Biasing in MOSFET Amplifiers

- Biasing: Creating the circuit to establish the desired DC voltages and currents for the operation of the amplifier

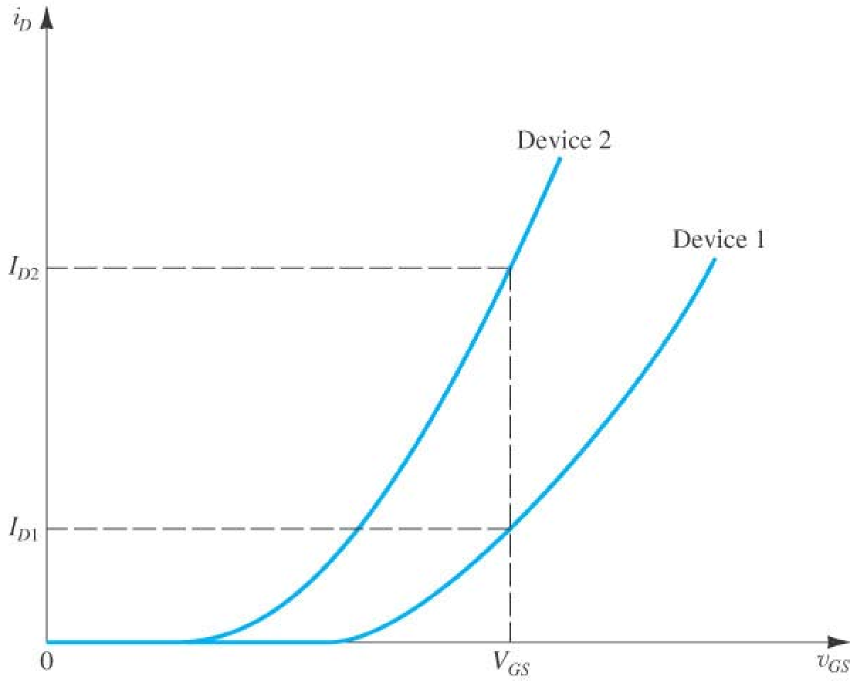
- Four common ways:
  1. Biasing by fixing V_{GS}
  2. Biasing by fixing V_G and connecting a resistance in the Source
  3. Biasing using a Drain-to-Gate Feedback Resistor
  4. Biasing Using a Constant-Current Source

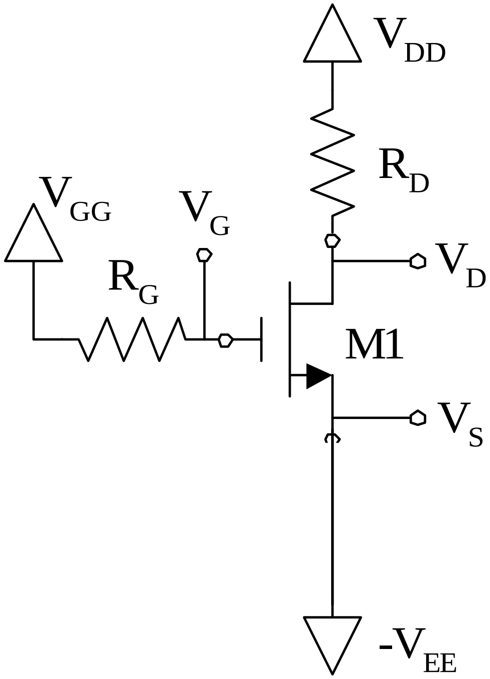
Biasing in MOSFET Amplifiers

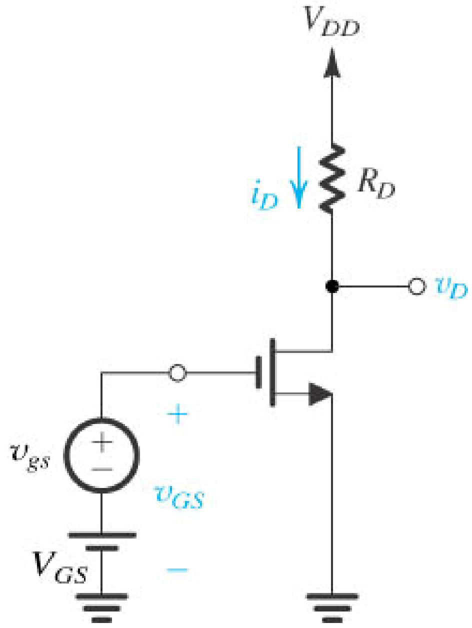
- Biasing by fixing V_{GS}

$$I_D = \frac{1}{2} k_n' \frac{W}{L} (V_{GS} - V_t)^2$$

$$k_n' = \mu_n \frac{\varepsilon_{ox}}{t_{ox}} = \mu_n C_{ox}$$



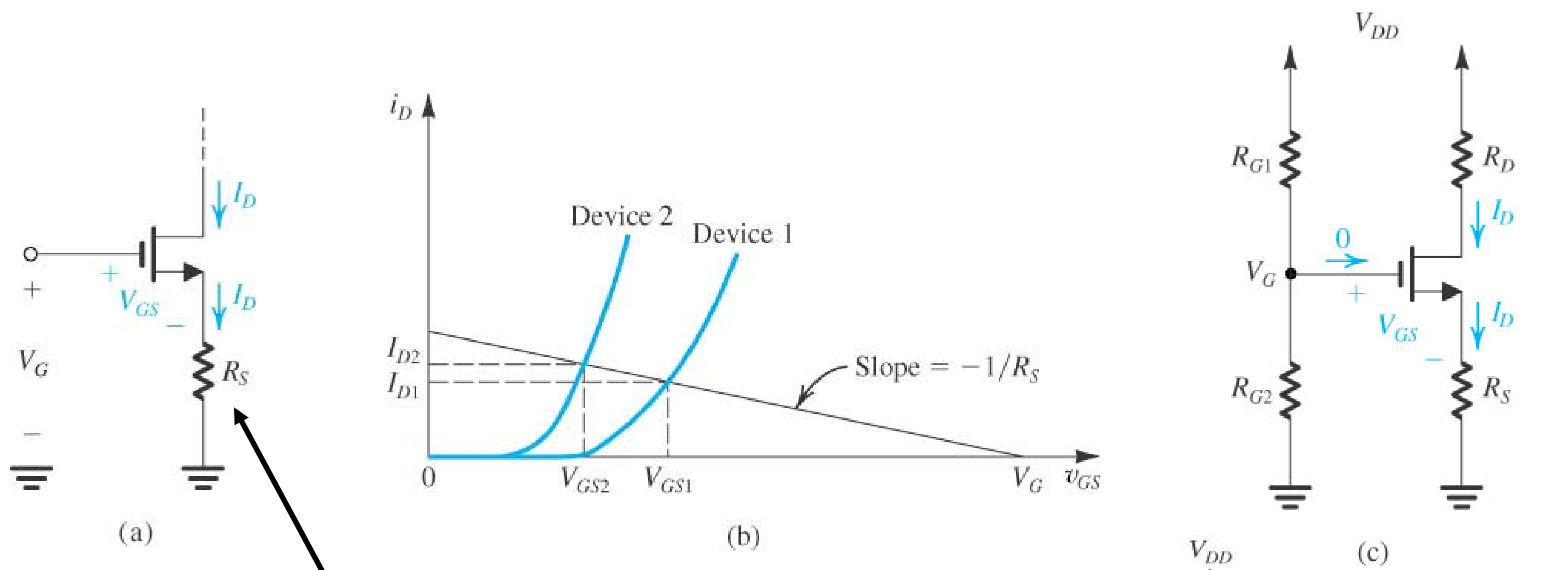




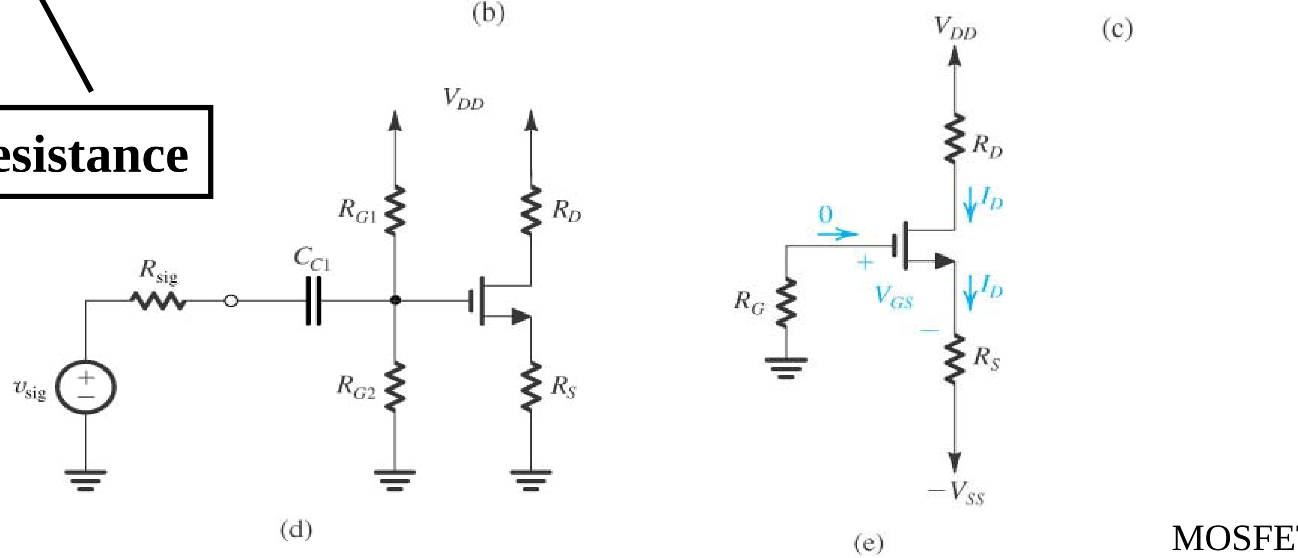
When the MOSFET device is changed (even using the same supplier), this method can result in a large variability in the value of I_D. Devices 1 and 2 represent extremes among units of the same type.

