EEC 332 - Analog Integrated Circuits

Lecture 6
MOS Current-Steering Circuits and Small Signal Operation of Current Mirror

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1 MOS Current-Steering Circuits

Once a constant current has been generated, it can be replicated to provide dc bias or load currents for the various amplifier stages in an IC. Current mirrors can obviously be used to implement this current-steering function.

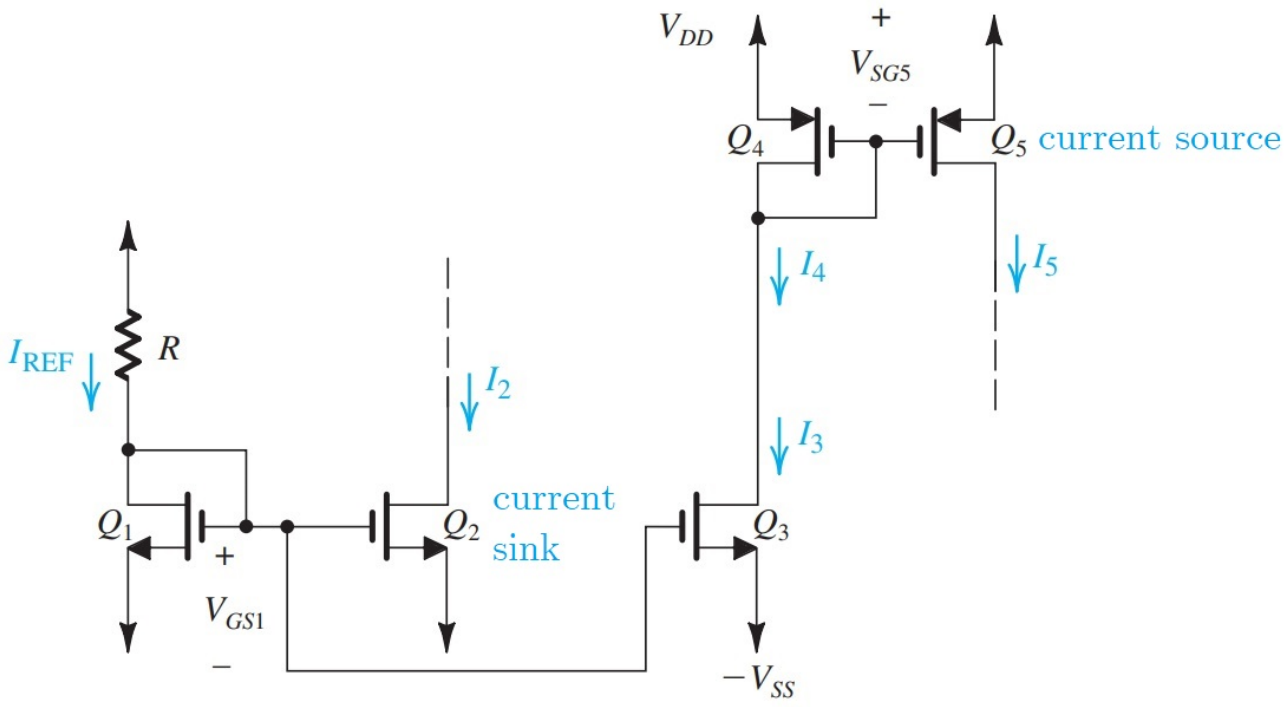

Figure 1: A current-steering circuit

$$I_2 = I_{\text{REF}} \frac{(W/L)_2}{(W/L)_1} \tag{1}$$

$$I_3 = I_{\text{REF}} \frac{(W/L)_3}{(W/L)_1} \tag{2}$$

To ensure operation in the saturation region, the voltages at the drains of Q_2 and Q_3 are constrained as follows:

$$V_{DS} \geq V_{OV} \tag{3}$$

Where :

$$V_{DS} = V_D - (-Vss) \tag{4}$$

$$V_{OV} = V_{GS} - V_t \tag{5}$$

$$\tag{6}$$

Therefore

$$V_{D2},\ V_{D3} \geq -V_{SS} + V_{GS1} - V_{tn} \tag{7}$$

or, equivalently,

$$V_{D2},\ V_{D3} \geq -V_{SS} + V_{OV1} \tag{8}$$

where V_{OV1} is the overdrive voltage at which Q_1, Q_2, and Q_3 are operating.
In other words, the drains of Q_2 and Q_3 will have to remain higher than $-V_{SS}$ by at least the overdrive voltage.
I_3 is fed to the input side of a current mirror formed by PMOS transistors Q_4 and Q_5. This mirror provides

$$I_5 = I_4 \frac{(W/L)_5}{(W/L)_4} \tag{9}$$

where $I_4 = I_3$. To keep Q_5 in saturation (PMOS), its drain voltage should be

$$V_{DS5} \leq V_{DD} - |V_{OV5}| \tag{10}$$

where V_{OV5} is the overdrive voltage at which Q_5 is operating.
Finally, an important point to note is that in the circuit of Fig 1, while Q_2 pulls its current I_2 from a circuit , Q_5 pushes its current I_5 into a circuit . Thus :
Q_5 is called a current source,
Q_2 is called a current sink

