Spring 2019 Purdue University

ECE 255: L24

Common Gate and Common Base Amplifiers

(Sedra and Smith, 7th Ed., Secs. 8.4.1, 8.4.2, 8.4.4)

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Announcements

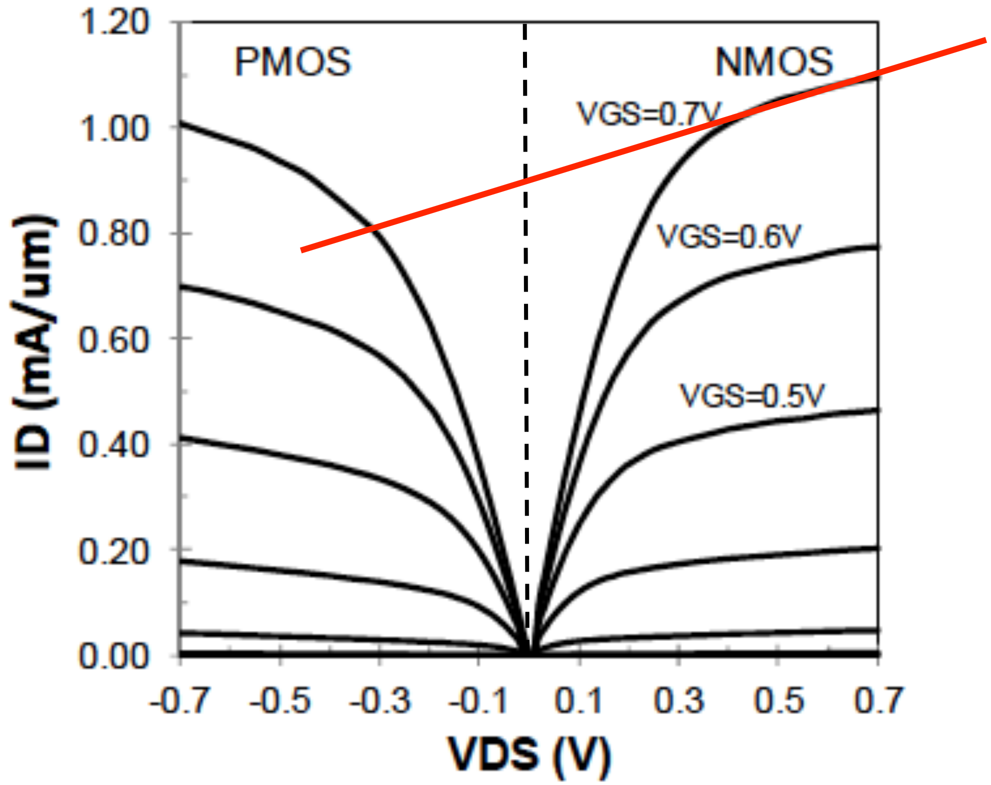
1) HW7 due at 5:00 PM Friday, March 22

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

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

4) Spice Project 3 will be due on April 17

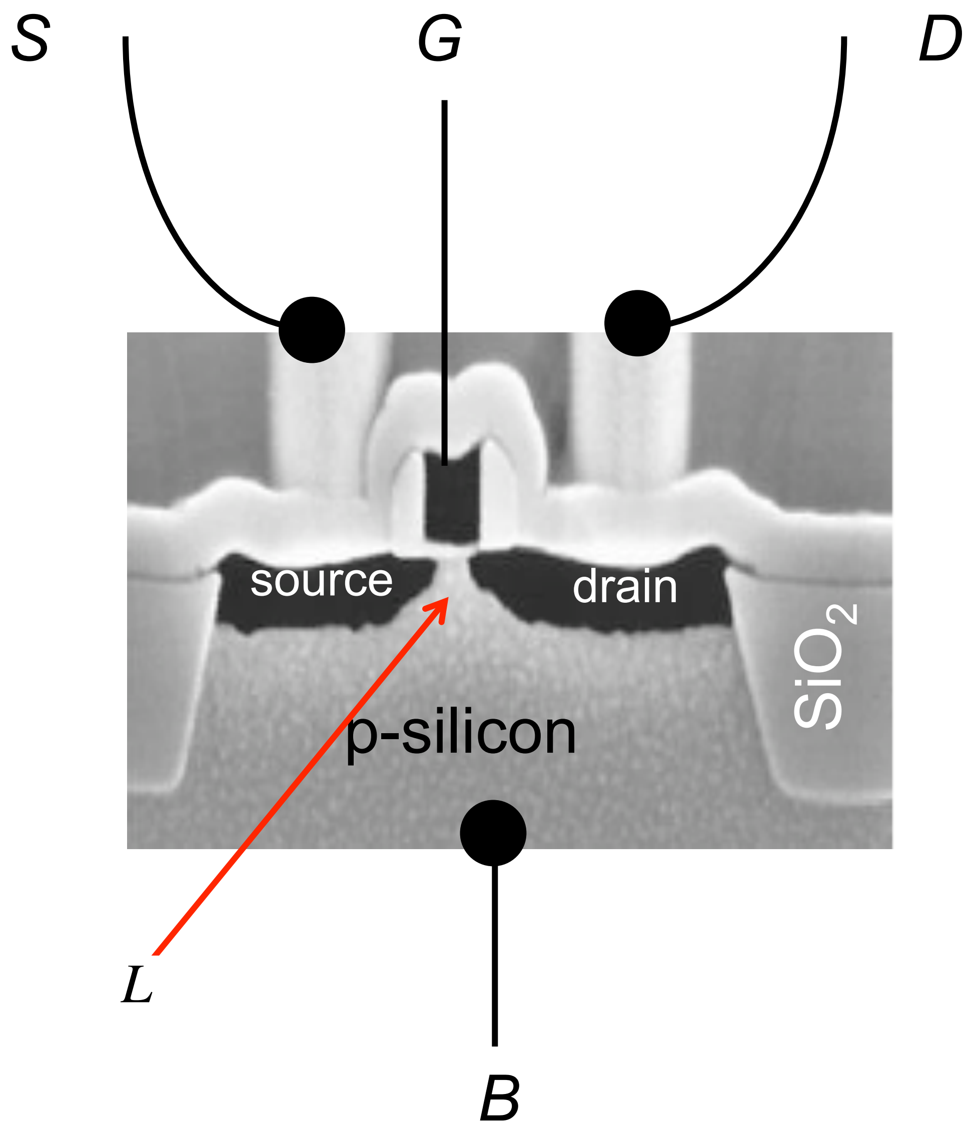
Output resistance



$$r_o = \frac{V_A}{I_D}$$

From: S. Natarajan, et al., "A 14nm Logic Technology Featuring 2nd-Generation FinFET Transistors, Air-Gapped Interconnects, Self-Aligned Double Patterning and a 0.0588 um^2 SRAM cell size," pp. 70-72. Tech. Digest, Intern. Electron Dev. Mtg, Dec. 2014.