Biasing in MOSFET Amplifiers

- Biasing by fixing V_G and connecting a resistance in the Source

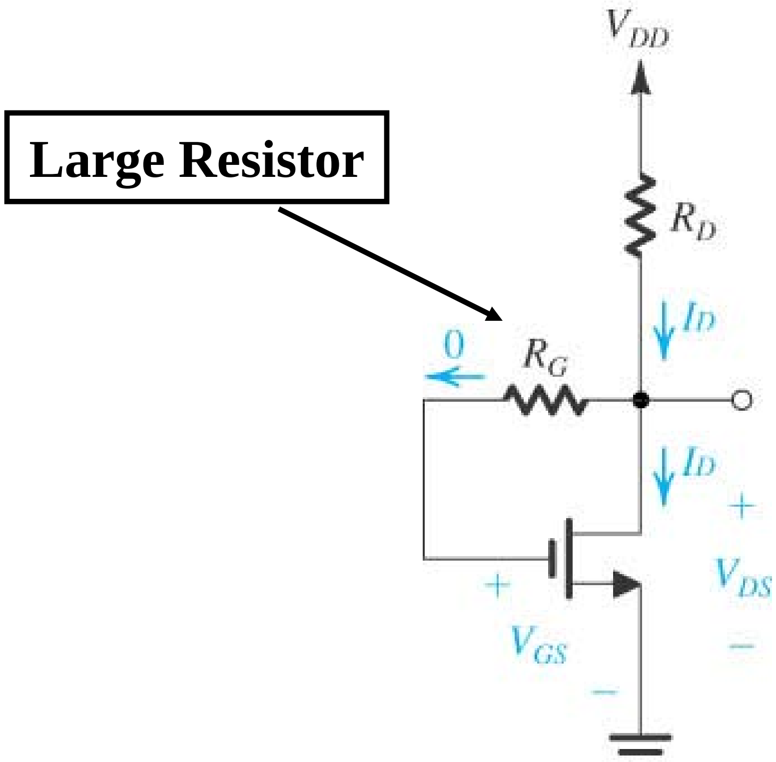


Degeneration Resistance



Biasing in MOSFET Amplifiers

- Biasing using a Drain-to-Gate Feedback Resistor



Biasing in MOSFET Amplifiers

- Biasing Using a Constant-Current Source

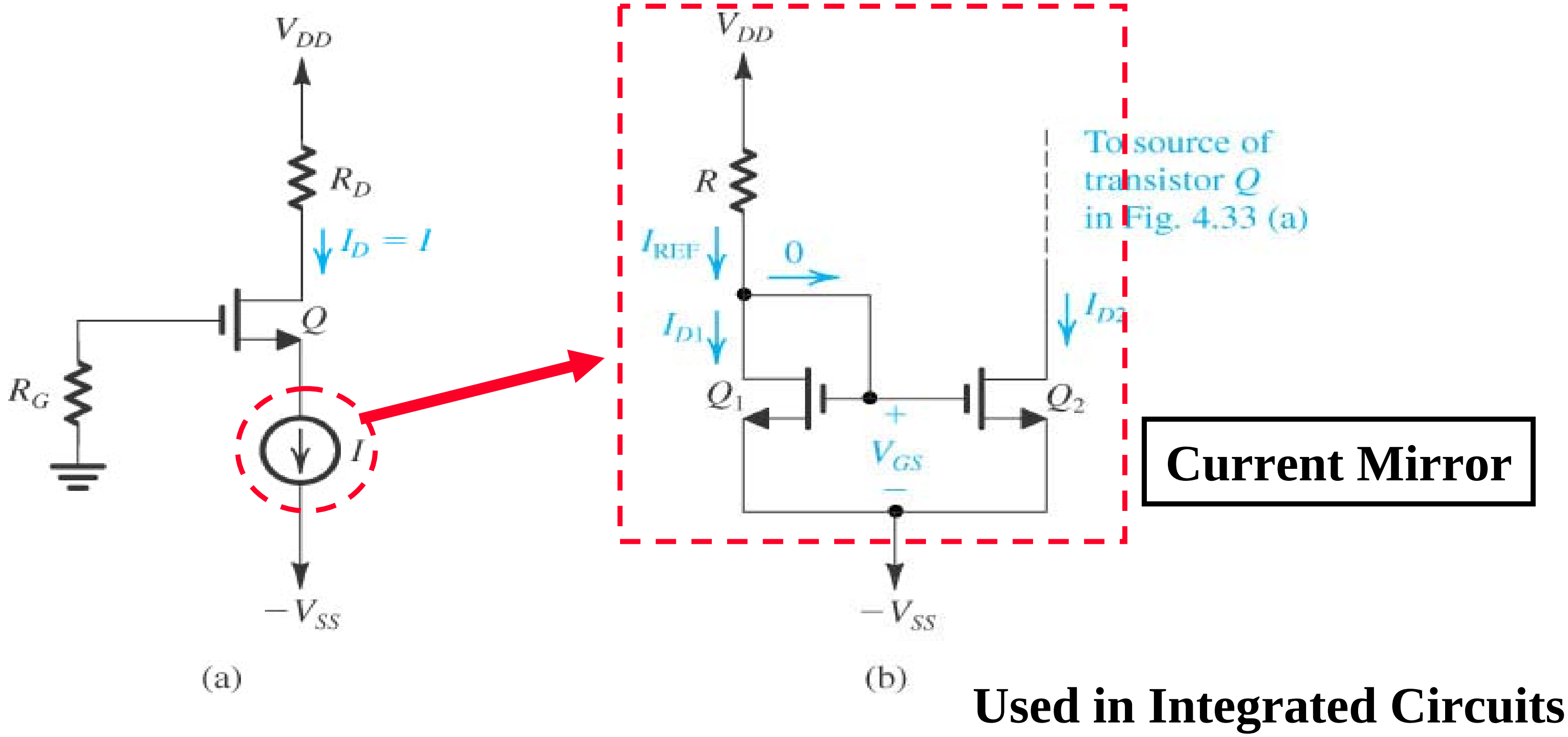
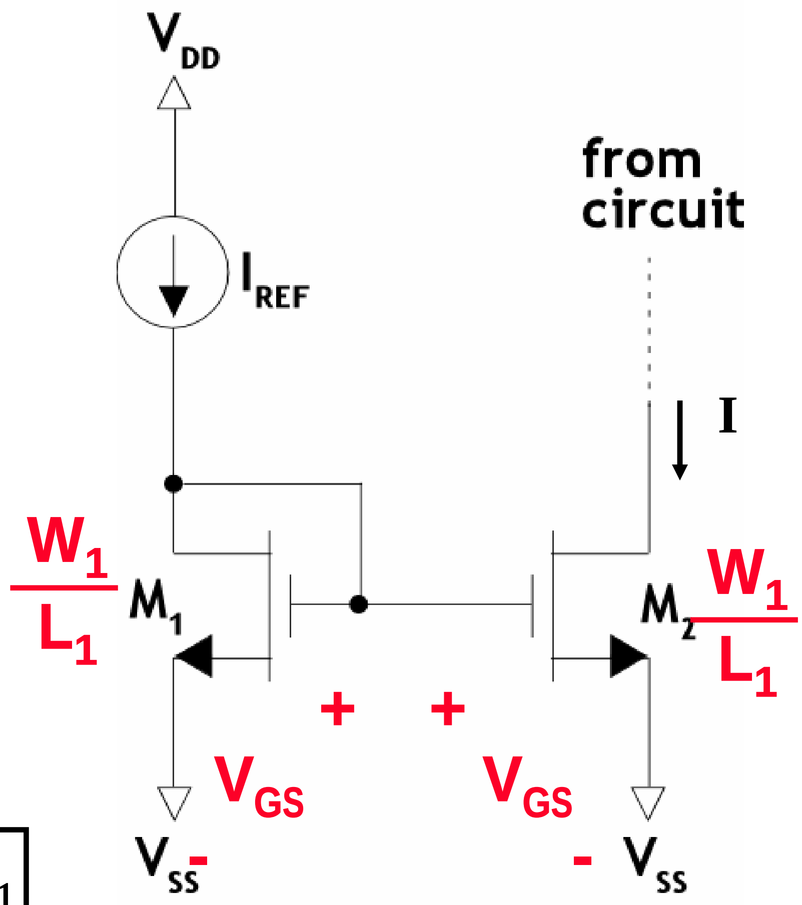


Figure 4.33 (a) Biasing the MOSFET using a constant-current source *I*. **(b)** Implementation of the constant-current source *I* using a current mirror.

Current Mirror DC Analysis

- The width and length (the W/L aspect ratio) and the parameters of the two transistors <u>*can be different*</u>
- We can choose W/L freely
- In this circuit, consider W/L of both MOSFETs are the same and transistors are identical. The Gate-Source voltages are also the same, then



$$I_{REF} = \tfrac{1}{2} k_n' \frac{W_1}{L_1} (V_{GS} - V_t)^2$$

$$I = \tfrac{1}{2} k_n' \frac{W_1}{L_1} (V_{GS} - V_t)^2$$

$$\frac{I}{I_{REF}} = \frac{W_1}{L_1} \cdot \frac{L_1}{W_1} = 1$$

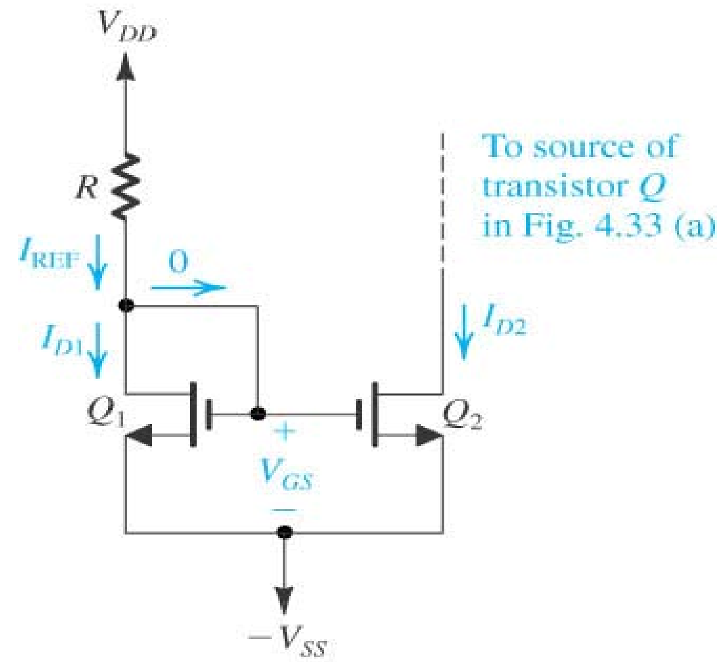
$$I = I_{REF}$$

Current Mirror DC Analysis

- Designing I_{REF}

$$I_{REF} = \frac{V_{DD} - V_{GS} + V_{SS}}{R}$$

$$I_{REF} = \tfrac{1}{2} k_n' \frac{W_1}{L_1} \left(V_{GS} - V_t\right)^2$$



(b)

- It is often needed to find the value of R in order to achieve a desired I_{REF}

Biasing of MOSFET Amplifier

- 1- Intro to MOS Field Effect Transistor (MOSFET)
- 2- NMOS FET
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- 4- DC Analysis of MOSFET Circuits
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- 6- MOSFET Small Signal Model
- <u>7- MOSFET Integrated Circuits</u>
- 8- CSA, CGA, CDA
- 9- CMOS Inverter & MOS Digital Logic

