Lecture 22 - Multistage Amplifiers (II)

DC Voltage and Current Sources

November 29, 2005

Contents:

1. DC voltage sources
2. DC current sources and sinks

Reading assignment:

Howe and Sodini, Ch. 9, §§9.4

Key questions

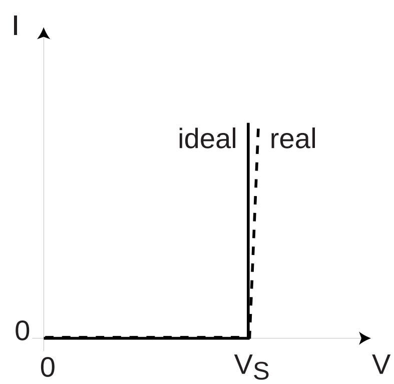
- How does one synthesize voltage and current sources?
- How can this be done in an economic way?

1. DC voltage sources

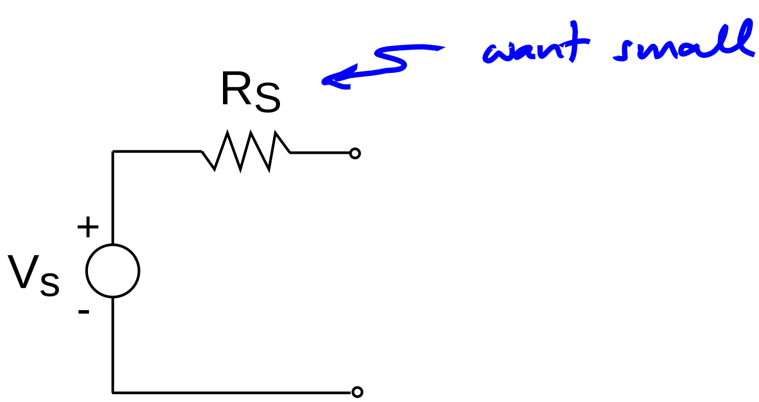
□ Features of voltage source:

- A well controlled voltage
- voltage does not depend on current drawn from source (*low internal resistance*).

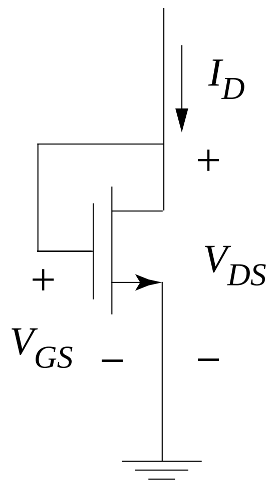
I-V characteristics of voltage source:

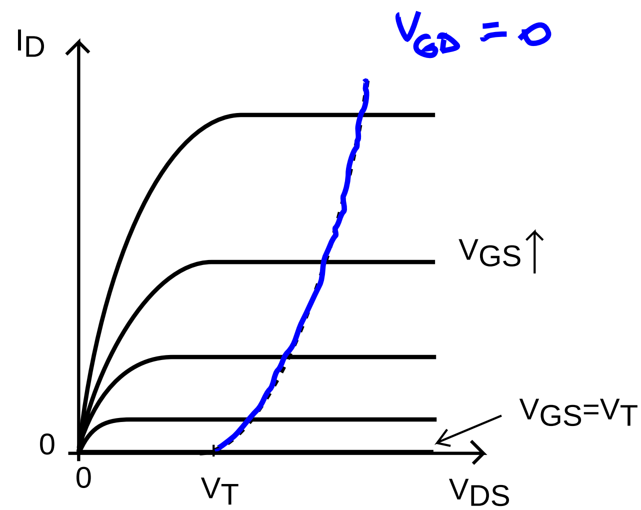


Equivalent circuit model of voltage source:



□ Consider MOSFET in "diode configuration":





I-V characteristics:

