Chapter 9
Operational Amplifiers

Important Parameters

Gain

Small-Signal Bandwidth

Large-Signal Bandwidth

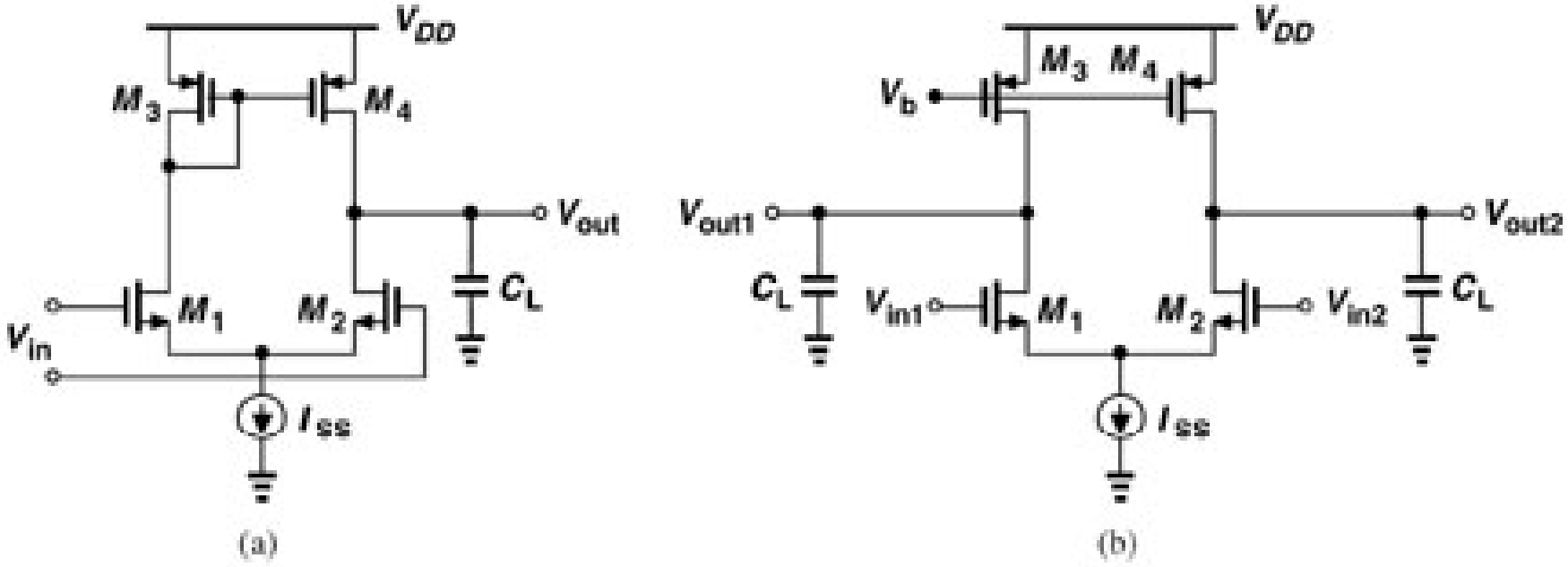
Output Swing

Linearity

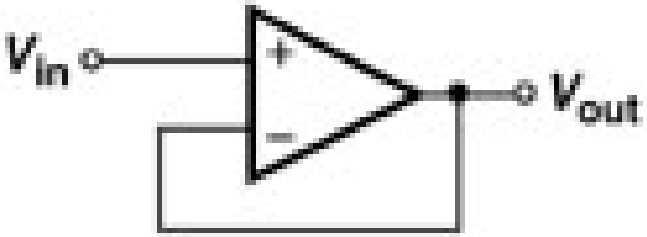
Noise and Offset

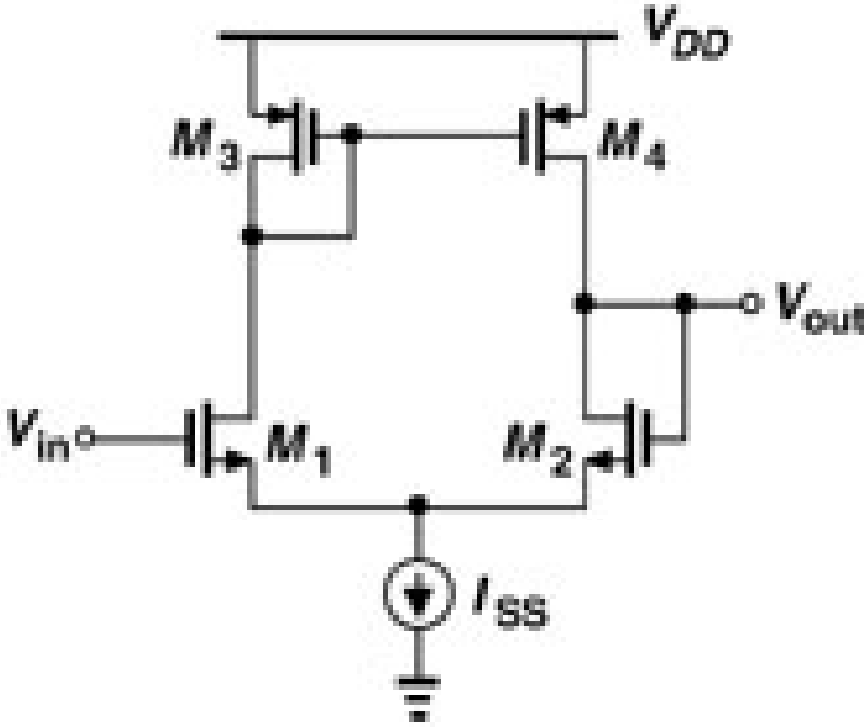
Supply Rejection

One-Stage Op Amps

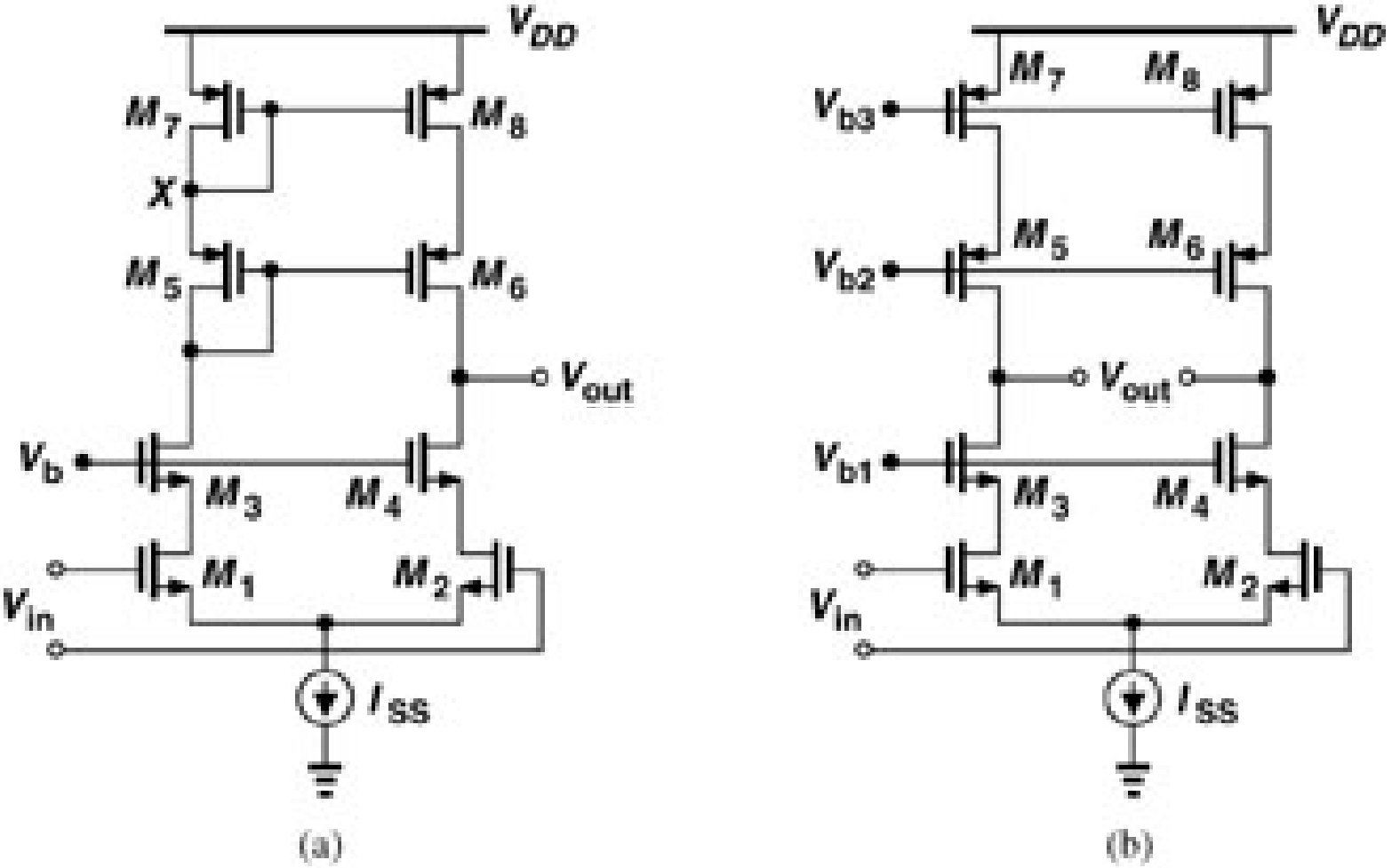


One-Stage Op Amp in Unity Gain Configuration

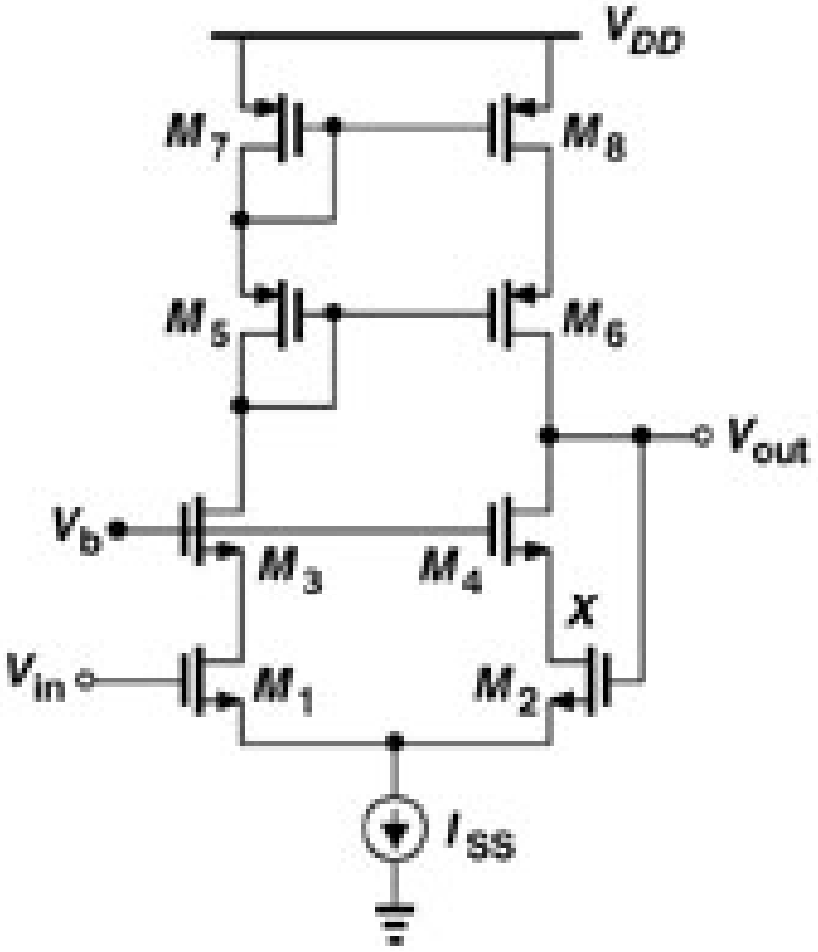


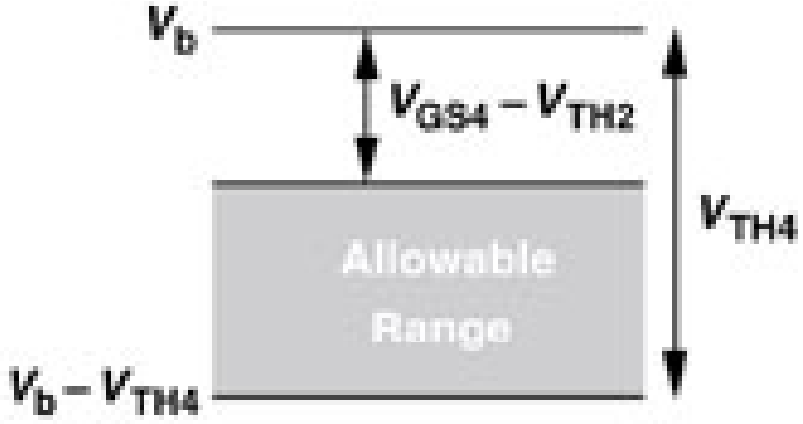


Cascode Op Amps

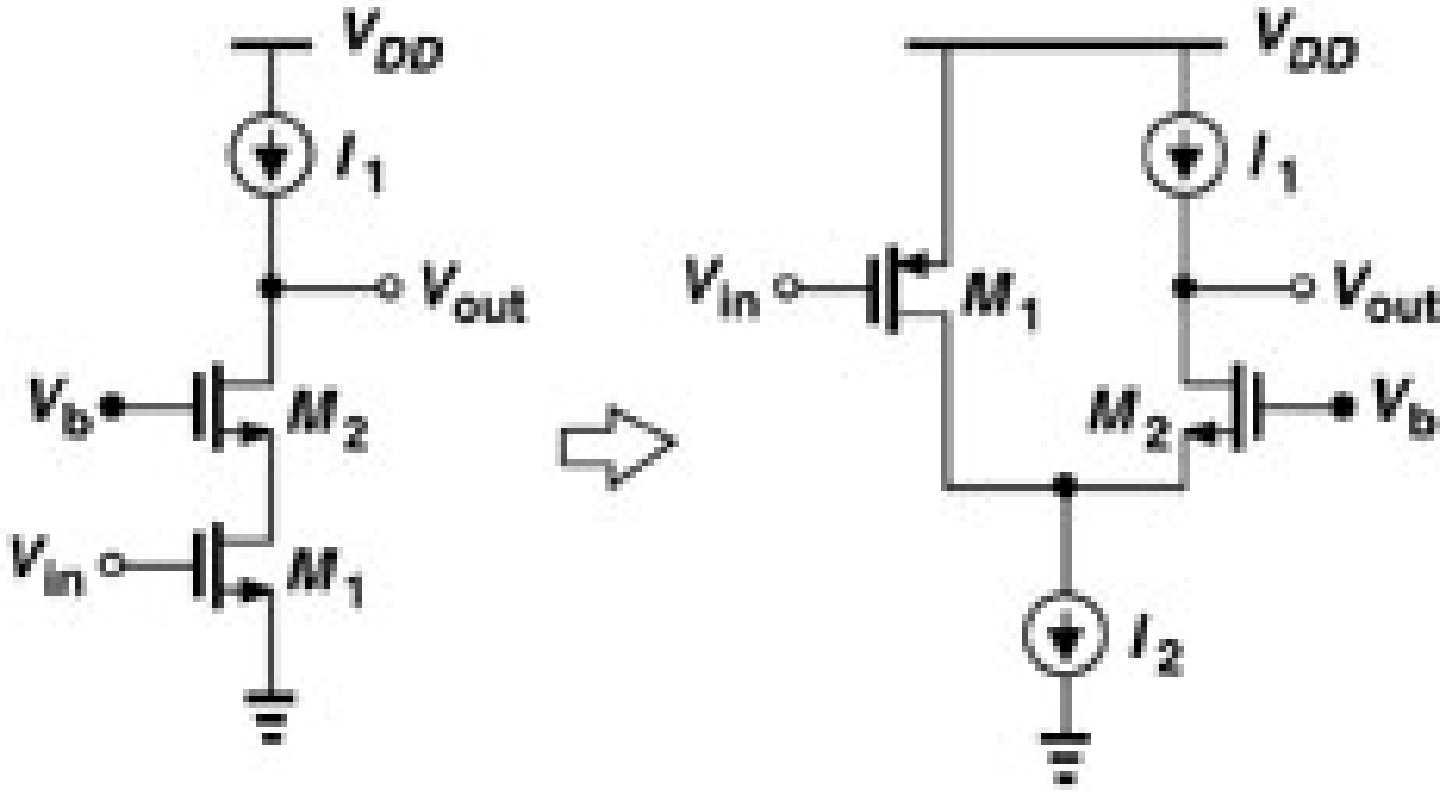


Unity Gain One Stage Cascode

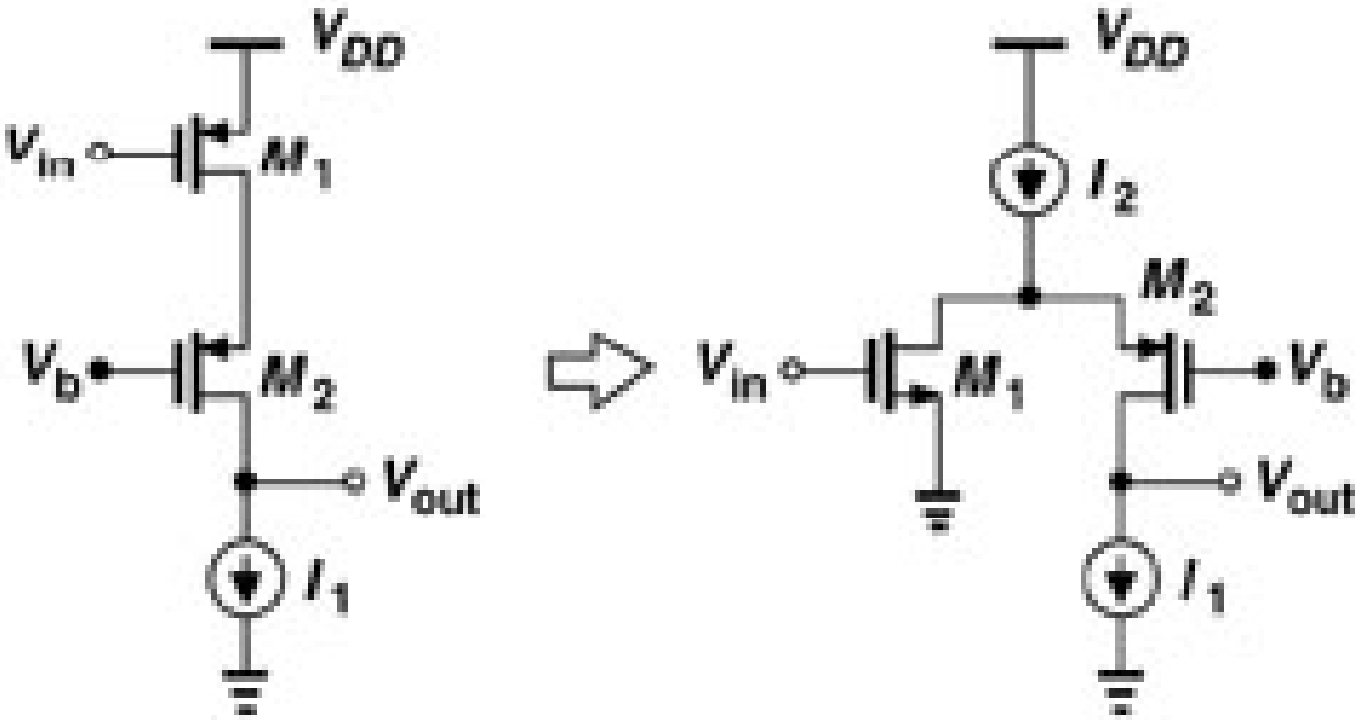




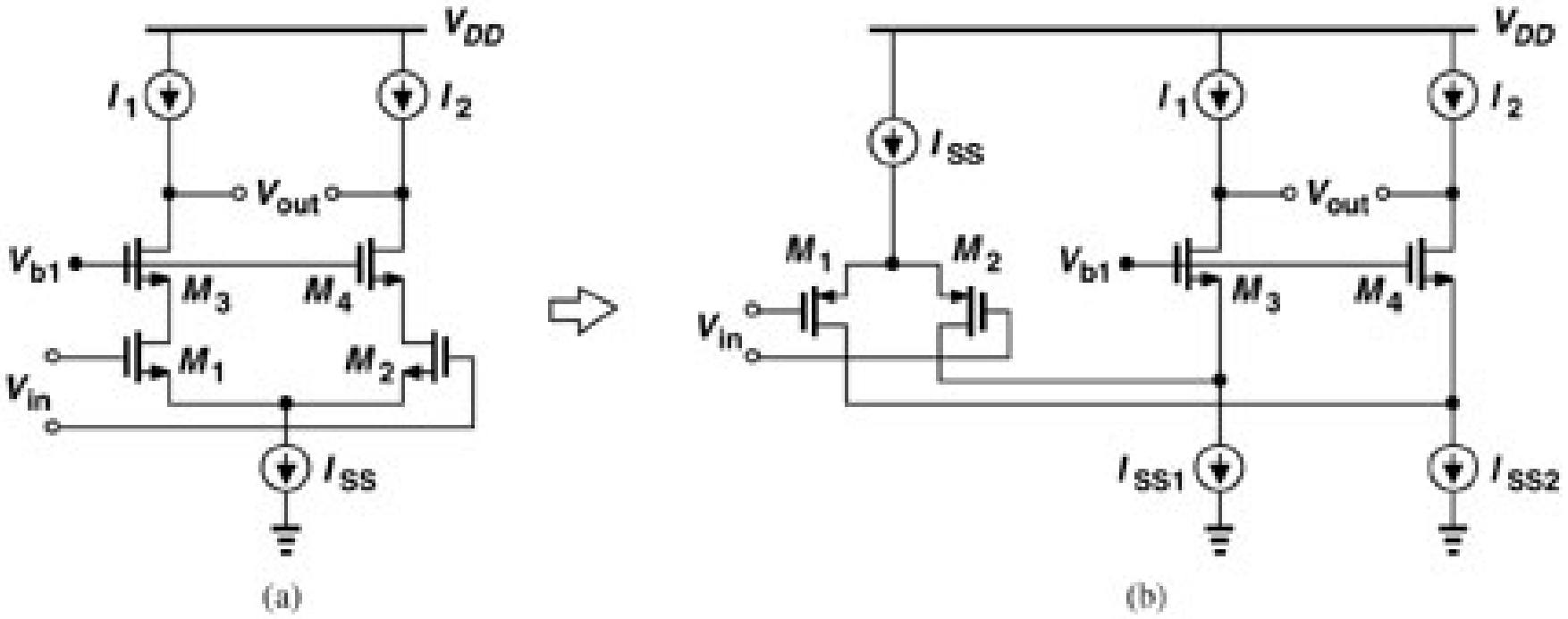
Folded Cascode Op Amps



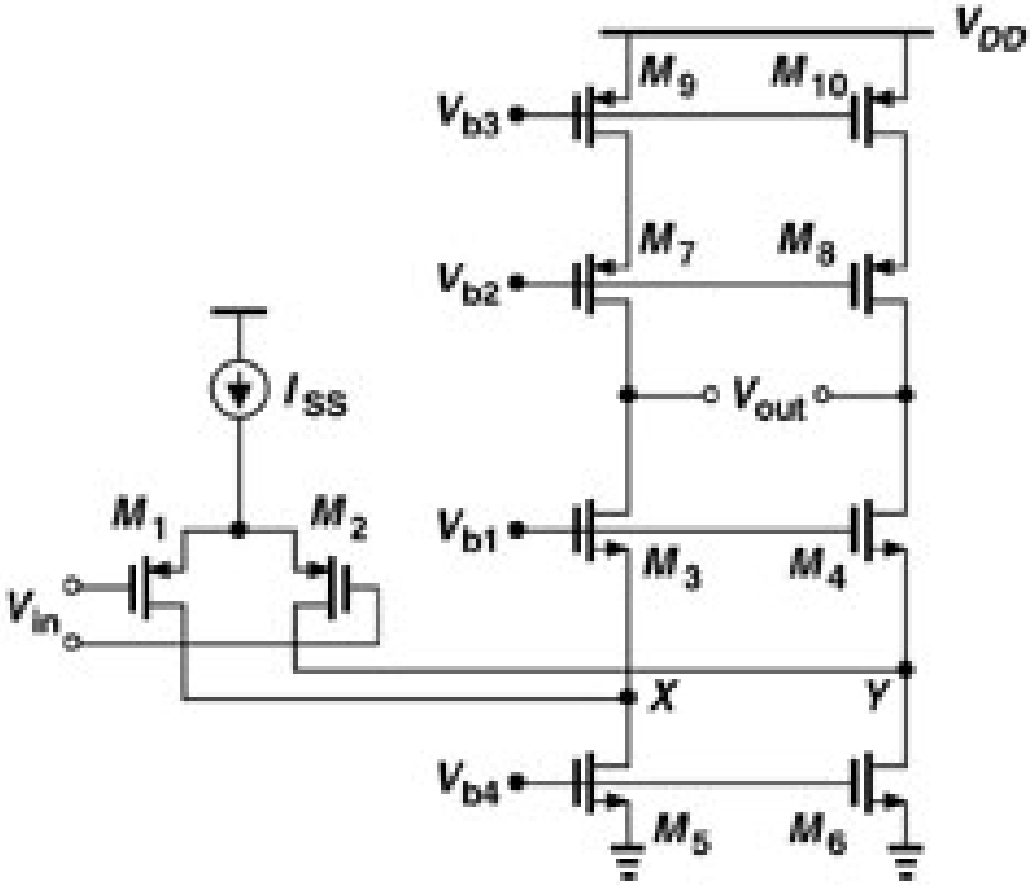
Folded Cascode Stages (cont.)



Folded Cascode (cont.)

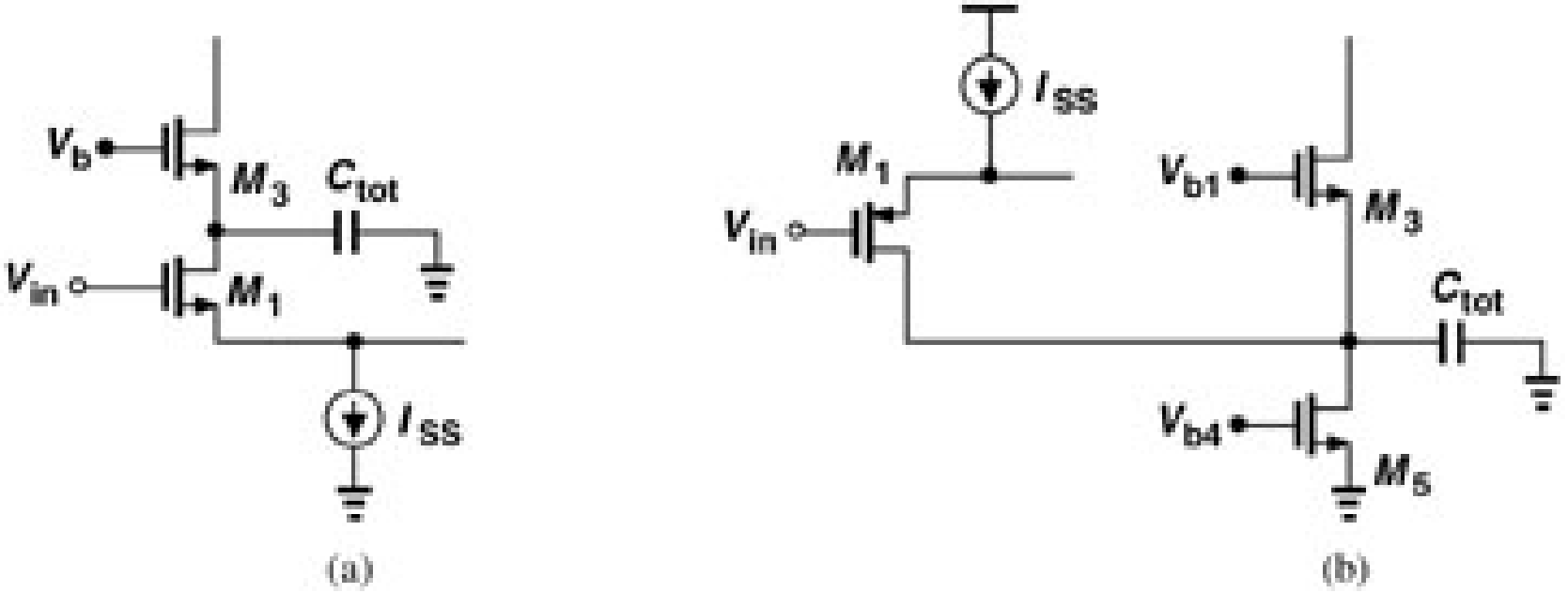


Folded Cascode (cont.)

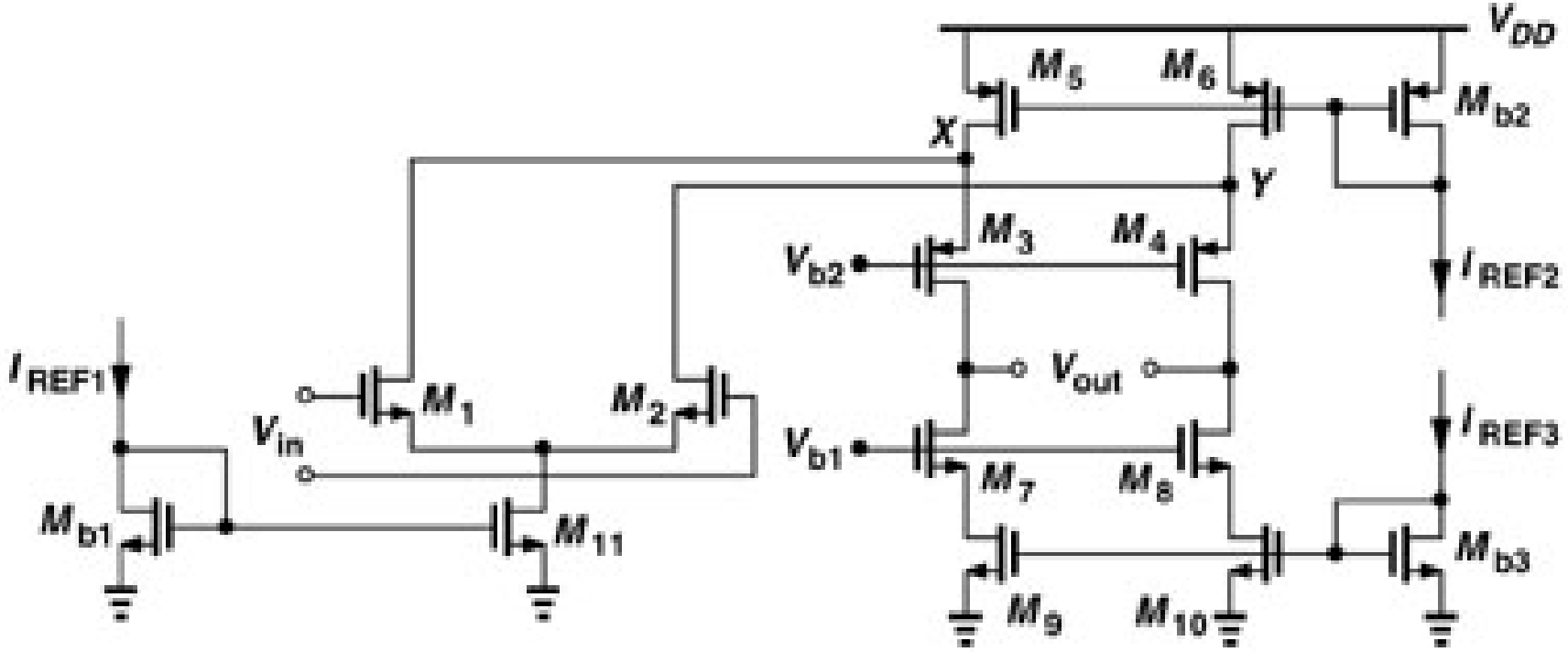


$$|A_v| \approx g_{m1}\{[(g_{m3}+g_{mb3})r_{o3}(r_{o1} \,||\, r_{o5})] || [(g_{m7}+g_{mb7})r_{o7}r_{o9}]\}$$