Output resistance

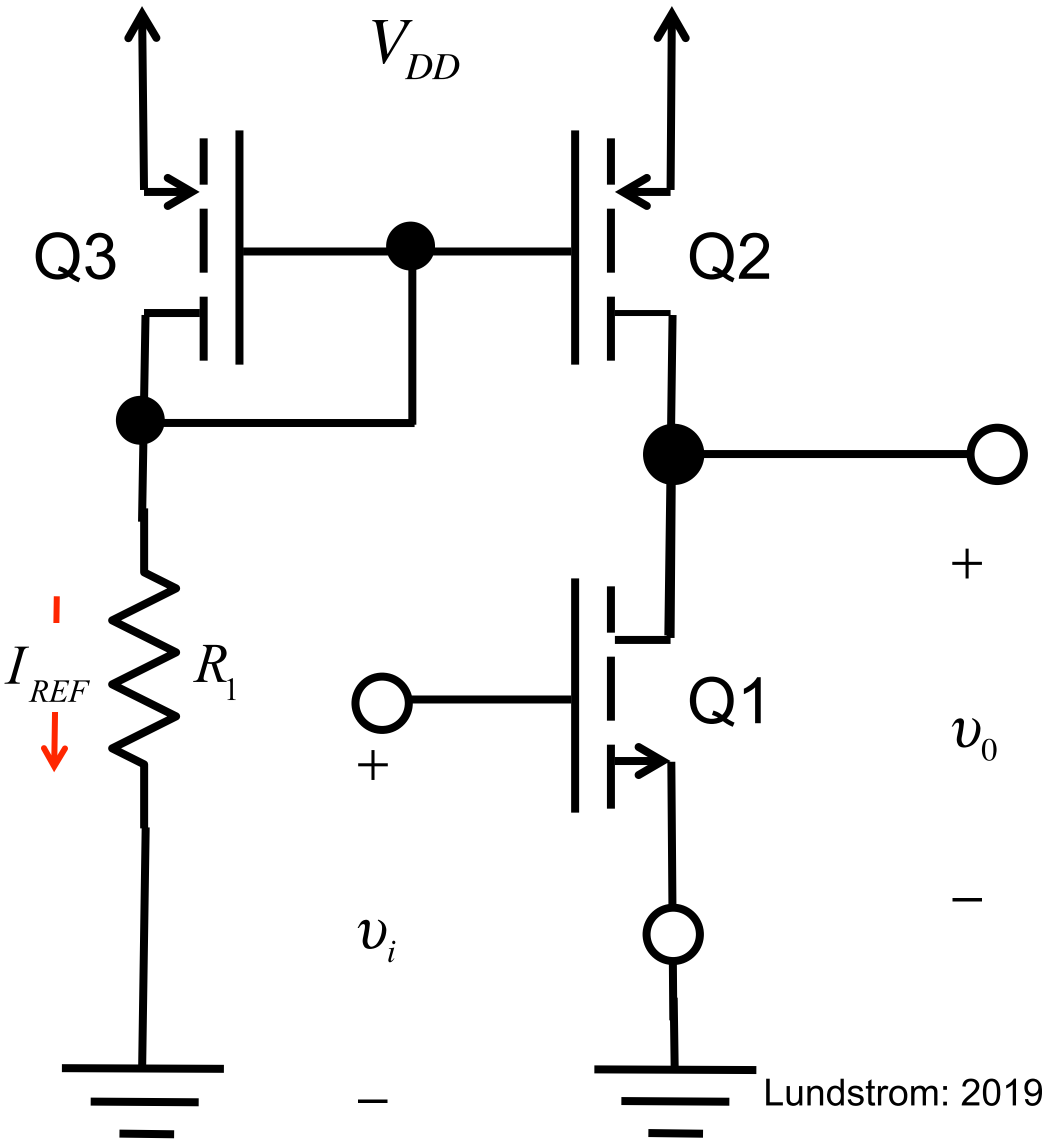


$$r_o = \frac{V_A}{I_D}$$

$$V_A = V_A' L$$

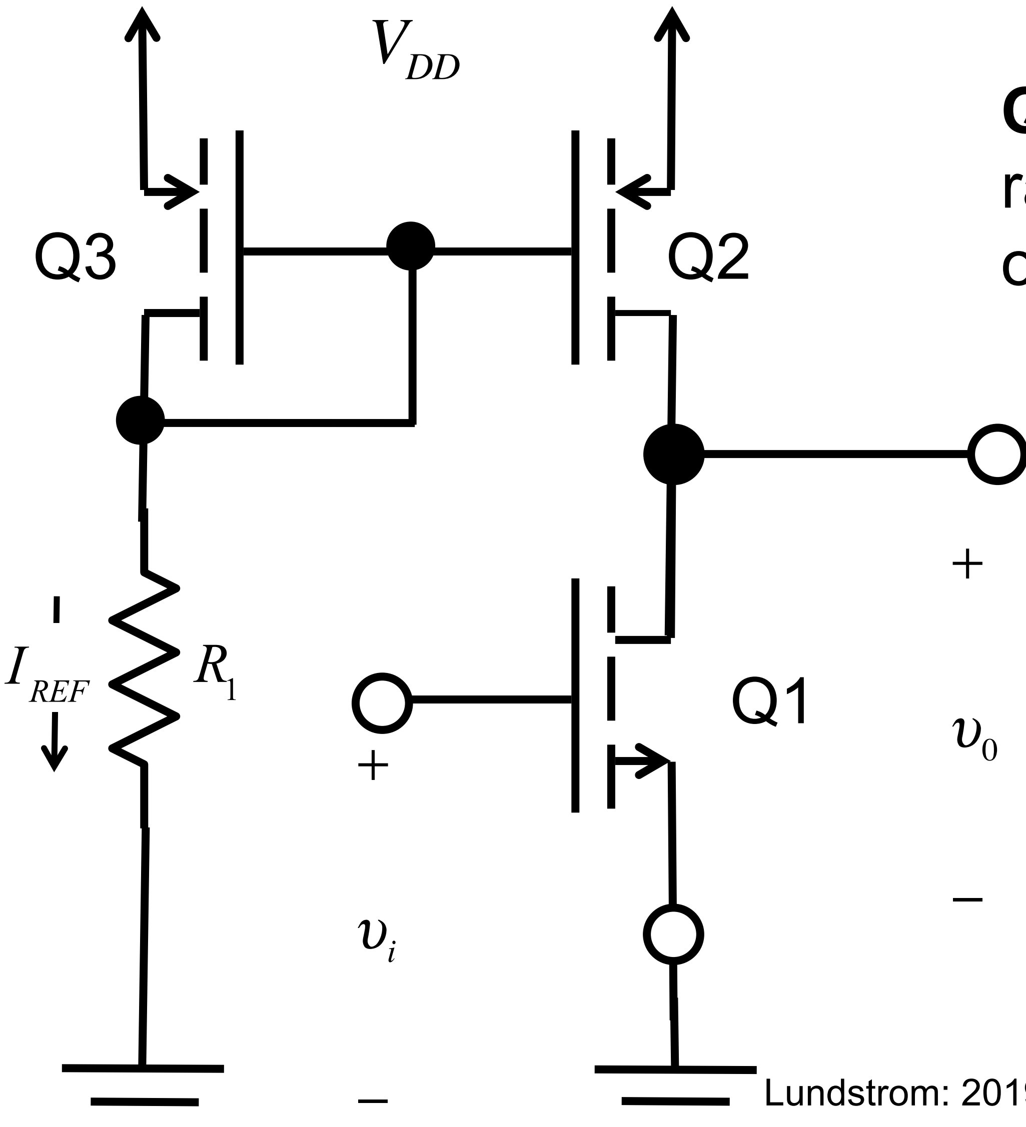
$$r_o \propto L$$

CS with active load



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

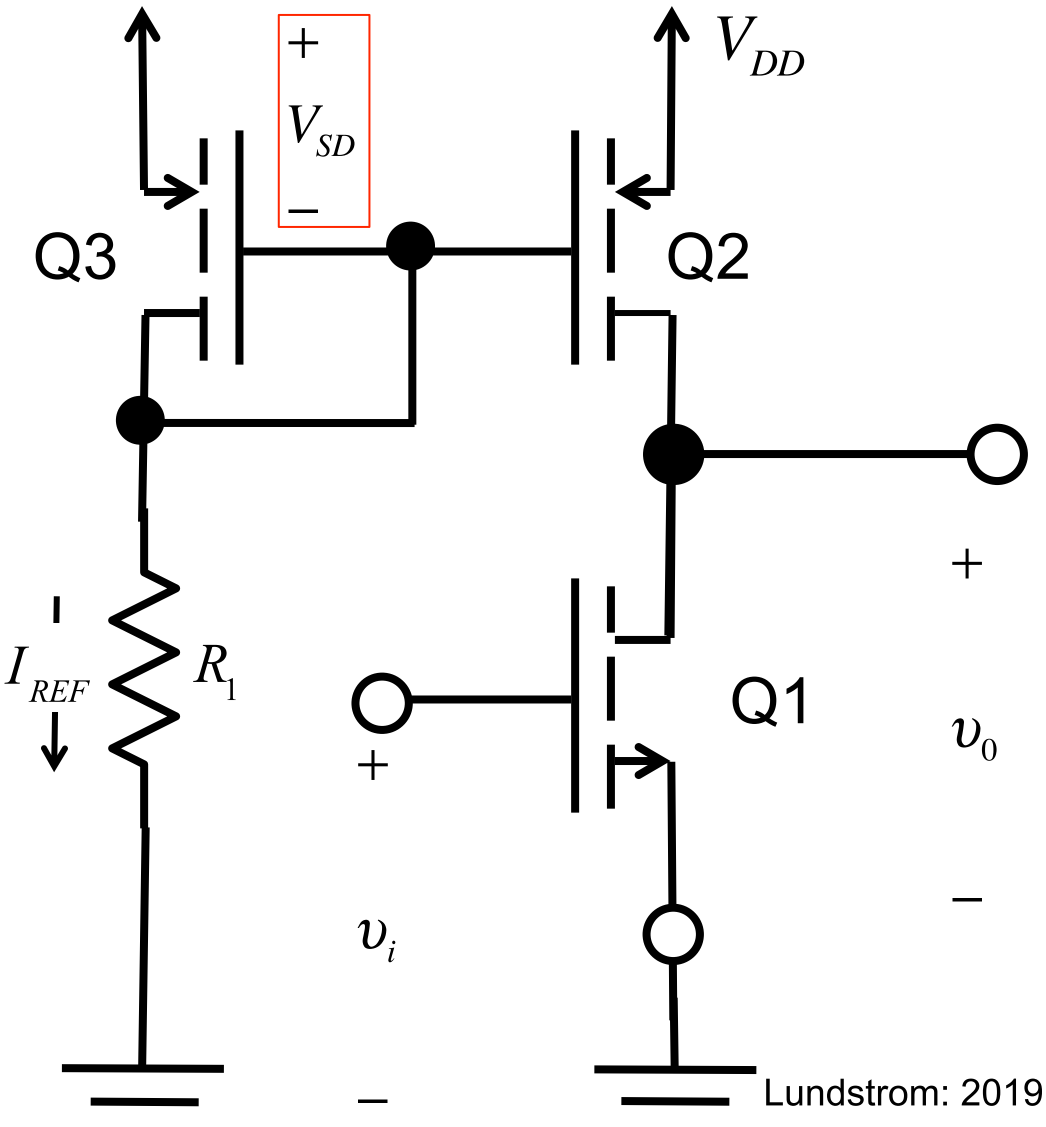
Output voltage range



Question: Over what range of voltages can the output voltage vary?