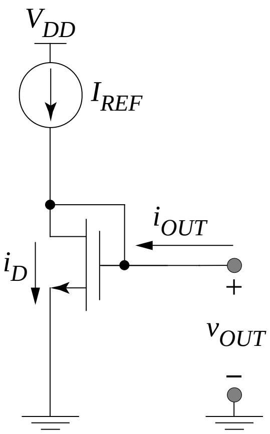
$$I_D = \frac{W}{2L}\mu C_{ox}(V_{GS} - V_T)^2 = \frac{W}{2L}\mu C_{ox}(V_{DS} - V_T)^2$$

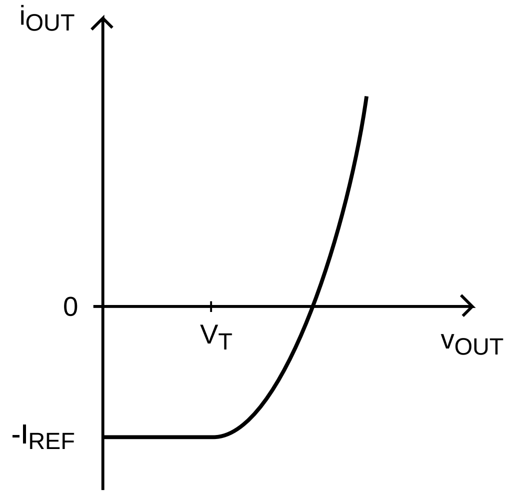
Beyond threshold, MOSFET looks like "diode" with quadratic I-V characteristics.

☐ How does one synthesize a voltage source with this?

Assume a current source is available.

for high I_{REF} and a very "fat" MOSFET, v_{out} rather insensitive to i_{OUT}





$V_{GS} = V_{DS}$ takes value needed to sink current:

$$I_D = I_{REF} + i_{OUT} = \frac{W}{2L}\mu C_{ox}(v_{OUT} - V_T)^2$$

Then:

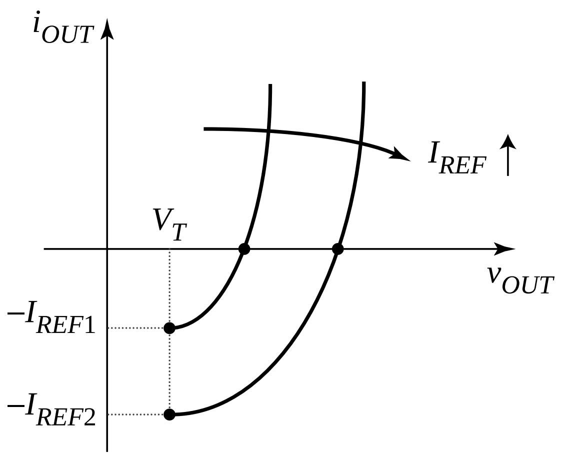
$$i_{OUT} = \frac{W}{2L}\mu C_{ox}(v_{OUT} - V_T)^2 - I_{REF}$$

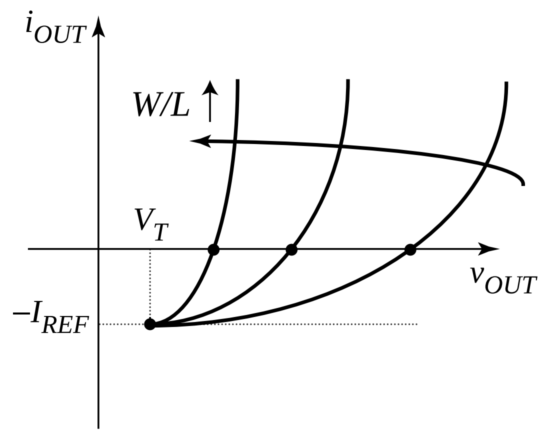
Solving for v_{OUT}:

$$v_{OUT} = V_T + \sqrt{\frac{I_{REF} + i_{OUT}}{\frac{W}{2L}\mu C_{ox}}}$$

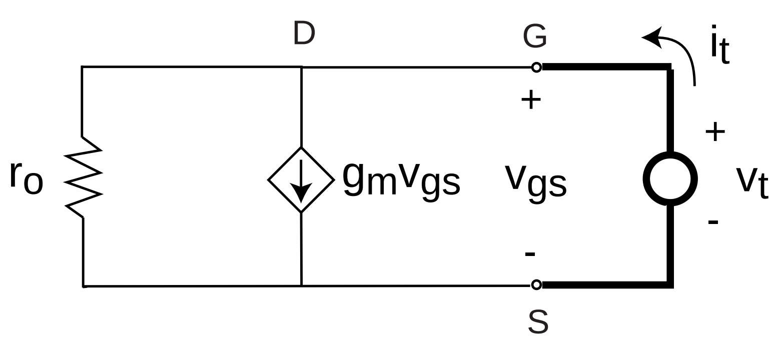
v_{OUT} is function of I_{REF} and W/L of MOSFET:

- $I_{REF} \uparrow \Rightarrow \; v_{OUT} \uparrow$
- $W/L \uparrow \Rightarrow \; v_{OUT} \downarrow$





□ Small-signal view of voltage source:

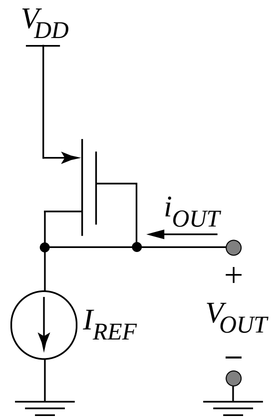


$$R_{out} = \frac{1}{g_m} // r_o \simeq \frac{1}{g_m}$$

R_{out} is small (good!).

(current can change a lot w/o voltage changing too much

□ PMOS voltage source:



Same operation and characteristics as NMOS voltage source.

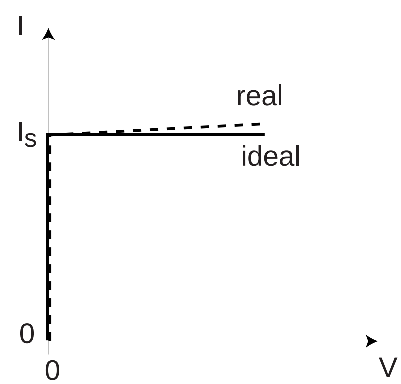
PMOS needs to be bigger to attain same R_{out}.

2. DC current sources and sinks

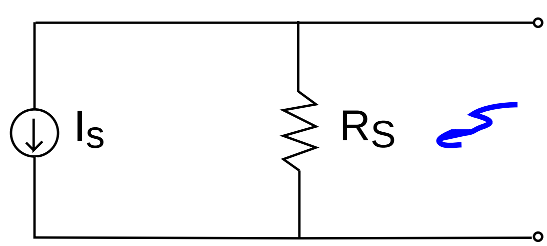
□ Features of current source:

- A well controlled current,
- supplied current does not depend on voltage across (*high internal resistance*)

I-V characteristics of current source:

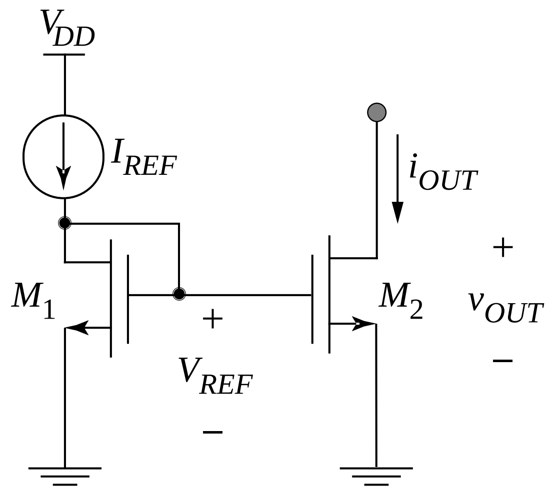


Equivalent circuit model of current source:



want high

□ Connect voltage source to another MOSFET:



V_{GS2}

$$I_{OUT} \simeq \frac{1}{2}\left(\frac{W}{L}\right)_2 \mu C_{ox}(V_{REF} - V_T)^2$$

