Spring 2019 Purdue University

ECE 255: L21

Discrete Amplifiers

(Sedra and Smith, 7th Ed., Sec. 7.5)

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Announcements

1) There is no HW due Monday, but HW7 (Practice Problems for Exam 2) will be discussed in class on Monday.

2) Exam 2 is Tuesday, March 5, 6:30-7:30 PM PHYS 112

3) Professor Janes will hold a help session on Tuesday in ME 1061 at 1:30 PM.

4) No class on Friday, March 8

Announcements

For Exam 2, you should be prepared on: (HW5- HW7)

1) DC analysis / design of 4-resisitor bias circuit

2) Small signal models

3) Reducing a circuit diagram to a s.s. equiv. circuit

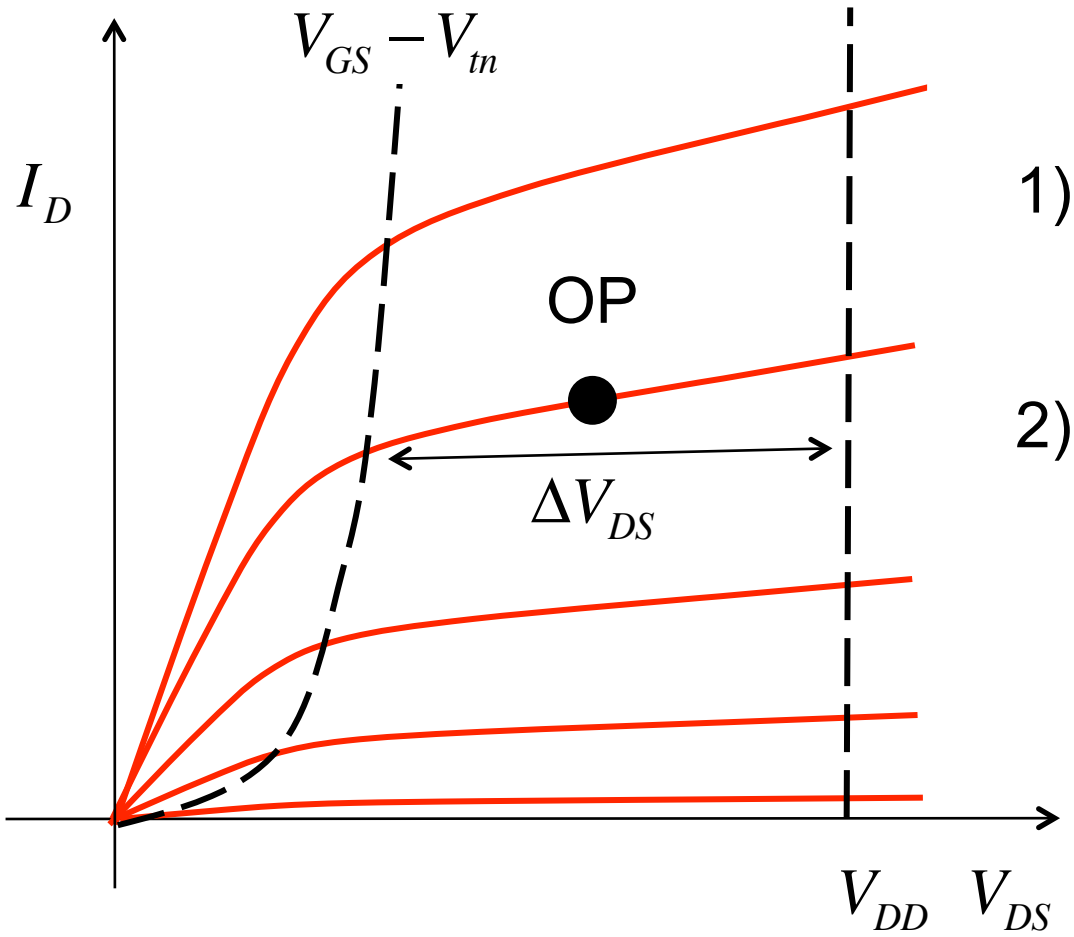
3) Amplifier configurations

4) CE and CS in detail

Outline

1) 4-resistor bias circuits
2) Common Source
3) Common Gate
4) Common Drain
5) Amplifier analysis examples

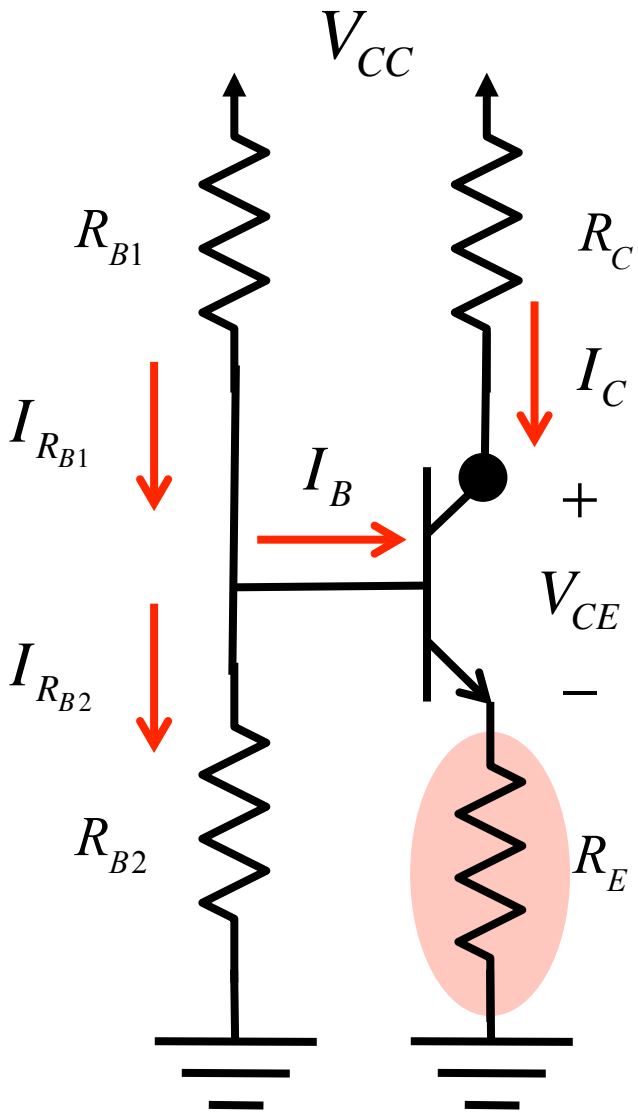
Operating point and bias circuit design



1) Insensitive to device variations (e.g. beta, V_t)

2) Transistor should stay in the active region.

Classic 4-resistor bias circuit



"Rule of thumb"

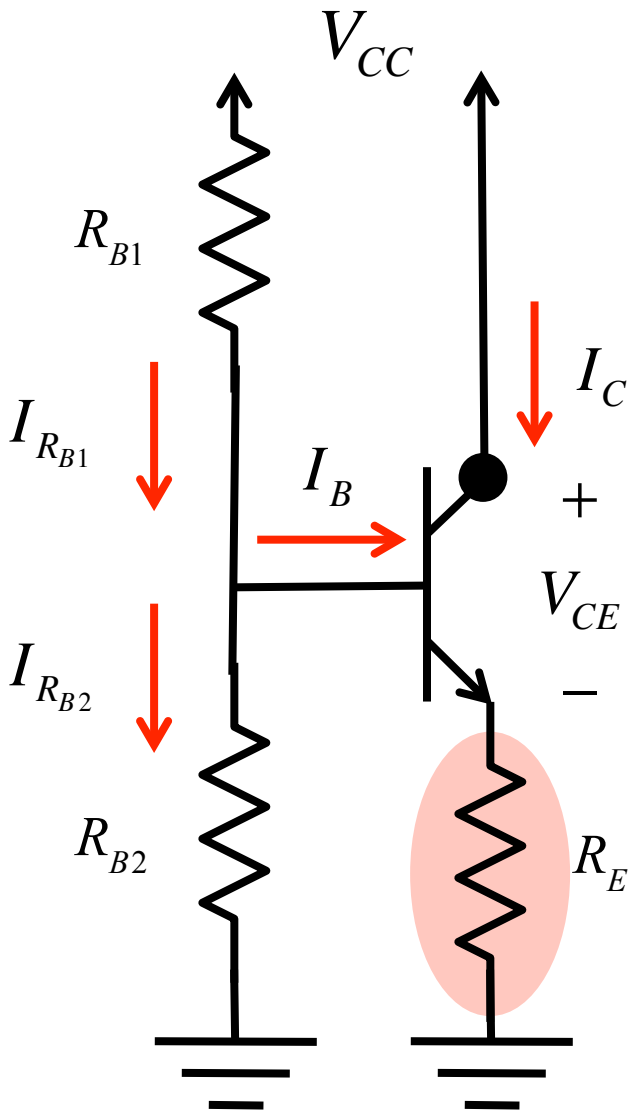
$$I_{R_{B1}} = 10 I_B$$

$$I_C = \frac{\beta\left(V_{th} - V_{BE}\right)}{R_{th} + (\beta + 1) R_E}$$

$$V_{th} = \frac{R_{B2}}{R_{B1} + R_{B2}} V_{CC}$$

$$R_{th} = R_{B1} \parallel R_{B2}$$

Classic 4-resistor bias circuit works with $R_C = 0$

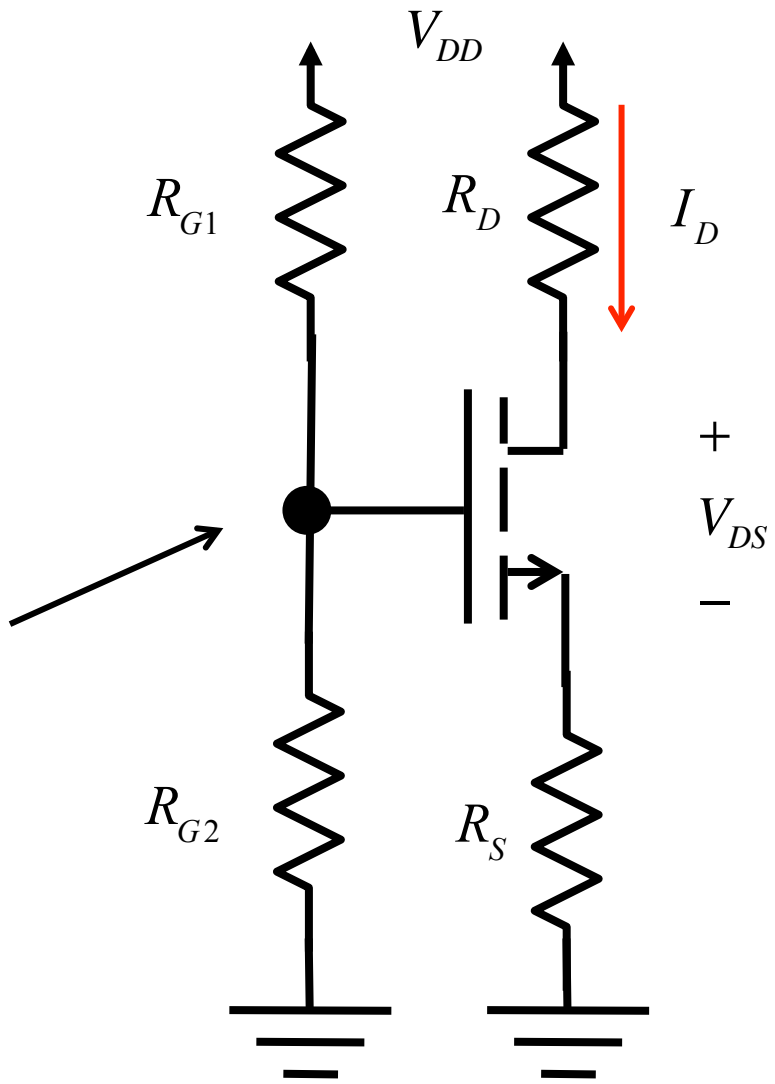


$$I_C = \frac{\beta\left(V_{th} - V_{BE}\right)}{R_{th} + \left(\beta + 1\right)R_E}$$

