ECE 523/421 – Analog Electronics

Lecture 12: Differential Amplifiers: Small Signal Operation

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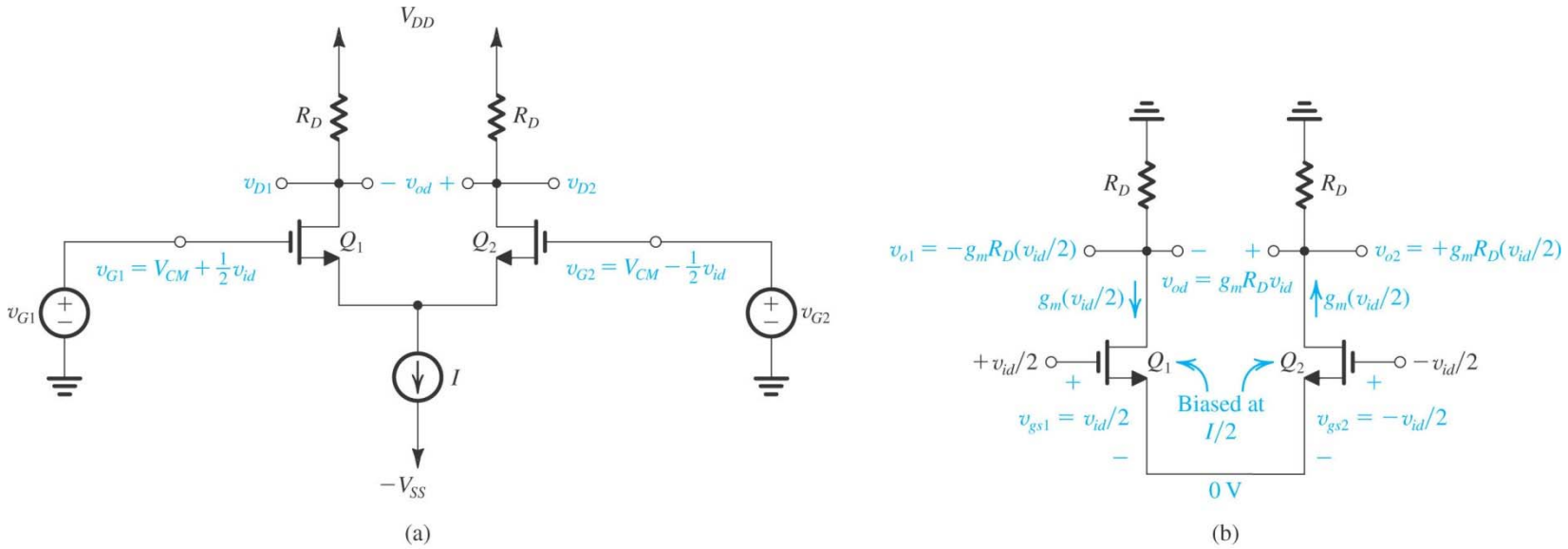
Review of Last Lecture

- **MOS Differential Amplifier**
- **Common Mode Input**
- **Differential Model Input**
- **Large Signal Operation**

Today's Lecture

- **MOS Small Signal Differential Amplifier**
- **Half-Circuit Differential Mode**
- **Half-Circuit Common Mode**
- **Active Load Differential Amplifier**
- **CMRR**