MOSFET Design Space

- Modern integrated circuits use MOSFETs extensively
  - Very high densities of transistors – up to 10^9 transistors/cm^2 in some ULSI memory arrays.
  - Off-chip discrete resistors and capacitors are ***NOT*** commonly used
  - On-chip resistors and capacitors generally ***small***
  - Multistage amplifiers are usually ***DC-coupled***
- Transistors used wherever possible to implement current sources, resistors, capacitors,

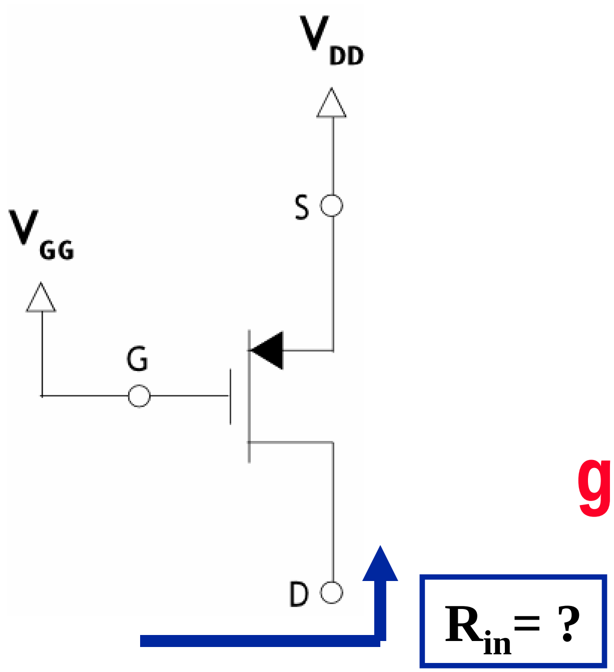
Using MOSFETs to implement R's and C's

- Resistors:
  - Active Loads (large R's)
  - Diode-connected loads (small R's)
  - MOSFET Triode-Region (moderate R's)
- Capacitors
  - Most obvious is the gate-body capacitor
  - Can be used to have variable-capacitors as well
- Current Mirrors

MOSFET Active Loads

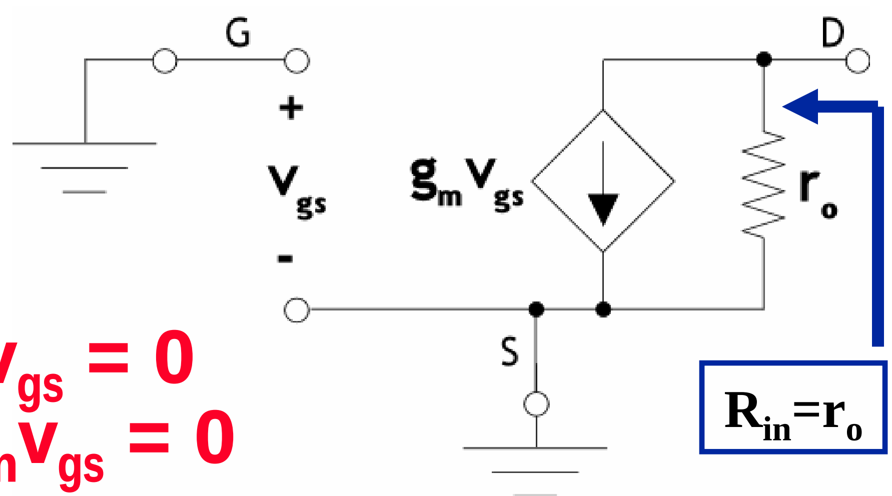
- MOSFETs used as an active load for high resistances:
  - MOSFET is held in saturation with the source and gate held at a constant DC voltage
  - Drain connected to circuit
  - r_o is inversely proportional to I_D

$$r_o = \frac{1}{\lambda \cdot I_D}$$



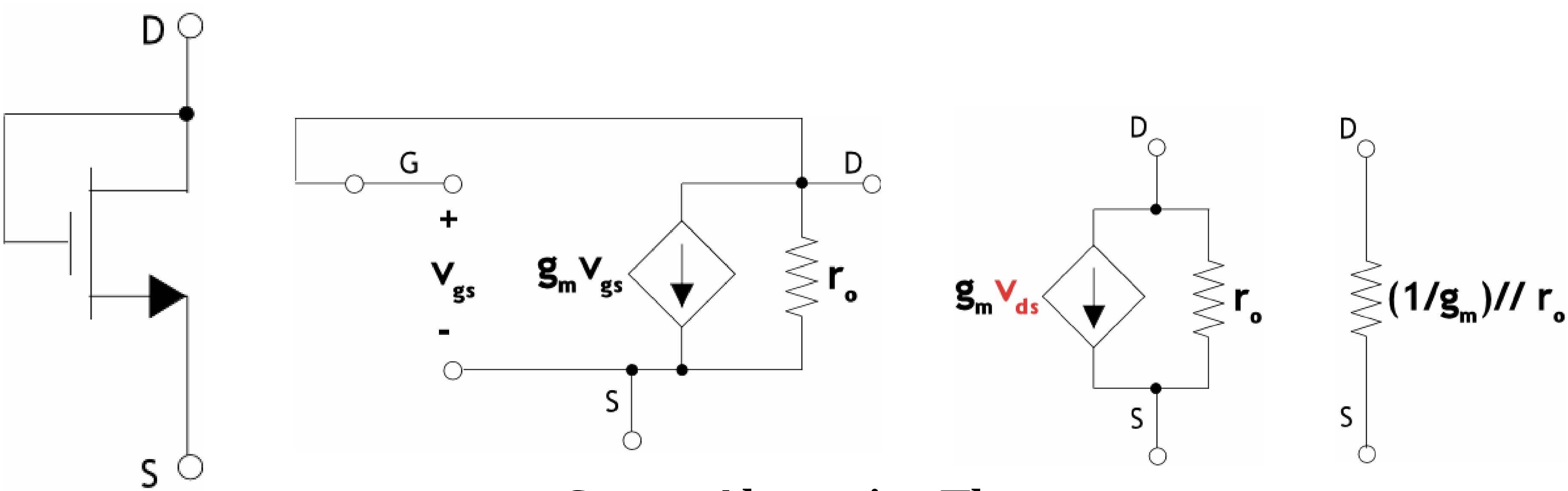
$v_{gs} = 0$

$g_m v_{gs} = 0$



Diode-Connected MOSFETs

- A Diode connected MOSFET can be used to achieve small resistances:
  - **The Drain is directly connected to Gate, and therefore it can only be operated in saturation (or cutoff)**

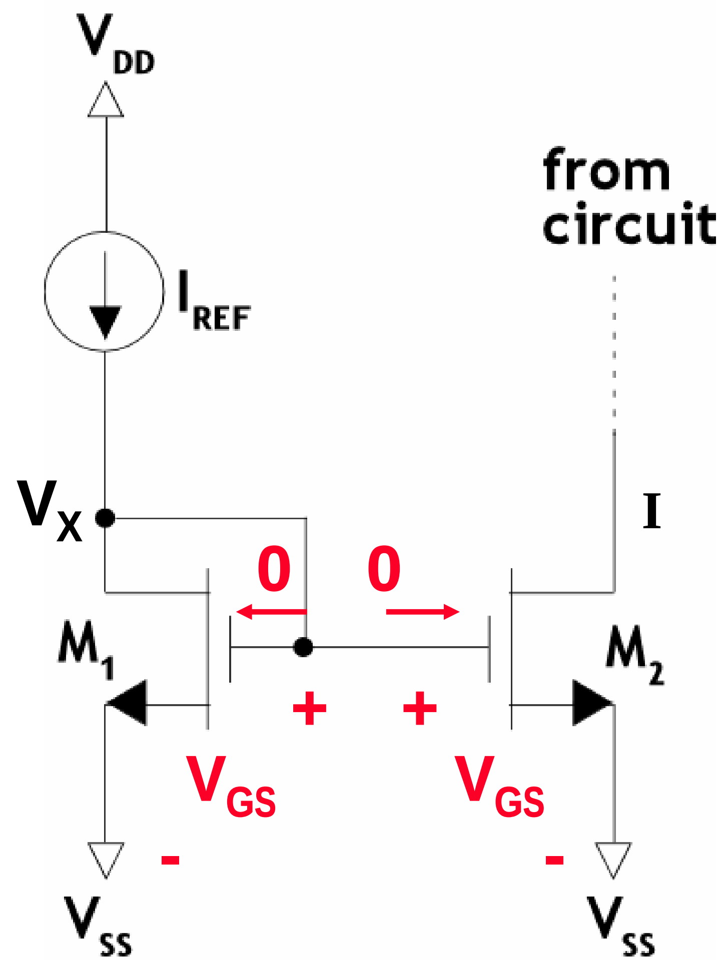


Source Absorption Theorem

MOSFET Current Mirrors

- Used extensively in MOSFET IC applications
- Often r_o,is neglected. Since there is no gate current, the drain currents of M1 and M2 are identical
- In practice, $I_{REF} \neq I$ due to finite r_o. (Not included in EC1)

$$I_{REF} = \frac{1}{2} k_n' \frac{W_1}{L_1} (V_X - V_t)^2 (1 + \lambda V_X)$$

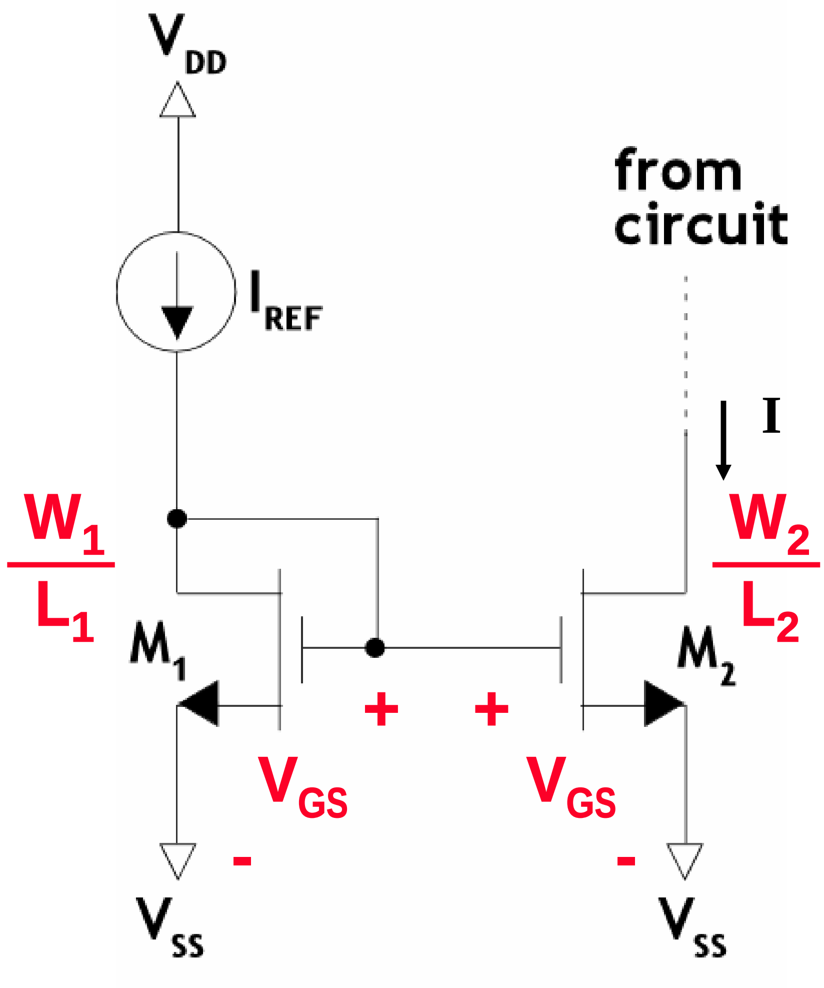


$$V_X = V_{GS1} = V_{DS1}$$

The current I will also depend on V_{DS2}

Current Mirror DC Analysis

- The width and length (the W/L aspect ratio) of MOSFETs can be designed almost freely
- Since the W/L of M_1 and M_2 need not be the same, the size ratios can affect current ratios

