Spring 2019 Purdue University

ECE 255: L29

MOS Differential Pair with Active Loads

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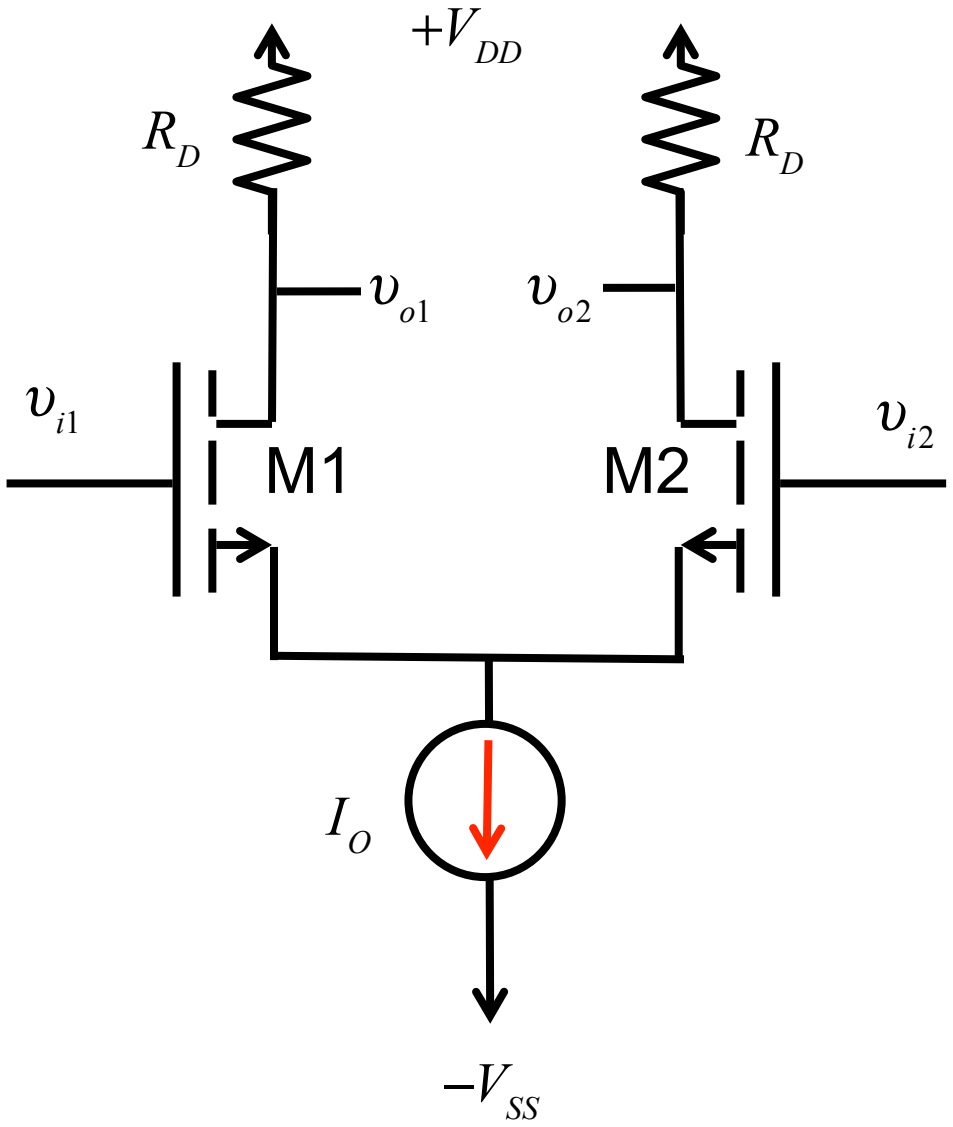
Announcements

HW9 Due 5:00 PM Friday, April 12 in EE-209 dropbox

Outline

1) Quick Review
2) MOS Op Amps
3) Active loads
4) Simple analysis
5) Small signal circuit
6) Short circuit transconductance
7) Output resistance
8) Summary

Source coupled pair

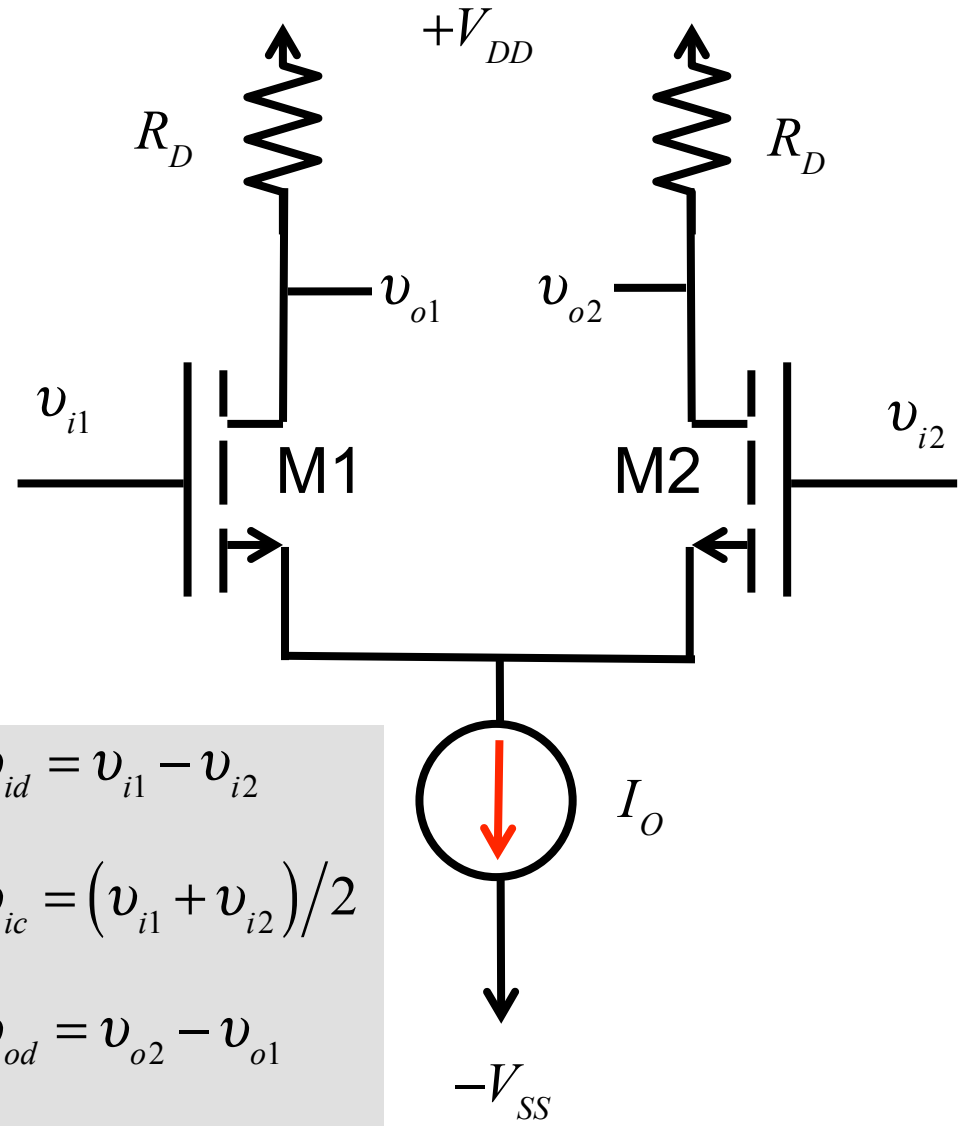


$$v_{id} = v_{i1} - v_{i2}$$

$$v_{ic} = \left(v_{i1} + v_{i2}\right)/2$$

$$v_{od} = v_{o2} - v_{o1}$$

Small-signal results: differential



$$\upsilon_{id} = \upsilon_{i1} - \upsilon_{i2}$$

$$\upsilon_{ic} = \left(\upsilon_{i1} + \upsilon_{i2}\right)/2$$

$$\upsilon_{od} = \upsilon_{o2} - \upsilon_{o1}$$

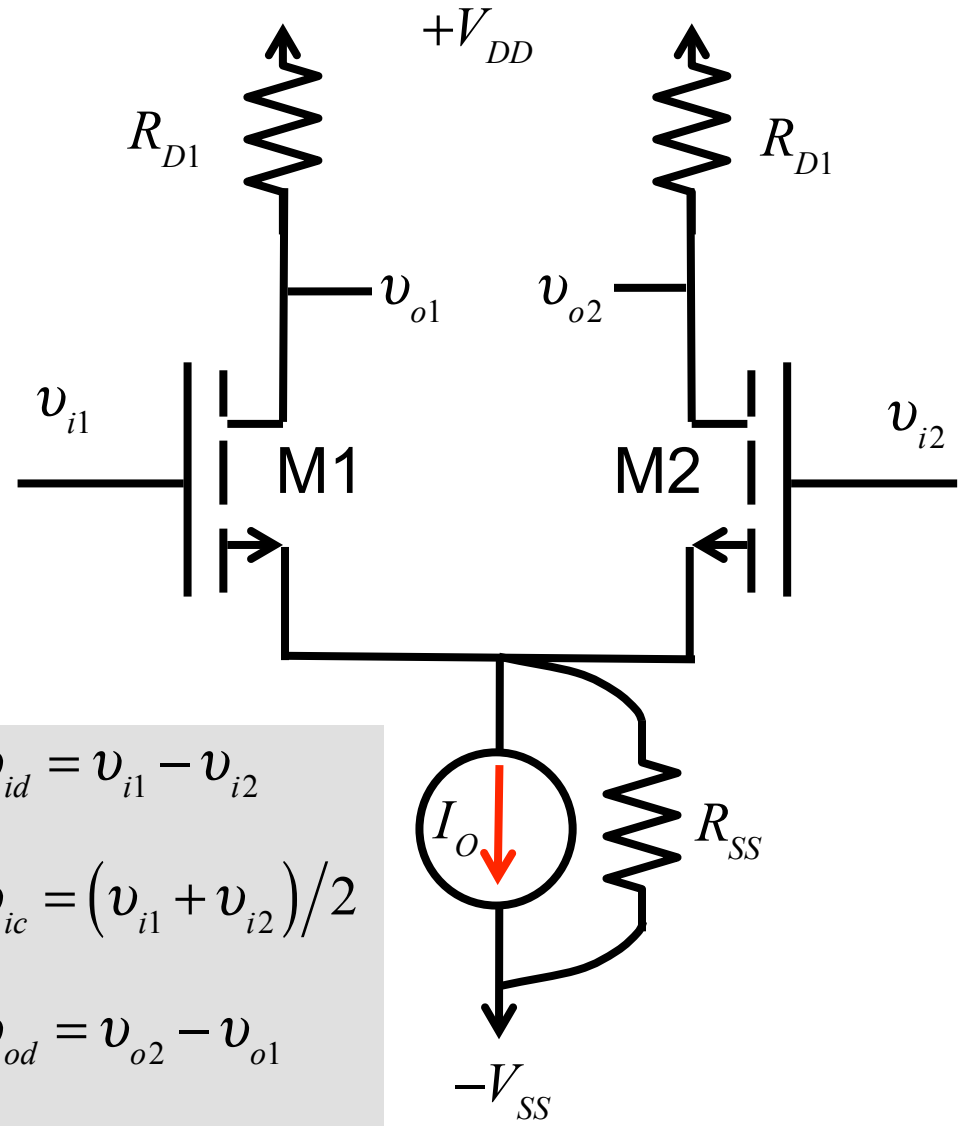
$$A_{dm} = \frac{\upsilon_{od}}{\upsilon_{id}}$$

