Spring 2019 Purdue University

ECE 255: L25

Cascode Amplifiers

(Sedra and Smith, 7th Ed., Sec. 8.5)

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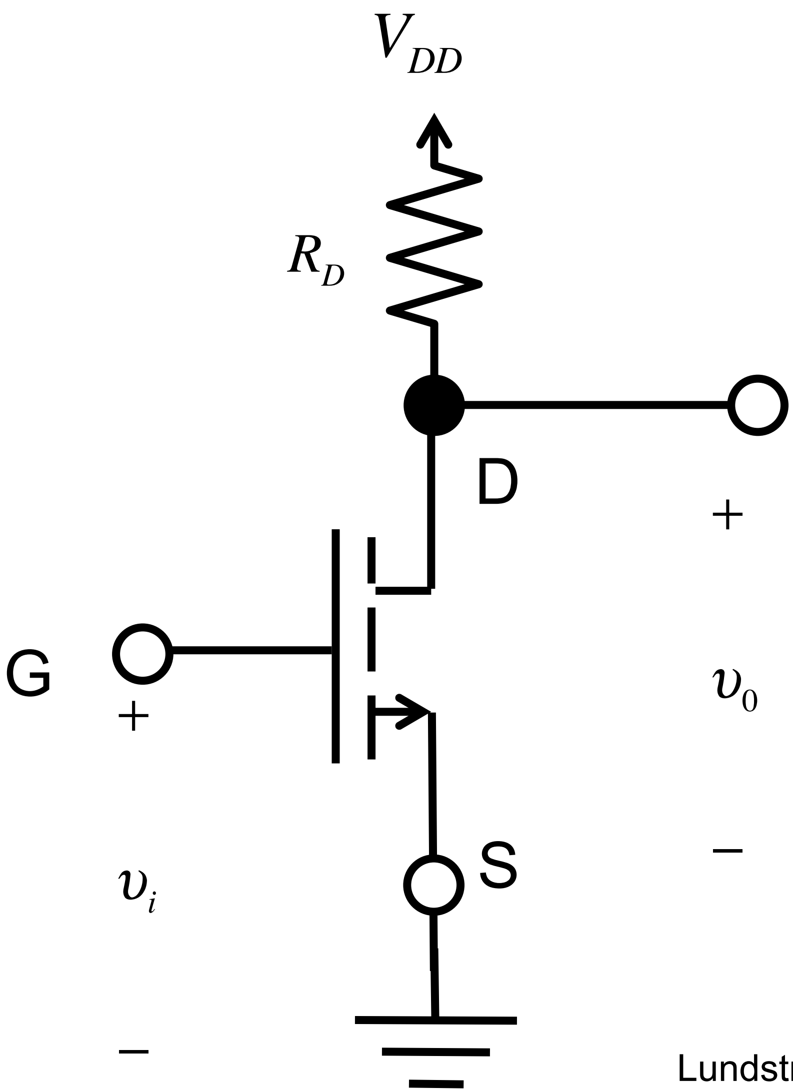
Announcements