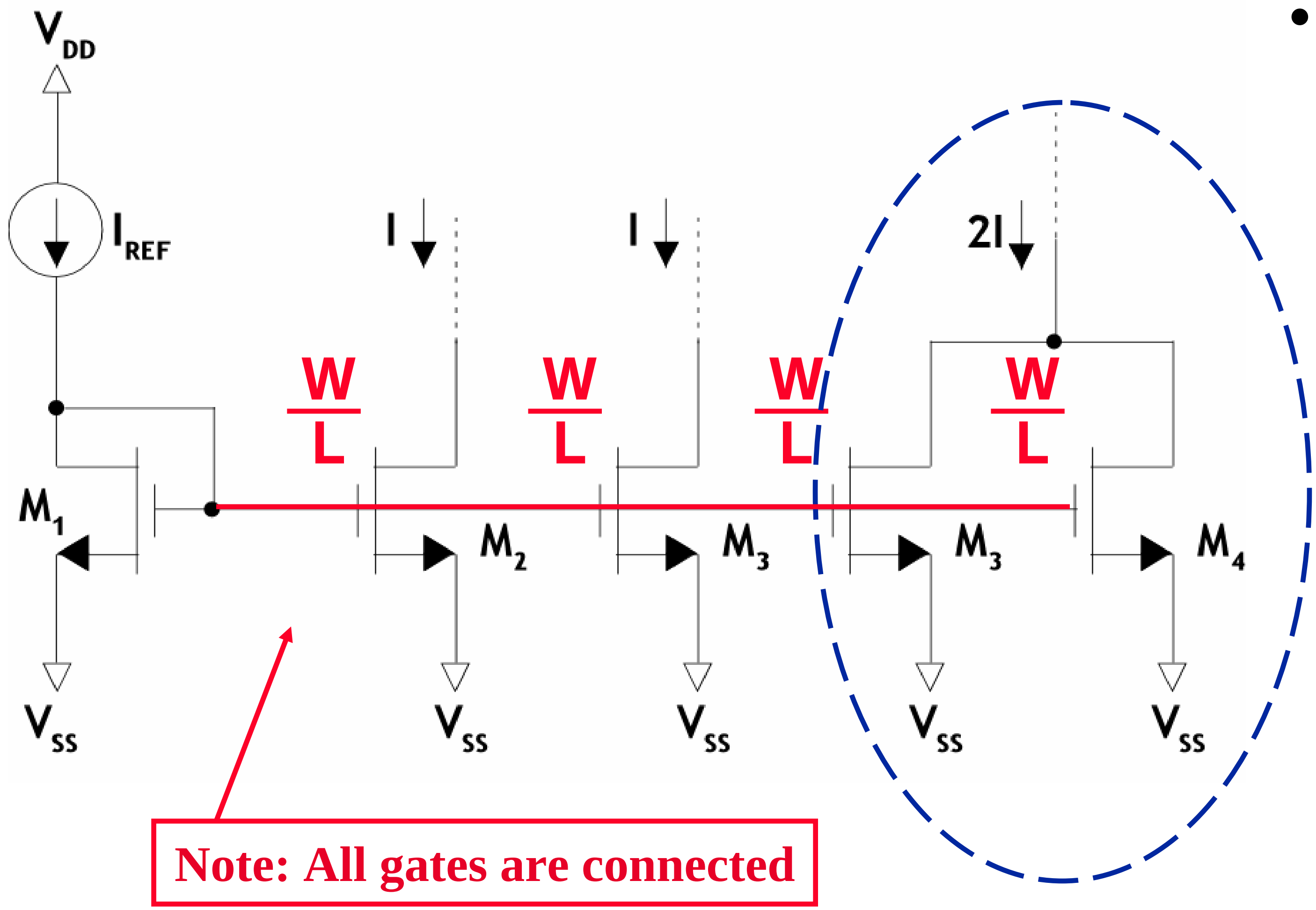


$$I_{REF} = \tfrac{1}{2} k_n' \frac{W_1}{L_1} (V_{GS} - V_t)^2$$

$$I = \tfrac{1}{2} k_n' \frac{W_2}{L_2} (V_{GS} - V_t)^2$$

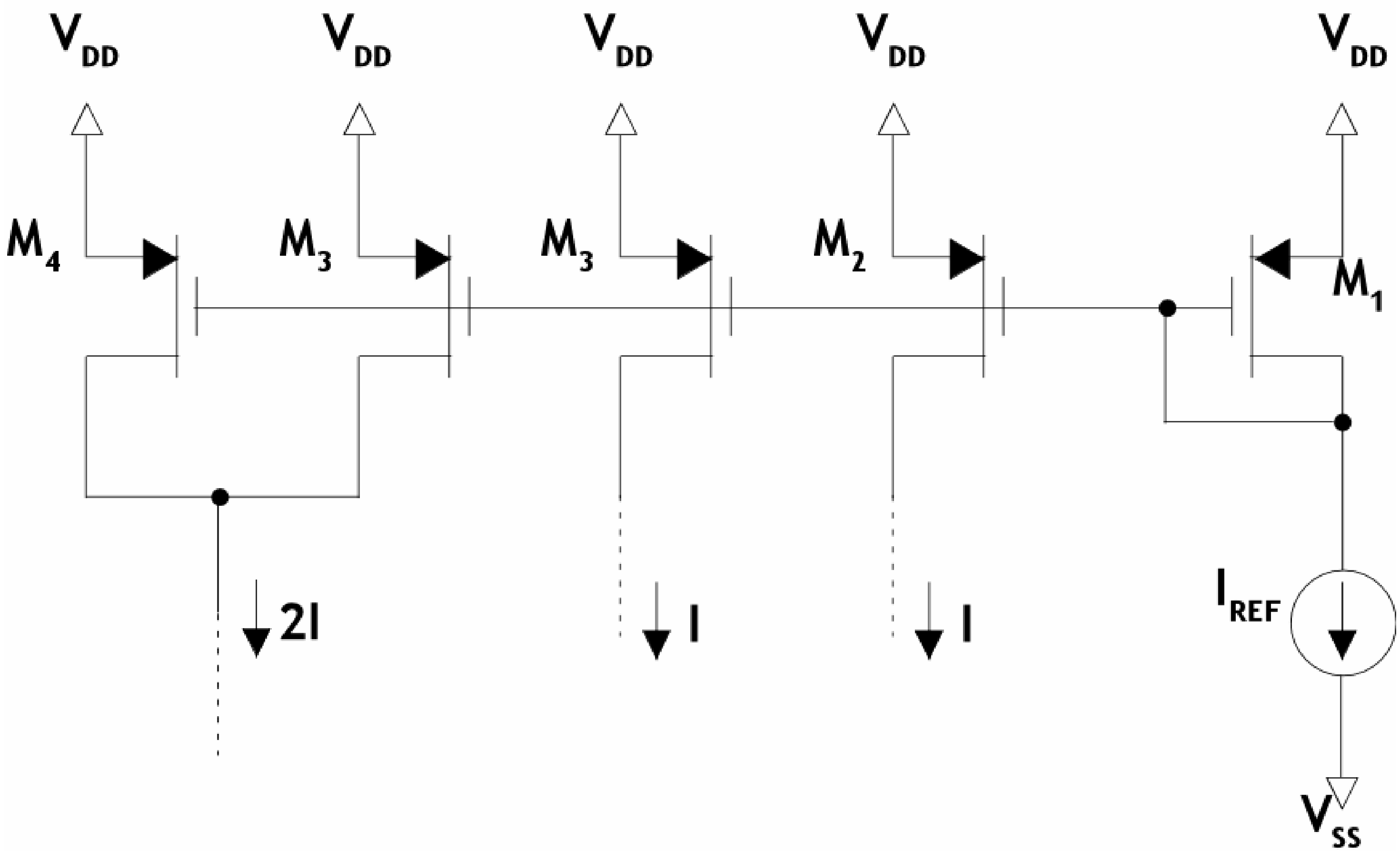
$$\boxed{\frac{I}{I_{REF}} = \frac{W_2}{L_2} \cdot \frac{L_1}{W_1}}$$

Current Scaling (Steering)

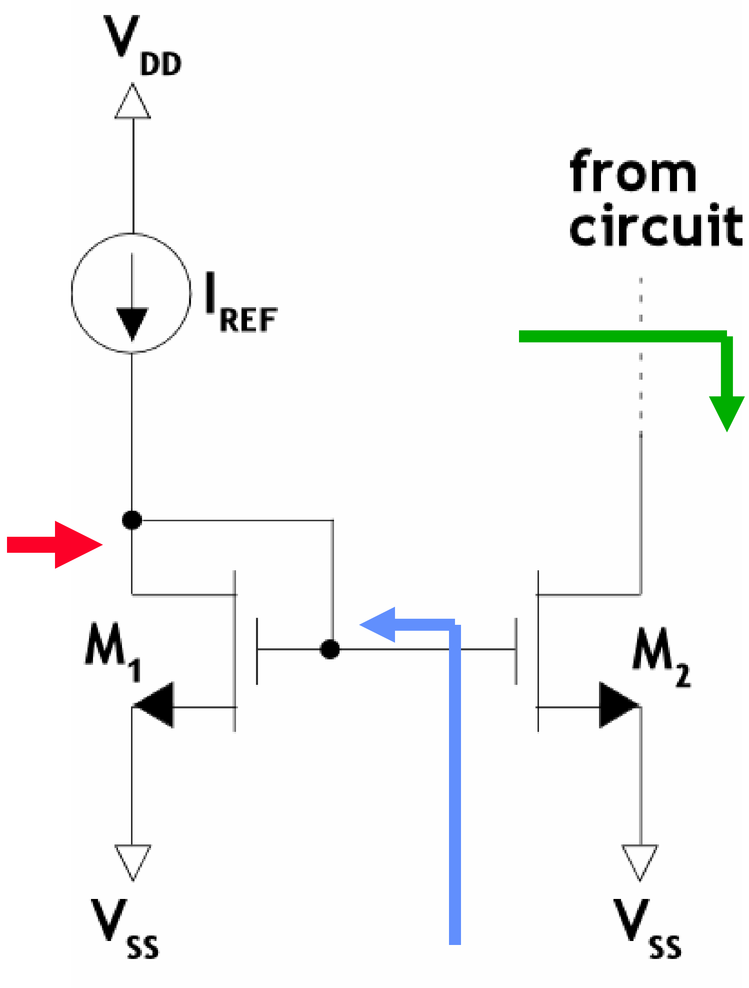


- Ratio of aspect ratios can be selected to achieve nearly any scale factor I/I_{REF}

