IIT ROORKEE

NPTEL ONLINE CERTIFICATION COURSE

Microelectronics: Devices to Circuits

MOS Differential Amplifiers

SUDEB DASGUPTA

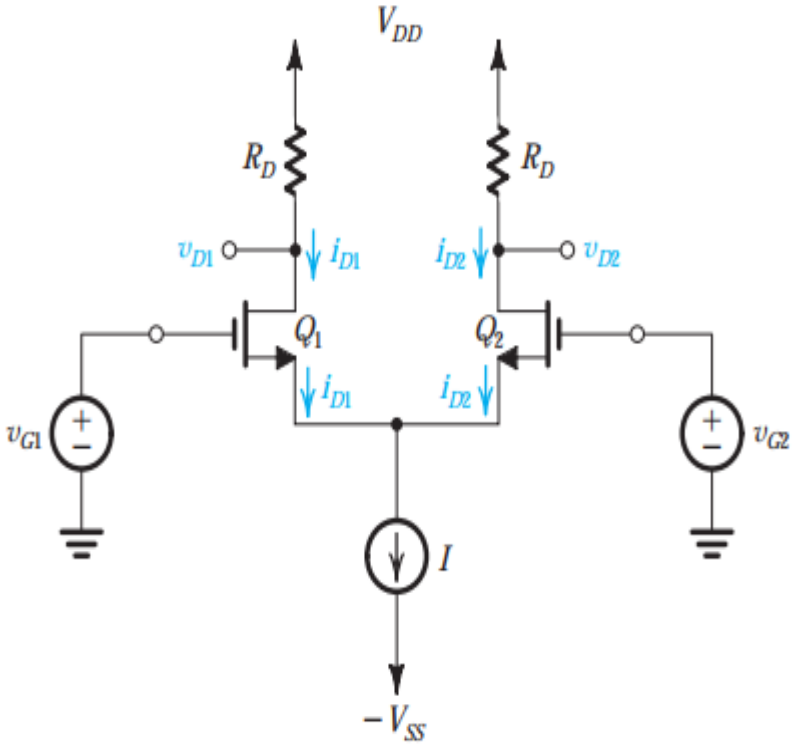
DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING



Outline

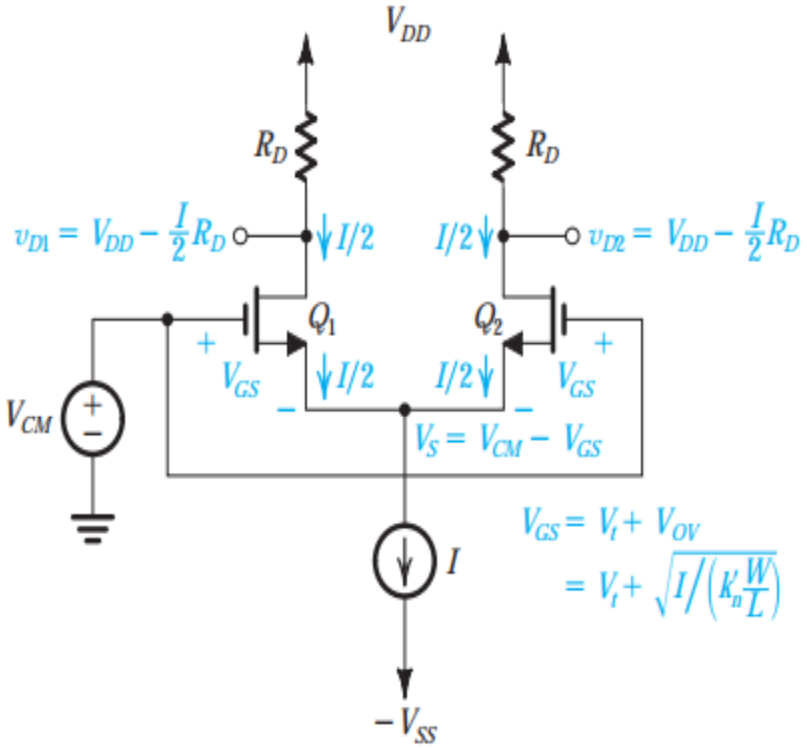
- MOS Differential Pair
- Operation with common mode input voltage
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- Differential to single ended conversion
- Active loaded MOS Differential Amplifier
- Differential Gain of the Active-Loaded MOS Pair
- Input and Output Resistance and Differential gain
- Common-mode gain and CMRR
- Recapitulation