1) HW8 due at 5:00 PM Friday, March 29

2) Exam 3 is at 6:30 PM, Tuesday, April 2

3) Spice Project 3 will be due on April 17

CS amplifier

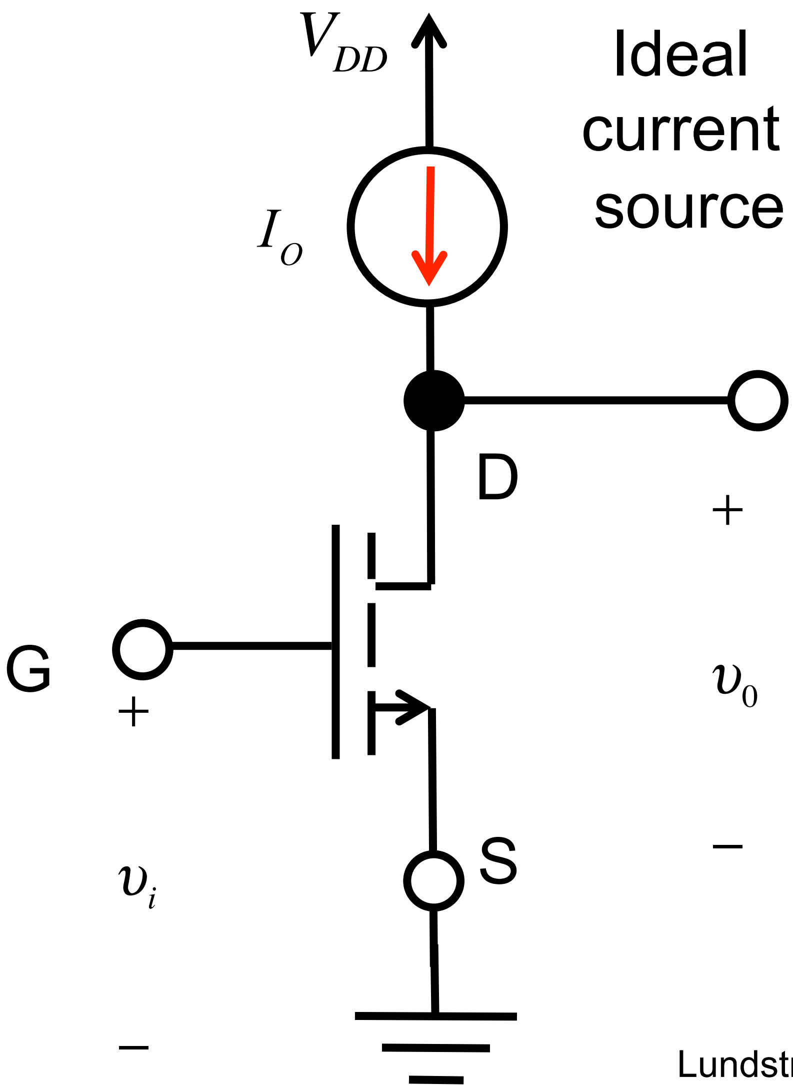


$$A_{\upsilon_o} = \frac{\upsilon_o}{\upsilon_i} = -g_m R_D$$

$$R_{in} = \infty$$

$$R_o = R_D$$

CS amplifier with active load



Ideal current source

$R_O = \infty$

$$A_{v_o} = \frac{v_o}{v_i} = -g_m r_o$$

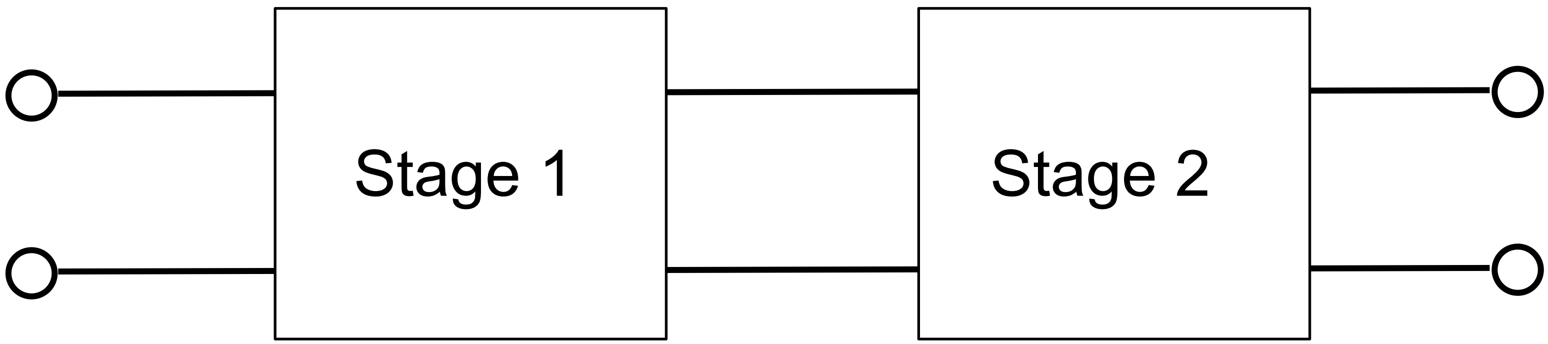
$$A_{v_o} = -A_0$$

$$R_{in} = \infty$$

$$R_o = r_o$$

But this gain is not large enough

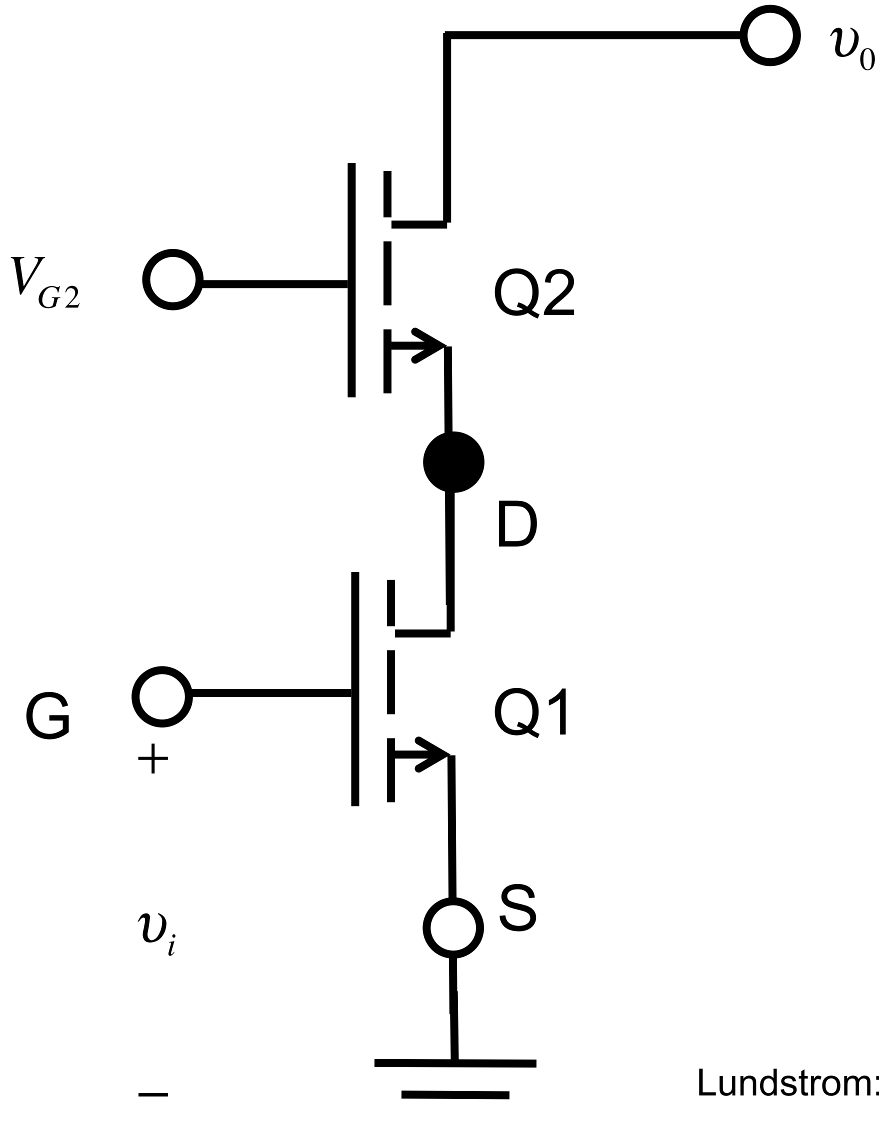
Solution: cascade amplifiers



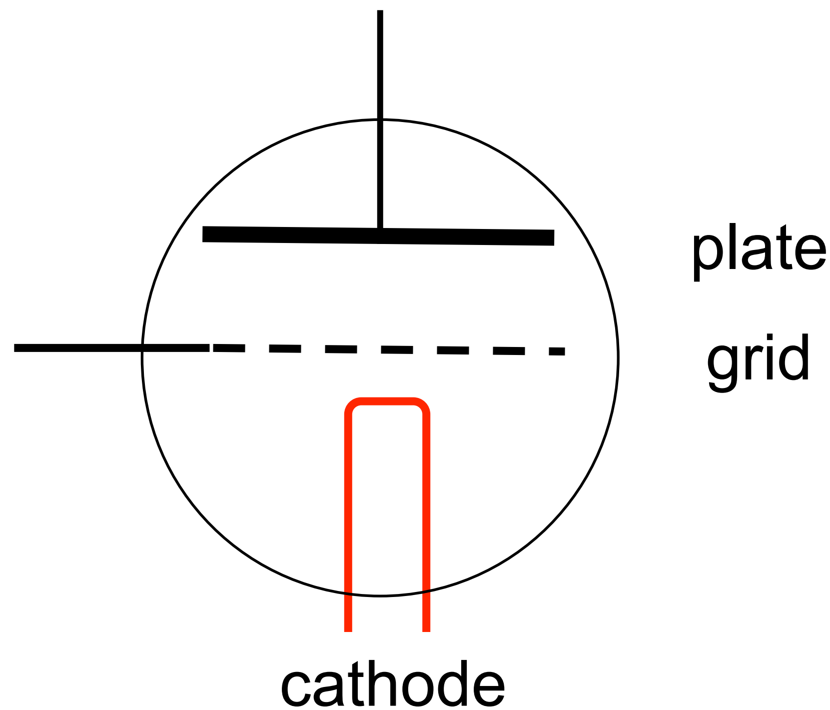
Examples: CE:CE CC:CE CE:CC

CE:CB or CS:CG = “cascode”

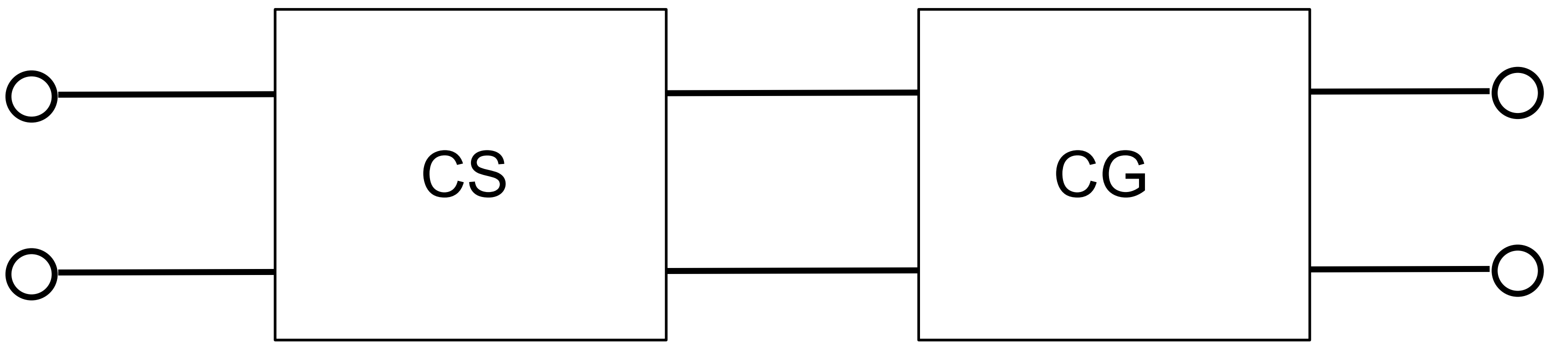
Basic cascode



“cascaded cathode”



Cascode amplifiers



Discrete transistor version first

Then MOS IC cascodes

Outline

1) Introduction

2) Discrete cascode

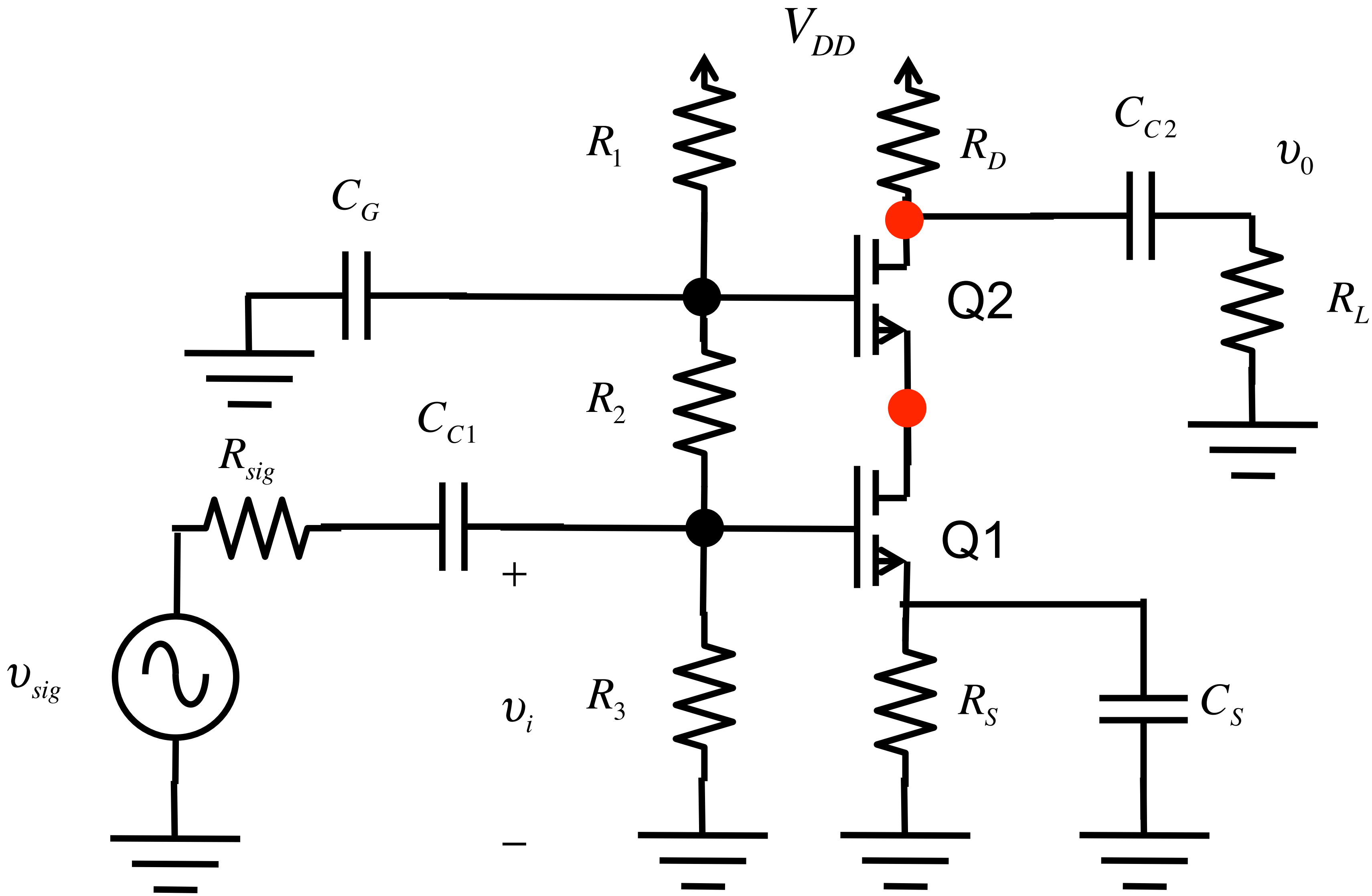
3) IC MOS cascode

4) Discussion

5) BJT cascode

6) Summary

Discrete CS:CG cascode



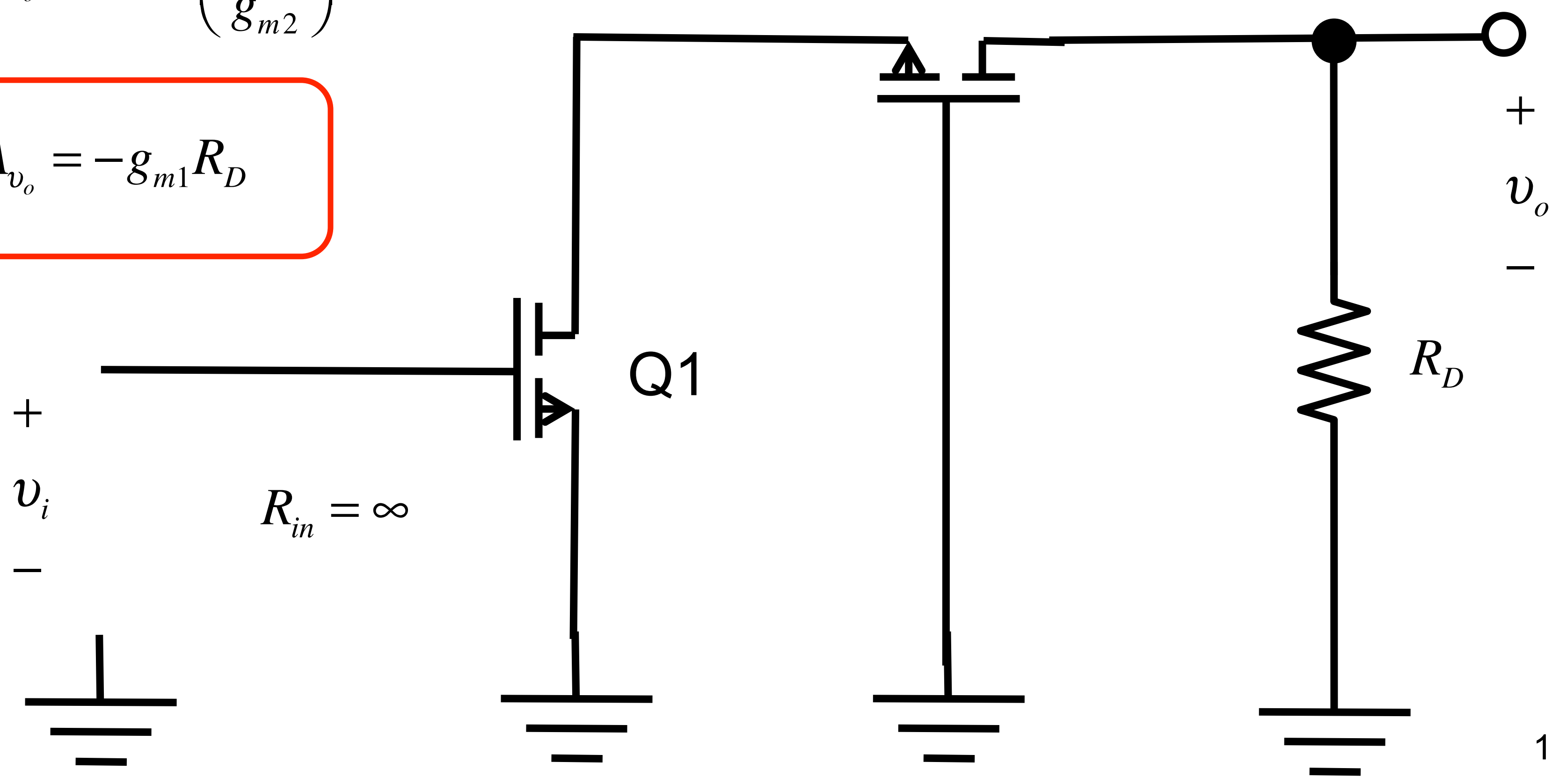
CS:CG discrete cascode (without bias resistors)

