Textbook Notes

MOSFET Amplifiers

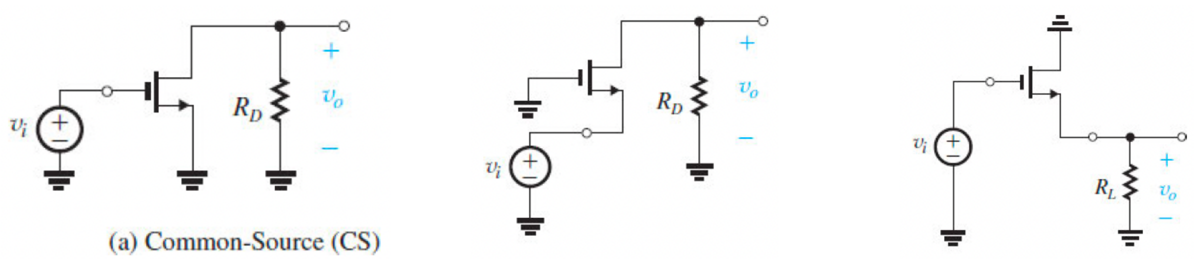
MOSFET Review + Non-Idealities

Body Effect

- in integrated circuits the substrate is shared across many MOS transistors
- to maintain the cutoff condition for all substrate-channel junctions, we connect the substrate to:
    - most negative power supply for NMOS
    - most positive power supple for PMOS
- resulting V_{SB} source-body voltage will be reverse-biased and affect device operation
- consider an NMOS whose substrate is negative relative to source then the depletion region will be widened and the channel depth will be reduced

$$V_t = V_{t0} + \gamma \left[\sqrt{2\phi_f + V_{SB}} - \sqrt{2\phi_f} \right]$$

Basic MOSFET Amplifier Configurations



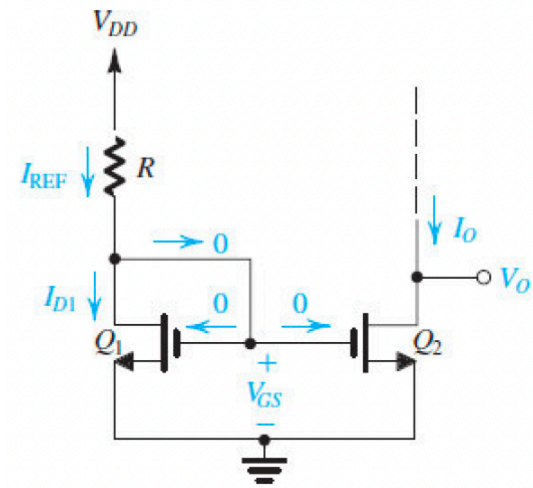
(a) Common-Source (CS)

(b) Common-Gate (CG)

(c) Common-Drain (CD) or Source Follower

Current Mirrors

- current mirrors used to easily generate stable reference currents at various locations on the integrated circuit



- most basic relationship for the current mirror is:

$$\frac{I_O}{I_{REF}} = \frac{(W/L)_2}{(W/L)_1}$$

- Q_2 must be in saturation in order to supply a constant-current output, so we place a restriction on V_O such that

$$V_O \geq V_{OV}$$

- proper nomenclature:
  - PMOS current mirror is more aptly a current source
  - NMOS current mirror is more aptly a current sink

Basic Gain Cell

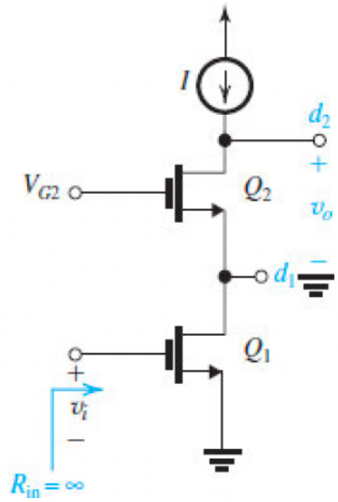
- is a common-source amplifier driven by a bias current

$$R_{in} = \infty$$
$$A_{vo} = -g_m r_o$$
$$R_o = r_o$$

- the circuit has an intrinsic gain of $g_m r_o$, which with a little more manipulation we can find to be V_A/V_T, meaning it is entirely process dependent