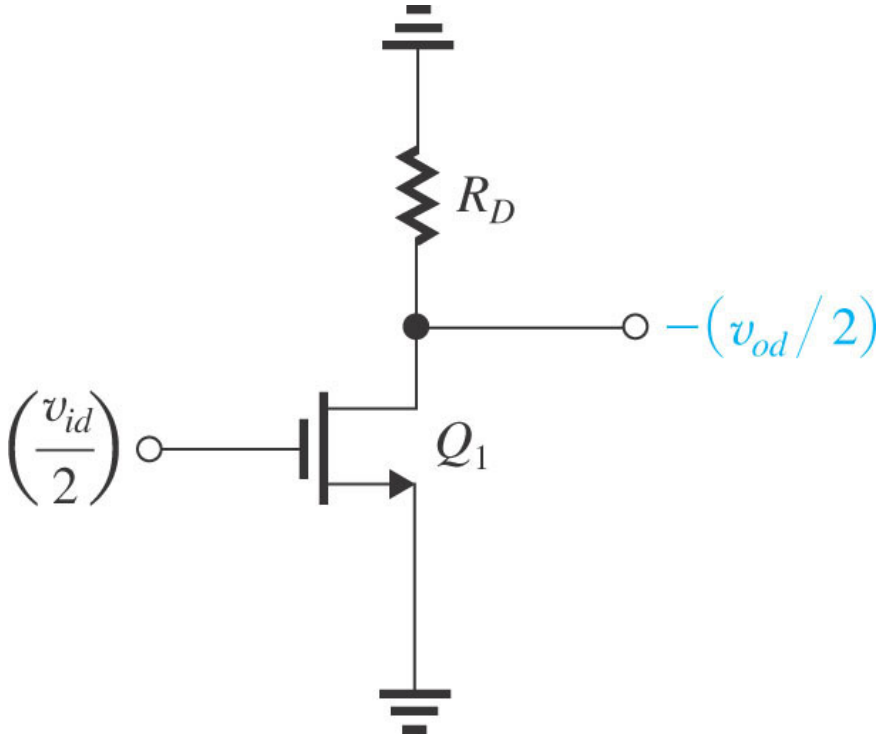
MOS Differential Gain



$$g_m = \frac{2I_D}{V_{OV}} = \frac{I}{V_{OV}}$$

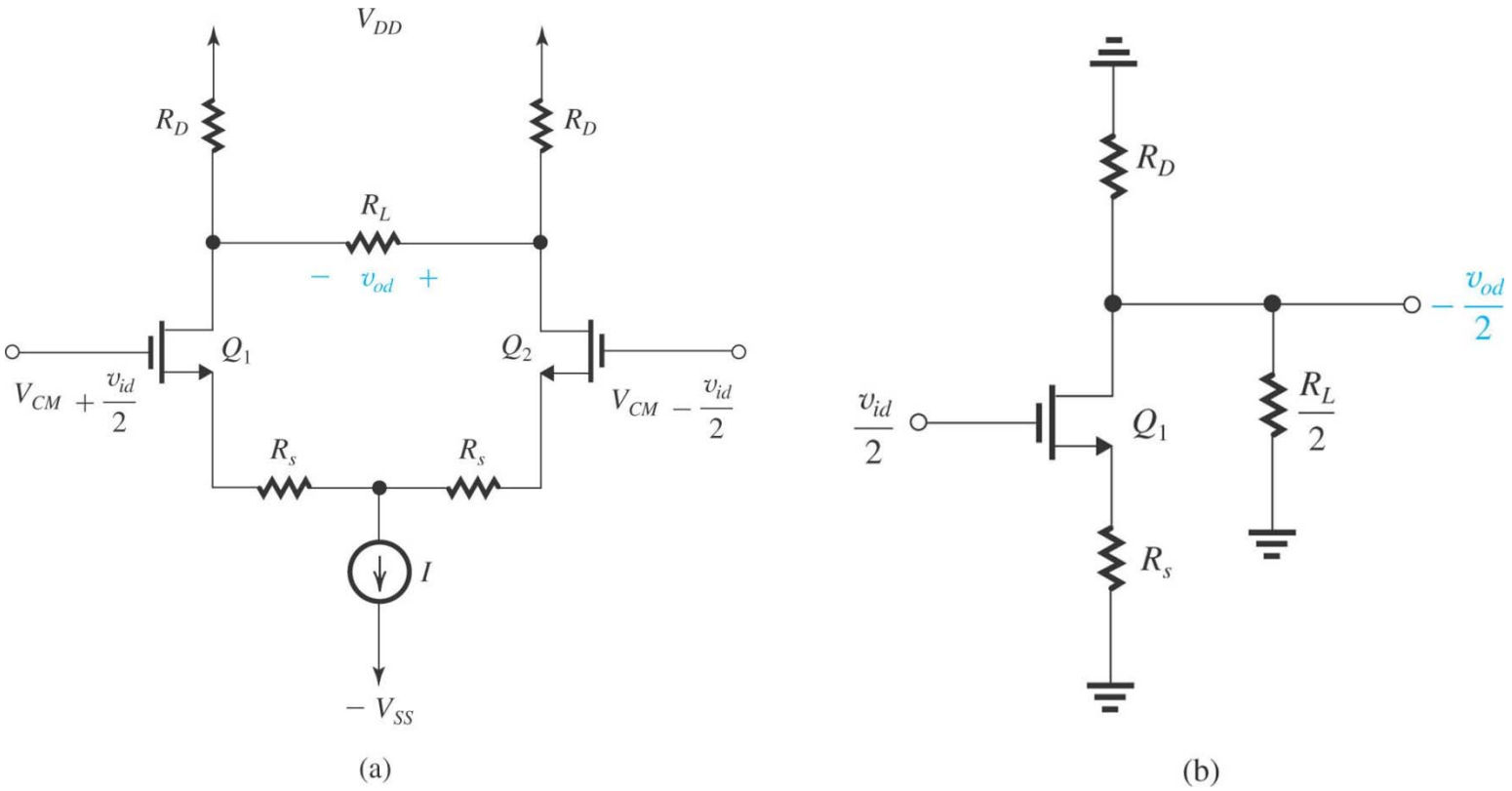
$$A_d = \frac{v_{od}}{v_{id}} = g_m R_D$$

