ECE 523/421 – Analog Electronics

Lecture 15: Differential Amplifiers: With Active Loads

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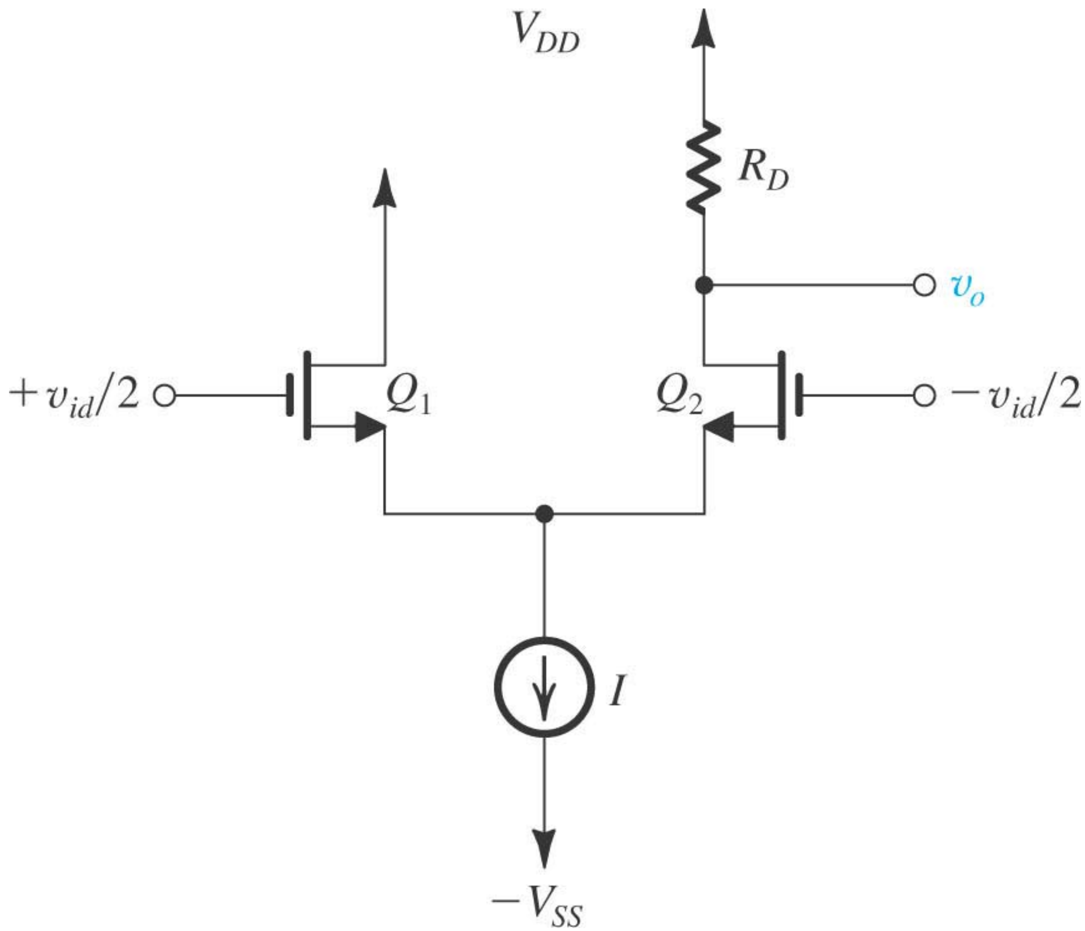
Review of Last Lecture

- Offset in MOS Differential Amplifier
- Offset in BJT Differential Amplifier

Today's Lecture

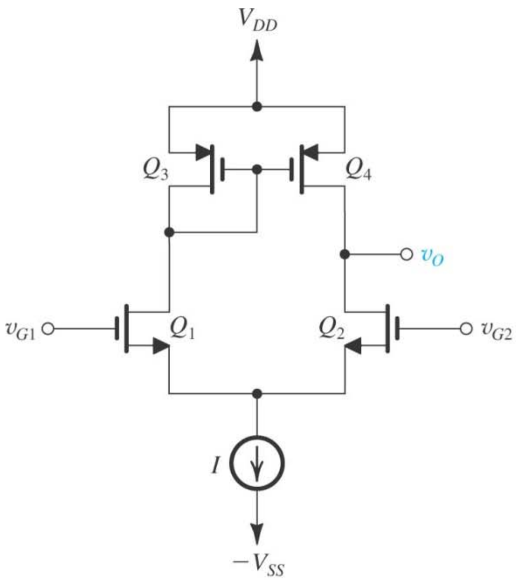
- Differential Gain of Active-Loaded MOS Pair
- Common Gain of Active-Loaded MOS Pair
- CMRR of Active-Loaded MOS Pair
- Differential Gain of Active-Loaded BJT Pair
- Common Gain of Active-Loaded BJT Pair
- CMRR of Active-Loaded BJT Pair
- Examples: Multistage Differential Amplifier

Basic Differential to Single-Ended Conversion

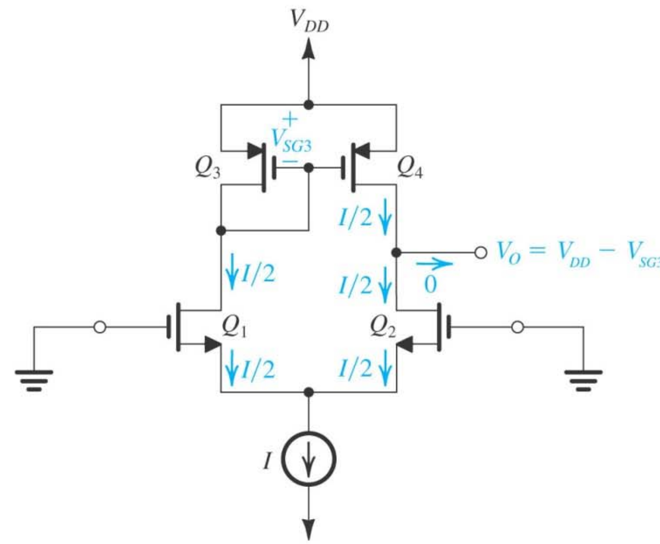


Drain current signal on Q1 is wasted!