V_{GS1}

$$I_{REF} \simeq \frac{1}{2}\left(\frac{W}{L}\right)_1 \mu C_{ox}(V_{REF} - V_T)^2$$

Then:

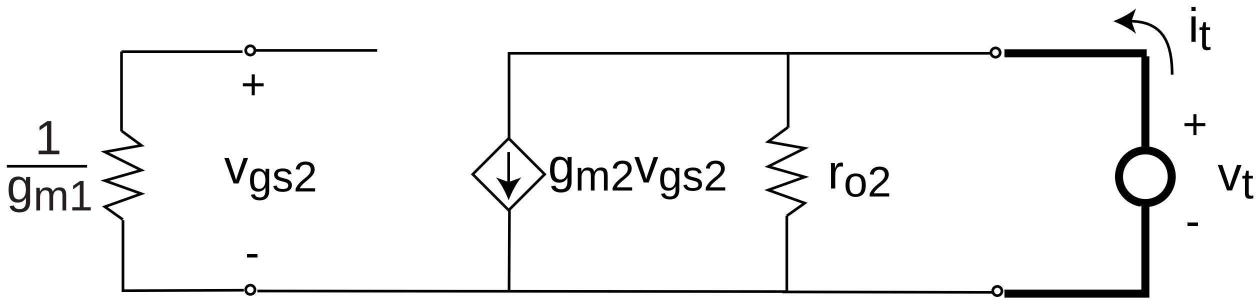
$$I_{OUT} = I_{REF}\,\frac{\left(\frac{W}{L}\right)_2}{\left(\frac{W}{L}\right)_1}$$

I_{OUT} scales with I_{REF} by W/L ratios of two MOSFETs (*current mirror* circuit).

Well "matched" transistors important.

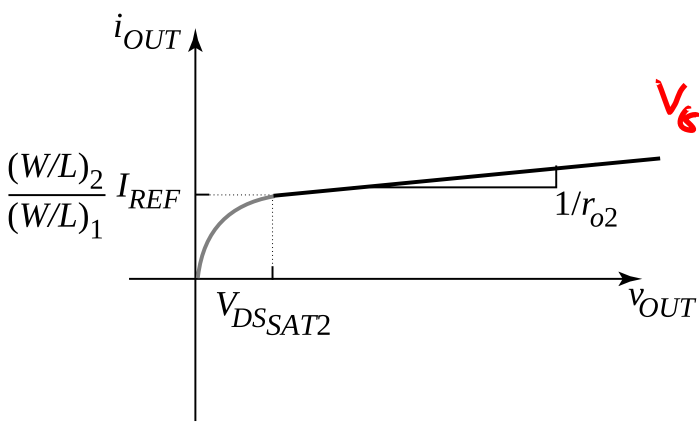
(same V_T, t_{ox}, etc.)

- Small-signal view of current source:



$$R_{out} = r_{o2}$$

I-V characteristics of NMOS current source:



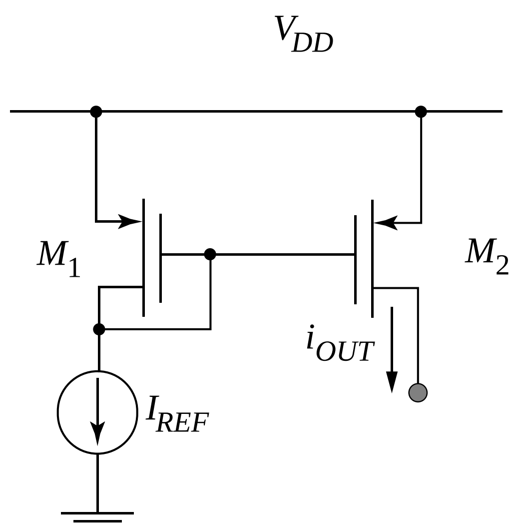
$V_{GS2} = V_{REF}$

□ PMOS current source

- NMOS current source *sinks* current to ground.