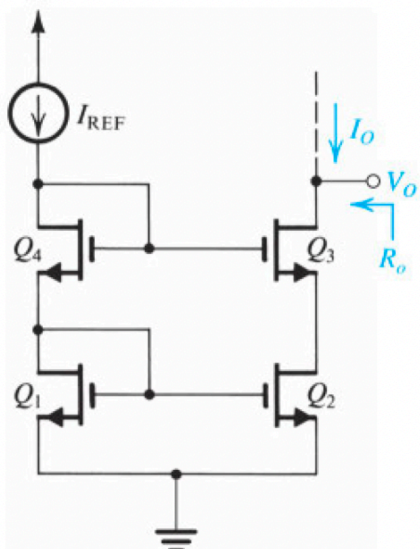
Cascode Amplifiers

- cascoding is when we connect a common-gate transistor to provide current buffering in the output of a common-source amplifier
- current-buffering provides a higher output resistance, helps to increase the voltage gain



$$R_o = g_{m2} r_{o2} r_{o1}$$

Cascode Current Mirror



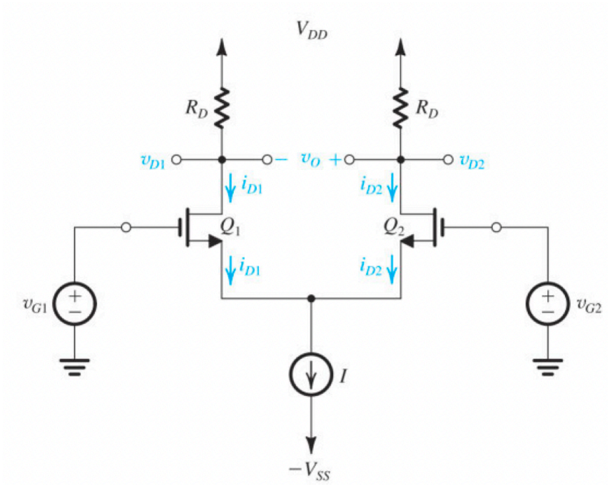
- for output resistance, we assume that because of low incremental resistances of the diode-connected transistors, the signal voltage at the gates of the bias voltages will be almost zero

$$R_o \approx g_{m3} r_{o3} r_{o2}$$

- cascoding increases output resistance of the current mirror by factor $g_{m3} r_{o3}$
- drawback is that the cascode current mirror uses up a lot of available voltage
  - simple current mirror operates with V_{OV} across the output transistor, but
  - cascode current mirror requires a minimum voltage of $V_t + 2V_{OV}$

Differential Amplifiers

- differential pair consists of two matched transistors whose sources are joined together and biased with a constant current source I
  - current source is often itself a current mirror
  - for the time being lets assume the source is ideal with ∞ output resistance



- we need two voltages to feed the differential pair

$$v_{G1} = V_{CM} + \frac{v_{id}}{2}$$
$$v_{G2} = V_{CM} - \frac{v_{id}}{2}$$

Operation with Common-Mode Input

- when the two input voltages are the same (i.e., there is only a common-mode input voltage) then we see that the currents across the two transistors are the same as well

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

- the voltage at each of the drain terminals will be

$$V_{D1} = V_{D2} = V_{DD} - \frac{IR_D}{2}$$

- and the output voltage between the two drains will be 0, makes sense as there is no differential input applied and the currents through both transistors is the same
- another important aspect is the input common-mode range
  - highest value of V_{CM} is that Q_1 and Q_2 remain in saturation
  - lowest value of V_{CM} is that the current source must be allowed to produce current I

$$V_{CM_{max}} = V_t + V_{D1,2} = V_t + V_{DD} - \frac{IR_D}{2}$$
$$V_{CM_{min}} = -V_{SS} + V_{OV_{mirror}} + V_t + V_{OV}$$

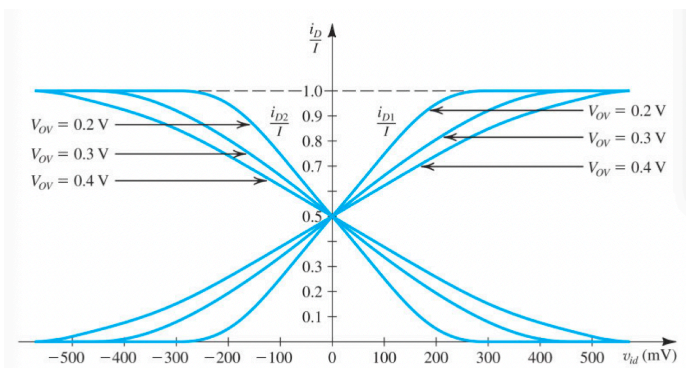
Operation with Differential Input

- say we apply a differential input by grounding the gate of Q_2 and applying a signal v_{id} to the gate of Q_1
  - then we will have $i_{D1} > i_{D2}$ and correspondingly $v_{D1} < v_{D2}$
- for the bias current I to flow entirely in one of the two transistors (no sharing at all) then we need to first find value of v_{GS1}

