

\[ \text{KCL at } S_3, S_4 \]

\[
\frac{N_{ds,1}}{T_{ds,1}} + \frac{N_{ds,2}}{T_{ds,2}} + \frac{N_{ds,1} - N_{ds,2}}{T_{ds,3}} = (N_{in} - N_{ds,1})g_{m_3} + (-N_{ds,1})(2g_{mb,1} + g_{m,3}) = 0
\]

\[
N_{ds,1} \left[ \frac{1}{T_{ds,1}} + \frac{1}{T_{ds,2}} + \frac{1}{T_{ds,3}} + 2(g_{m_3} + g_{mb,1}) \right] = g_{m_3}N_{in} + \frac{N_{ds,2}}{T_{ds,3}}
\]

\[
N_{ds,1} = \frac{1}{2g_{m_3}} \left( g_{m_3}N_{in} + \frac{N_{ds,2}}{T_{ds,3}} \right)
\]

where \( g_{m,i} = g_{m_i} + g_{mb_i} \quad i = 1, 2, \ldots, 6 \)

\[ \text{KCL at } D_6 \]

\[
\frac{N_{ds,6}}{T_{ds,6}} - \frac{N_{out}}{T_{ds,5}} + \frac{N_{ds,6} - N_{ds,1}}{T_{ds,3}} + g_{m_3}(N_{in} - N_{ds,1}) + g_{mb,3}(-N_{ds,1})
\]

\[
- g_{m_5}(-N_{ds,6}) - g_{mb,5}(-N_{ds,6}) = 0
\]

\[
N_{ds,6} \left[ \frac{1}{T_{ds,6}} + \frac{1}{T_{ds,5}} + \frac{1}{T_{ds,3}} + g_{m_5} \right] + g_{m_3}N_{in} - g_{m_5}N_{ds,6} - \frac{N_{out}}{T_{ds,5}} - \frac{N_{out}}{T_{ds,1}}
\]

\[
N_{ds,6} = \frac{1}{g_{m_5}} \left( g_{m_3}N_{ds,6} - g_{m_3}N_{in} + \frac{N_{out}}{T_{ds,5}} \right)
\]
KCL at output

\[ \frac{V_{\text{out}}}{g_{ds2}} + \frac{V_{\text{out}} - V_{ds6}}{g_{ds6}} + \left(\frac{g_m + g_{mb3}}{g_m + g_{mb6}}\right)(-V_{ds6}) = 0 \]

\[ = g_m \]

\[ V_{\text{out}} \left(\frac{1}{g_{ds2}} + \frac{1}{g_{ds6}}\right) - V_{ds6} \left(\frac{g_m}{g_m + g_{mb6}}\right) \]

\[ \Rightarrow \]

\[ V_{\text{out}} = \left(g_{ds2} \parallel g_{ds6}\right) \cdot g_m \cdot N_{ds6} \]

1, 2, 3 \Rightarrow Block Diagram:

2. Two forward paths:
   1. \( V_{\text{in}} \rightarrow A \rightarrow B \rightarrow V_{\text{out}} \)
   2. \( V_{\text{in}} \rightarrow C \rightarrow B \rightarrow V_{\text{out}} \)

Two loops:
   1) \( A \rightarrow B \rightarrow A \)
   2) \( B \rightarrow C \rightarrow B \)

\[ P_1 = \frac{1}{2} g_m \cdot \left(\frac{1}{g_{ds2} \parallel g_{ds6}}\right) \]

\[ P_2 = -g_m \cdot \left(\frac{1}{g_{ds2} \parallel g_{ds6}}\right) \]
\[ L_1 = \frac{1}{2} \cdot \left( \frac{g_m + g_{ms}}{I_{ds3}} \right) \]

\[ L_2 = \frac{1}{I_{ds6}} \cdot \left( \frac{I_{ds2} || I_{ds5}}{} \right) \]

Both loops touch each other and the forward paths.

\[
A_n(0) = \frac{P_1 + P_2}{1 - L_1 - L_2} = -\frac{1}{2} g_m \left( \frac{I_{ds2} || I_{ds5}}{I_{ds2} + I_{ds5}} \right) \left( \frac{1}{\frac{I_{ds2}}{I_{ds2}} + \frac{I_{ds5}}{I_{ds5}}} - \frac{1}{\frac{1}{2} (g_m + g_{ms}) \cdot I_{ds3}} \right)
\]

\[ A_n(0) \approx -\frac{1}{2} g_m \left( \frac{I_{ds2} \cdot I_{ds5}}{I_{ds2} + I_{ds5}} \cdot \frac{1}{2 (g_m + g_{ms}) \cdot I_{ds3}} \right) \]