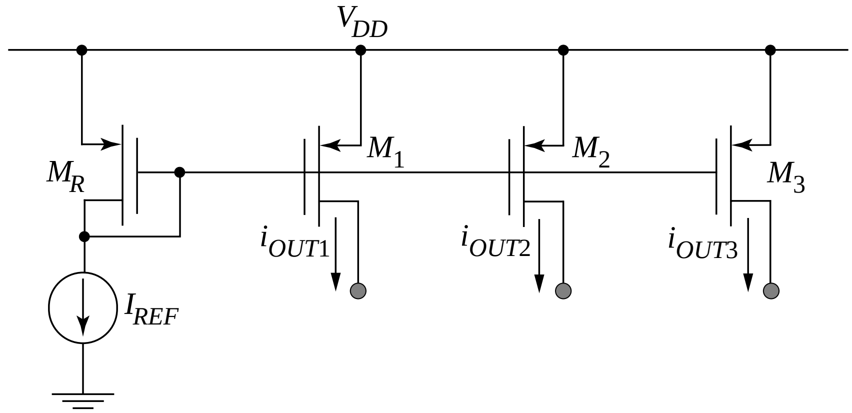
- PMOS current source *sources* current from positive supply.

PMOS current mirror:



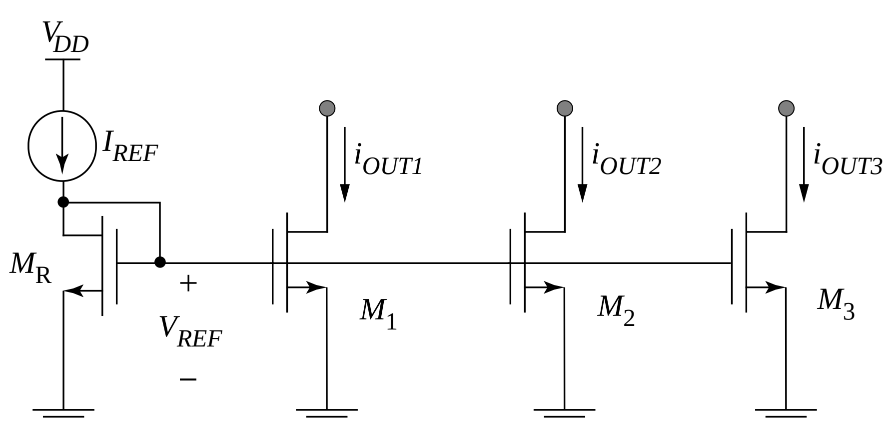
□ Multiple current sources

Since there is no DC gate current in MOSFET, can tie up multiple current mirrors to single current source:



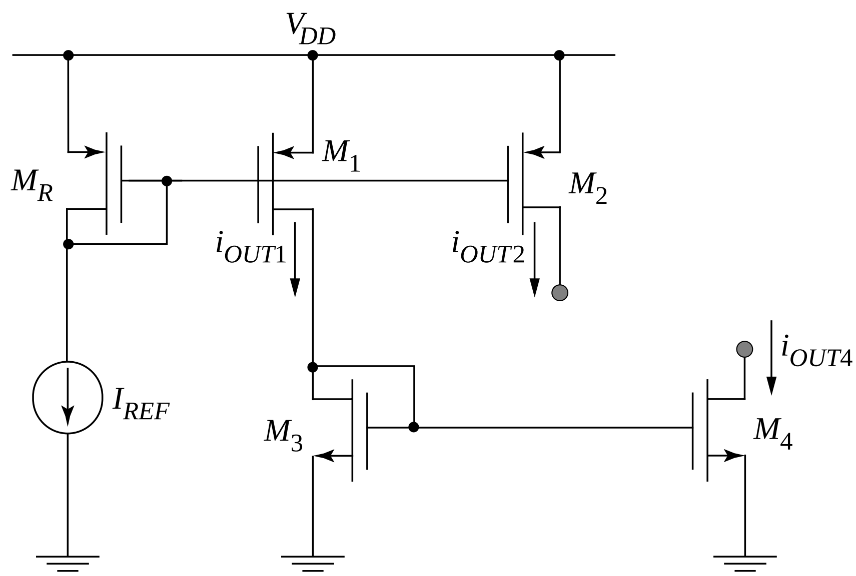
$$I_{OUTn} = I_{REF} \frac{\left(\frac{W}{L}\right)_n}{\left(\frac{W}{L}\right)_R}$$