MOS Differential Pair



Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Operation with common mode input voltage



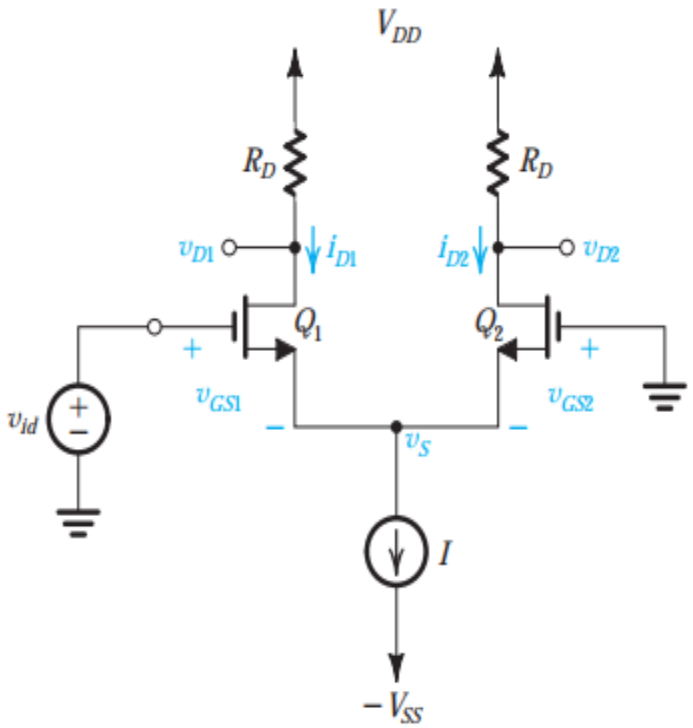
$$v_{D1} = v_{D2} = V_{DD} - \frac{I}{2}R_D$$

$$V_{CMax} = V_t + V_{DD} - \frac{I}{2}R_D$$

$$V_{CMin} = -V_{SS} + V_{CS} + V_t + V_{OV}$$

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Operation with differential input