$$V_{th} = \frac{R_{B2}}{R_{B1} + R_{B2}} V_{CC}$$

$$R_{th} = R_{B1} \parallel R_{B2}$$

Classic 4-resistor bias circuit (MOS)

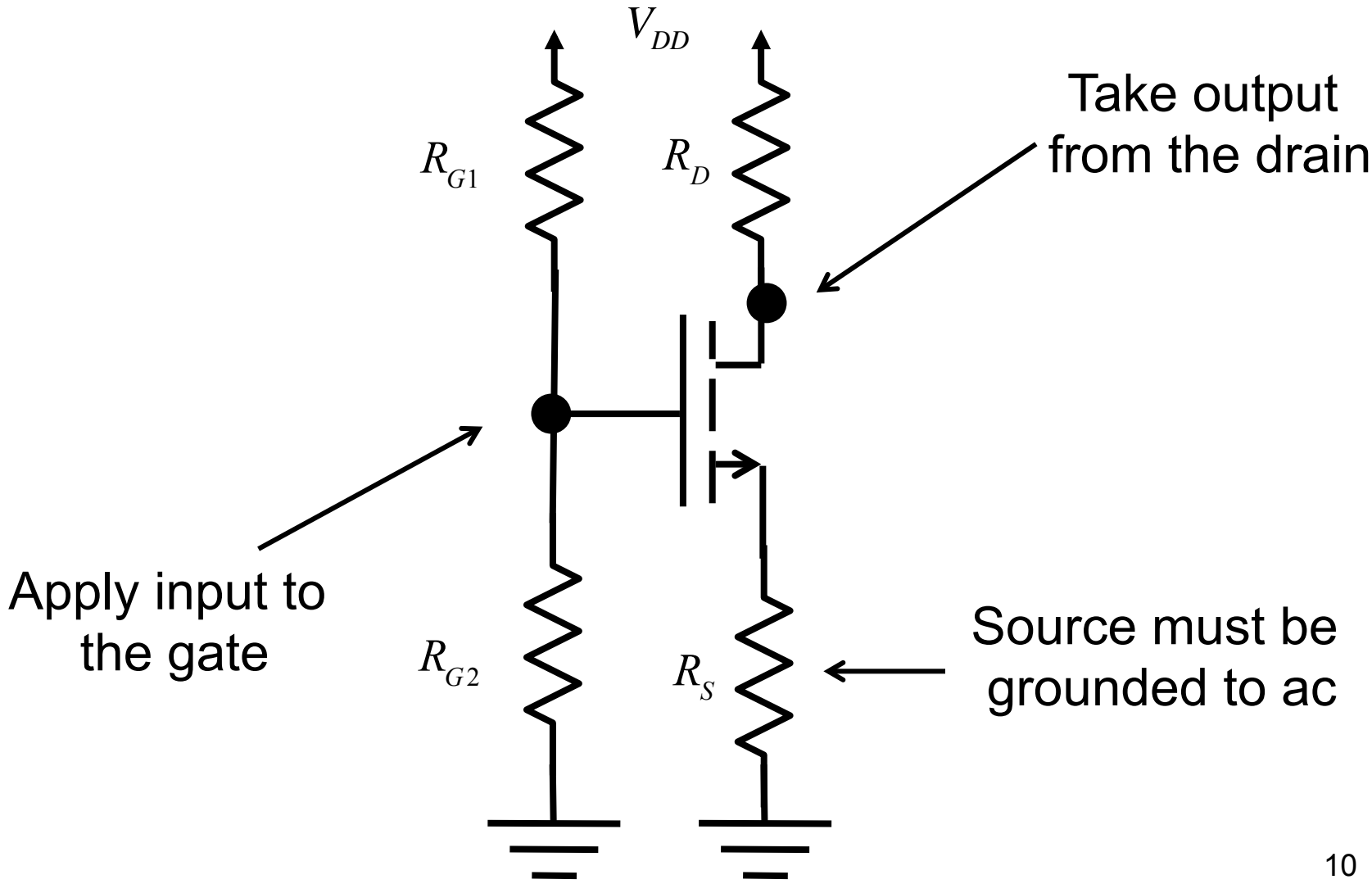


True voltage divider

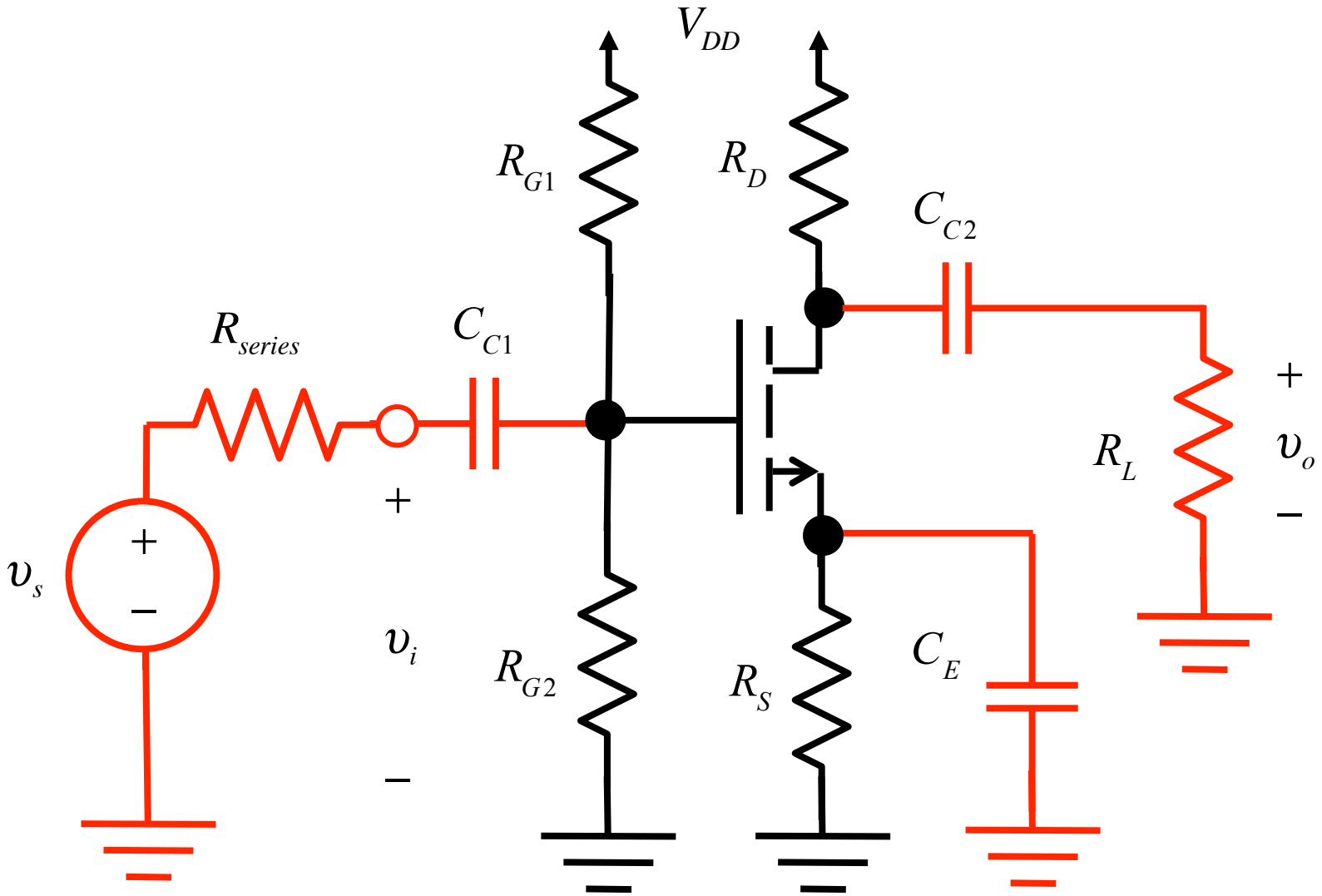
Outline

1) 4-resistor bias circuits
2) **Common Source**
3) Common Gate
4) Common Drain
5) Amplifier analysis example