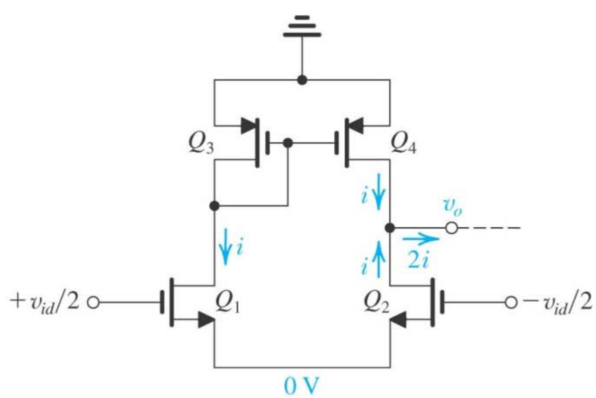
Active-Loaded MOS Diff-Amp



(a)

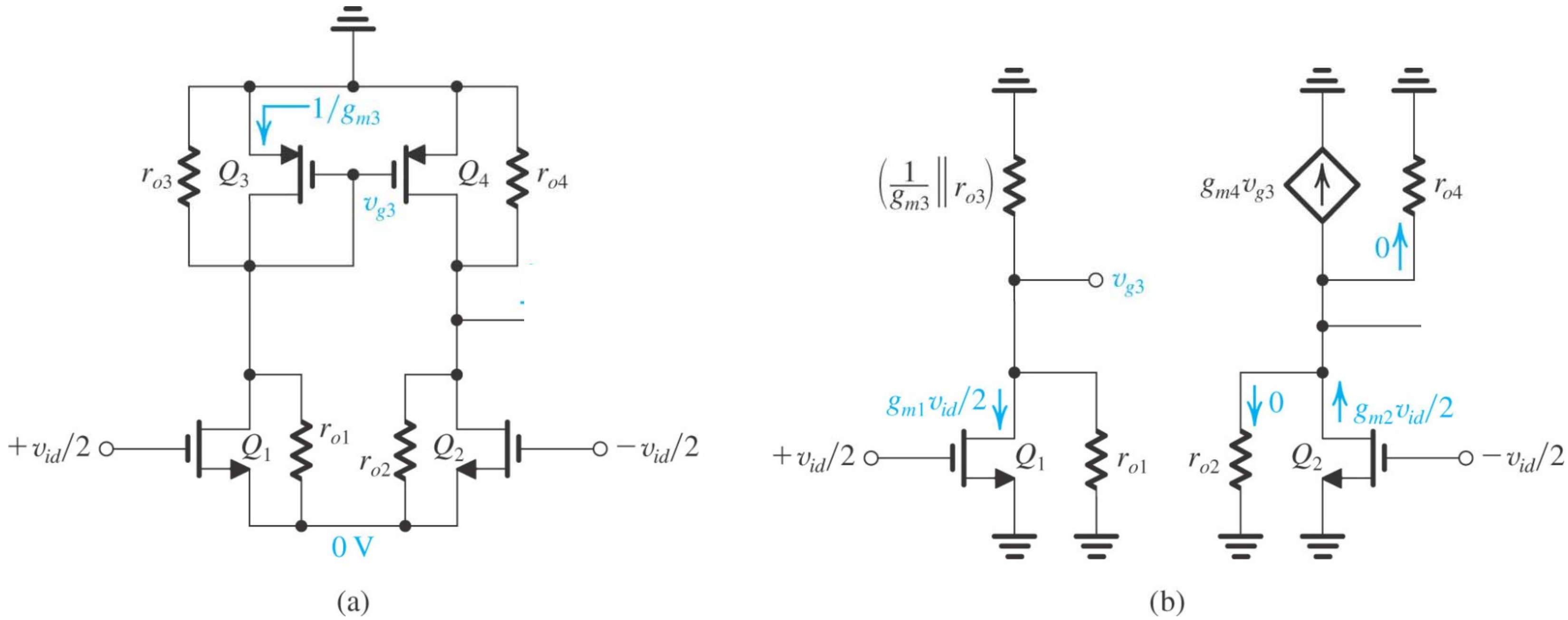


(b)