$$v_{GS1} = V_t + \sqrt{2}V_{OV}$$

- then we see that

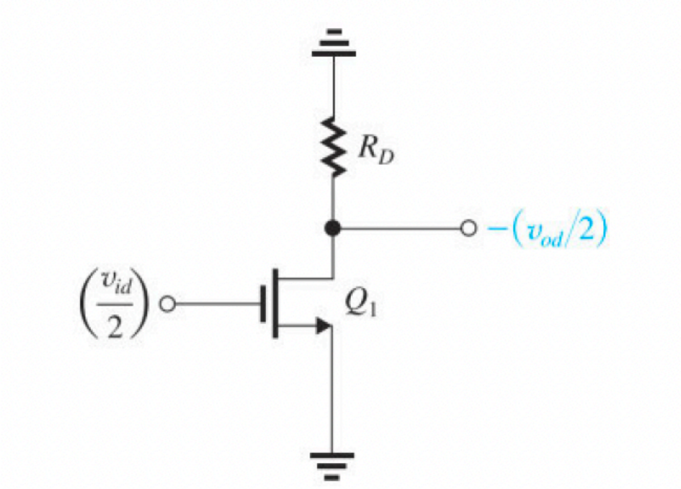
$$\begin{aligned} v_{id_{max}} &= v_{GS1} + v_S \\ &= V_t + \sqrt{2}V_{OV} - V_t \\ &= \sqrt{2}V_{OV} \end{aligned}$$



- the linear rage of operation of the differential pair can be expanded by increasing the value of V_{OV} but then we also dissipate more power, which may be a serious limitation
- the difference in performance between a complementary/balanced input and a single-ended input is too subtle for us to care about right now
- when the output is taken between the two drains (as compared to one drain and ground) the signal will have a purely signal (no DC) component
- the signal voltage at the joint source connection must be zero, acting as a virtual ground

The Differential Half-Circuit

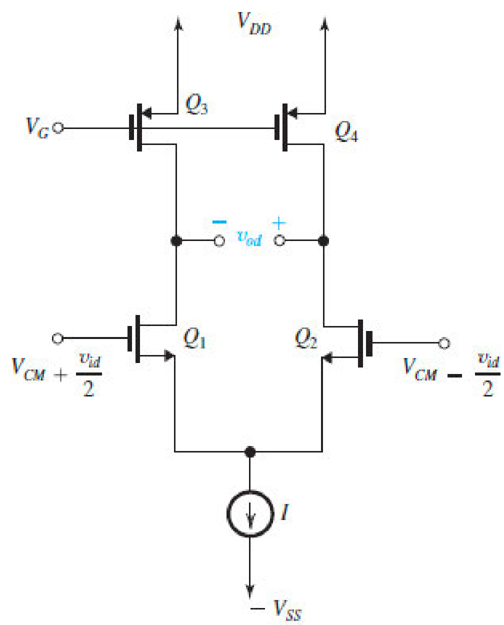
- when a symmetrical differential amplifier is fed with a balanced differential input, then its performance can be determined by considering only a half-circuit



- then we see that the differential gain is given by

$$A_d = g_m(R_D||r_o)$$

Differential Amplifiers With Current-Source Loads

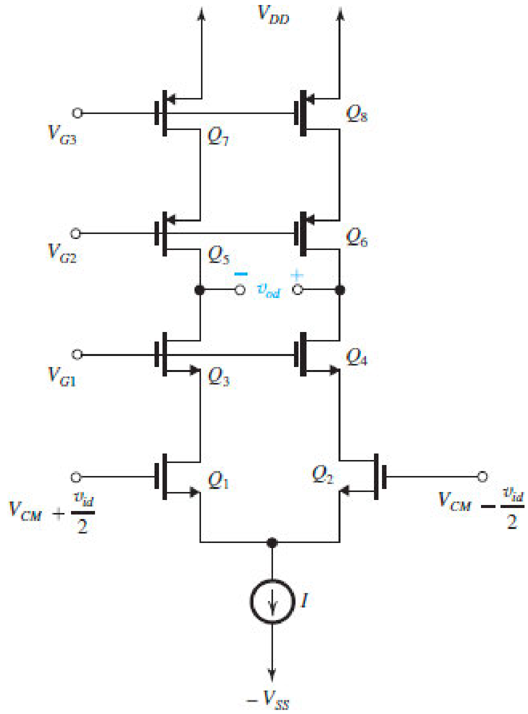


(a)

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

The Cascode Differential Amplifier

- as we did with the current mirror, we can increase the gain of the differential amplifier using the cascode configuration



(a)

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

Power Amplifiers

Class A

Class B

Class AB

Frequency Response