Telescopic vs. Folded Cascode Pole

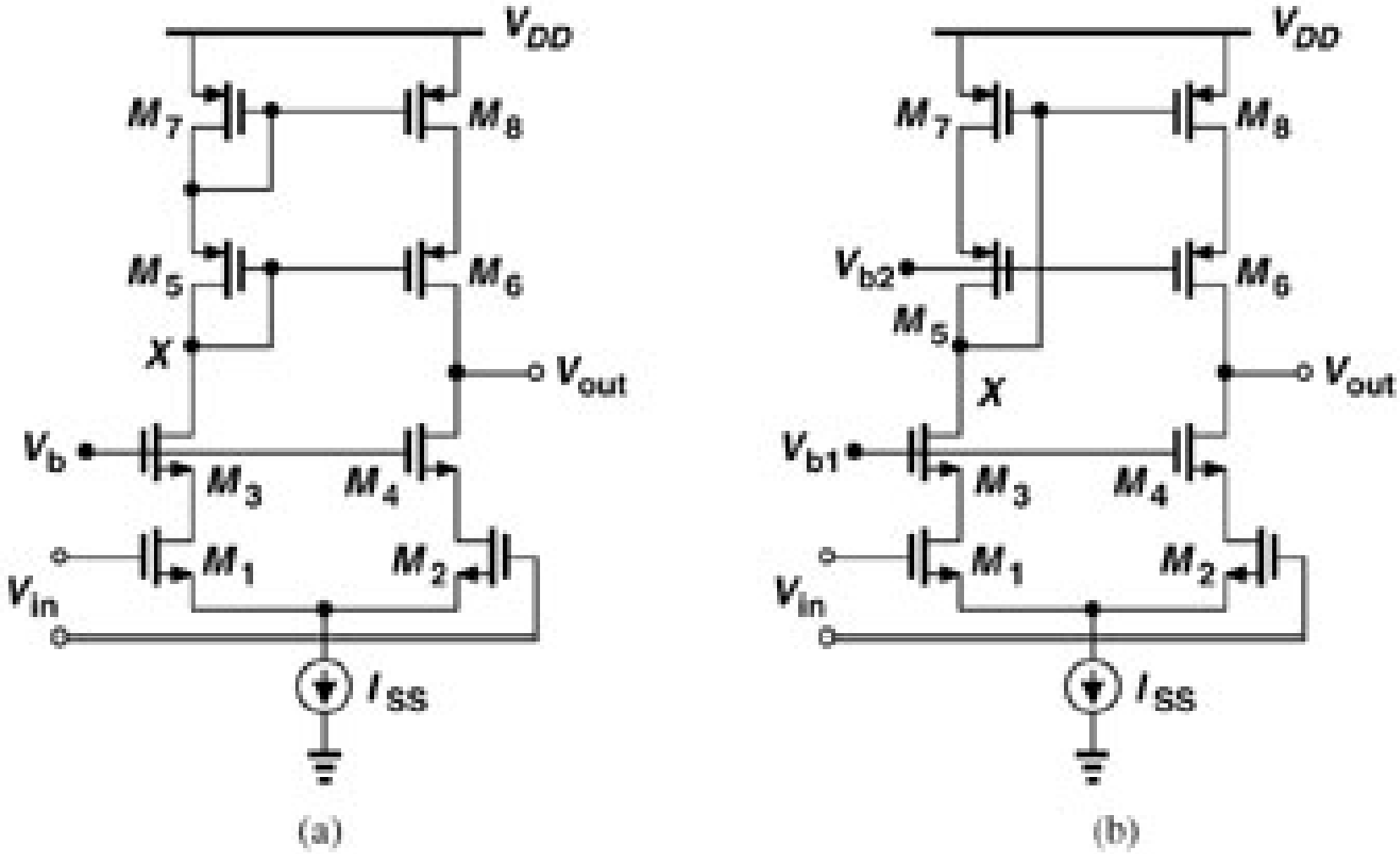


Example Folded-Cascode Op Amp

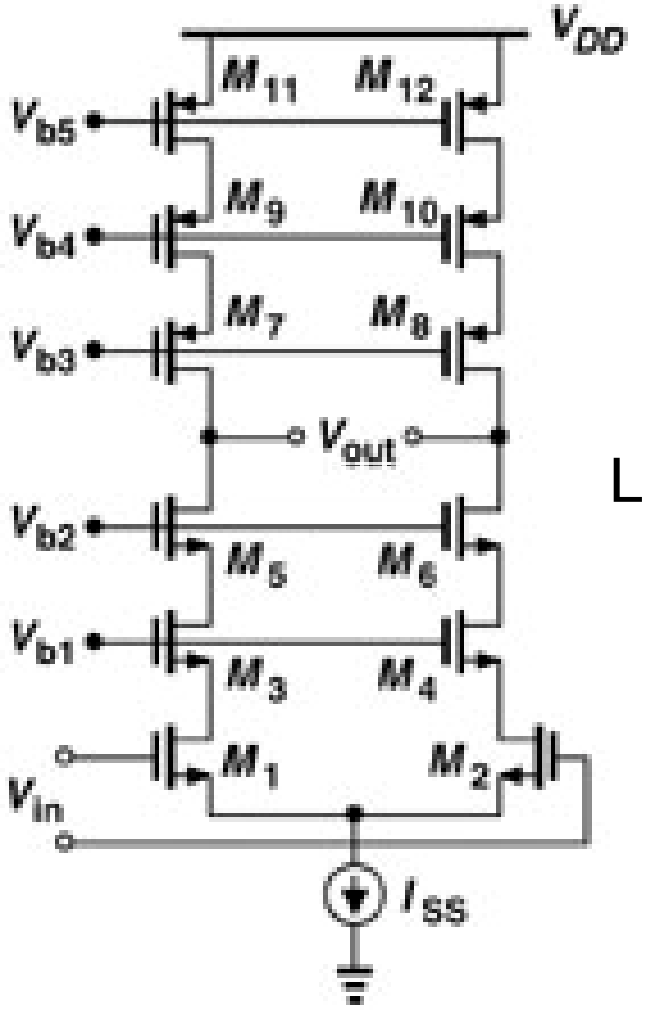


See Example 9.6

Single-Ended Output Cascode Op Amps



Triple Cascode

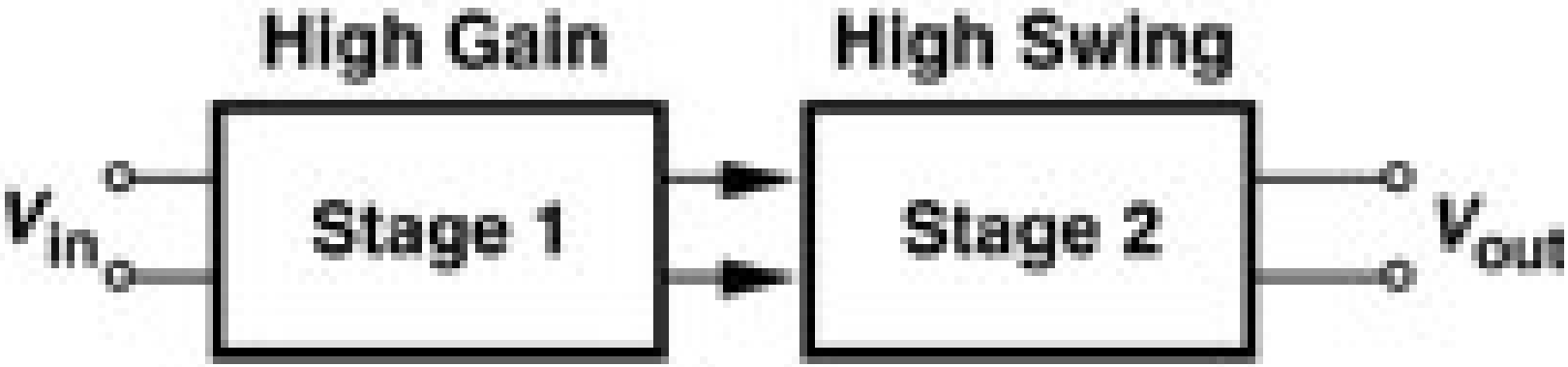


A_v app. $(g_m r_o)^3/2$

Limited Output Swing

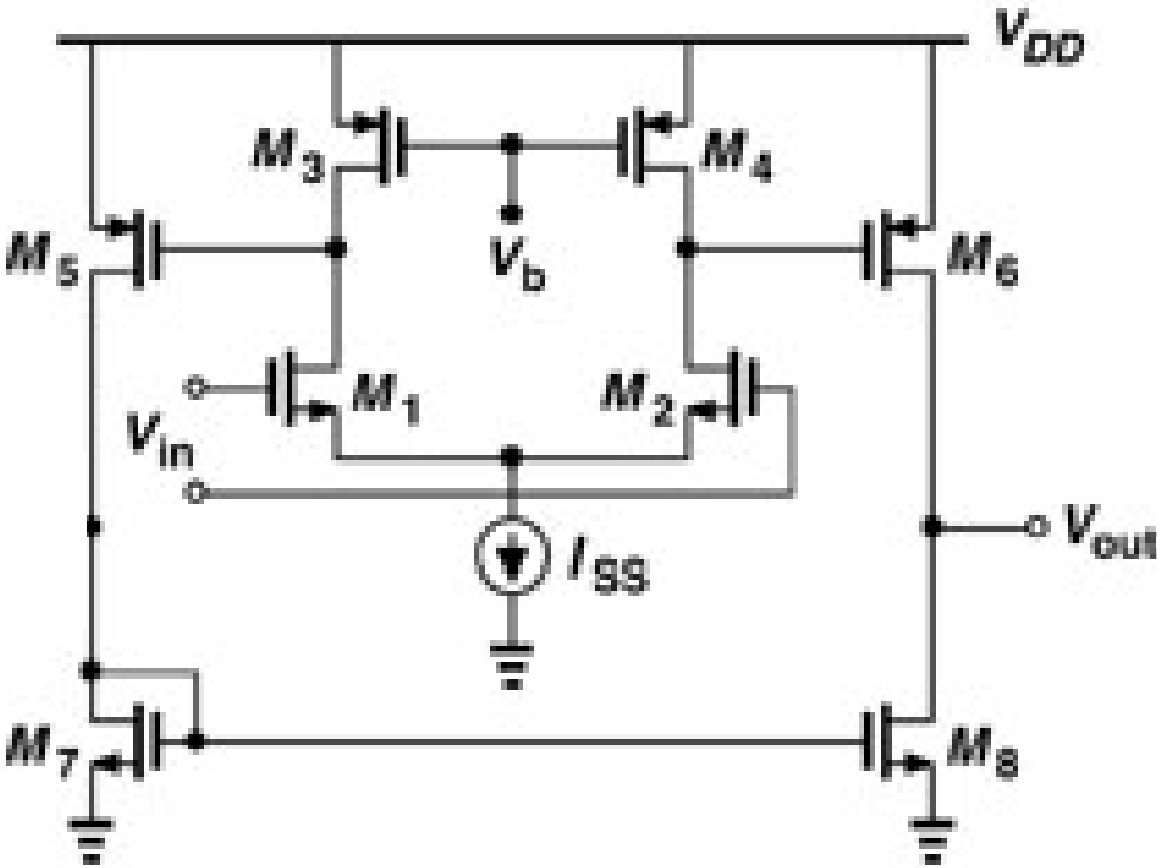
Complex biasing

Two-Stage Op Amps

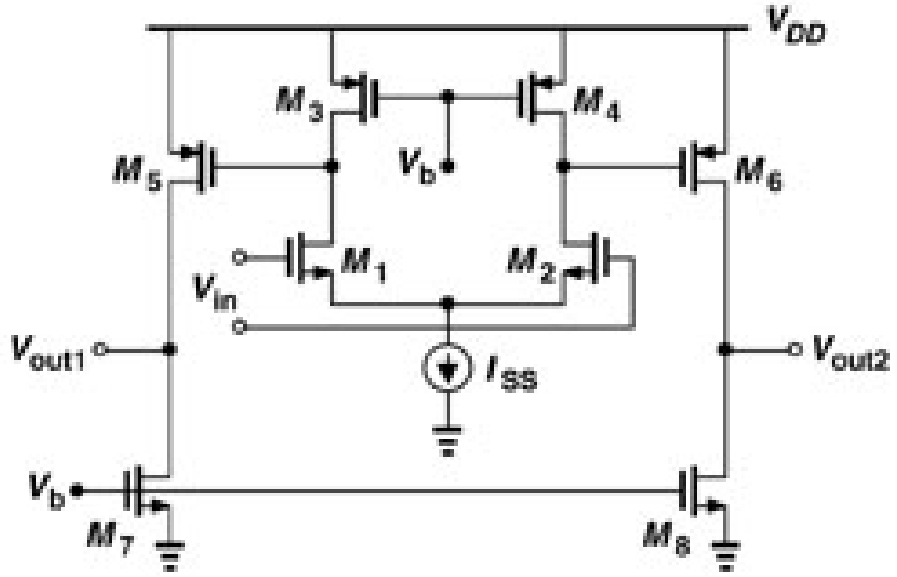


Design Approach for Two-Stage Op Amps

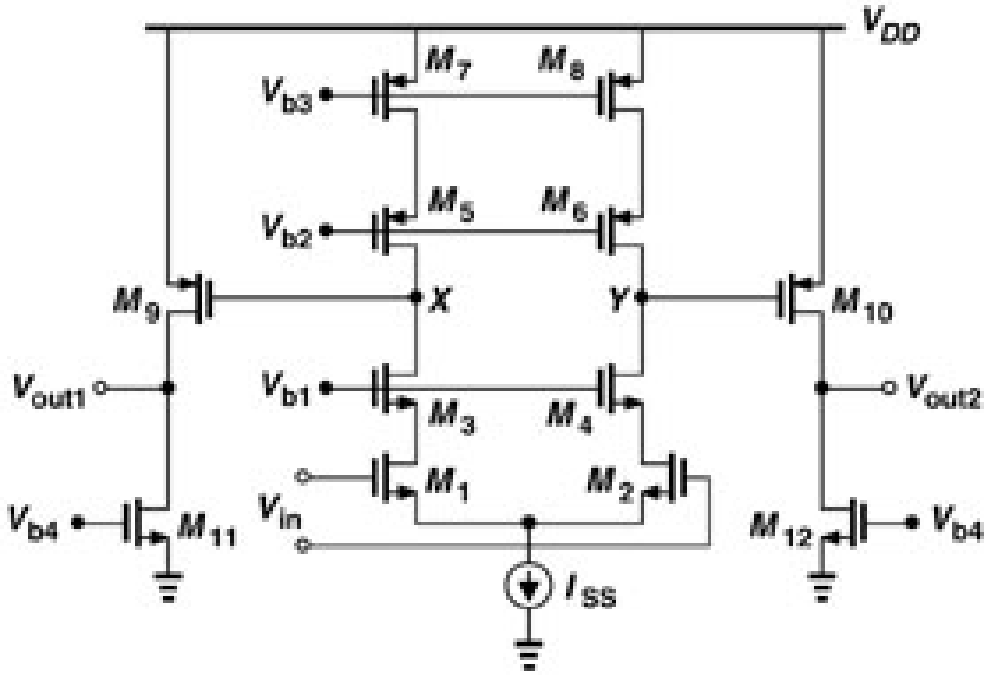
Single-Ended Output Two-Stage Op Amp



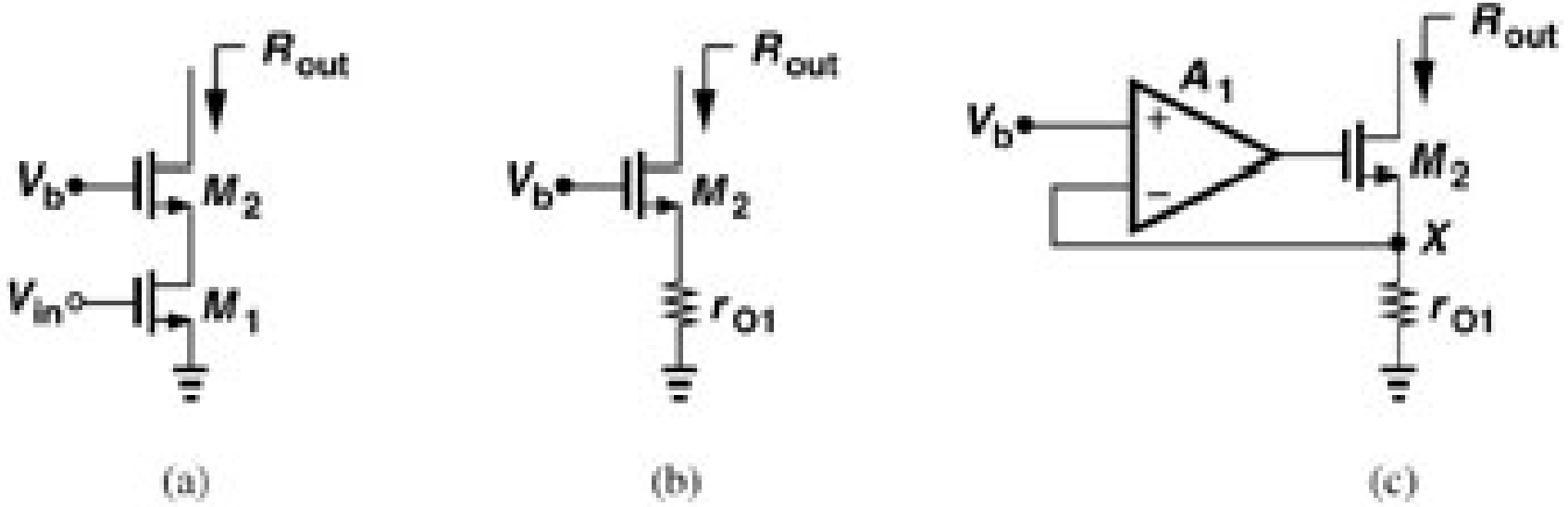
Simple Implementation of a Two-Stage Op-Amp



Two-Stage Op-Amp employing Cascading

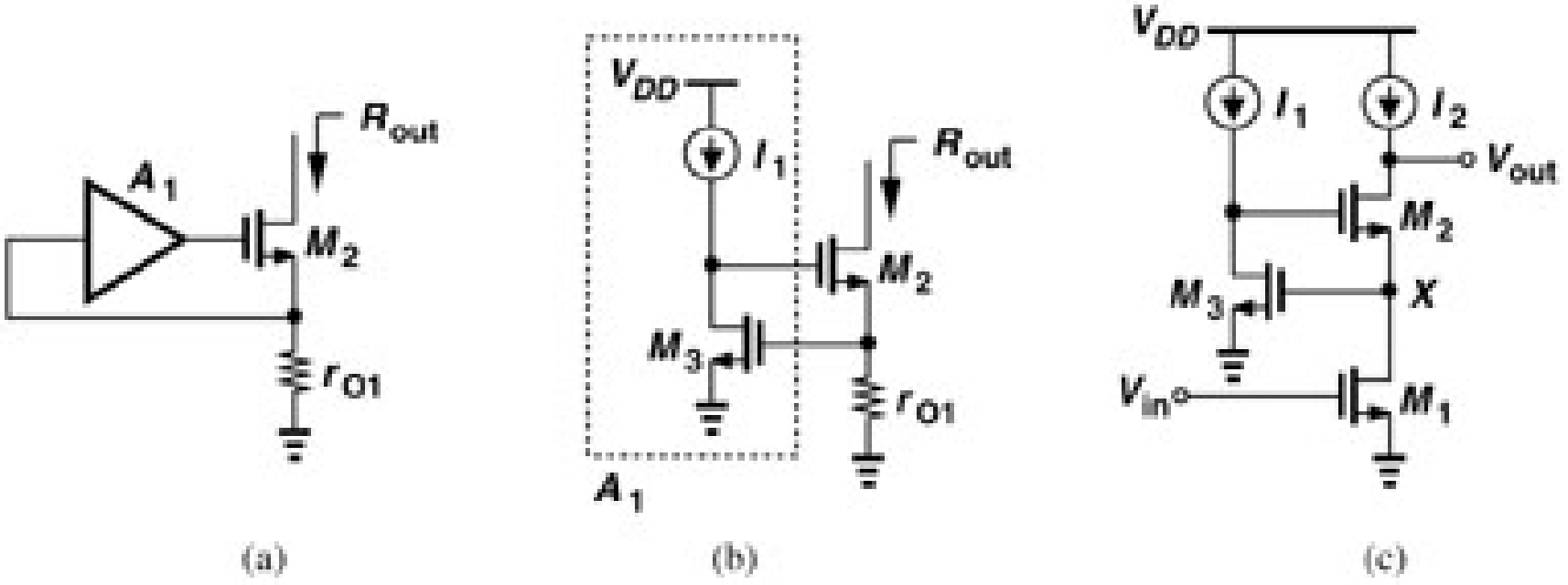


Output Impedance Enhancement With Feedback

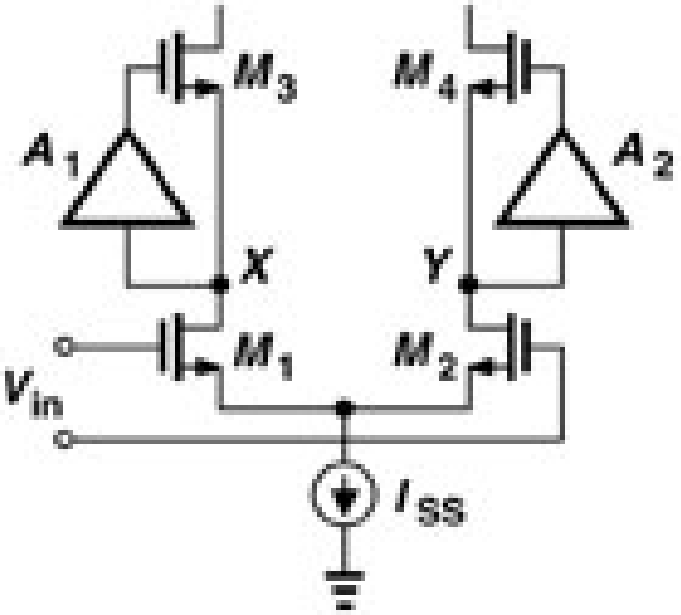


$$Rout = A_1 g_{m2} r_{o2} r_{o1}$$

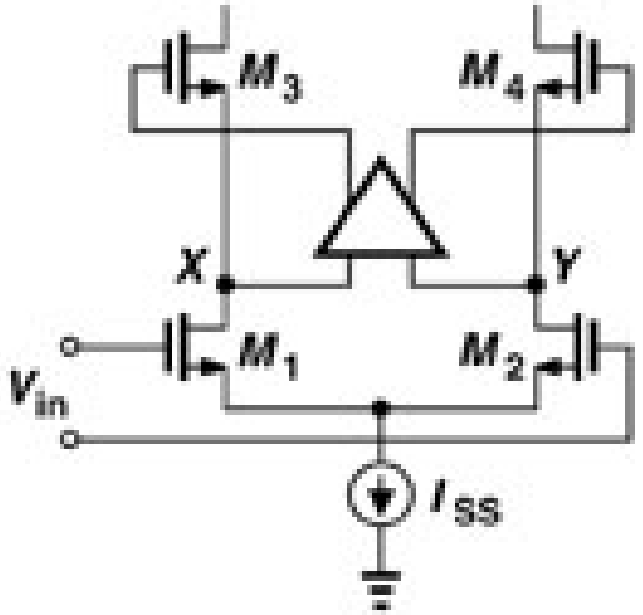
Gain Boosting in Cascode Stage



Differential Gain Boosting

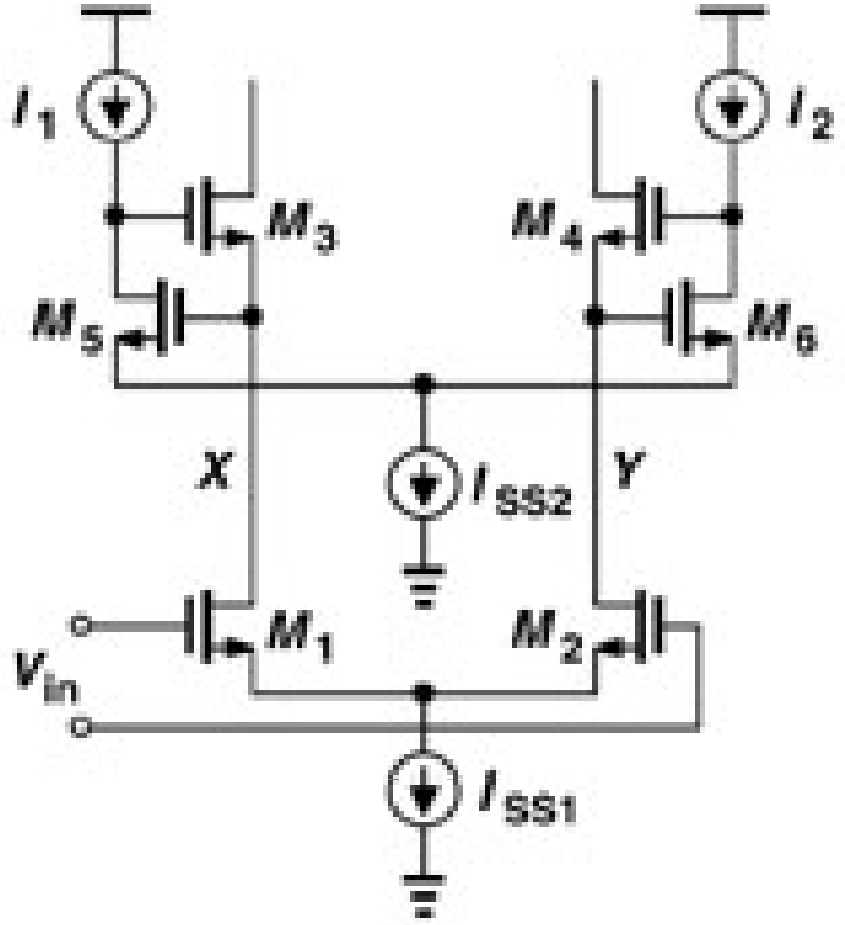


(a)