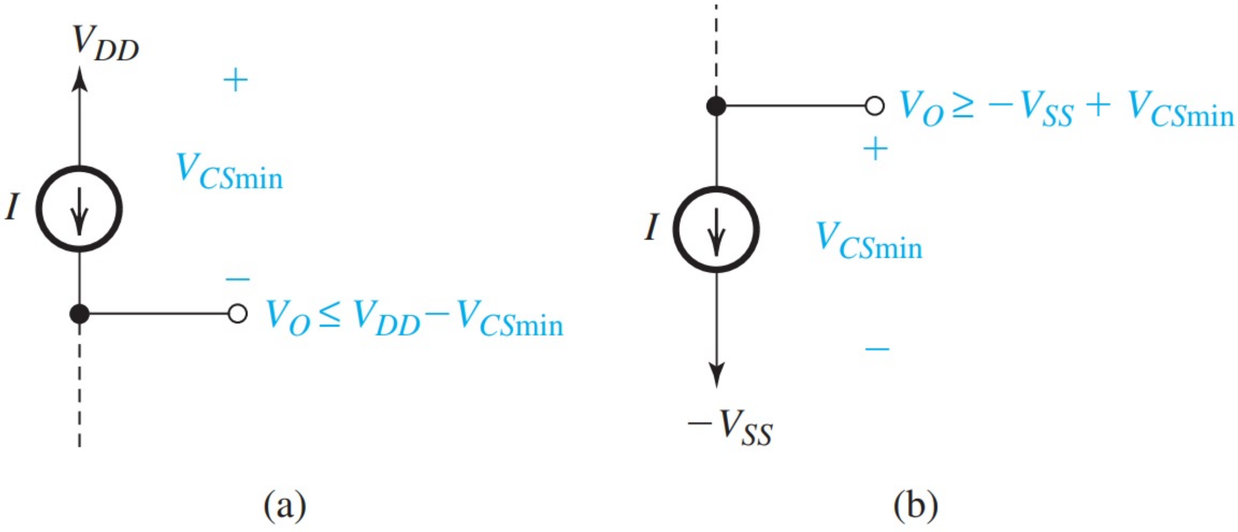

Figure 2: (a) A current source; and (b) a current sink.

2 Small-Signal Operation of Current Mirrors

In addition to their use in biasing, current mirrors are sometimes employed as current amplifiers. It is therefore useful to derive the small-signal parameters of the current mirror, that is, input resistance R_{in}, output resistance R_o , and short circuit current gain A_{is}

Figure 3 (a) shows a MOS current mirror biased with a dc input current I_{D1} and fed with a small-signal input current i_i. Note that V_{GS} and I_{D2} are the resulting dc quantities, while v_{gs} and i_o are signal quantities.

Replacing Q_1 and Q_2 with their small-signal models results in the circuit in Figure 3 (b). Observe that the controlled current source $g_{m1}v_{gs}$ appears across its control voltage v_{gs} and thus can be replaced by a resistance, $1/g_{m1}$ (ohm's law), as shown in Figure 3 (c). For the latter circuit we can obtain