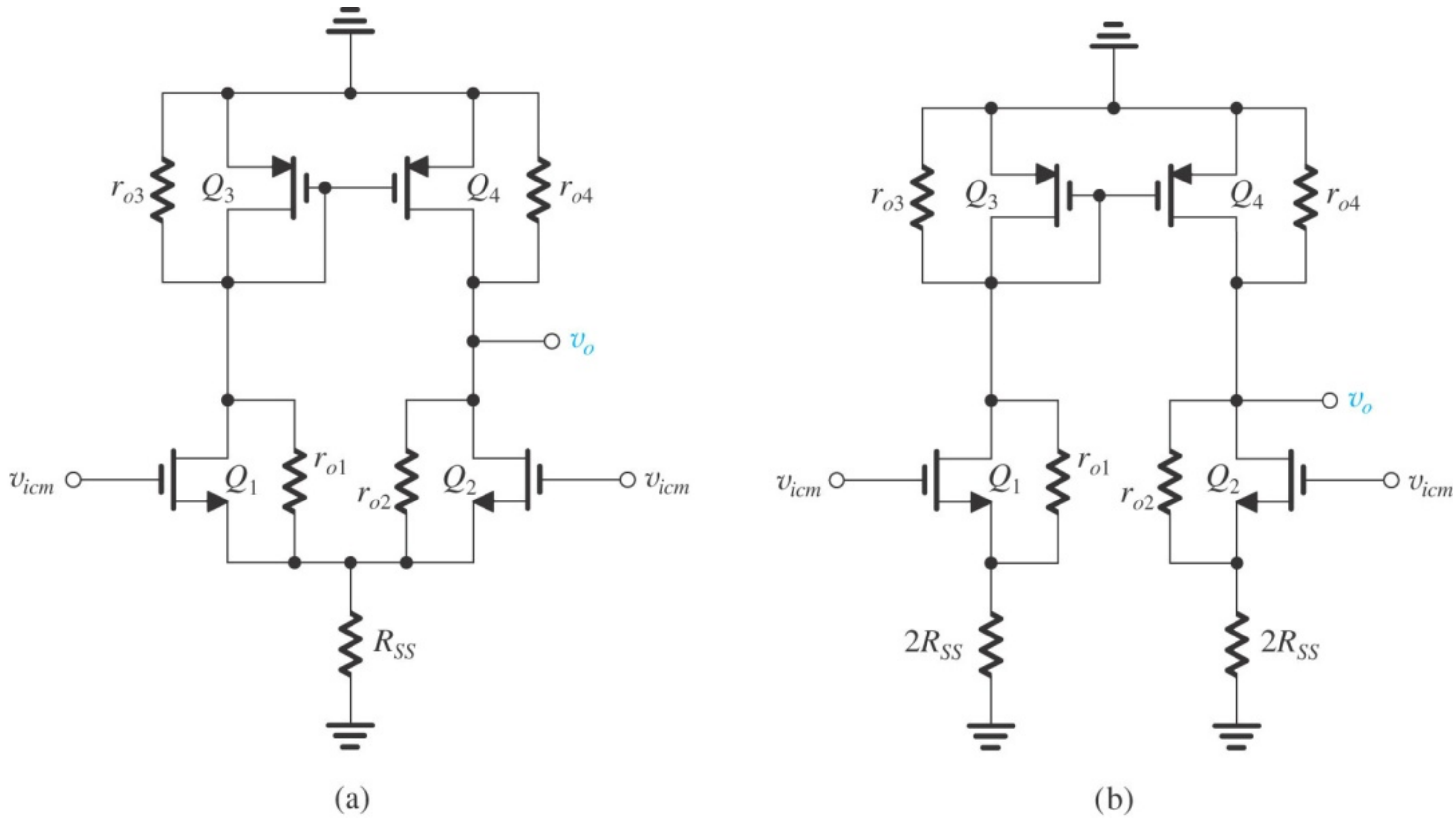
(c)

Differential Gain of Active-Load MOS Pair



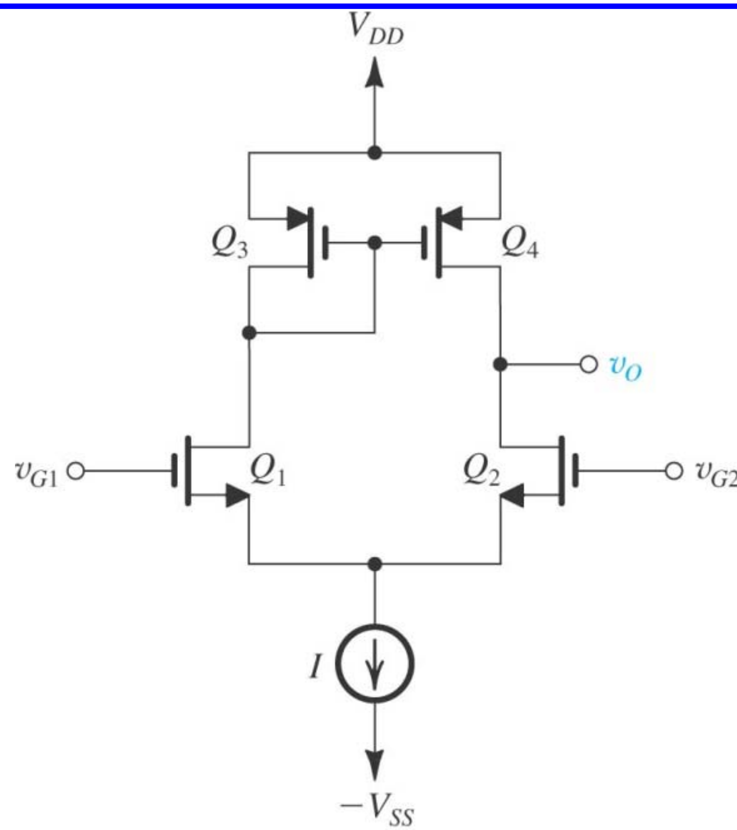
$$A_d = \frac{v_o}{v_{id}} \approx \left(\frac{g_{m2}}{2} + \frac{g_{m1}}{2}\frac{g_{m4}}{g_{m3}} \right)\left(r_{o2} \| r_{o4}\right) \approx g_m \left(r_{o2} \| r_{o4}\right)$$

Common Gain of Active-Load MOS Pair



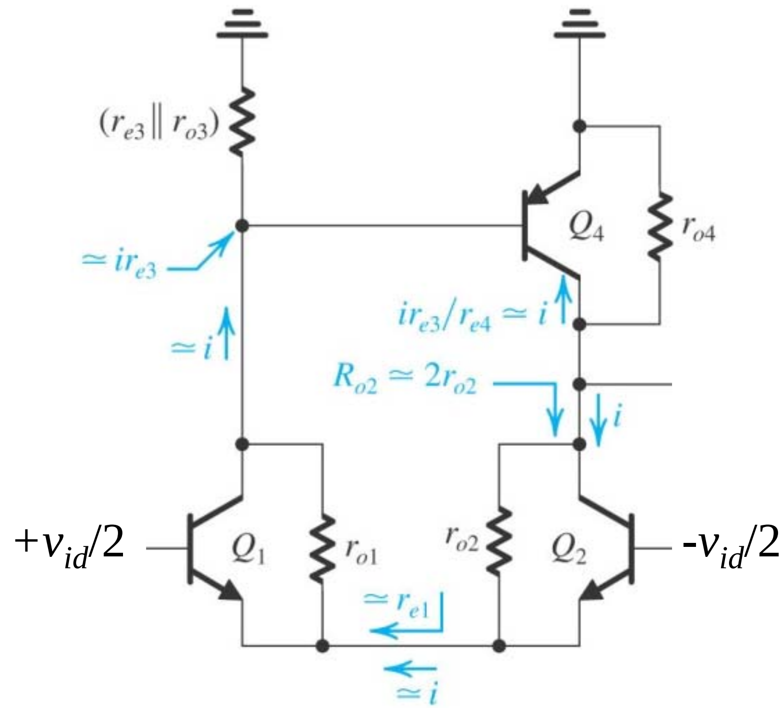
$$A_{cm} = \frac{v_o}{v_{icm}} \approx \left(\frac{1}{2R_{SS}} \left(\frac{1}{g_{m3}} \| r_{o3} \right) g_{m4} - \frac{1}{2R_{SS}} \right) r_{o4} \approx \frac{-1}{2 g_{m3} R_{SS}}$$