$$I = \frac{1}{2}\left(K_n \frac{W}{L}\right)(v_{GS1} - v_t)^2$$

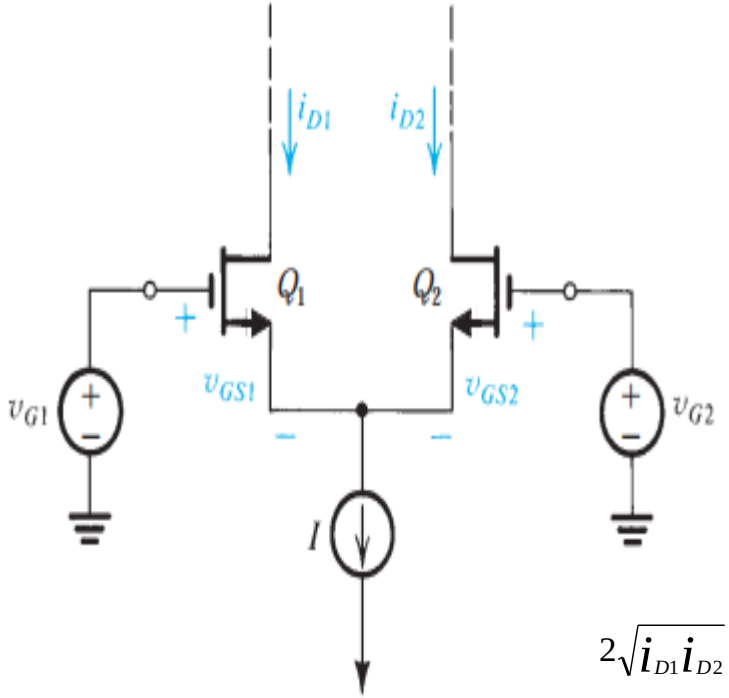
$$v_{GS1} = v_t + \sqrt{2}V_{oV}$$

$$v_{id\max} = \sqrt{2}V_{oV}$$

$$-\sqrt{2}V_{oV} \le v_{id\max} \le \sqrt{2}V_{oV}$$

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Large Signal Operation



$$I_{D1} = \frac{1}{2} K_n \frac{W}{L} (v_{GS1} - V_t)^2$$

$$I_{D2} = \frac{1}{2} K_n \frac{W}{L} (v_{GS2} - V_t)^2$$

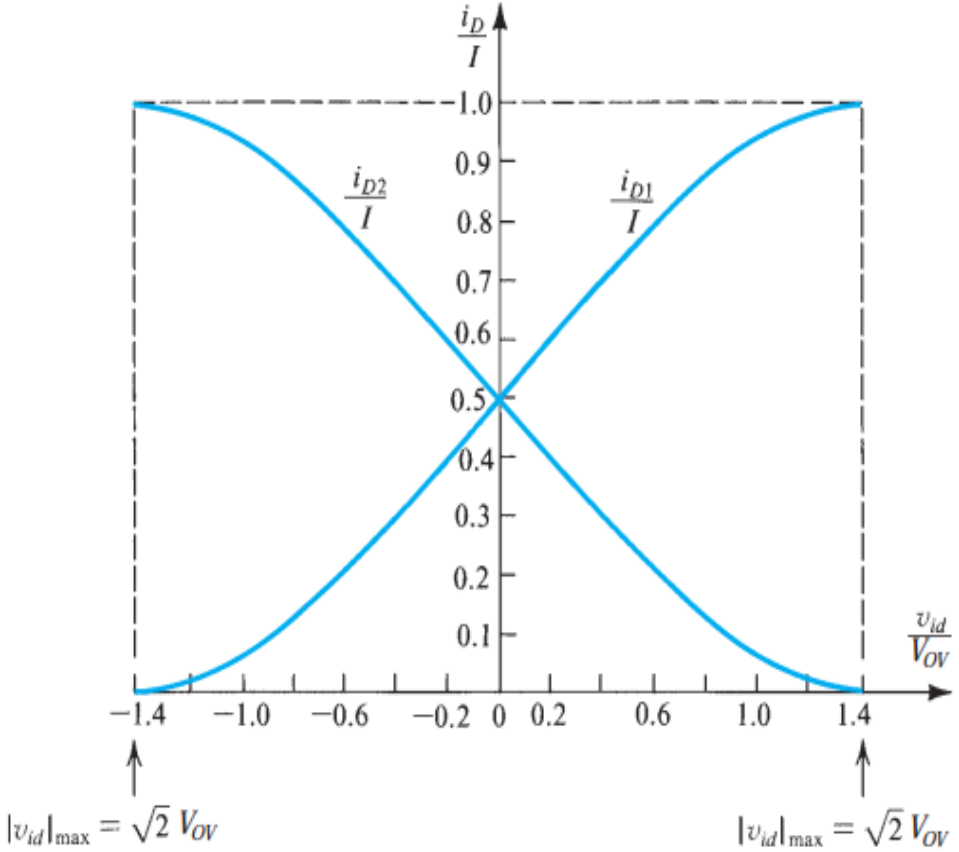
$$v_{GS1} - v_{GS2} = v_{G1} - v_{G2} = v_{id}$$