$$v_0\big|_{min} < v_0 < v_0\big|_{max}$$

Minimum output voltage

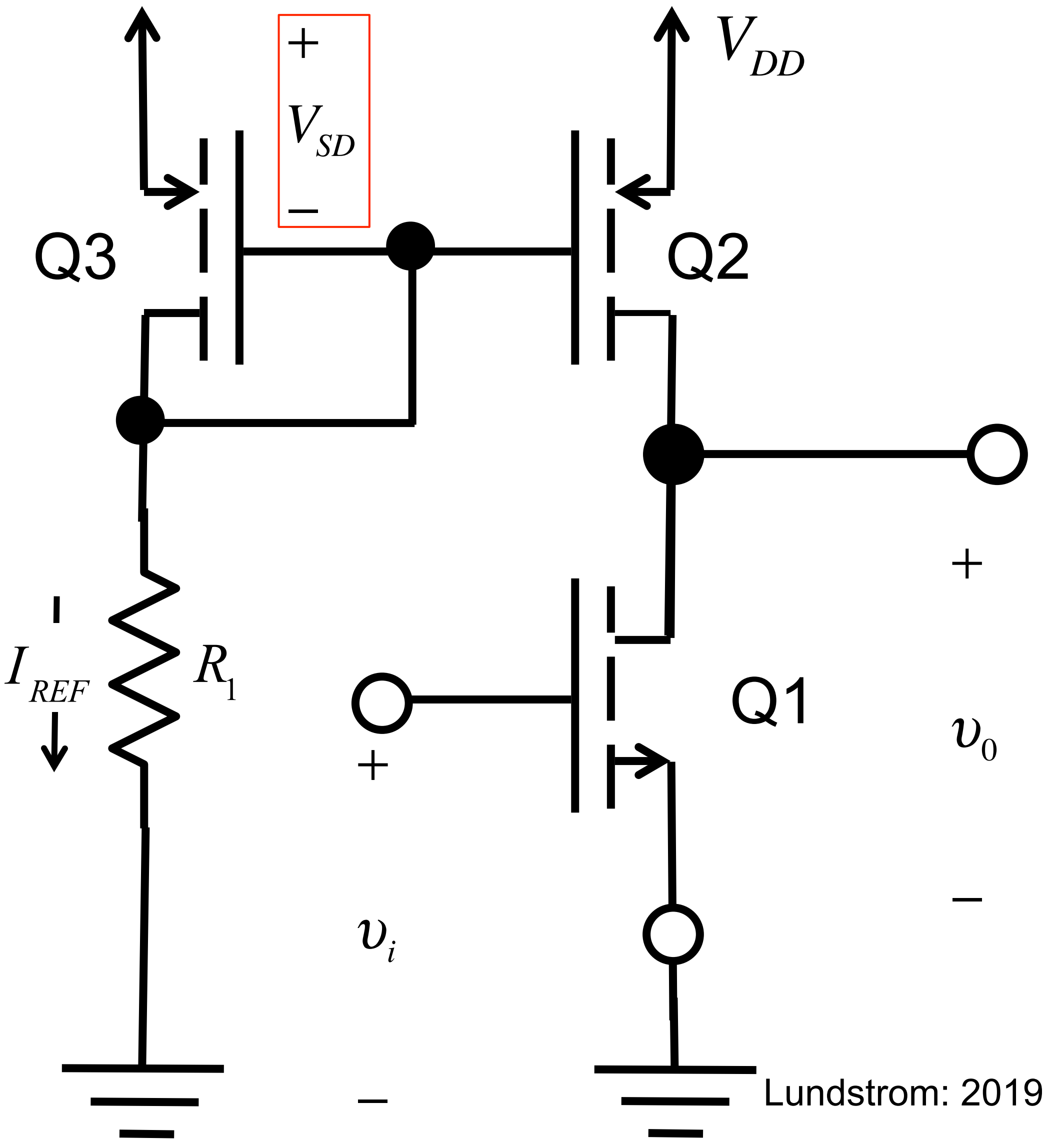


$$\upsilon_{DS} > V_{GS} - V_{tn}$$

$$\upsilon_o > V_{GS} - V_{tn}$$

$$\upsilon_o\big|_{\min} = V_{GS} - V_{tn}$$

Maximum output voltage



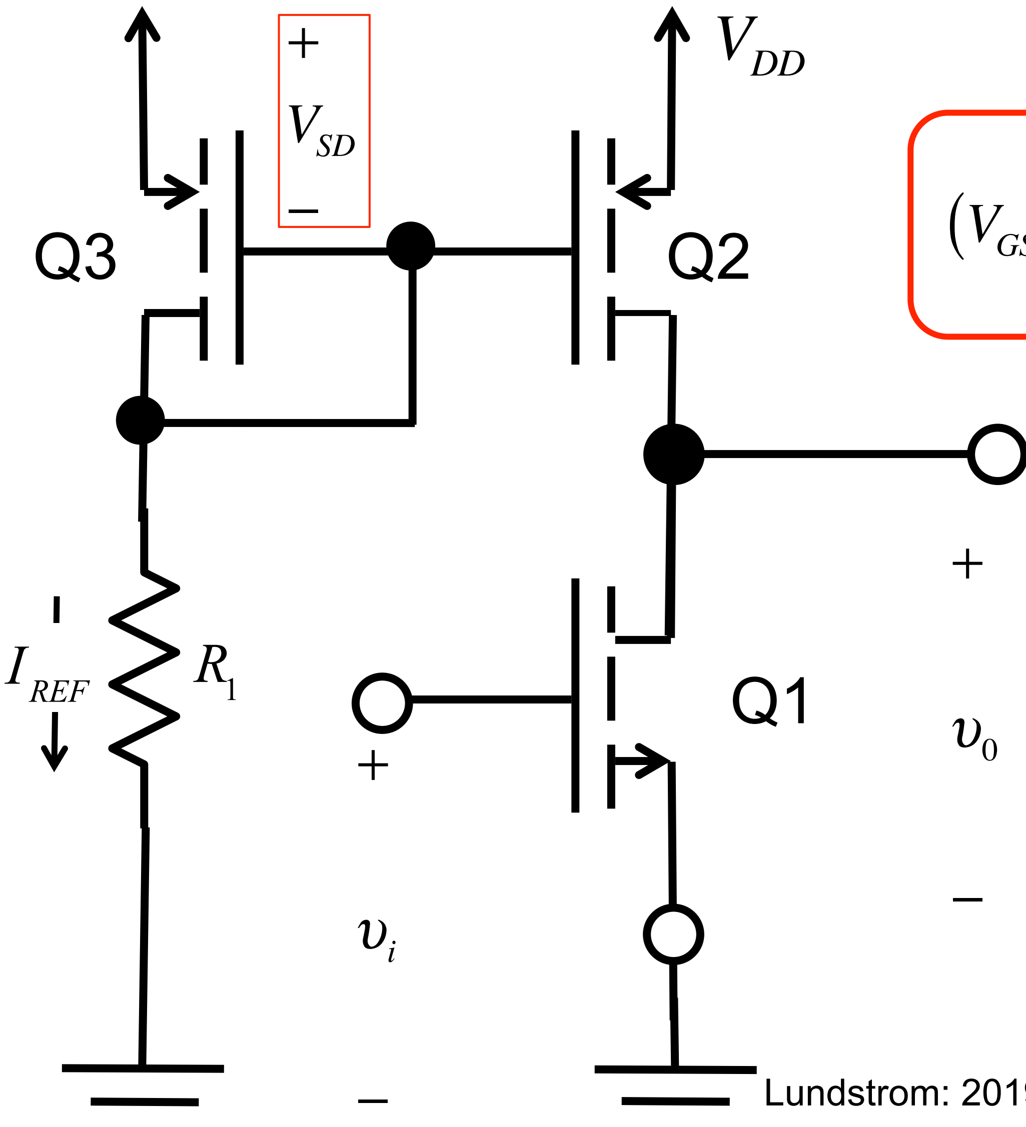
$$\upsilon_{SD} > V_{SG} - |V_{tp}|$$

$$V_{DD} - \upsilon_o > V_{SG} - |V_{tp}|$$

$$\upsilon_o < V_{DD} - \left(V_{SG} - |V_{tp}|\right)$$

$$\upsilon_o\big|_{max} = V_{DD} - \left(V_{SG} - |V_{tp}|\right)$$

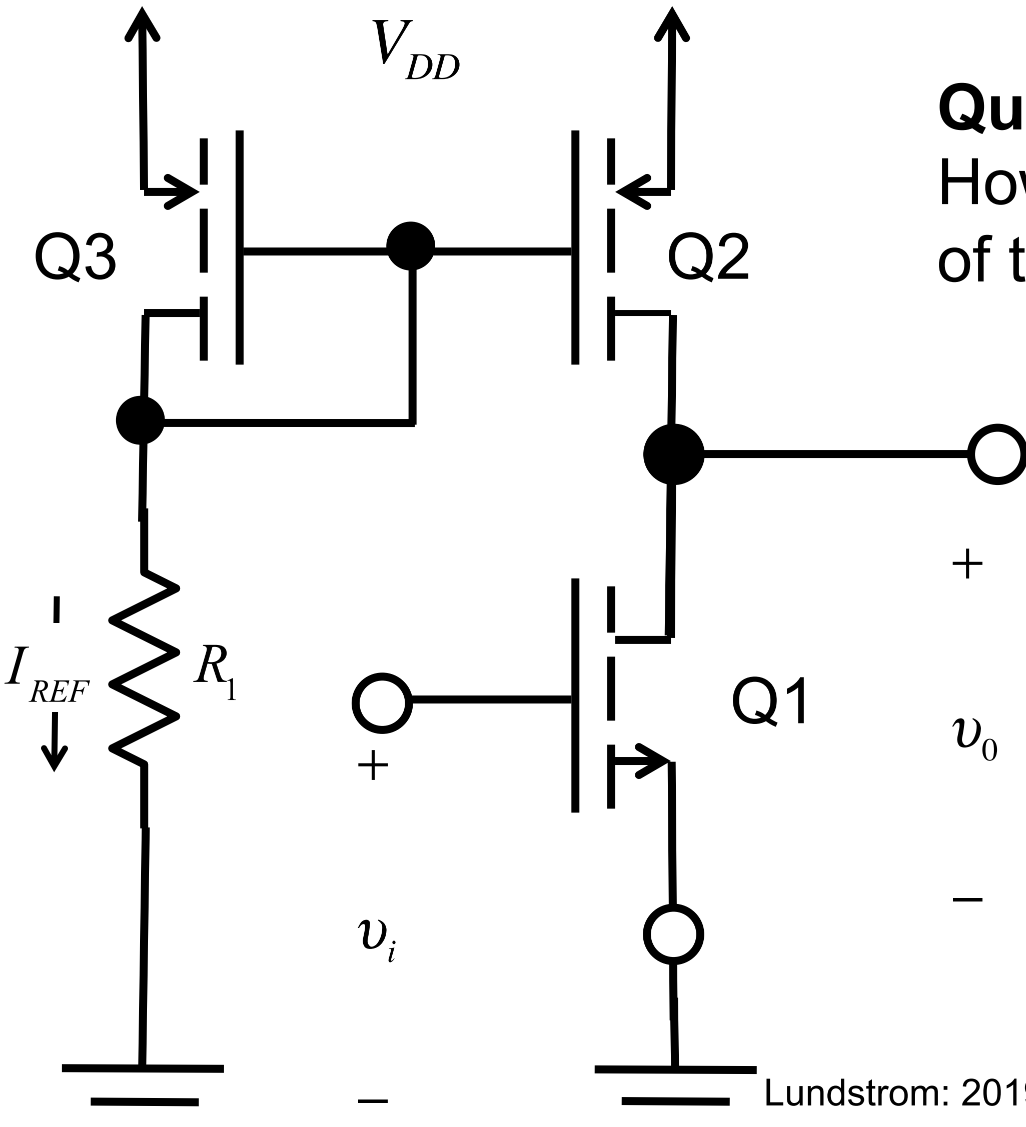
Maximum output voltage



$$\left(V_{GS}-V_{tn}\right)<\upsilon_o<V_{DD}-\left(V_{SG}-\left|V_{tp}\right|\right)$$

(p. 533 in S&S)

CS with active load



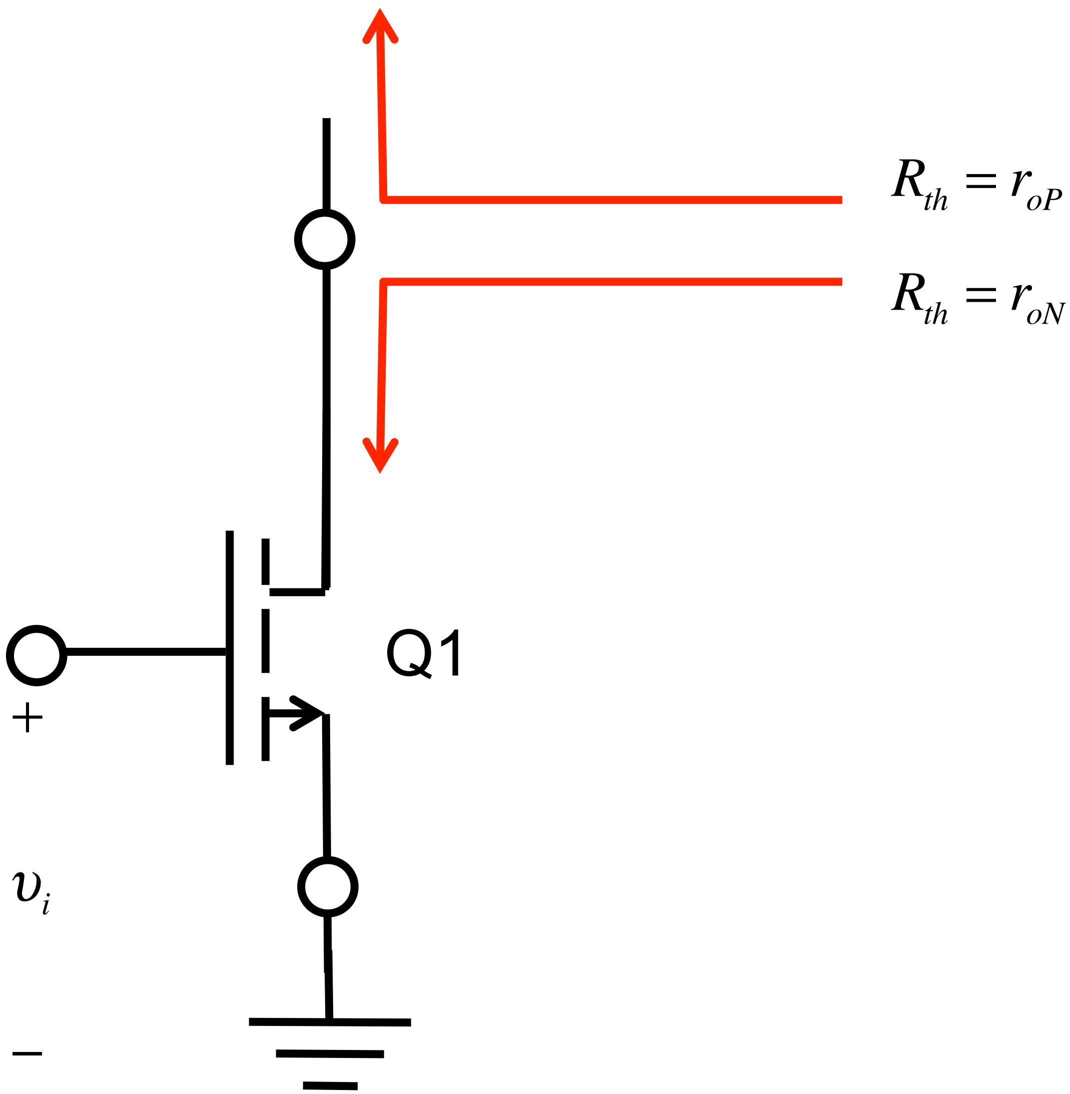
Question:
How can we increase the gain of the basic cell?