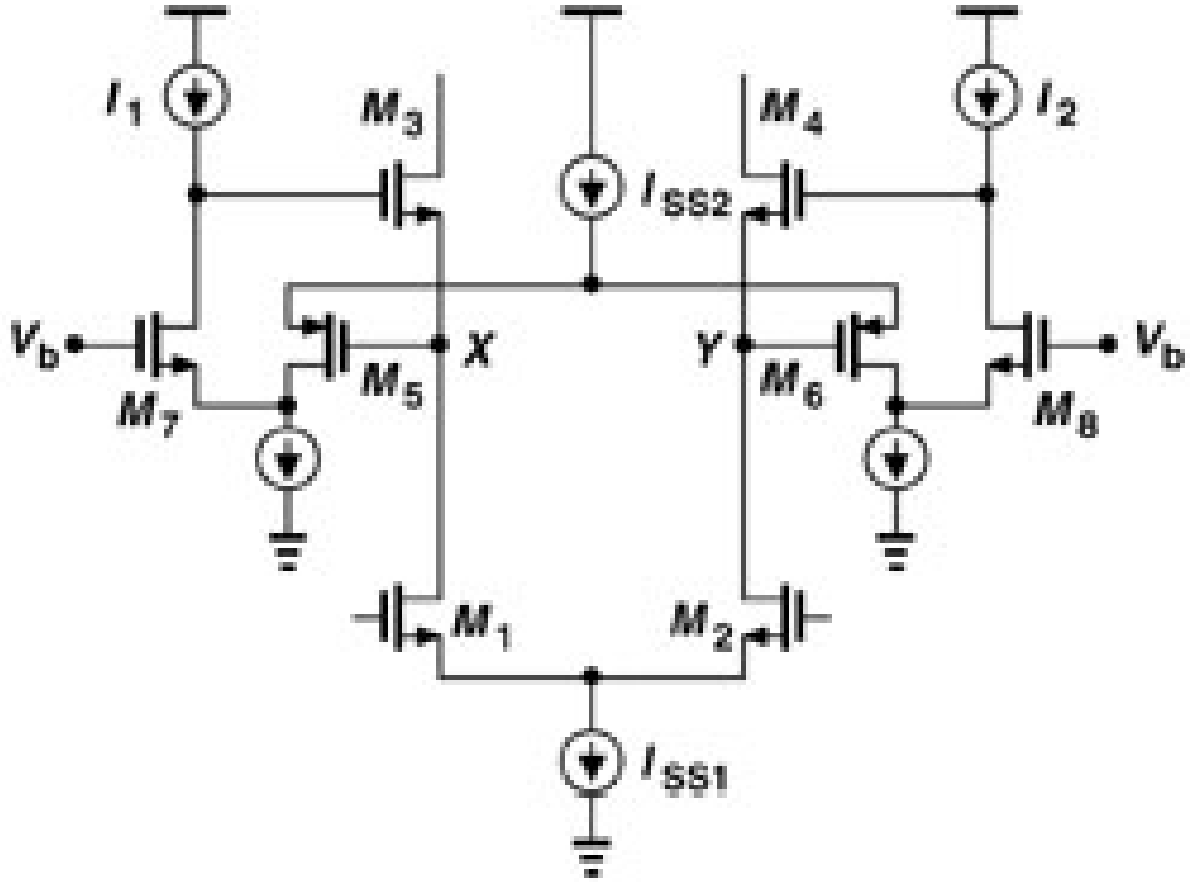


(b)

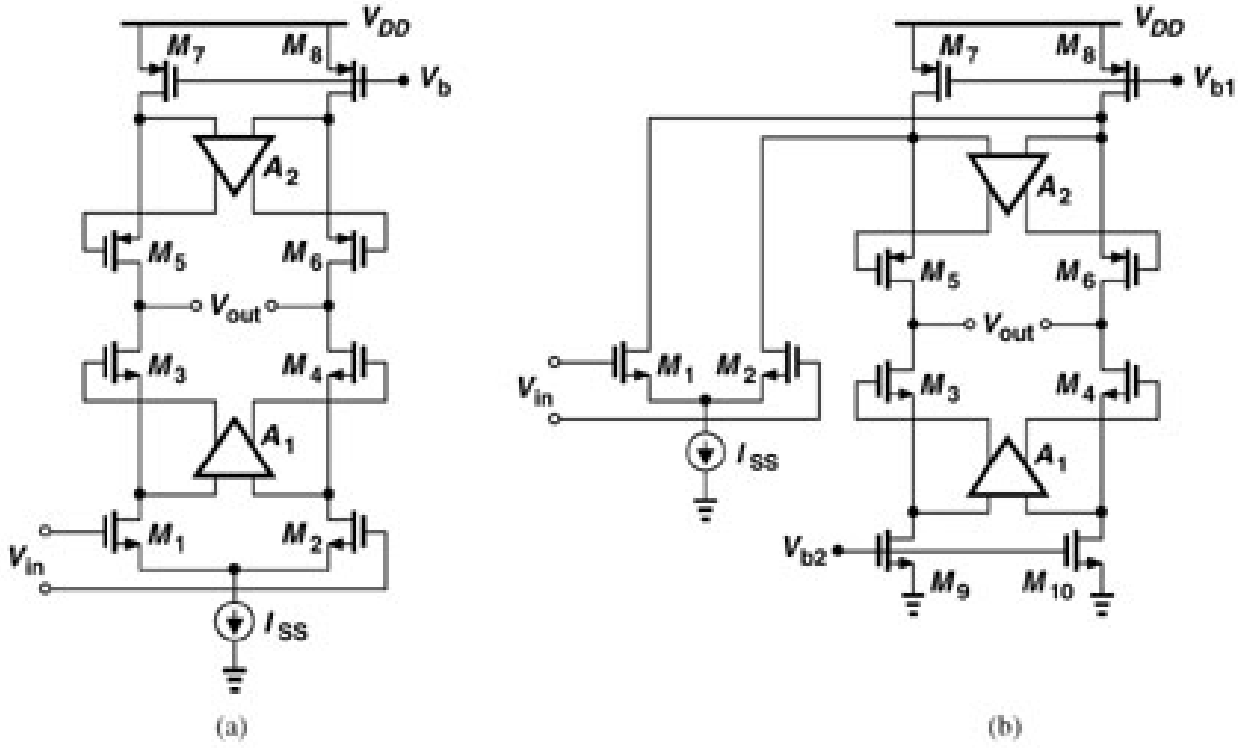
Differential Gain Boosting (cont.)



Differential Gain Boosting (cont.)



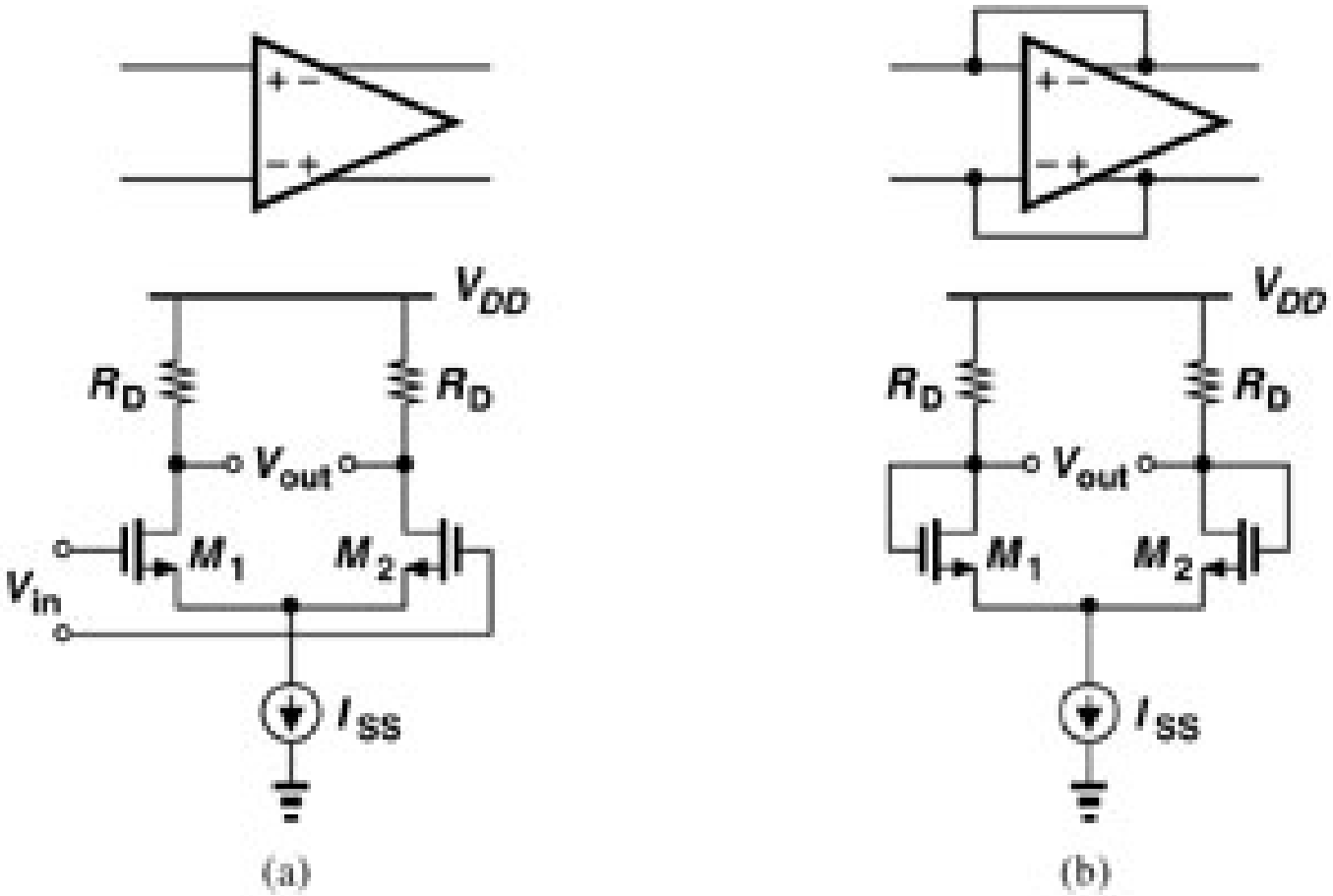
Gain Boosting applied to both signal path and load devices



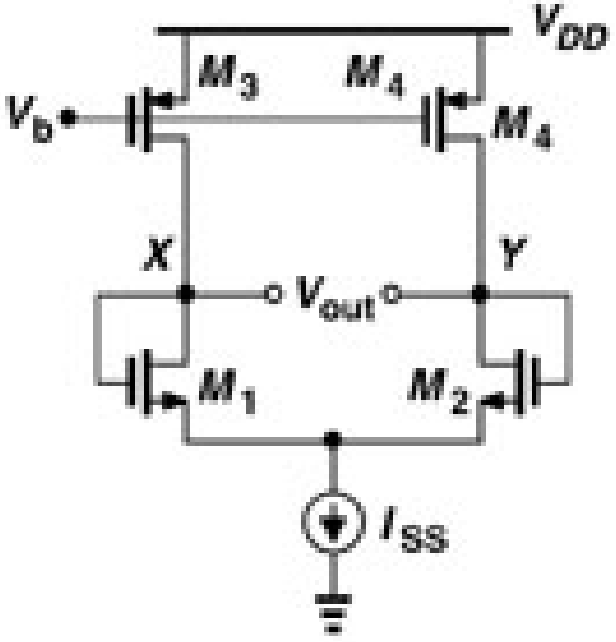
Comparison

	Gain	Output Swing	Speed	Power Dissipation	Noise
Telescopic	Medium	Medium	Highest	Low	Low
Folded-Cascode	Medium	Medium	High	Medium	Medium
Two-Stage	High	Highest	Low	Medium	Low
Gain-Boosted	High	Medium	Medium	High	Medium

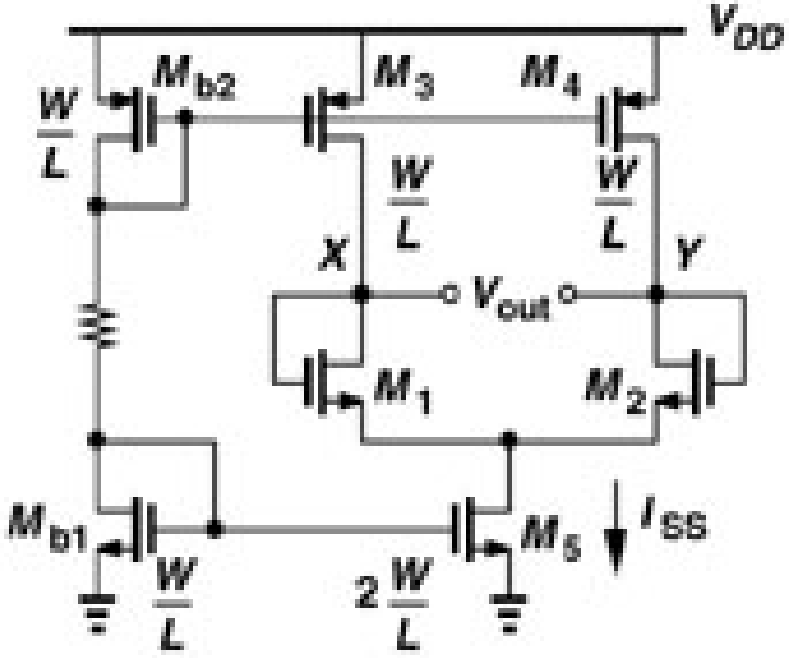
Common-Mode Feedback



Common-Mode Feedback (cont.)

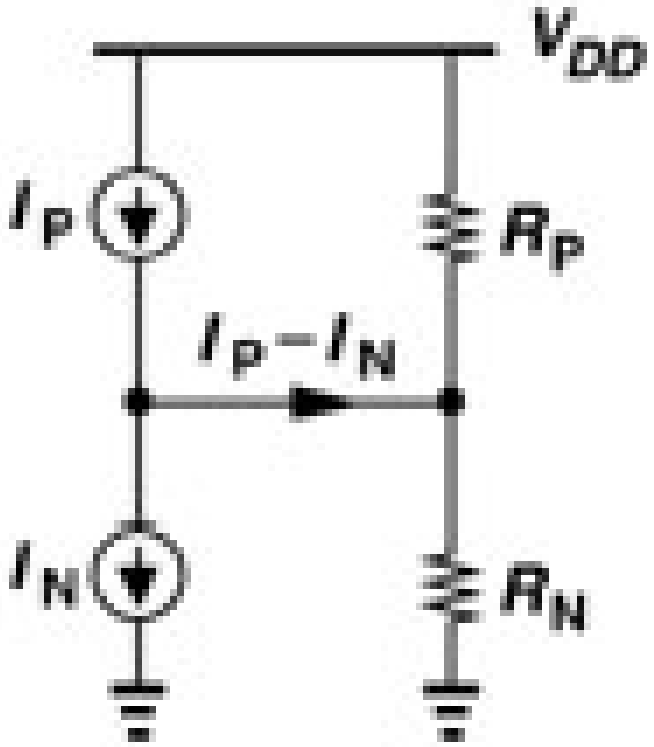


(a)

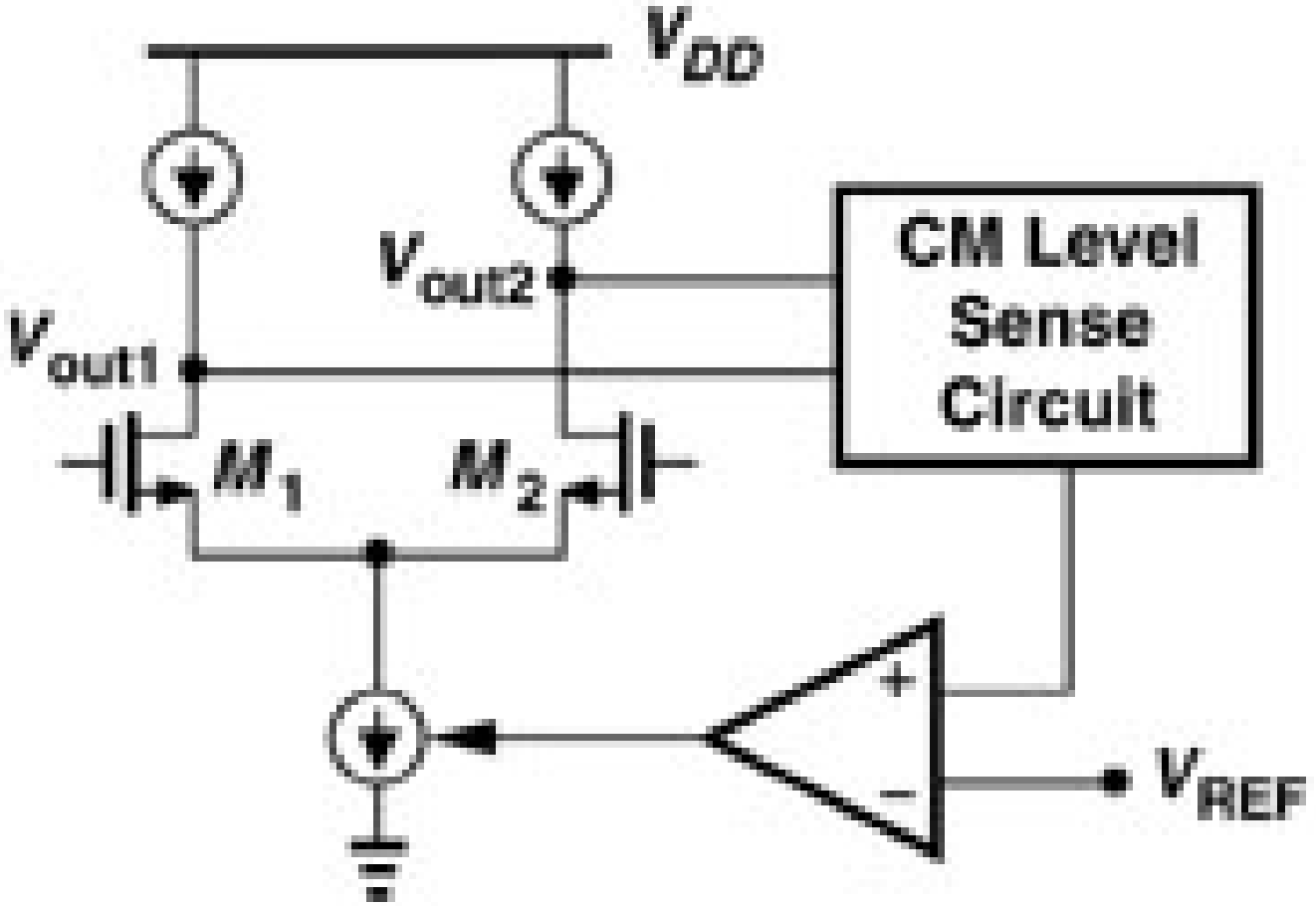


(b)