$$\sqrt{i_{D1}} - \sqrt{i_{D2}} = \sqrt{\frac{1}{2} K_n \frac{W}{L}} v_{id}$$

$$i_{D1} + i_{D2} = I$$

$$2\sqrt{i_{D1} i_{D2}} = I - \frac{1}{2} K_n \frac{W}{L} v_{id}^2$$

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

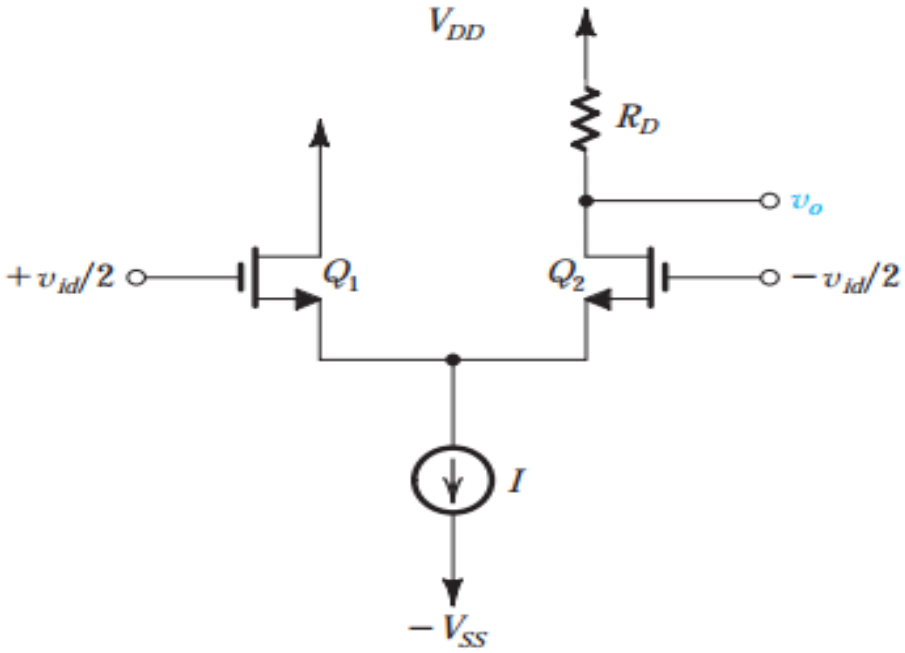


$$i_{D2} = \frac{I}{2} - \left(\frac{I}{V_{OV}}\right)\left(\frac{v_{id}}{2}\right)\sqrt{1 - \left(\frac{\frac{v_{id}}{2}}{V_{oV}}\right)^2}$$

$$i_{D1} = \frac{I}{2} + \left(\frac{I}{V_{OV}}\right)\left(\frac{v_{id}}{2}\right)\sqrt{1 - \left(\frac{\frac{v_{id}}{2}}{V_{oV}}\right)^2}$$

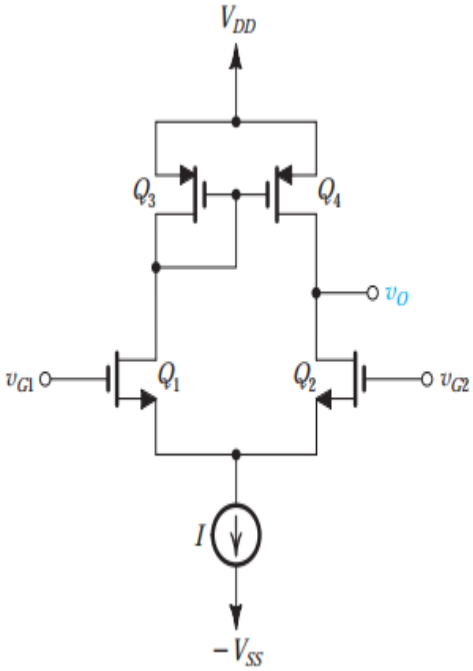
Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