Differential Half-Circuit



$$A_d = \frac{v_{od}}{v_{id}} = g_m\left(R_D \| r_o\right)$$

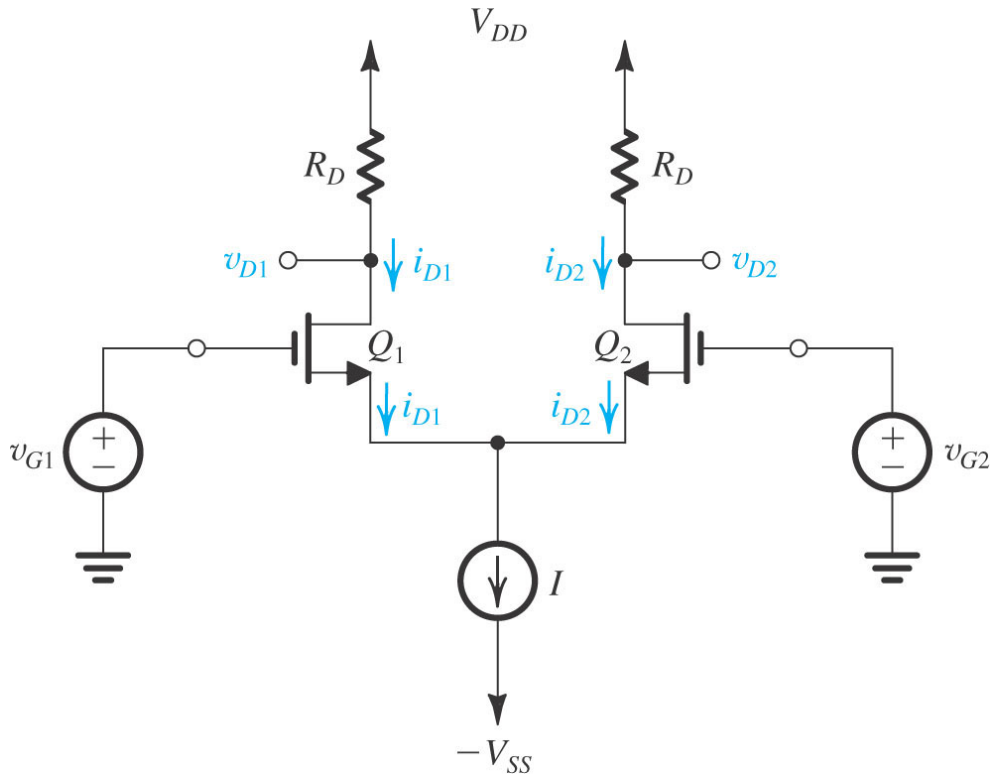
Example: Differential Half-Circuit



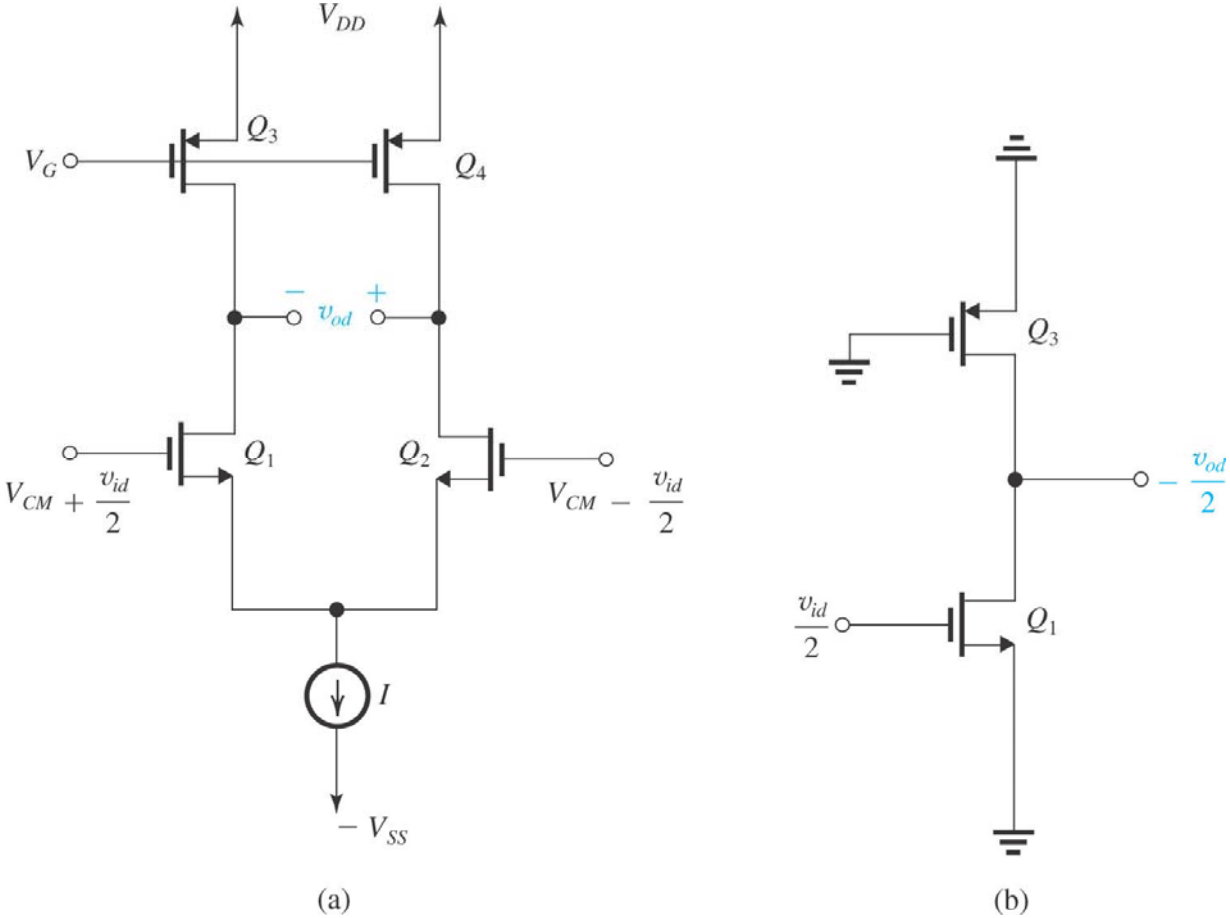
$$A_d = \frac{v_{od}}{v_{id}} = \frac{R_D \| (R_L/2)}{1/g_m + R_S}$$

Example: MOS Differential Amplifier

1) Let I=0.8mA, (W/L)=100, K'_n=0.2mA/V^2, V_A=20V, R_D=5KΩ. Find V_{OV}, g_m, r_o, and A_d.