CMRR of Active-Load MOS Pair



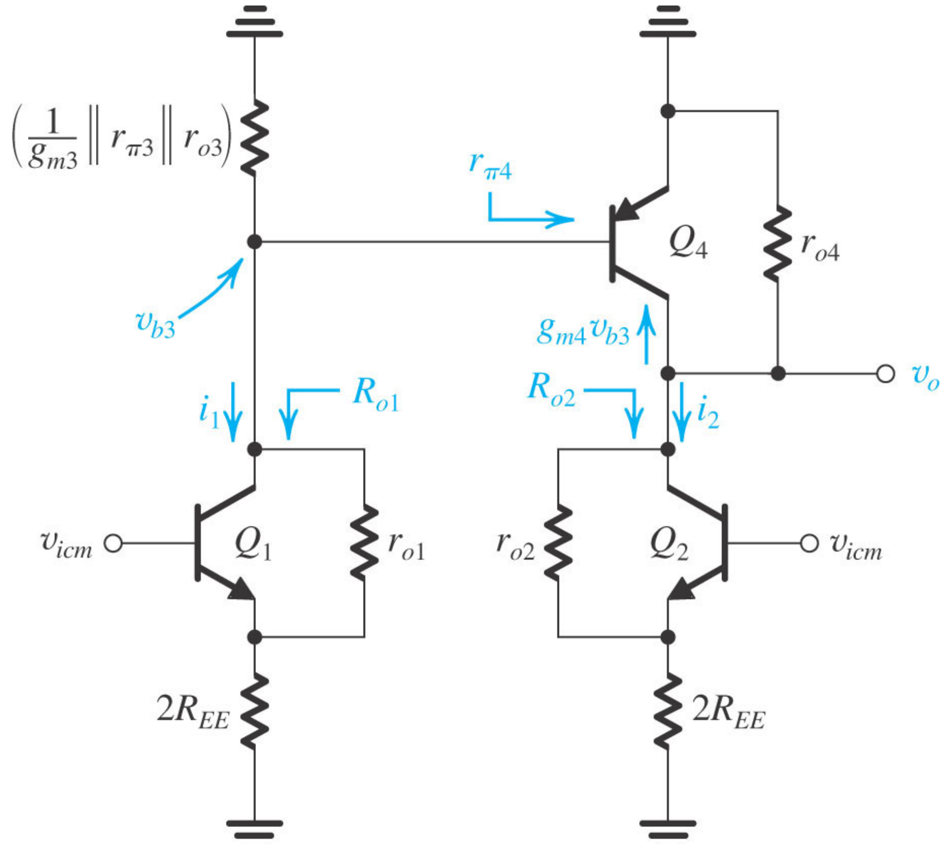
$$CMRR = \frac{A_d}{A_{cm}} \approx (g_m r_o)(g_m R_{SS})$$

Differential Gain of Active-Load BJT Pair



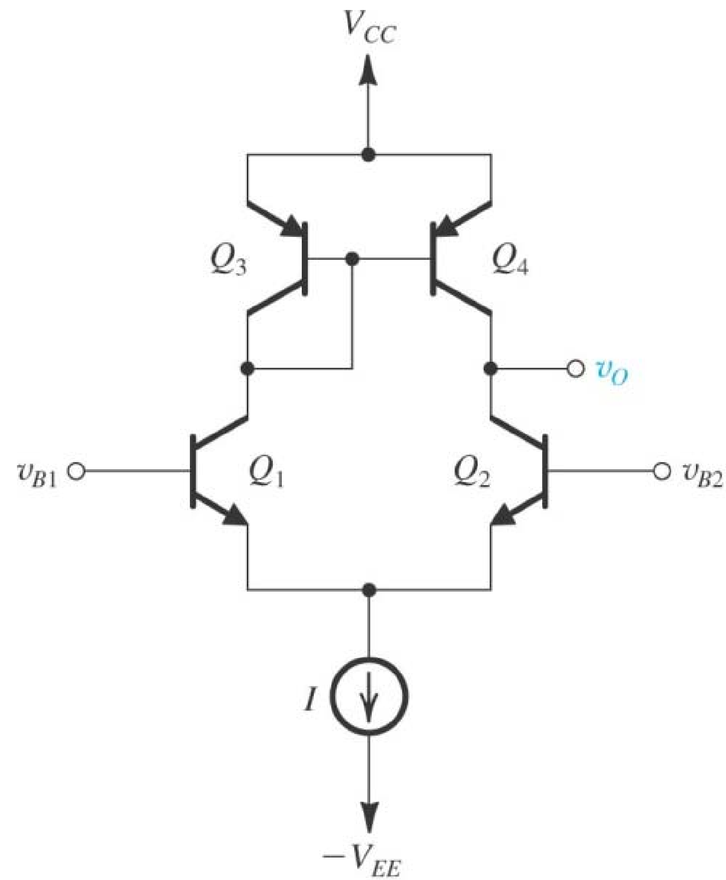
$$A_d = \frac{v_o}{v_{id}} \approx \left(\frac{g_{m2}}{2} + \frac{g_{m1}}{2} \frac{g_{m4}}{g_{m3}} \right) \left(r_{o2} \| r_{o4} \right) \approx g_m \left(r_{o2} \| r_{o4} \right)$$