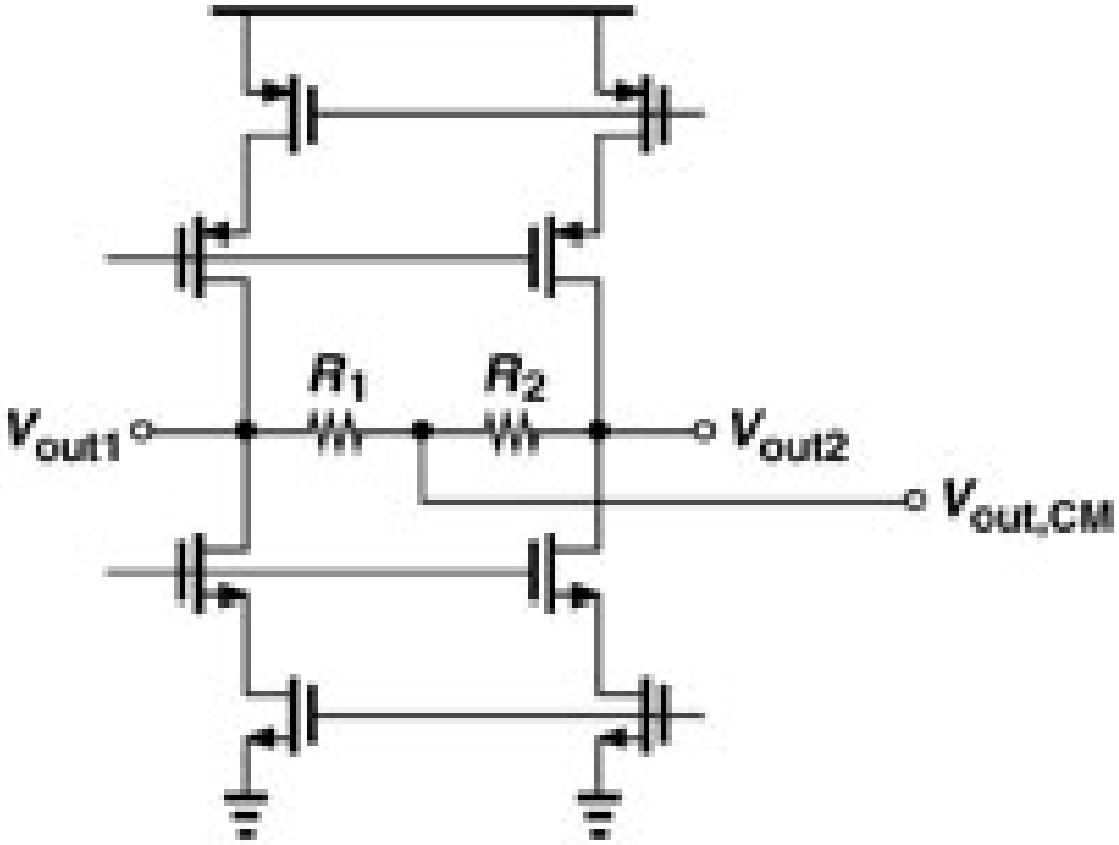
High Gain Amp Model



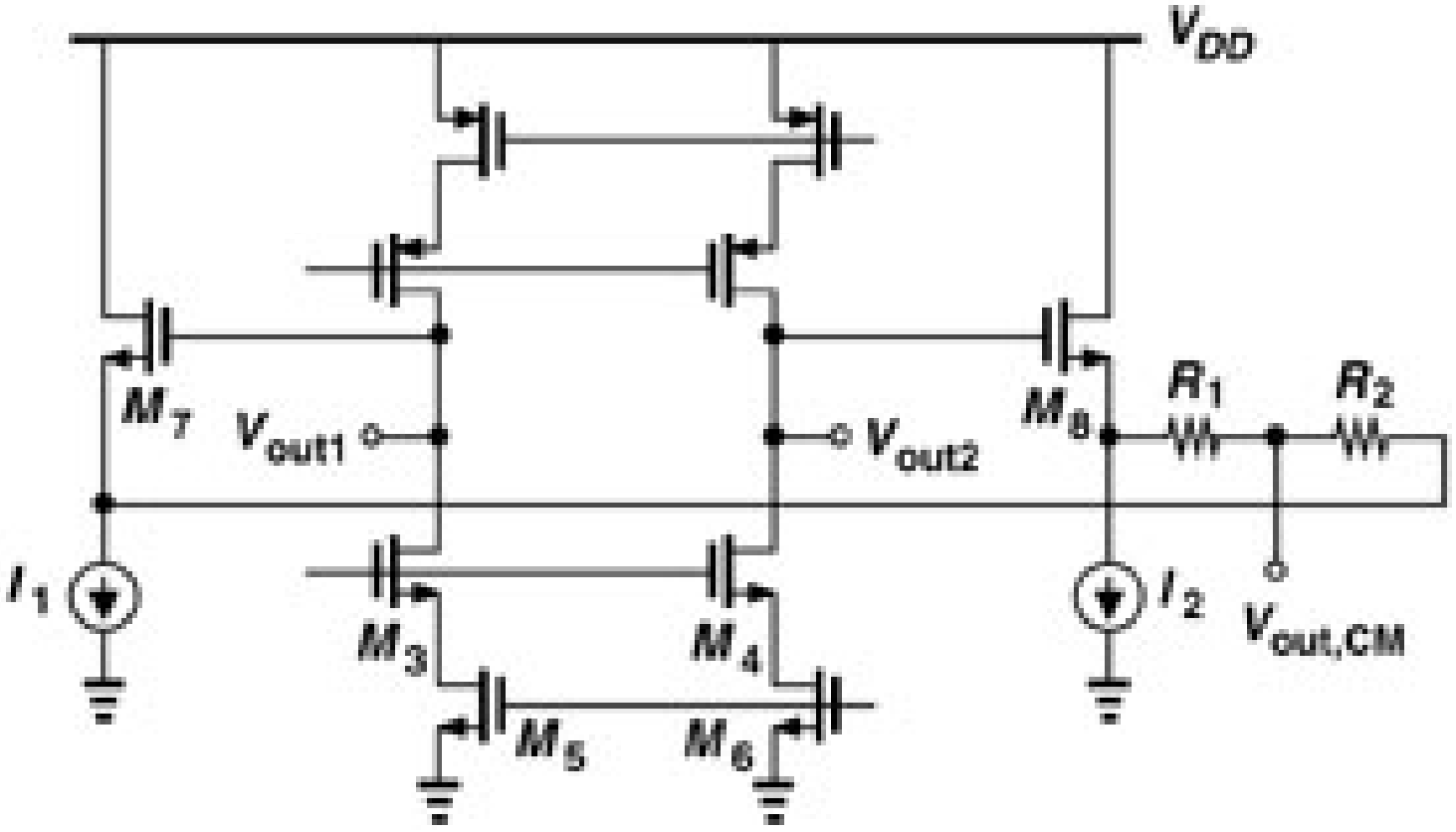
Common-Mode Feedback (cont.)