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

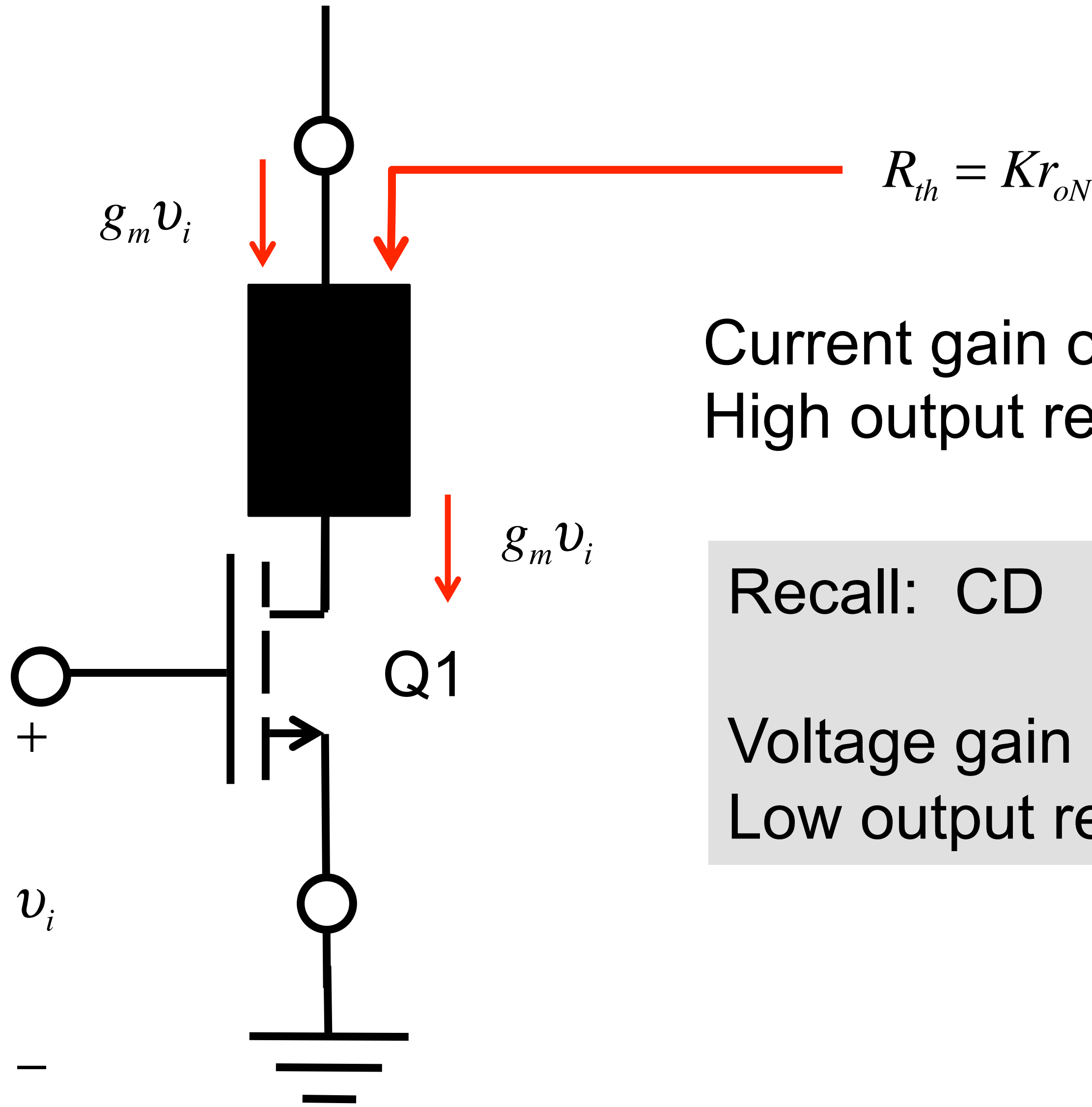
increase output resistance of Q1

increase output resistance of Q2

Focus on Q1



Focus on Q1



Current gain of 1
High output resistance

Recall: CD

Voltage gain of 1
Low output resistance

Outline

1) Introduction

2) Review of CG without r_o

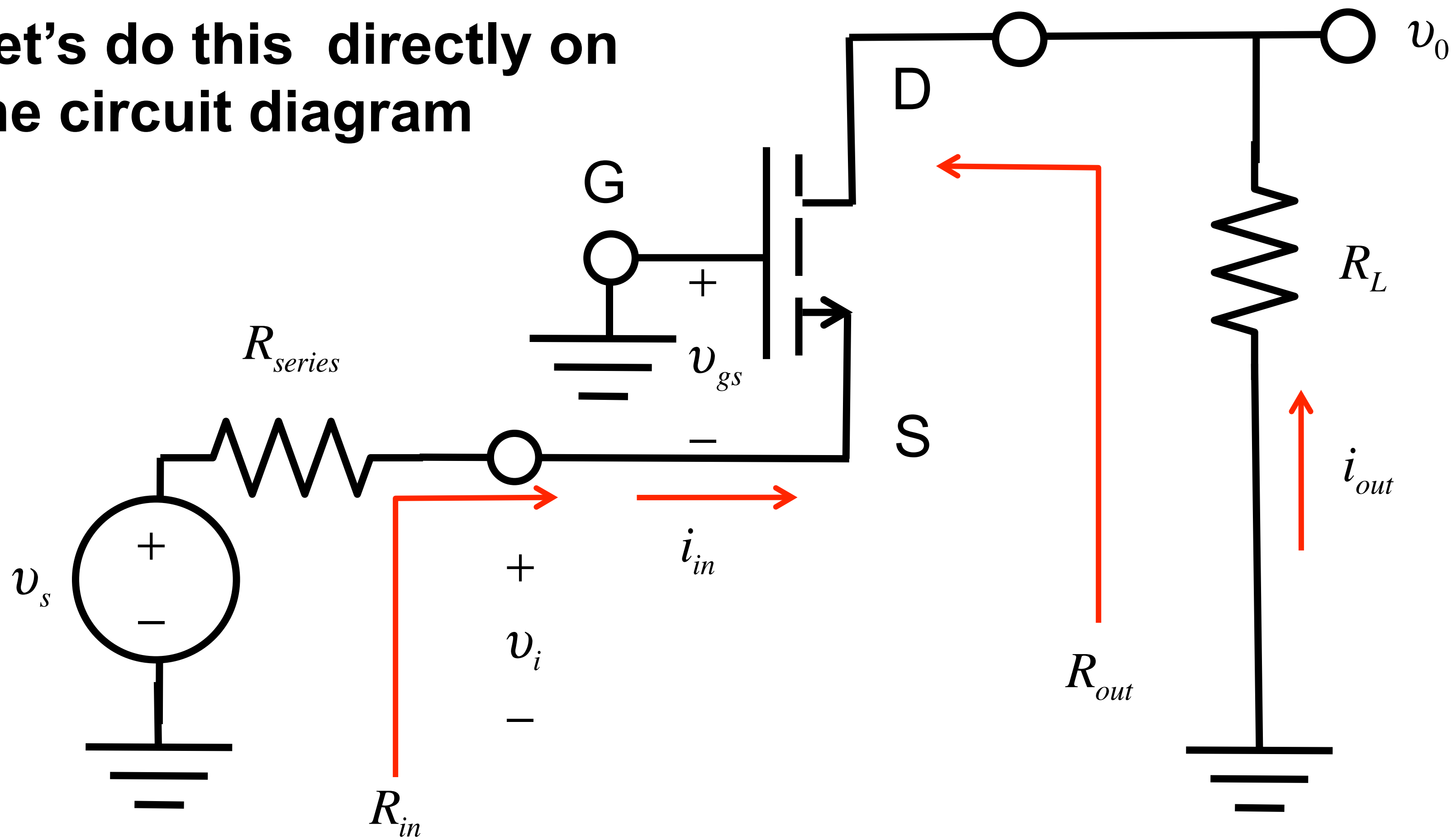
3) CG with r_o included

4) CB

5) CS with source resistance

Basic CG without r_o

Let's do this directly on the circuit diagram



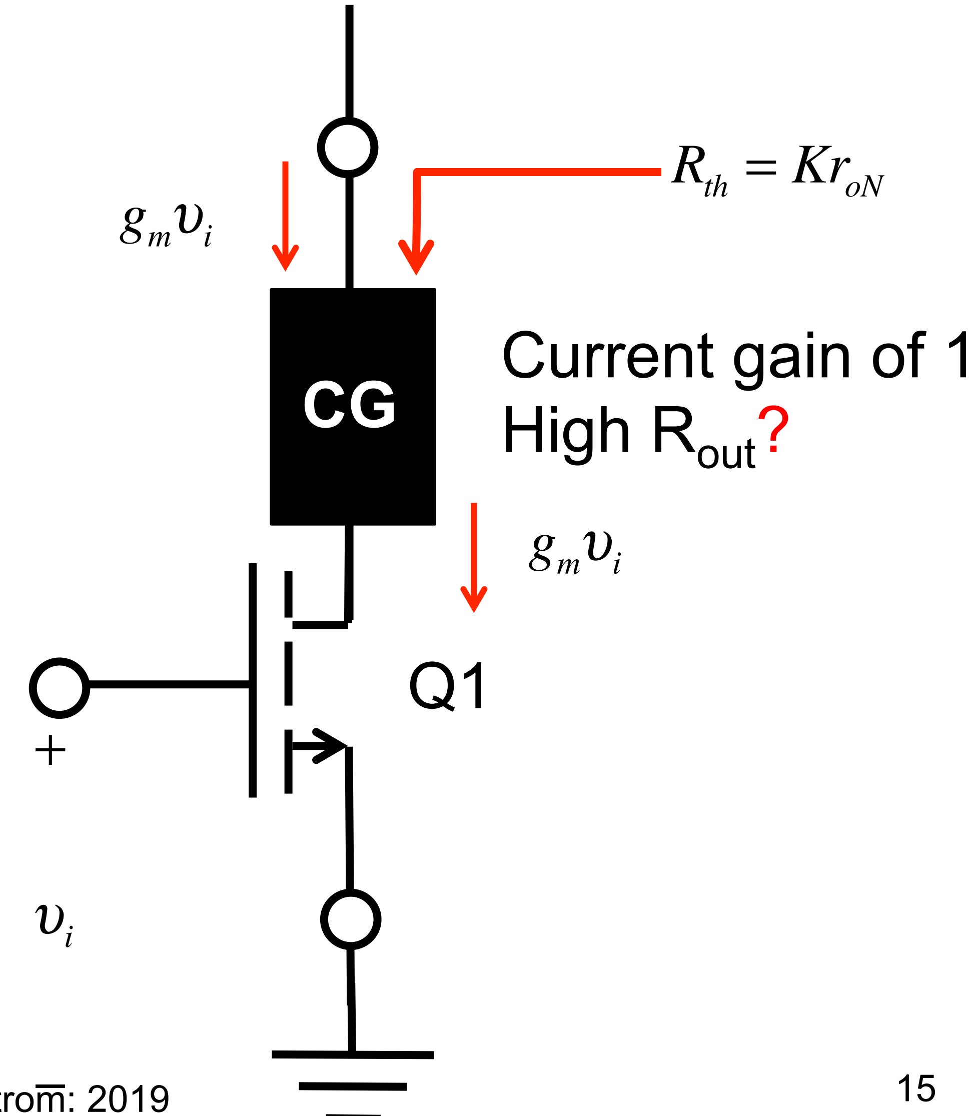
CG Results (w/o r_o)

$$A_v = \frac{v_o}{v_i} = +g_m R_L$$

$$R_o = \infty$$

$$R_{in} = \frac{1}{g_m}$$

$$A_I = 1$$

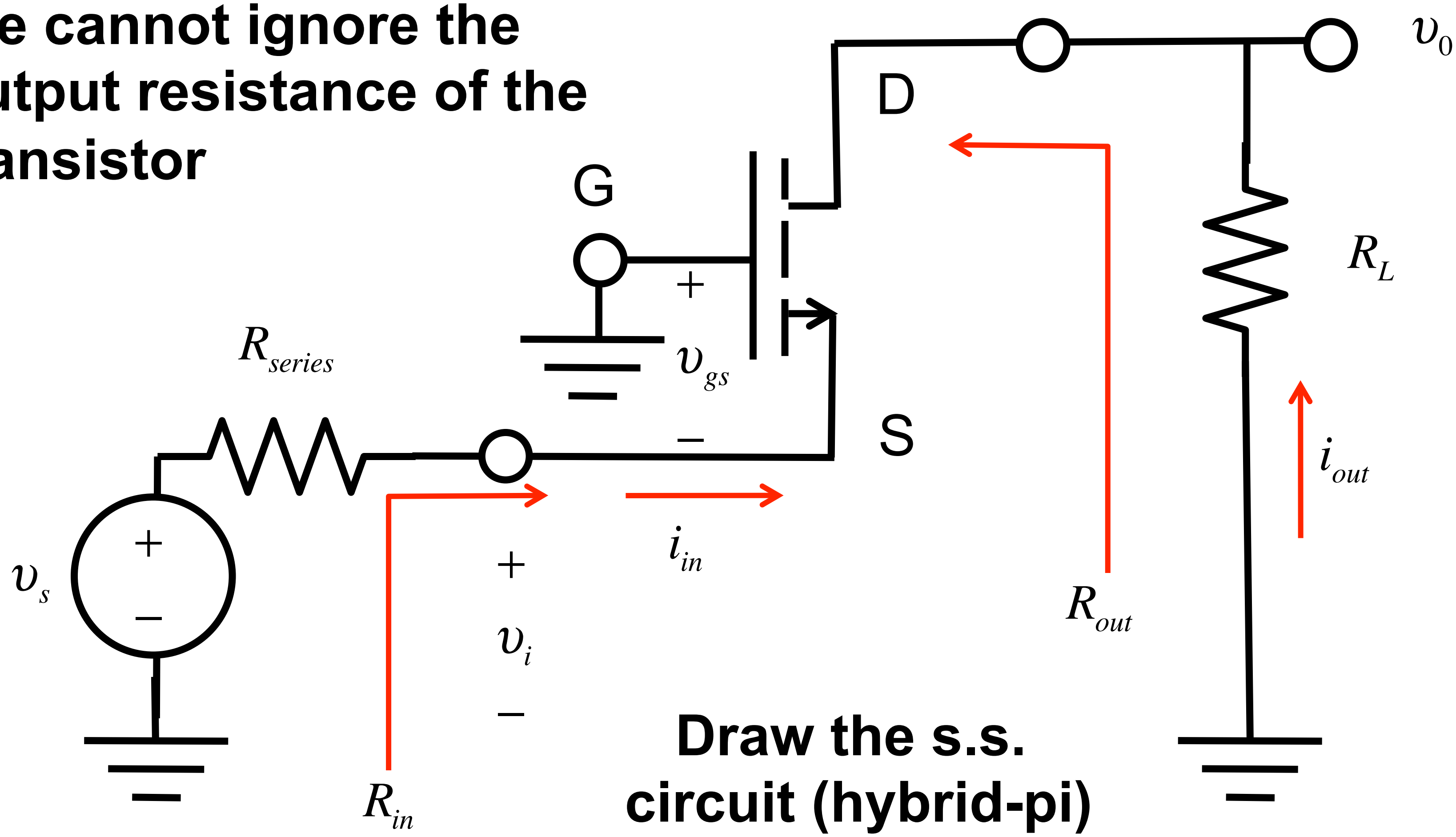


Outline

1) Introduction
2) Review of CG with r_o
3) **CG with r_o included**
4) CB
5) CS with source resistance