Similar idea with NMOS current sinks:



□ *Multiple current sources and sinks*

Often, in a given circuit, we need current sources and sinks. Can build them all out of a single current source:



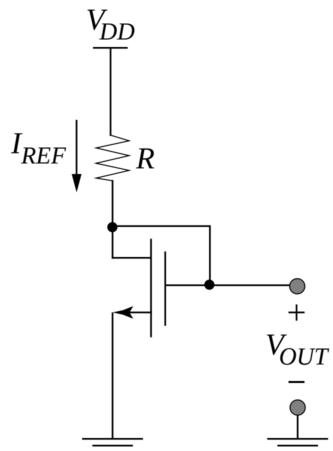
$$I_{OUT1} = I_{REF}\,\frac{\left(\frac{W}{L}\right)_1}{\left(\frac{W}{L}\right)_R}$$

$$I_{OUT2} = I_{REF}\,\frac{\left(\frac{W}{L}\right)_2}{\left(\frac{W}{L}\right)_R}$$

$$I_{OUT4} = I_{OUT1}\,\frac{\left(\frac{W}{L}\right)_4}{\left(\frac{W}{L}\right)_3} = I_{REF}\,\frac{\left(\frac{W}{L}\right)_4\left(\frac{W}{L}\right)_1}{\left(\frac{W}{L}\right)_3\left(\frac{W}{L}\right)_R}$$

□ Generating I_{REF}:

Simple circuit:



$$I_{REF} = \frac{V_{DD} - V_{OUT}}{R}$$

$$V_{OUT} = V_T + \sqrt{\frac{I_{REF}}{\frac{W}{2L}\mu C_{ox}}}$$

For large W/L, $V_{OUT} \rightarrow V_T$:

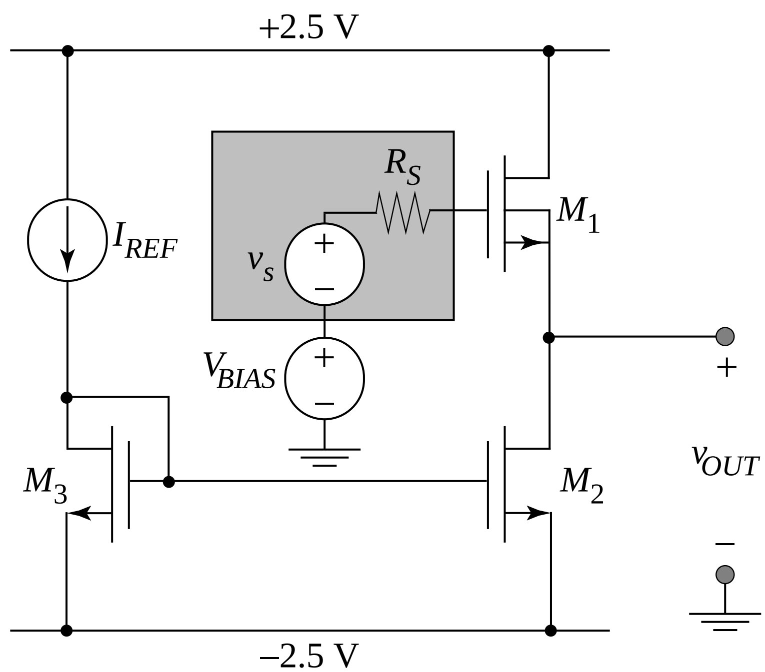
$$I_{REF} \simeq \frac{V_{DD} - V_T}{R}$$

- Advantages:
  - I_{REF} set by value of resistor.
- Disadvantages:
  - V_{DD} also affects I_{REF}.
  - V_T and R are function of temperature $\Rightarrow I_{REF}(T)$.

In real world, more sophisticated circuits used to generate I_{REF} that are V_{DD} and T independent.

□ Can now understand more complex circuits.

