Q1

* First identify the point of symmetry & simplify. (Vs is the point of symmetry)

* Ignore all the capacitors and solve for dc gain.

\[ \frac{V_{out}}{V_{in}} \] 

\[ g_m \Delta V_{in} + g_m \Delta V_x = 0 \] 

\[ \Delta V_x \approx -\Delta V_{in} \] 

At mode X

\[ \Delta V_{out} \approx \frac{g_m}{2g_d} \Delta V \] 

(Contribution only due to \( \Delta V_{in} \))

* Before we perform frequency analysis, trace the signal path from input to the output.

* There is no pole at the input because we are using ideal voltage sources or when \( V_{in} \) increases by \( \Delta V \), the change is instantaneous.

→ When \( V_{in} \) by \( \Delta V \), current through \( M1 \) increases, which will decrease the voltage at mode X.

→ Question is how fast will the voltage at mode X change? (or what is the time constant @ X).

→ Now include all the capacitances
What is the total capacitance at mode X?
- Two gate-to-source capacitances (M3 & M4)
- What about C?
- C is a Miller capacitance (Why?)

\[ \Delta V_x = \frac{-\Delta V}{(1 + \frac{s}{\omega_x})} \]

Therefore for calculating the location of the poles decompose C using Miller theorem.

Total capacitance at mode X up:
\[ C_x = 2C_{gs} + \left( 1 + \frac{g_m}{2g_d} \right) C \quad \text{\scriptsize (Cgd is small compared to C)} \]

Total capacitance at mode Vout:
\[ C_{out} = C + C_L \quad \text{\scriptsize (Ignore any Cgd Y)} \]

Now compute the total resistance at mode X:
\[ R_x = \frac{1}{g_m} \parallel \frac{1}{g_d} \parallel \frac{1}{g_{d_M}} = \frac{1}{g_m} \]

Due to M3, due to M2, due to M1.

Therefore, the pole at mode X is located at:
\[ \omega_x = \frac{g_m}{2C_{gs} + \left( 1 + \frac{g_m}{2g_d} \right) C} \]

To derive this replace M1 & M2 by the following circuit:

\[ \frac{1}{g_m} \parallel \frac{2C_{gs} + \left( 1 + \frac{g_m}{2g_d} \right) C}{g_{M1} g_{M2}} \]
Now simplify to the output stage

\[ \Delta V_x \quad \Delta V \]

Location of the pole at the output stage

- Output impedance \( V_{out} \)
  \[ R_{out} = \frac{V}{g_d} \parallel \frac{V}{g_d} = \frac{2V}{g_d} \]

- \( \omega_{out} \approx \frac{g_d}{2(c+c_L)} \)

Calculate the location of zero

At zero (by definition) the output signal = 0 occurs when the signal cancel each other at the output node.

Or

\[ -g_m V_x - g_m V_{im} - \Delta C V_x = 0 \]

\[ \text{current through } M_4 \]
\[ \text{current through } M_2 \]
\[ \text{current through } C \]

Use the relation between \( V_x \) and \( \Delta V \) and remember \( V_{im} = \Delta V \)

\[ \frac{g_m}{1+\frac{s}{\omega_m}} \Delta V + g_m \Delta V - \Delta C \Delta V = 0 \quad \text{compare} \quad (1 - \frac{s}{\omega_z}) \]

\[ \Rightarrow \text{location of zero} \quad s_z = \frac{-2g_m}{g/\omega_m - C} \quad \omega_z = \frac{2g_m}{g/\omega_m - C} \]

\[ \Rightarrow -\frac{2g_m}{C} \quad \text{zemin} \quad \text{RHS} \quad \text{verify} \parallel \]

RHS

The complete open loop transfer function is given by

\[ T(s) = \frac{-g_m}{2g_d} \frac{(1+\frac{s}{\omega_z})}{(1+\frac{s}{\omega_m})(1+\frac{s}{\omega_{out}})} \]

dc gain
How to draw Bode plot.

For the problem 1, the poles \( \omega_m \) & \( \omega_out \) are close to each other and zero \( \omega_z \) is far away. (Verify!!)

To hand calculate Bode plot, first draw magnitude and phase plot for each pole & zero independently.

Add all the response together.

Zero is located far away and does not affect the Bode-plot.
* First find the dc gain (ignore all capacitances) and calculate the small signal gain.

* Identify point of symmetry ($V_s$).

* No pole at the input node, because $V_{in^-}$ is an ideal voltage source.

* $V_x = \frac{g_m}{2g_d} \Delta V$ — use small signal.

and $V_{out} = -\frac{g_m}{g_d} V_x$  [M4 to a commonsource amplifier]

DC gain = $-\frac{g_m^2}{4g_d^2}$  [additionally, half decrease $V_{in+}$ by $\Delta V$.]

* Location of poles @ node $x$ and node @ output — Miller capacitance

* Total capacitance @ node $x$ = $C_{gs} + C_{gd} + (1 + \frac{g_m}{g_d})C_{gd} = C_x$

* Total resistance @ node $x$ = $\frac{1}{\frac{1}{g_d} + \frac{1}{g_d}} = \frac{2}{g_d}$

Location of the pole = $g_d/2C_x = \omega_x$

Location of the output poles = $g_d/(C_{C_L} + C_{gd})$, Miller capacitance.

* Zero due to path $I_1 + I_2 = V_x$ — zero due to path $V_{out} = 0$ and currents $I_1 + I_2 = 0$

At zero $V_{out} = 0$:

$\frac{V_x}{g_m V_x + 8C V_x} = 0$  

$\Rightarrow \frac{1}{g_m} = \frac{8C}{V_x}$

Final transfer function: $A(s) = -\frac{g_m}{g_d} \frac{1}{1 - \frac{8Cg_m}{V_x}}$