$$A_{\upsilon_o} = A_{\upsilon_1} \times A_{\upsilon_2}$$

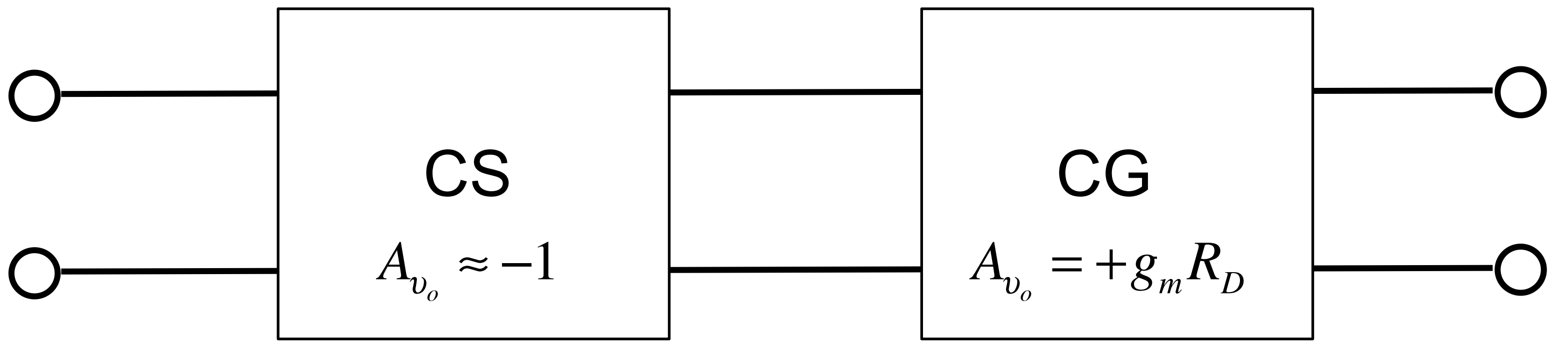
$$R_o = R_D$$

$$A_{\upsilon_o} = -g_{m1}\left(\frac{1}{g_{m2}}\right) \times g_{m2} R_D$$

$$A_{\upsilon_o} = -g_{m1} R_D$$



CS:CG cascode summary



- Input resistance of CS
- Output resistance of CS
- Voltage gain of CS

(excellent high frequency response)

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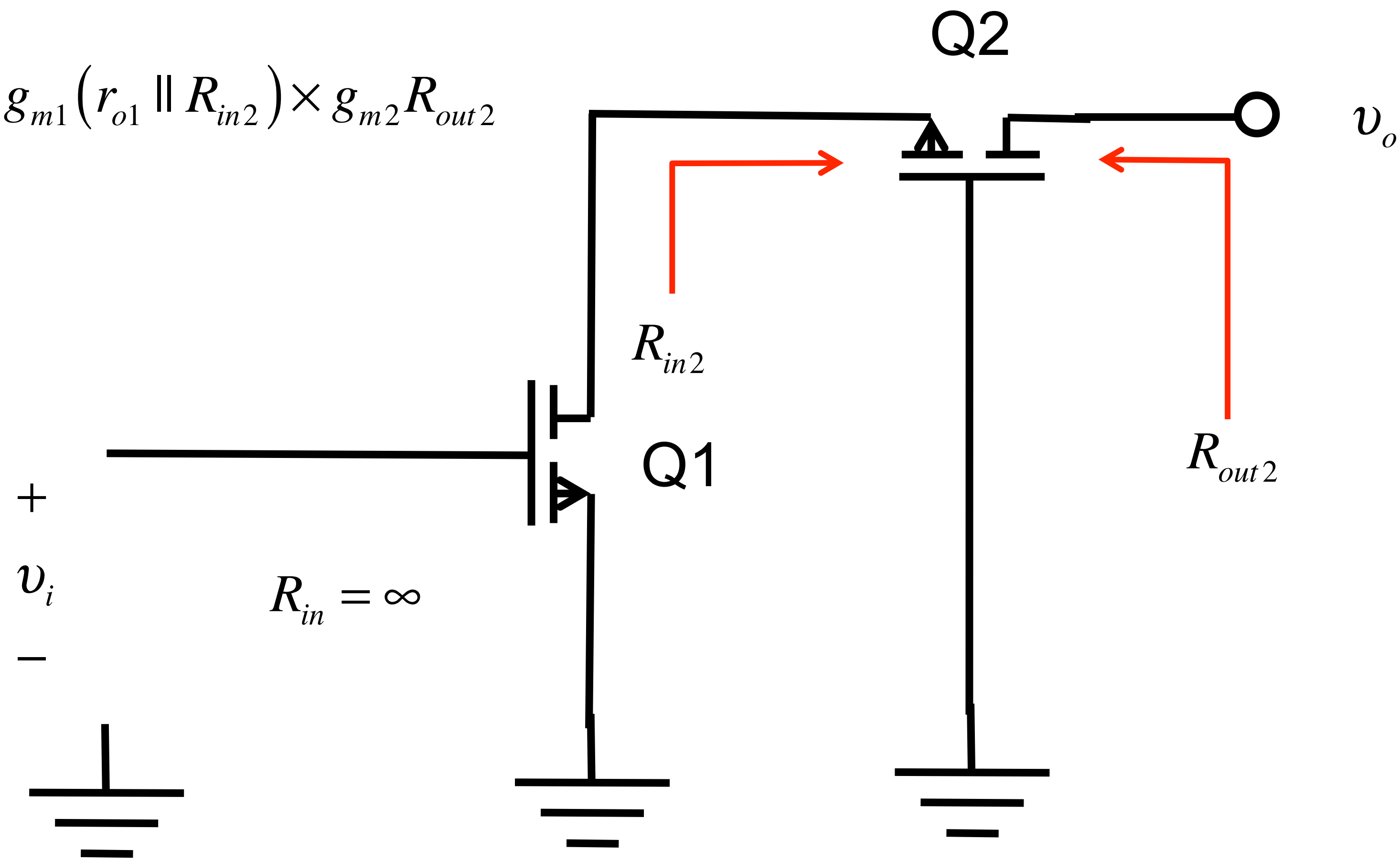
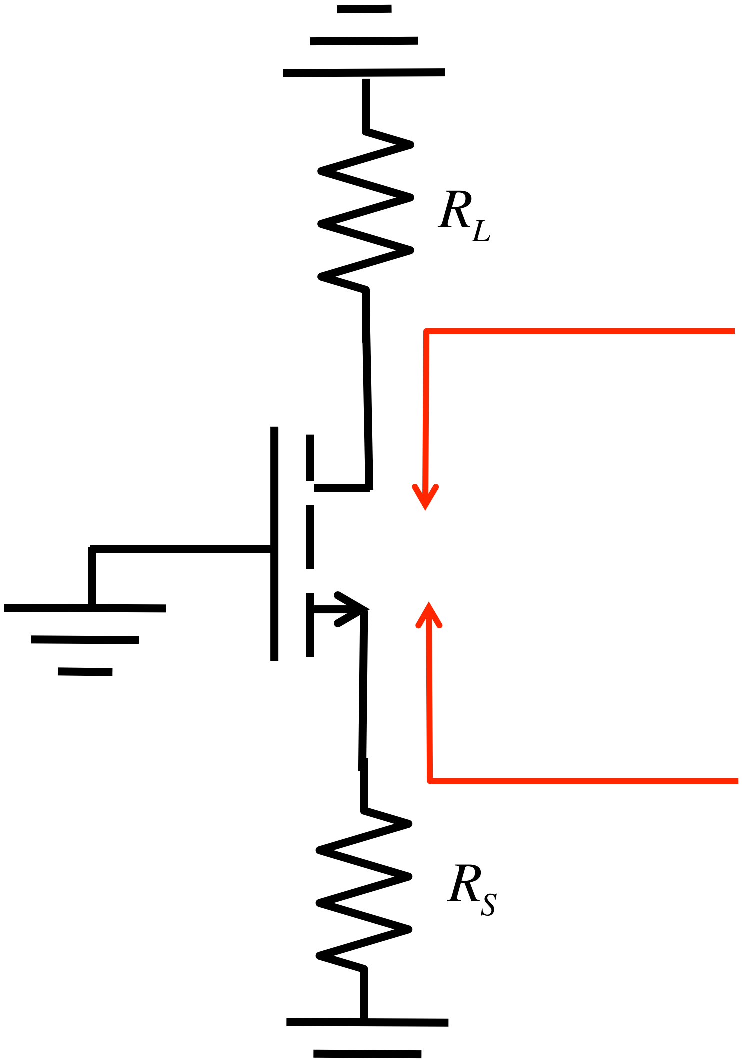
CS:CG cascode (IC)

$$A_{v_o} = A_{v_1} \times A_{v_2}$$

$$A_{v_o} = -g_{m1}\left(r_{o1} \parallel R_{in2}\right) \times g_{m2} R_{out2}$$