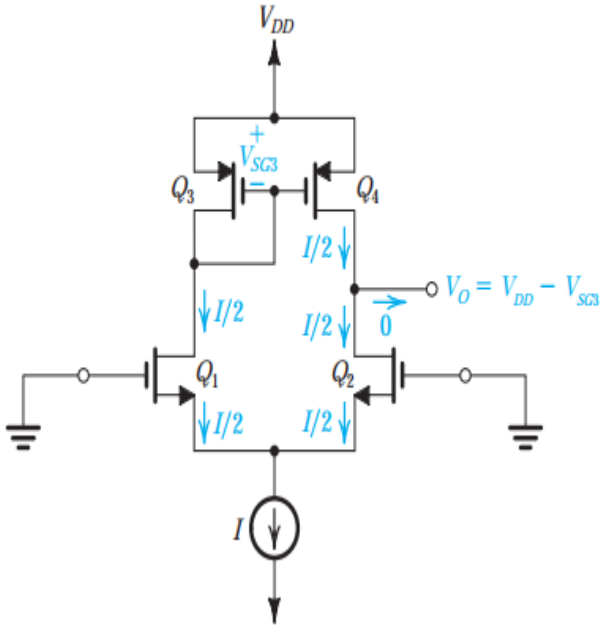
Differential to single ended conversion

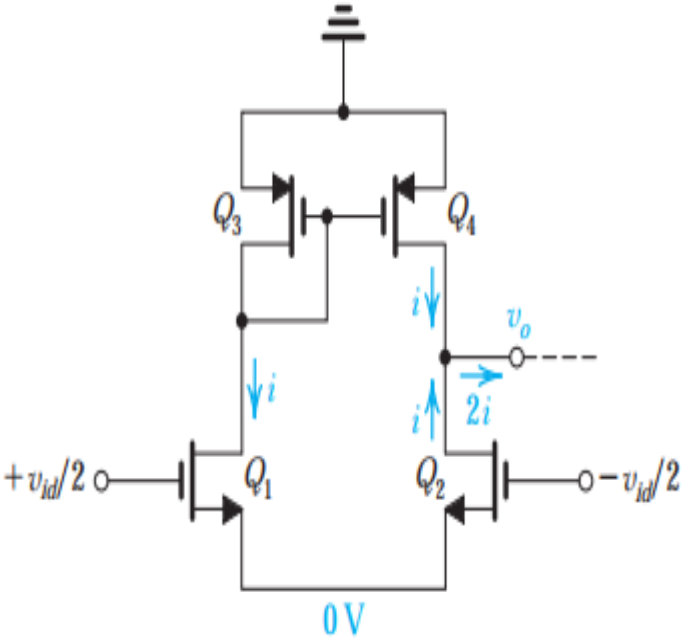


Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Active loaded MOS Differential Amplifier

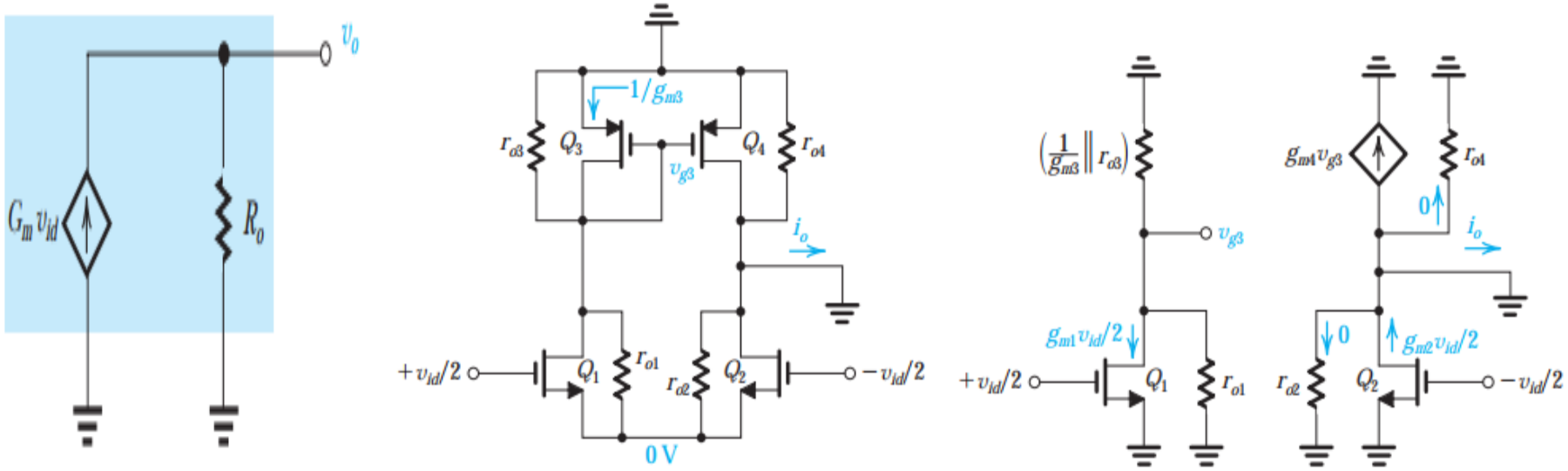






Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Differential Gain of the Active-Loaded MOS Pair



Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

$$v_{g3} = -g_{m1}\left(\frac{v_{id}}{2}\right)\left(\frac{1}{g_{m3}} \| r_{O3} \| r_{o1}\right) \qquad r_{01} \text{ and } r_{03} >> \frac{1}{g_{m3}} \qquad v_{g3} = -\left(\frac{g_{m1}}{g_{m2}}\right)\left(\frac{v_{id}}{2}\right)$$

$$i_o = -g_{m4}v_{g3} + g_{m2}\left(\frac{v_{id}}{2}\right) \qquad i_o = g_{m1}\left(\frac{g_{m4}}{g_{m3}}\right)\left(\frac{v_{id}}{2}\right) + g_{m2}\left(\frac{v_{id}}{2}\right) \qquad G_m = \frac{i_0}{v_{id}} = g_m$$

$$g_{m1} = g_{m2} = g_m \qquad g_{m3} = g_{m4} \qquad i_0 = g_m v_{id} \qquad G_m = \frac{i_0}{v_{id}}$$

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Input and Output Resistance and Differential gain

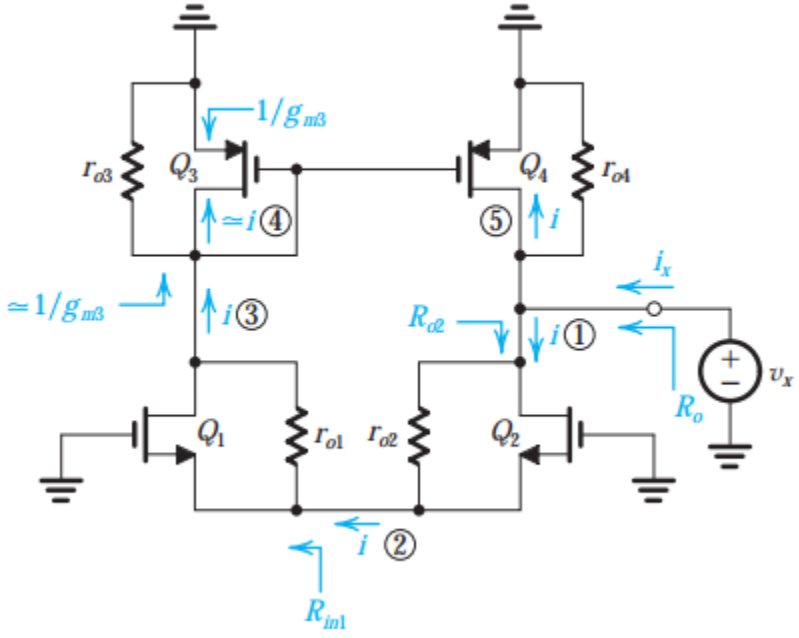
$$R_{in1} = \frac{1}{g_{m1}} \qquad R_{O2} = 2r_{o2}$$