$$A_{dm} = +g_m R_D$$

$$R_{in} = \infty$$

$$R_{out} = 2R_C$$

Small-signal results: common mode



$$v_{id} = v_{i1} - v_{i2}$$

$$v_{ic} = \left(v_{i1} + v_{i2}\right)/2$$

$$v_{od} = v_{o2} - v_{o1}$$

$$\frac{v_{o1}}{v_{ic}} = \frac{v_{o2}}{v_{ic}} \approx -\frac{R_D}{2R_{SS}}$$

$$A_{cm} = \frac{v_{od}}{v_{ic}} = 0$$

$$R_{D2} = R_{D1} + \Delta R_D$$

$$A_{cm} = -\frac{\Delta R_D}{2R_{SS}}$$

$$CMRR = \frac{\left|A_{dm}\right|}{\left|A_{cm}\right|}$$

$$CMRR = \frac{2g_m R_{SS}}{\Delta R_D / R_D}$$

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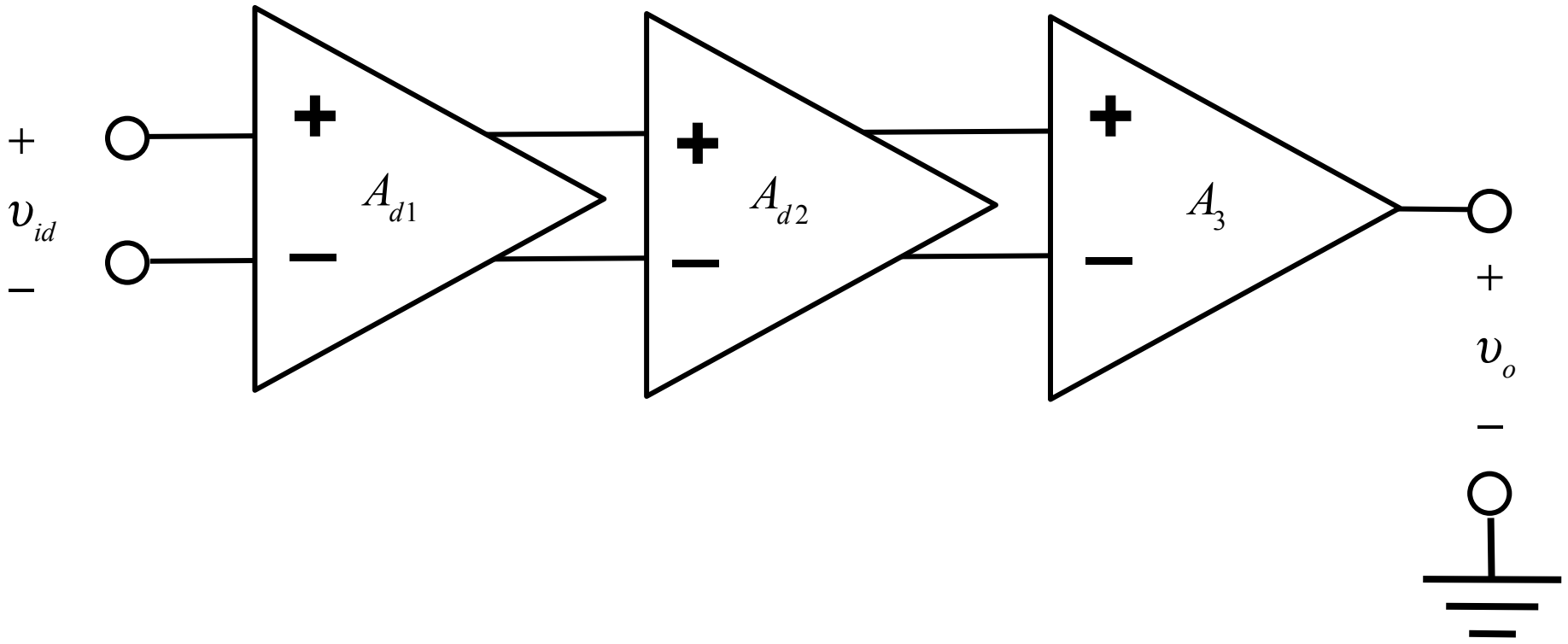
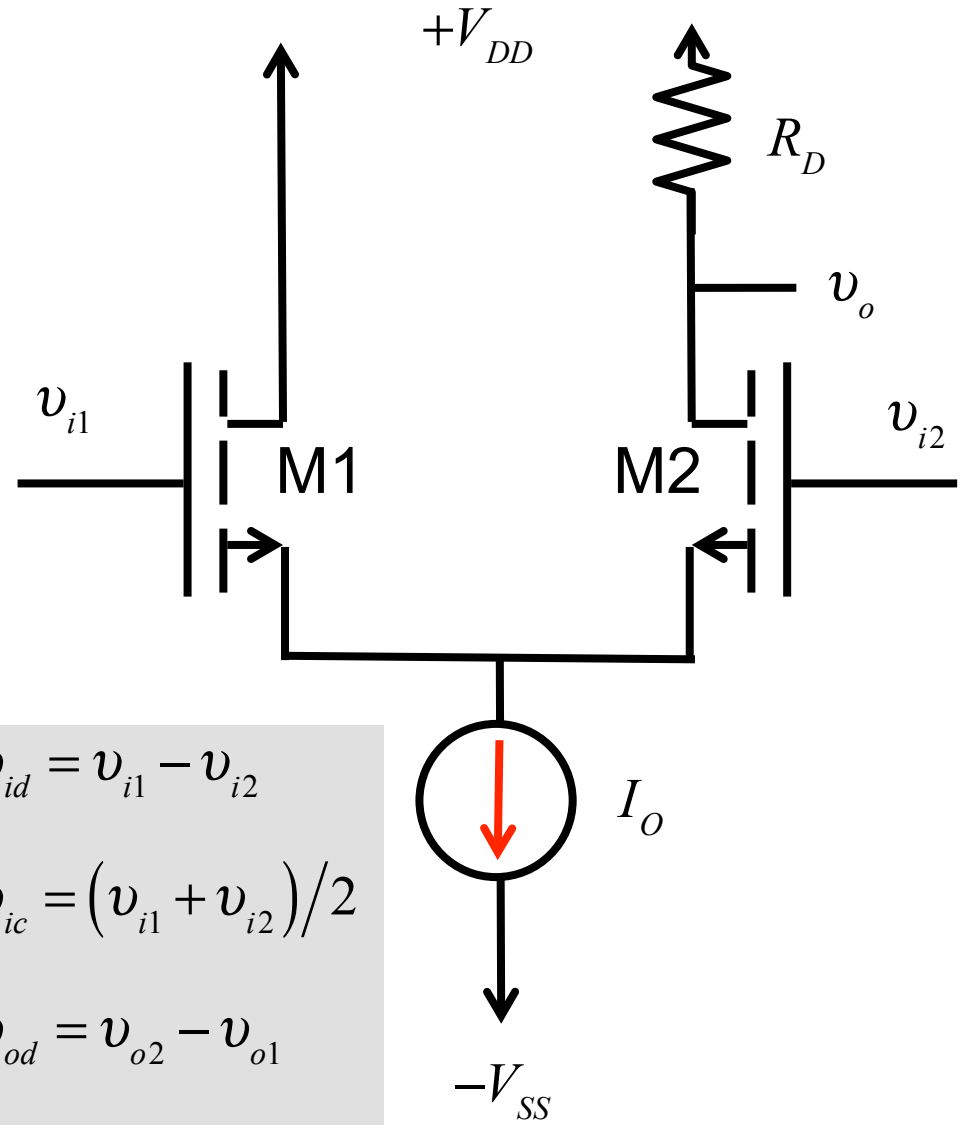
MOS Op Amp



Differential input to single ended output



$$A = \frac{\upsilon_o}{\upsilon_{id}}$$

$$A = \frac{g_m}{2} R_D$$

$$\upsilon_{id} = \upsilon_{i1} - \upsilon_{i2}$$

$$\upsilon_{ic} = \left(\upsilon_{i1} + \upsilon_{i2}\right)/2$$

$$\upsilon_{od} = \upsilon_{o2} - \upsilon_{o1}$$

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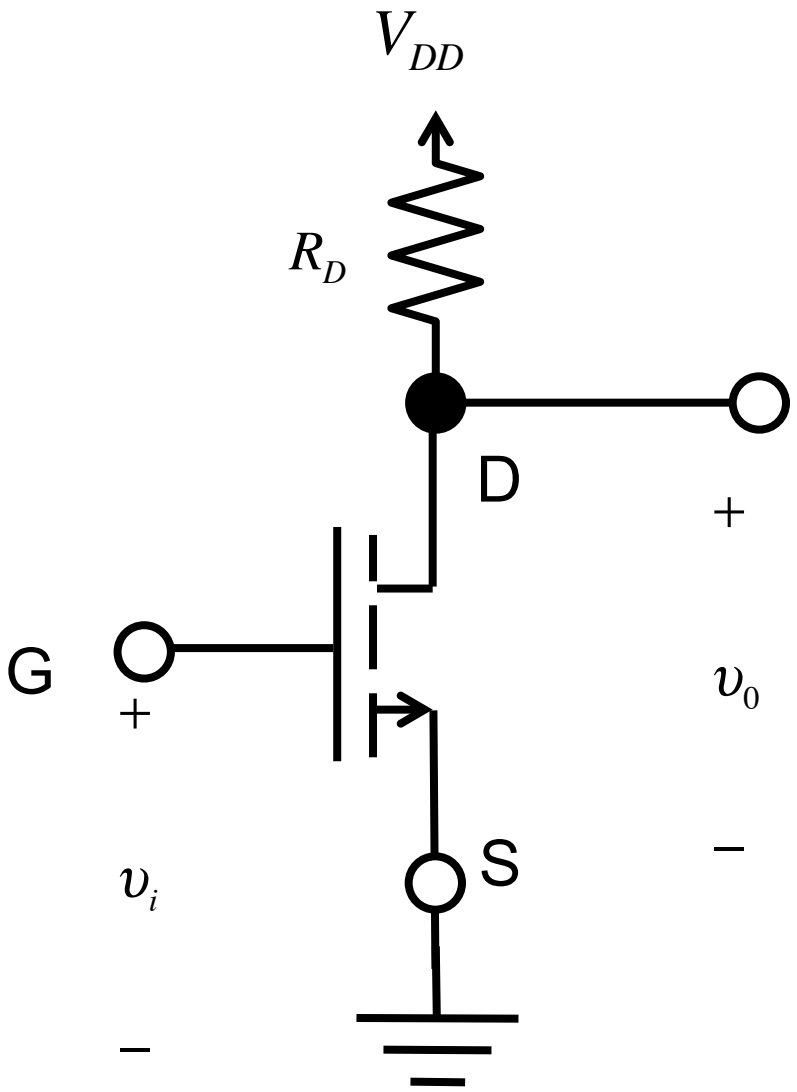
Recall: CS resistive load