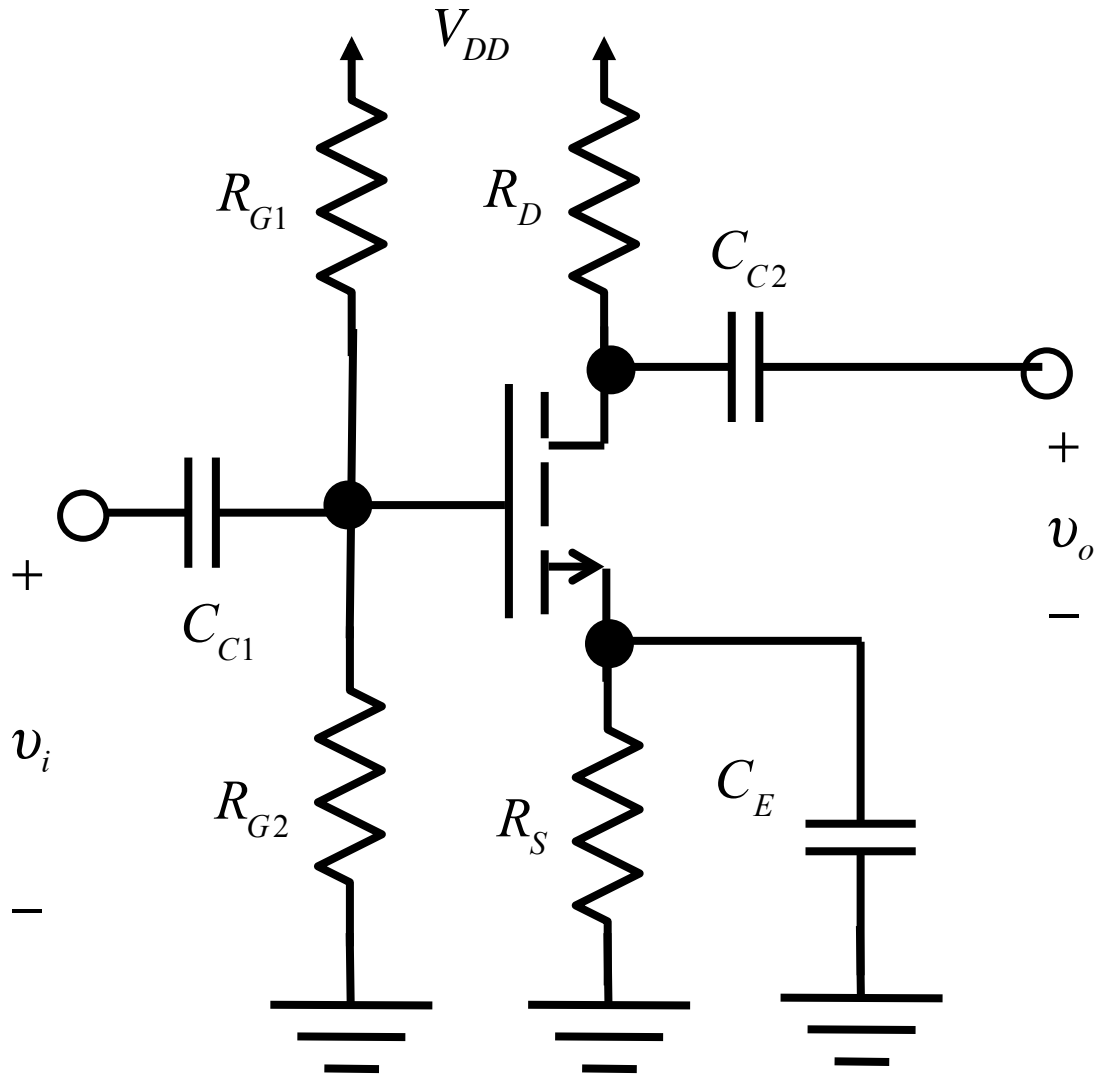
Common Source



Common Source



Common Source w/o signal and load

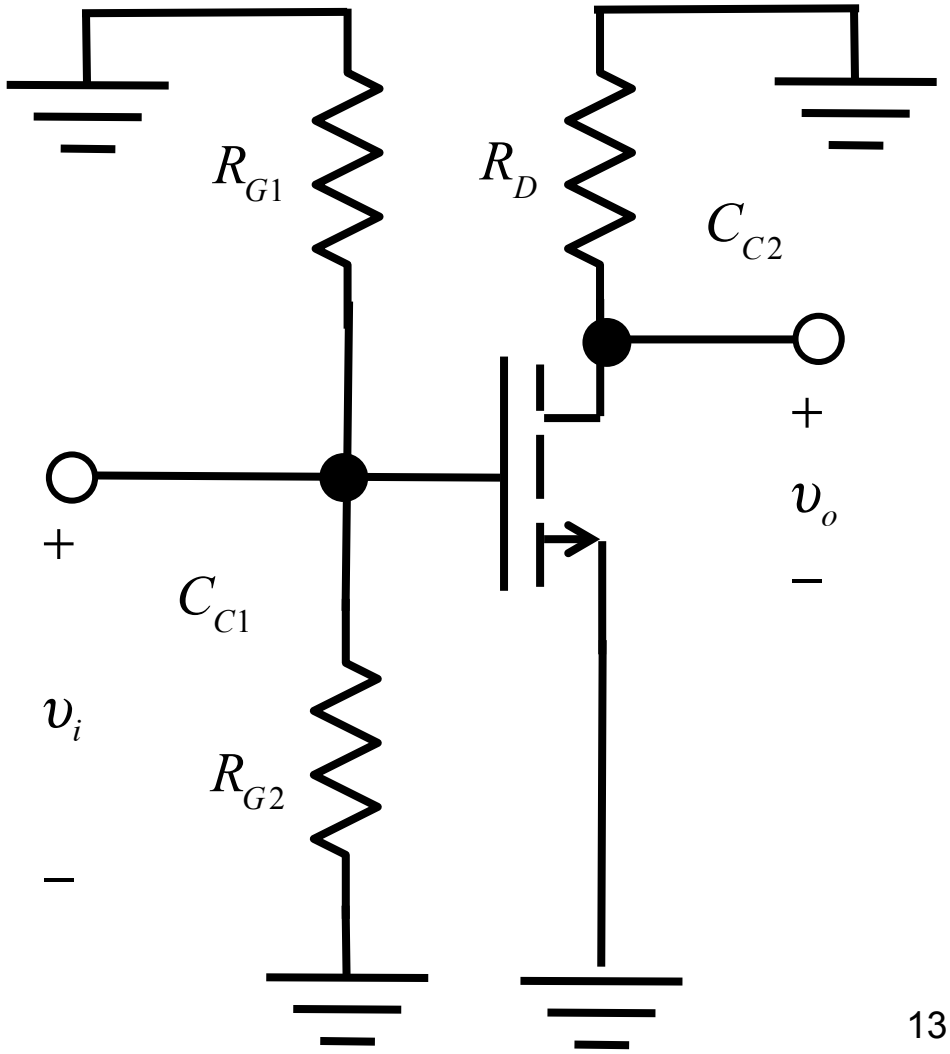


Common Source (AC)

$$A_{v_i} = -g_m R_D$$

$$R_{in} = R_{G1} \parallel R_{G2}$$

$$R_o = R_D$$



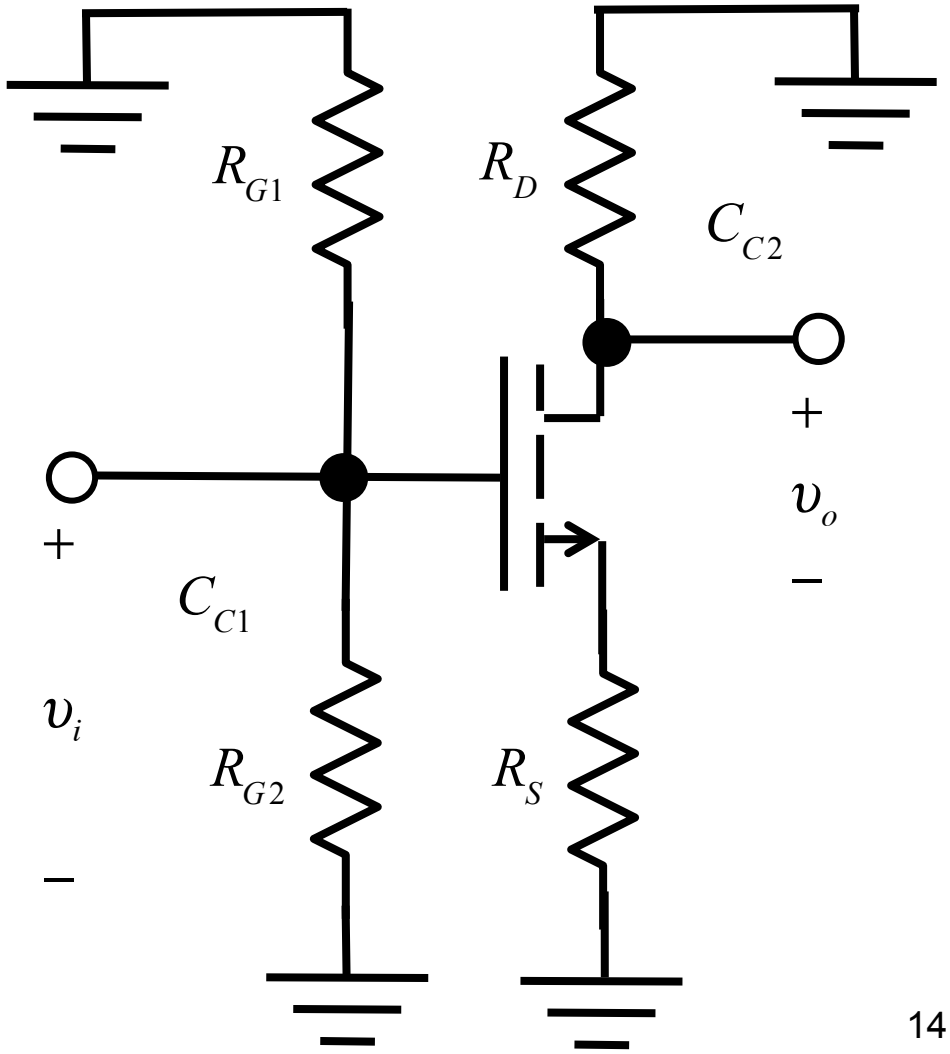
Common Source with source degeneration (AC)