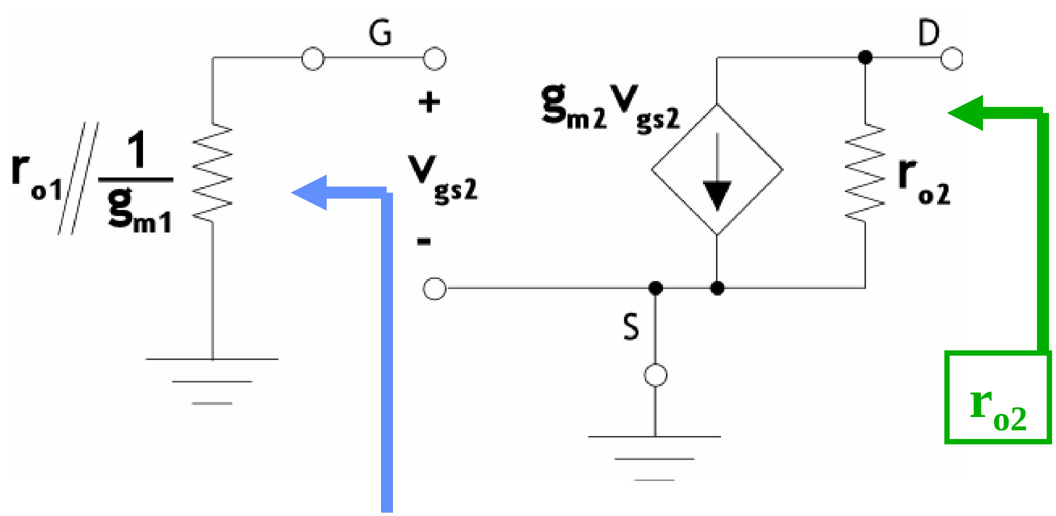
Current Mirroring – Pushing and Pulling



Small Signal



- Transistor M1 is diode connected and acts like a resistor to s.-s. ground.



Outline of Chapter 5

- 1- Intro to MOS Field Effect Transistor (MOSFET)
- 2- NMOS FET
- 3- PMOS FET
- 4- DC Analysis of MOSFET Circuits
- 5- MOSFET Amplifier
- 6- MOSFET Small Signal Model
- 7- MOSFET Integrated Circuits
- <u>8- CSA, CGA, CDA</u>
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DC and AC - Body-Effect / CLM

Three types of analysis:

- Neglect DC Body-Effect & DC CLM
- Use DC Body-Effect / Neglect DC CLM
- Use DC Body-Effect / Use DC CLM

DC Analysis

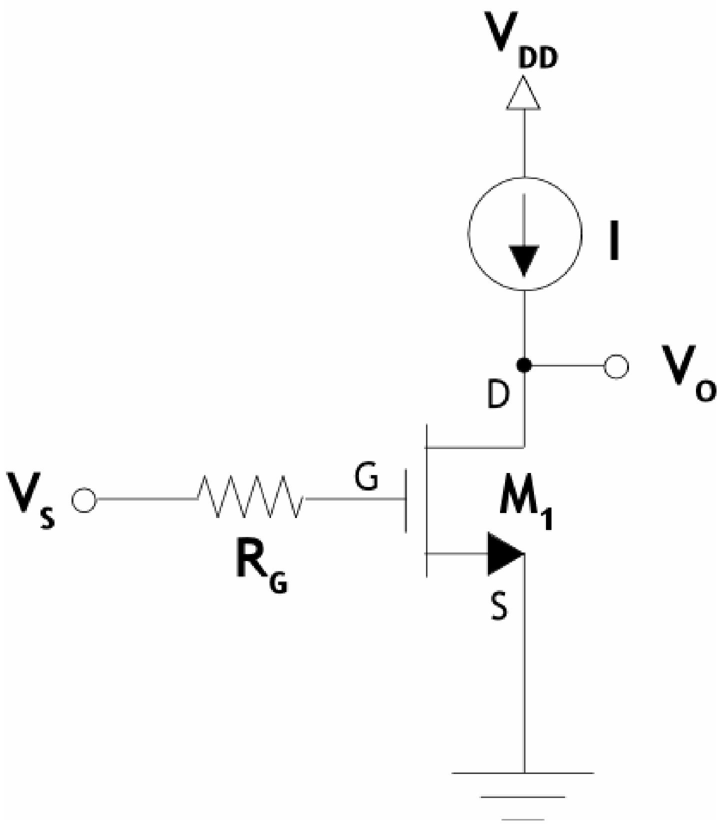
Use whatever DC values for V and I in the small-signal analysis

Three types of analysis:

- Neglect AC Body-Effect & AC CLM
- Use AC Body-Effect / Neglect AC CLM
- Use AC Body-Effect / Use CLM

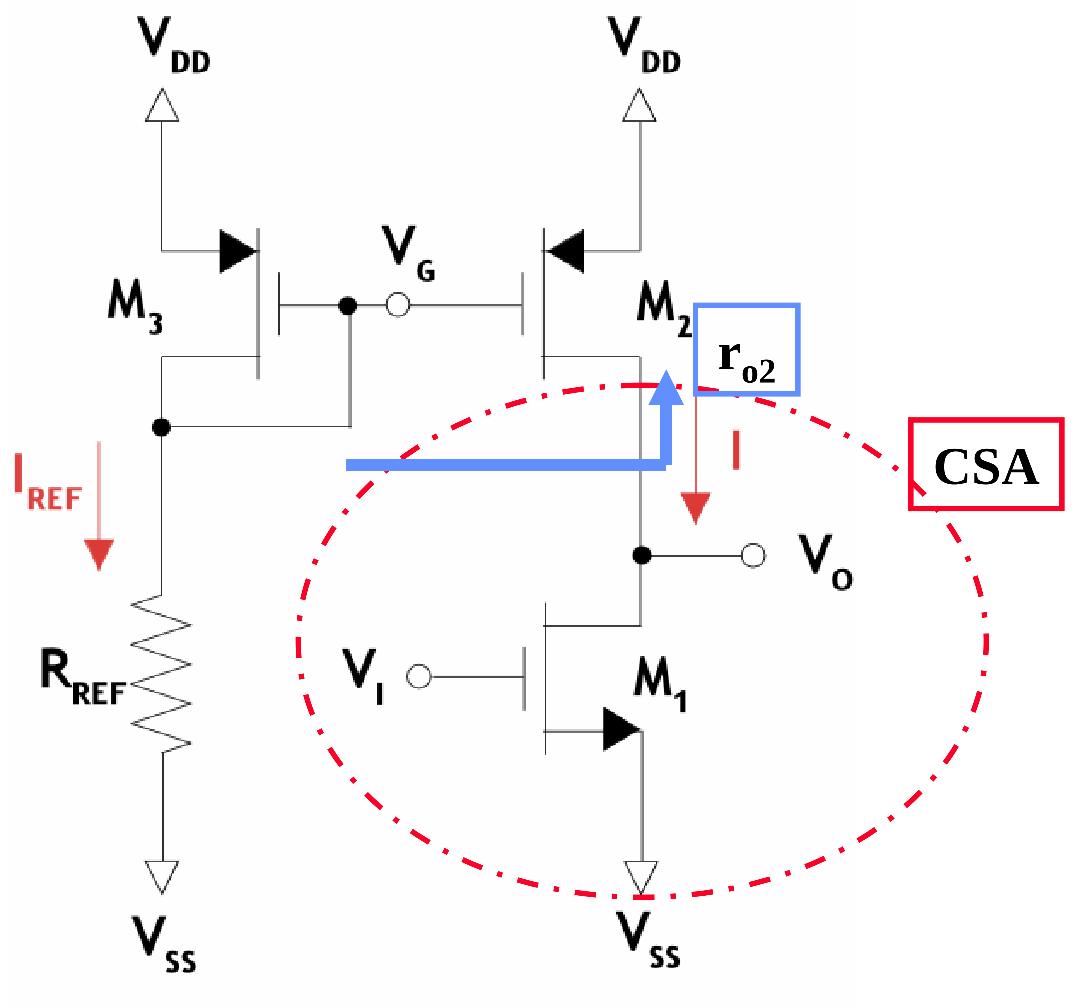
AC Analysis (small-signal)

Common Source Amplifier (CSA)

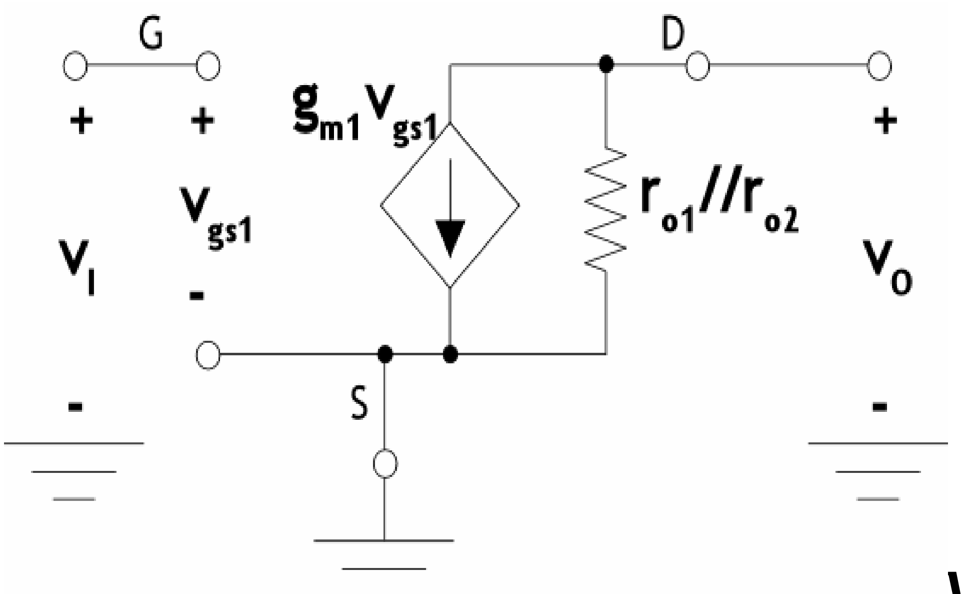


- Current source I implemented with current mirror.
- Current mirror provides active load at drain
- Source terminal grounded – no DC or AC Body effect