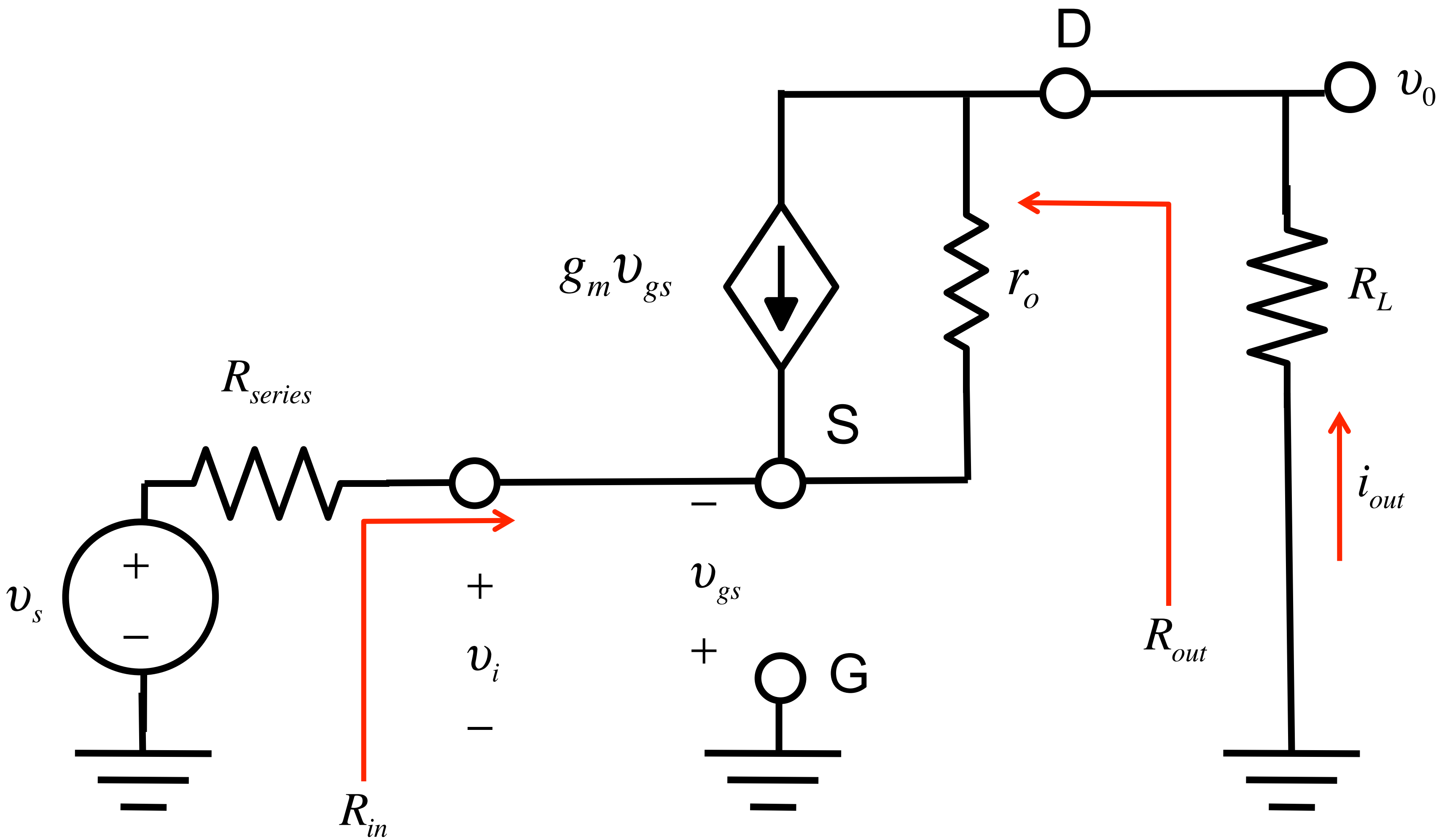
CG with r_o

We cannot ignore the output resistance of the transistor

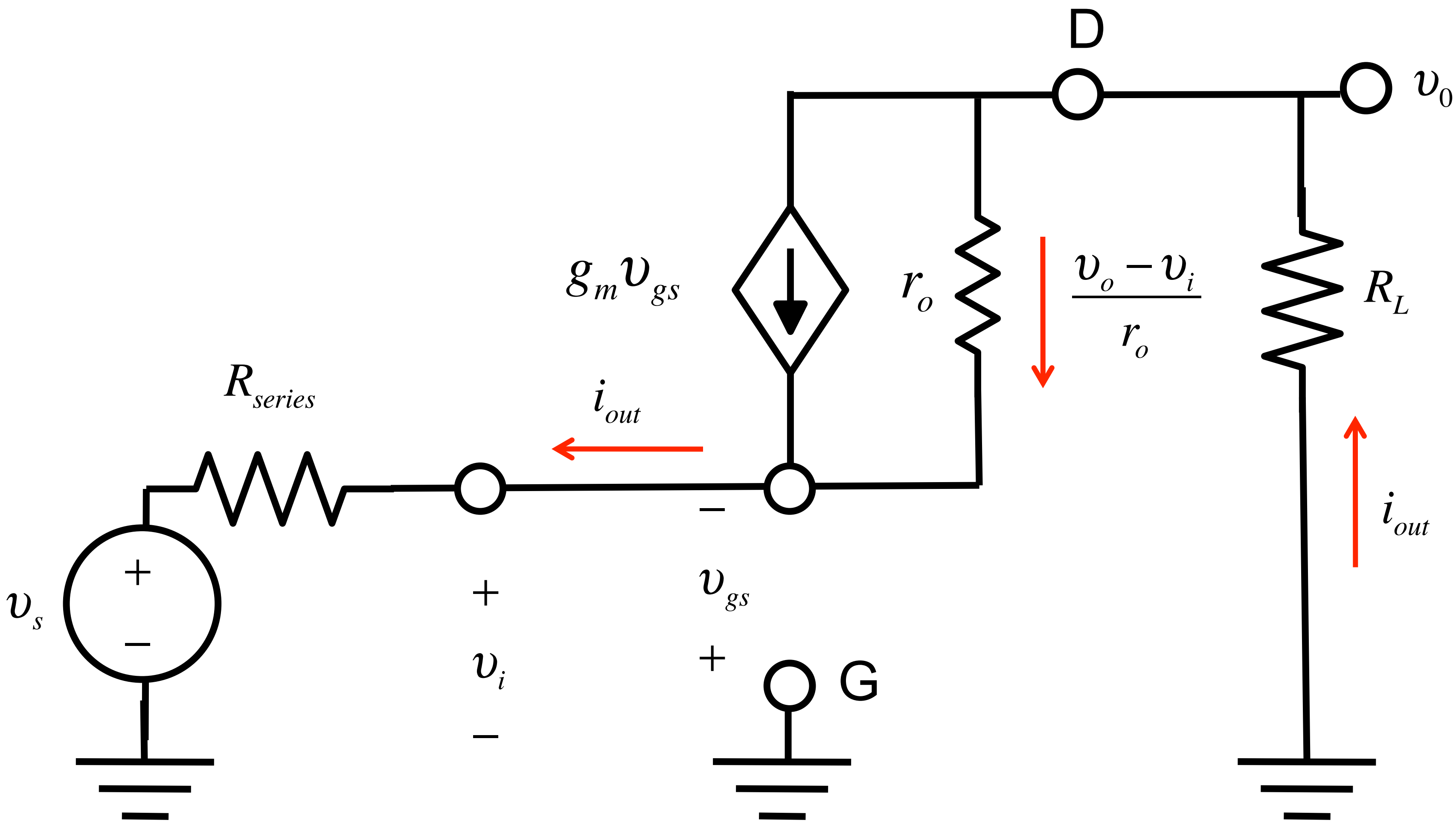


Draw the s.s. circuit (hybrid-pi)

s.s. circuit (hybrid-pi)



Voltage gain



Voltage gain

$$\upsilon_o = -i_{out} R_L$$

$$\upsilon_o = -\left[g_m \upsilon_{gs} + \frac{\upsilon_0 - \upsilon_i}{r_0} \right] R_L$$

$$\upsilon_o = -\left[-g_m \upsilon_i + \frac{\upsilon_0 - \upsilon_i}{r_0} \right] R_L$$

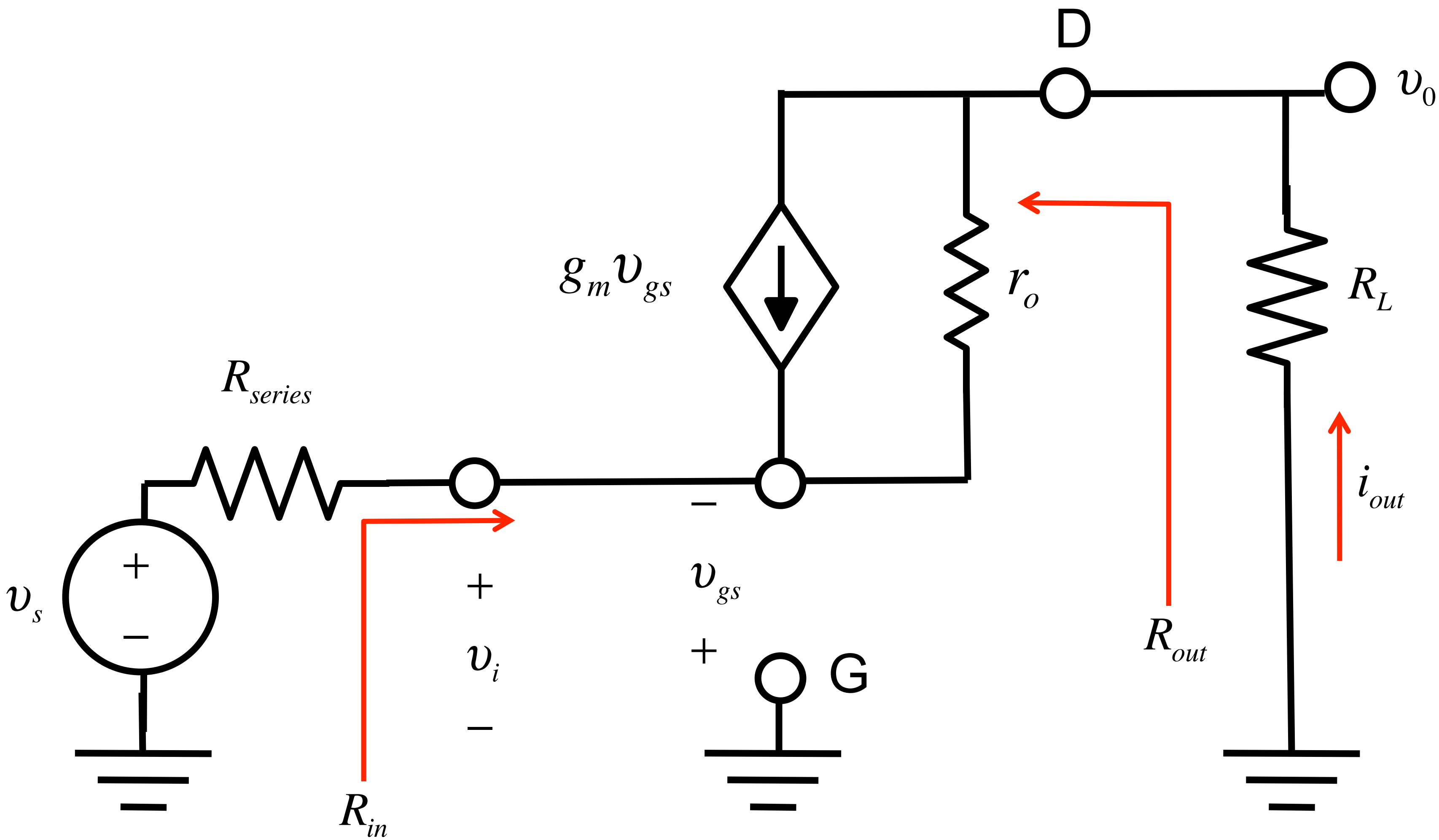
$$\upsilon_o \left[1 + R_L / r_o \right] = \left[g_m + 1/r_0 \right] R_L \upsilon_i$$

$$A_{\upsilon_o} = \frac{\upsilon_o}{\upsilon_i} = \frac{\left(g_m + 1/r_0 \right) R_L}{\left(1 + R_L / r_o \right)}$$

