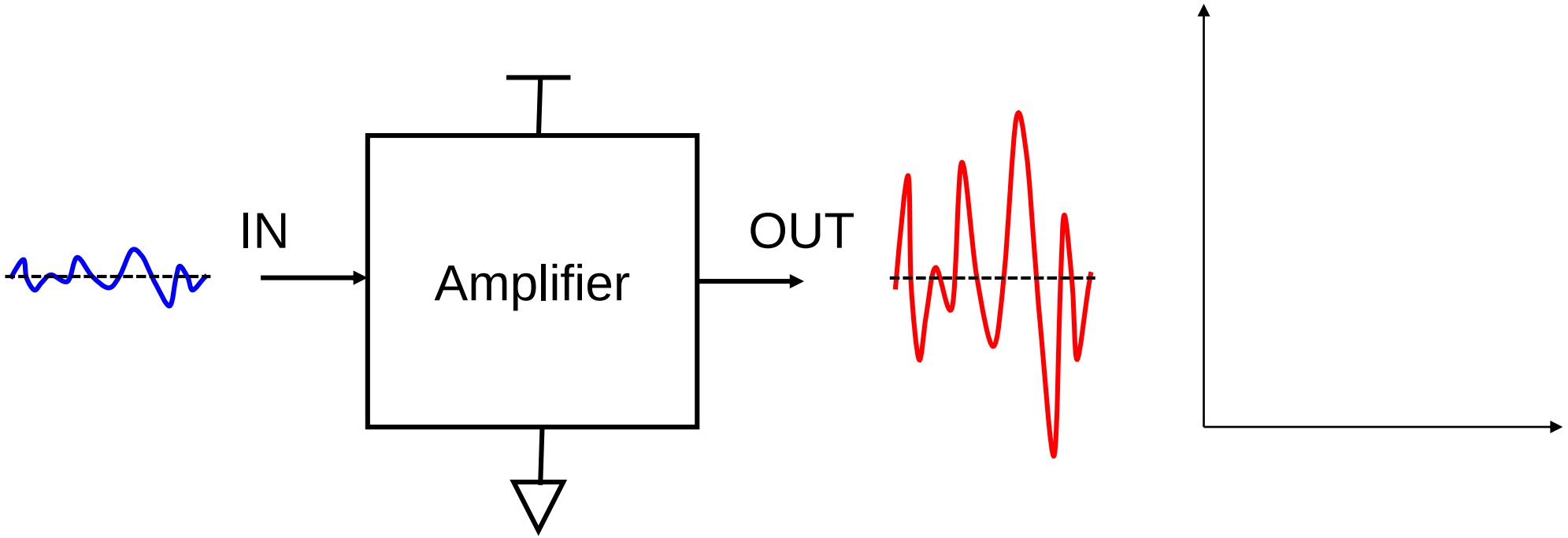
Common Source Amplifier

Hanwool Jeong

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Amplifier?

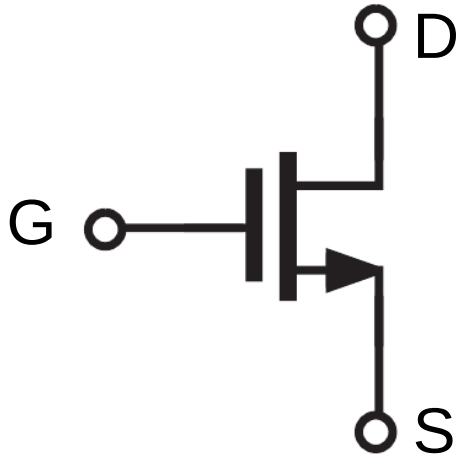
- A device that generates output signal that is proportional to the input signal in a “constant” ratio. Gain is defined as $\Delta V_{out}/\Delta V_{in}$
- We will focus on “voltage” signal first and note that “voltage change” is amplified.

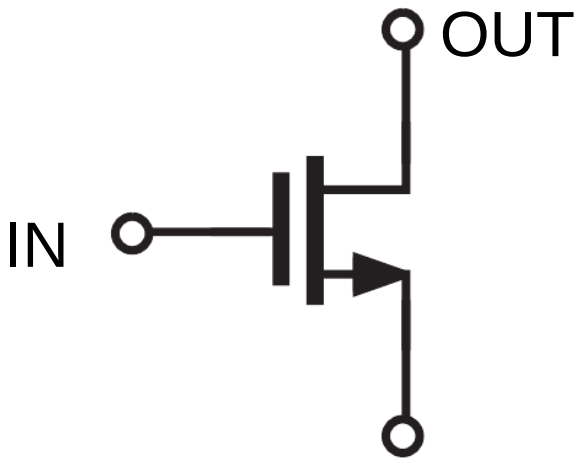


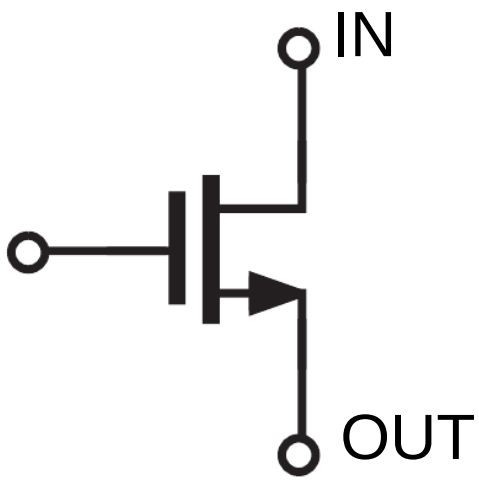
Utilizing a Single MOSFET as an Amplifier

