Prob-1. Determine in which of the two cases (a) $g_{mp} > g_{mn}$ (b) $g_{mp} < g_{mn}$ the circuit will be unstable and why? $g_{mp}$ and $g_{mn}$ are respective transconductances of MP and MN.

$L_1 = -g_{m1} R_2 g_{mp} \frac{1}{g_{m2}}$

$L_2 = + g_{m1} R_2 g_{mn} \frac{1}{g_{m2}}$

$(g_{mp} > g_{mn})$ yields net negative feedback loop $\Rightarrow$ STABLE

$(g_{mp} < g_{mn})$ yields net positive feedback loop $\Rightarrow$ UNSTABLE

(only if magnitude of $g$)
**Prob-2.** A second order system has an open loop transfer function $H(s) = \frac{2000}{(\frac{s}{10} + 1)(\frac{s}{p} + 1)}$ and feedback factor of $\beta$.

Determine the location of pole $p$ for which the loop phase margin is $45^\circ$ if (a) $\beta = 1/2$ and (b) $\beta = 1/20$. Show the bode plot of loop transfer function for both the cases.

- $45^\circ$ phase margin implies 2nd pole is located at 0 dB (opposing).

$$L(s) = H(s) \cdot \beta$$

$$L(s) \bigg|_{\beta = \frac{1}{2}} = \frac{1000}{(1 + \frac{s}{10})(1 + \frac{s}{p})} \quad \rightarrow \quad \text{want} \quad p = 10^4 \quad \text{for} \quad 45^\circ \text{PM}.$$  

$$L(s) \bigg|_{\beta = \frac{1}{20}} = \frac{100}{(4 + \frac{s}{10})(1 + \frac{s}{p})} \quad \rightarrow \quad \text{want} \quad p = 10^3 \quad \text{for} \quad 45^\circ \text{PM}.$$
**Prob-3.** Figure below shows a non-inverting amplifier achieved by connecting an opamp in negative feedback configuration. Assuming open loop gain of opamp $A=\infty$, the closed loop gain $Vout/Vin$ of the circuit is given by $1+R1/R2$ which is simply $1/\beta$ where $\beta$ is the feedback factor $R2/(R1+R2)$. Find the expression for closed loop gain if $A$ is finite and determine % error in the closed loop gain for (a) $A=1000$ and (b) $A=10000$.

\[ \beta = \frac{R2}{R1+R2} \]

\[
\begin{align*}
\text{Closed loop gain} &= \frac{V_{out}}{V_{in}} = \frac{A}{1+AB} = \frac{1}{\beta} \frac{AB}{1+AB} \\
\text{Ideal gain} &= \frac{R2}{R1+R2} \\
\text{Error} &= 1 - \frac{AB}{1+AB} = \frac{1}{1+AB}
\end{align*}
\]
**Prob-4.** A system is said to be unstable if any of the poles lie in right half of the s-plane. This property can be used to convert a second order system into oscillator by using negative feedback and choosing a proper feedback function. Find the closed loop transfer function $V_{out}(s)/V_{in}(s)$ of the system and show how the location of poles change w.r.t $k$ in s-plane.

\[
H(s) = \frac{A}{s^2 + \frac{w_n}{Q_0}s + w_n^2}
\]

\[
\Delta(s) = \frac{V_{out}(s)}{V_{in}(s)} = \frac{H(s)}{1 - H(s) \cdot ks}
\]

\[
A \left( s \right) = \frac{A}{s^2 + s \left( \frac{w_n}{Q_0} - Ak \right) + w_n^2}
\]