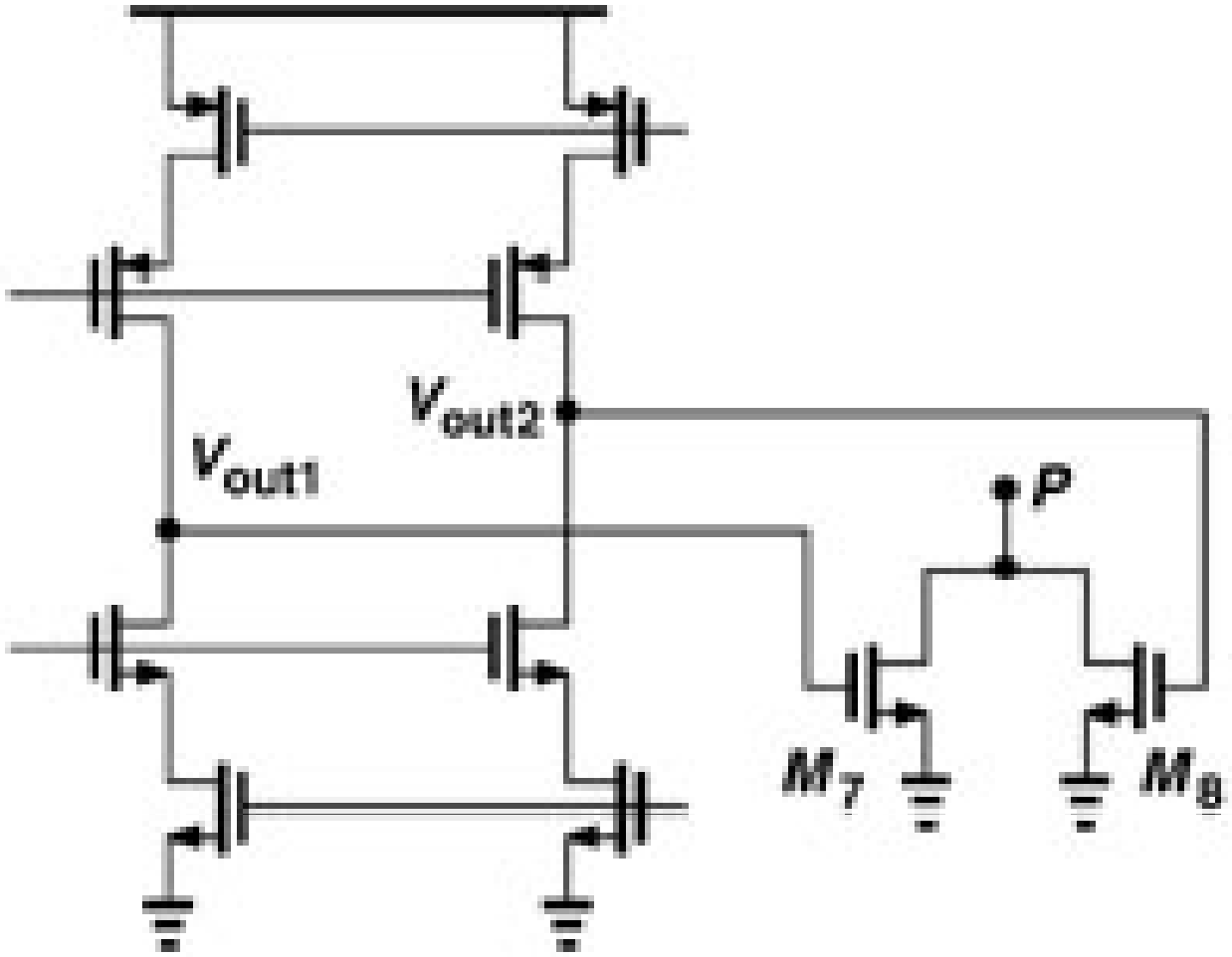
Resistive Sensing



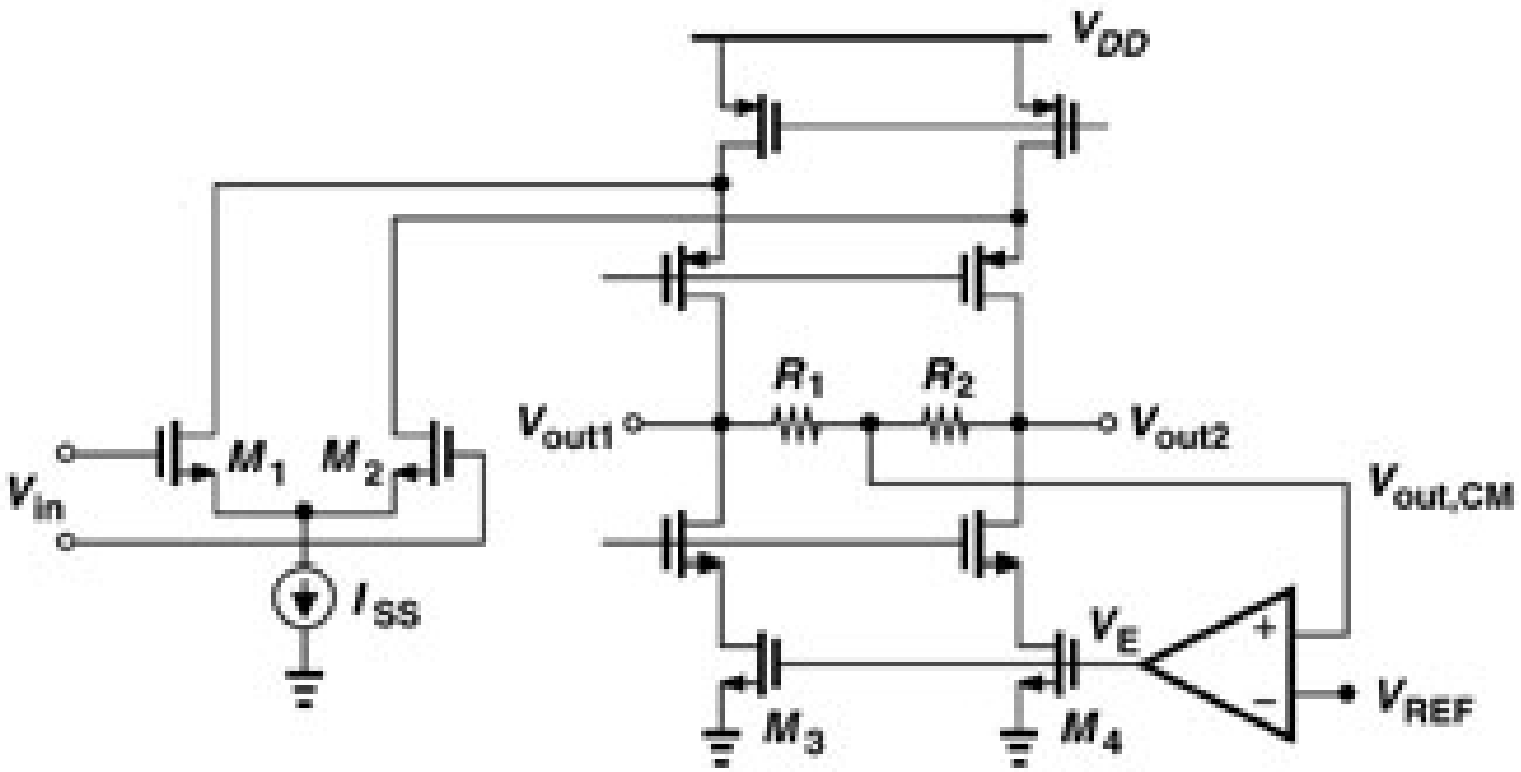
Source-Follower Buffering



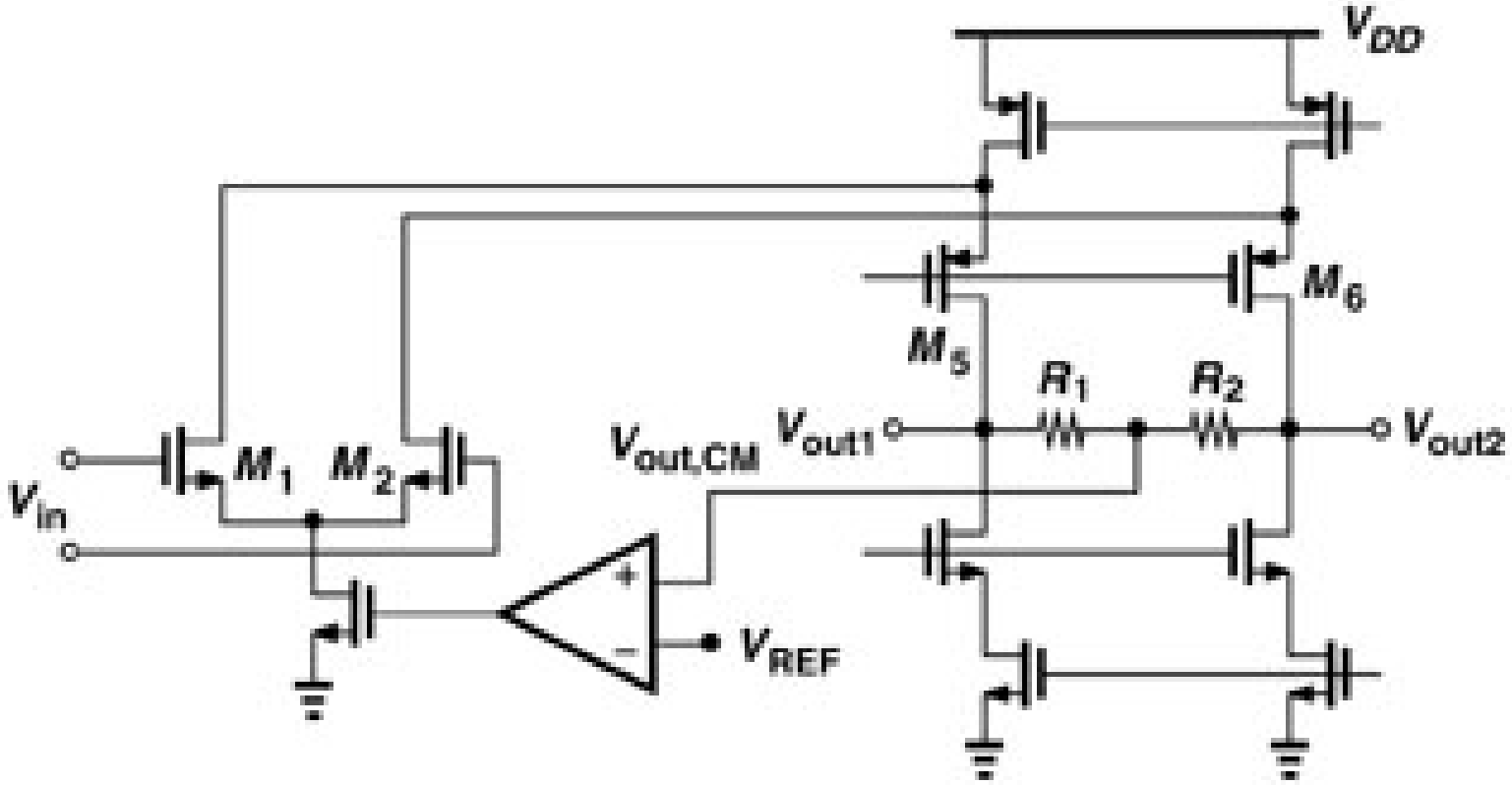
Deep Triode FET CM Sensing



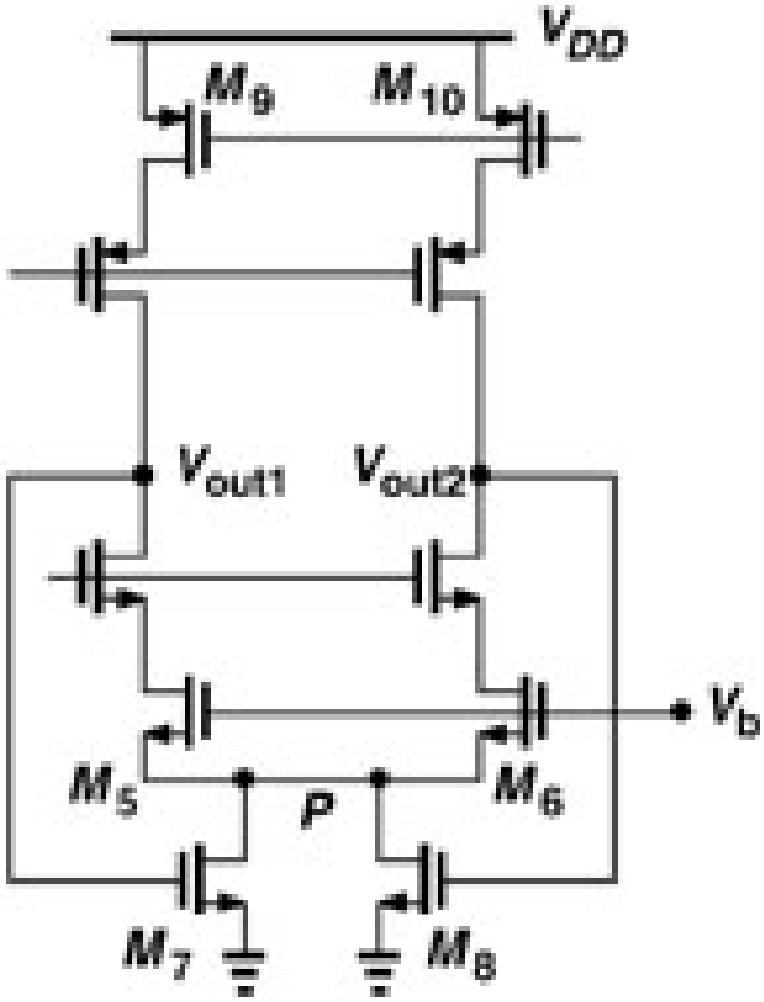
CMFB Example



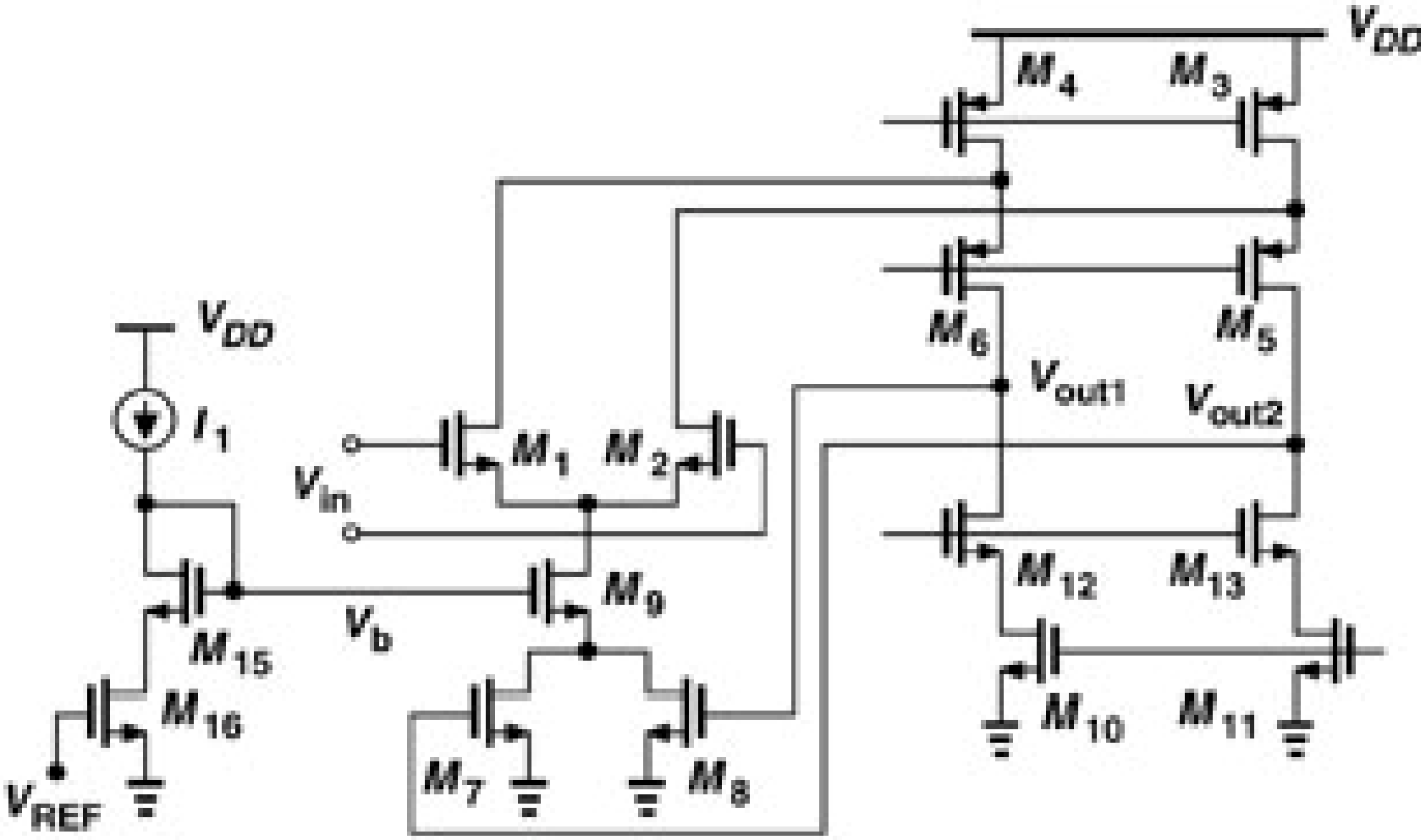
Alternative CMFB for Folded Cascode



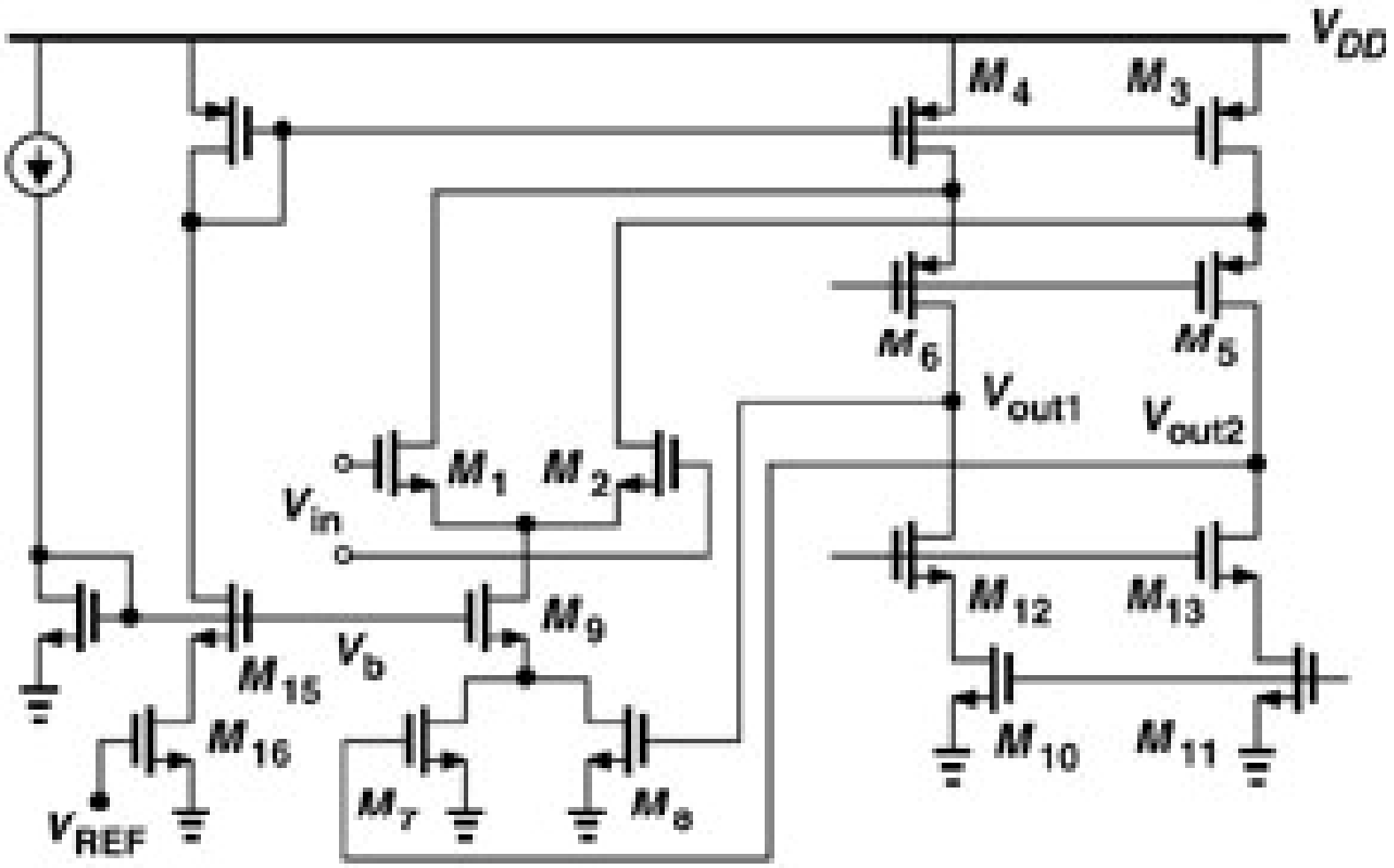
Simplified CMFB with Triode Devices



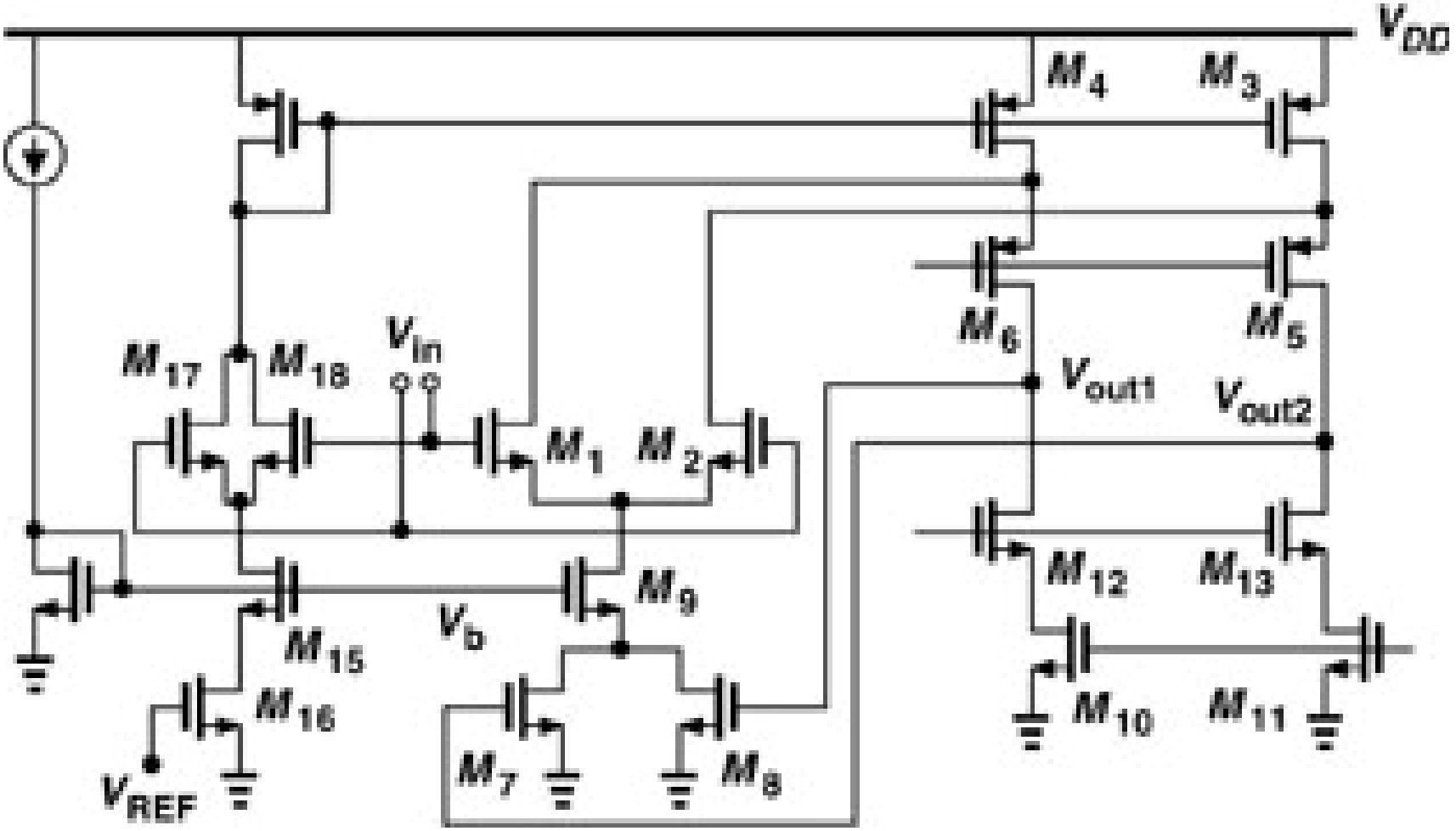
CMFB Triode Example with Reference



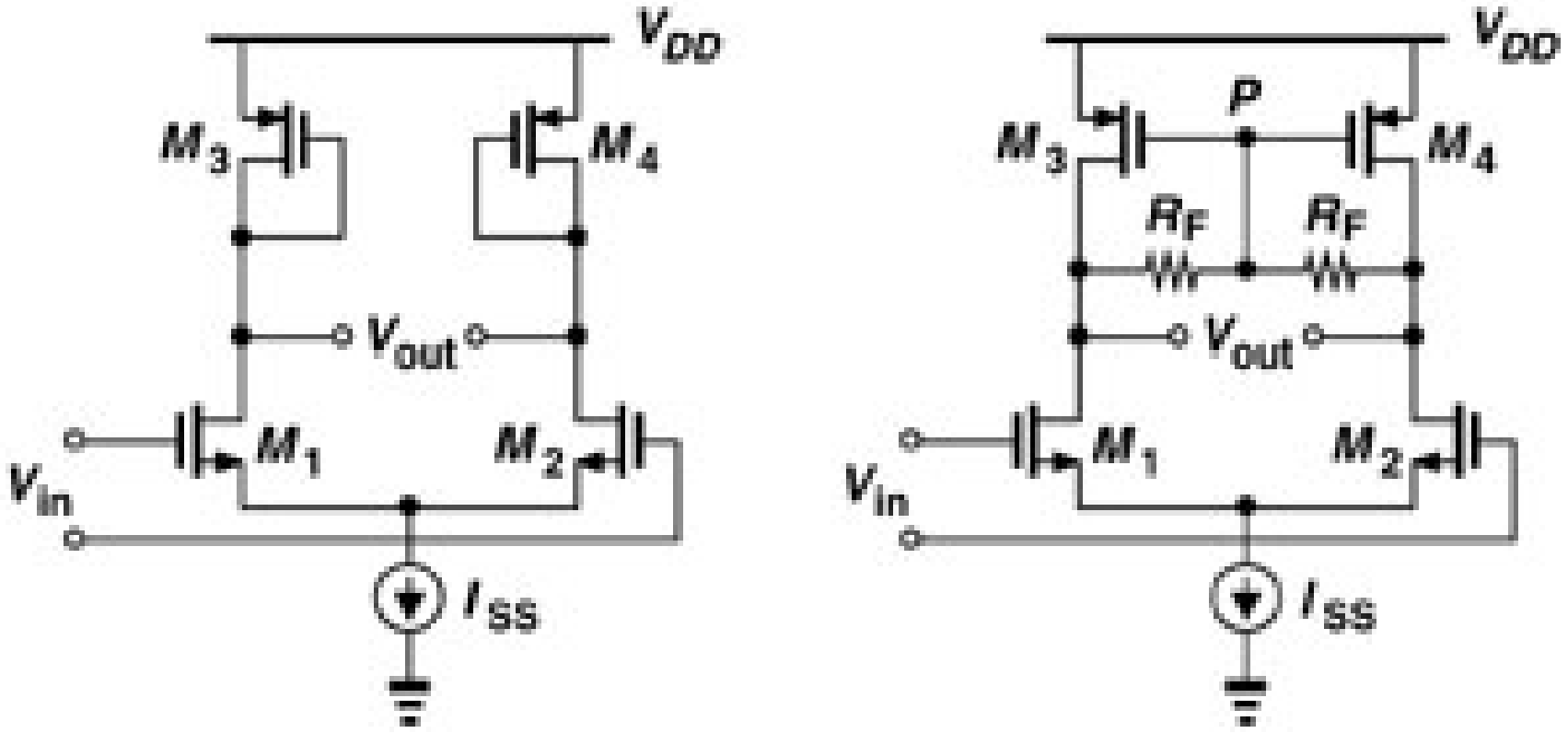
CMFB Triode Example with Reference (cont.)



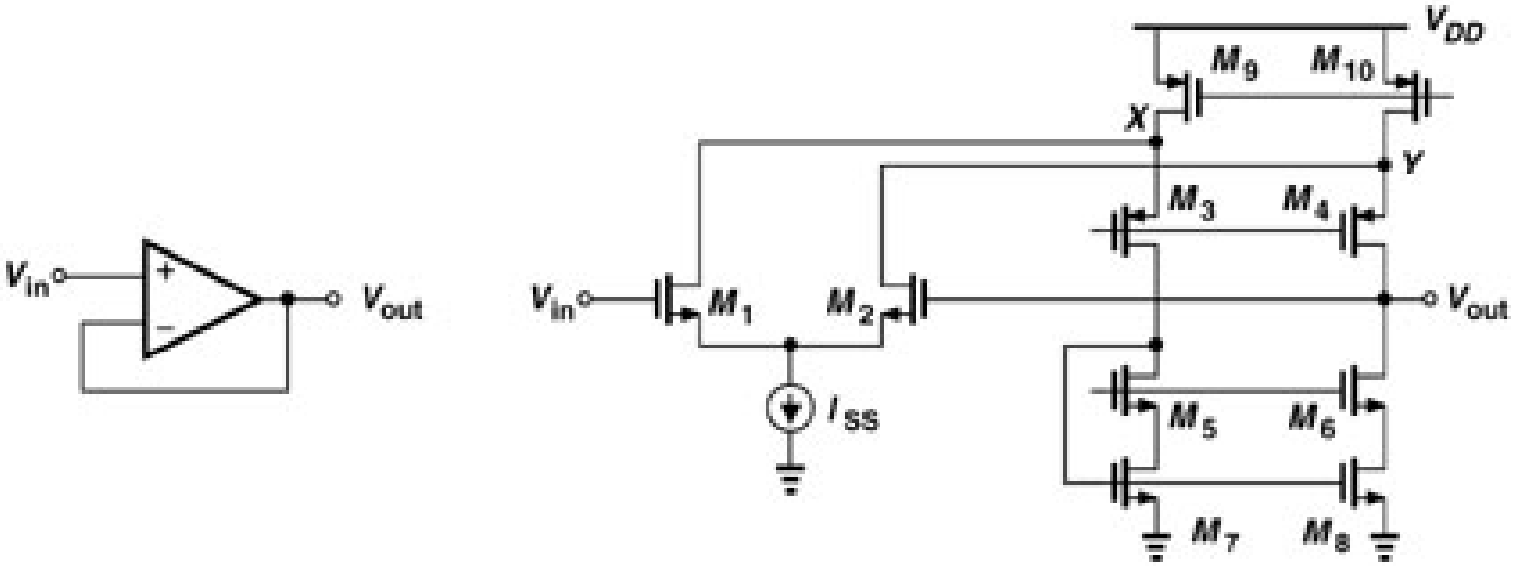
CMFB Triode Example with Reference (cont.)