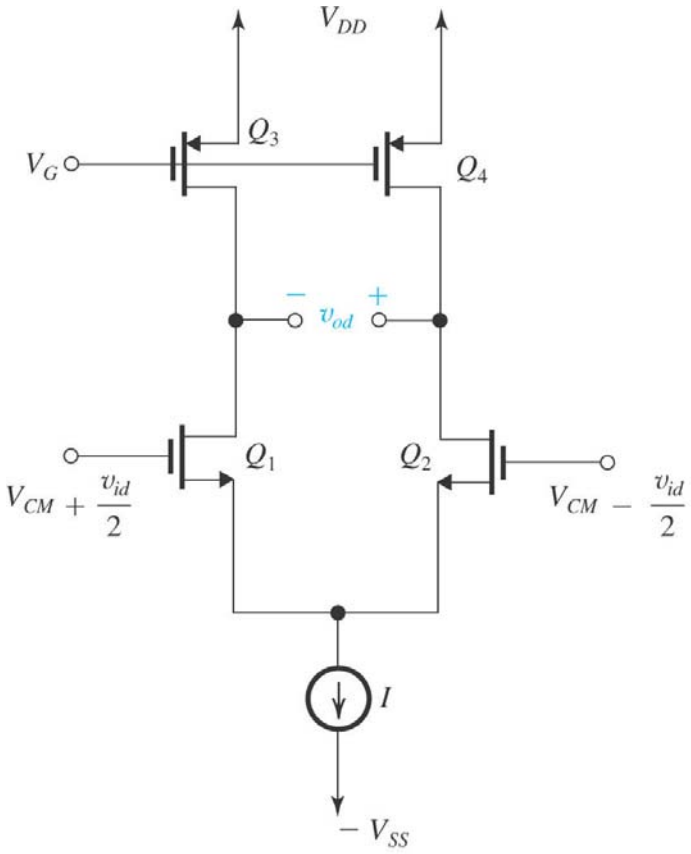
Differential Amplifier with Active Load



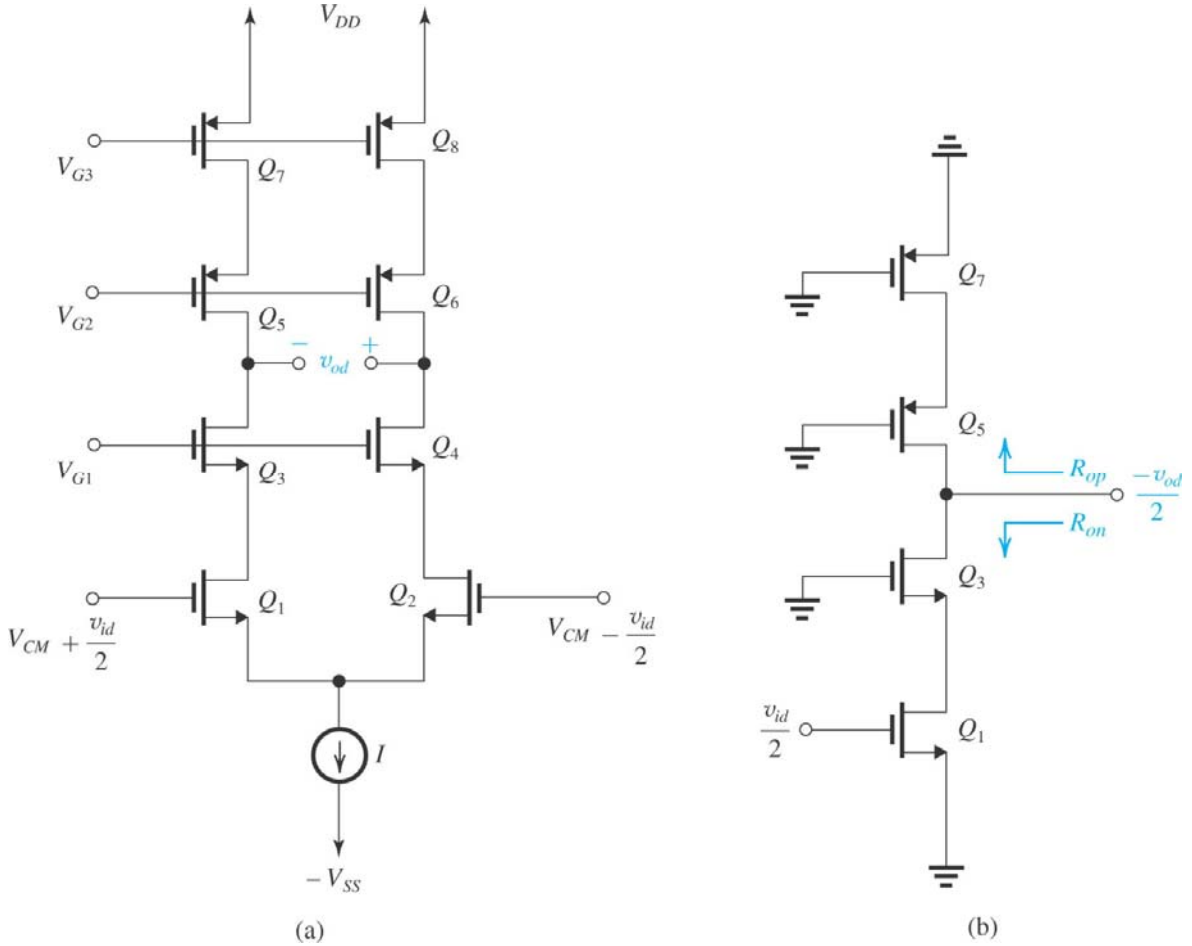
$$A_d = \frac{v_{od}}{v_{id}} = g_m\left(r_{o1} \| r_{o3}\right)$$