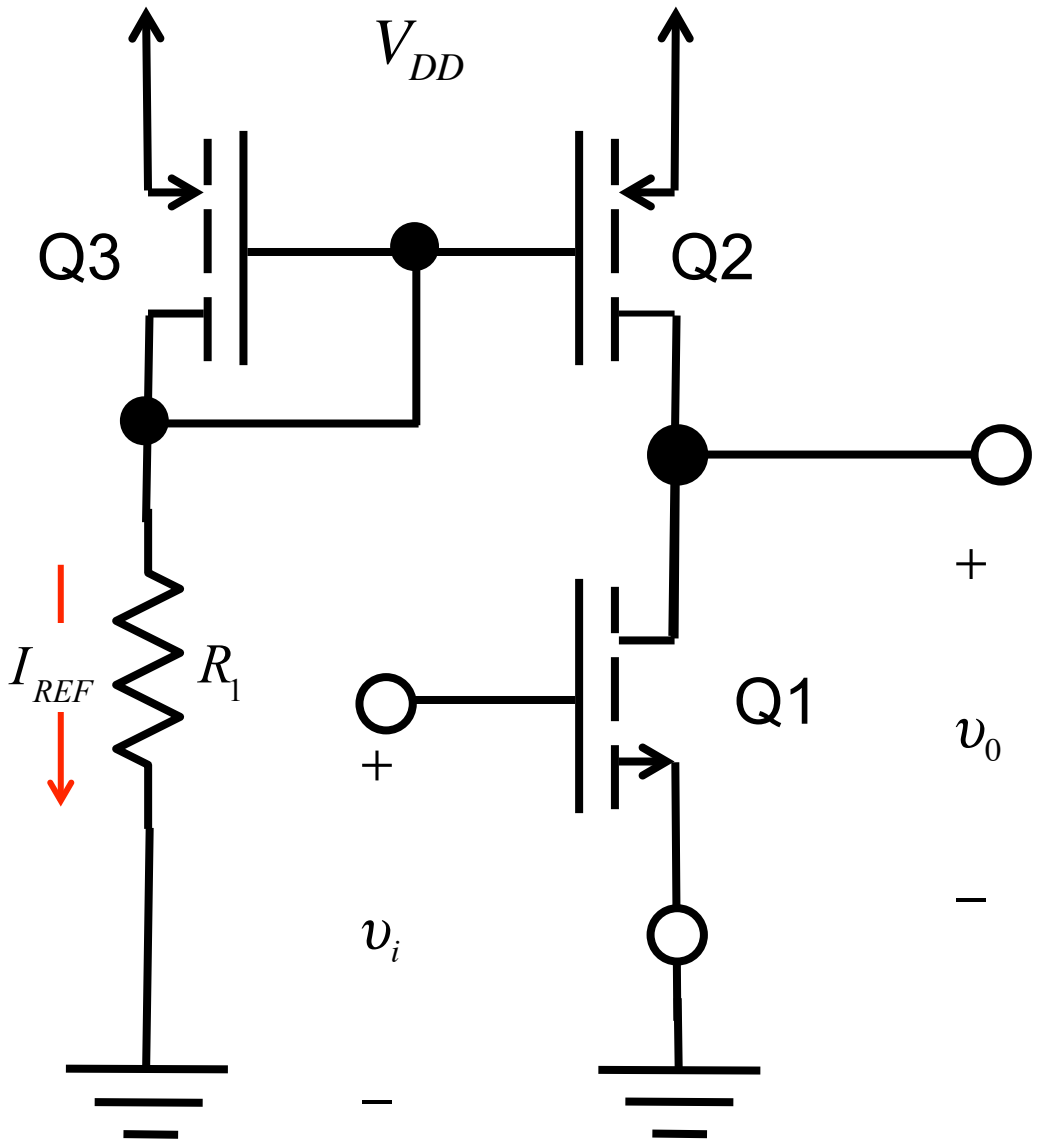


$$A_{\upsilon_o} = \frac{\upsilon_o}{\upsilon_i} = -g_m R_D$$

$$R_{in} = \infty$$

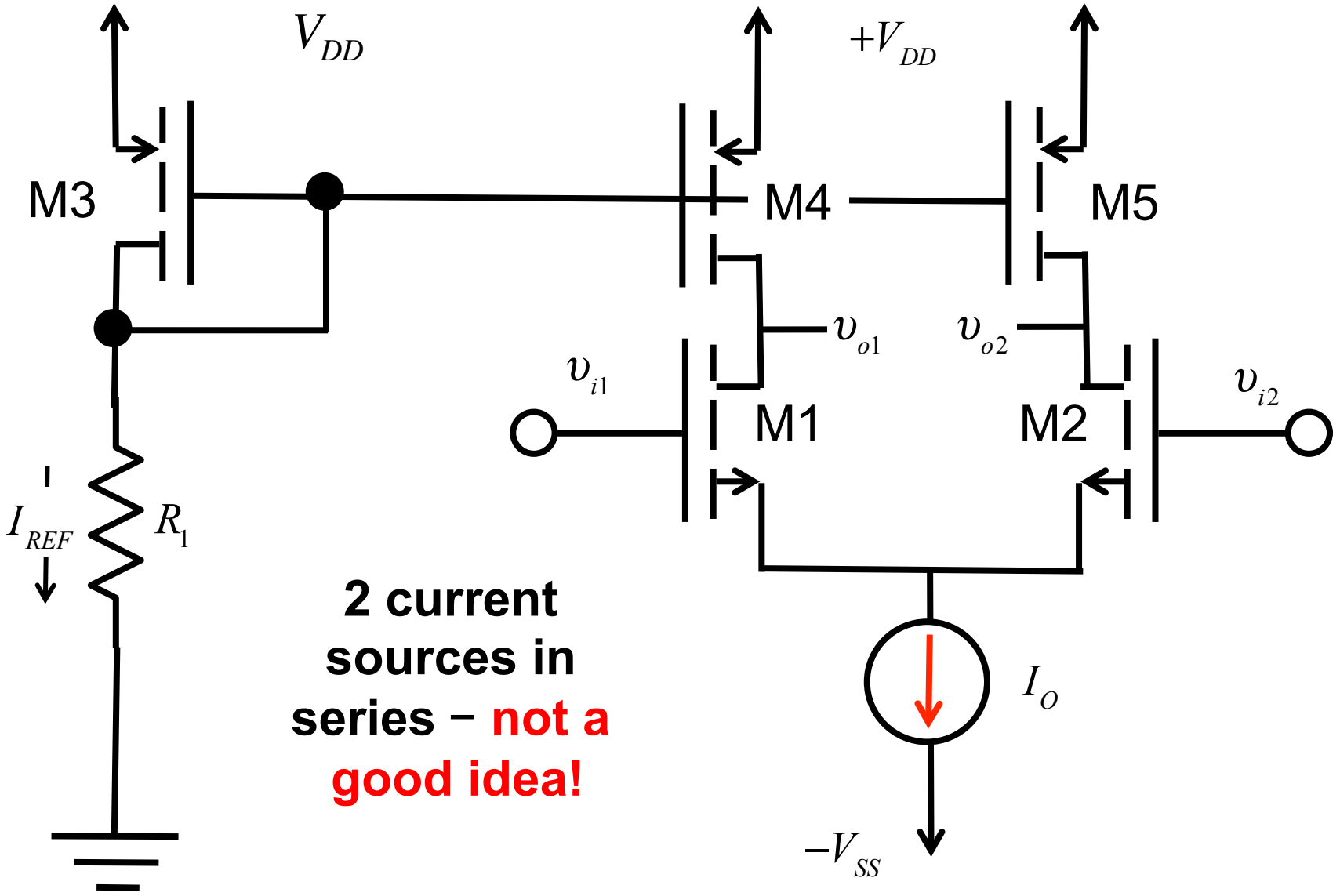
$$R_o = R_D$$

Recall: CS Active load



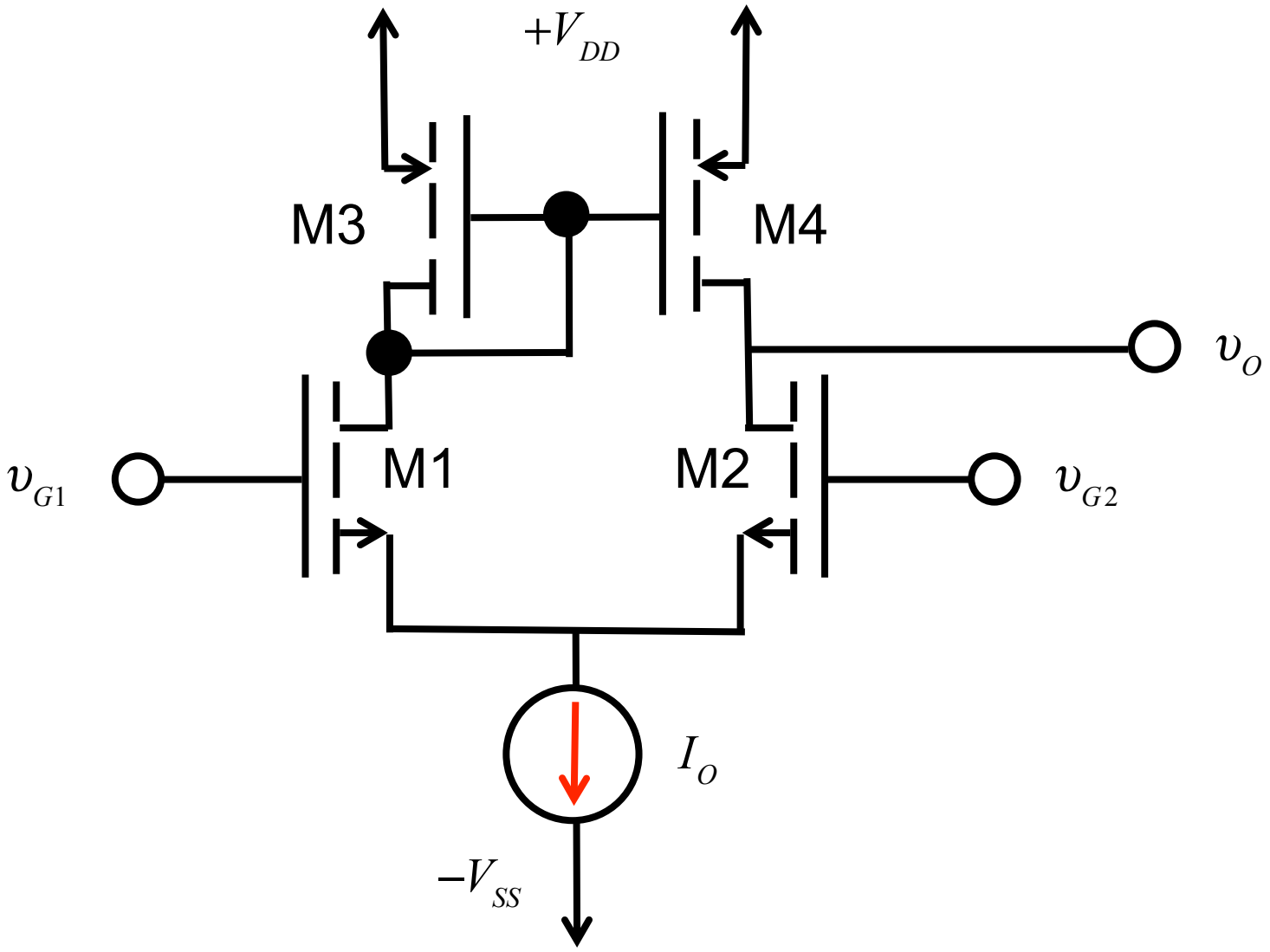
$$A_{v_o} = -g_m \left(r_{oN} \parallel r_{oP} \right)$$

Differential pair with active load?



2 current sources in series – not a good idea!

Current mirror loaded differential pair



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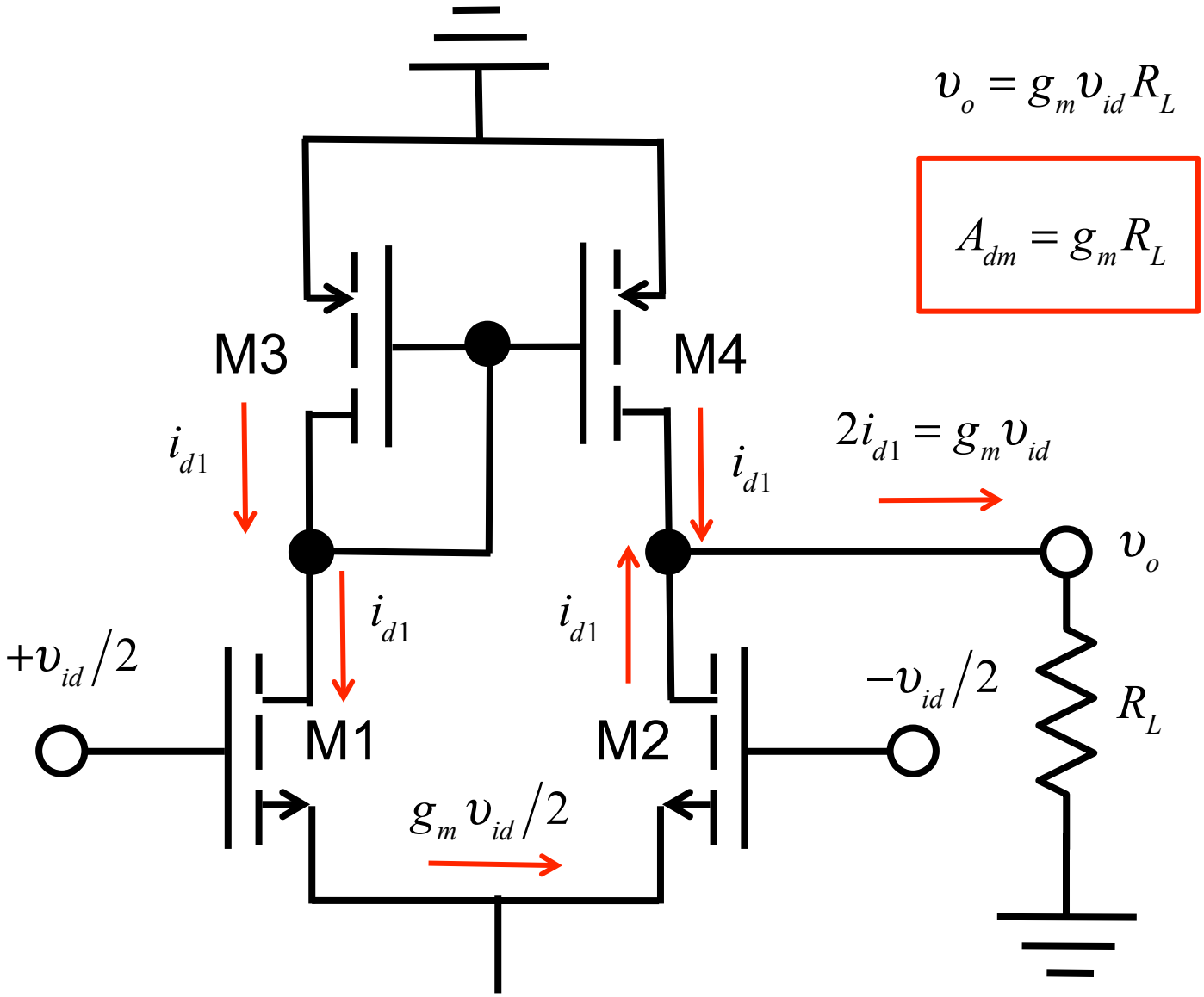
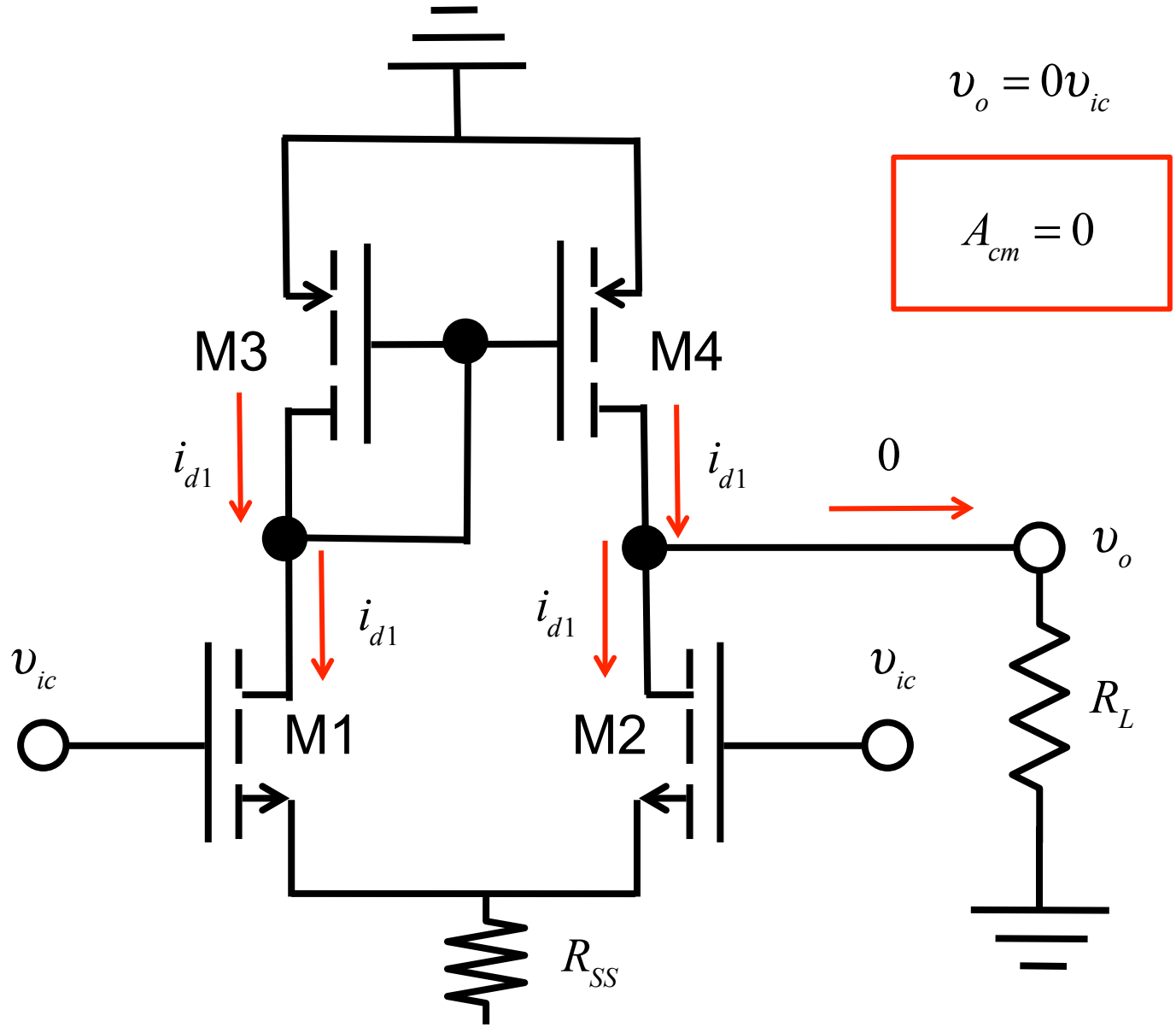
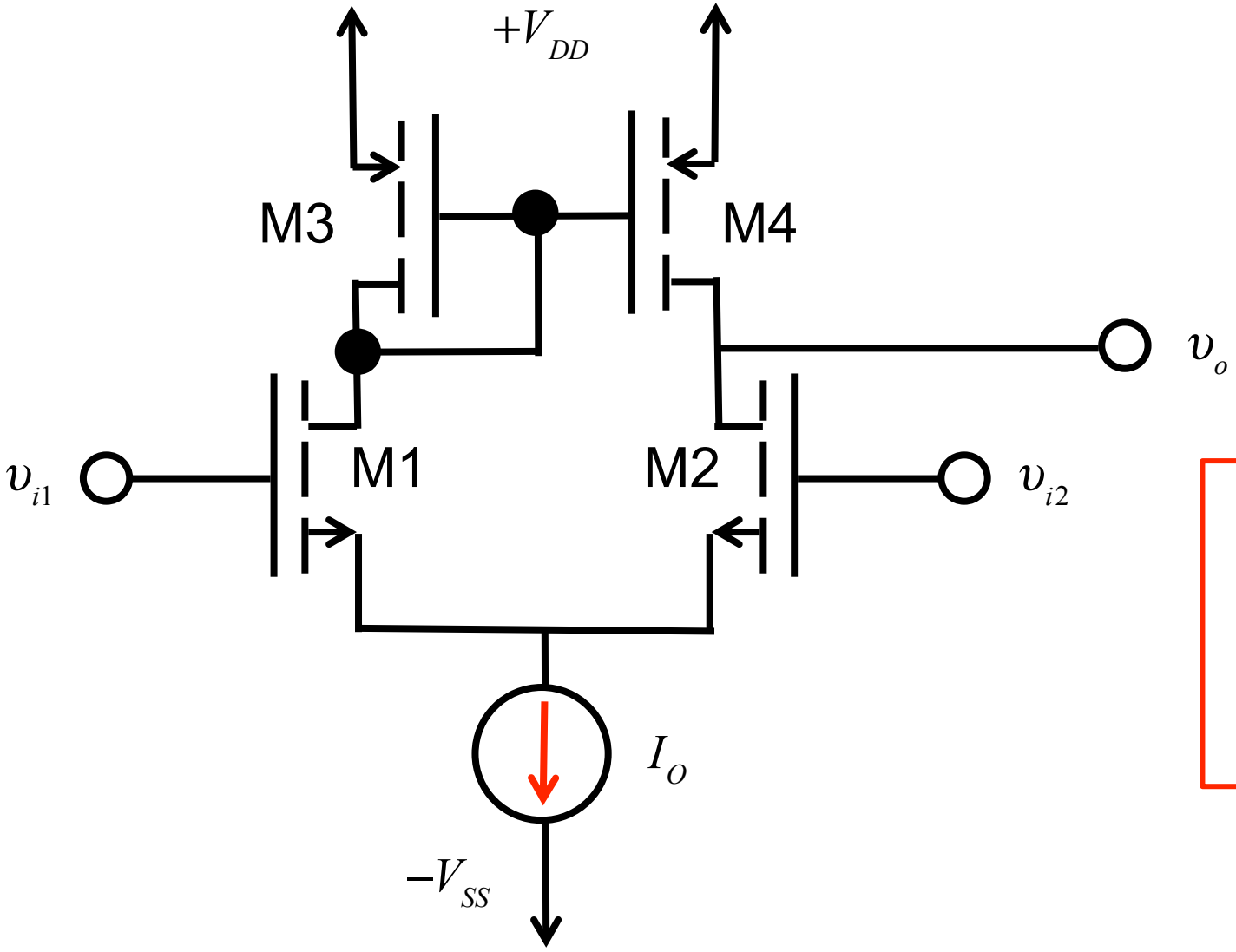
Small signal (differential)