Differential Pair with CMFB

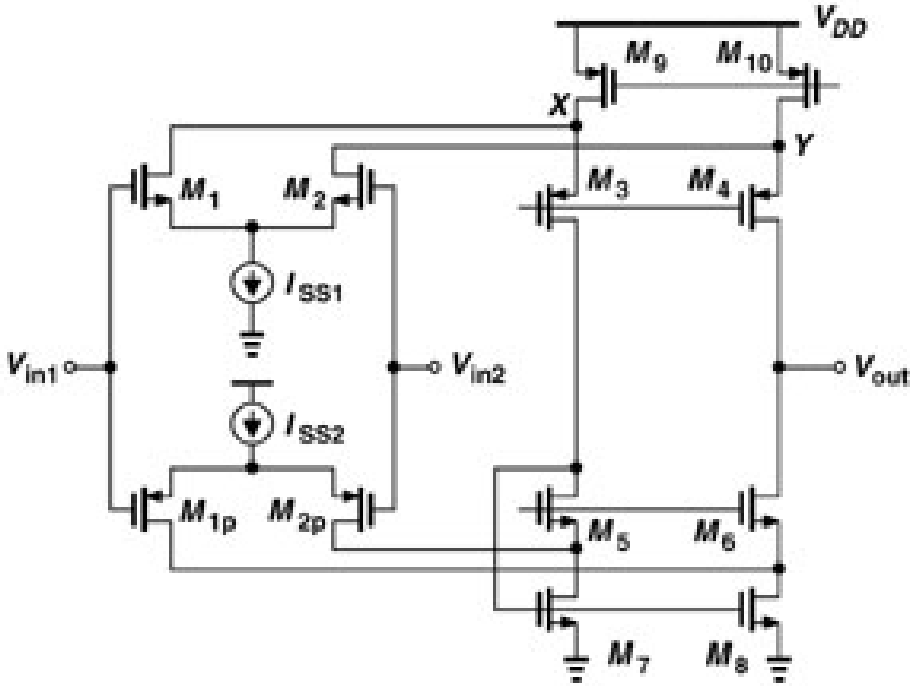


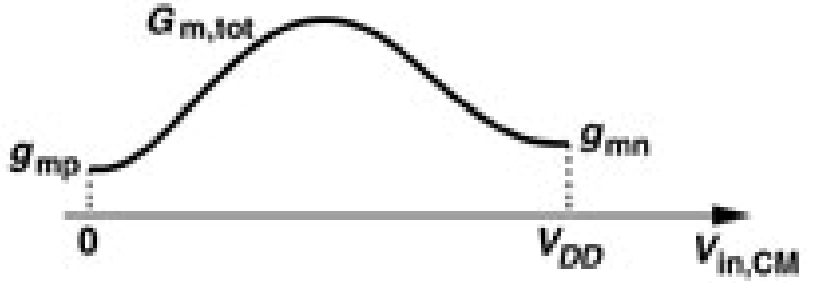
Input Range Limitations



Unity-Gain Buffer

Extension of Input CM Range

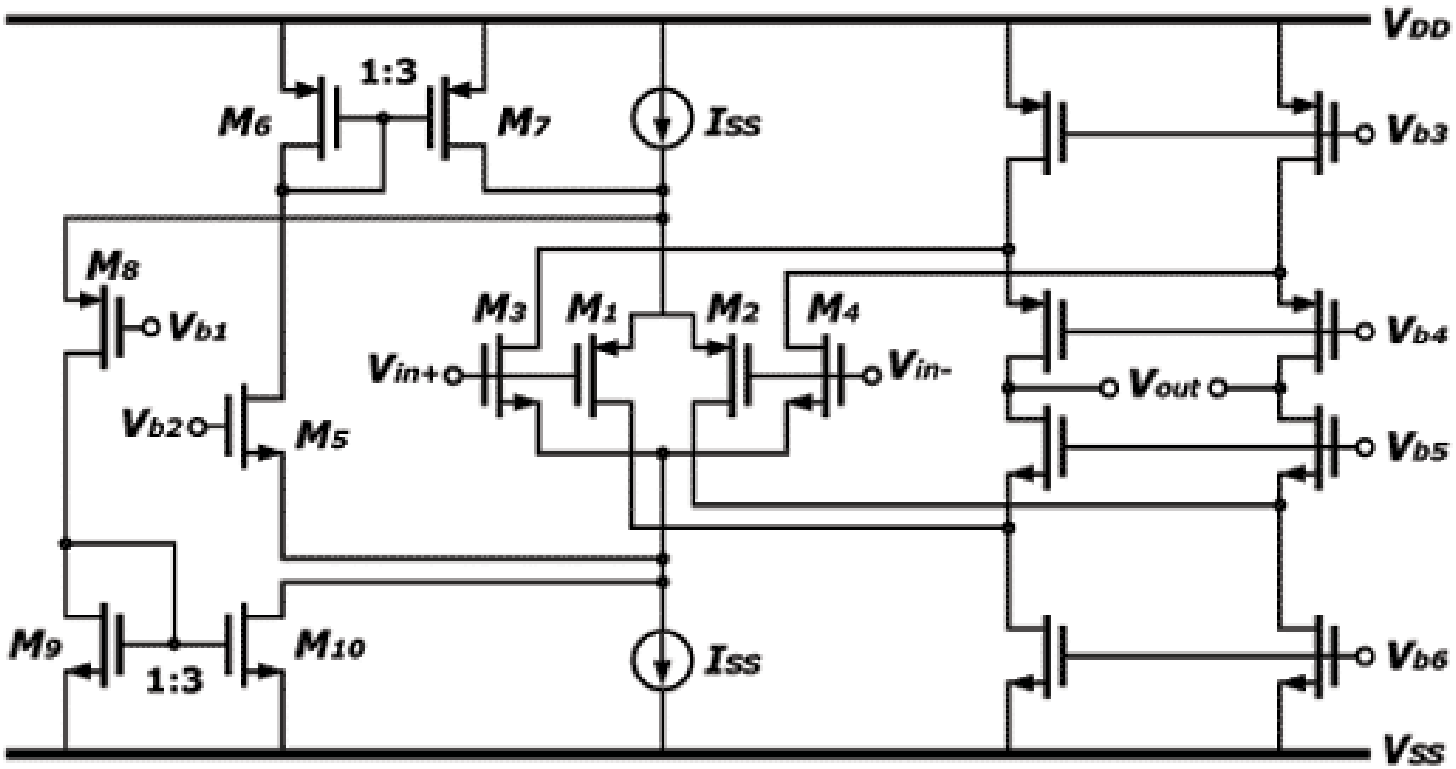




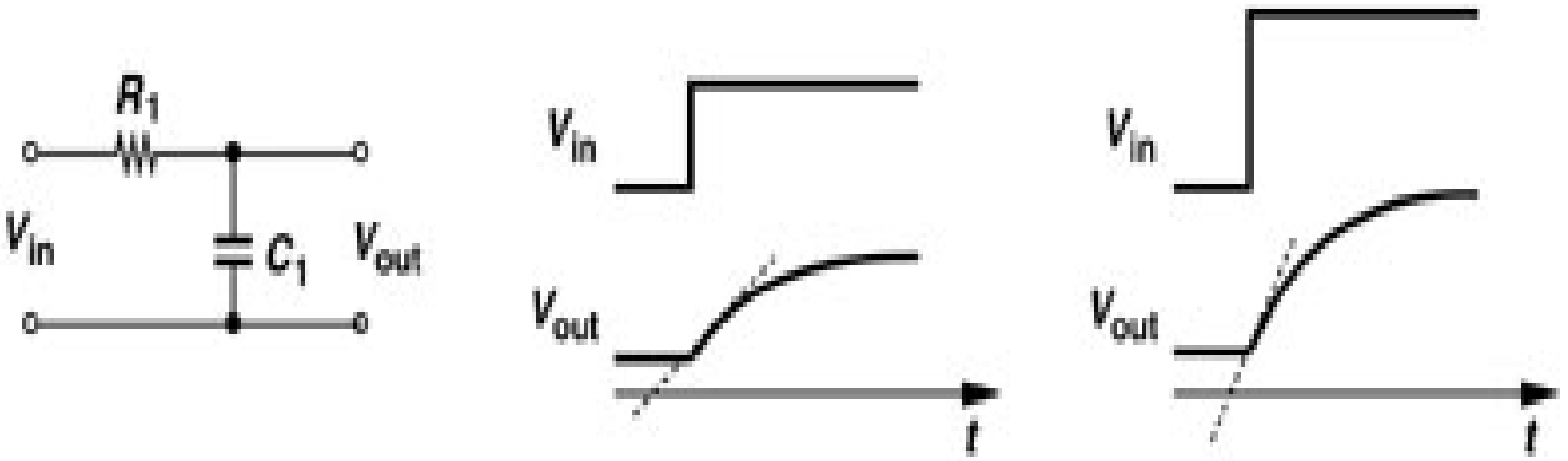
Variation of equivalent transconductance with the input CM level