Example: MOS Differential Amplifier

1) Let K'_n=400uA/V^2, K'_p=100uA/V^2, $|V_t|$=0.5, $|V'_A|$=10V/um, I=200uA, L=0.36um, $|V_{OV}|$=0.2V find (W/L) and A_d.



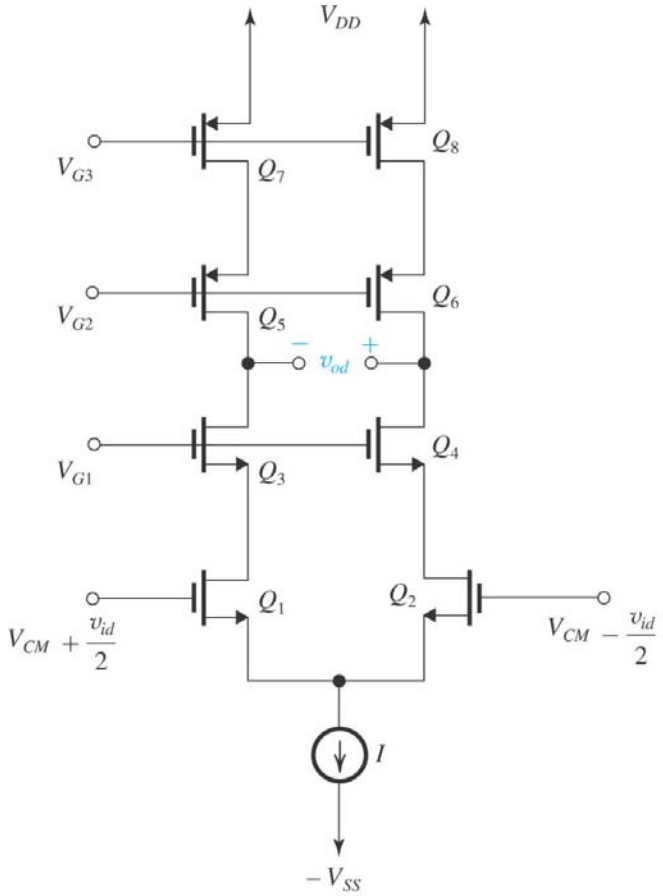
Cascode Differential Amplifier



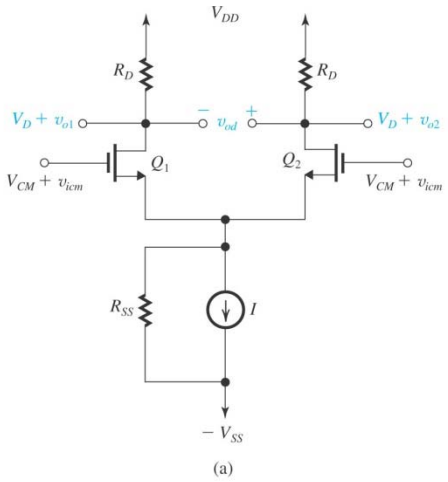
$$A_d = \frac{v_{od}}{v_{id}} = g_{m1}\left(R_{on} \| R_{op}\right) \qquad R_{on} = \left(g_{m3} r_{o3}\right) r_{o1} \qquad R_{op} = \left(g_{m5} r_{o5}\right) r_{o7}$$