Recall L24



$$R_{out} = r_o + \left(1 + g_m r_o\right) R_{series}$$

$$R_{out} \approx r_o + \left(g_m r_o\right) R_S$$

$$R_{out} \approx \left(g_m r_o\right) R_S$$

$$R_{in} = \frac{\left(r_o + R_L\right)}{\left(1 + g_m r_o\right)}$$

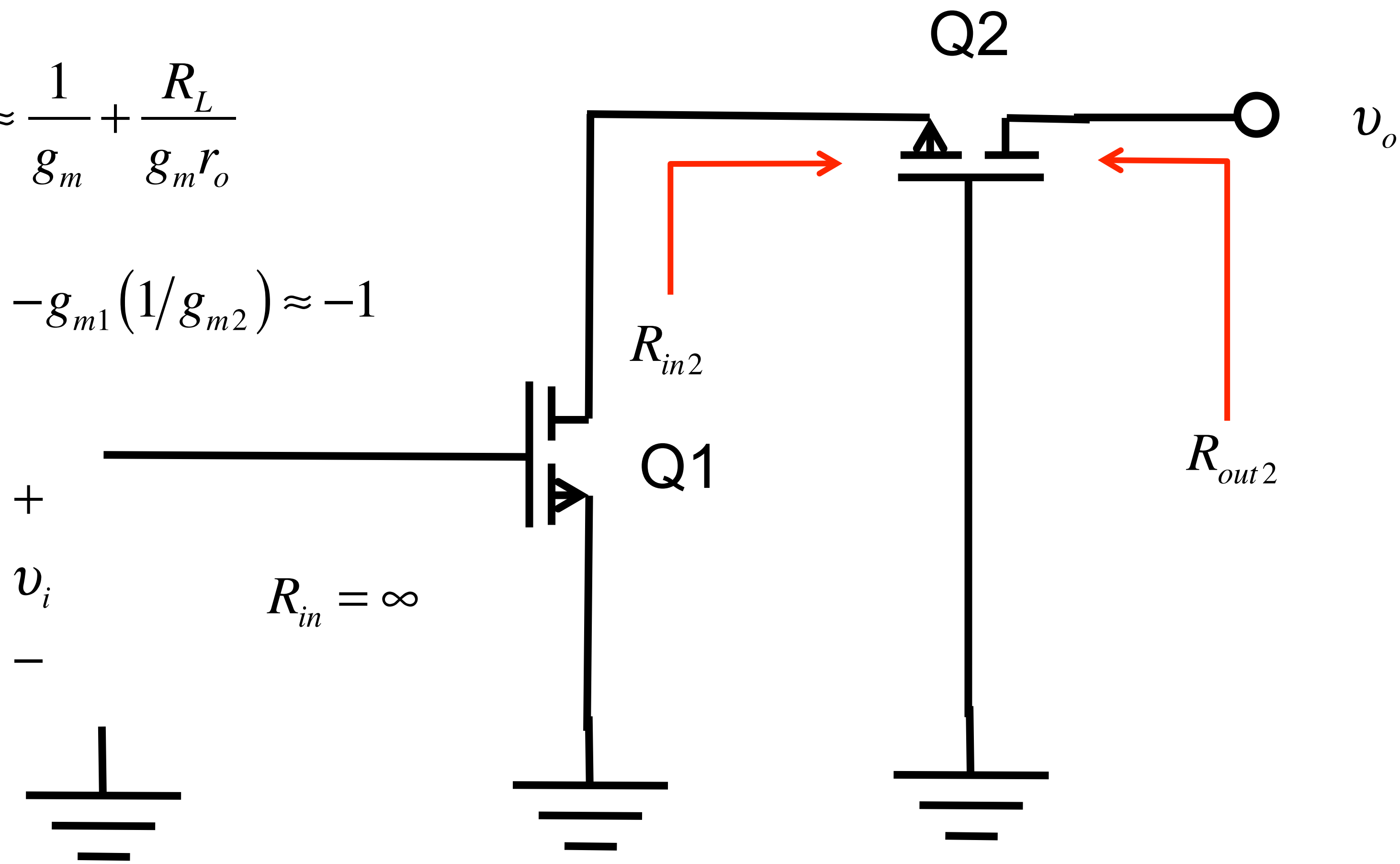
$$R_{in} \approx \frac{1}{g_m} + \frac{R_L}{g_m r_o}$$