Common Gain of Active-Load BJT Pair



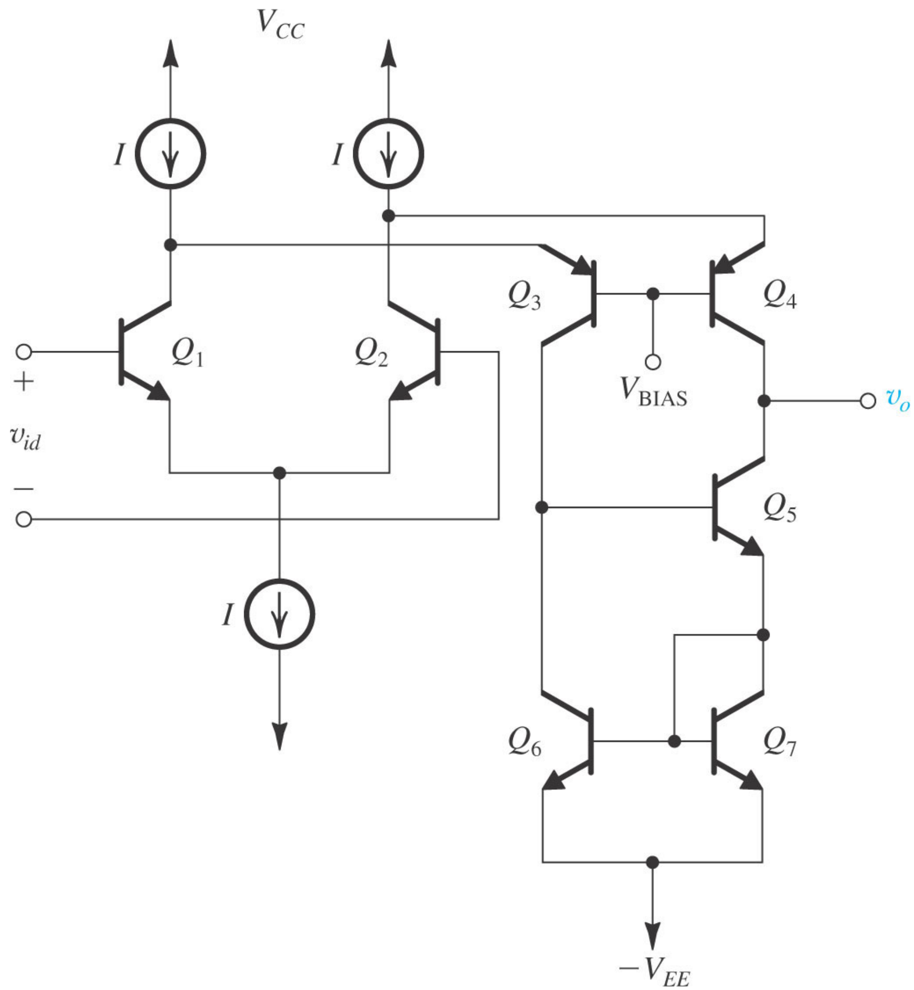
$$A_{cm} = \frac{v_o}{v_{icm}} \approx \left(\frac{1}{2R_{EE}} \left(\frac{1}{g_{m3}} \| r_{o3} \| r_{\pi 3} \| r_{\pi 4} \right) g_{m4} - \frac{1}{2R_{EE}} \right) r_{o4} \approx \frac{-r_{o4}}{\beta_3 R_{EE}}$$

CMRR of Active-Load MOS Pair



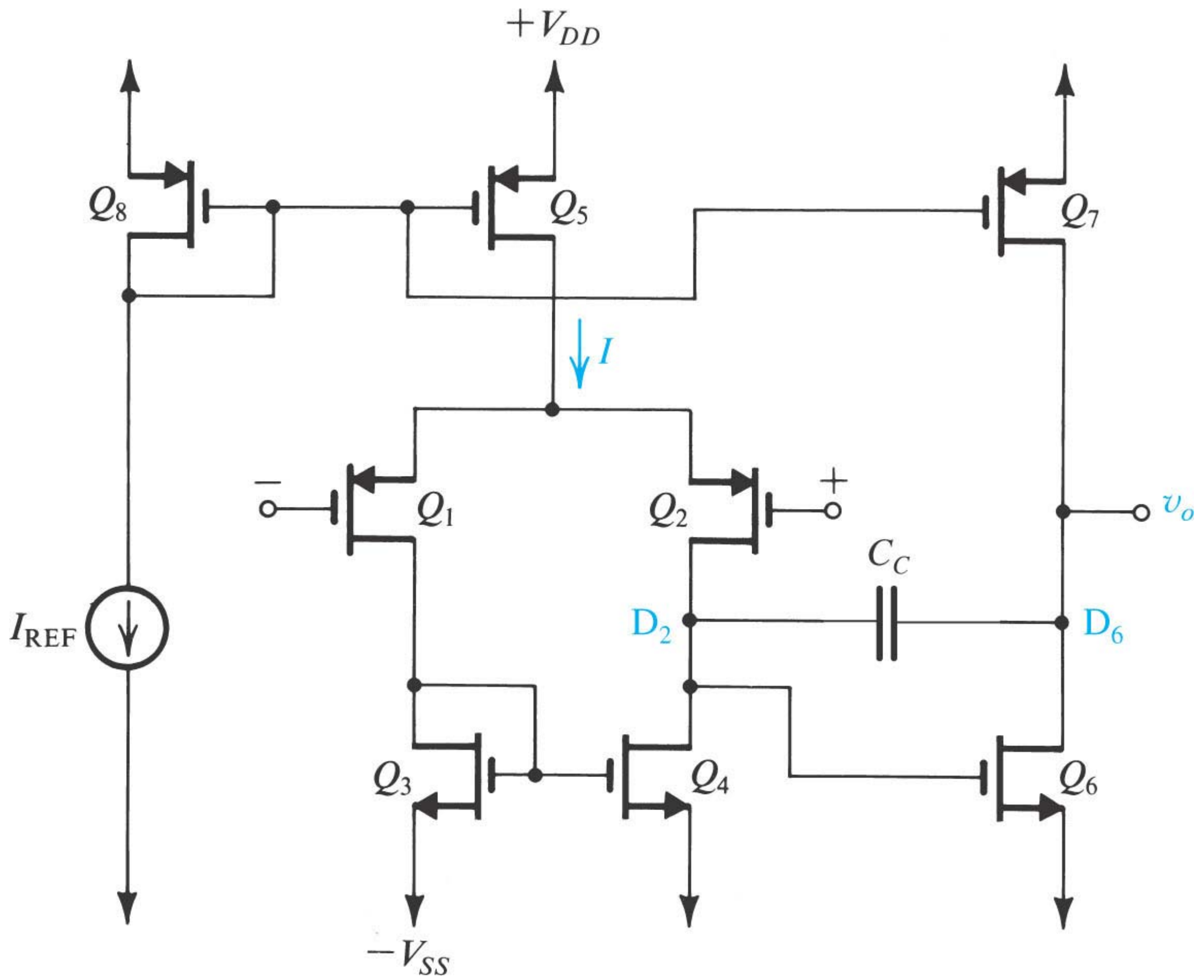
$$CMRR = \frac{A_d}{A_{cm}} \approx \frac{1}{2}\beta_3\left(g_m R_{EE}\right)$$