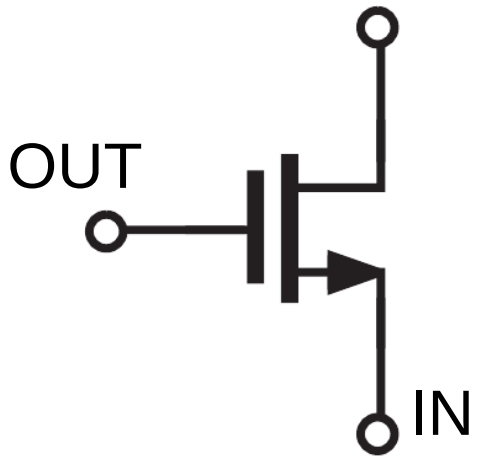
- There are three nodes, which nodes should be allocated as “input” and “output”?
- Consider the two following things:
  1) V_{GS} or V_{DS} can change I_{DS} in MOSFET
  2) In the saturation region, I_{DS} is less sensitive to V_{DS}.

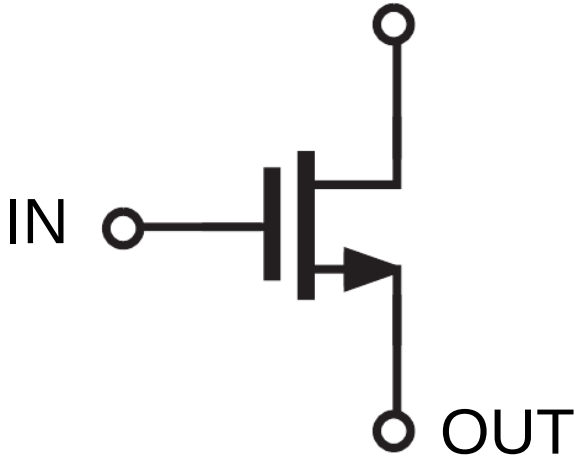
  ➔ Input should be reflected to V_{GS} while output is related to I_{DS}