$$R_O = (r_{o2} \| r_{o4})$$

$$A_d = g_m (r_{o2} \| r_{o4})$$

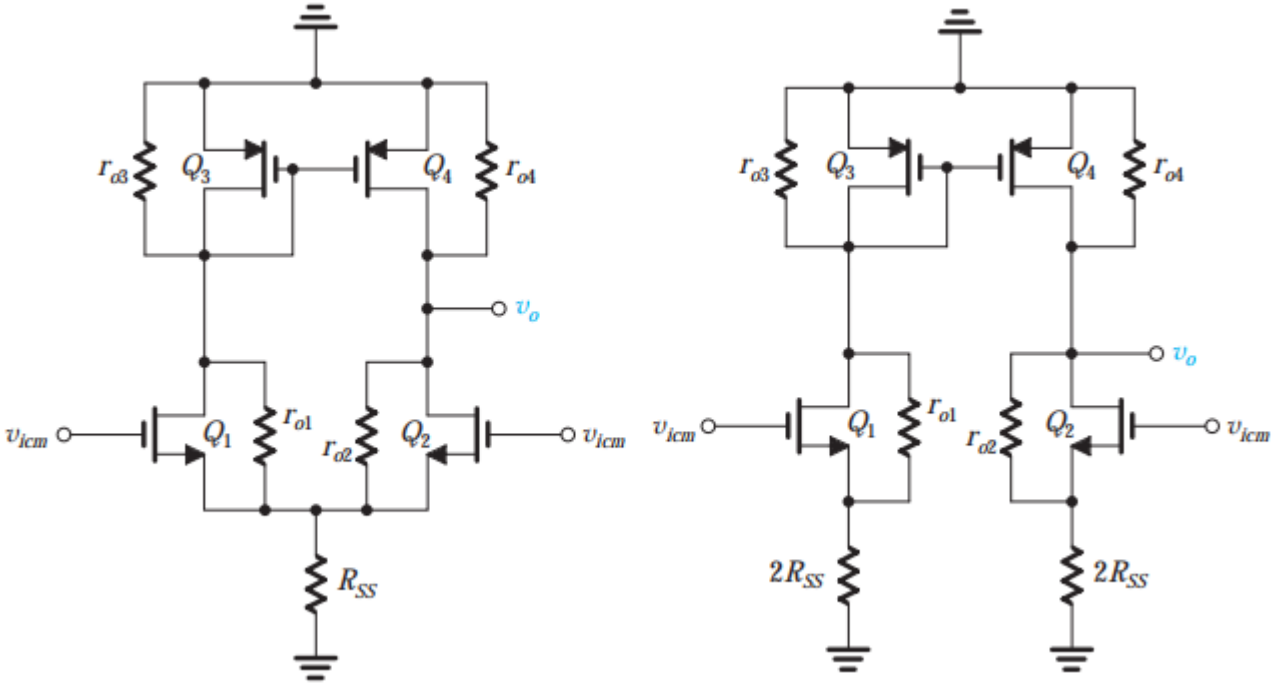
$$r_{o2} = r_{o4} = r_o$$

$$A_d = \frac{1}{2} g_m r_o$$

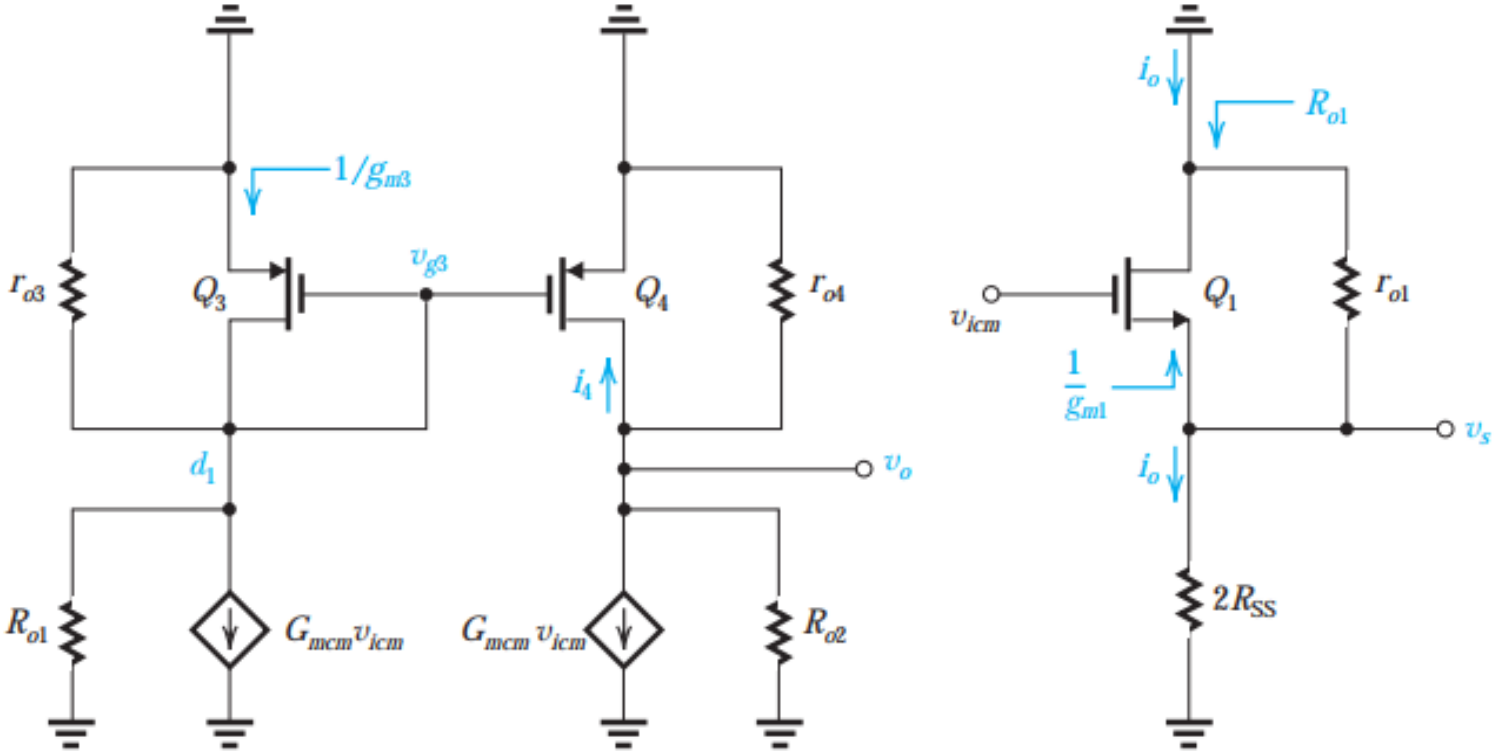


Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Common-mode gain and CMRR



Source: Microelectronics Circuits, Sedra and Smith, Fifth edition



Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

$$i_o = \frac{v_{icm}}{2R_{SS}} \qquad G_{mcm} = \frac{1}{2R_{SS}}$$

$$R_{o2} = 2R_{SS} + r_{o2} + (g_{m2} r_{o2})(2R_{SS})$$

$$R_{o1} = 2R_{SS} + r_{o1} + (g_{m1} r_{o1})(2R_{SS})$$

$$v_{g3} = -G_{mcm} v_{icm} \left(R_{o1} \| r_{o3} \| \frac{1}{g_m} \right)$$

$$i_4 = g_{m4} v_{gs3} = g_{m4} v_{g3}$$

$$i_4 = -g_{m4} G_{mcm} v_{icm} \left(R_{o1} \| r_{o3} \| \frac{1}{g_{m3}} \right)$$

$$G_{mcm} v_{icm} + i_4 + \frac{v_o}{R_{o2}} + \frac{v_o}{r_{o4}}$$

$$v_o = -v_{icm} \frac{r_{04} \| R_{o2}}{2R_{SS}} \left[1 - g_{m4} \left(R_{o1} \| r_{o3} \| \frac{1}{g_{m3}} \right) \right]$$

$$A_{cm} = -\frac{r_{o4}}{2R_{ss}} \frac{1}{1 + g_{m3} r_{o3}}$$

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Recapitulation

- The CMRR for the MOSFETs diff-amp is also a strong function of output resistance of the constant current source.
- The CMRR can be increased by increasing the output resistance of the current source.
- The CMRR can be increased by using the casocde current mirror.
- single-ended, the active-loaded MOS differential amplifier has a low common-mode gain and, correspondingly, a high CMRR.
- The differential transmission of the signal on the chip also minimizes its susceptibility to corruption with noise and interference.

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Thank You