Example: Folded Cascode & Wilson Op Amp



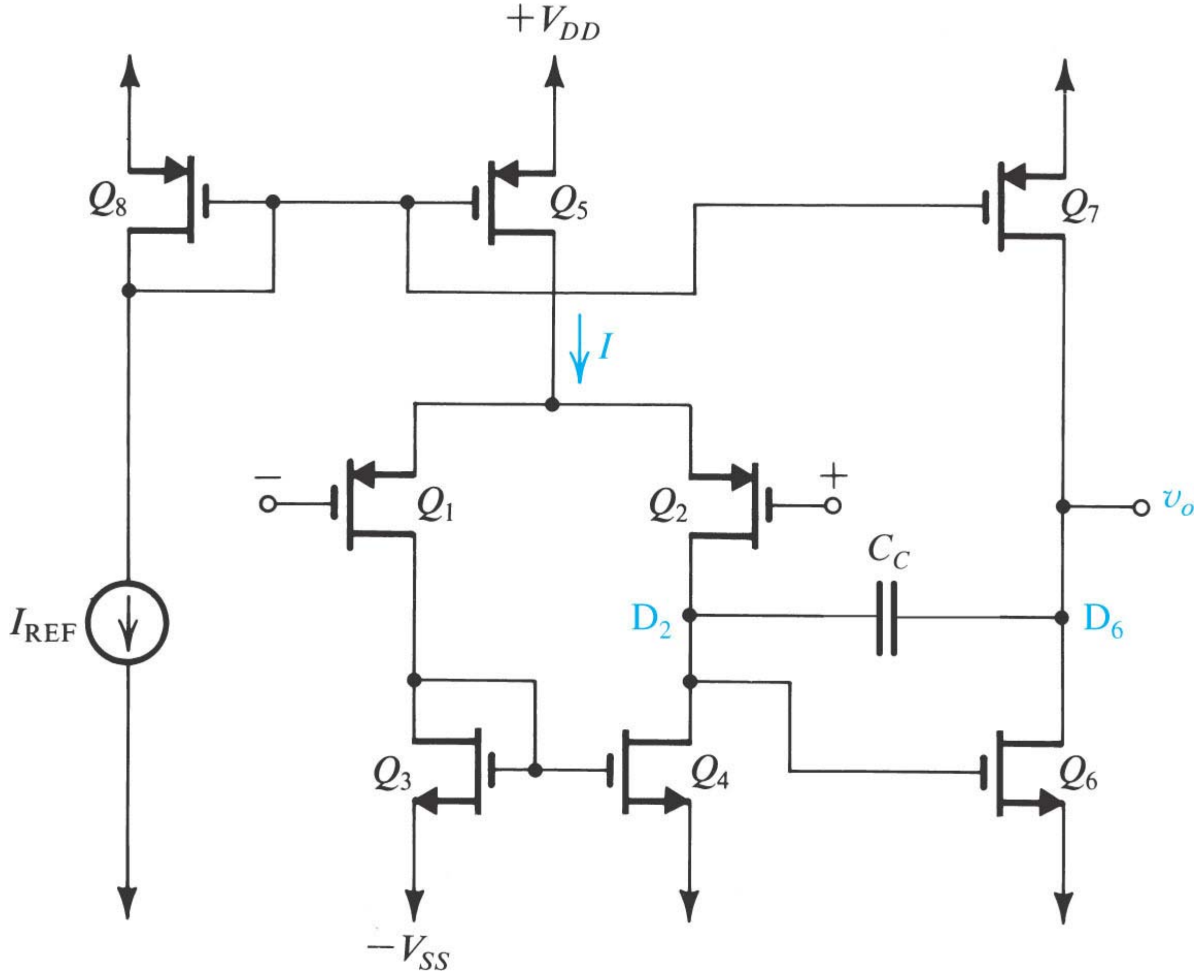
$$G = \frac{A_o}{A_{id}} \approx g_m \left(\beta_4 r_{o4} \middle\| \beta_5 \frac{r_{o5}}{2} \right)$$