"b" part of quadratic formula

\[
s = \frac{-b \pm \sqrt{(\frac{b}{2a})^2 - \frac{c}{a}}}{2a}
\]

\[
(b = 0) \rightarrow k = \frac{w_n}{\frac{a_0}{A}} \rightarrow \text{poles on } j\omega \text{-axis (all imaginary)}
\]

\[
(b > 0) \rightarrow k < \frac{w_n}{\frac{a_0}{A}} \rightarrow \text{STABLE (poles on left half plane)}
\]

\[
(b < 0) \rightarrow k > \frac{w_n}{\frac{a_0}{A}} \rightarrow \text{UNSTABLE}
\]
Prob-5. A common source amplifier with DC gain \( g_m R \) and pole location \( \frac{1}{\beta RC} \) is connected in negative feedback configuration as shown in figure below. Determine the closed loop transfer function \( \frac{V_{out}(s)}{V_{in}(s)} \), closed loop DC gain and closed loop -3dB bandwidth of the circuit. Show the bode plot for gain and phase for (a) \( \beta = 0 \) (b) \( \beta = 1 \) and (c) \( \beta = 1/2 \) and compare the DC gain and Bandwidth of the closed system with that of open loop gain and bandwidth of common source amplifier. Consider \( r_o = \infty \).

\[
A(s) = \frac{V_{out}(s)}{V_{in}(s)} = \frac{-g_m R \frac{1}{1+g_m R \beta}}{1 + g_m R \frac{1}{1+g_m R \beta}} = \frac{-g_m R}{1 + g_m R \beta} \cdot \frac{1}{1 + \frac{S RC}{1 + g_m R \beta}}
\]

When \( \beta = 0 \), \( A(s) \) is same as open loop.

\[
\text{gain} = -\frac{g_m R}{1+g_m R \beta}
\]

\[
\text{BW} = \frac{1}{RC} (1+g_m R \beta)
\]

For \( \beta = \frac{1}{2} \), \( \beta = 1 \),

\( A(s) \) sees decrease in gain and increase in BW, by \( 1 + g_m R \beta \).
**Prob-6** For the circuit shown below, considering each pole causes a $3dB$ drop in gain at pole frequency, find (a) minimum gain $k$ if $R=1K\Omega$ and (b) minimum value of $R$ if $k=0.25$ for which the circuit will oscillate and determine the expression for frequency of oscillation in both the cases. Consider $r_o=\infty$ and $g_m=1mA/V$ for all the PMOS.

Each stage to contribute $45^\circ$ phase delay results in positive FB loop.

45° is at pole frequency, where gain is reduced by $\sqrt{2}$ ($3dB$).

$$\text{Loggain at that frequency } = \frac{k (g_m R)^4}{(\sqrt{2})^4}$$

$$(R=1k\Omega) \rightarrow \text{Want Loggain } k \left(\frac{g_m R}{\sqrt{2}}\right)^4 > 1 \rightarrow k > \left(\frac{\sqrt{2}}{g_m R}\right)^4 = 4$$

$$(k=0.25) \rightarrow k \left(\frac{g_m R}{\sqrt{2}}\right)^4 > 1 \rightarrow R > \left(\frac{\sqrt{2}}{g_m}\right) \cdot k^{1/4} = 2k\Omega$$
Prob-7. Design a CMOS realization for the following Boolean expressions

(a) Select (S) Logic

<table>
<thead>
<tr>
<th>Select (S)</th>
<th>Logic</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2-input NAND gate</td>
</tr>
<tr>
<td>1</td>
<td>2-input NOR gate</td>
</tr>
</tbody>
</table>

(b) $Y = (A+B)\cdot C + D\cdot E$

(c) $A\cdot B + B\cdot C + C\cdot A$

\[ Y = S \cdot (A+B) + \overline{S} \cdot (A\overline{B}) \]
**Prob-8.** For the linear oscillator shown, find the oscillation frequency $\omega_0$ and $R_x$ value required to ensure oscillation.

The oscillation frequency $\omega_0$ is given by $\omega_0 = \frac{\sqrt{3}}{RC}$.

The loop gain condition for oscillation is $|\text{Loop gain} (s=j\omega_0)| = \left| \frac{R}{R_x \left( \frac{1}{2} \right)} \right|^3 \geq 1$.

Thus, $R_x \leq \frac{1}{2} R$. 

Read 60° phase shift.