$$A_{v_i} = \frac{-g_m R_D}{1 + g_m R_S}$$

$$A_{v_i} = -\frac{R_D}{1/g_m + R_S}$$

$$R_{in} = R_{G1} \parallel R_{G2}$$

$$R_o = R_D$$



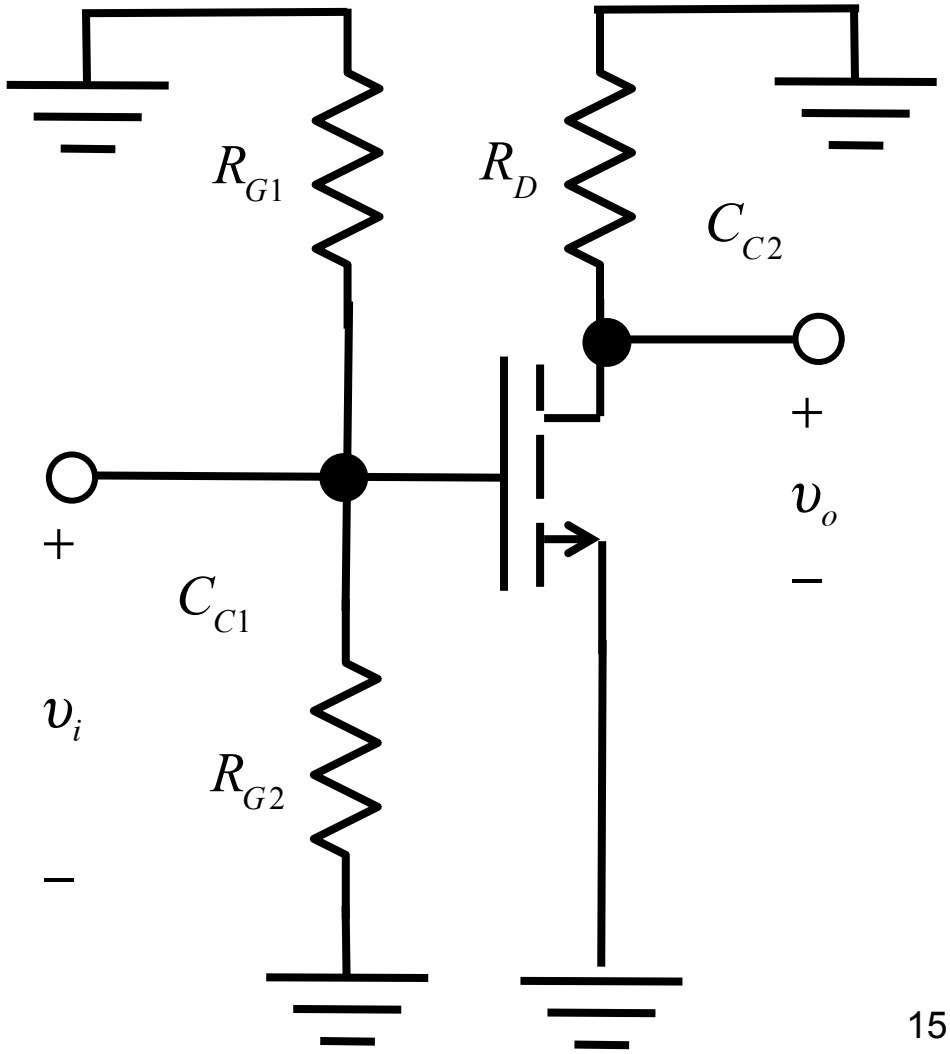
Common Source with $R_S = 0$ (AC)

$$A_{v_i} = -g_m R_D$$

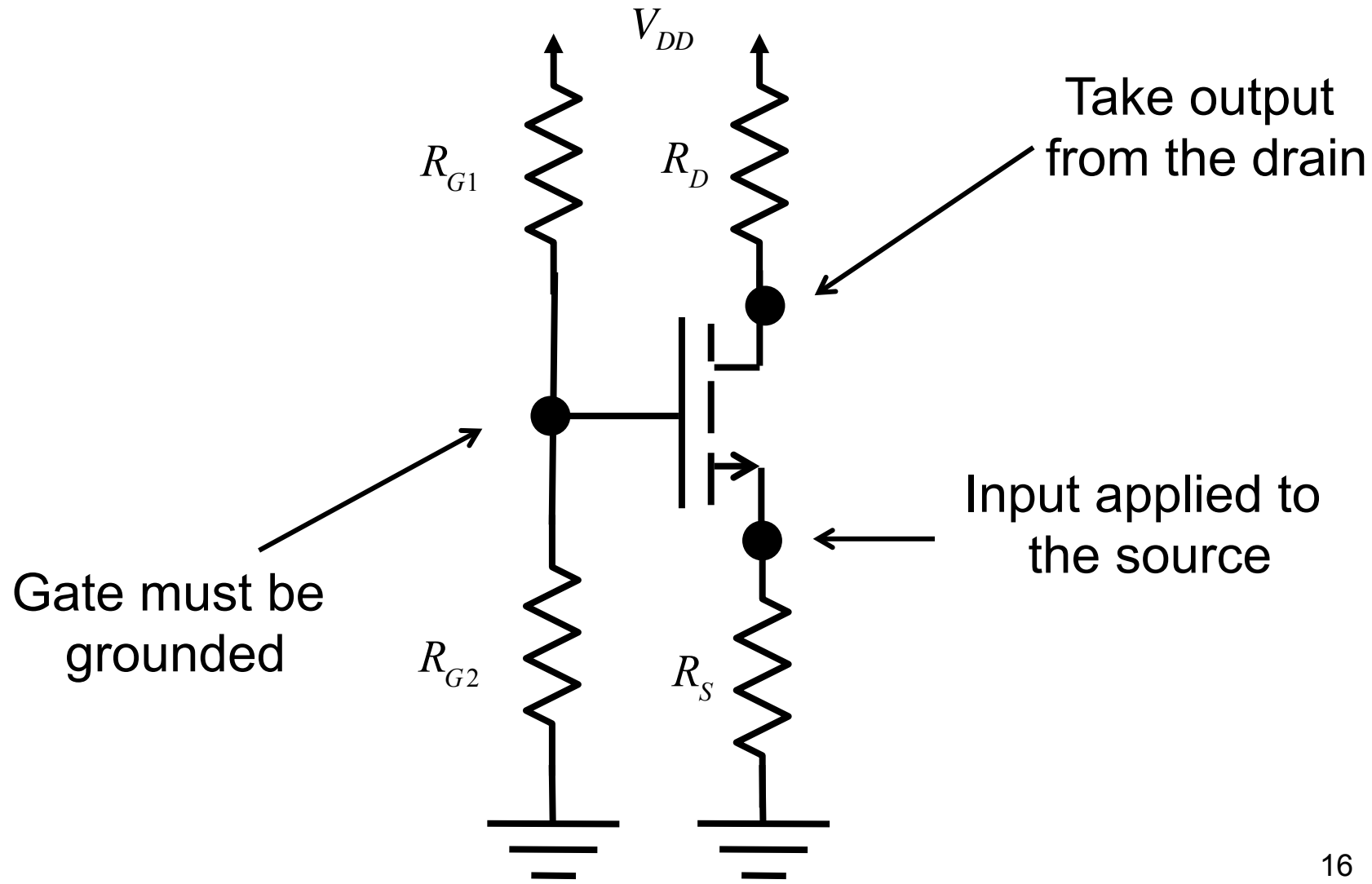
$$A_{v_i} = -\frac{R_C}{1/g_m}$$

$$R_{in} = R_{G1} \parallel R_{G2}$$

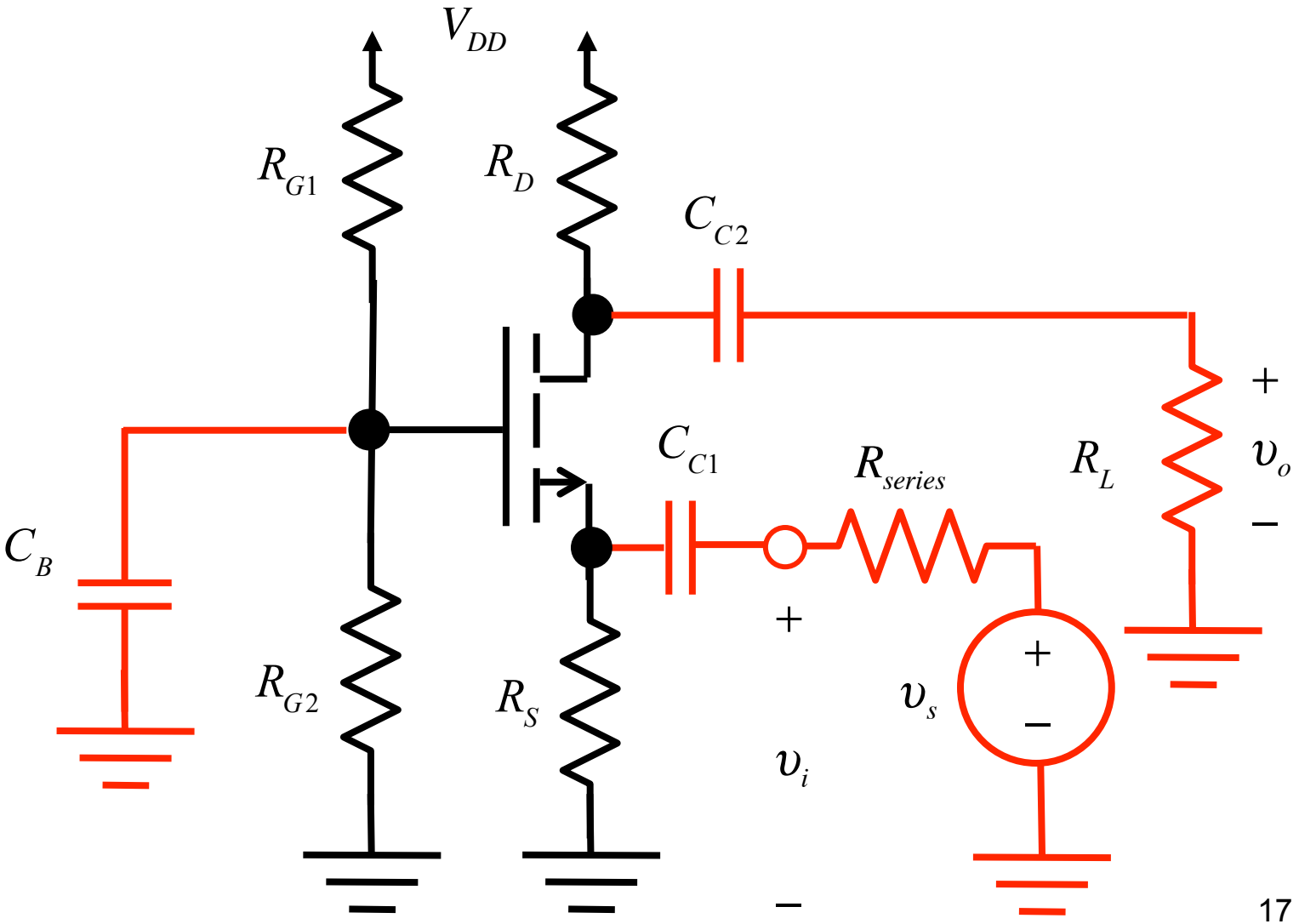
$$R_o = R_D$$



Common Gate


V_{DD}
R_{G1}
R_D
Take output from the drain
Input applied to the source
Gate must be grounded
R_{G2}
R_S