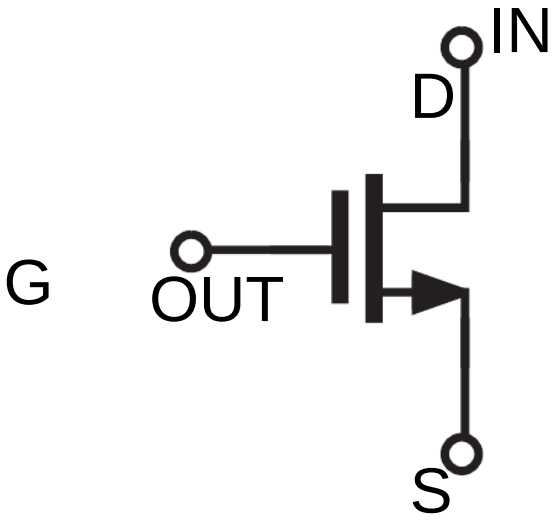


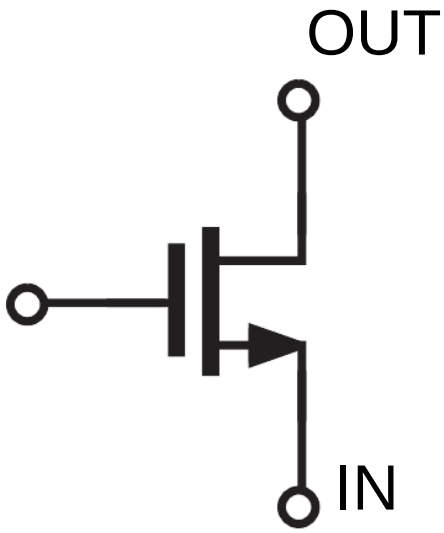

OUT
IN


IN
OUT


OUT
IN

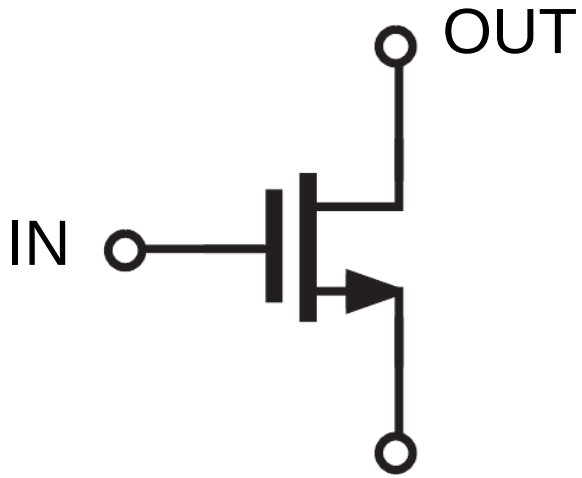

IN
OUT


G
IN
D
OUT
S

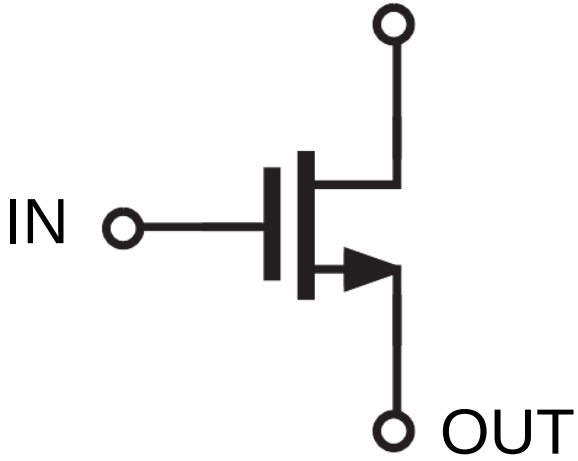

OUT
IN

Three Survivors

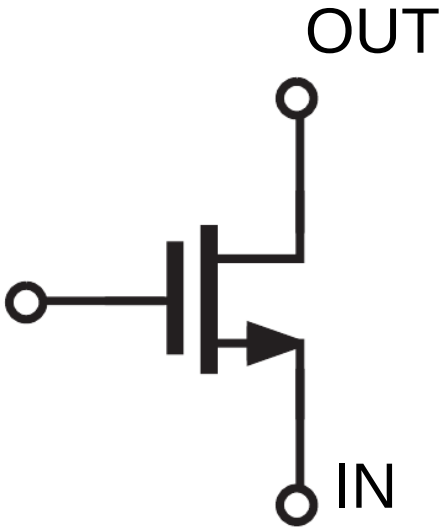
- What will we do the remaining third node?
  ➔ It can offer “reference” both to input & output **commonly**



Common Source



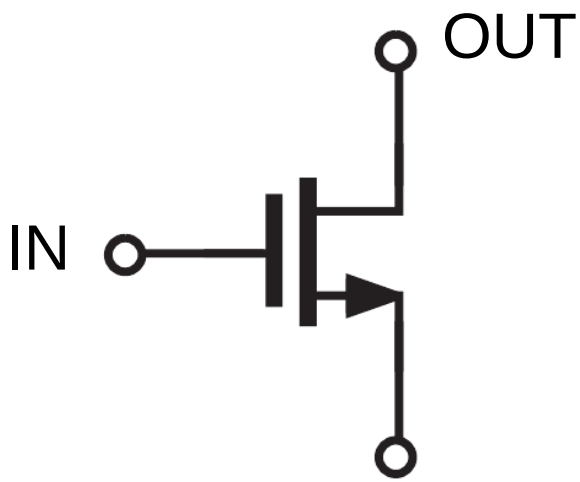
Common Drain



Common Gate

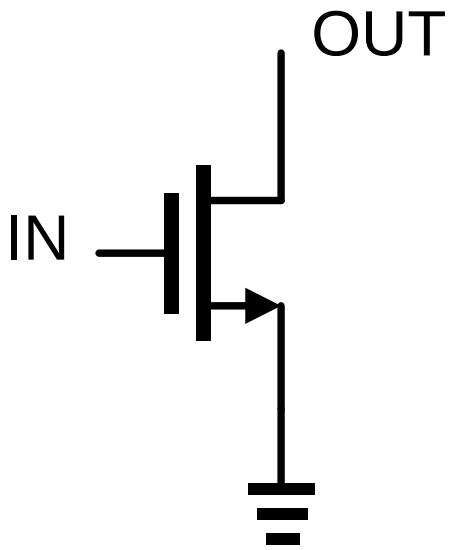
Common Source (CS) Amplifier

- How should it work? Roughly,
  V_{in} changes ➔ V_{GS} of MOSFET changes ➔ I_{DS} changes ➔ ??
- We should think of the there following things:
  1) Better to fix source voltage, so that ΔV_{in} is reflected into ΔV_{GS}.
  2) We need something that can converts I_{DS} into voltage, V_{out}.
  3) Is there any constraint for operation region of MOSFET?



Grounding Source

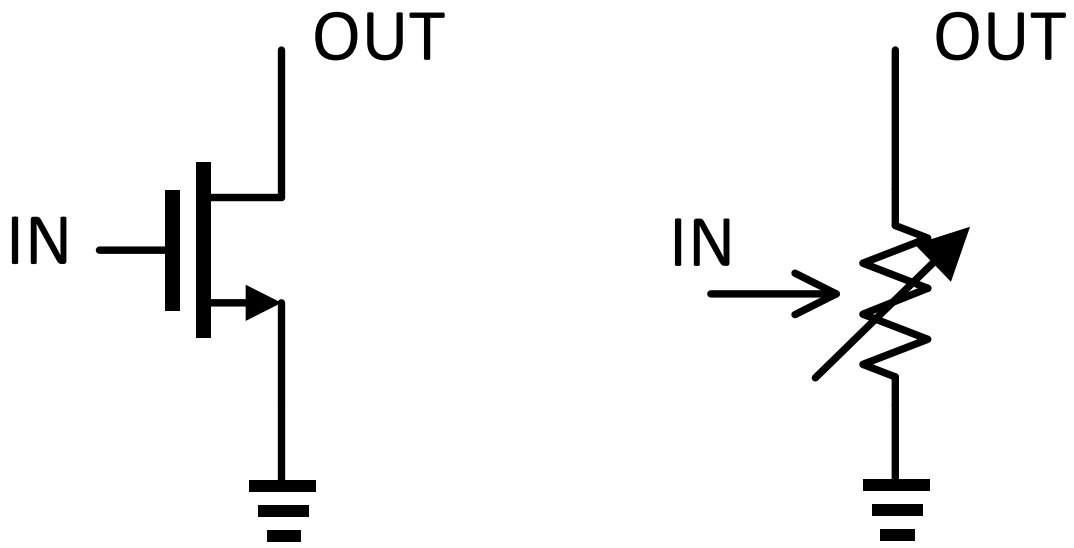
- There may be other many ways but simply,



- Now, ΔV_{in} is reflected into ΔV_{GS}, that results in ΔI_{DS}
- Next it is time to converts ΔI_{DS} into ΔV_{out}. How?