Example: 2-Stage CMOS Op Amp Gain



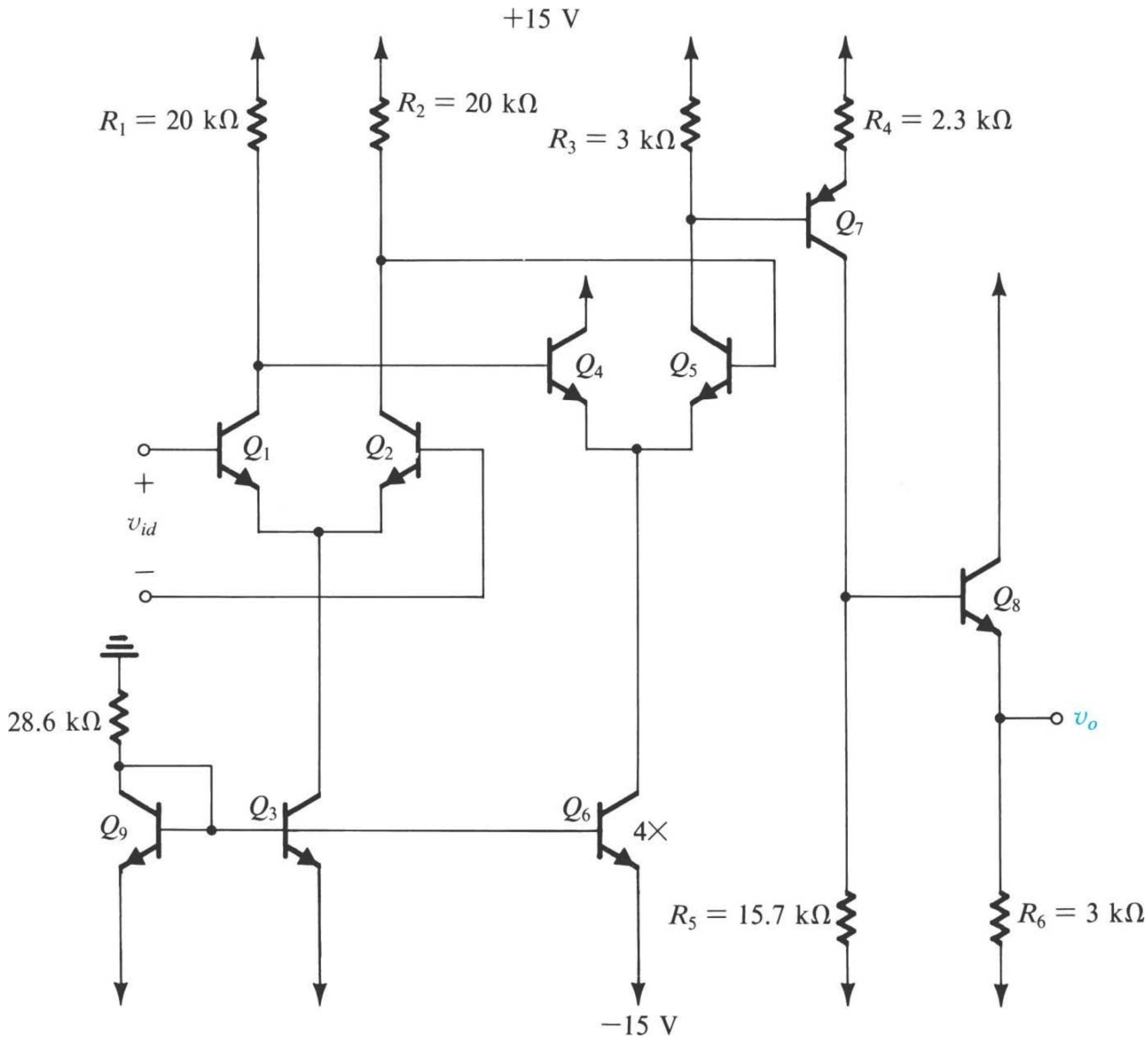
$$G = \frac{A_o}{A_{id}} \approx \left(-g_{m1}\left(r_{o2} \| r_{o4}\right)\right)\left(-g_{m6}\left(r_{o6} \| r_{o7}\right)\right)$$