First stage gain

$$A_{\upsilon_1} = -g_{m1}\left(r_{o1} \parallel R_{in2}\right)$$

$$R_{in2} \approx \frac{1}{g_m} + \frac{R_L}{g_m r_o}$$

$$A_{\upsilon_1} = -g_{m1}\left(1/g_{m2}\right) \approx -1$$



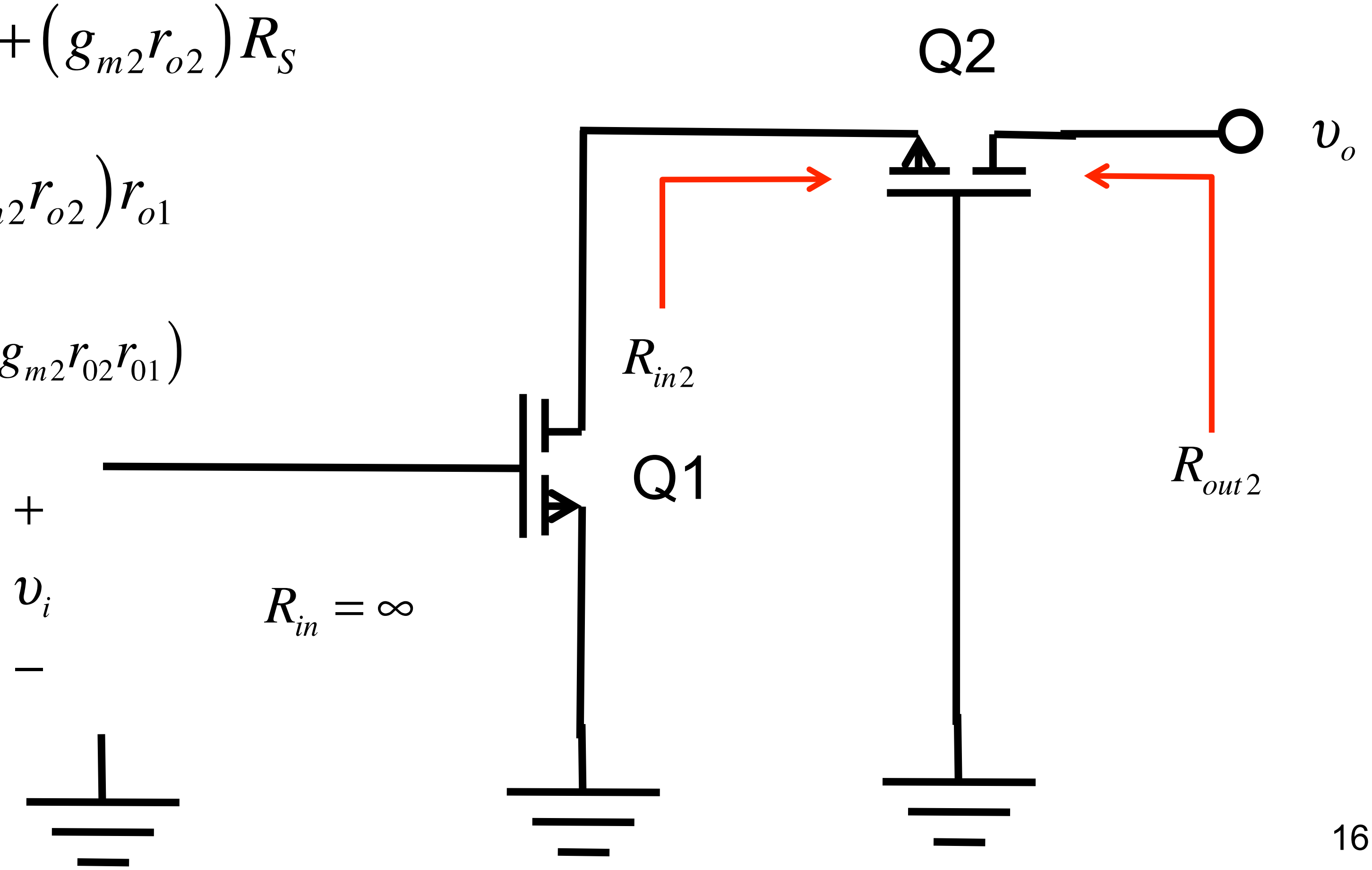
Second stage gain

$$A_{\upsilon_2} = +g_{m2} R_{out2}$$

$$R_{out2} \approx r_{o2} + \left(g_{m2} r_{o2}\right) R_S$$

$$R_{out2} \approx \left(g_{m2} r_{o2}\right) r_{o1}$$

$$A_{\upsilon_2} = +g_{m2}\left(g_{m2} r_{02} r_{01}\right)$$



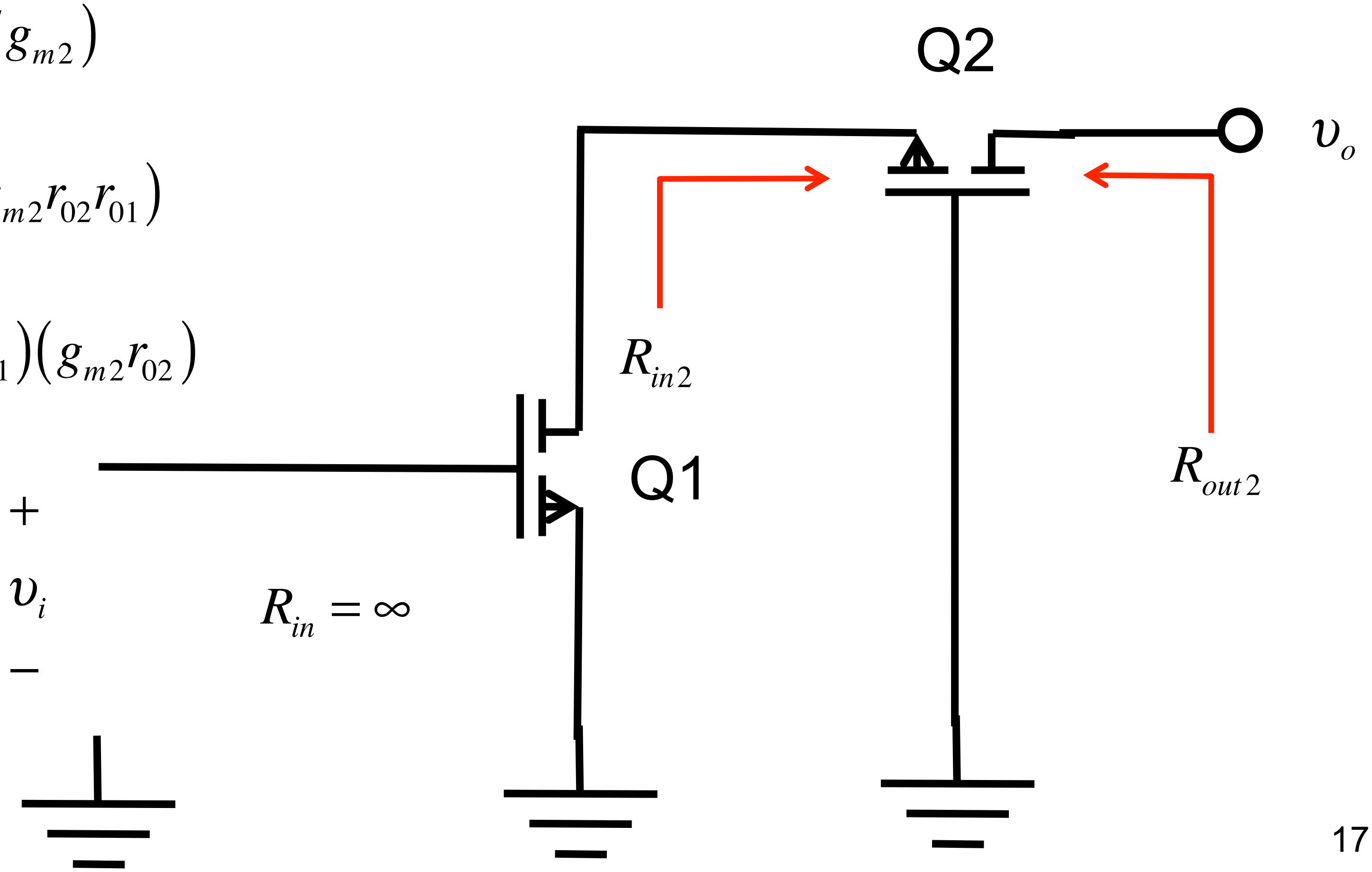
Total gain

$$A_{\upsilon_o} = A_{\upsilon_1} \times A_{\upsilon_2}$$

$$A_{\upsilon_1} = -g_{m1}\left(1/g_{m2}\right)$$

$$A_{\upsilon_2} = +g_{m2}\left(g_{m2}r_{02}r_{01}\right)$$

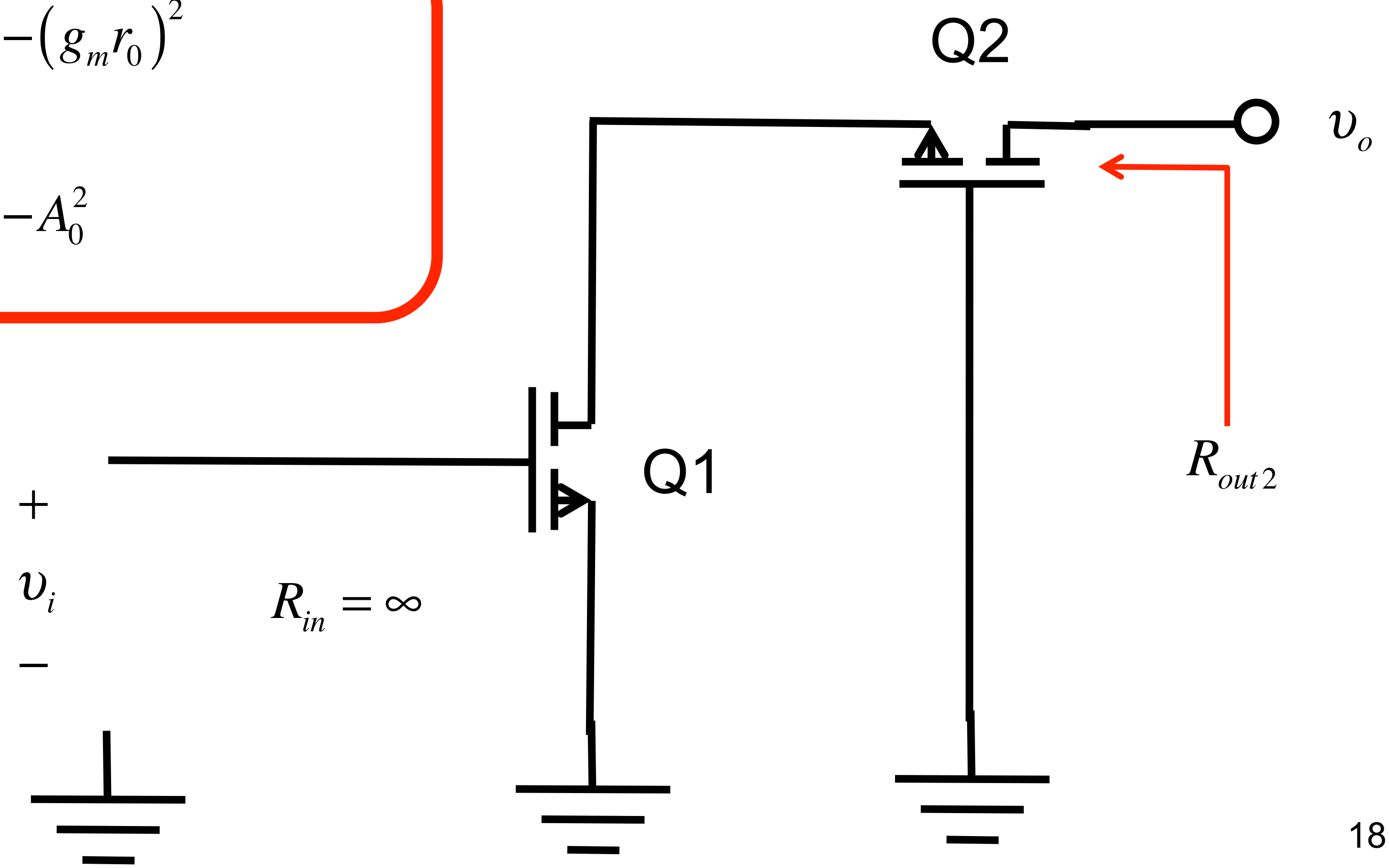
$$A_{\upsilon_o} = -\left(g_{m1}r_{01}\right)\left(g_{m2}r_{02}\right)$$



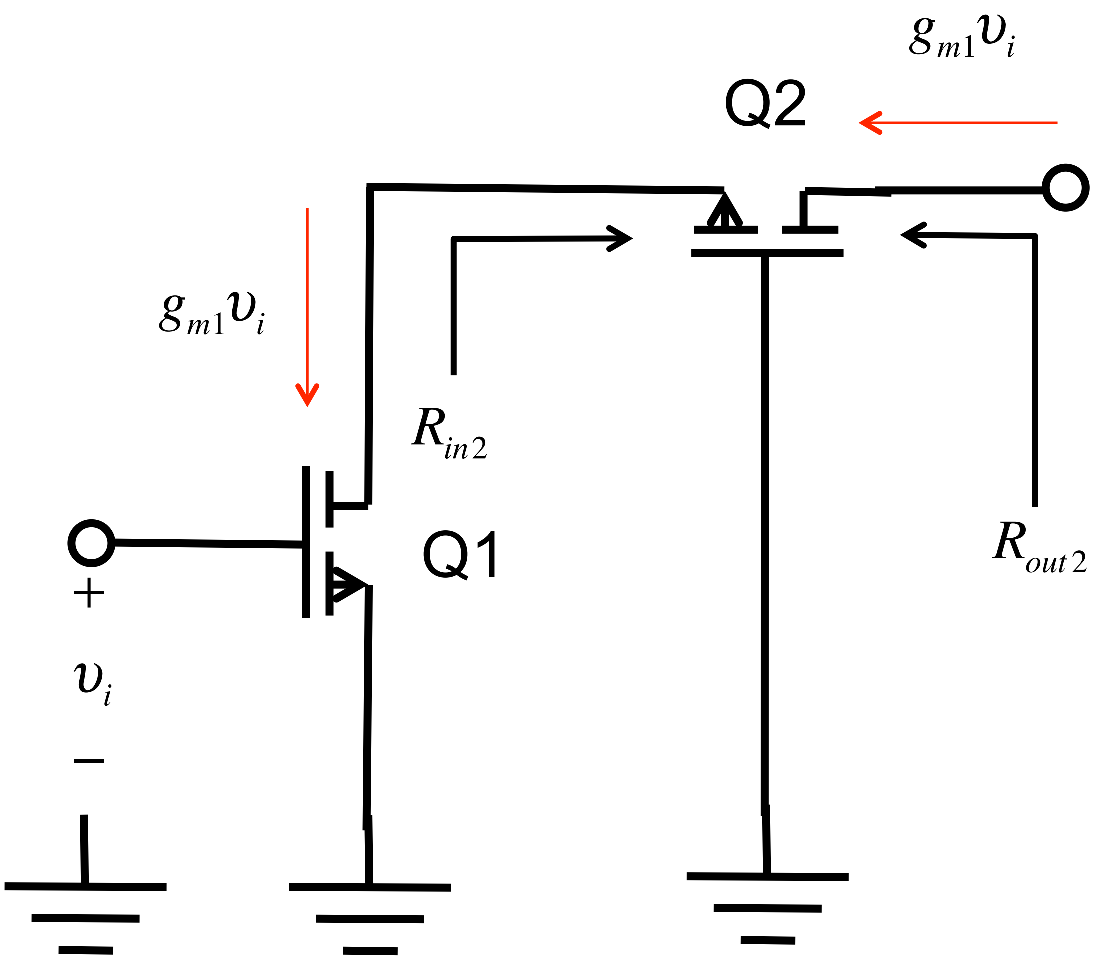
Total gain of cascode

$$A_{v_o} = -(g_m r_0)^2$$

$$A_{v_o} = -A_0^2$$



An easier way



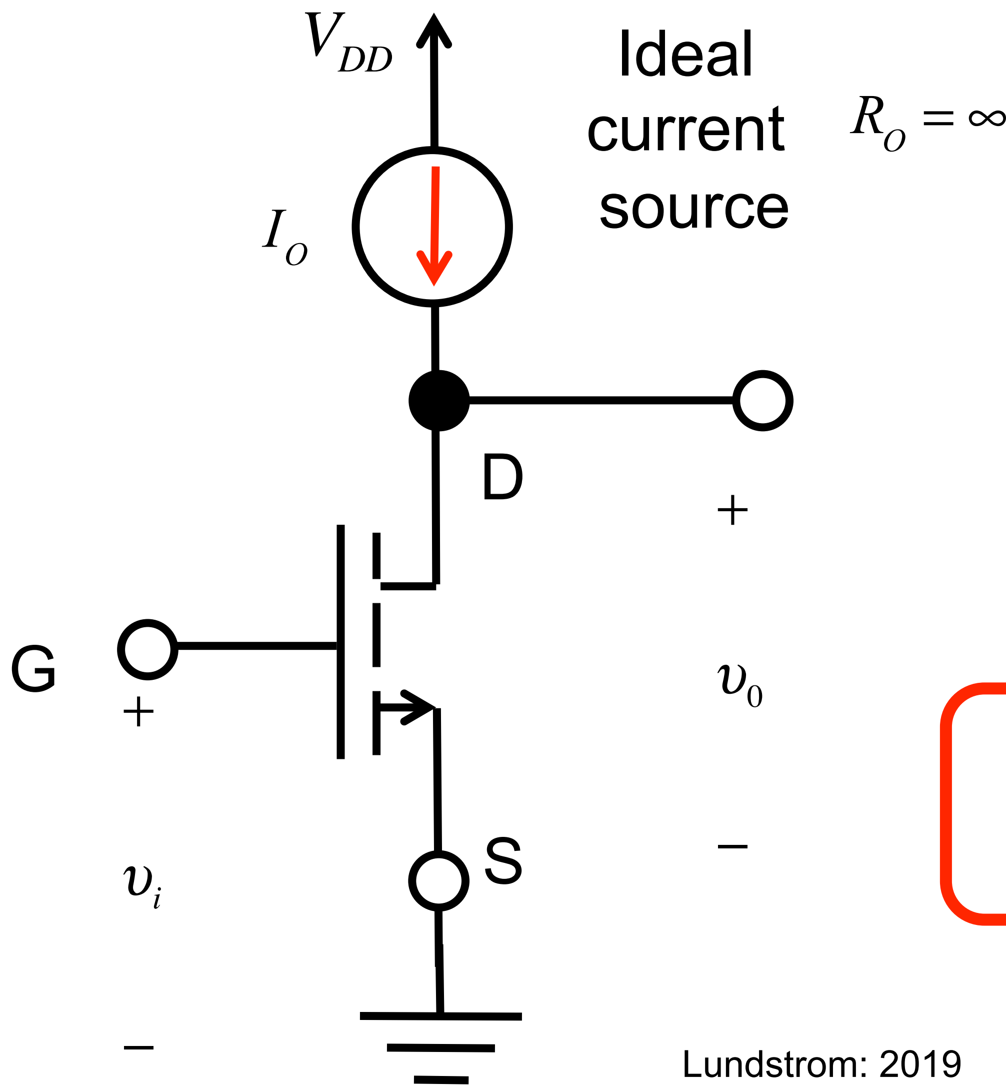
$$\upsilon_o = -\left(g_{m1}\upsilon_i\right)R_{out2}$$