Common Gate

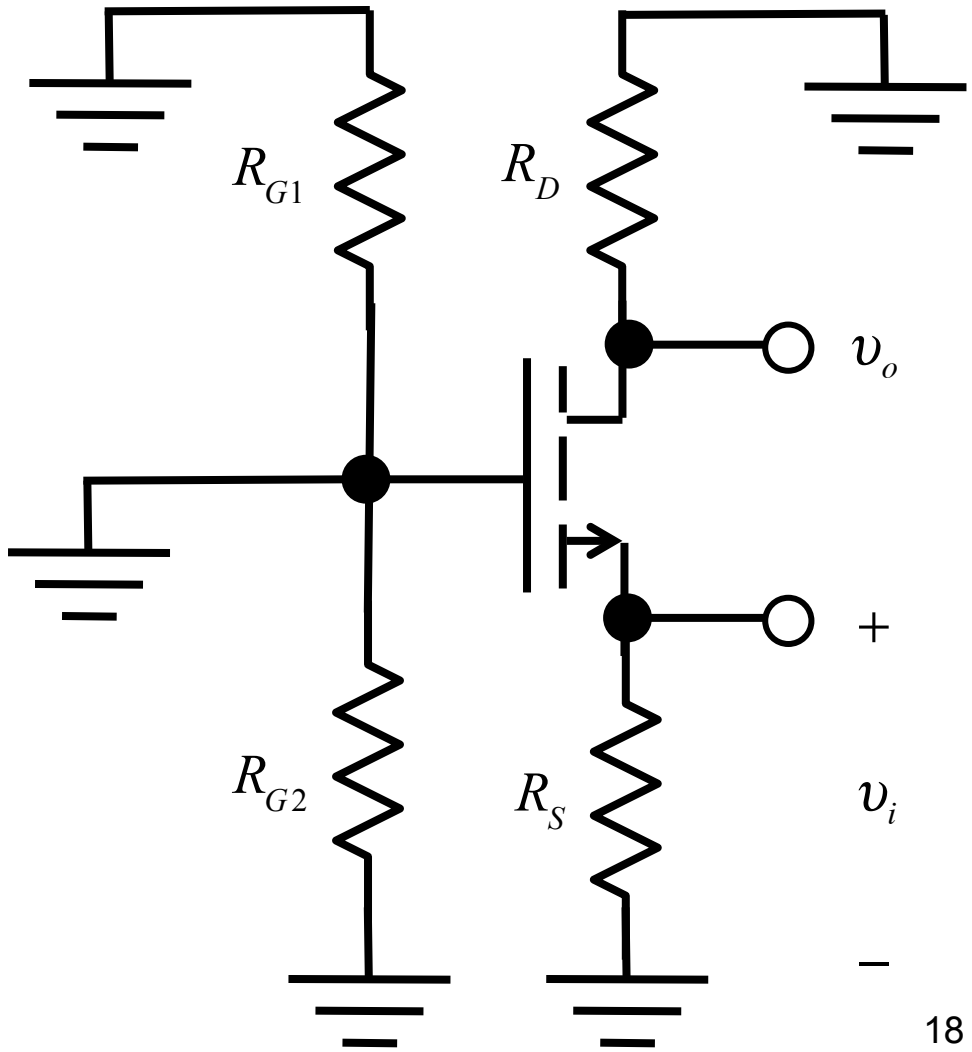

V_{DD}
R_{G1}
R_D
C_{C2}
C_{C1}
R_{series}
R_L
C_B
R_{G2}
R_S
υ_i
υ_s
υ_o
+
−

Common Gate (AC)