Two Folded Cascode op amp

with constant equivalent transconductance

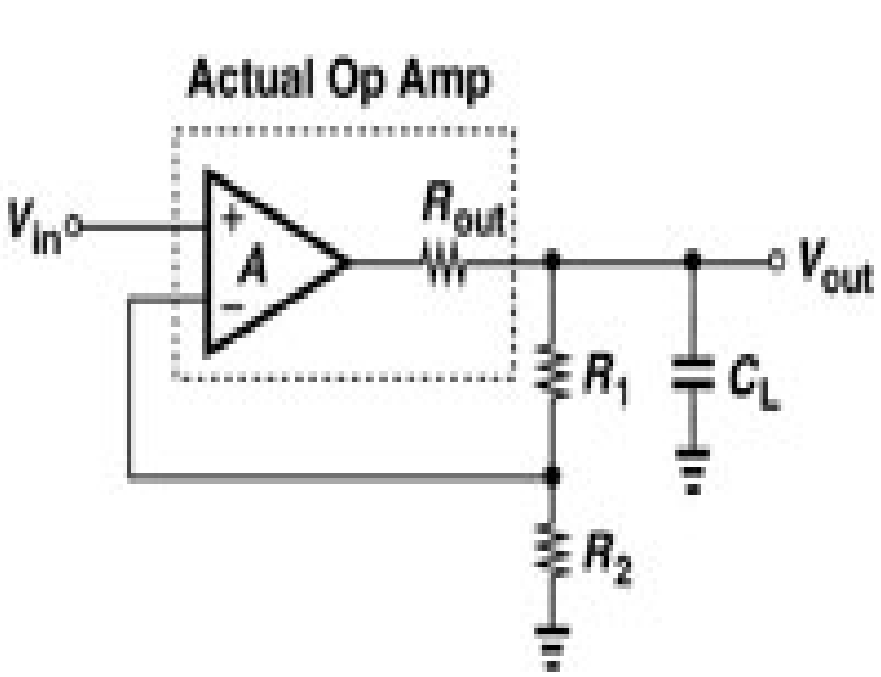


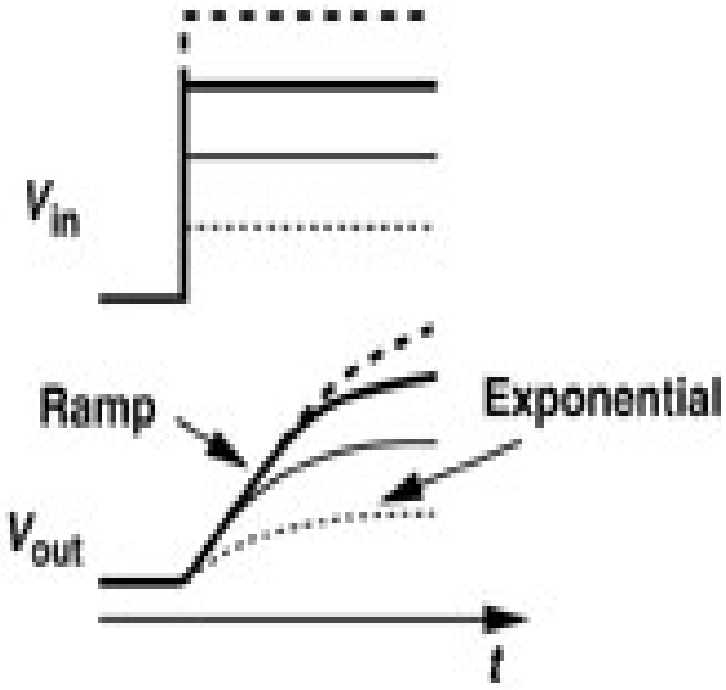
Slew Rate



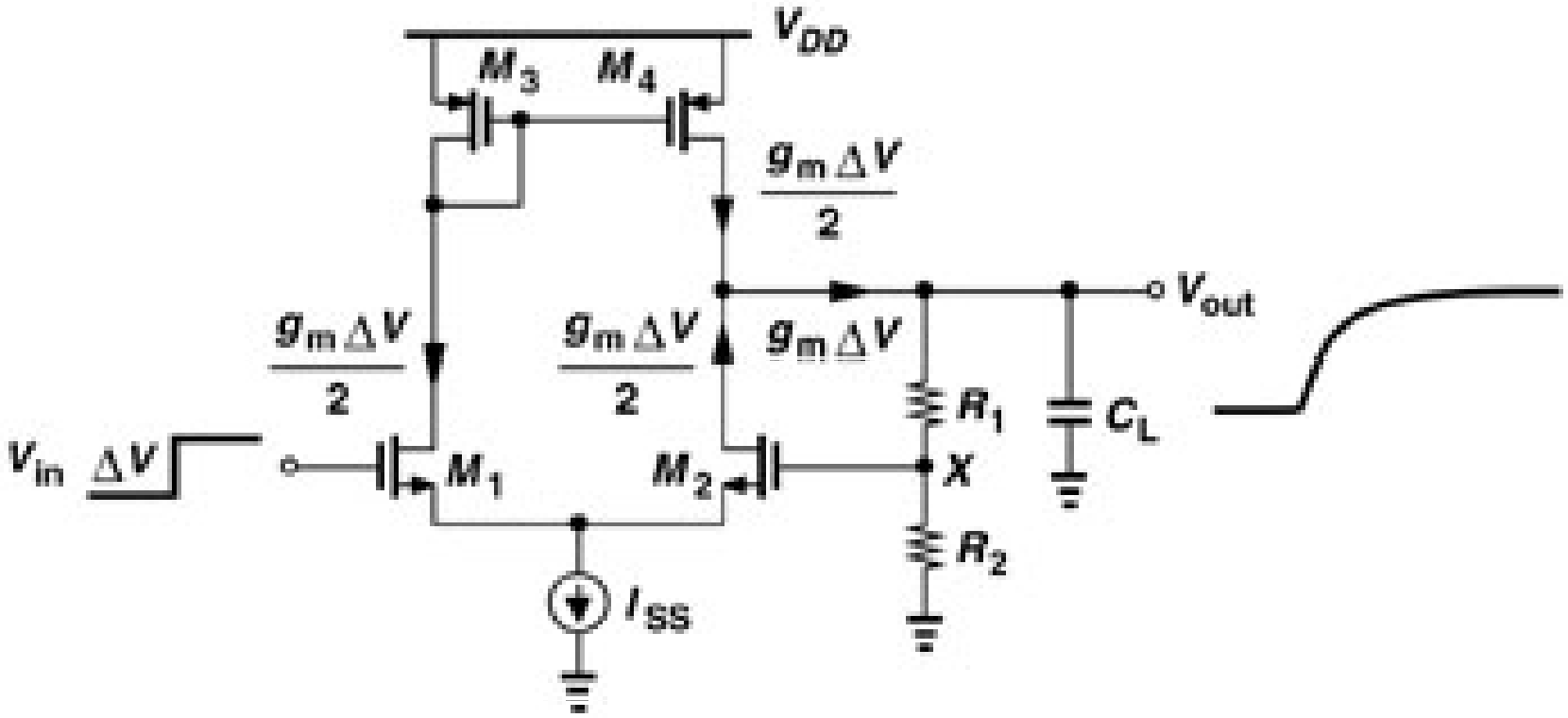
Linear RC Step Response

Slewing in Op Amp

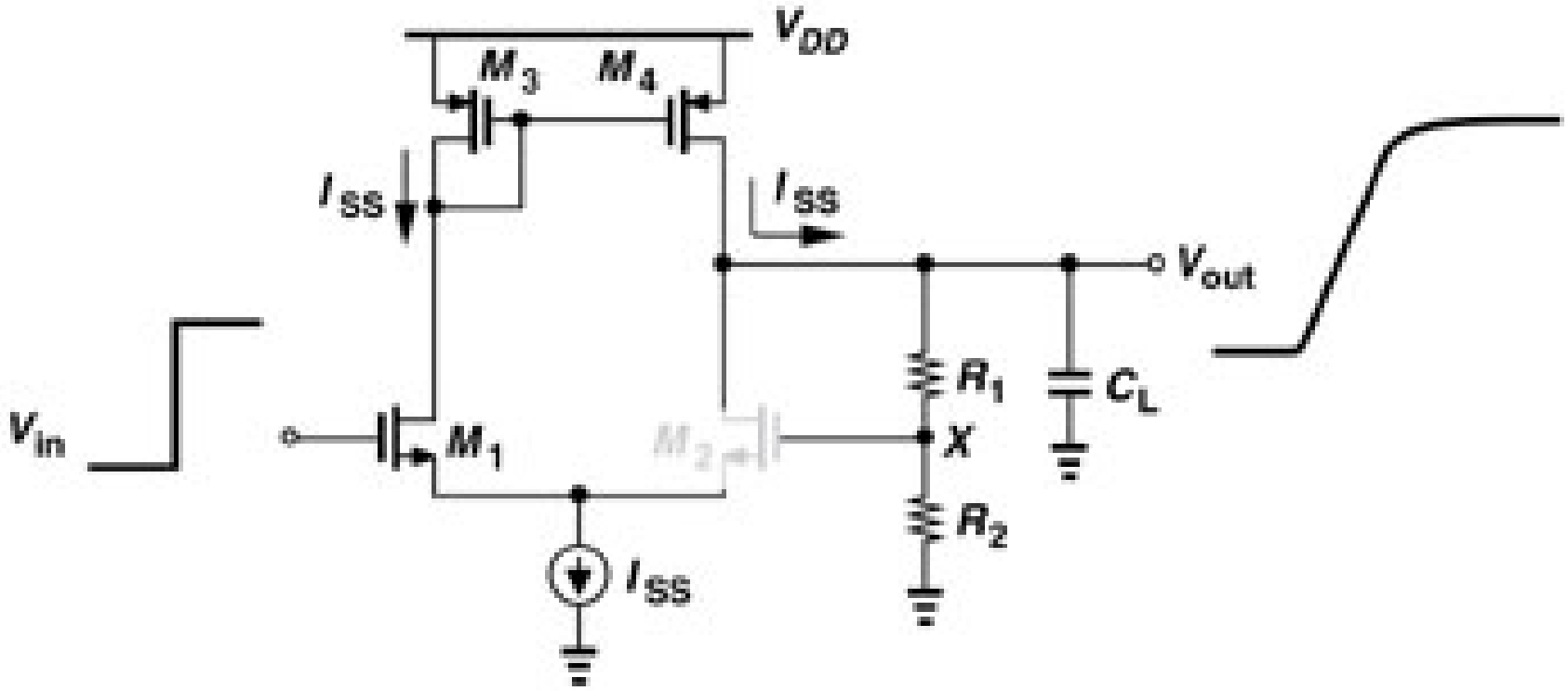




Small-Signal Operation of Op Amp

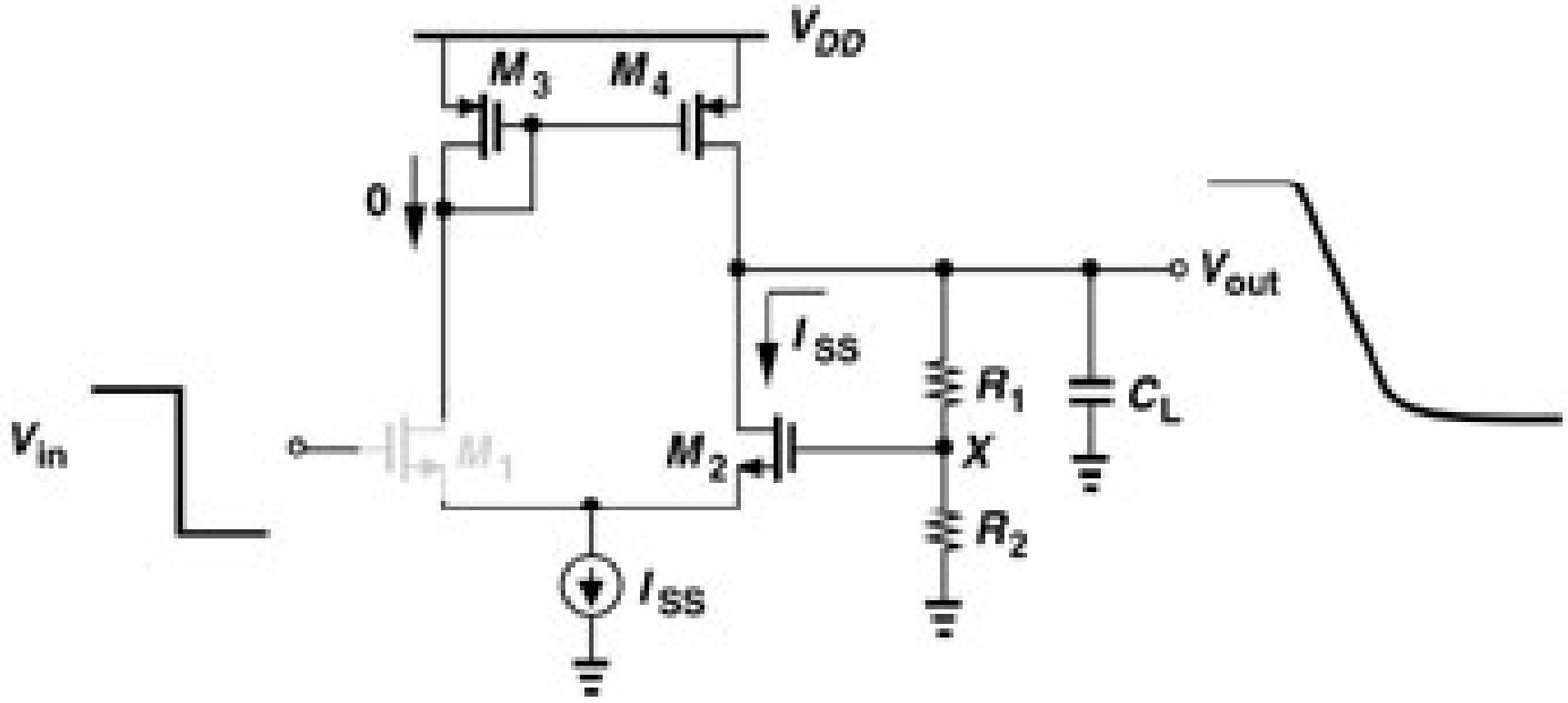


Op Amp Slewing