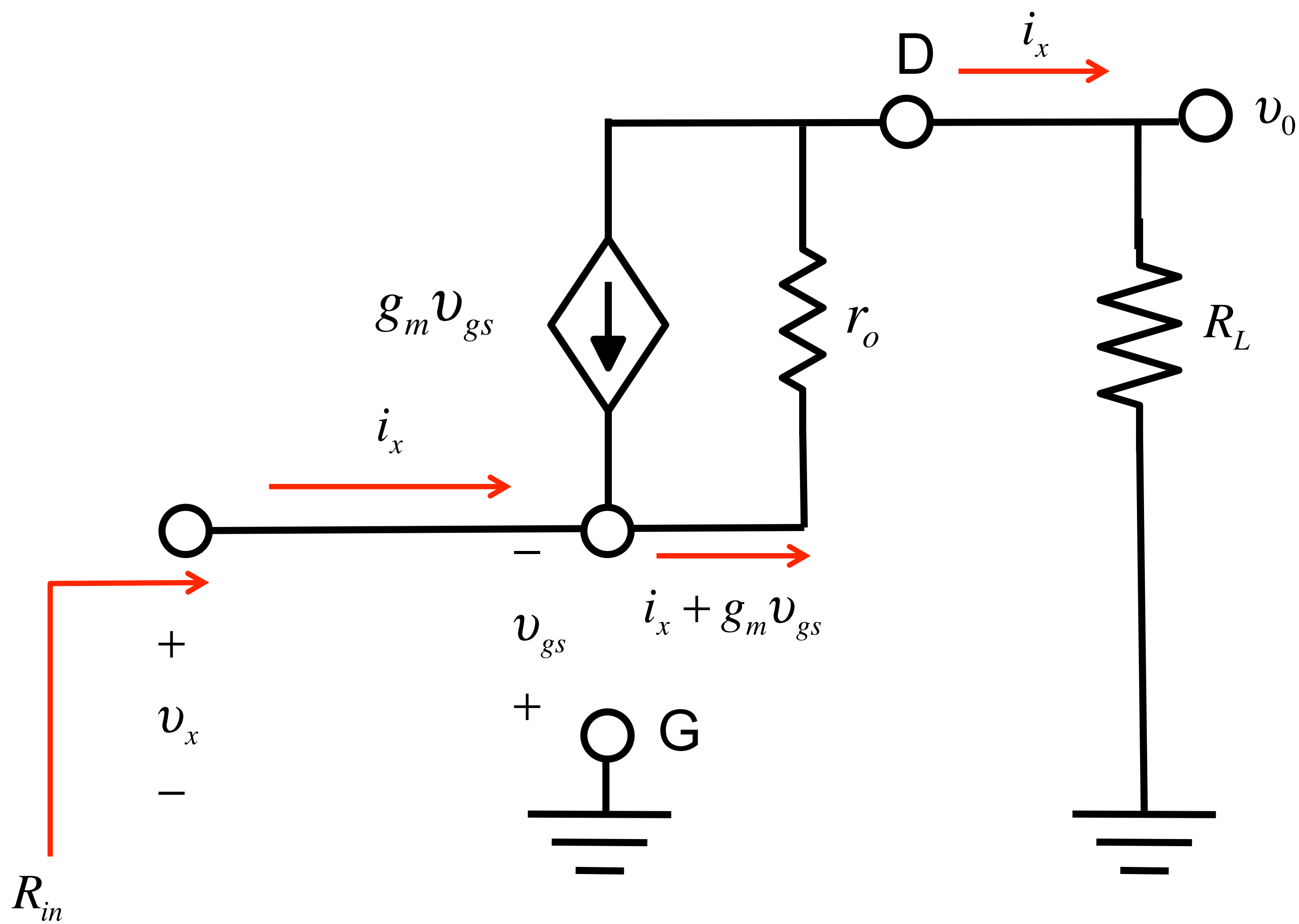
$$r_0 >> R_L$$

$$A_{\upsilon_o} \rightarrow g_m R_L$$

Input resistance



Input resistance



Input resistance

$$\upsilon_x - \upsilon_{r_o} - \upsilon_{R_L} = 0$$

$$\upsilon_x = \upsilon_{r_o} + \upsilon_{R_L}$$

$$\upsilon_x = \left[i_x + g_m \upsilon_{gs} \right] r_o + i_x R_L$$

$$\upsilon_x = i_x r_o + g_m \upsilon_{gs} r_o + i_x R_L$$

$$\upsilon_x = i_x r_o - g_m \upsilon_x r_o + i_x R_L$$

$$\upsilon_x \left(1 + g_m r_o \right) = i_x \left(r_o + R_L \right)$$

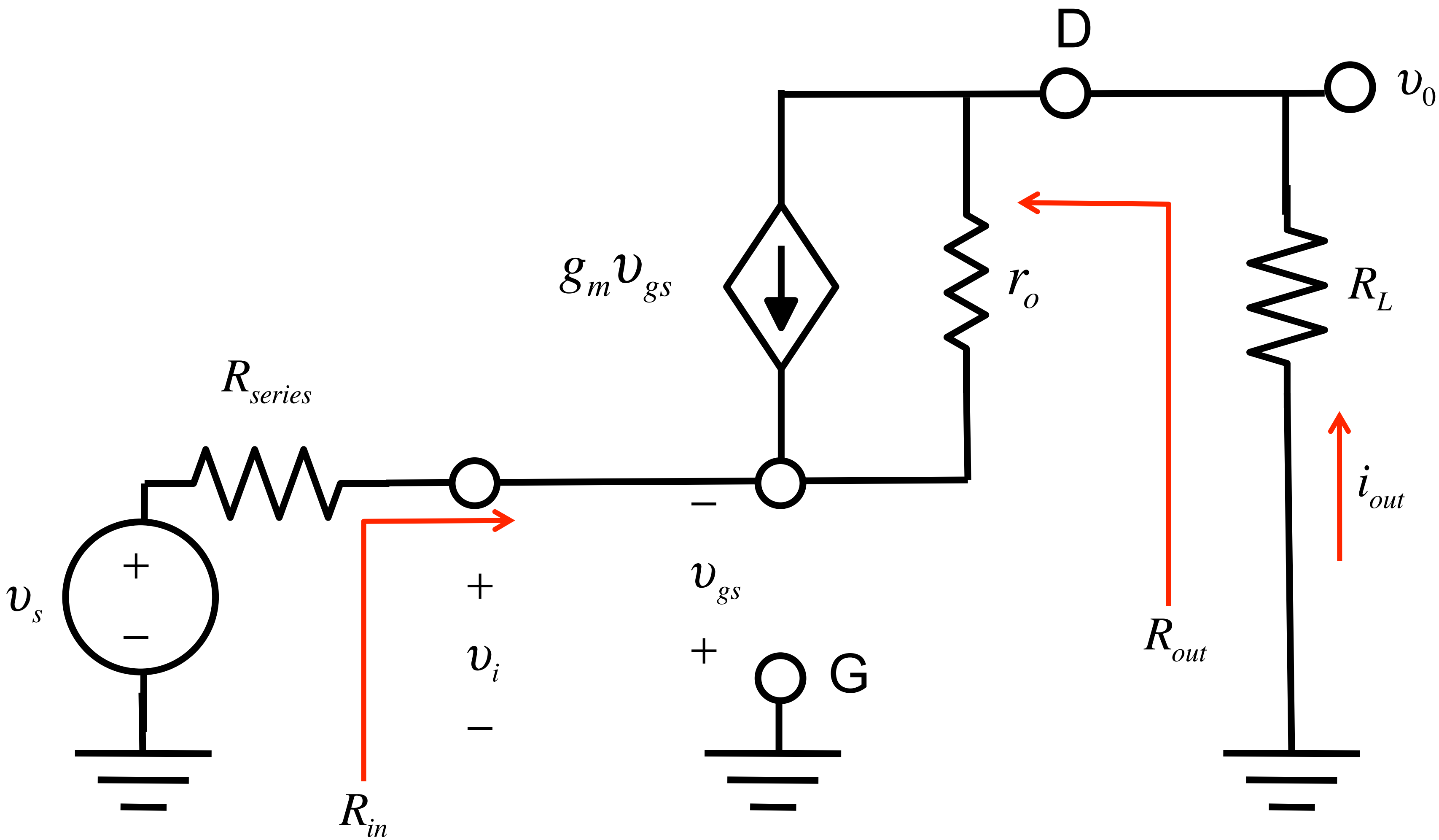
$$\frac{\upsilon_x}{i_x} = \frac{\left(r_o + R_L \right)}{\left(1 + g_m r_o \right)}$$