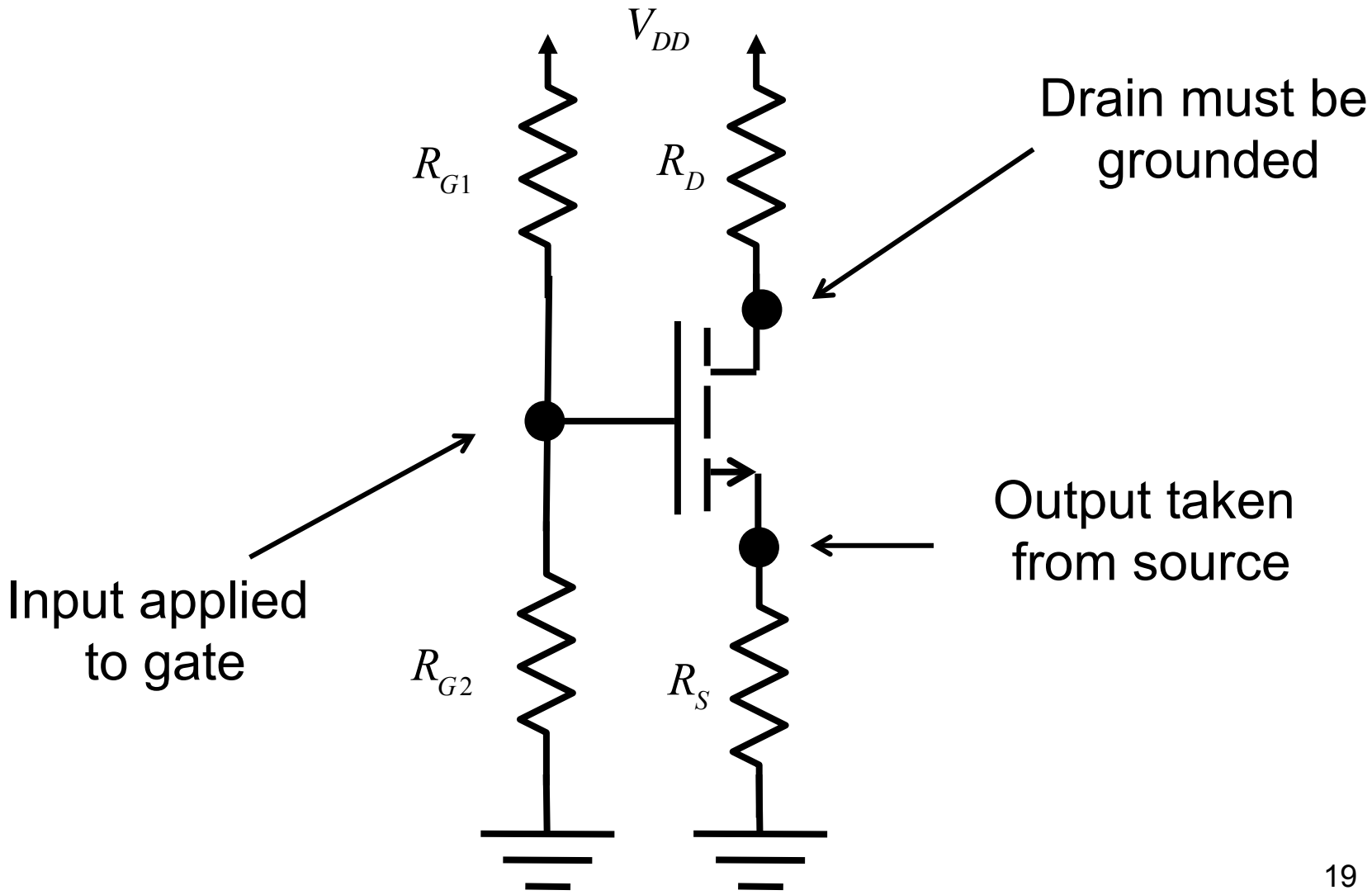
$$A_{v_i} = +g_m R_D$$

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

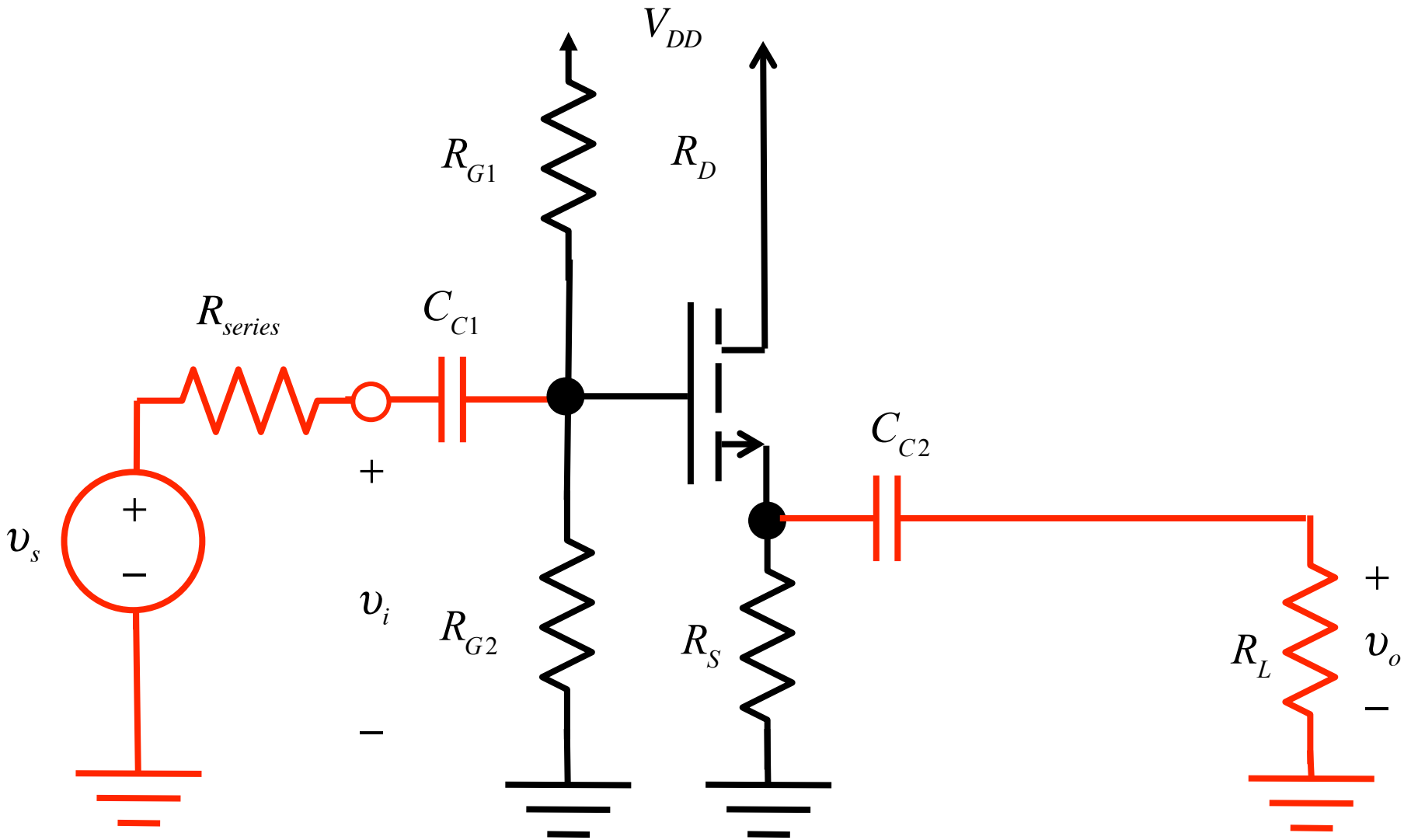
$$R_o = R_D$$



Common Drain



Common Drain

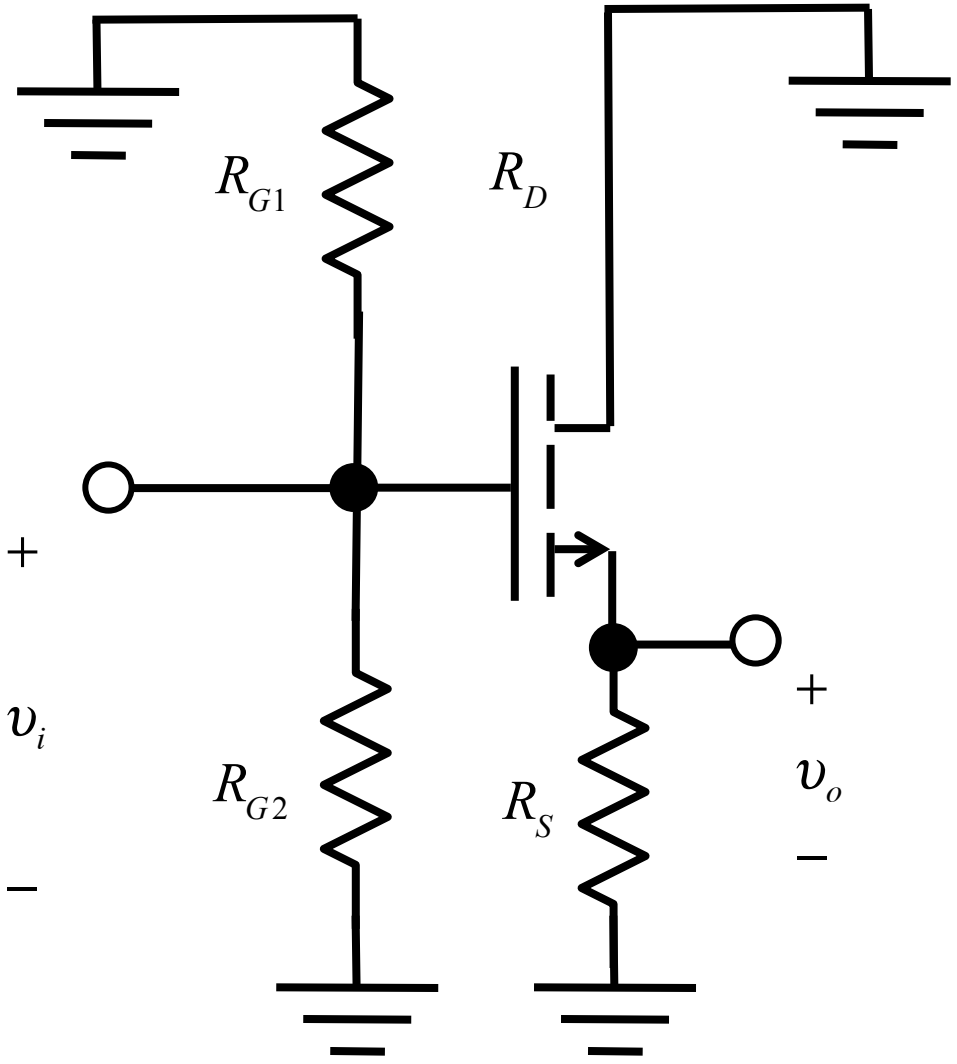


Common Drain (AC)

$$A_{v_i} = \frac{g_m R_S}{1 + g_m R_S}$$

$$R_{in} = R_{G1} \parallel R_{G2}$$

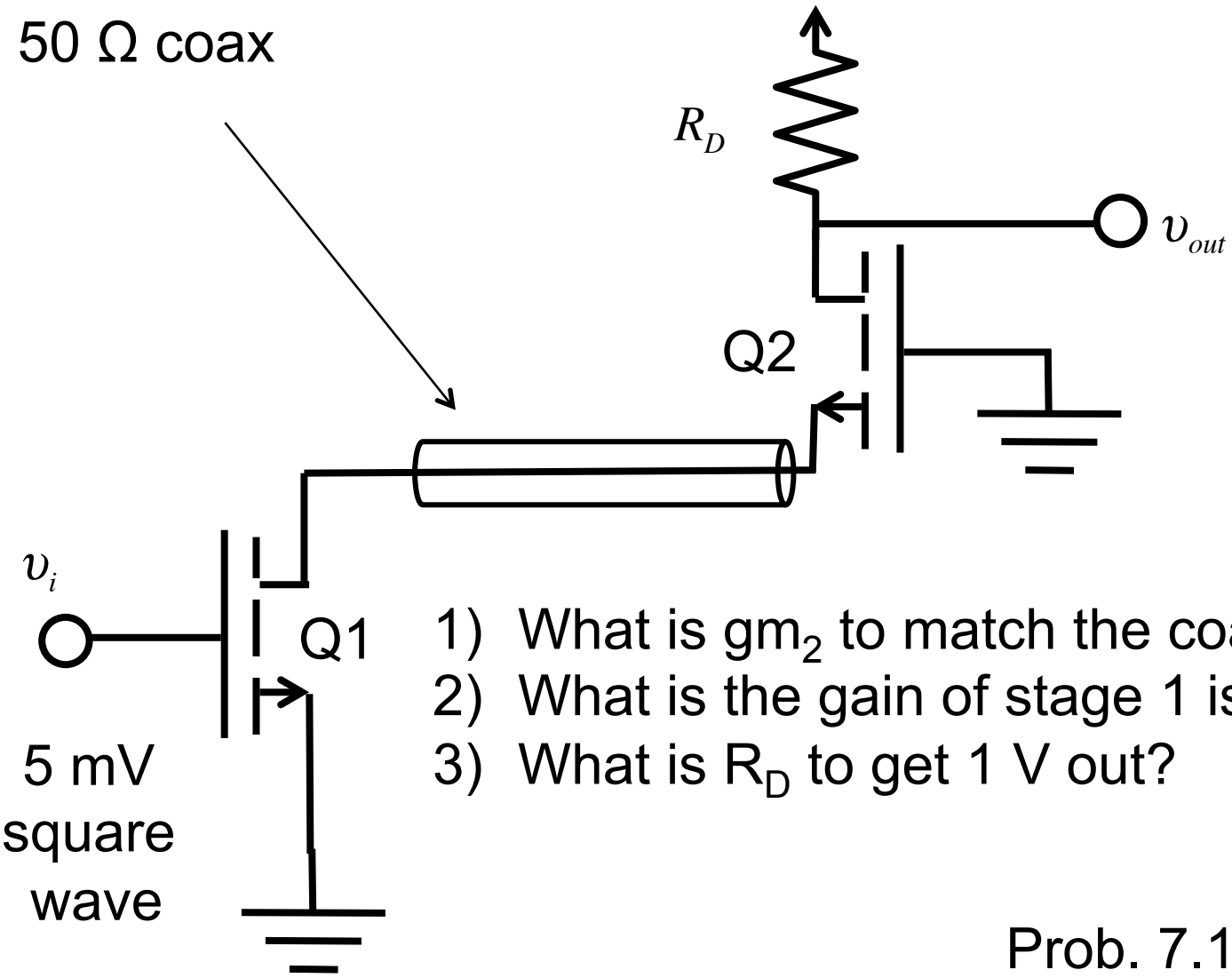
$$R_o = \frac{1}{g_m}$$



Outline

1) 4-resistor bias circuits
2) Common Source
3) Common Gate
4) Common Drain
5) **Amplifier analysis example**