Small signal (common mode)



Current mirror loaded differential pair



$$A_{dm} = g_m R_L$$

$$A_{cm} = 0$$

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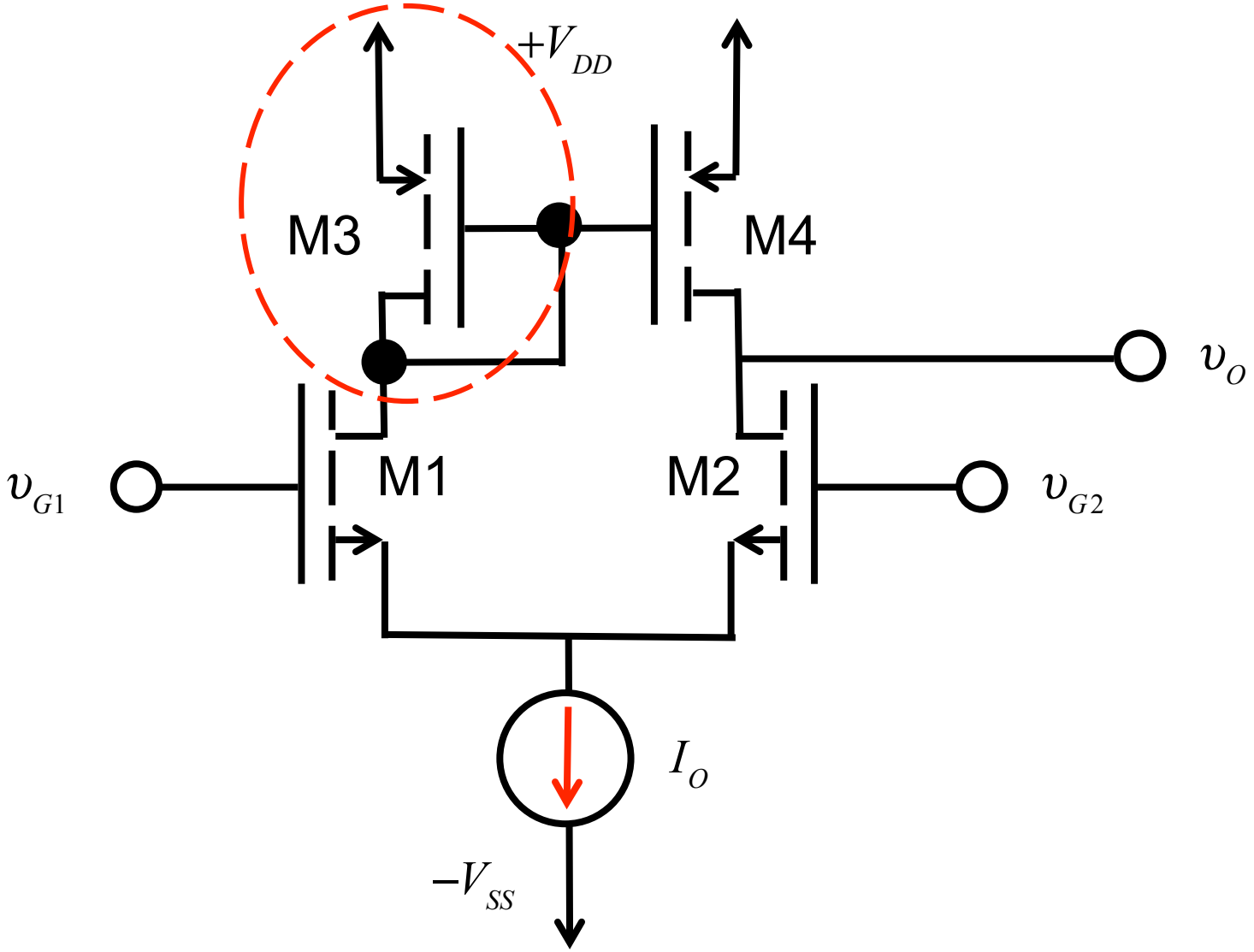
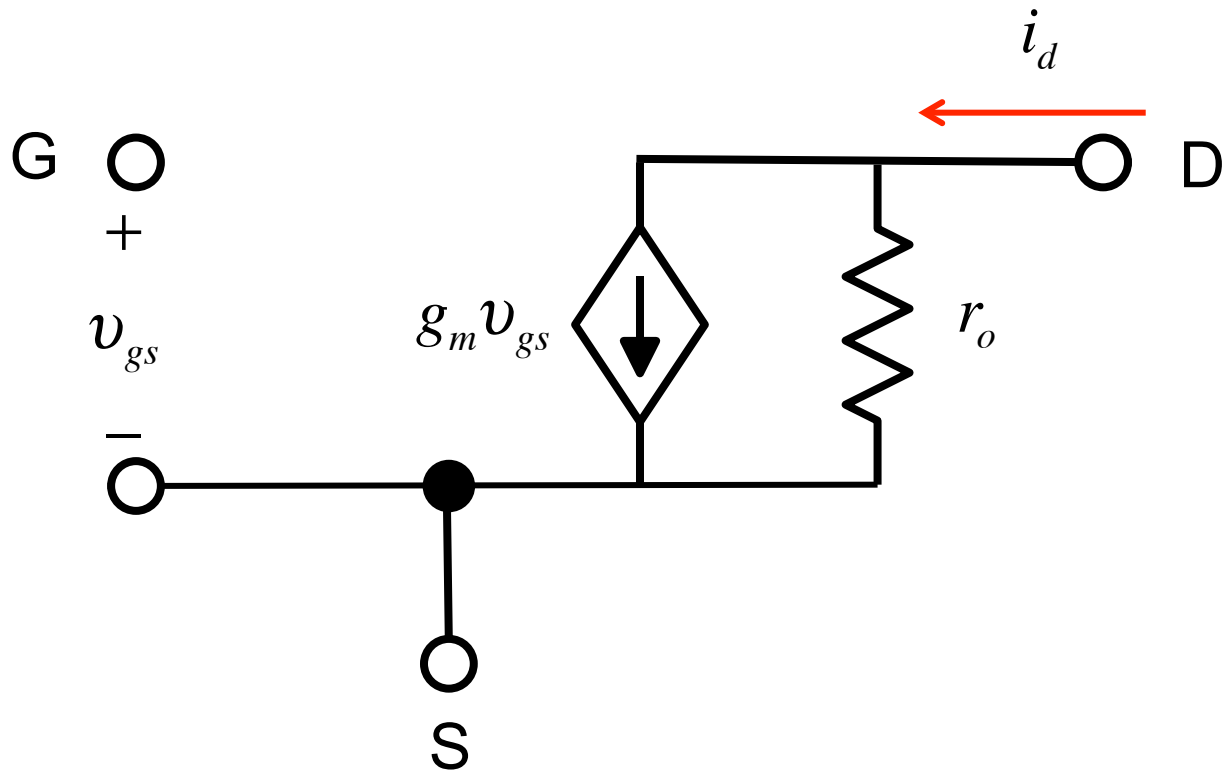
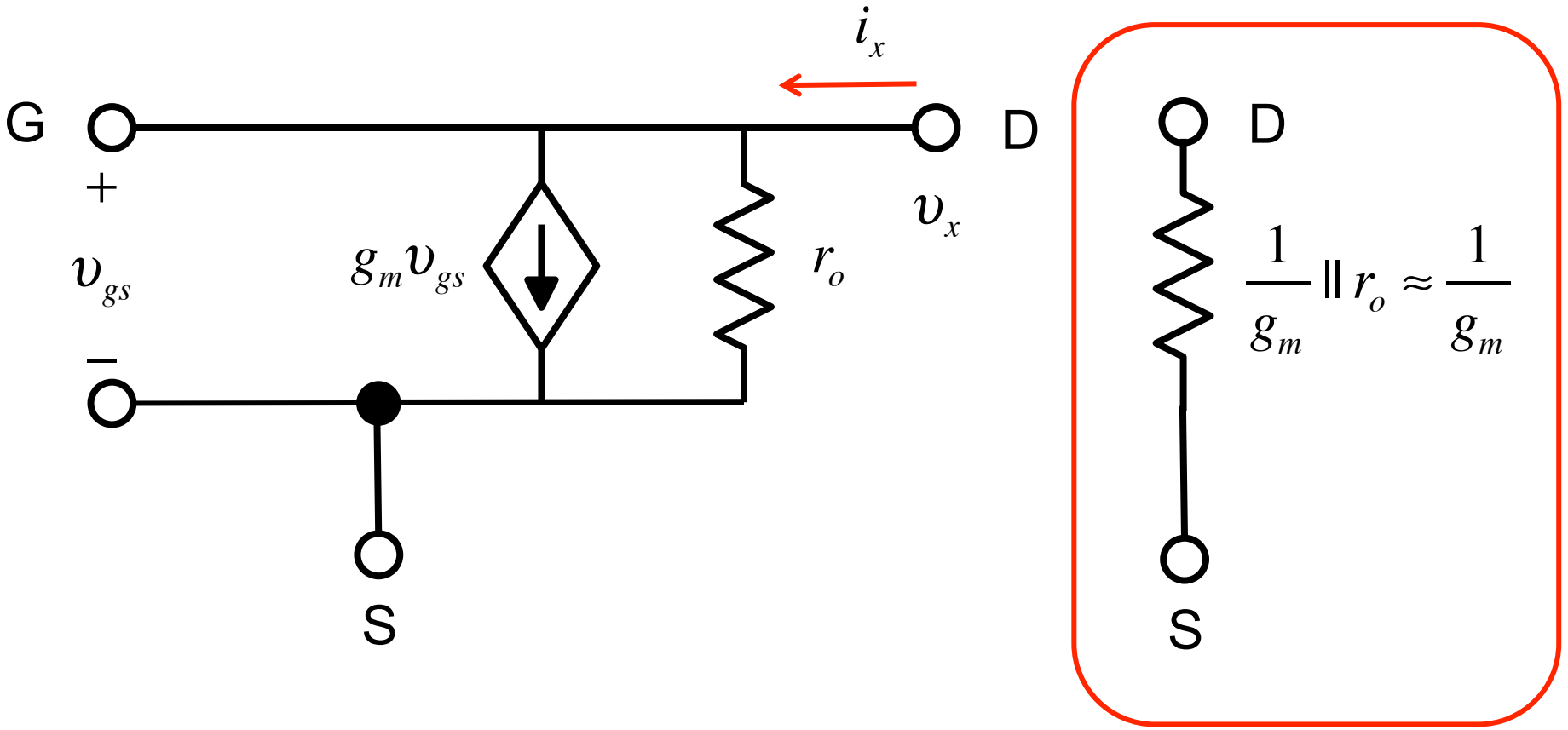
Small signal circuit