Remember that MOSFET is a Variable Resistor

- How do we design a circuit so that variable resistance effect can be observed at OUT in terms of V_{out}?

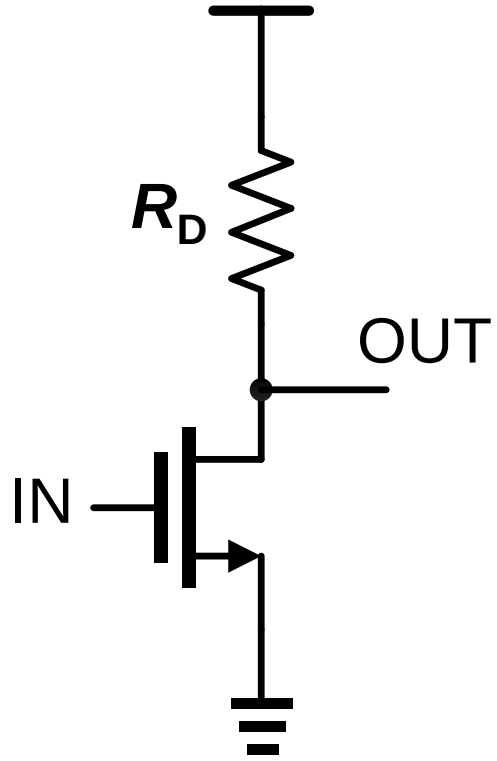


Adding a Resistor

- Now we can realize

$$\Delta V_{in} \rightarrow \Delta V_{GS} \rightarrow \Delta I_{DS} \rightarrow \Delta V_{out}$$

- R_D can be realized in many ways.

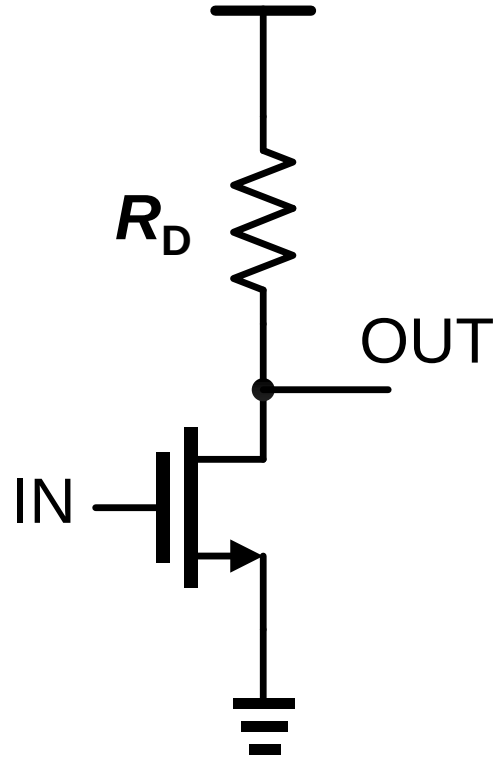


Gain Determination in CS Amplifier

- Procedure is $\Delta V_{in} = \Delta V_{GS} \rightarrow \Delta I_{DS} \rightarrow \Delta V_{out}$
- Gain = $\Delta V_{out}/\Delta V_{in}$ can be determined step by step

$$\frac{\Delta V_{out}}{\Delta V_{in}} = \frac{\Delta I_{DS}}{\Delta V_{GS}} \times \frac{\Delta V_{out}}{\Delta I_{DS}} = -g_m \times R_D$$

Transconductance, g_m, of MOSFET



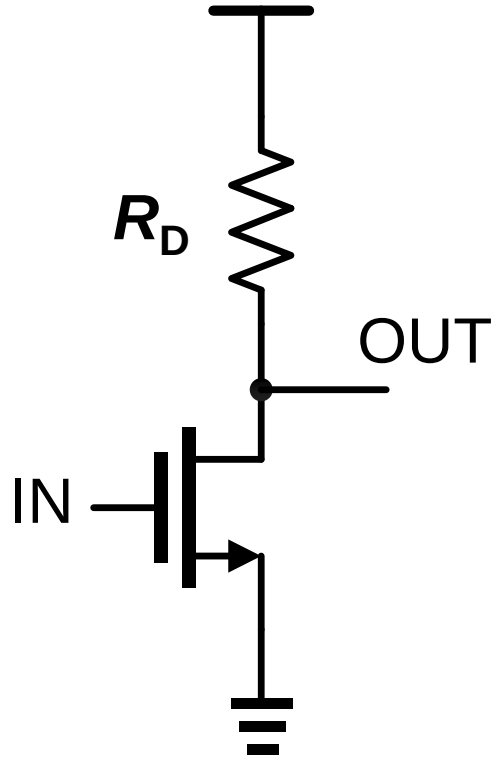
- Transconductance is determined by the following model that relates ΔV_{GS} to ΔI_{DS}.

$$I_D = \begin{cases} 0 & \textbf{Cut-off} \\ \frac{1}{2}\mu_n C_{ox}\frac{W}{L}[2(V_{GS}-V_{TH})V_{DS}-V_{DS}^2] & \textbf{Triode} \\ \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})^2(1+\lambda V_{DS}) & \textbf{Saturation} \end{cases}$$

Triode or Saturation? Or Both?

