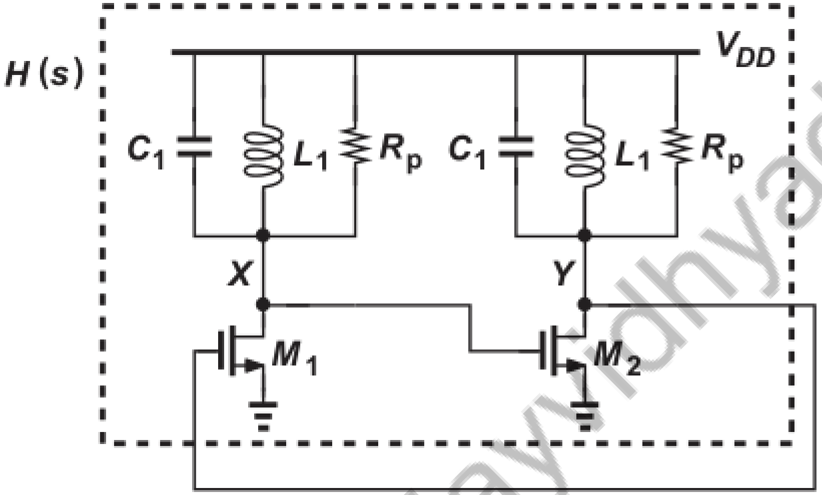
LC oscillator.



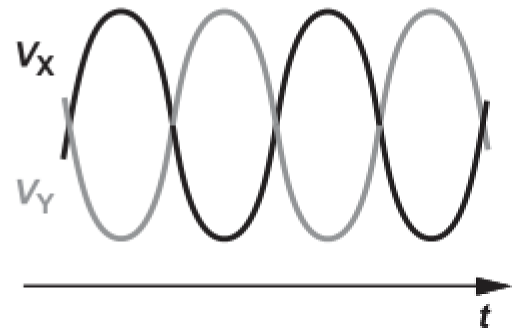
(a) (b)

Oscillators

LC oscillator.



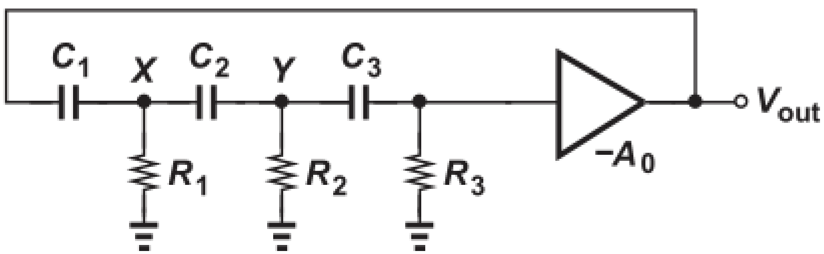
(a)

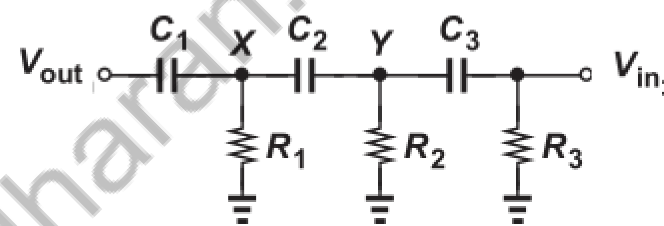


(b)

Oscillators

PHASE SHIFT OSCILLATOR





$$V_X = \frac{R}{R+\frac{1}{Cs}} = \frac{RCs}{1+RCs}$$

$$\frac{V_{out}}{V_{in}} = \frac{(RCs)^3}{(RCs+1)^3}.$$

For oscillation to occur at ω_1, this phase must reach 180°:

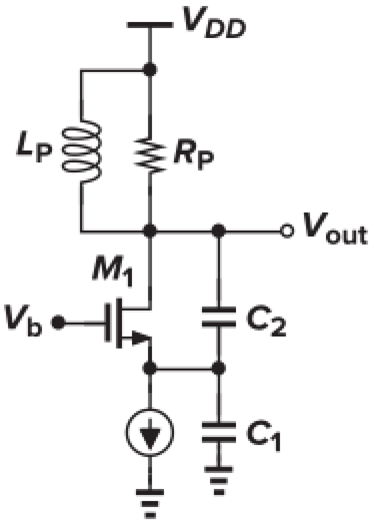
$$\tan^{-1}(RC\omega_1) = 30^\circ.$$

It follows that

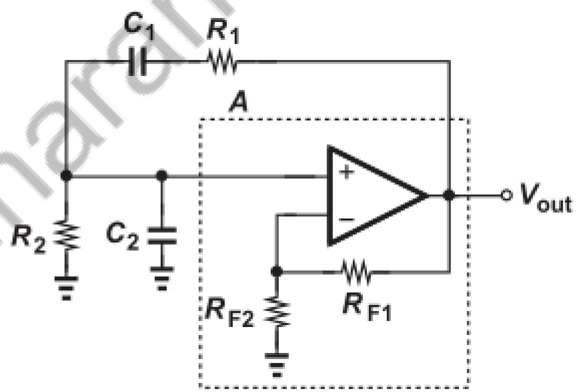
$$\omega_1 = \frac{1}{\sqrt{3}RC}.$$

That is, the gain of the amplifier must be at least:
A = 2.

Oscillators



Colpitts oscillator



Wien-bridge oscillator.

$$\omega_1 = \frac{1}{RC}.$$

$$A = 3.$$

That is, we choose $R_{F1} \geq 2R_{F2}$.

Thankyou