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

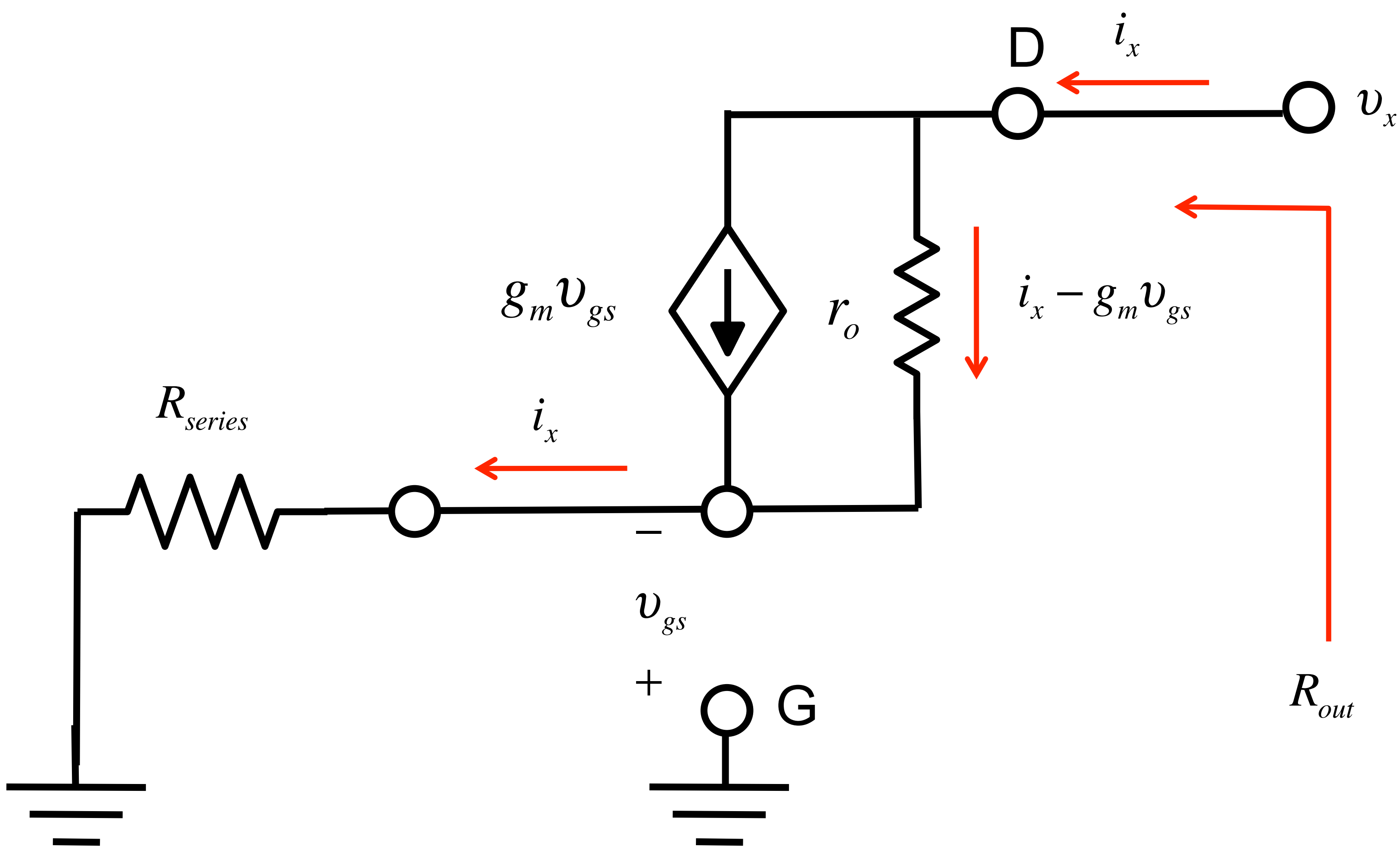
$$g_m r_0 >> 1$$

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

Output resistance



Output resistance



Output resistance

$$\upsilon_x - \upsilon_{r_o} - \upsilon_{R_{series}} = 0$$

$$\upsilon_x = \upsilon_{r_o} + \upsilon_{R_{series}}$$

$$\upsilon_x = \left[i_x - g_m \upsilon_{gs} \right] r_o + i_x R_{series}$$

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

$$\upsilon_{gs} = -i_x R_{series}$$

$$\upsilon_x = i_x r_o - g_m \left(-i_x R_{series}\right) r_o + i_x R_{series}$$

$$g_m r_0 >> 1$$

$$R_{out} \approx r_o + g_m r_o R_{series}$$

$$\upsilon_x = i_x \left[r_o + \left(1 + g_m r_o\right) R_{series} \right]$$

Current gain

$$A_{\upsilon_o} = \frac{(g_m + 1/r_0)R_L}{(1 + R_L/r_o)}$$

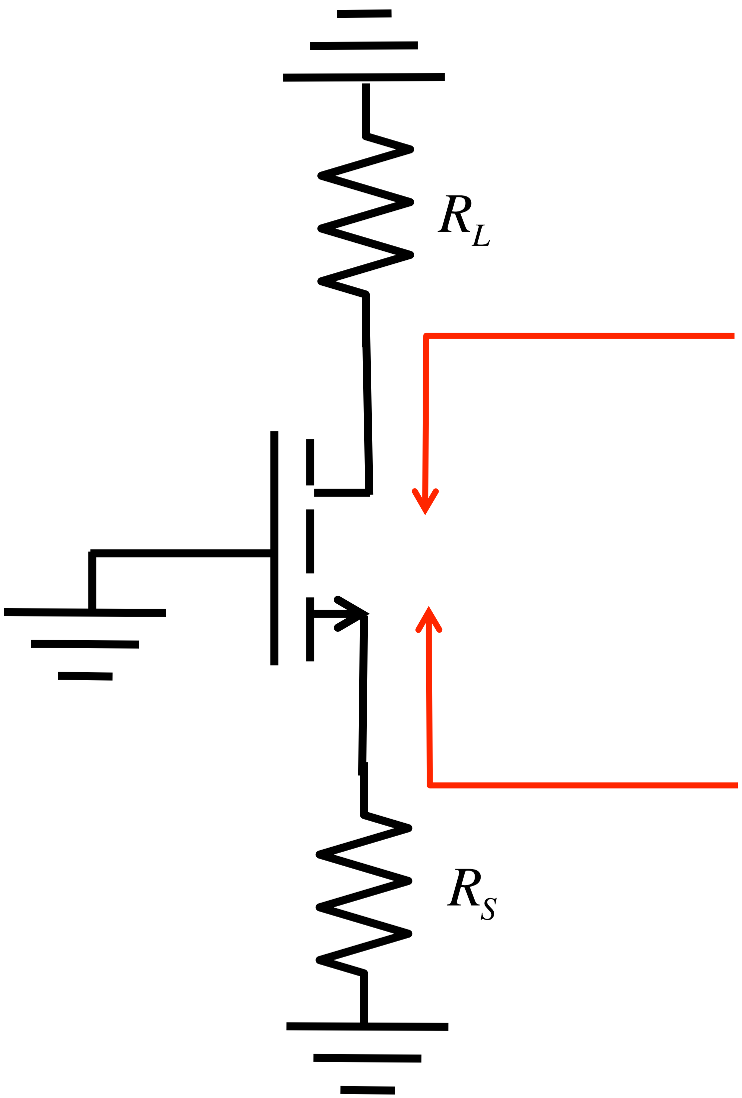
$$R_{in} = \frac{(r_o + R_L)}{(1 + g_m r_o)}$$

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

$$A_I = \frac{\upsilon_o/R_L}{\upsilon_i/R_{in}} = A_{\upsilon_o}\frac{R_{in}}{R_L}$$

$$A_I = 1$$

CG Summary



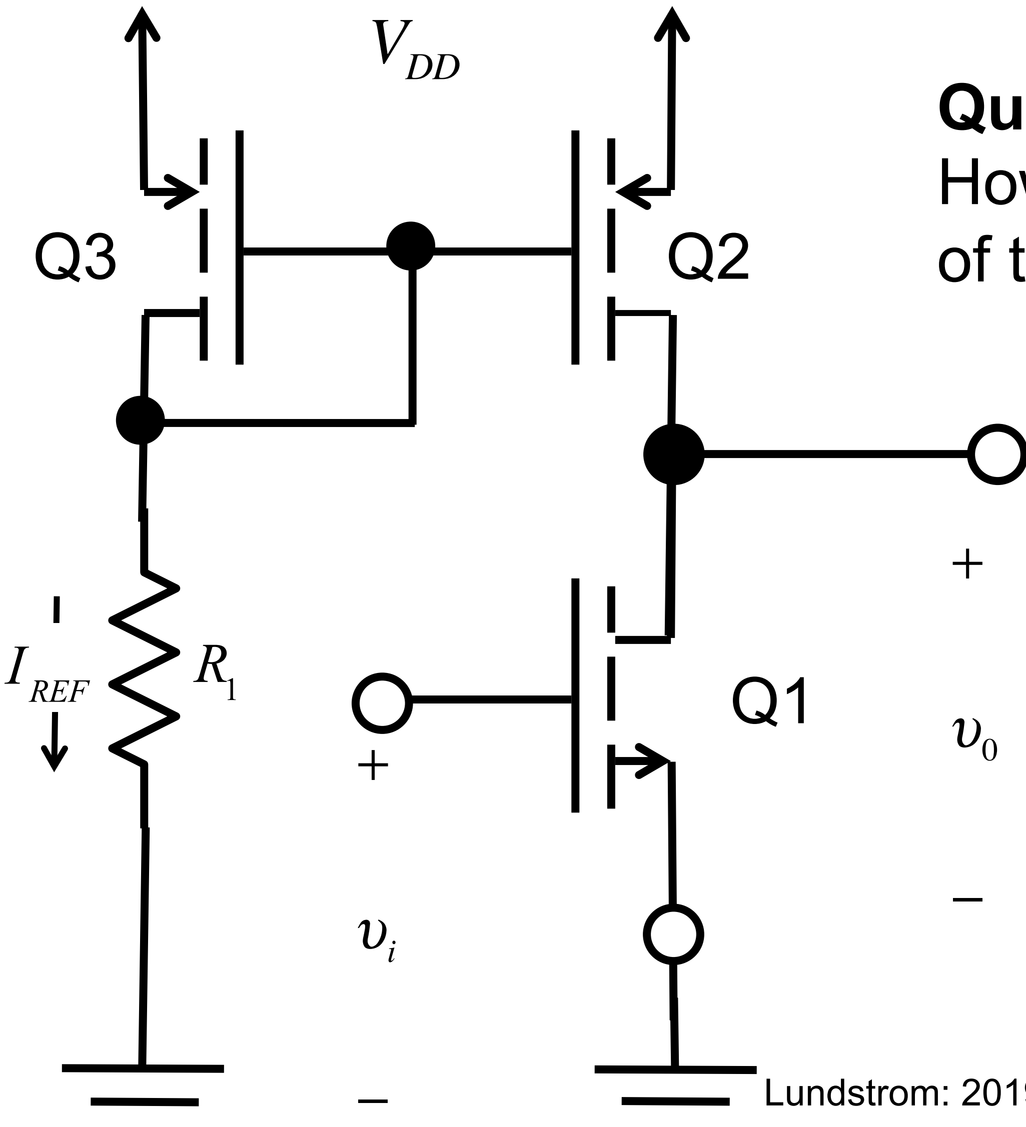
$$R_{out} = r_o + \left(1 + g_m r_o\right) R_{series}$$

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

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

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

CS with active load

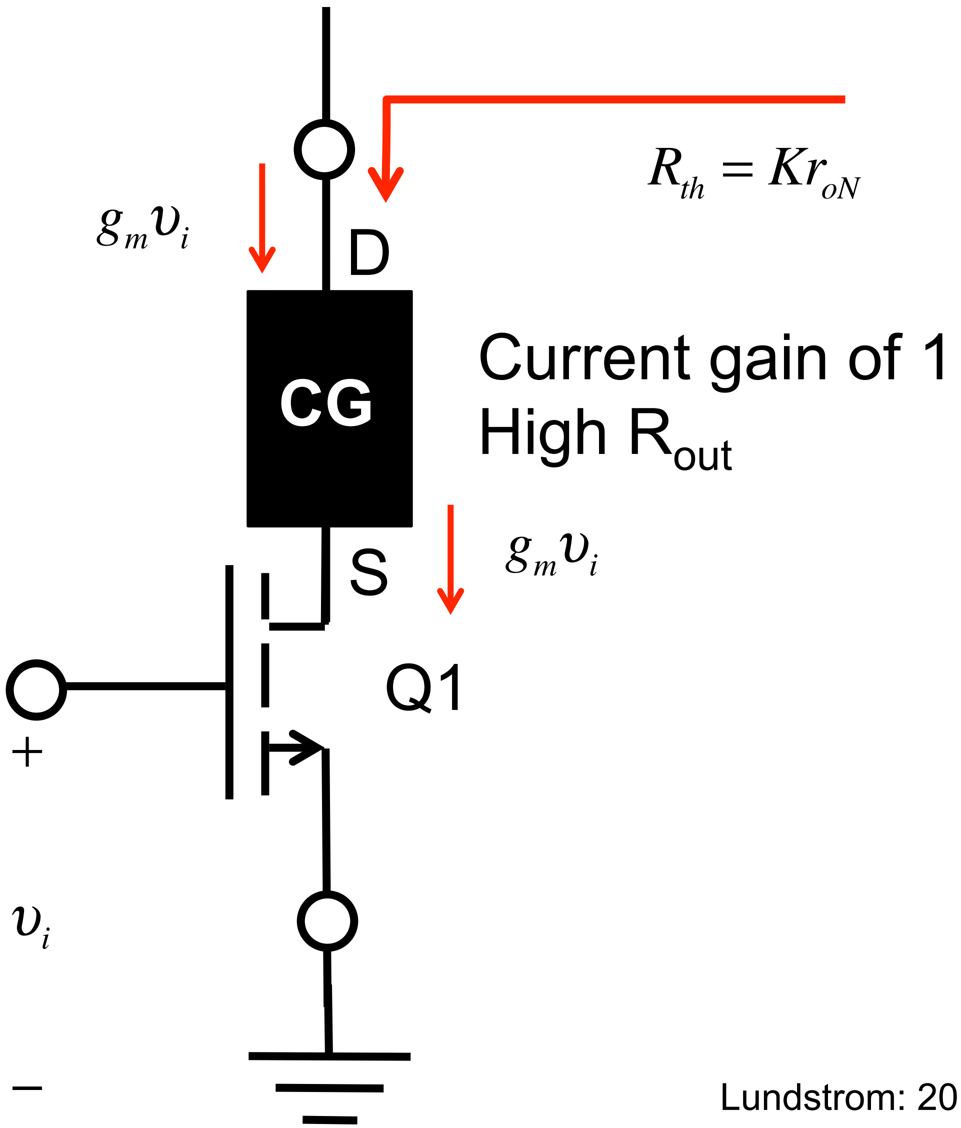


Question:
How can we increase the gain of the basic cell?