- Which region is desirable for MOSFET to operate as CS amplifier?

$$I_D = \begin{cases} 0 & \textbf{Cut-off} \\ \frac{1}{2}\mu_n C_{ox}\frac{W}{L}[2(V_{GS}-V_{TH})V_{DS}-V_{DS}^2] & \textbf{Triode} \\ \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})^2(1+\lambda V_{DS}) & \textbf{Saturation} \end{cases}$$



- Consider $\Delta V_{in} = \Delta V_{GS}$ ➔ ΔI_{DS} ➔ ΔV_{out}.
- It is desirable to make I_{DS} only dependent to ΔV_{in} and V_{DS} effect on I_{DS} should be minimized.
  ➔ MOSFET should be in the **saturation region**.

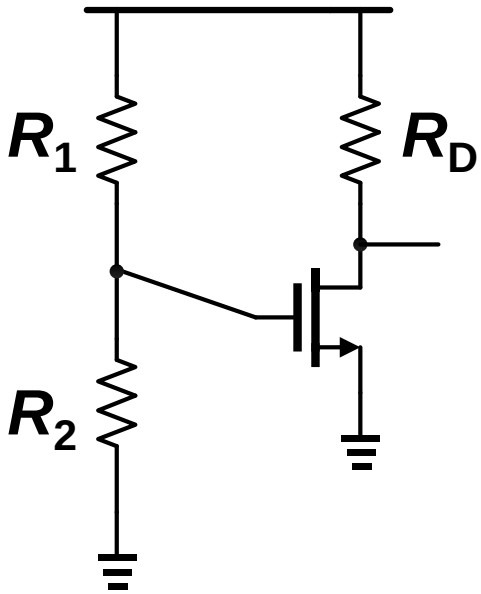
Aim of Biasing

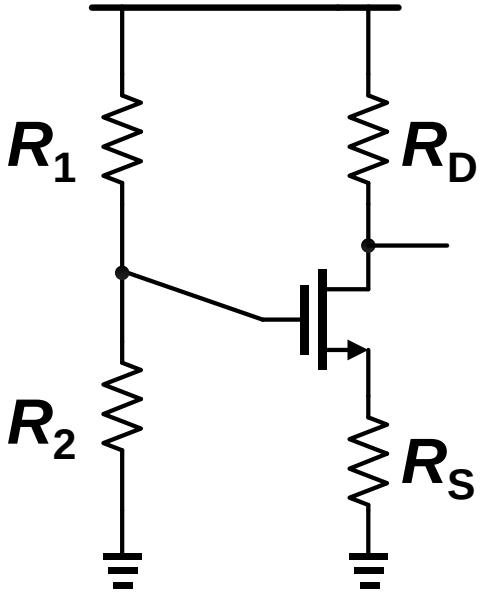
- MOSFET should be in saturation region, that is

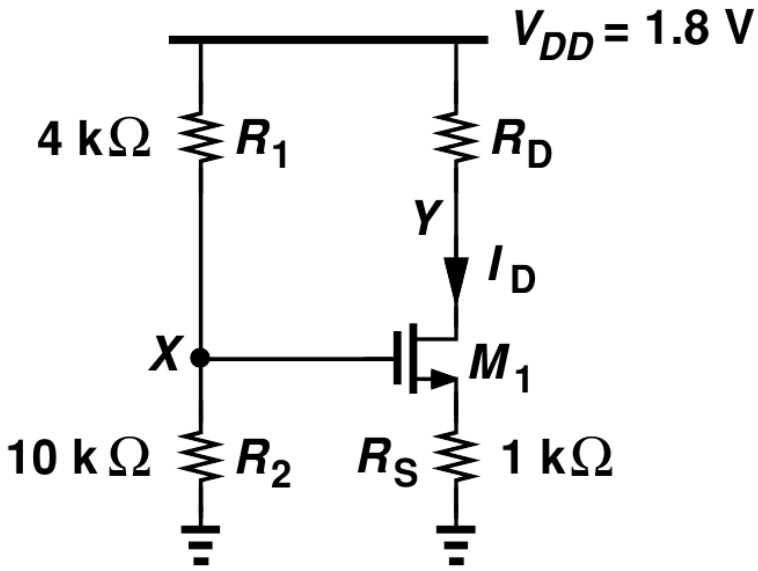
$$V_{GS} > V_{TH} \qquad \text{and} \qquad V_{DS} > V_{GS} - V_{TH}$$

- IN and OUT range may not make the MOSFET saturation

➔ We should design a circuit that forces MOSFET be in saturation region for interested input range.