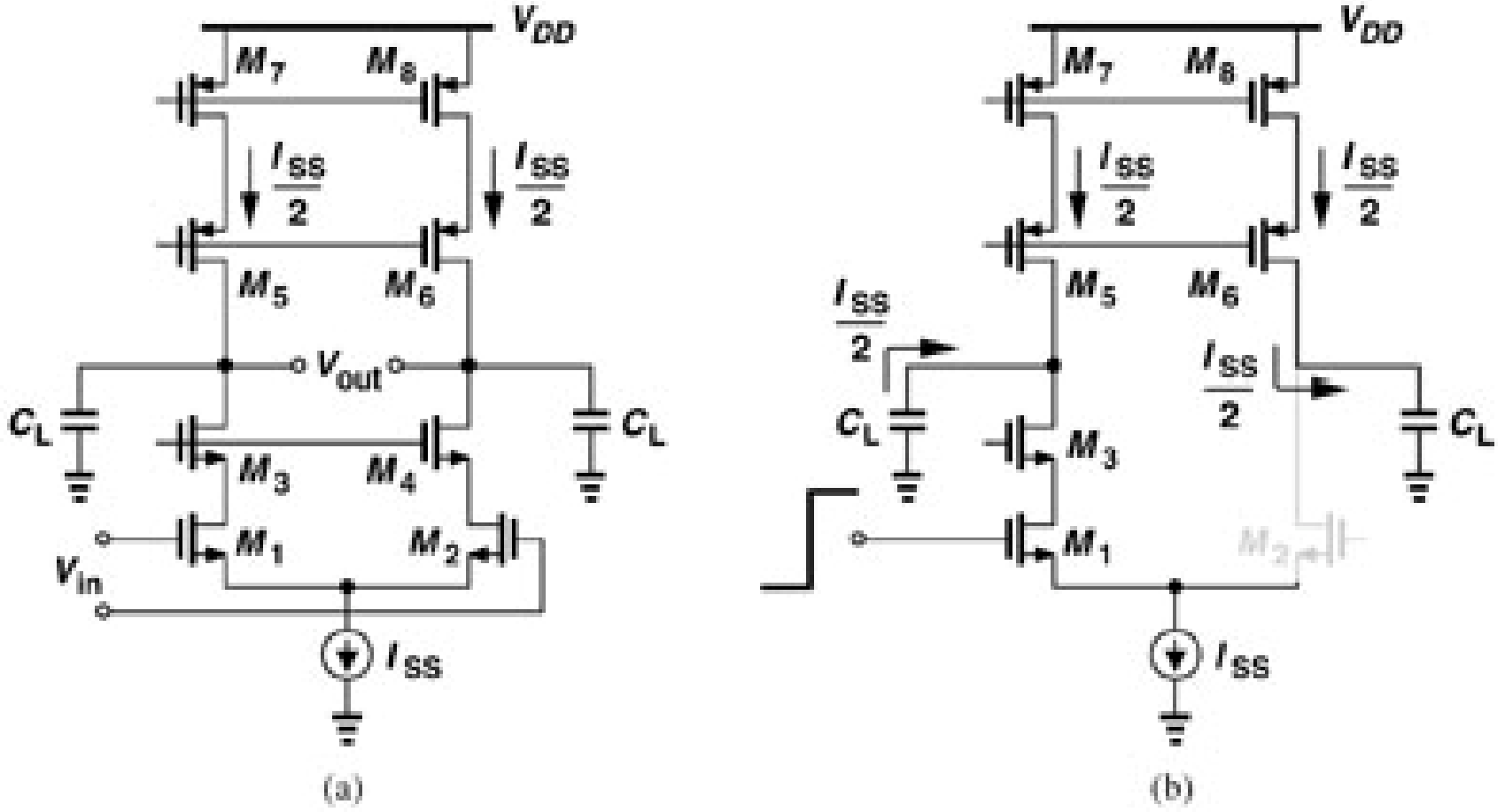


Slew rate = V/S = I/C

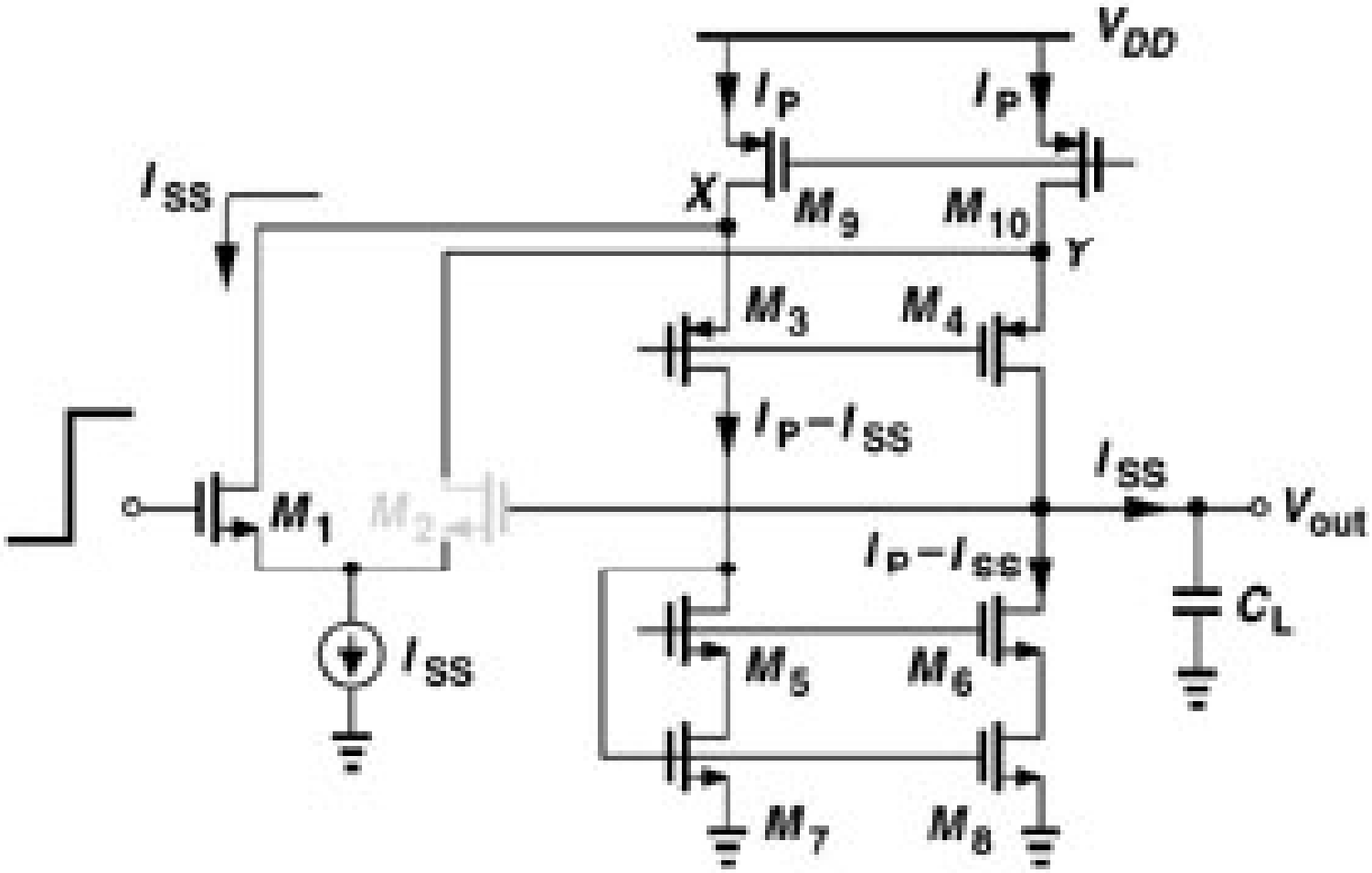
Op Amp Slewing (cont.)



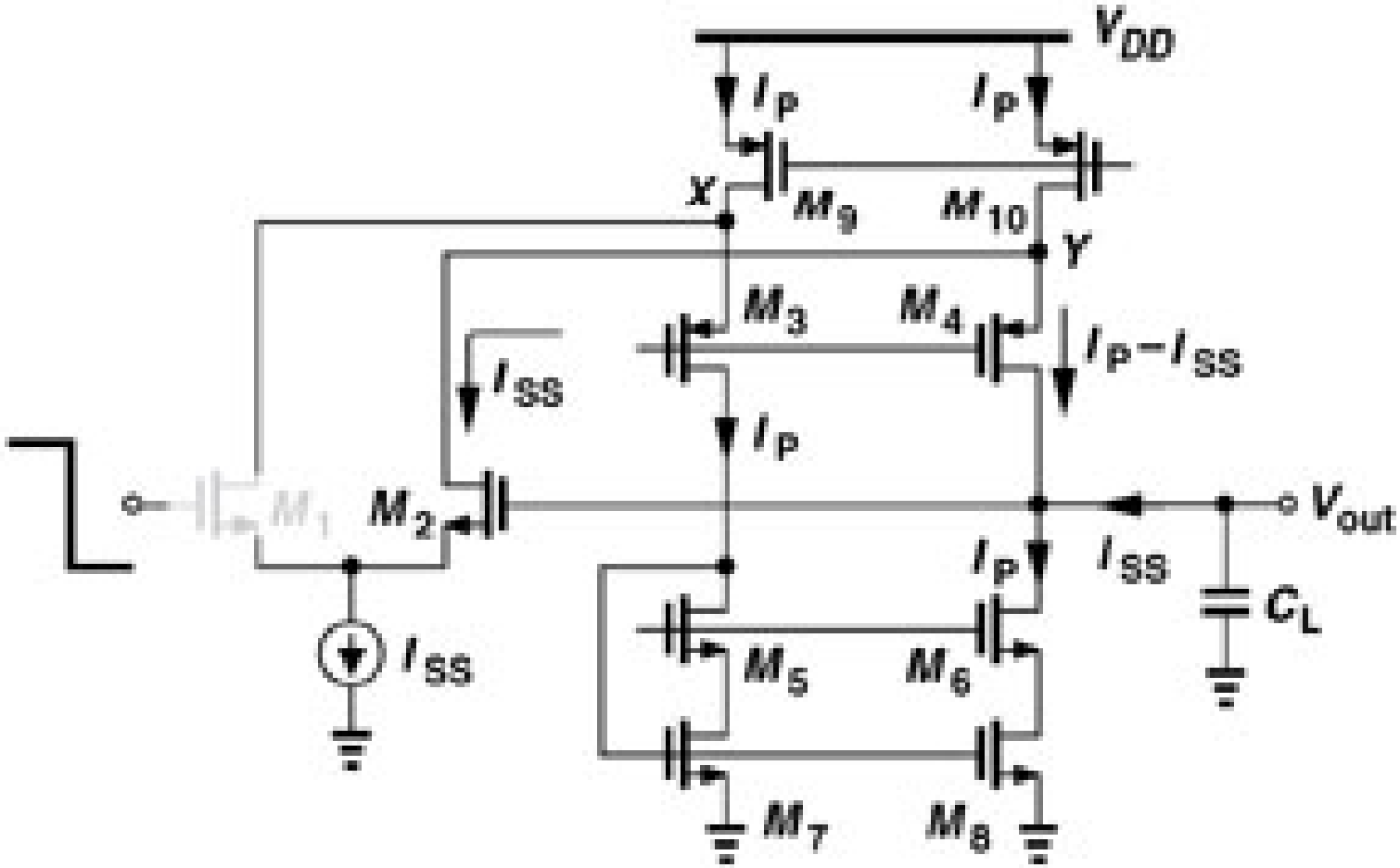
Slewing in Telescopic Op Amp



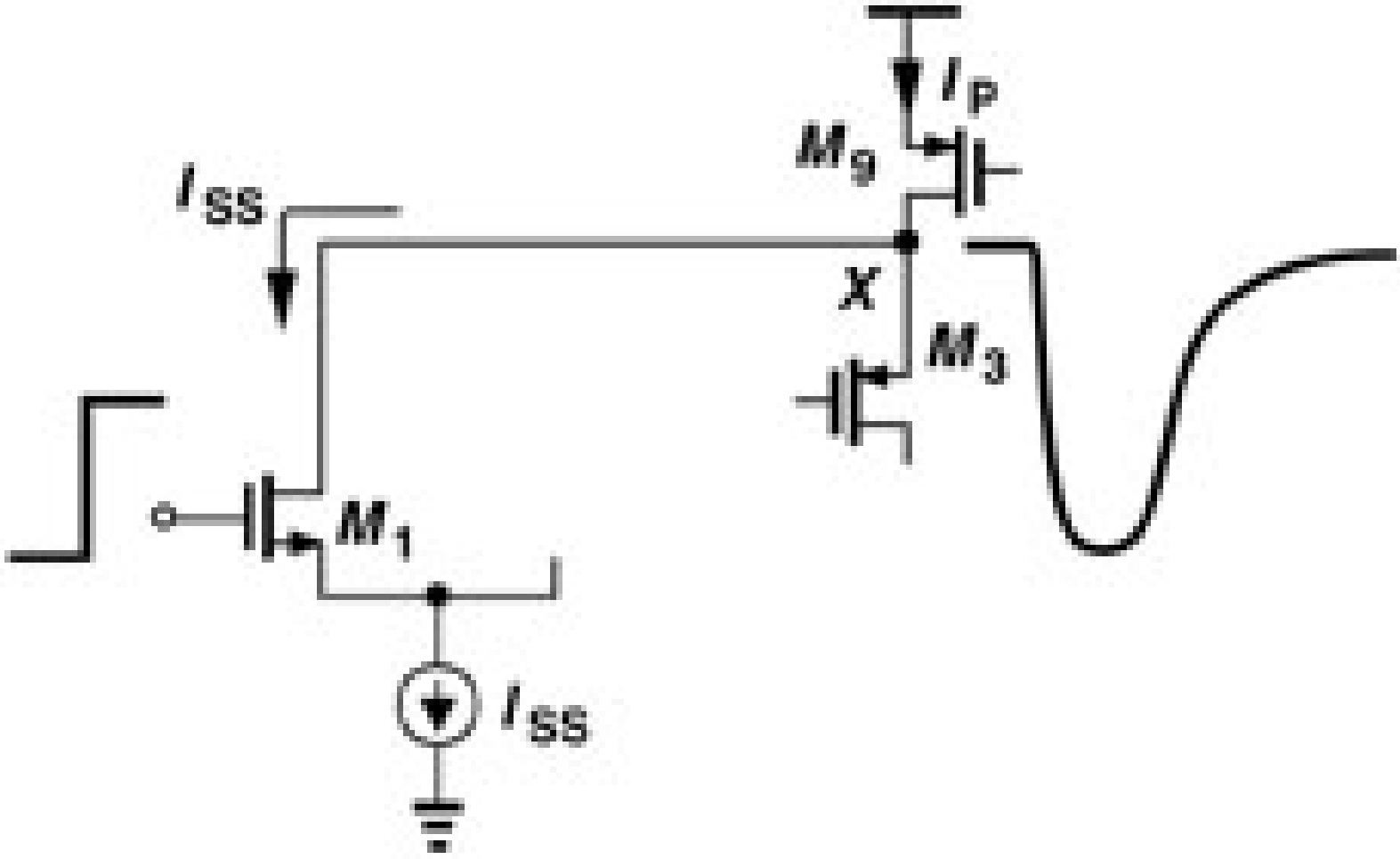
Folded-Cascode Slewing



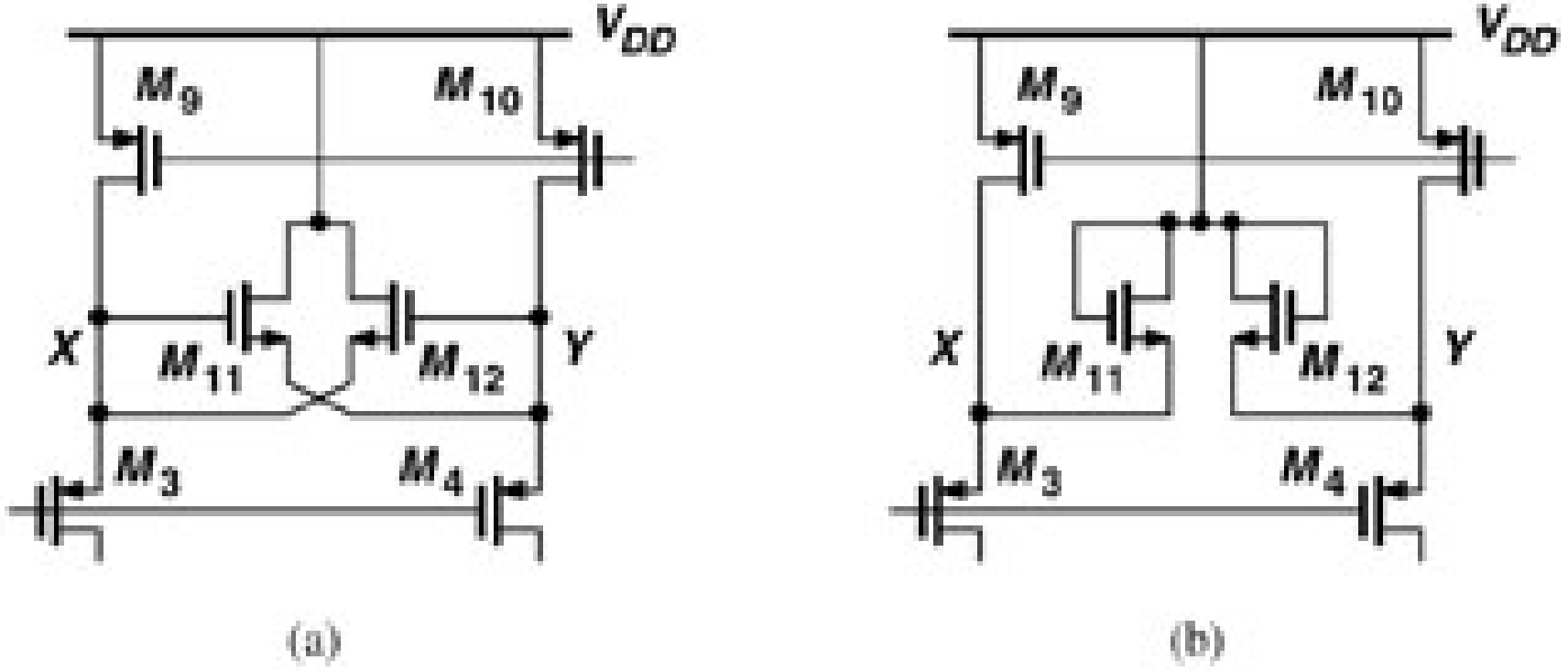
Folded-Cascode (cont.)



Slewing Recovery



Slewing Recovery (cont.)



Power Supply Rejection