CSA with Current Mirror



CSA Small Signal Analysis



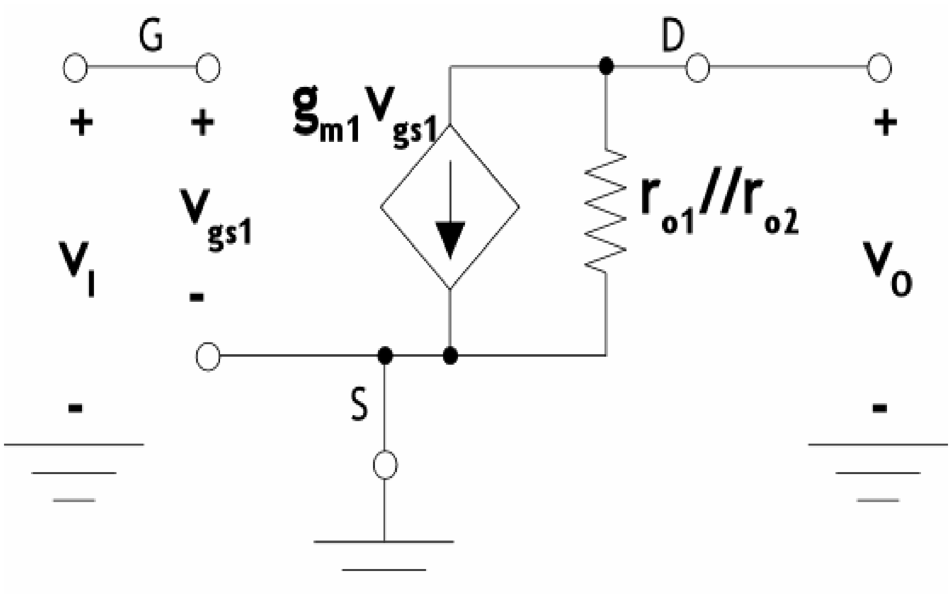
- From MOSFET Current-Mirror: only r_{o2} appears in analysis

$$v_{gs1} = v_i$$

$$v_{out} = -g_{m1}\left(r_{o1} \| r_{o2}\right) v_{gs1}$$

$$A_V = \frac{v_{out}}{v_i} = -g_{m1}\left(r_{o1} \| r_{o2}\right)$$

CSA Input/Output Resistance



- Input Resistance

$$R_{IN} \Rightarrow \infty$$

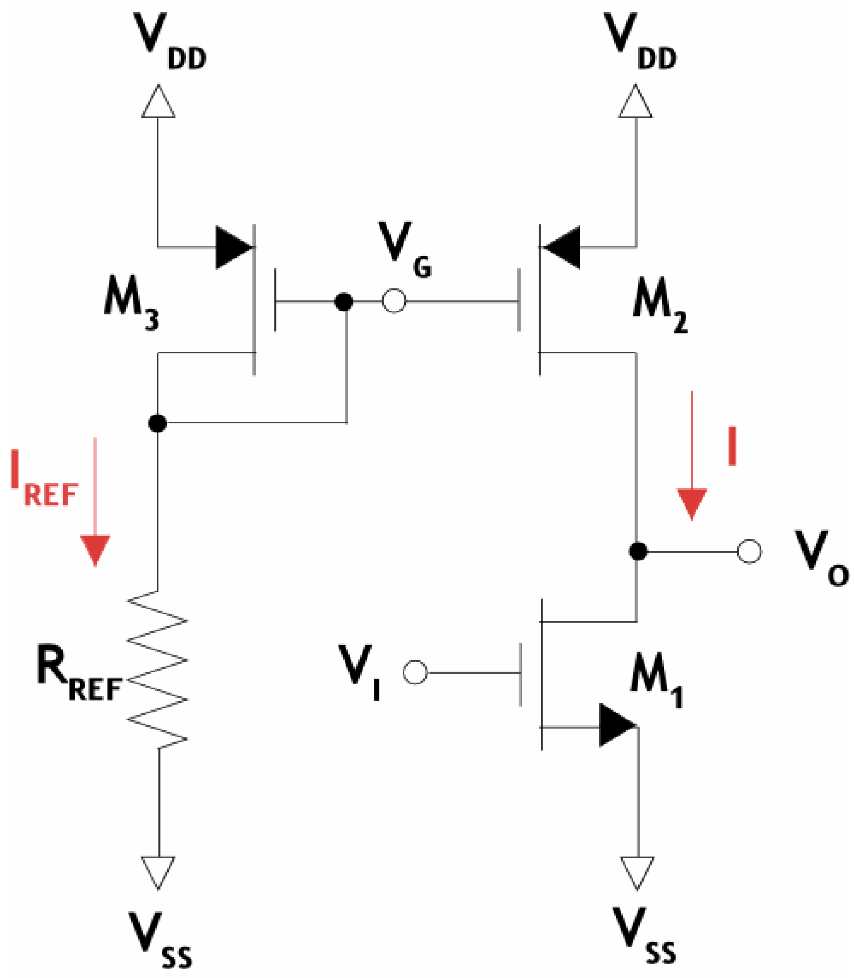
- Output resistance

$$v_{gs1} = 0$$

$$g_{m1}v_{gs1} = 0$$

$$R_{OUT} = r_{o1} \| r_{o2}$$

CSA Calculations



In practice, difficult to keep all transistors operating in saturation

V_{OUT} is hard to control, and sensitive to: W/L, V_G, and CLM

$\lambda_1 = |\lambda_2| = 0.01V^{-1}$

$V_{t1} = |V_{t2}| = 1V$

$k_p' = 50\mu A/V$

$k_n' = 125\mu A/V$

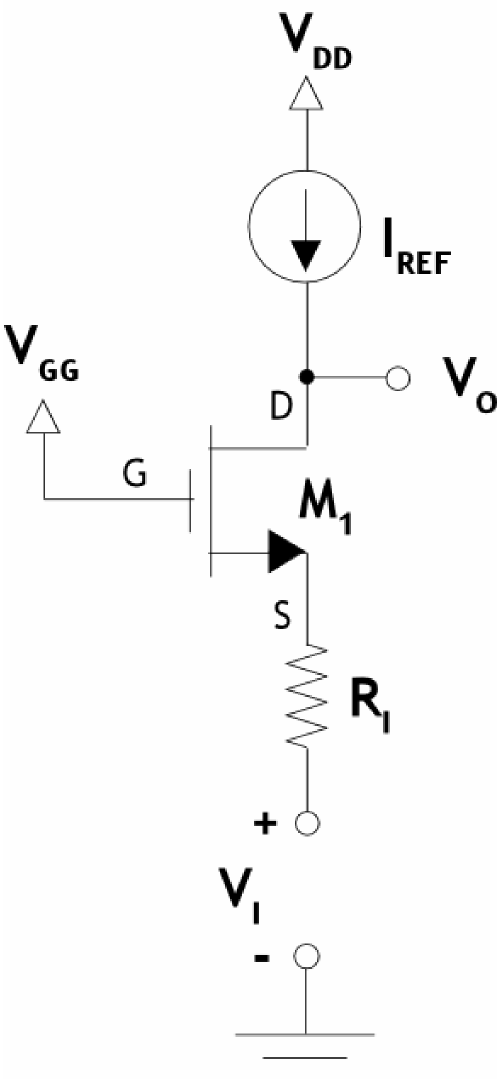
$\frac{W_2}{L_2} = 50, \frac{W_1}{L_1} = 40$

$V_{DD} = 5V, V_{SS} = -2V$

$R_{REF} = 1k\Omega$

Hand:	SPICE:
$V_G = 2.567V$	$V_G = 2.58V$
$I = 2.596mA$	$I = 2.57mA$
$V_{OUT} = 3.855V$	$V_{OUT} = 2.895V$
$g_{m1} = 5.192m A/V$	$A_V = -102.4 V/V$
$r_o = 38.52k\Omega$	
$A_V = -100 V/V$	

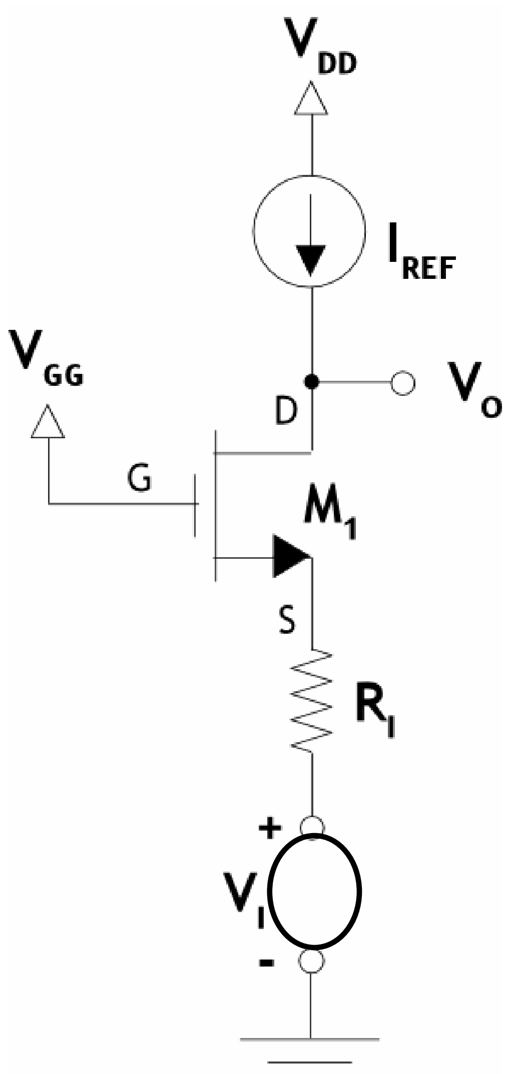
Common Gate Amplifier (CGA)



- A pMOS current mirror is used as I_{REF} including the output resistance.
- The gate terminal held at a DC voltage. (AC Ground)
- Since source terminal not at signal ground, the body effect is present.