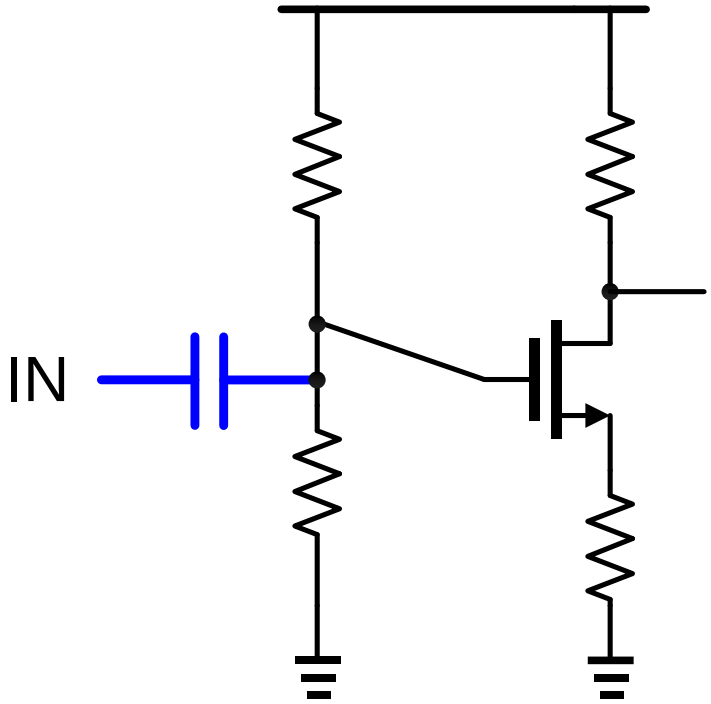






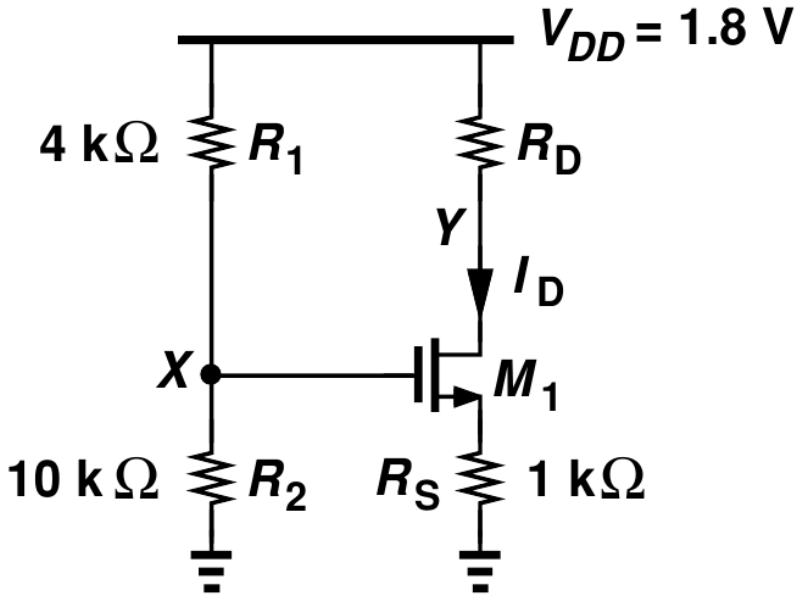
IN Acceptation

- We can utilize a capacitor. What is the definition of a capacitor?



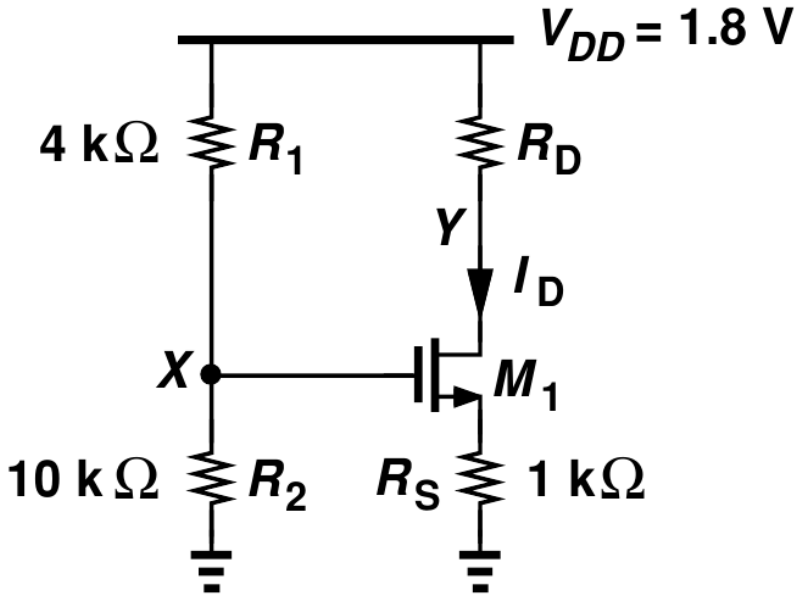
Example 7.1

Determine the bias current of M_1 in Fig. 7.1 assuming $V_{TH} = 0.5\,\text{V}$, $\mu_n C_{ox} = 100\,\mu\text{A/V}^2$, $W/L = 5/0.18$, and $\lambda = 0$. What is the maximum allowable value of R_D for M_1 to remain in saturation?



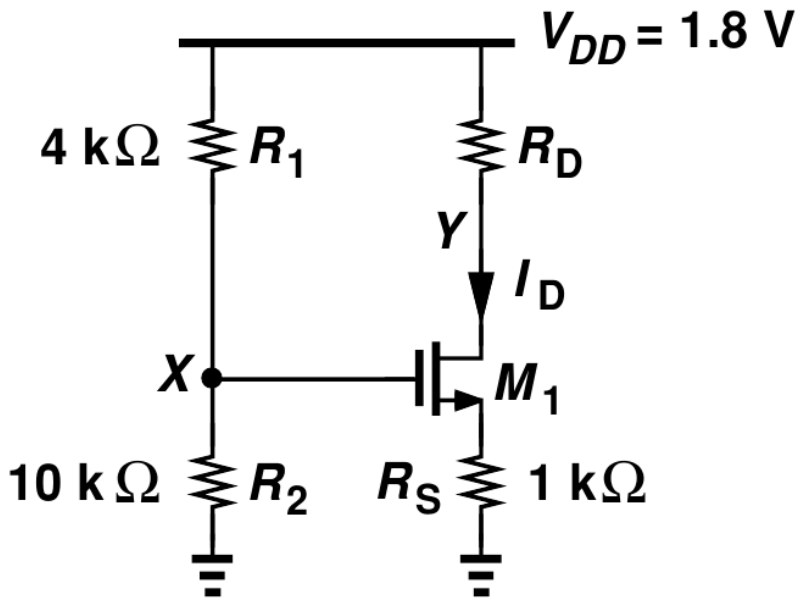
Example 7.2

In the circuit of Example 7.1, assume M_1 is in saturation and $R_D = 2.5\,\text{k}\Omega$ and compute (a) the maximum allowable value of W/L and (b) the minimum allowable value of R_S (with $W/L = 5/0.18$). Assume $\lambda = 0$.