Example: CMOS Op Amp Offset Cancellation

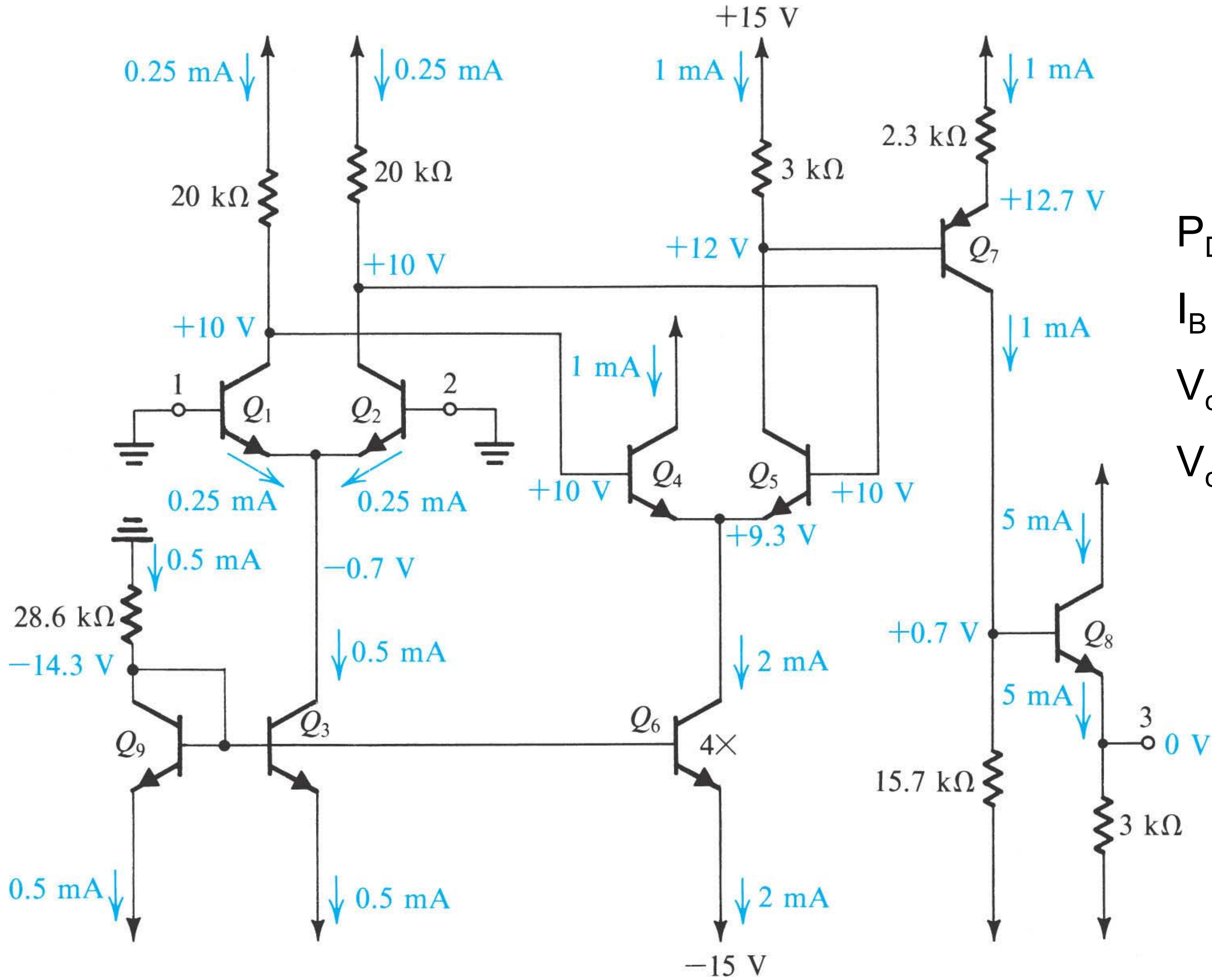


$$\frac{(W/L)_6}{(W/L)_4} = 2\frac{(W/L)_7}{(W/L)_5}$$

Example: 4-Satge BJT Op Amp



Example: 4-Satge BJT Op Amp DC Analysis



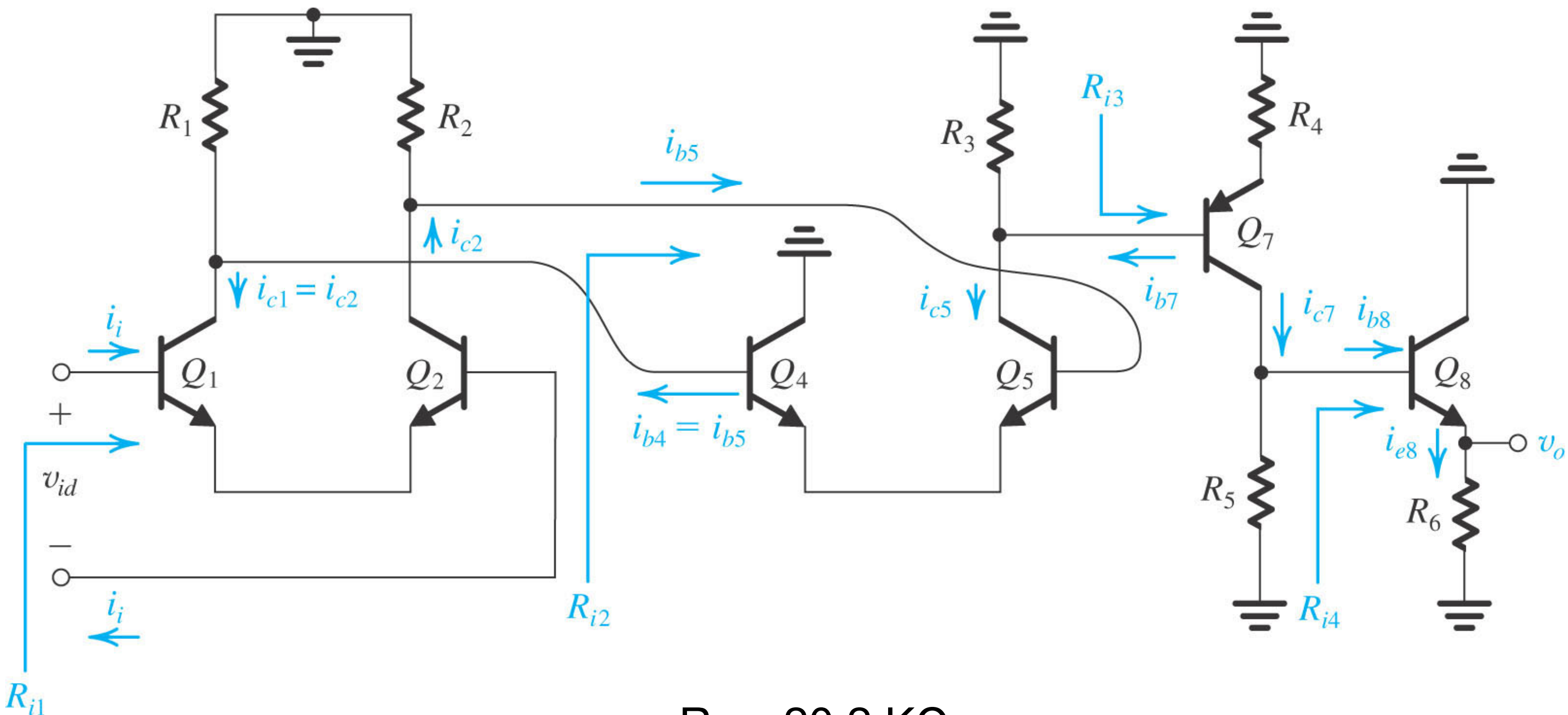
P_{DC} = 262.5 mW

I_B = 2.5 uA

V_{cm}(max) = +10.5 V

V_{cm}(min) = +14.1 V

Example: 4-Satge BJT Op Amp AC Analysis



R_{in} = 20.2 KΩ

R_{out} = 152 Ω

A_V = 8256