$$R_{out2} \approx \left(g_{m2}r_{o2}\right)r_{o1}$$

$$A_{\upsilon_i} = -\left(g_m r_o\right)^2$$

$$A_{\upsilon_o} = -A_0^2$$

Recall: CS amplifier with active load



$$A_{v_o} = -g_m r_o$$

$$A_{v_o} = -A_0$$

Cascode: $A_{v_o} = -\left(A_0\right)^2$

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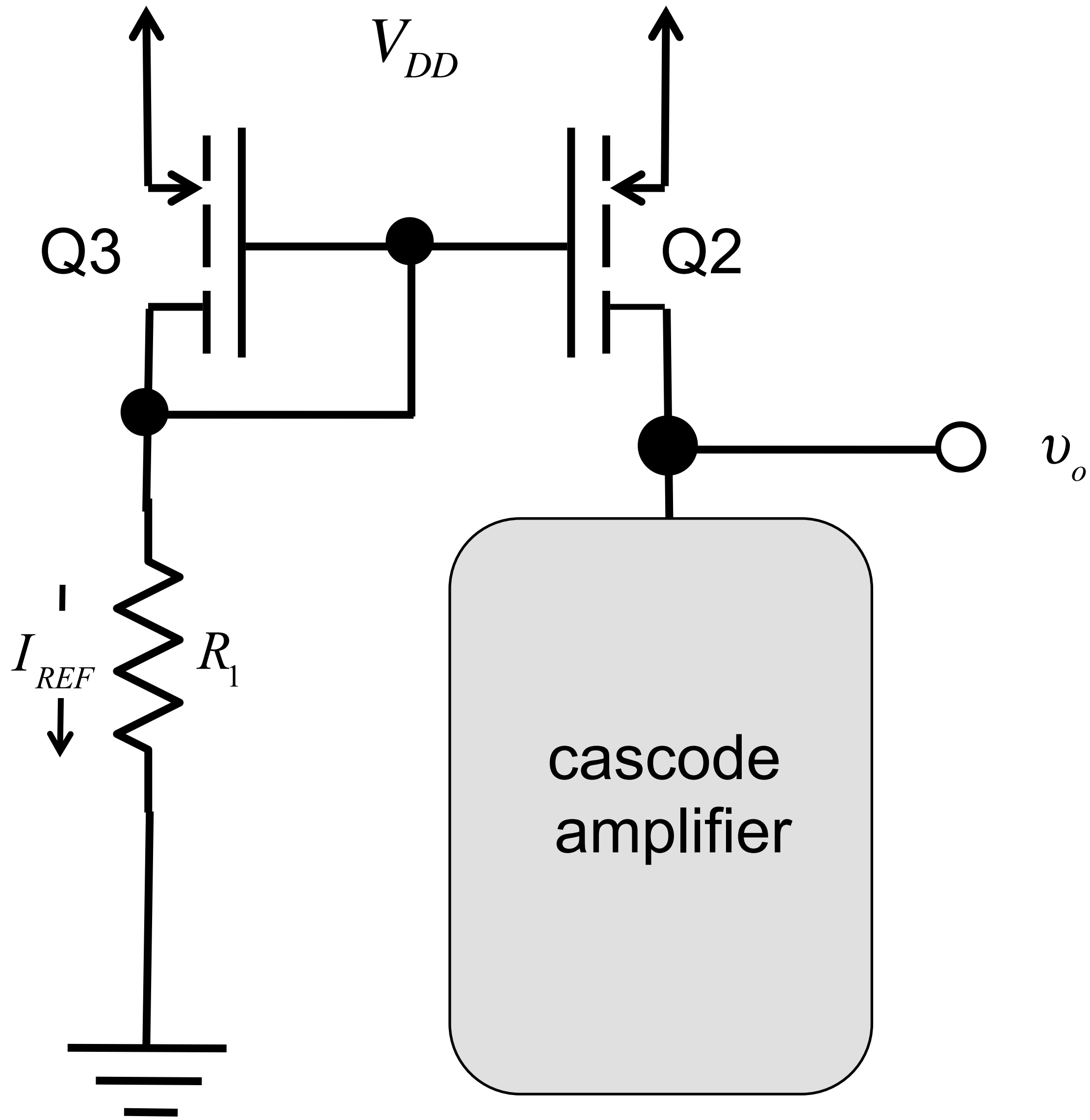
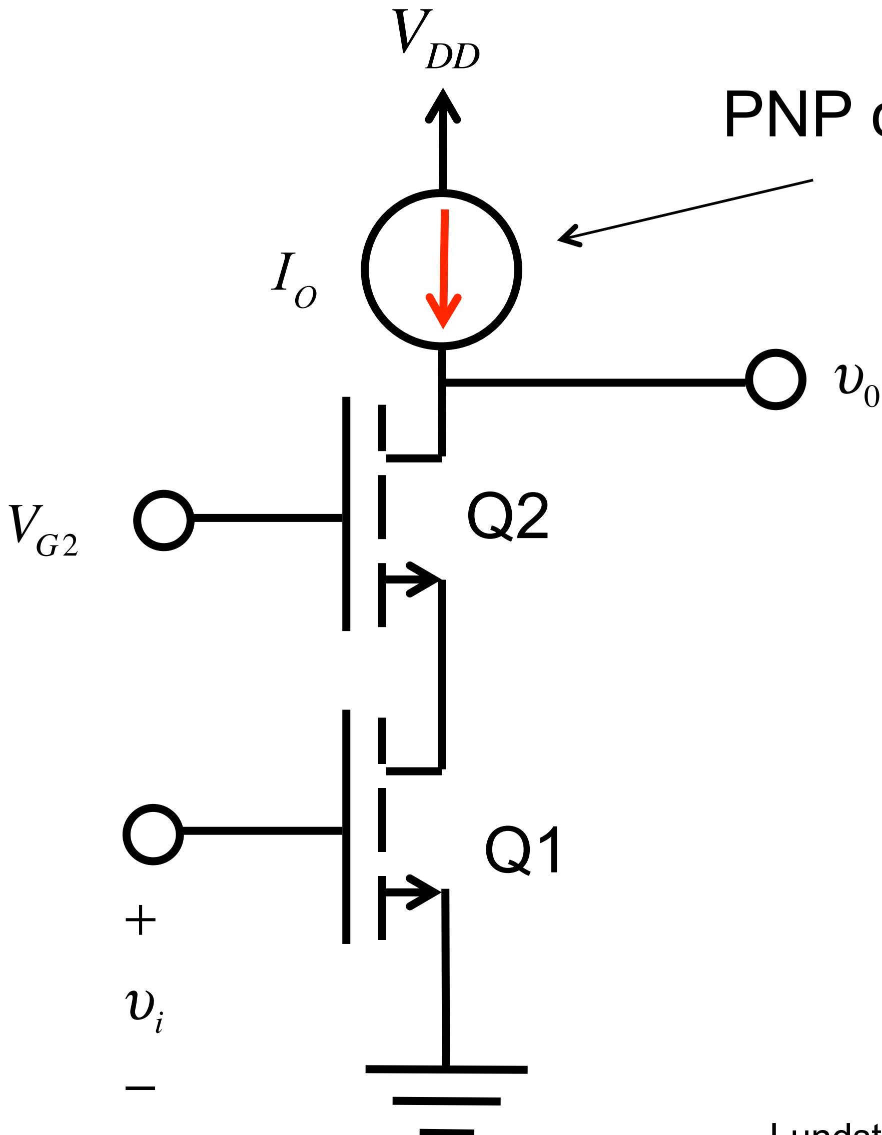
Implementation



Implementation



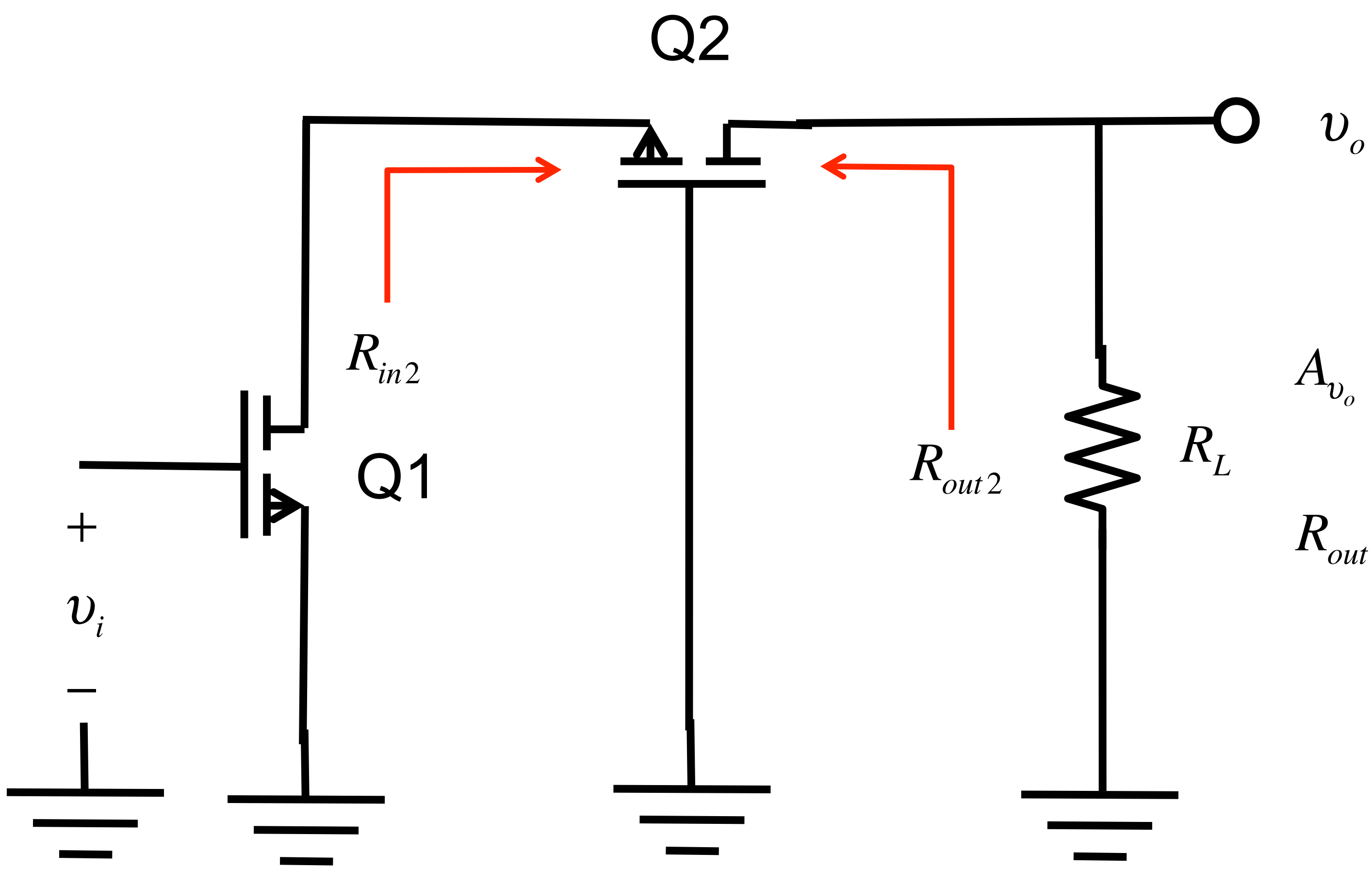
$$A_{v_o} = -\left(g_m r_0\right)^2$$

$$A_{v_o} = -g_m\left[\left(g_m r_0\right) r_o\right] \| \, r_{op}$$

$$A_{v_o} \approx -g_m r_o = -A_0$$

The solution is to use a cascode current course. (S&S p. 549)

