First identify all mirrors and then bias current flowing through each transistor:

→ Q1, Q2, Q3 are mirrors with current = I_b

→ Q14, Q7, Q6 are mirrors with current = I_b

→ Q10, Q11, Q12, Q13 is a cascaded mirror with bias current = I_b/2

Simplify by replacing mirrors by equivalent current sources or sinks.

Identify point of symmetry (Vs) and split the input stage.

Vs is constant for a differential input change.
Now trace the path of the current.

1) If $V_{in^+}$ increases by $\Delta V$ then the current through Q4 increases by $g_m \Delta V$.

Now the drain of Q4 is connected to source of Q8, therefore the voltage of node A will decrease (remember current through Q4 will pull the voltage at node A down).

Question: By how much?

→ Now Q4 requires extra current = $g_m \Delta V$

If the current through Q8 decreases by $g_m \Delta V$, then Q4 can steal this current from $I_1$.

→ How much does the source voltage have to decrease to decrease the current through Q8 by $g_m \Delta V$?

$$g_m \Delta V_A = g_m \Delta V$$

$$\Delta V_A \approx -\Delta V$$

Change in $V_A$ is approximately the same as $V_{in^+}$.

Similarly, the voltage at node B decreases by the same amount as $\Delta V$. 
Therefore, at the output mode, $V_{out}$, the equivalent circuit is given by:

\[ \Delta V_{out} = (r_1 \parallel r_2) \cdot 2g_{m}AV \]

Key is to find the values of $r_1$ and $r_2$. 

\[ r_2 \text{ is due cascaded stage } Q11 \& Q13. \]

Therefore \[ r_2 = g_m r_{ds} \] [See previous lecture examples].

To calculate draw back the path from \( V_{out} \)

\[ \text{(Transistor numbers are important).} \]

To calculate \( r_4 \) we keep \( V_{in} \) fixed and write small signal equations for \( Q5, Q6, Q9. \)

\[ Q5: \quad \Delta I_1 = g_d \Delta V_s \quad -(i) \]
\[ Q6: \quad \Delta I_2 = -g_d \Delta V_s \quad -(i\!i) \]
\[ Q9: \quad \Delta I_{out} = g_m \Delta V_s - g_d \Delta V_{out} \quad -(i\!i\!i) \]

\[ \Delta I_2 - \Delta I_1 = \Delta I_{out} - (iv) \quad \text{current conservation @ node } V_s. \]

\[ \Rightarrow \Delta V_s = \frac{\Delta I_{out}}{2g_d} \quad \text{(from (iv) \& (i) \& (ii))} \]

Substituting \( Q9. \)

\[ \Delta I_{out} = \frac{g_m}{2g_d} \Delta I_{out} - g_d \Delta V_{out} \]

or \[ r_1 = \frac{\Delta V_{out}}{\Delta I_{out}} = \frac{g_m}{2g_d^2} \]
Therefore gain using \( r_1 = \frac{g_m}{2g_d} \) and \( r_2 = \frac{g_m}{2g_d} \):

\[
\Delta V_{\text{out}} = \left( \frac{g_m}{g_d} \right) \left( \frac{g_m}{2g_d} \right) 2g_m \Delta V
\]

or

\[
\frac{\Delta V_{\text{out}}}{2\Delta V} = \frac{g_m}{3g_d}
\]

2\( \Delta V \) because the input voltage swing \((V_{\text{in}}^+ - V_{\text{in}}^-)\) to 2\( \Delta V \).

\[
\text{Gain} = \frac{g_m}{3g_d}
\]

Input voltage swing

\[
V_{\text{dd}} - V_{\text{eff6}} - V_{\text{th}} \geq V_{\text{in}}^+ \geq V_{\text{eff3}} + V_{\text{eff5}} + V_{\text{th}}
\]

[Remember \( V_{gs} = V_{\text{eff}} + V_{\text{th}} \)]

Output voltage swing

\[
V_{\text{dd}} - V_{\text{eff6}} - V_{\text{eff9}} \geq V_{\text{out}} \geq V_{\text{b}} - V_{\text{th}}
\]

Power dissipation

\[
P_d = 4V_{\text{dd}}I_b
\]