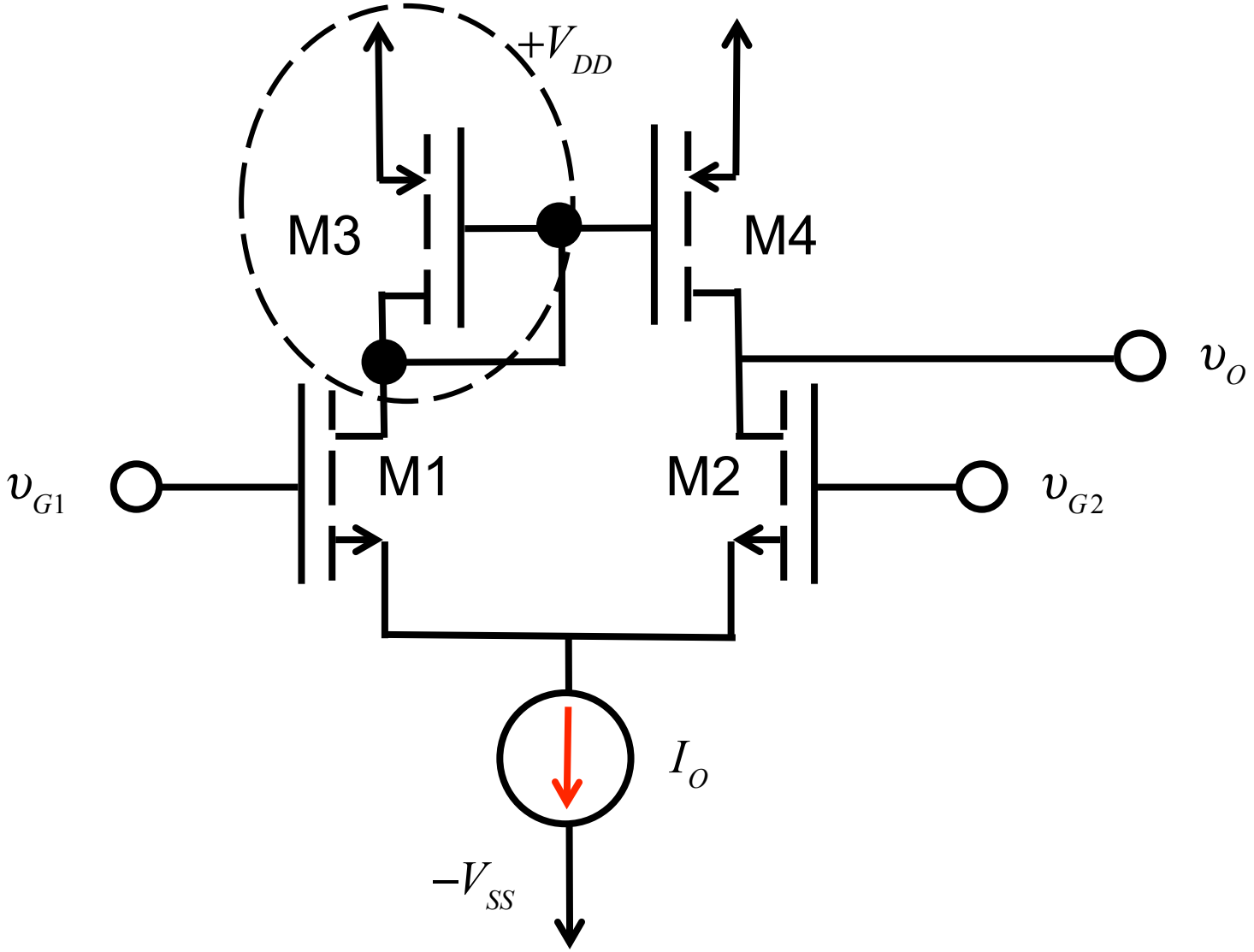
Hybrid-pi MOSFET model



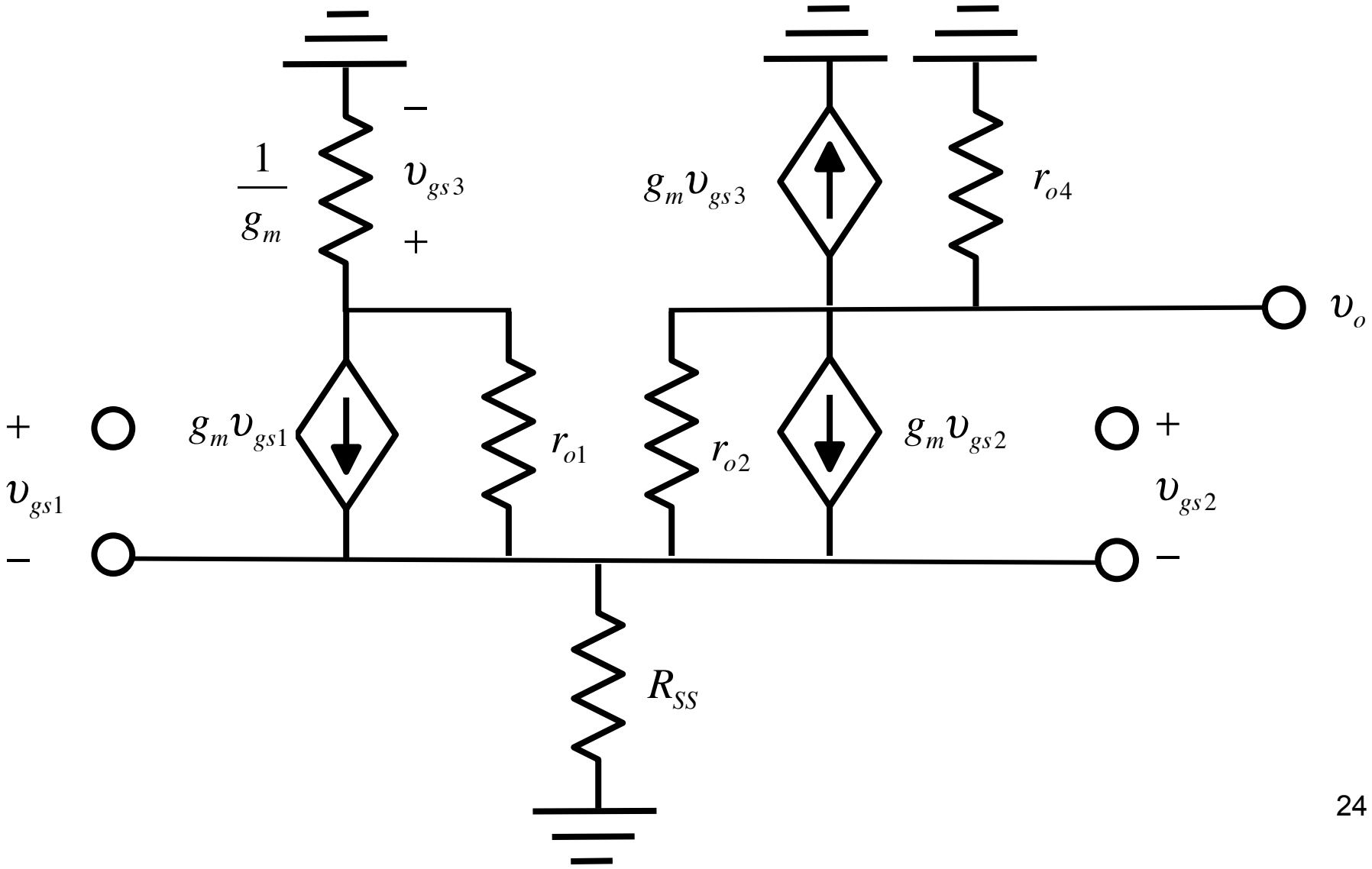
Diode connected MOSFET



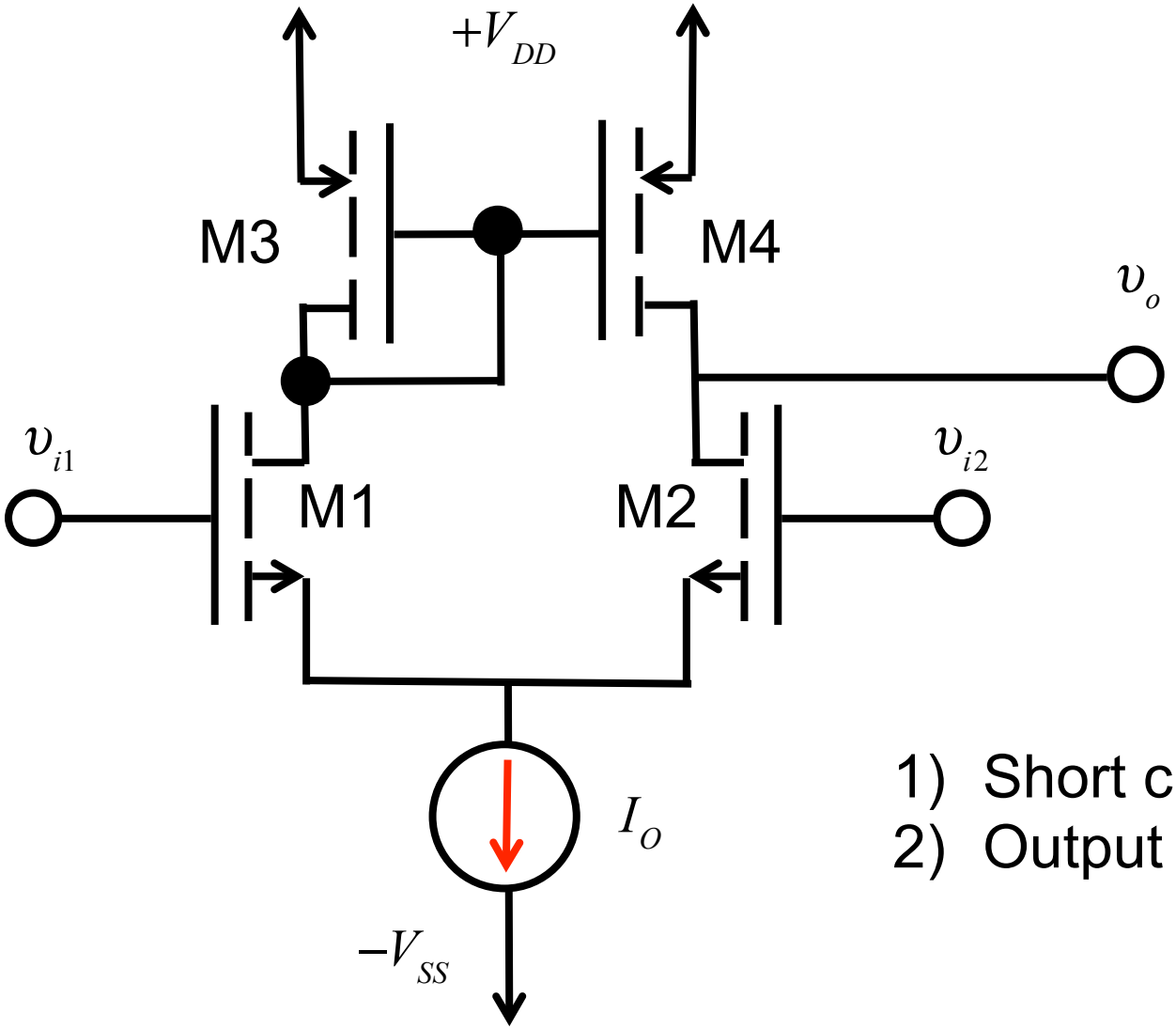
Small signal circuit



Small signal circuit



Roadmap for small signal analysis



1) Short circuit current
2) Output resistance

Outline

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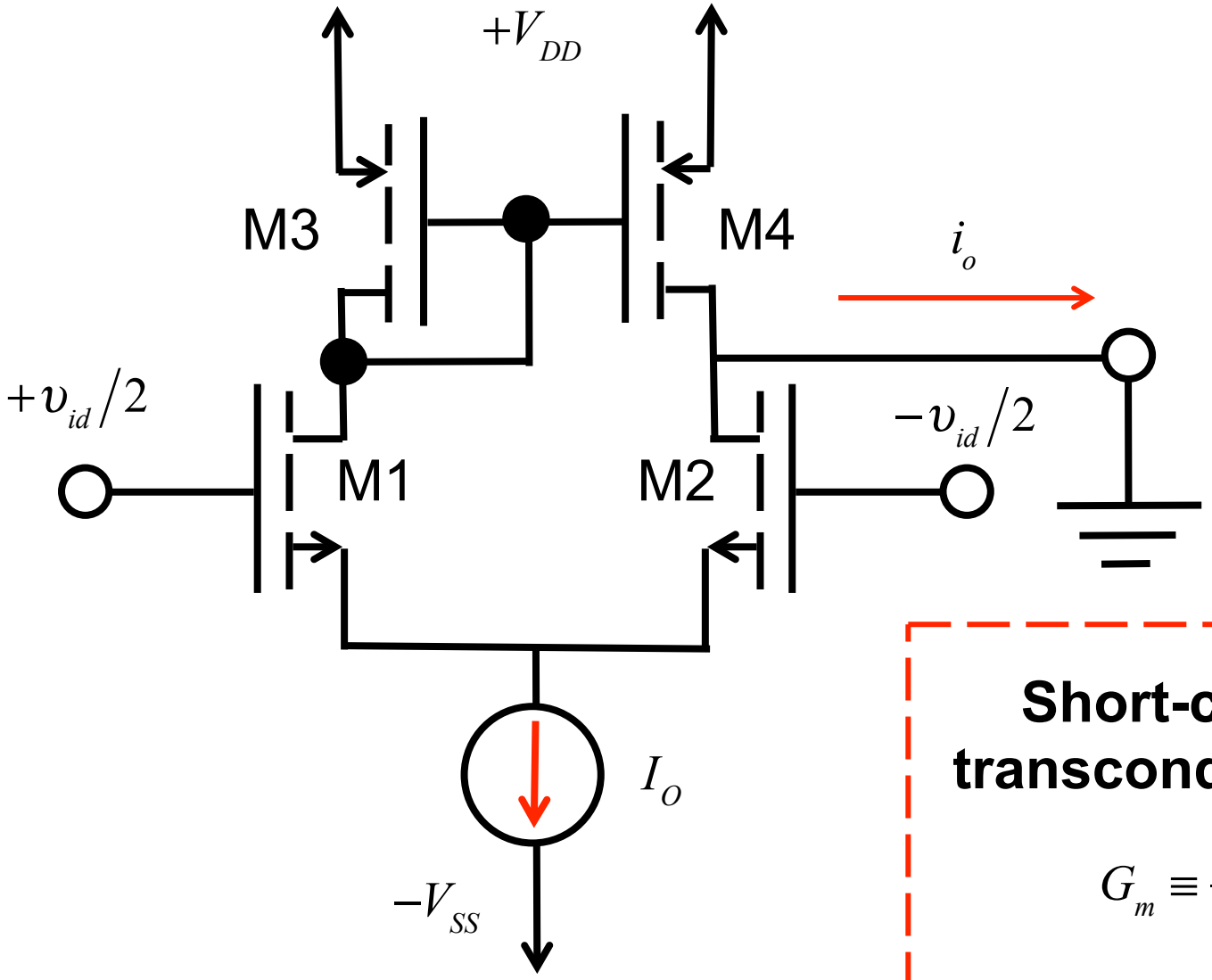
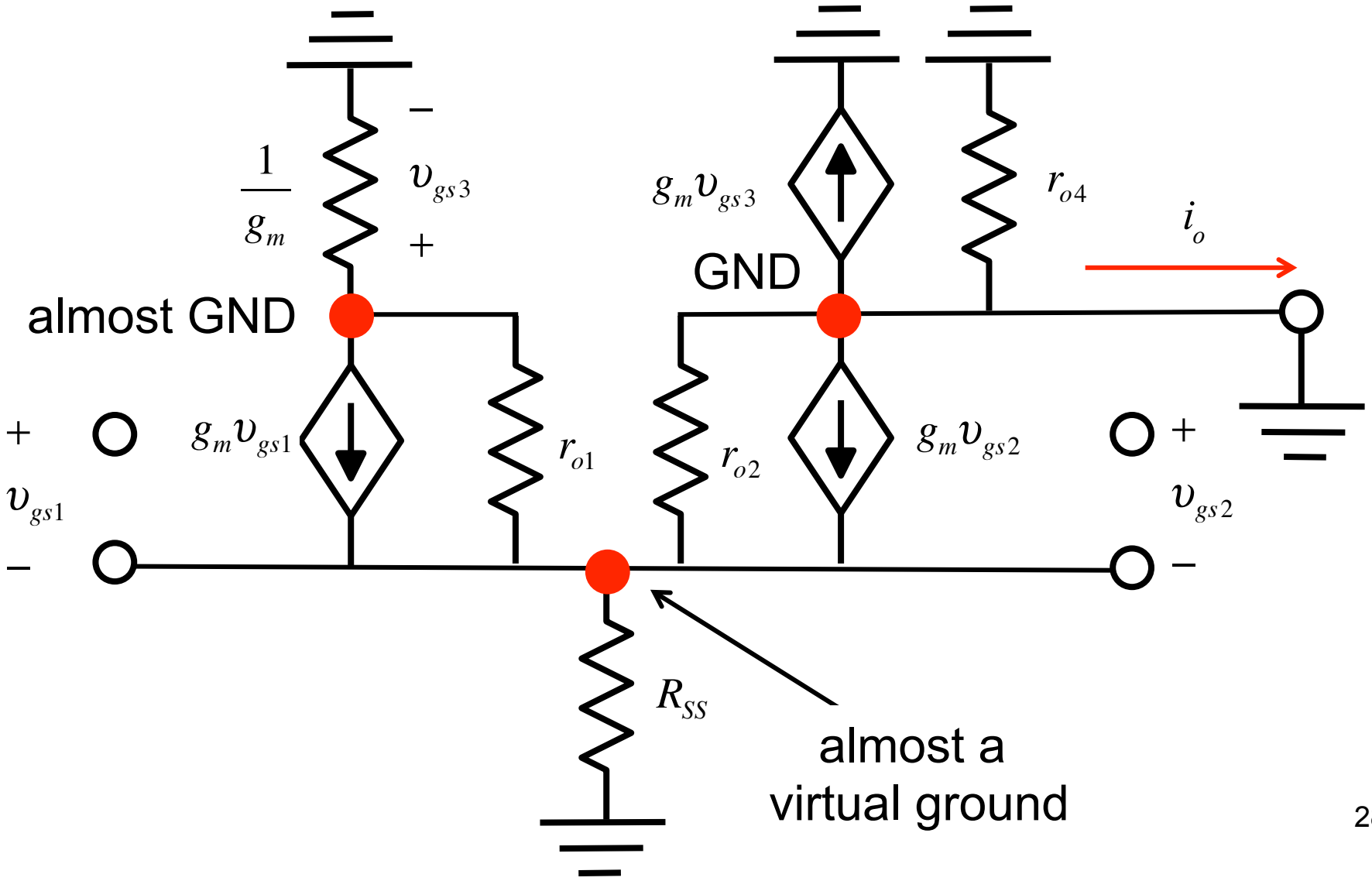
Short circuit current / transconductance