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

increase output resistance of Q1

Summary



$$R_{out} = r_o + (g_m r_o) R_S$$

$$R_{out} \approx (g_m R_S) r_{oN}$$

$$R_{out} \approx (g_m r_{oN}) r_{oN}$$

$$R_{out} \approx K r_{oN}$$

Outline

1) Introduction

2) Review of CG without r_o

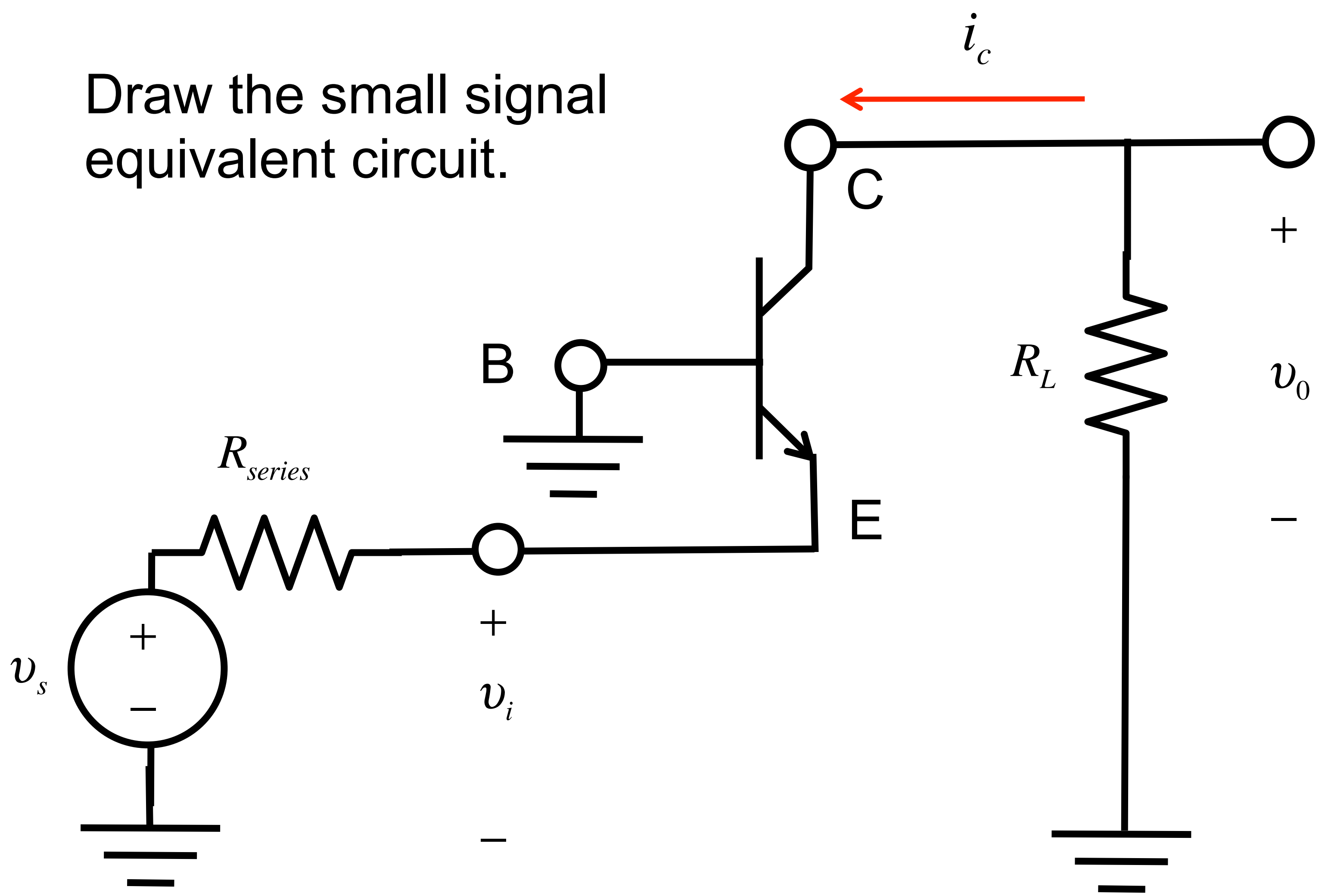
3) CG with r_o included

4) CB

5) CS with source resistance

Basic CB without r_o

Draw the small signal equivalent circuit.



Basic CB results

$$A_v = \frac{\upsilon_o}{\upsilon_i} = +g_m R_C$$

$$R_o = R_C$$

$$R_{in} = \frac{r_\pi}{\beta + 1}$$

Now include r_o in the analysis

Basic CB results with r_o

CG

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

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

CB

$$R_{in} = \frac{(r_o + R_L)}{1 + \frac{r_o}{r_\pi/(\beta+1)} + \frac{R_L}{r_\pi}}$$

$$R_{out} = r_o + (1 + g_m r_o)(R_{series} \parallel r_\pi)$$

Outline

1) Introduction

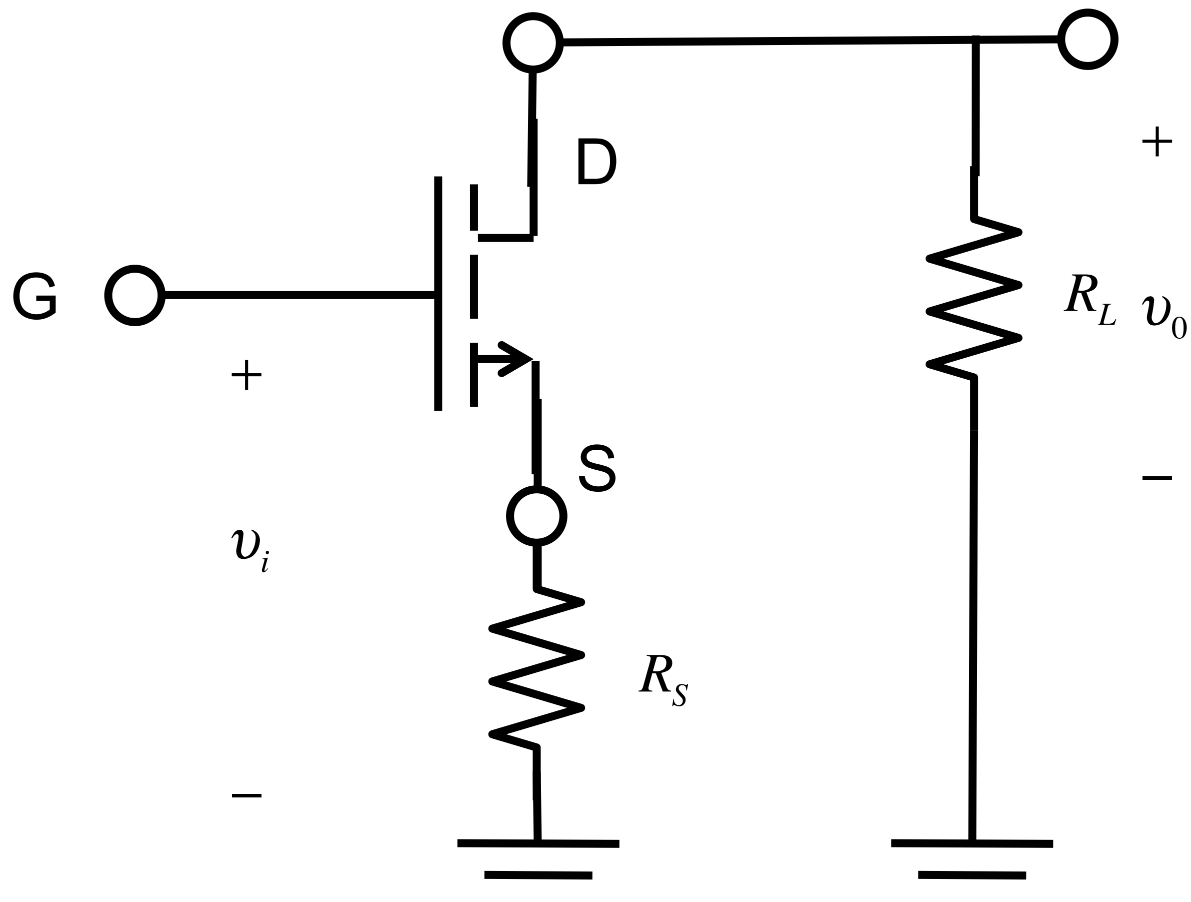
2) Review of CG without r_o

3) CG with r_o included

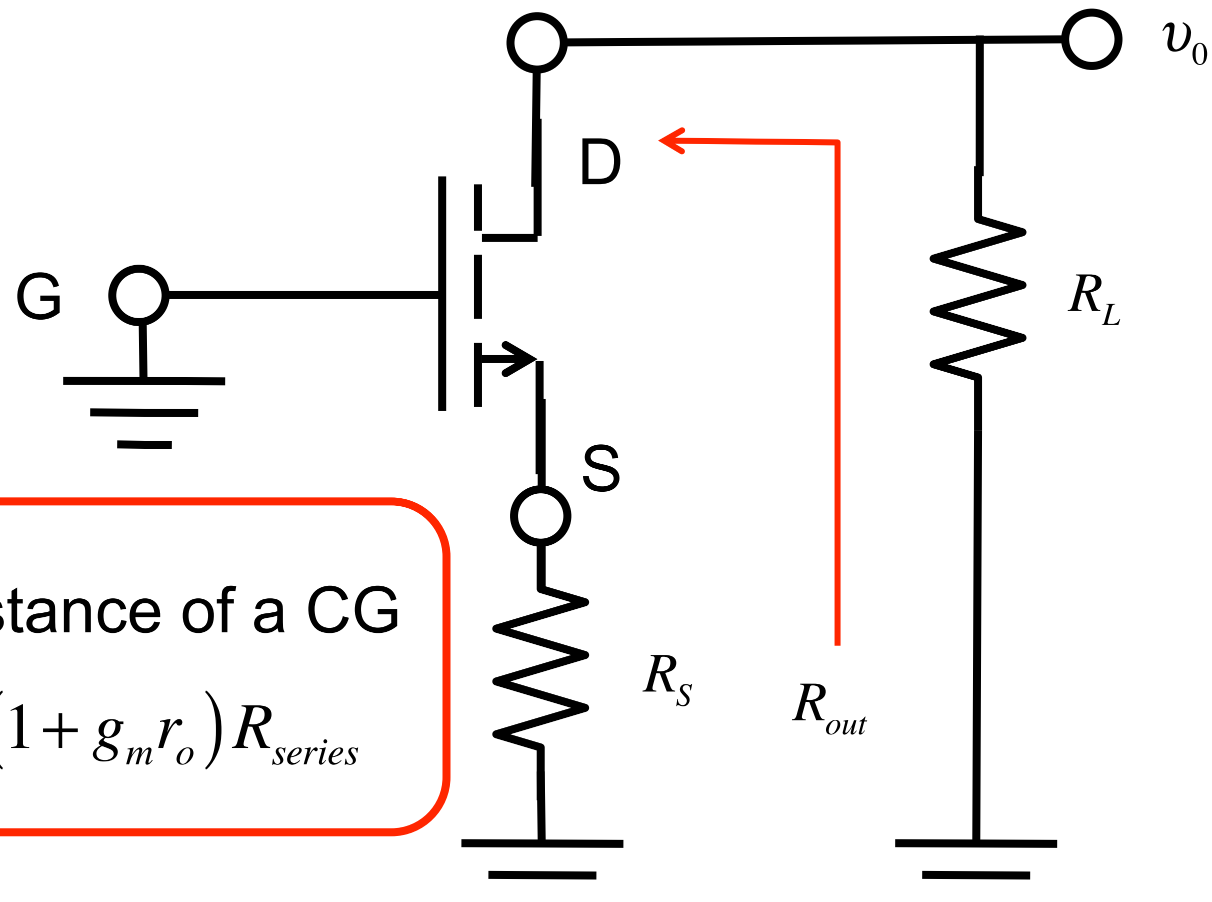
4) CB

5) CS with source resistance

CS with source degeneration



Output resistance: CS with source degeneration



Output resistance of a CG

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

Summary

Including r_o complicates small signal analysis

But, as we will discuss next week we can take advantage of r_o.

Questions

1) Introduction
2) Review of CG without r_o
3) CG with r_o included
4) CB
5) CS with source resistance