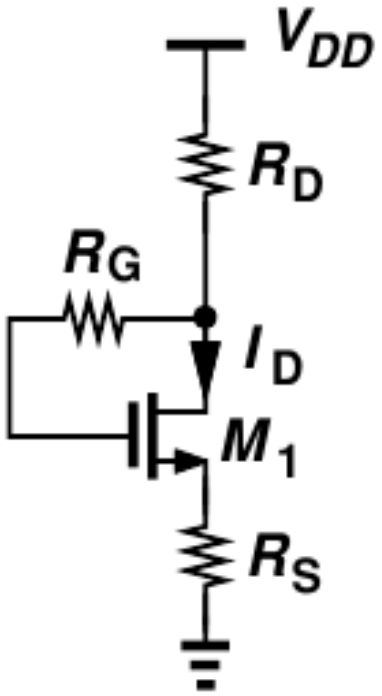


Efficient Way to Guaratee $V_{DS} > V_{GS} - V_{TH}$

- Self-biased MOS Stage



vs.



$$I_D R_D + V_{GS} + R_S I_D = V_{DD}$$

$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}[V_{DD} - (R_S + R_D)I_D - V_{TH}]^2$$

Example 7.3

Calculate the drain current of M_1 in Fig. 7.3 if $\mu_n C_{ox} = 100\,\mu\text{A/V}^2$, $V_{TH} = 0.5\,\text{V}$, and $\lambda = 0$. What value of R_D is necessary to reduce I_D by a factor of two?

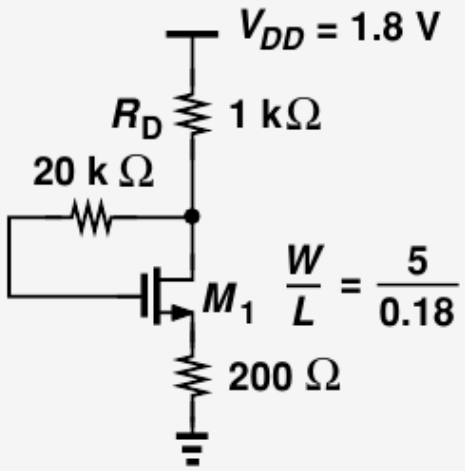


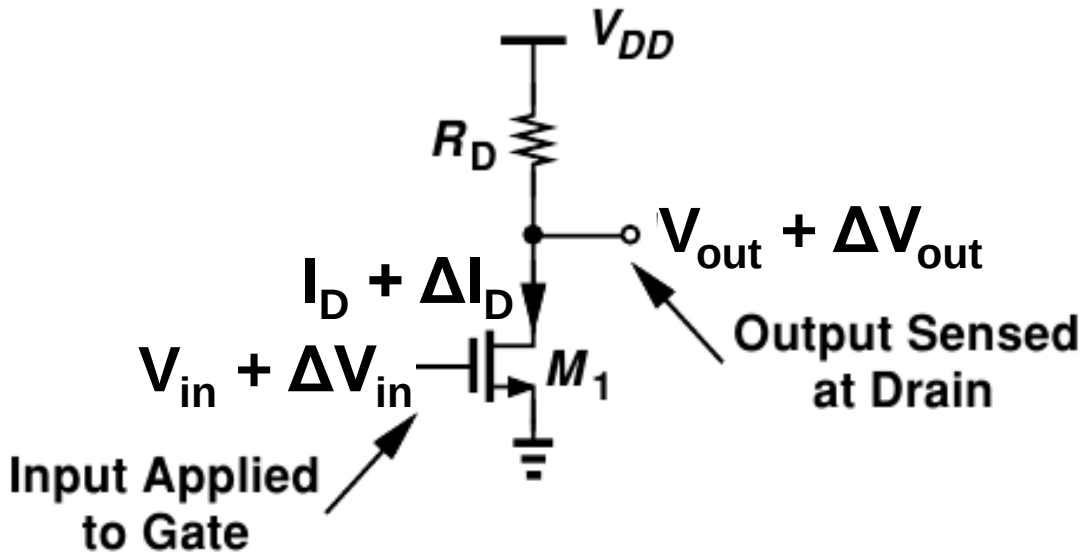
Figure 7.3 Example of self-biased MOS stage.

Revisit Transconductance

- Recall that in CS amplifier

$\Delta V_{in} = \Delta V_{GS} \rightarrow \Delta I_{DS} \rightarrow \Delta V_{out}$ and $\frac{\Delta V_{out}}{\Delta V_{in}} = \frac{\Delta I_{DS}}{\Delta V_{GS}} \times \frac{\Delta V_{out}}{\Delta I_{DS}} = -g_m \times R_D$

- If input varies **in sufficiently small range** with biased MOSFET, it is highly efficient to assume gm is constant for input range.