Typically used as second stage of a multi-stage amplifier circuit

CGA – DC Analysis

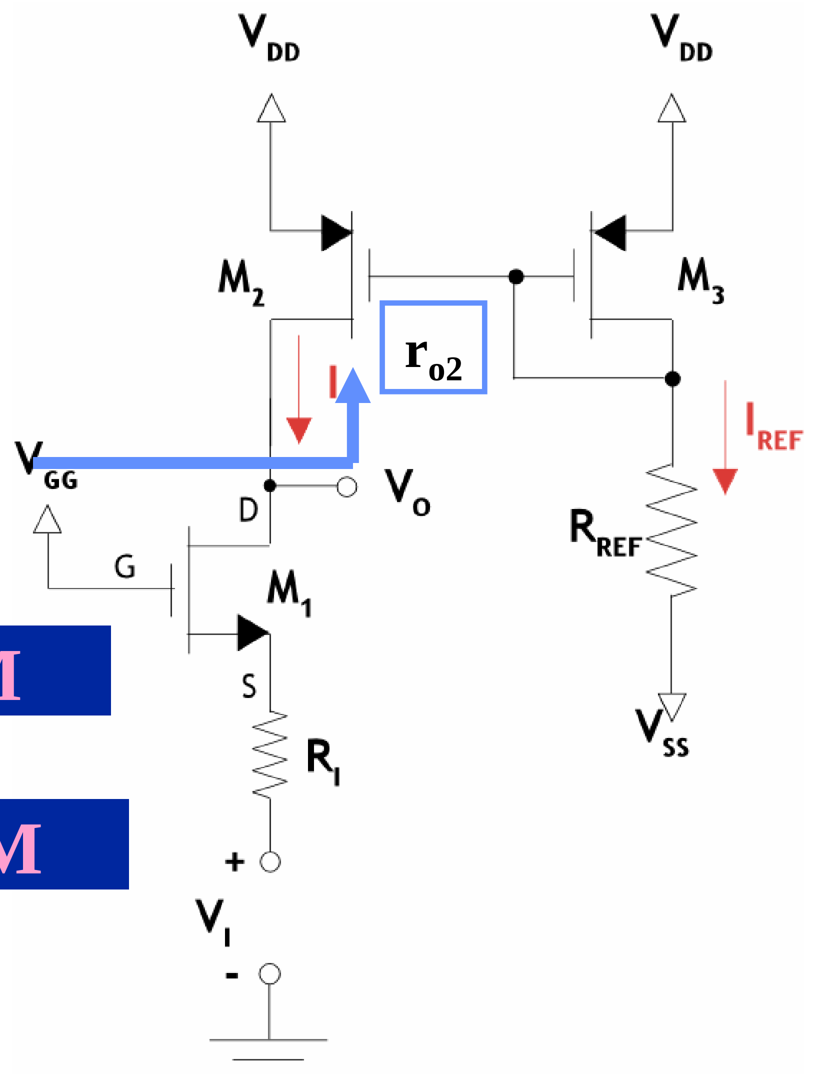


- Current mirror is assumed to be ideal during the DC analysis, thus $I_{REF}=I$
- DC voltage at the source terminal (V_S) must be obtained from driving the current I_{REF} through the transistor.
- This assumes that the input voltage source V_I is set to zero
- R_I is part of the source voltage
- Solve for V_O, with V_S and V_G known, and including CLM

$$I = \tfrac{1}{2} k_n' \frac{W}{L} \left(V_G - V_S - V_t\right)^2 \left[1 + \lambda \cdot \left(V_O - V_S\right)\right]$$

CGA

- Replace with a current source including output resistance r_{o2}



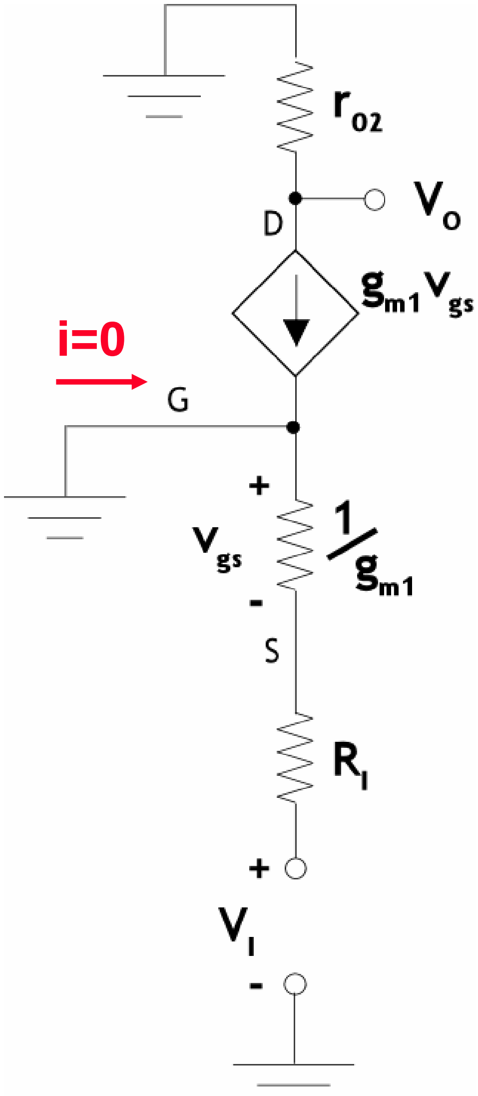
Choice of analysis:

Neglect AC Body-Effect & CLM

Use AC Body-Effect / Neglect CLM

Use AC Body-Effect / Use CLM

CGA – No Body Effect or CLM



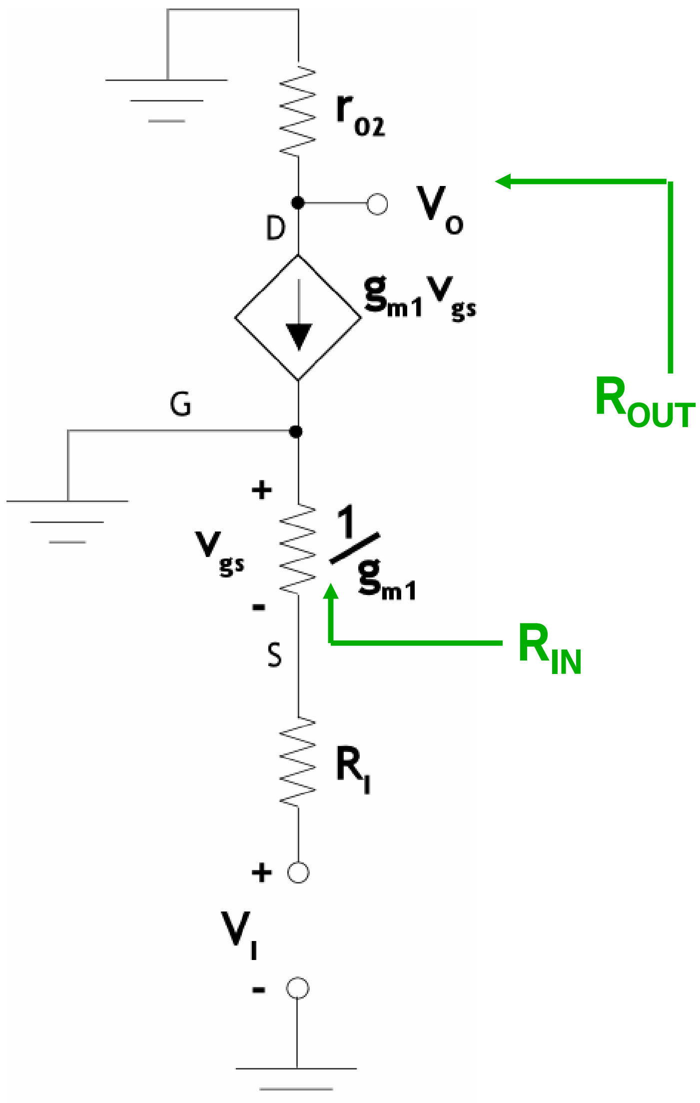
$$v_o = -g_m v_{gs} \cdot r_{o2}$$

$$v_{gs} = -\frac{\frac{1}{g_{m1}}}{\frac{1}{g_{m1}} + R_I} v_I$$

Non Inverting

$$A_V = \frac{v_o}{v_I} = \frac{r_{o2}}{\frac{1}{g_m} + R_I}$$

CGA – R_{IN} & R_{OUT}, No Body Effect or CLM

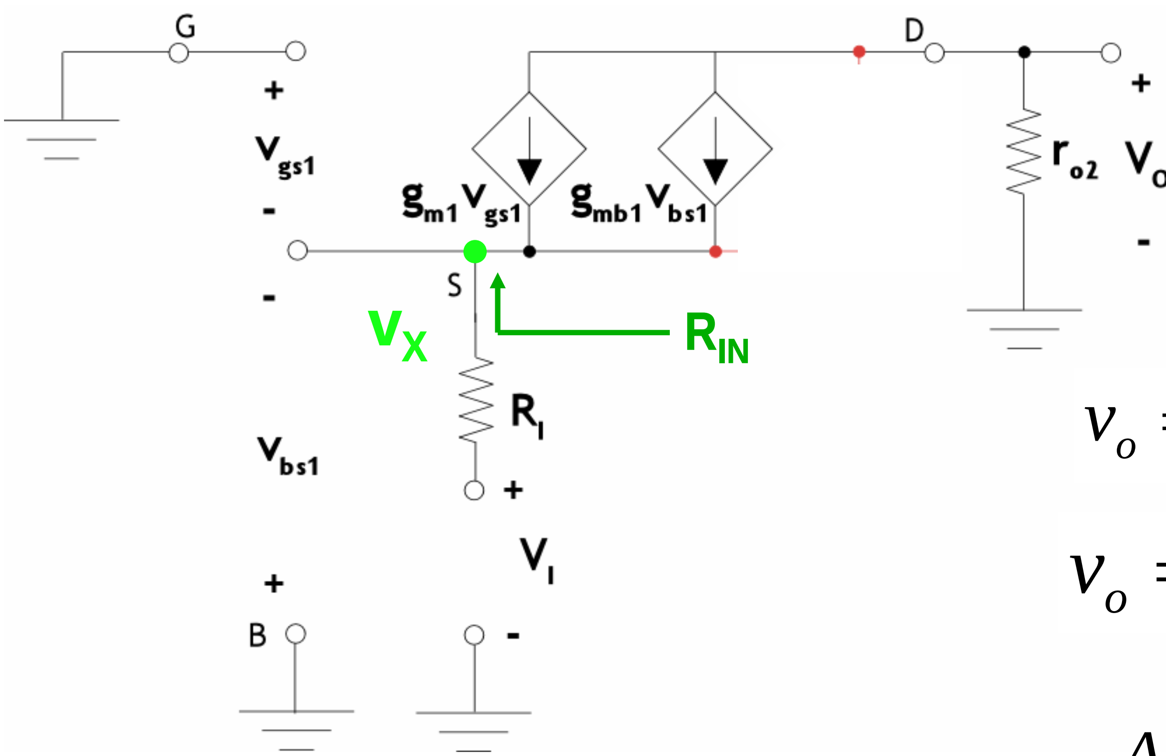


$$R_{IN} = \frac{1}{g_{m1}}$$

$$v_I = 0$$

$$R_{OUT} = r_{o2}$$

CGA – With Body Effect & no CLM



Solve at v_x first:

$$v_{bs1} = v_{gs1} = -v_x$$

$$v_o = -(g_{m1}v_{gs1} + g_{mb1}v_{bs1})r_{o2}$$

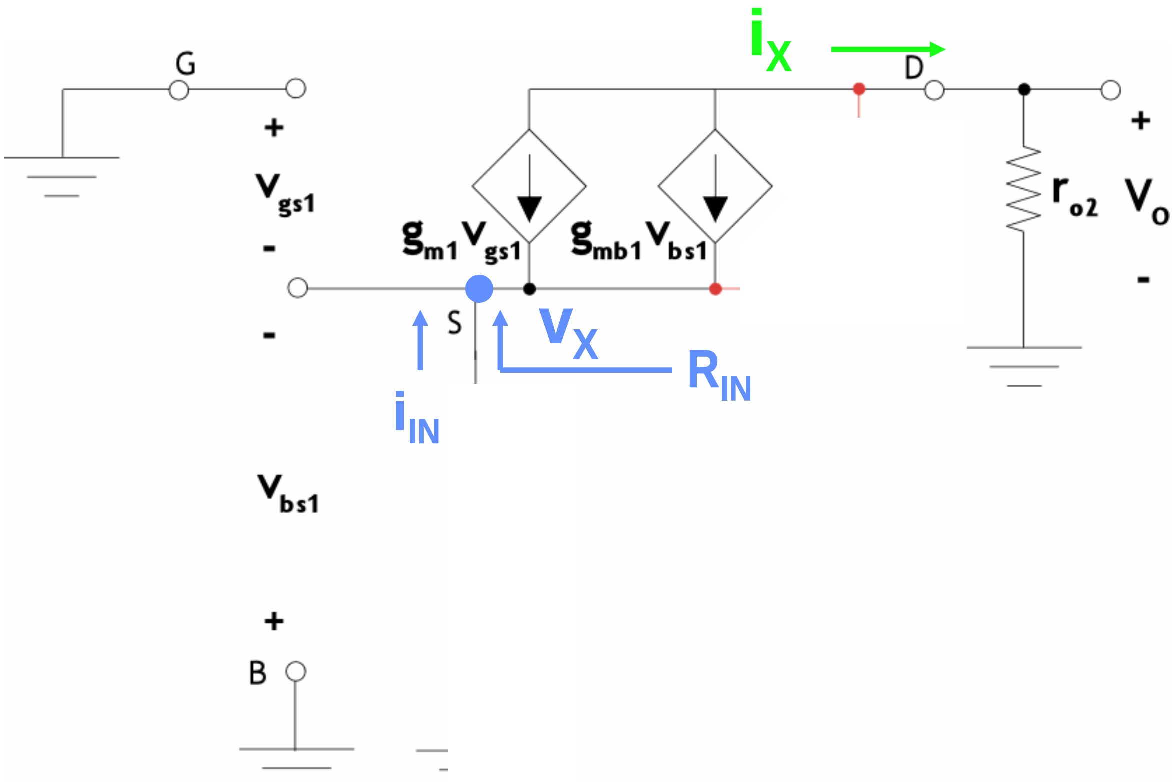
$$v_o = -(g_{m1}v_x + g_{mb1}v_x)r_{o2}$$

$$A_V = \frac{v_o}{v_x} = (g_{m1} + g_{mb1})r_{o2}$$

Include R_I and solve for total voltage gain in term of R_{IN}

$$A_{V-total} = \frac{v_o}{v_i} = \frac{v_o}{v_x}\cdot\frac{v_x}{v_i} = (g_m + g_{mb})r_{o2}\cdot\frac{R_{IN}}{R_{IN}+R_I}$$

CGA – R_{IN} With Body Effect & no CLM



$$v_{bs1} = v_{gs1} = -v_x$$

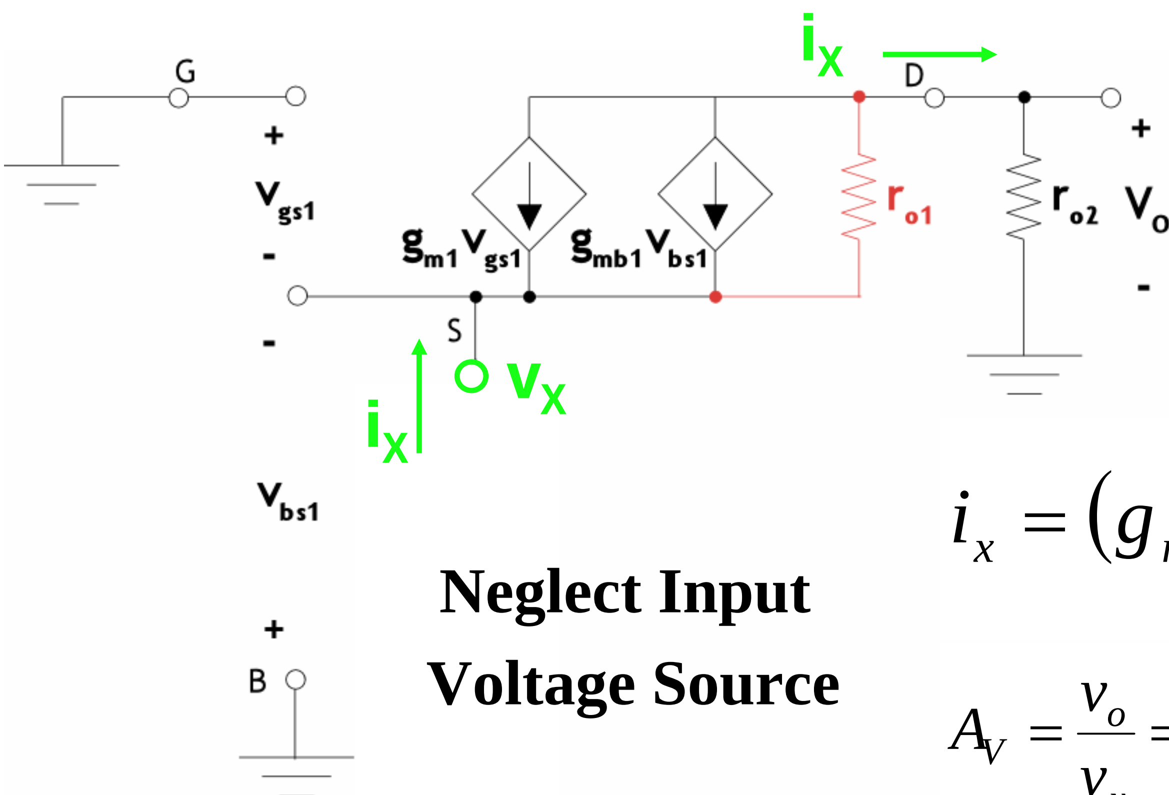
$$i_x = (g_{m1} + g_{mb1})v_x$$

$$i_{in} = (g_{m1} + g_{mb1})v_x$$

Neglect Input Voltage Source

$$R_{IN} = \frac{1}{g_{m1} + g_{mb1}}$$

CGA - With Body Effect & CLM



$$v_x = -v_{gs}$$

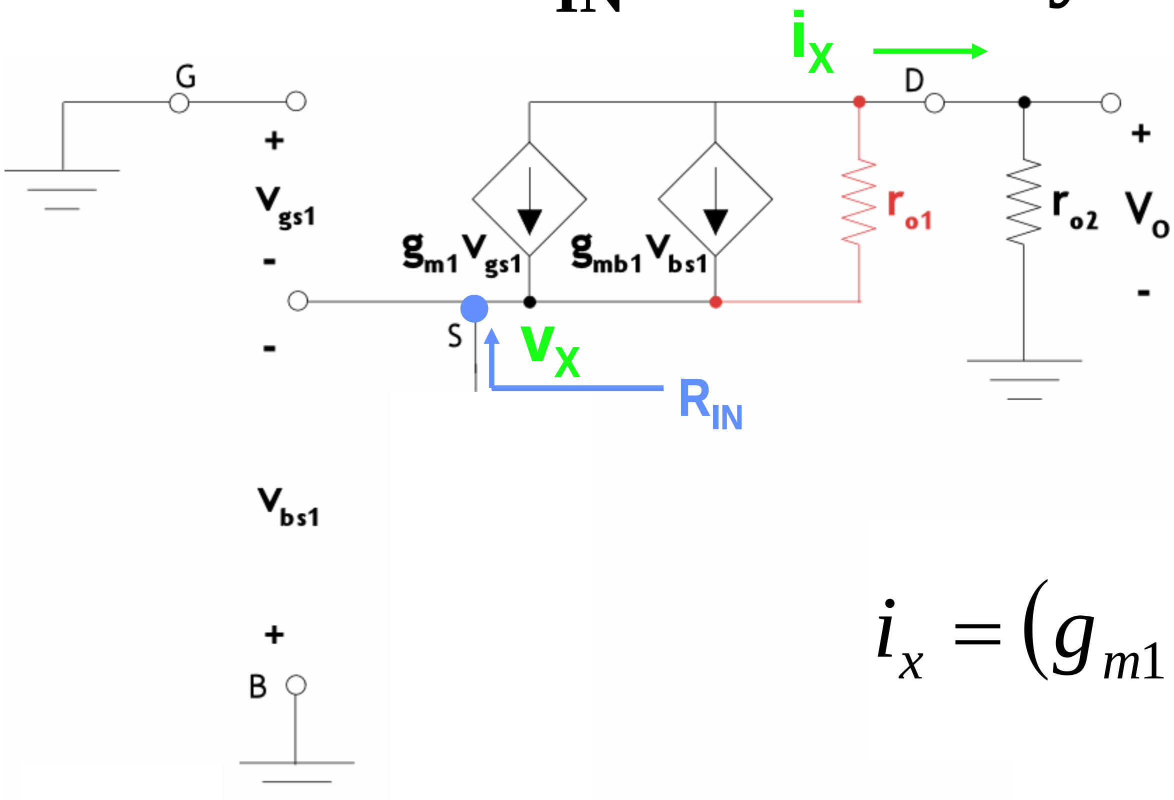
$$v_o = i_x \cdot r_{o2}$$

$$i_x = (g_{m1} + g_{mb1})v_x + \frac{v_x - v_o}{r_{o1}}$$

Neglect Input Voltage Source

$$A_V = \frac{v_o}{v_x} = (r_{o1} \| r_{o2}) \cdot \left(\frac{1}{r_{o1}} + g_{m1} + g_{mb1} \right)$$

CGA – R_{IN} With Body Effect & CLM



$$v_o = i_x \cdot r_{o2}$$

$$i_x = (g_{m1} + g_{mb1})v_x + \frac{v_x - v_o}{r_{o1}}$$

Neglect Input Voltage Source

$$R_{IN} = \frac{v_x}{i_x} = \frac{1 + \frac{r_{o2}}{r_{o1}}}{\frac{1}{r_{o1}} + g_{m1} + g_{mb1}}$$