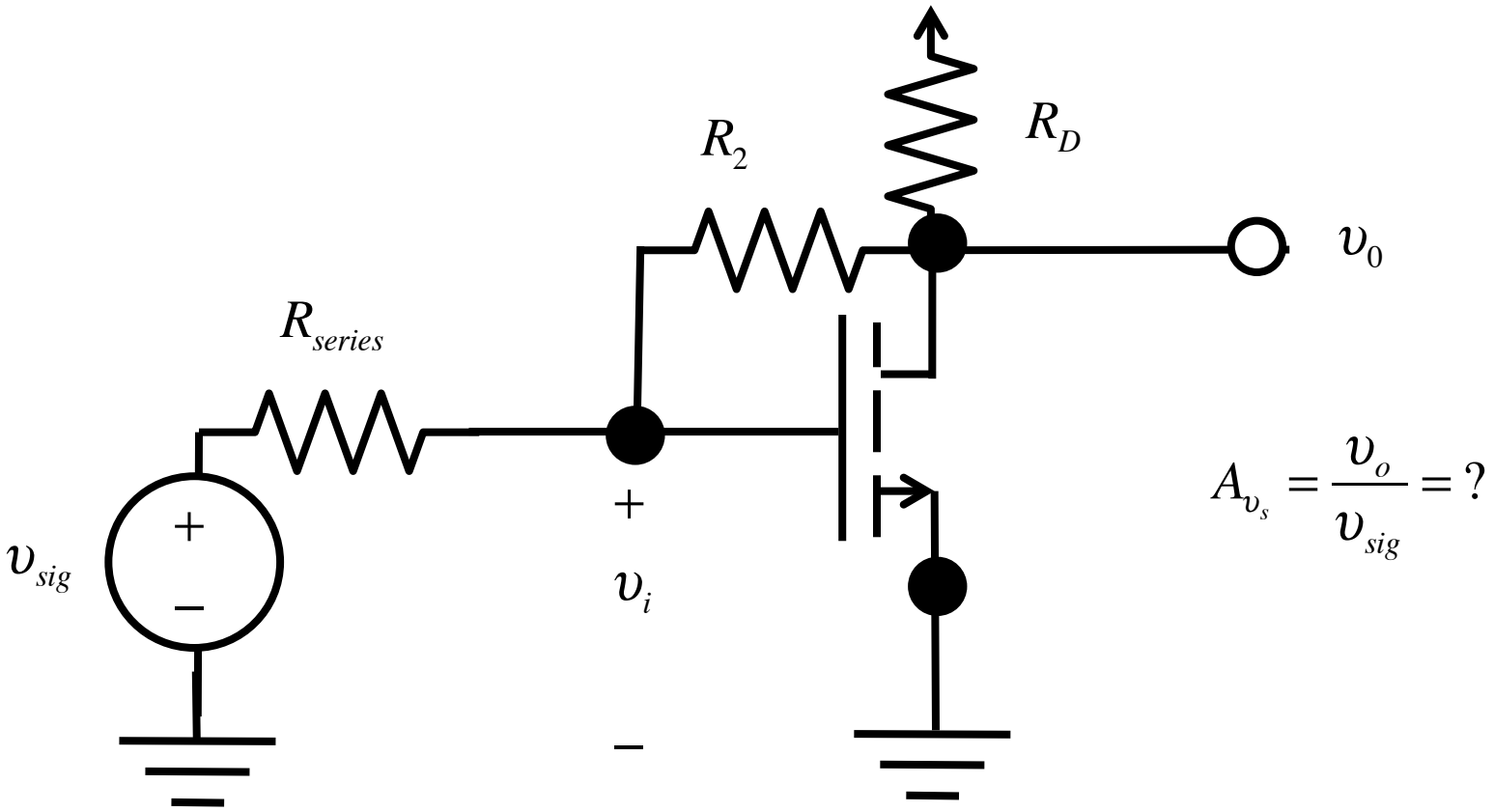
Amplifying high frequency pulses



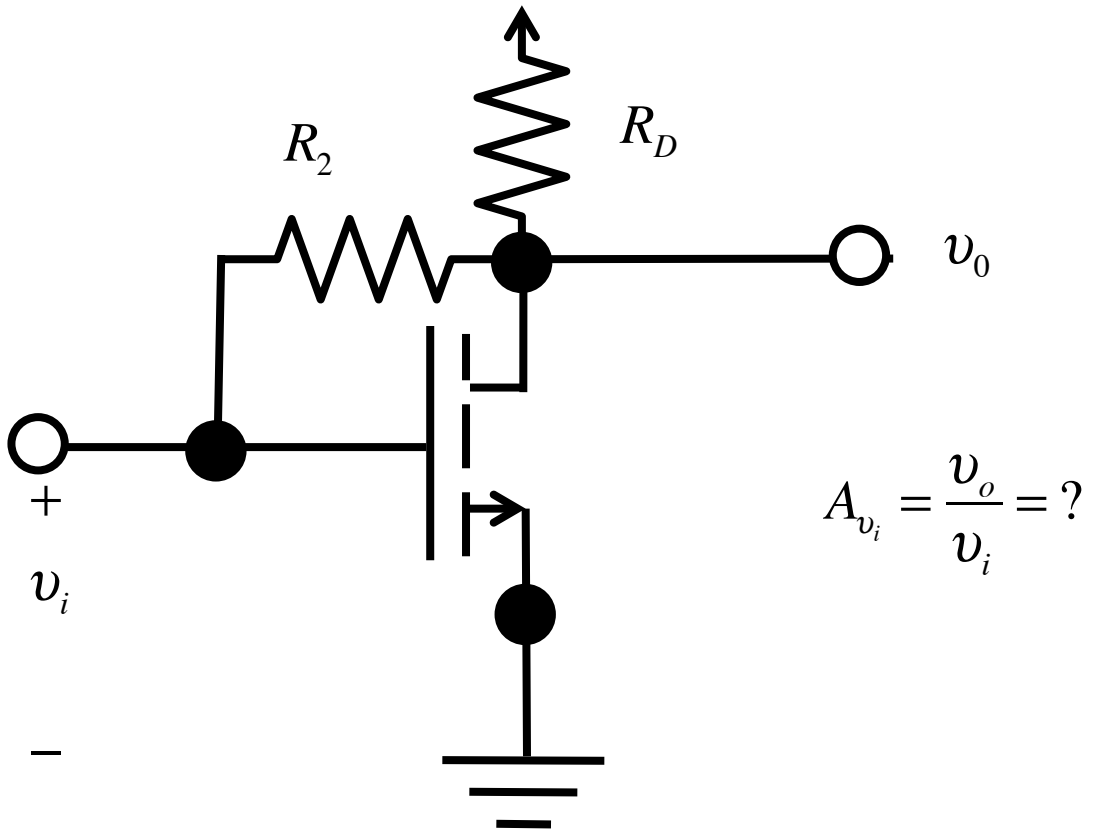
1) What is gm_2 to match the coax?
2) What is the gain of stage 1 is $gm_1 = gm_2$?
3) What is R_D to get 1 V out?

Prob. 7.120 S&S

Feedback amplifier



Feedback amplifier

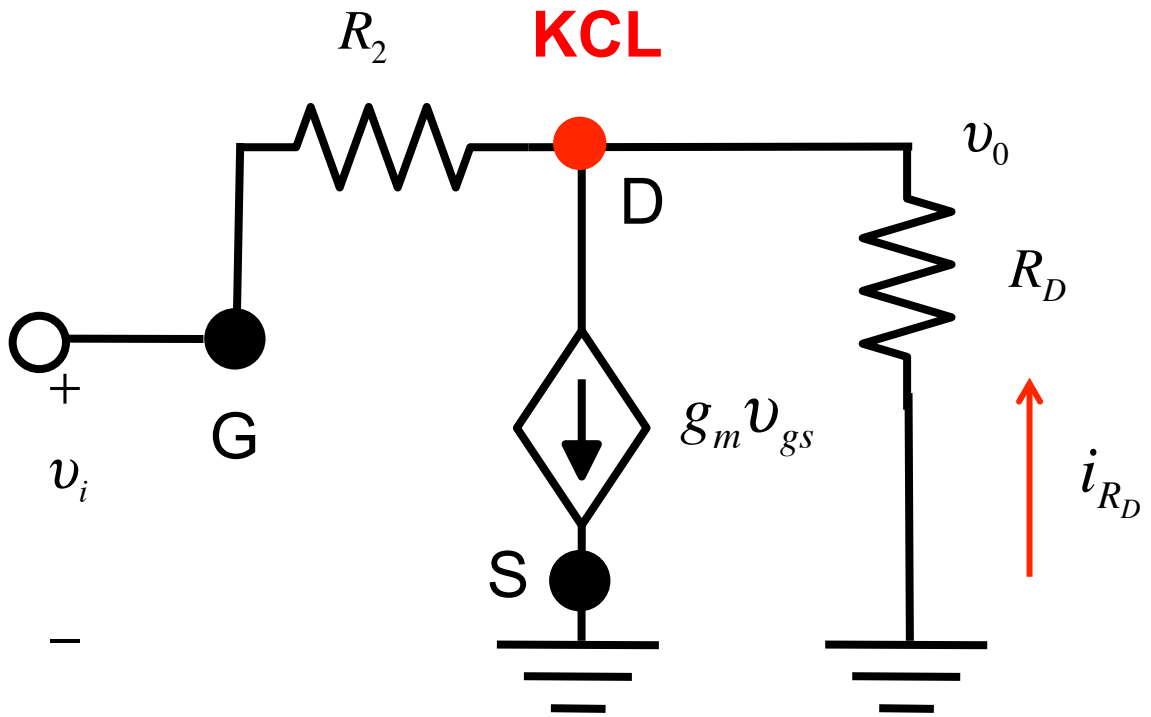


Intrinsic amplifier

s.s. model

$$A_{v_o} = \frac{v_o}{v_i} = ?$$

$$v_o = -i_{R_D} R_D$$



KCL

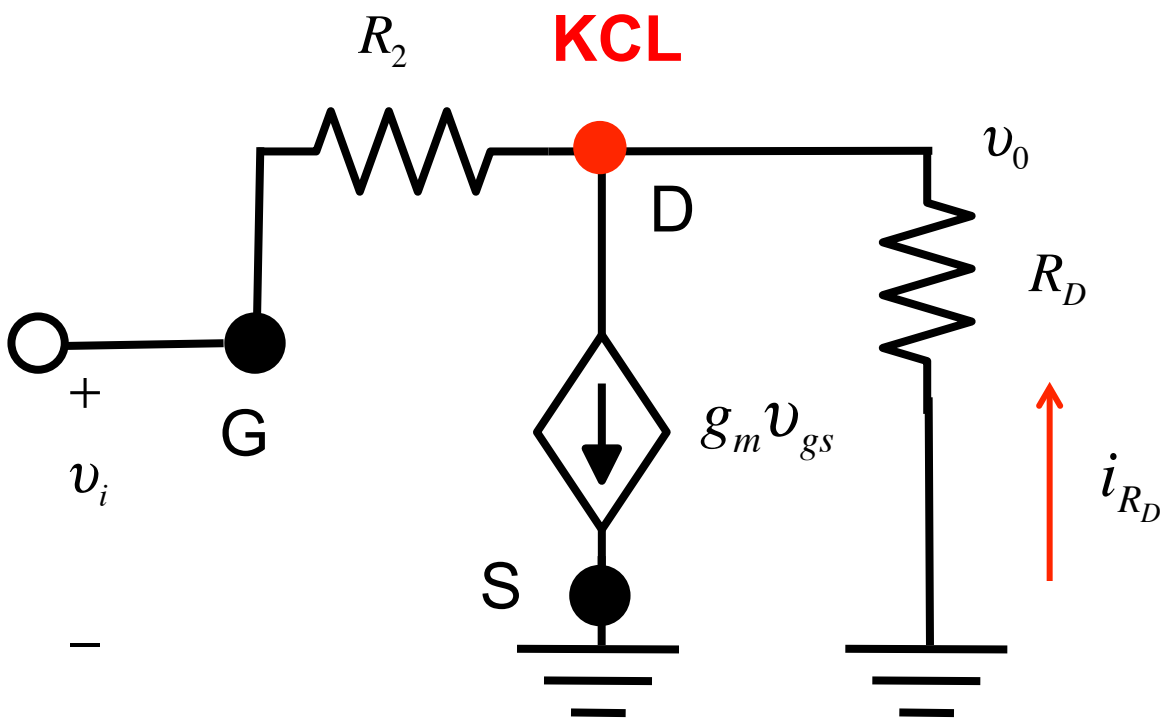
$$\upsilon_o = -i_{R_D} R_D$$

$$i_{R_D} = g_m \upsilon_{gs} + \frac{(\upsilon_o - \upsilon_i)}{R_2}$$

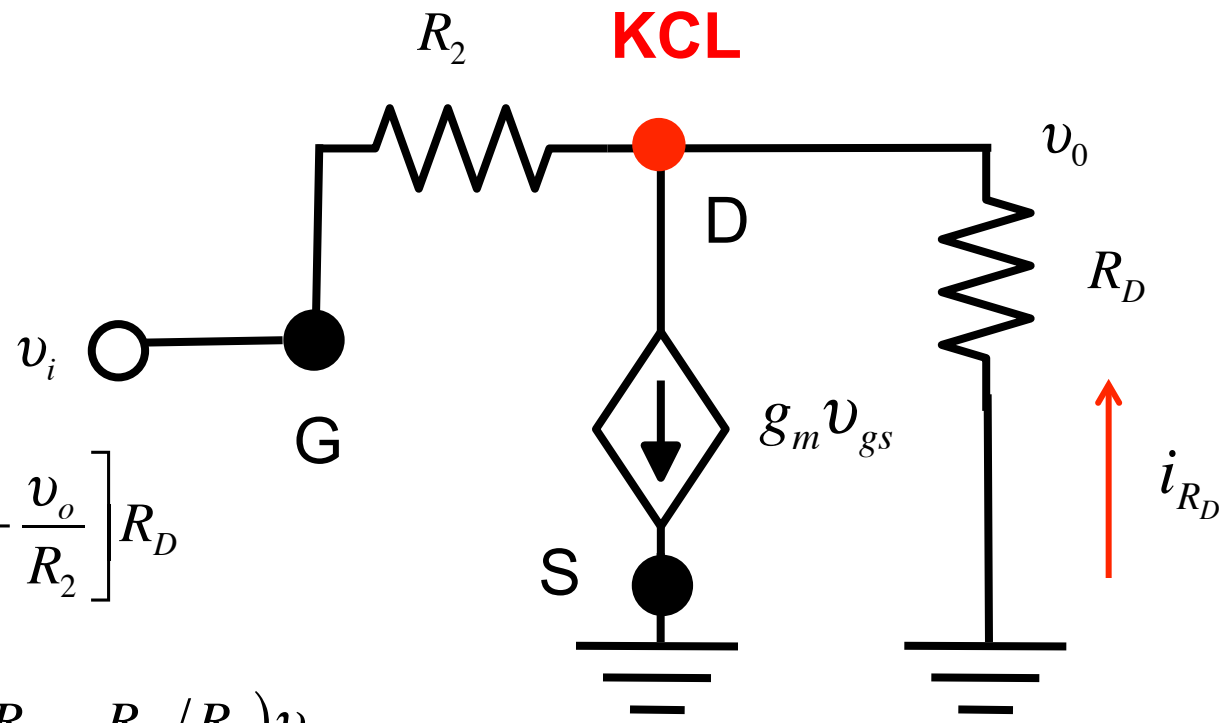
$$i_{R_D} = g_m \upsilon_i + \frac{(\upsilon_o - \upsilon_i)}{R_2}$$