Include a load resistor

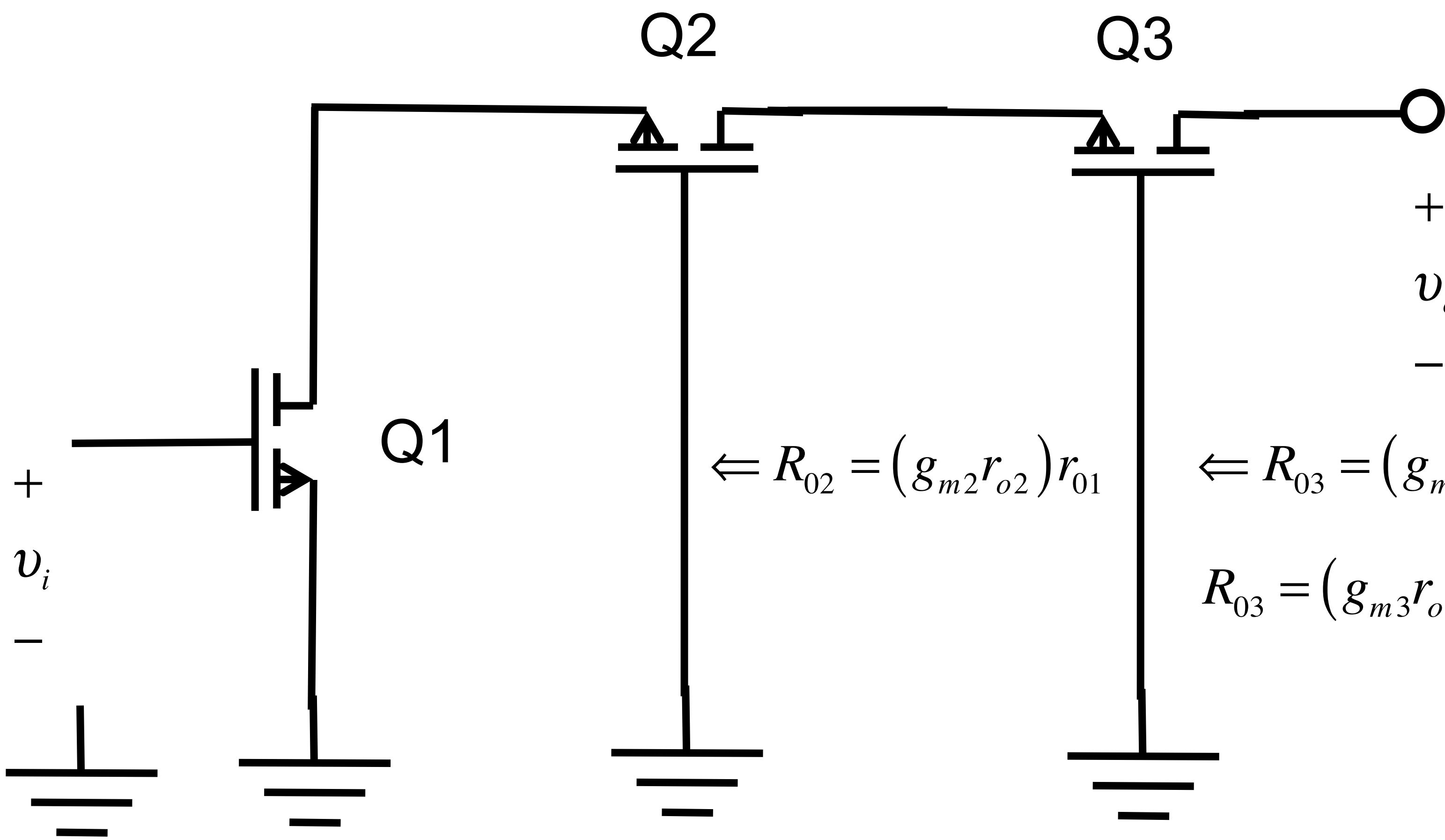


$$A_{v_o} = -g_{m1}R_{out2} \parallel R_L$$

$$R_{out2} = (g_{m2}r_{o2})r_{o1}$$

But now, can you find the gain of stage 1 (it depends on R_L!). See S&S, Sec. 8.5.3

Double cascode



$$\Leftarrow R_{02} = (g_{m2} r_{o2}) r_{01}$$

$$\Leftarrow R_{03} = (g_{m3} r_{o3}) R_{02}$$

$$R_{03} = (g_{m3} r_{o3})(g_{m2} r_{o2}) r_{01}$$

$$A_{\upsilon_o} = -g_m R_{o3}$$

$$A_{\upsilon_o} = -(g_m r_0)^3$$

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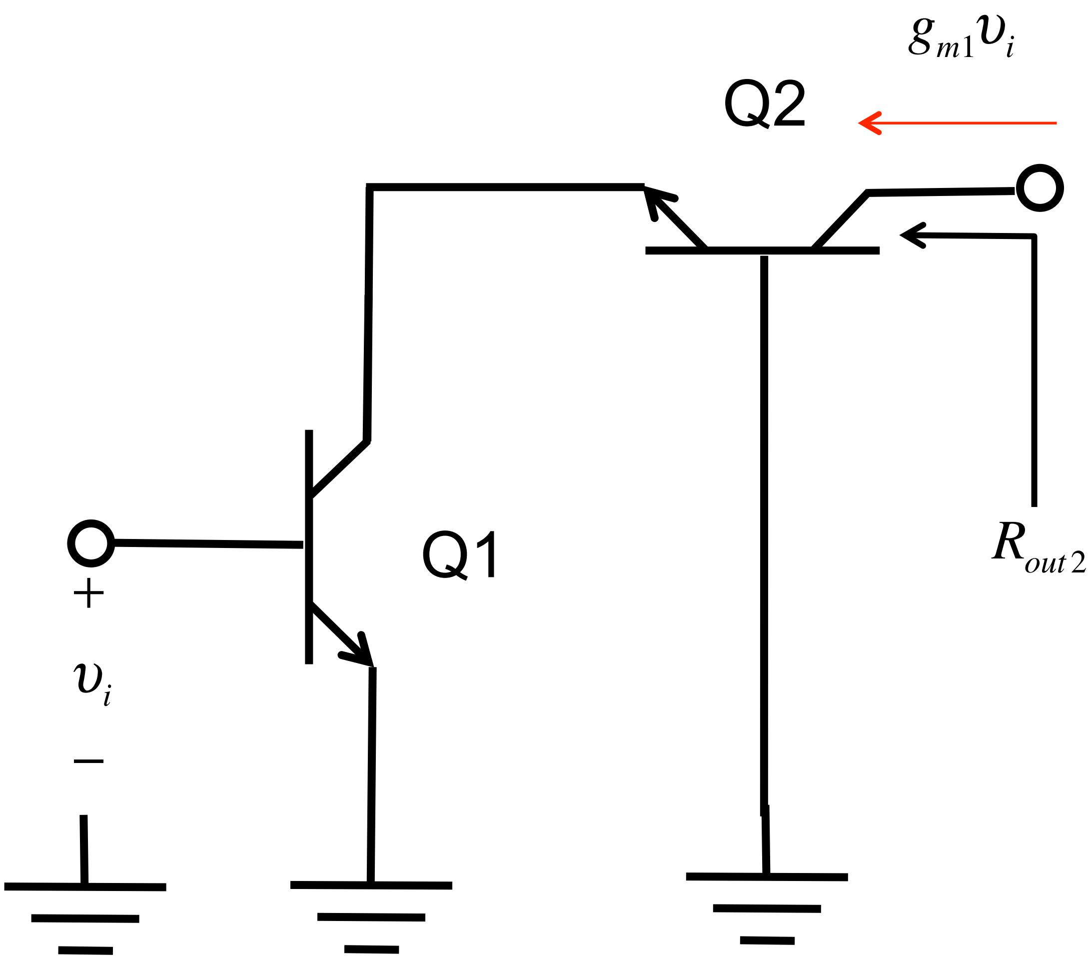
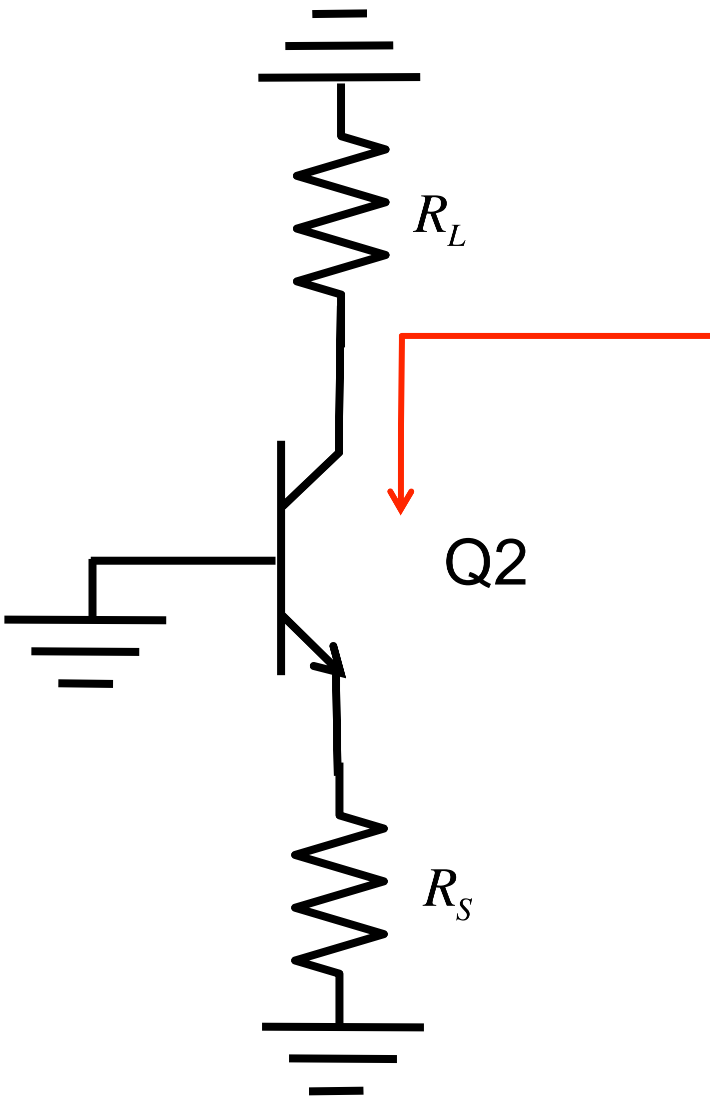
BJT cascode