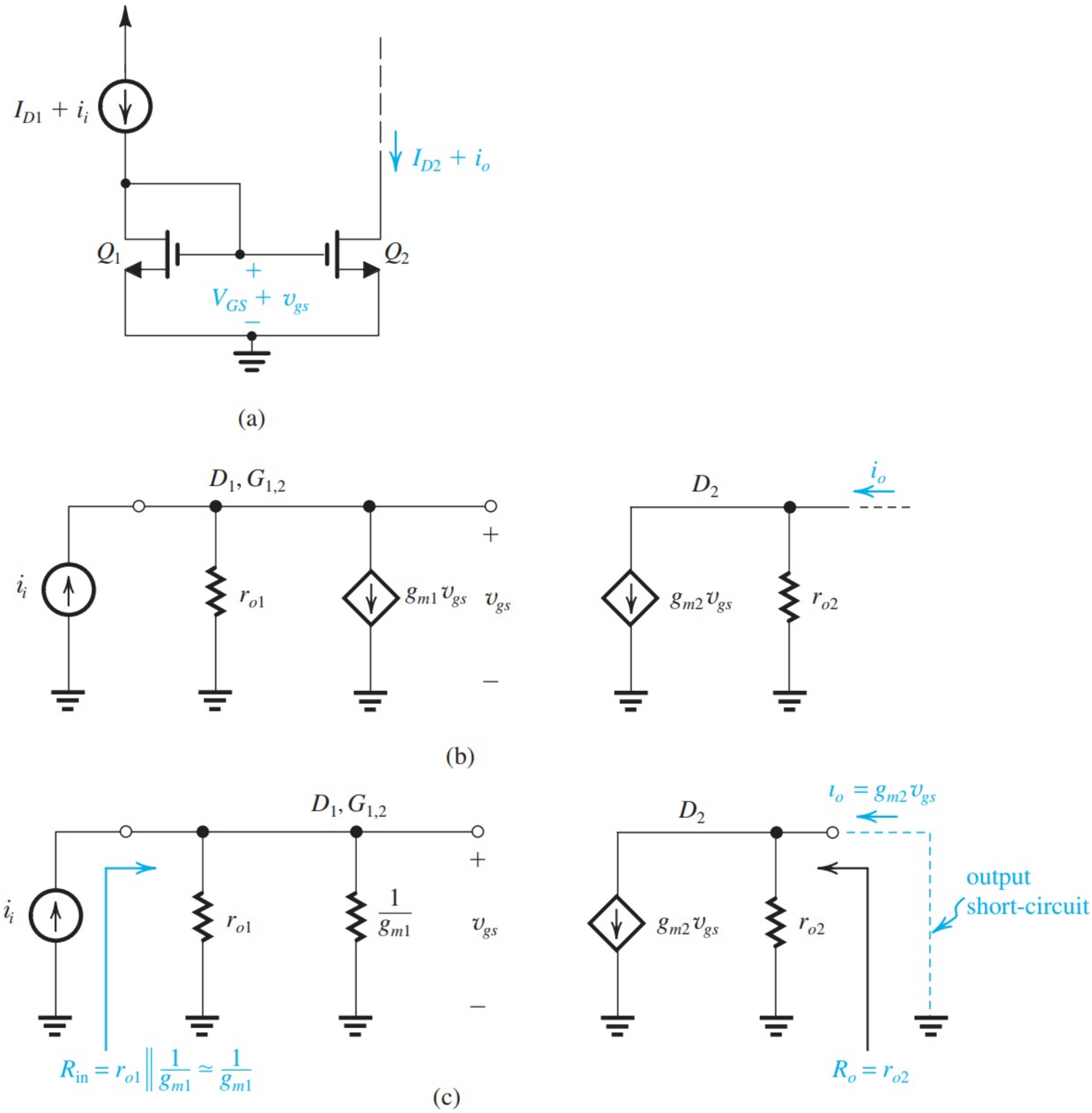

Figure 3: Obtaining the small-signal parameters of the MOS current mirror as a current amplifier.

Input resistance

$$\boldsymbol{R_{\text{in}} = r_{o1} \| \frac{1}{g_{m1}} \simeq \frac{1}{g_{m1}}} \tag{11}$$

Output resistance

$$\boldsymbol{R_o = r_{o2}} \tag{12}$$

Short circuit current gain

$$\boldsymbol{A_{is} = \left.\frac{i_o}{i_i}\right|_{v_{d2}=0} = \frac{g_{m2} v_{gs}}{i_i} \simeq \frac{g_{m2} i_i / g_{m1}}{i_i}} \tag{13}$$

Thus :

$$\boldsymbol{A_{is} = \frac{g_{m2}}{g_{m1}}} \tag{14}$$

Substituting for $g_{m1,2} = \mu_n C_{ox} (W/L)_{1,2} V_{OV}$, where V_{OV} is the overdrive voltage at which Q_1 and Q_2 are operating, yields for the short-circuit current gain

$$\boldsymbol{A_{is} = \frac{(W/L)_2}{(W/L)_1}} \tag{15}$$

We conclude that the current mirror is an excellent current amplifier: It has a relatively low input resistance ($1/g_{m1}$), a relatively high output resistance (r_{o2}), and a gain determined by the aspect ratios of the MOSFETs.