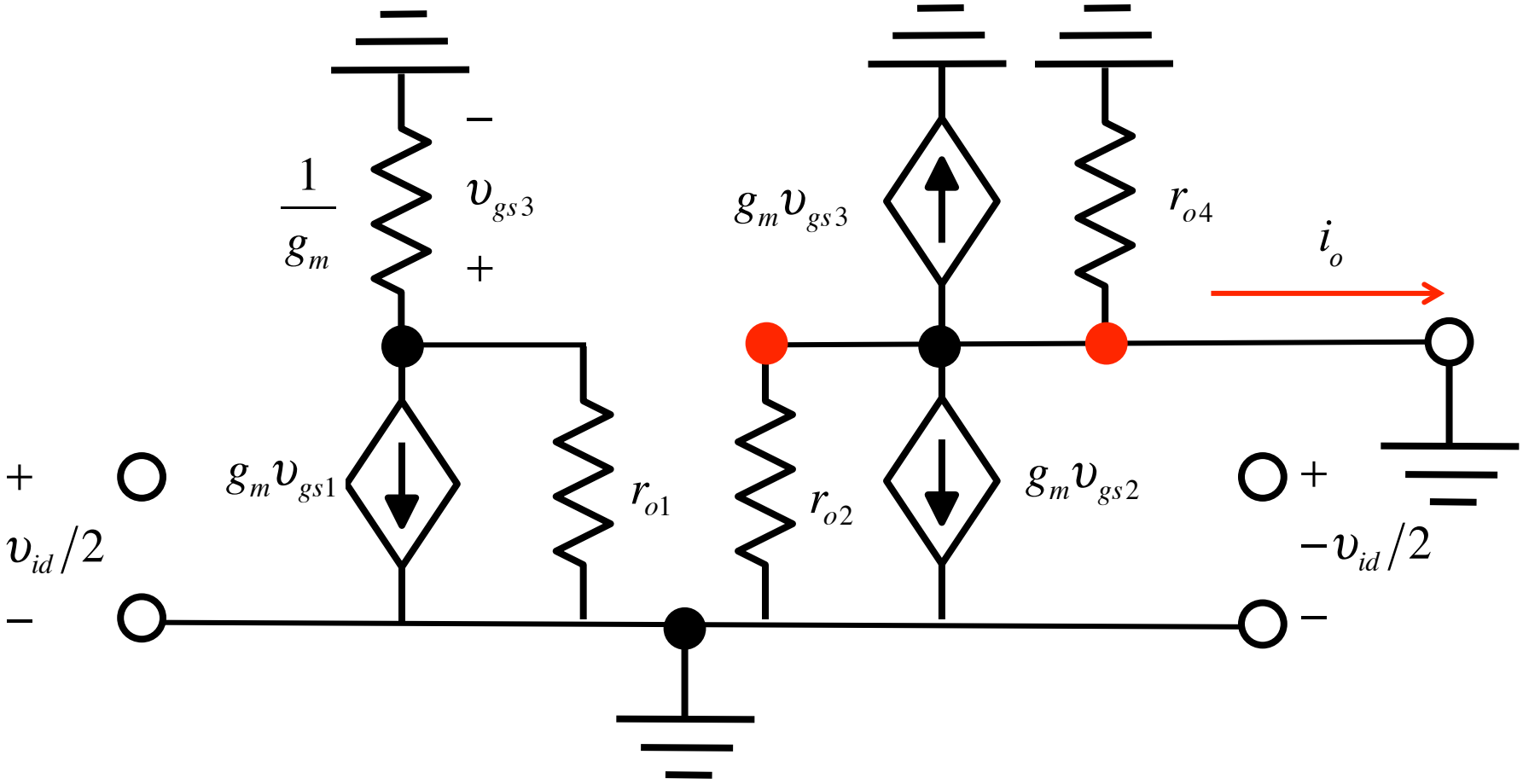
Short-circuit transconductance

$$G_m \equiv \frac{i_o}{\upsilon_{id}}$$

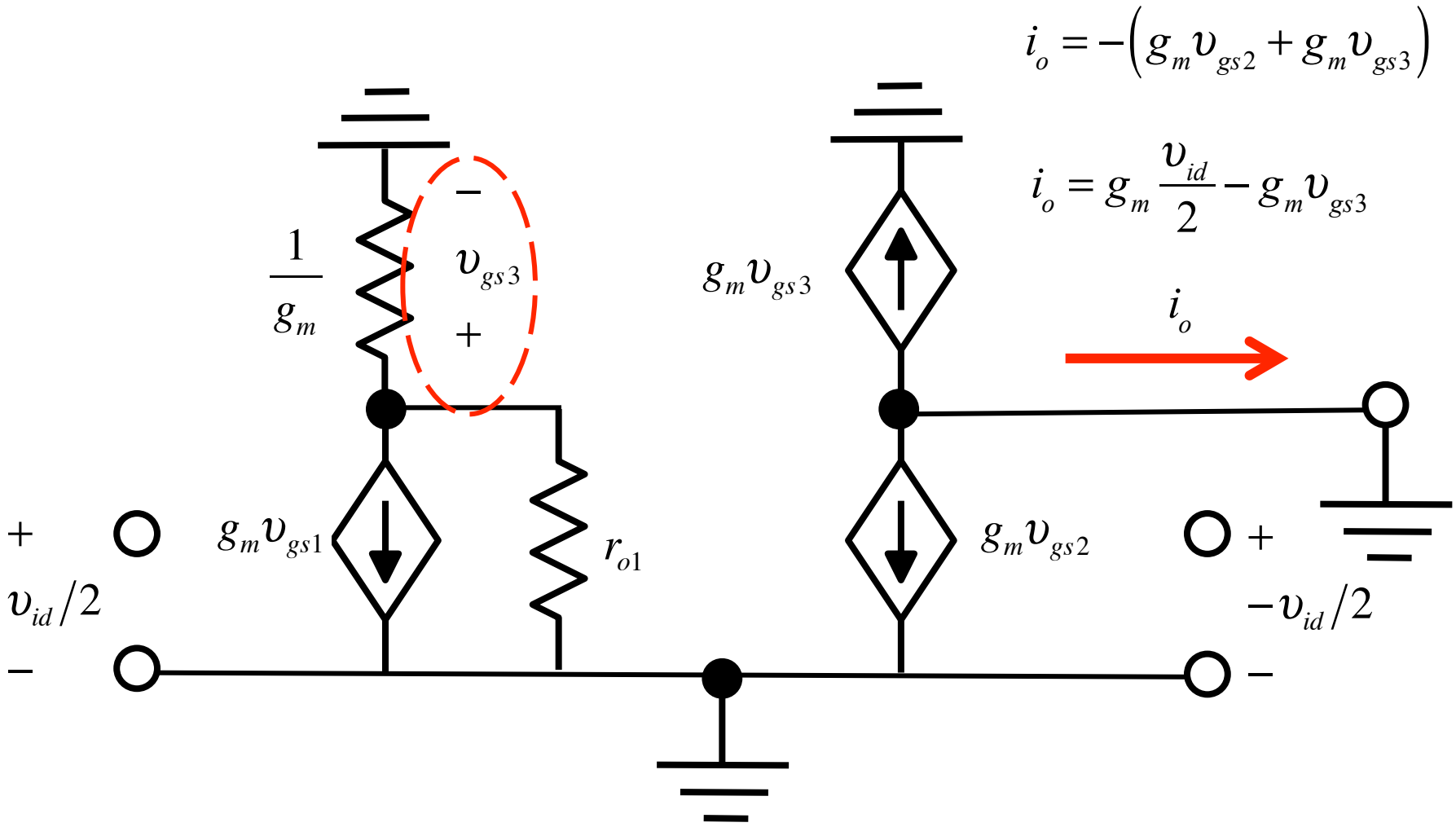
Short-circuit transconductance



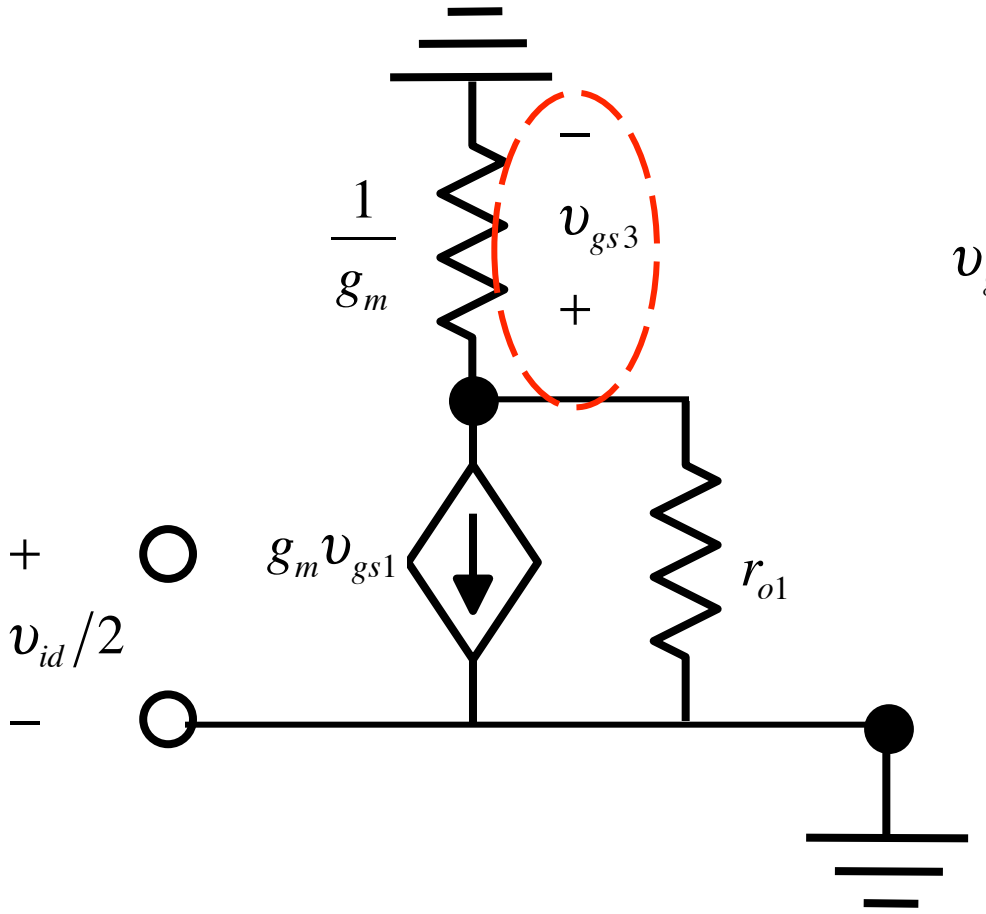
Short-circuit transconductance (2)



Short-circuit transconductance (3)

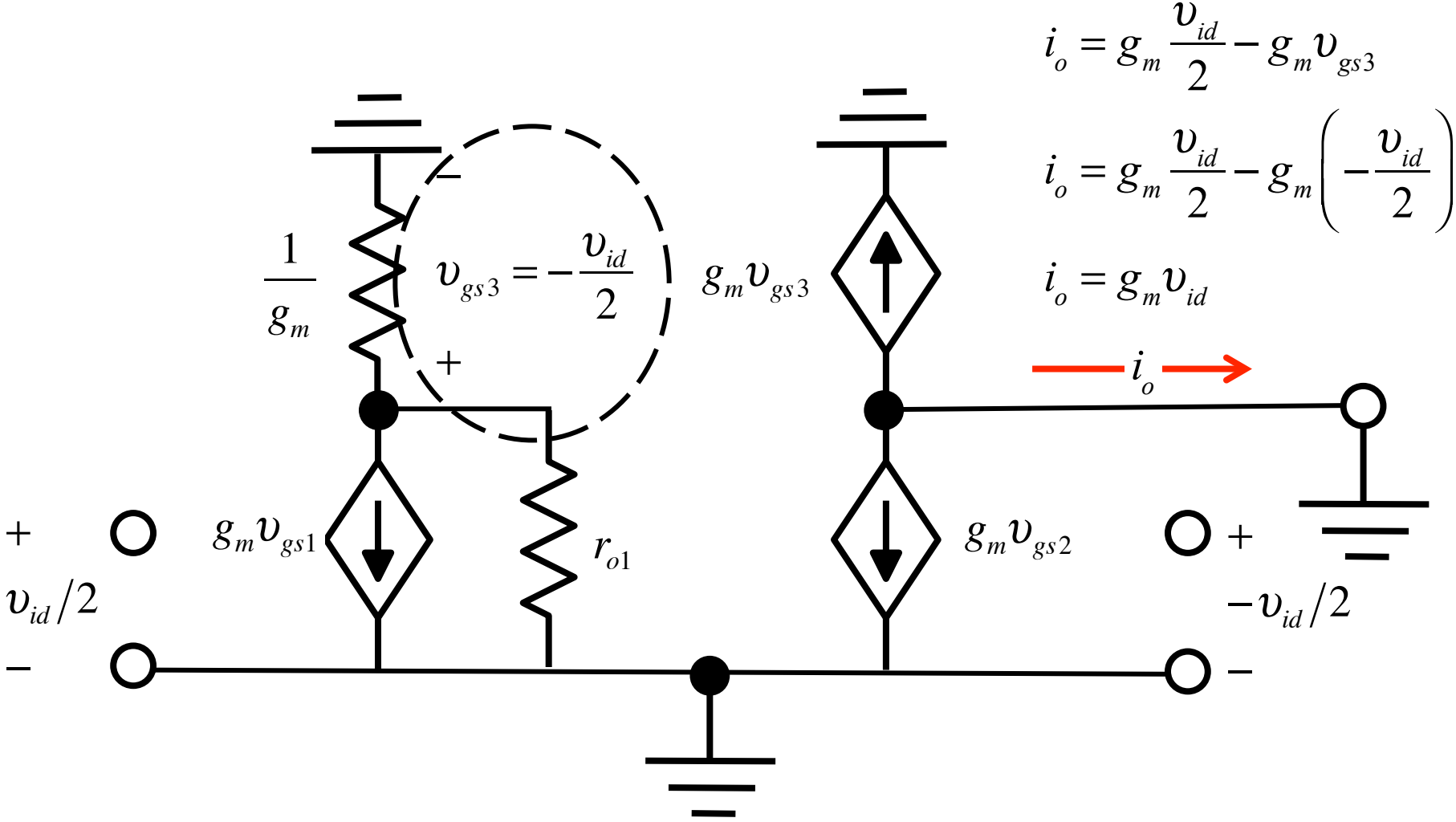


Short-circuit transconductance (4)