(Makes sense because the output resistance of the \( M_2 \), \( M_6 \) (2 \( M_3 \)) cascade is likely to be much greater than that of \( M_2 \))

3. Recall that the full SSM of each MOS (pMOST or nMOST) is:

```
  C_{gd}  \\
G----o----C_{gd}
       |  |
       |  |
       C_{gd}  \\
B----o----C_{gd}
       |  |
       |  |
       C_{gd}  \\
S----o----C_{gd}
       |  |
       |  |
       C_{gd}  \\
```

\[ \Rightarrow 2 \cdot g_m \cdot I_{ds} \]
There are only 3 nodes in the circuit that are not at ac ground (when \( V_{in} = 0 \)). These are the nodes with voltages \( V_{ds1}, V_{ds2}, \) and \( V_{out} \). Denote these nodes as nodes 1, 2, and 3, respectively.

That is, in the SSM version of the circuit, 
\[ V_1(s) = V_{ds1}(s), \quad V_2(s) = V_{ds2}, \quad \text{and} \quad V_3(s) = V_{out}(s). \]

Suppose a current \( i_j(s) \) is injected into node \( j \) of the circuit. With \( Z_i(k) = V_{il}(s)/i_j(s) \), it follows from 4 the circuit topology, and the assumption that 
\[ Z_{21}(s) = 0 \quad \text{and} \quad Z_{22}(s) = 0 \]

Therefore, the result of problem 3b on HW2 is applicable.

Let \( R_i = \) the small signal resistance to ground from node \( i \), 
\[ C_i = \] the capacitance 

Then \( \frac{1}{R_i C_i} = \) pole of circuit.

To find \( R_1, R_2, \) and \( R_3 \), use the SSM drawn above.

For prob. 1, with \( V_{in} = 0 \), \( R_{ds3} = \infty \), and \( T_{ds5} = \infty \):

**R_1**

Inject a test current \( i_x \) into node 1 (\( S_3, S_4 \)):
\[ i_x + \frac{N_x}{R_{ds1} R_{ds2}} = g_m^1 (-N_x) + g_m^4 (-N_x) = 0 \]
\[ R_1 = \frac{N_x}{i_x} = \frac{1}{g_m + g_m^4} = \frac{1}{2 g_m^1}. \]  \( \text{(5)} \)

**R_2**

Inject a test current \( i_x \) into node 2 (\( D_3 \)):
\[ i_x + \frac{N_x}{R_{ds2}} = g_m^2 (-N_x) + g_m^3 (-N_{ds1}) = 0 \]  \( \text{(6)} \)
\[ \Rightarrow \ N_{ds1} = [g_m^2 (-N_{ds1}) + g_m^4 (-N_{ds1})] \cdot (T_{ds1} \cdot T_{ds2}) \]
\[ \Rightarrow \ \ N_{ds1} = 0 \]
\[ \Rightarrow \ R_2 = \frac{1}{g_m^2} \]
\( R_3 \)  

With \( Rds_s = \infty \), \( i_{ds} \) is independent of \( V_{out} \).

\[ R_3 = Rds_s \]  

By inspection.

By inspection, (using \( \mathcal{O} \) and the circuit diagram), have:

\[ C_1 = C_{gd1} + C_{bd1} + C_{bs2} + C_{gs3} + C_{bs4} + C_{gs4} \]
\[ C_2 = C_{gd3} + C_{bd3} + C_{gd4} + C_{bd4} + C_{gs5} + C_{bs5} \]
\[ C_3 = C_{gd2} + C_{bd2} + C_{gd5} + C_{bd5} \]

\[ p_1 = - \left( \frac{2(gm_3 + gm_{bs})}{C_{gd1} + C_{bd1} + C_{bs2} + C_{gs3} + C_{bs4} + C_{gs4}} \right) \]
\[ p_2 = - \left( \frac{gm_3 + gm_{bs}}{C_{gd3} + C_{bd3} + C_{gd4} + C_{bd4} + C_{gs5} + C_{bs5}} \right) \]
\[ p_3 = - \left( \frac{1}{Rds_s (C_{gd2} + C_{bd2} + C_{gd5} + C_{bd5})} \right) \]

Note: \( p_3 \) is dom. pole because \( Rds_s >> Vg_{mj} \) \( i,j \)

Yet \( C_1, C_2, \) \& \( C_3 \) have same order of mag.