$$i_{R_D} = (g_m - 1/R_2)\upsilon_i + \frac{\upsilon_o}{R_2}$$

$$\upsilon_o = -i_{R_D} R_D = -\left[(g_m - 1/R_2)\upsilon_i + \frac{\upsilon_o}{R_2}\right] R_D$$



Open circuit voltage gain



$$v_o = -\left[\left(g_m - 1/R_2\right)v_i + \frac{v_o}{R_2}\right]R_D$$

$$v_o\left(1 + R_D/R_2\right) = -\left(g_m R_D - R_D/R_2\right)v_i$$

$$A_{v_o} = \frac{v_o}{v_i} = \frac{-\left(g_m R_D - R_D/R_2\right)}{\left(1 + R_D/R_2\right)}$$ ✓

Input resistance

$$v_x = i_x R_2 + v_d \qquad (1)$$

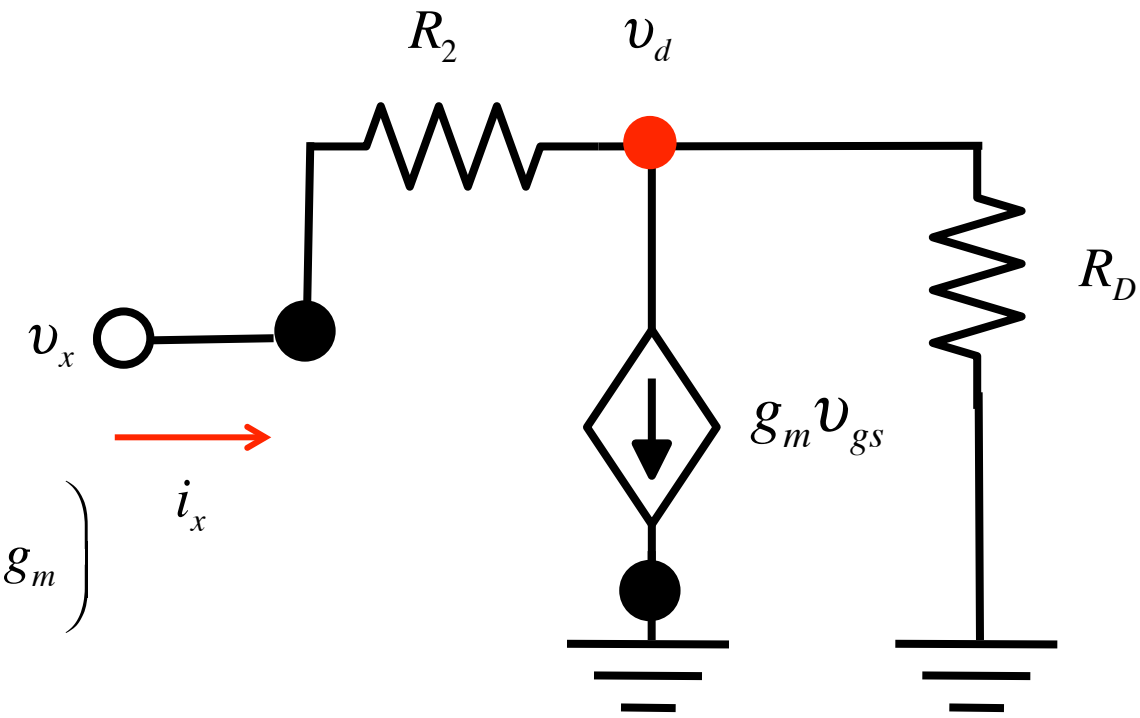
$$\frac{v_d - v_x}{R_2} + g_m v_x + \frac{v_d}{R_D} = 0$$

$$v_d \left[\frac{1}{R_2} + \frac{1}{R_D} \right] = v_x \left(\frac{1}{R_2} - g_m \right)$$

$$v_d = v_x \frac{\left(1/R_2 - g_m\right)}{\left(1/R_2 + 1/R_D\right)}$$

Return to (1)

$$v_x = i_x R_2 + v_x \frac{\left(1/R_2 - g_m\right)}{\left(1/R_2 + 1/R_D\right)}$$



Input resistance

$$v_x = i_x R_2 + v_x \frac{\left(1/R_2 - g_m\right)}{\left(1/R_2 + 1/R_D\right)}$$

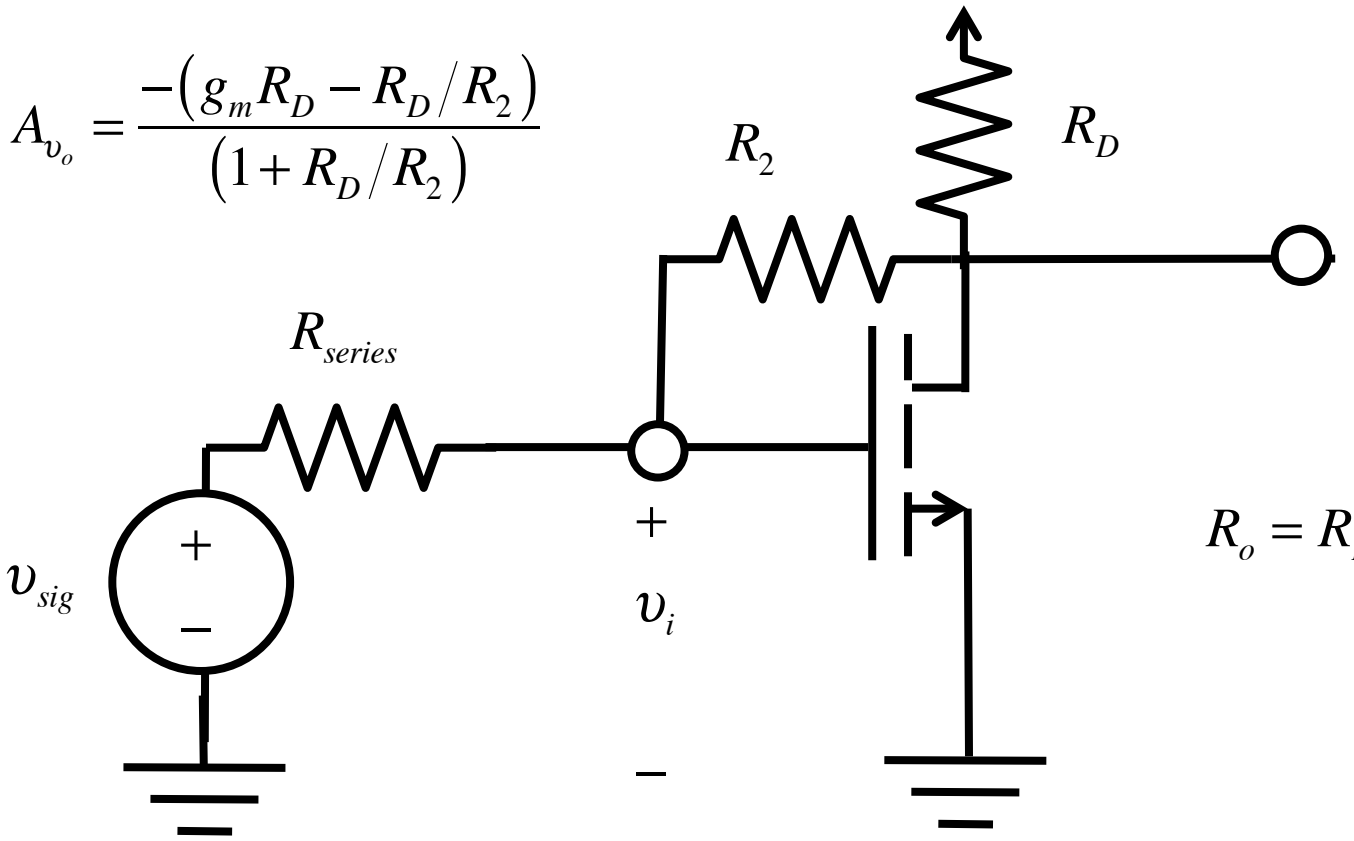
$$v_x \left[1 - \frac{\left(1/R_2 - g_m\right)}{\left(1/R_2 + 1/R_D\right)}\right] = i_x R_2$$

$$v_x \left[\frac{\left(1/R_D + g_m\right)}{\left(1/R_2 + 1/R_D\right)}\right] = i_x R_2$$

$$\frac{v_x}{i_x} = R_{in} = \frac{\left(1 + R_2/R_D\right)}{\left(1/R_D + g_m\right)}$$

Feedback amplifier

$$A_{v_o} = \frac{-\left(g_m R_D - R_D/R_2\right)}{\left(1 + R_D/R_2\right)}$$



$$R_o = R_D \,||\left(R_2 + R_{series}\right)$$

$$R_{in} = \frac{\left(1 + R_2/R_D\right)}{\left(1/R_D + g_m\right)}$$

Summary

The 4-resistor bias circuit can be used to make discrete transistor CS, CG, CD, CE,CB, and CC amplifiers.

Using the hybrid-pi small signal model for transistors, we can analyze the performance of **any** amplifier.

Discrete Amplifiers

1) 4-resistor bias circuits
2) Common Source
3) Common Gate
4) Common Drain
5) Amplifier analysis examples