Example: MOS Differential Amplifier

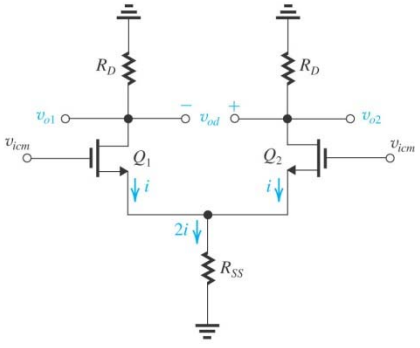
1) Let K'_n=400uA/V^2, K'_p=100uA/V^2, $|V_t|$=0.5, $|V'_A|$=10V/um, I=200uA, L=0.36um, $|V_{OV}|$=0.2V find (W/L) and A_d.



Common Mode Gain



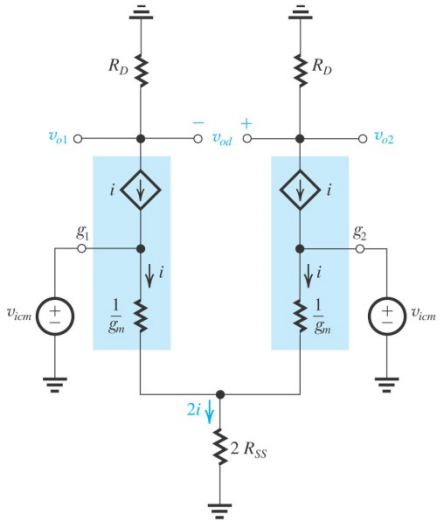
(a)



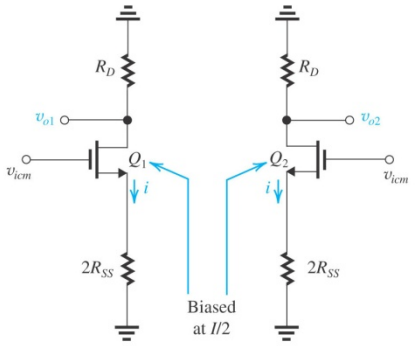
(b)

$$\frac{v_{o1}}{v_{icm}} = \frac{v_{o2}}{v_{icm}} = -\frac{R_D}{1/g_m + 2R_{SS}}$$

$$v_{od} = 0$$



(c)



(d)

**** Assuming differential output***

R_D Mismatch and Common Mode Gain

Ideal Case

$$\begin{cases} \dfrac{v_{o1}}{v_{icm}} = \dfrac{v_{o2}}{v_{icm}} = -\dfrac{R_D}{1/g_m + 2R_{SS}} \\ v_{od} = 0 \end{cases}$$

R_D Mismatch Case

$$A_{cm} = \frac{v_{od}}{v_{icm}} = -\frac{R_D}{1/g_m + 2R_{SS}}\left(\frac{\Delta R_D}{R_D}\right)$$

**** Assuming differential output***

g_m Mismatch and Common Mode Gain

Ideal Case

$$\begin{cases} \dfrac{v_{o1}}{v_{icm}} = \dfrac{v_{o2}}{v_{icm}} = -\dfrac{R_D}{1/g_m + 2R_{SS}} \\ v_{od} = 0 \end{cases}$$

g_m Mismatch Case

$$A_{cm} = \frac{v_{od}}{v_{icm}} = -\frac{R_D}{1/g_m + 2R_{SS}}\left(\frac{\Delta g_m}{g_m}\right)$$

**** Assuming differential output***

Common Mode Rejection Ration

$$CMRR = \frac{|A_d|}{|A_{cm}|} \qquad CMRR(dB) = 20\log\left(\frac{|A_d|}{|A_{cm}|}\right)$$

Examples:

R_D Mismatch Case

$$CMRR = \frac{1 + 2g_m R_{SS}}{(\Delta R_D / R_D)}$$

g_m Mismatch Case

$$CMRR = \frac{1 + 2g_m R_{SS}}{(\Delta g_m / g_m)}$$

**** Assuming differential output***