Small Signal Model

1) Only considers the "change" in signal of V_{in}, I_D, V_{out}, etc.

$$V_{GS} + \Delta V_{GS} \rightarrow v_{GS}$$

$$V_{in} + \Delta V_{in} \rightarrow v_{in}$$

$$V_{DD} \rightarrow 0 \text{ (Grounded)}$$

$$I_D + \Delta I_D \rightarrow i_D$$

$$V_{out} + \Delta V_{out} \rightarrow v_{out}$$

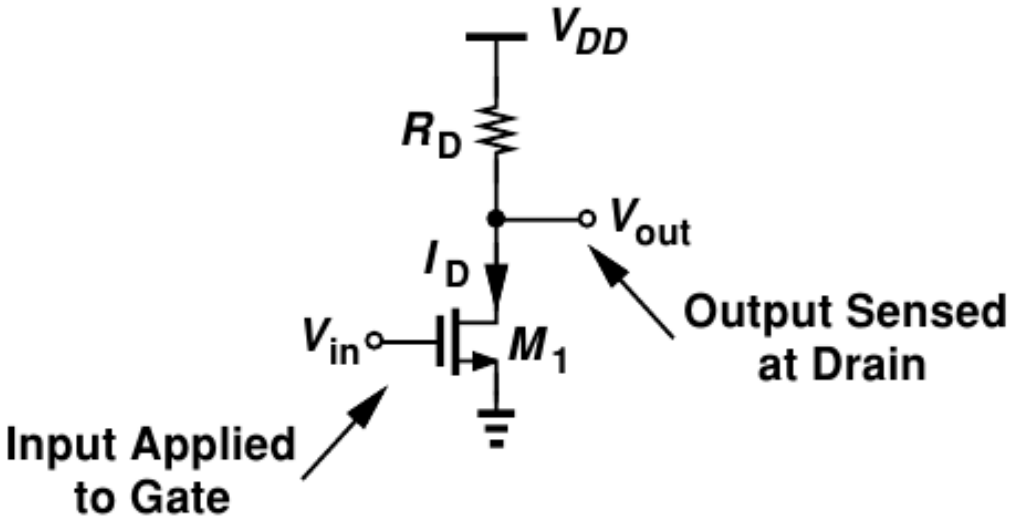
$$V_{DS} + \Delta V_{DS} \rightarrow v_{DS}$$

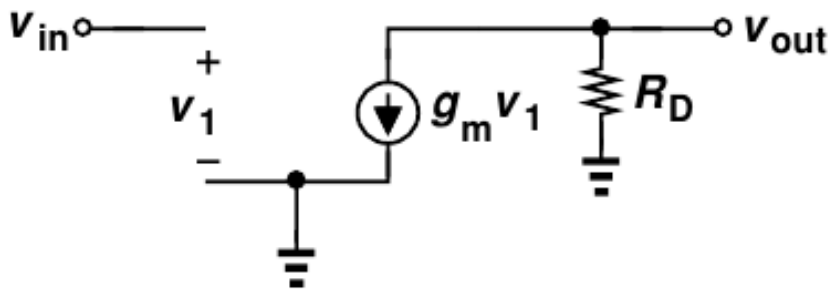
➔ Bias condition is not visible

2) Transconductance g_m is constant

➔ $g_m = \Delta I_D/\Delta V_{GS} = i_D/v_{GS} \approx \partial I_D/\partial V_{GS}$ (as "small" change in voltage)

Application of Small Signal Model





- The value of g_m? Neglecting channel length modulation,

$$g_m = \mu_n C_{ox} \frac{W}{L}(V_{GS} - V_{TH}) = \sqrt{2\mu_n C_{ox} \frac{W}{L} I_D}. = \frac{2I_D}{V_{GS} - V_{TH}},$$

Gain of CS Amplifier

- $\Delta V_{in} = \Delta V_{GS} \rightarrow \Delta I_{DS} \rightarrow \Delta V_{out}$ and $\frac{\Delta V_{out}}{\Delta V_{in}} = \frac{\Delta I_{DS}}{\Delta V_{GS}} \times \frac{\Delta V_{out}}{\Delta I_{DS}} = -g_m R_D$
- That is,

$$A_v = -\sqrt{2\mu_n C_{ox} \frac{W}{L} I_D} R_D.$$

- Bear in mind that MOSFET is all of the above is based on the assumption MOSET is in the saturation mode. That is,

$$V_{DD} - R_D I_D > V_{GS} - V_{TH}.$$

- What if I_D is increased to achieve higher gain? Then saturation mode may not be sustained.

Example 7.4

Calculate the small-signal voltage gain of the CS stage shown in Fig. 7.6 if $I_D = 1\,\text{mA}$, $\mu_n C_{ox} = 100\,\mu\text{A/V}^2$, $V_{TH} = 0.5\,\text{V}$, and $\lambda = 0$. Verify that M_1 operates in saturation.

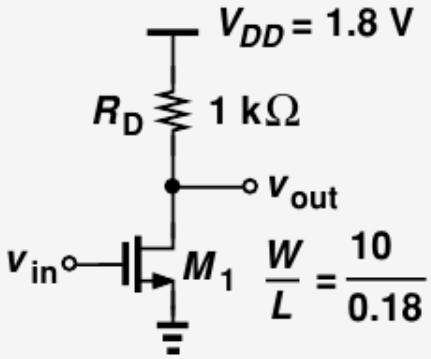


Figure 7.6 Example of CS stage.