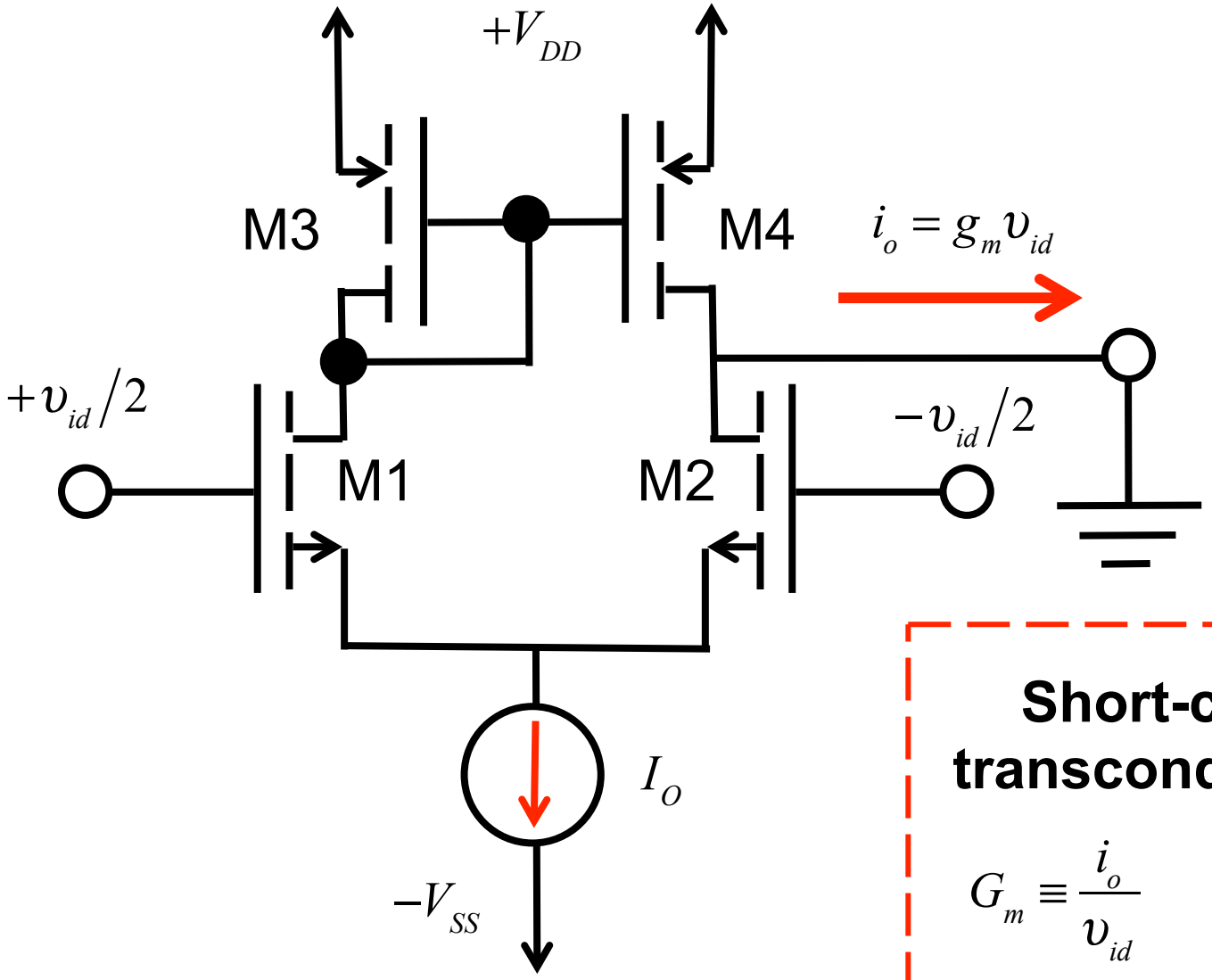


$$v_{gs3} = -g_m \frac{v_{id}}{2}\left(\frac{1}{g_m} \parallel r_{o1}\right) \approx -\frac{v_{id}}{2}$$

Short-circuit transconductance (5)



Short circuit tranconductance



Short-circuit transconductance

$$G_m \equiv \frac{i_o}{v_{id}} \qquad G_m = g_m$$

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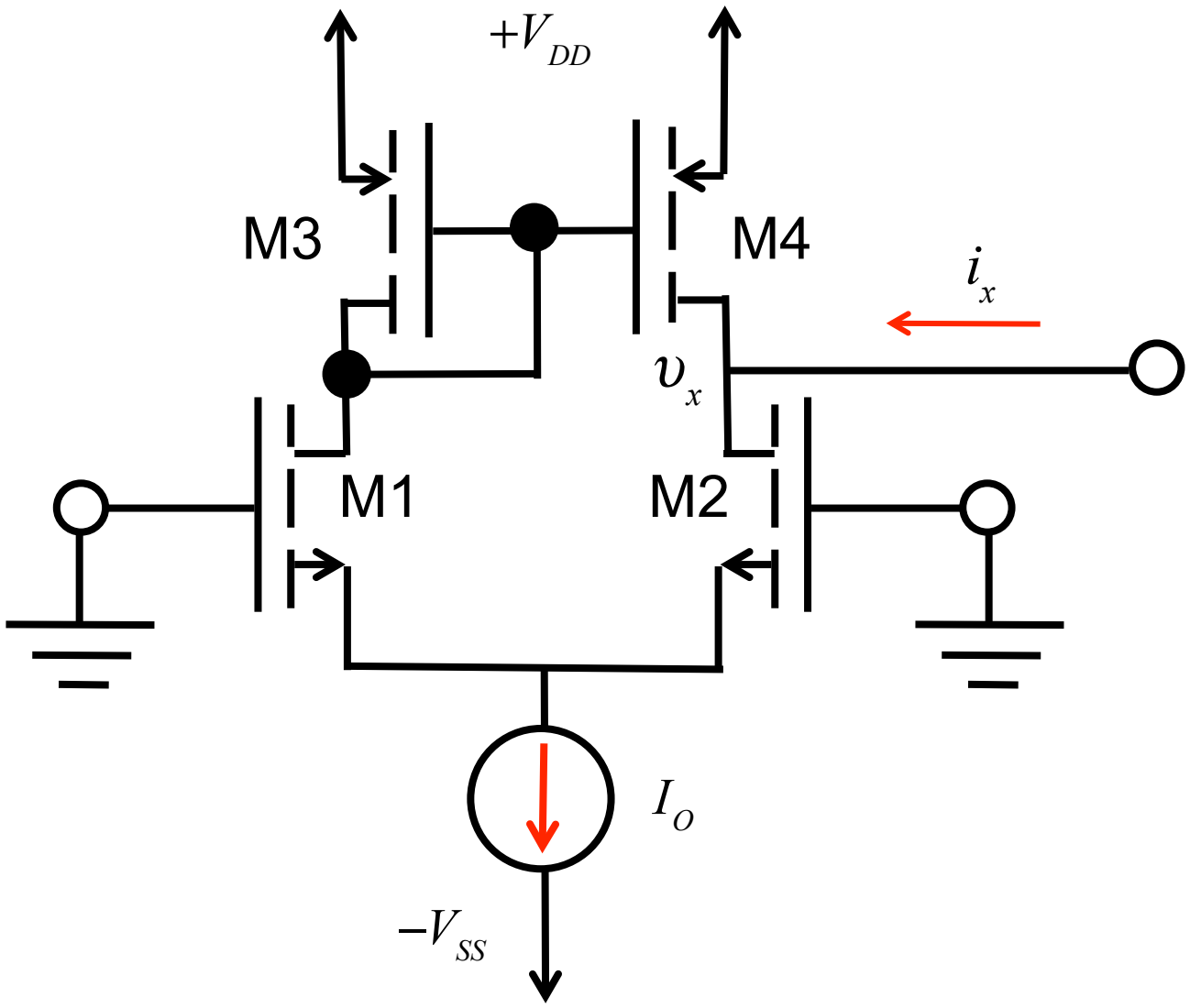
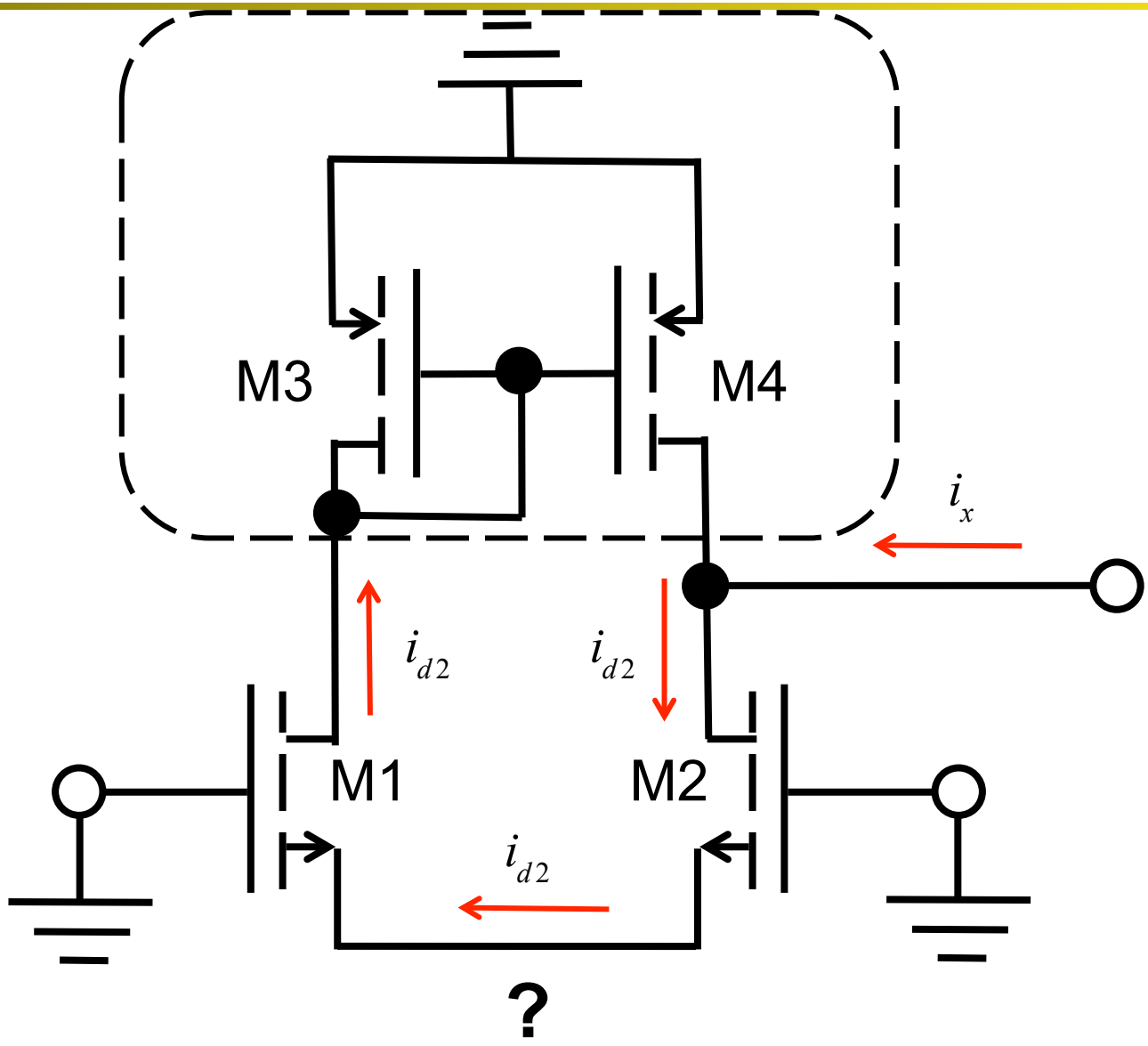
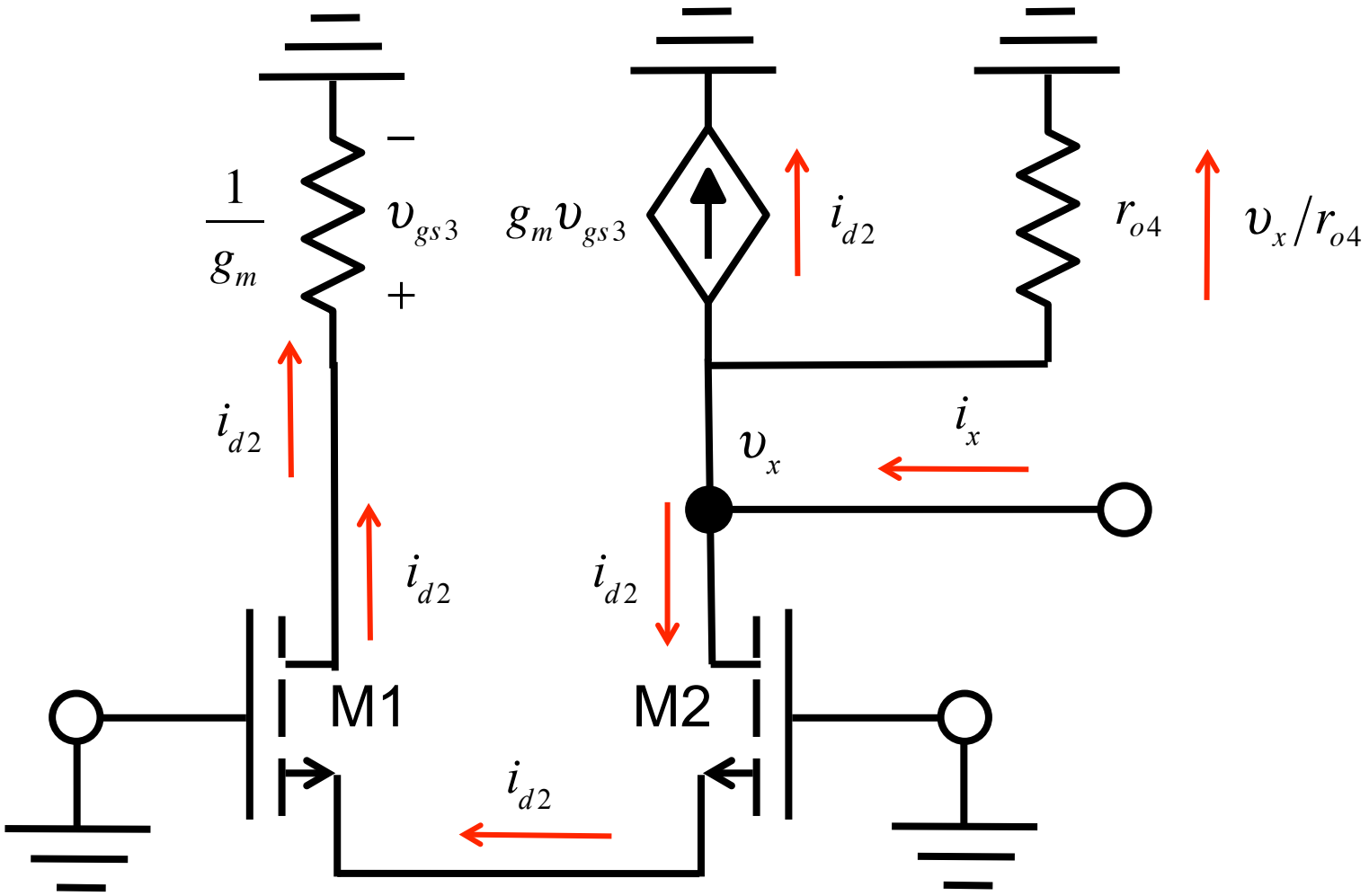
Output resistance