$$v_o = -\left(g_{m1}v_i\right)R_{out2}$$

Recall L24



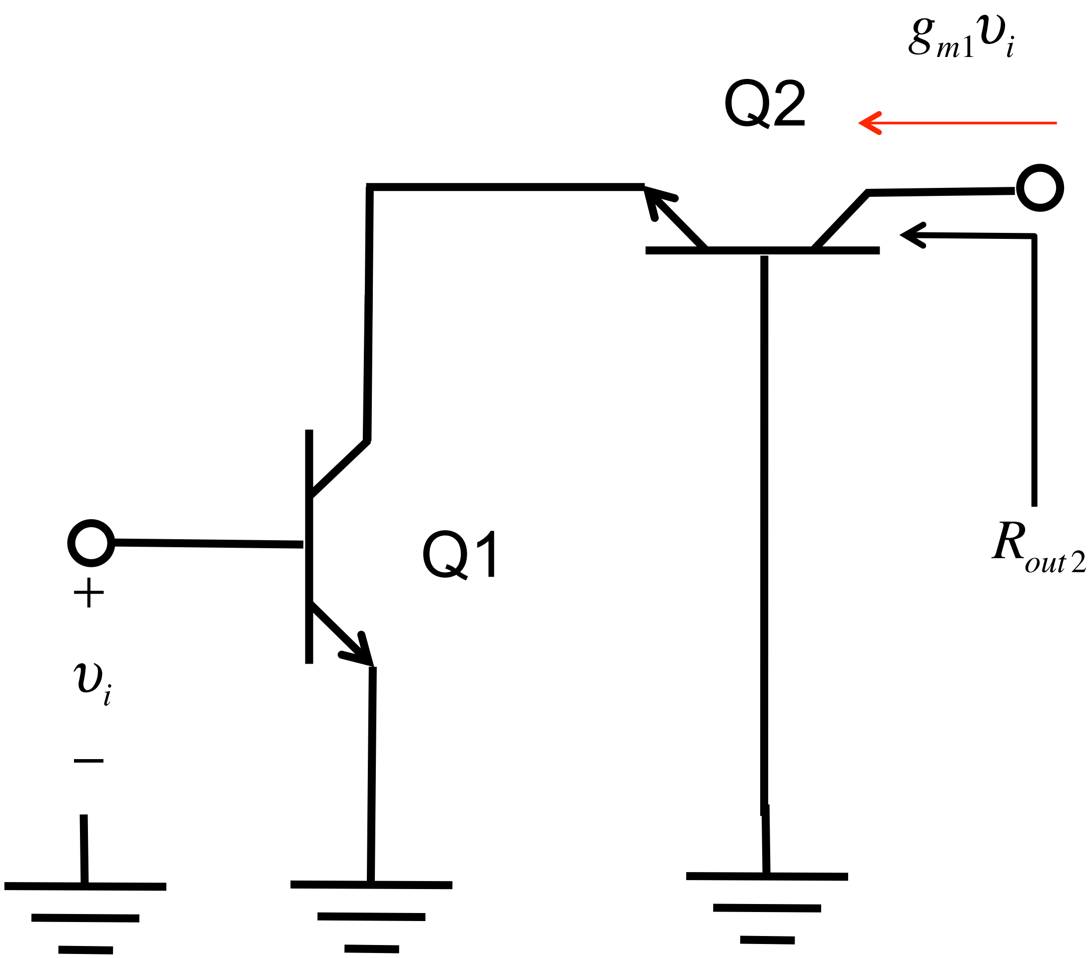
$$R_{out} = r_{o2} + \left(1 + g_{m2} r_{o2}\right)\left(R_S \parallel r_{\pi 2}\right)$$

$$R_{out} = r_{o2} + \left(1 + g_{m2} r_{o2}\right)\left(r_{o2} \parallel r_{\pi 2}\right)$$

$$R_{out} \approx \left(g_{m2} r_{o2}\right)\left(r_{o2} \parallel r_{\pi 2}\right)$$

cannot be as larges as
for the MOS case

BJT cascode



$$v_o = -\left(g_{m1}v_i\right)R_{out2}$$

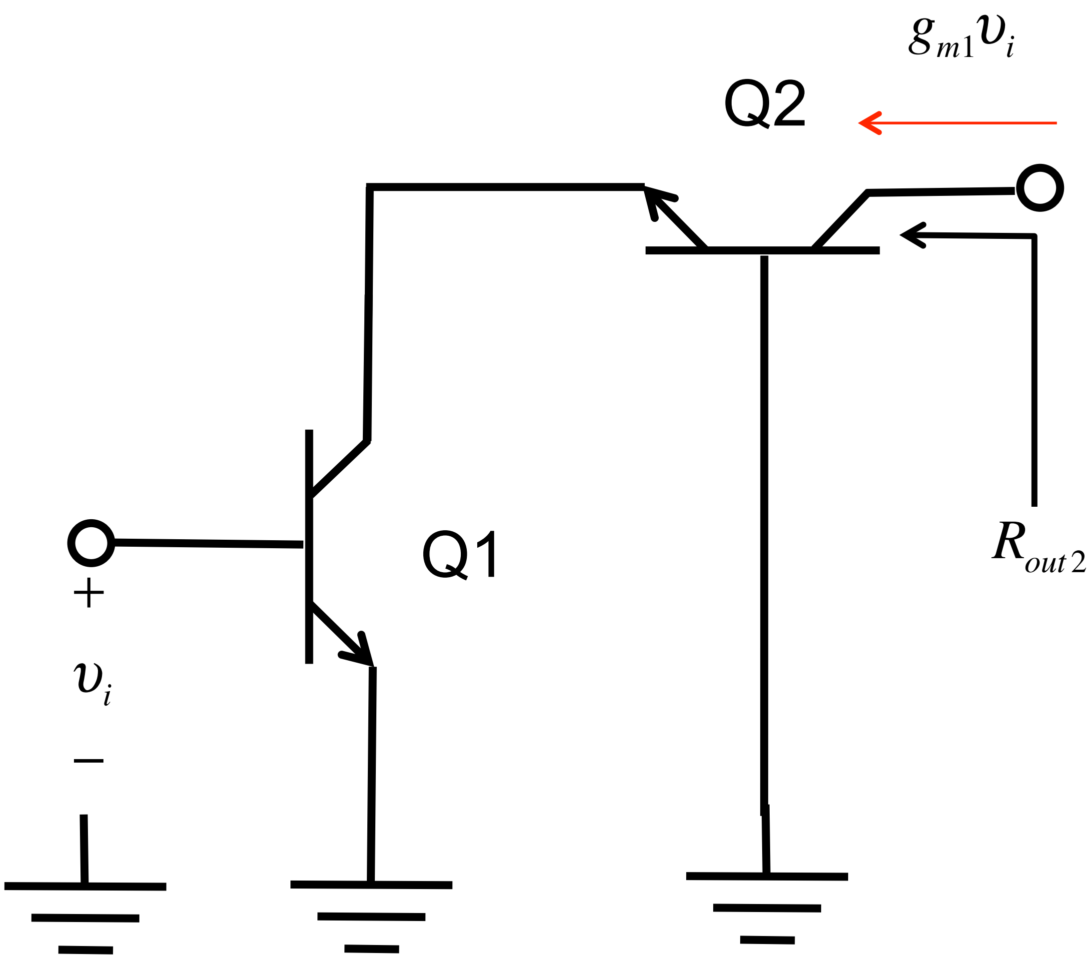
$$R_{out} \approx \left(g_{m2}r_{o2}\right)\left(r_{o2} \parallel r_{\pi 2}\right)$$

$$A_{v_o} = -g_{m1}\left(g_{m2}r_{o2}\right)\left(r_{o2} \parallel r_{\pi 2}\right)$$

$$A_{v_o}\Big|_{\max} = -g_{m1}\left(g_{m2}r_{o2}\right)r_{\pi 2}$$

$$A_{v_o}\Big|_{\max} = -\beta g_m r_o = -\beta A_0$$

BJT cascode



$$A_{v_o}\Big|_{\max} = -\beta A_0$$

See the discussion in Sec. 8.5.6 of S&S

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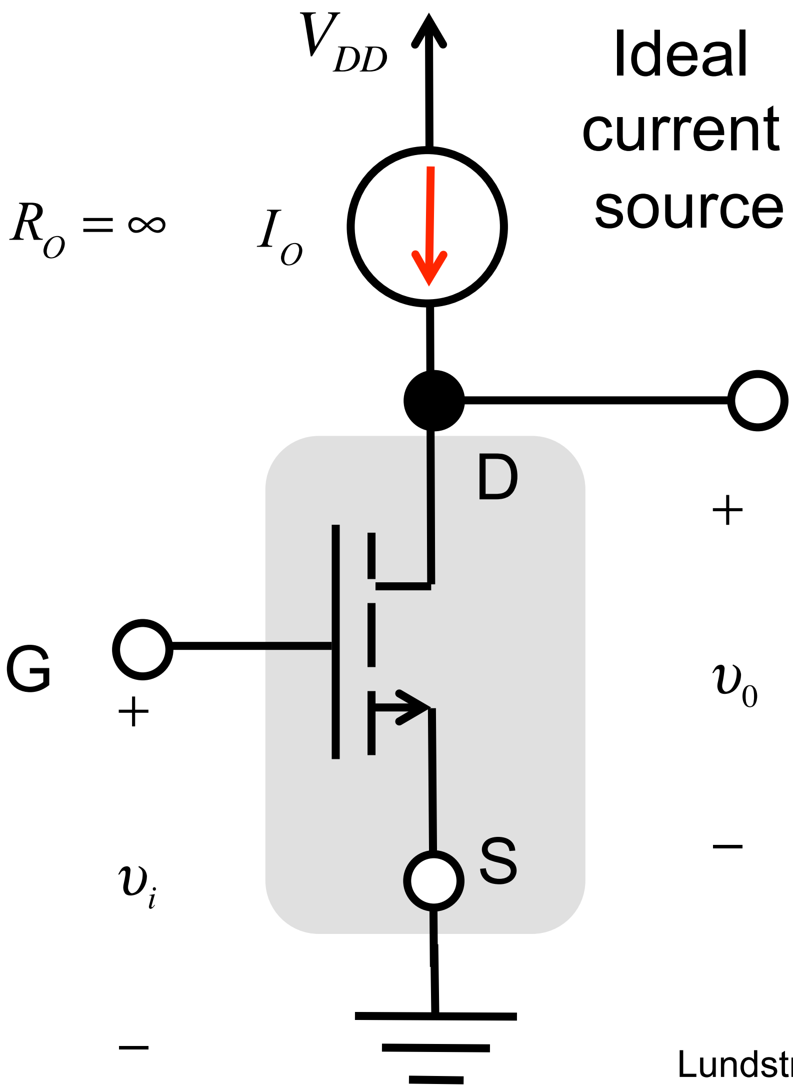
Summary



Common Source:

$$A_{\upsilon_o} = -g_m r_o$$

Cascode:

$$A_{\upsilon_o} = -(g_m r_o)^2$$

Double Cascode:

$$A_{\upsilon_o} = -(g_m r_o)^3$$

Questions

1) Introduction
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3) IC MOS cascode
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5) BJT cascodes
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