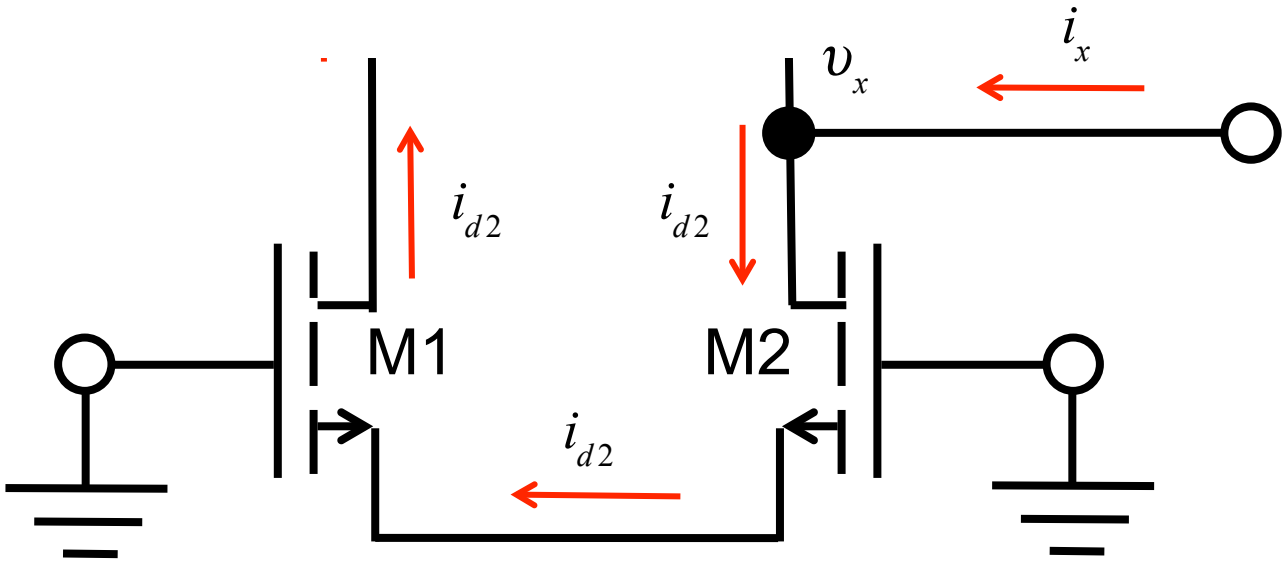
Output resistance (2)



Output resistance (3)



Output resistance looking into drain 2



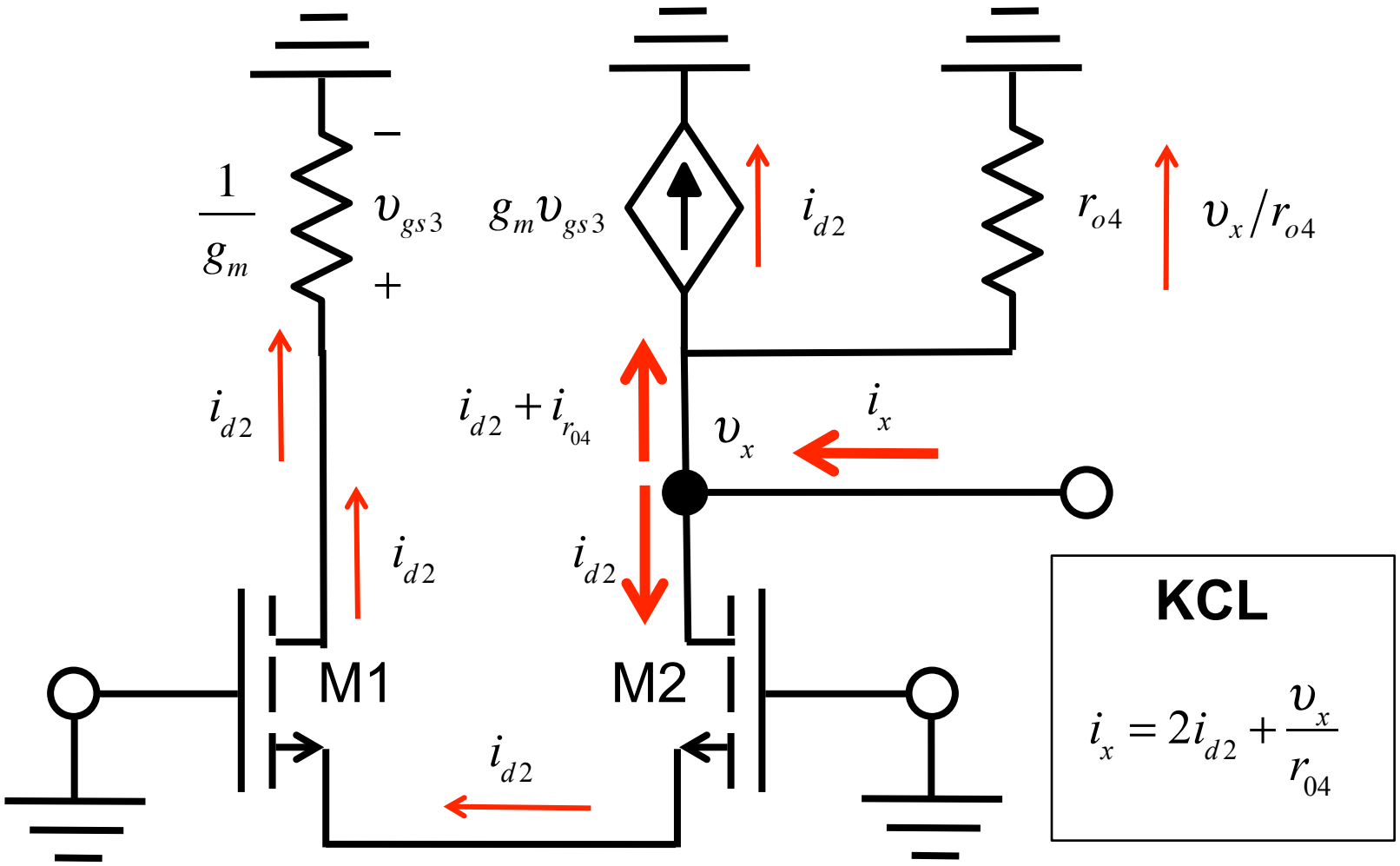
$$i_{d2} = \frac{v_x}{R_{o2}}$$

$$R_{o2} = r_{o2} + g_m r_{o2} R_S$$

$$R_{o2} = r_{o2} + g_m r_{o2} \frac{1}{g_m}$$

$$R_{o2} = 2r_{o2}$$

Finding i_x



KCL

$$i_x = 2i_{d2} + \frac{v_x}{r_{04}}$$

Small signal analysis

$$i_x = 2i_{d2} + \frac{\upsilon_x}{r_{04}}$$

$$i_{d2} = \frac{\upsilon_x}{R_{o2}}$$

$$R_{o2} = 2r_{o2}$$

$$i_x = \frac{2\upsilon_x}{2r_{o2}} + \frac{\upsilon_x}{r_{04}} = \upsilon_x \left(\frac{1}{r_{o2}} + \frac{1}{r_{o4}} \right)$$

$$R_{out} = r_{o2} \| r_{o4}$$

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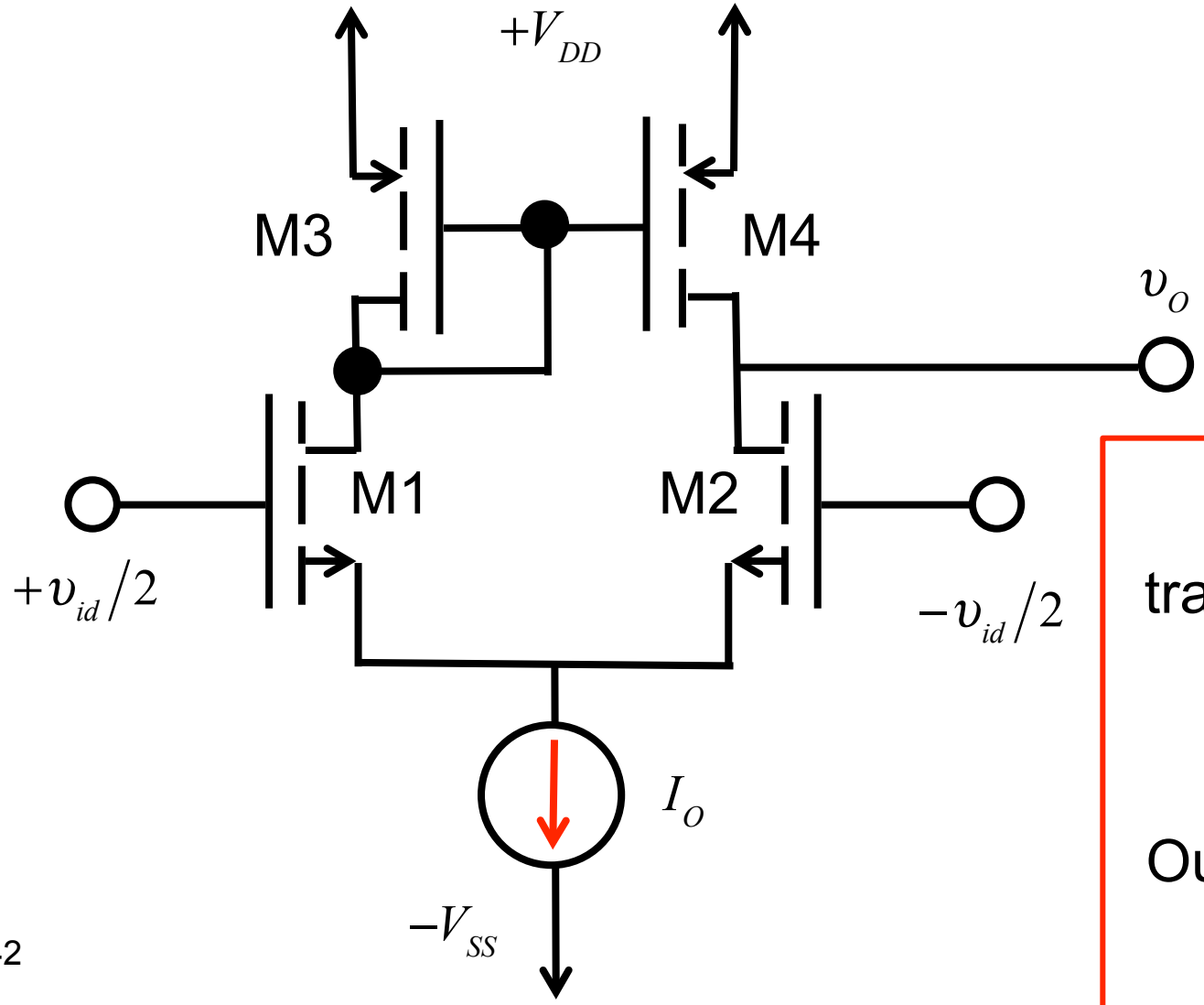
CM loaded differential pair



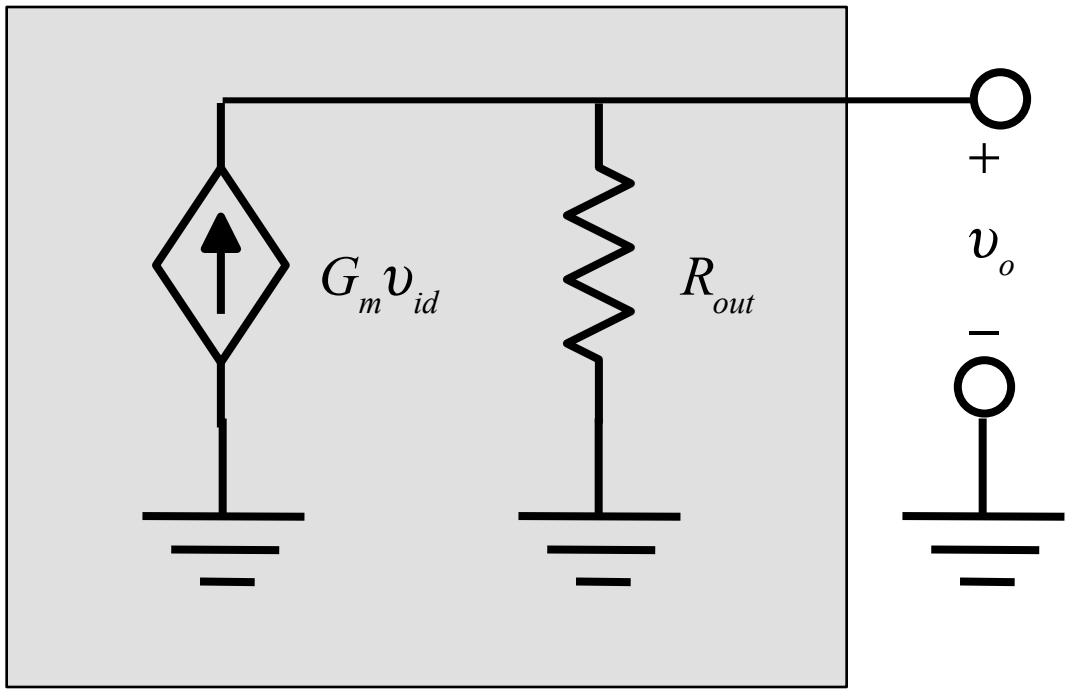
Short-circuit transconductance

$$G_m \equiv \frac{i_o}{v_{id}} = g_m$$

Output resistance

$$R_{out} = r_{o2} \| r_{o4}$$

SS output equivalent circuit of the amplifier



Questions

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