Examples:

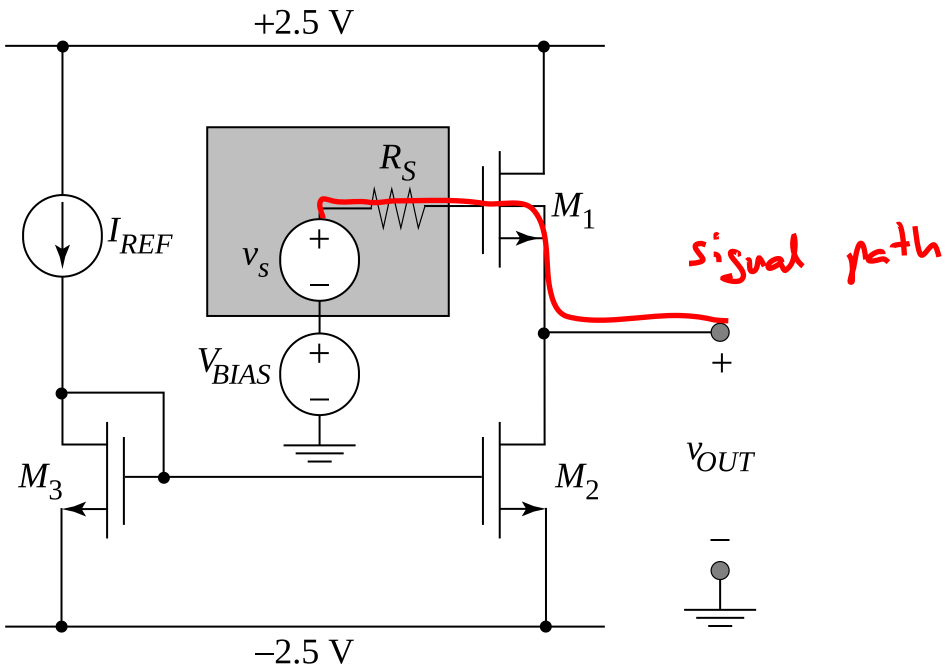


Amp stages:

What does it do?

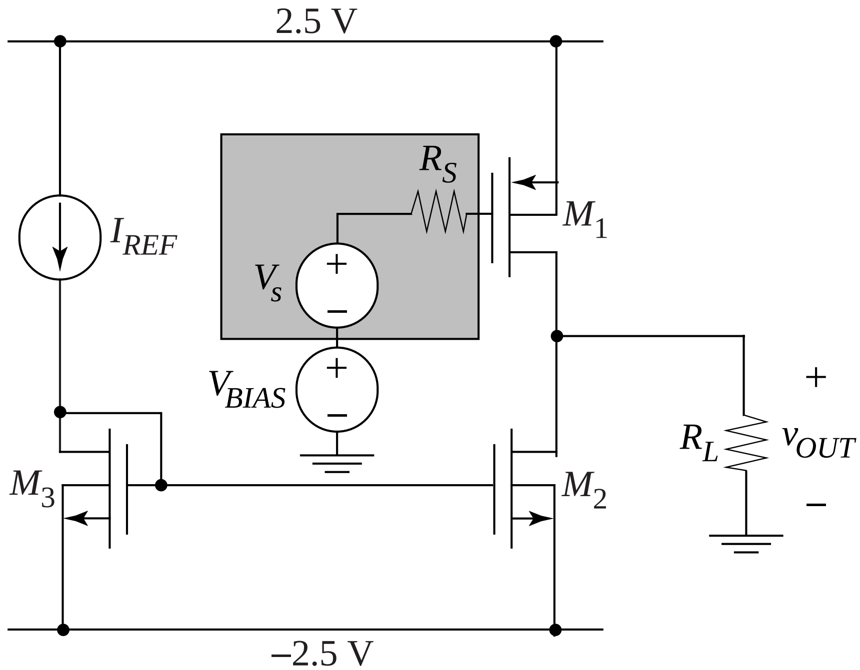
□ Can now understand more complex circuits.

Examples:



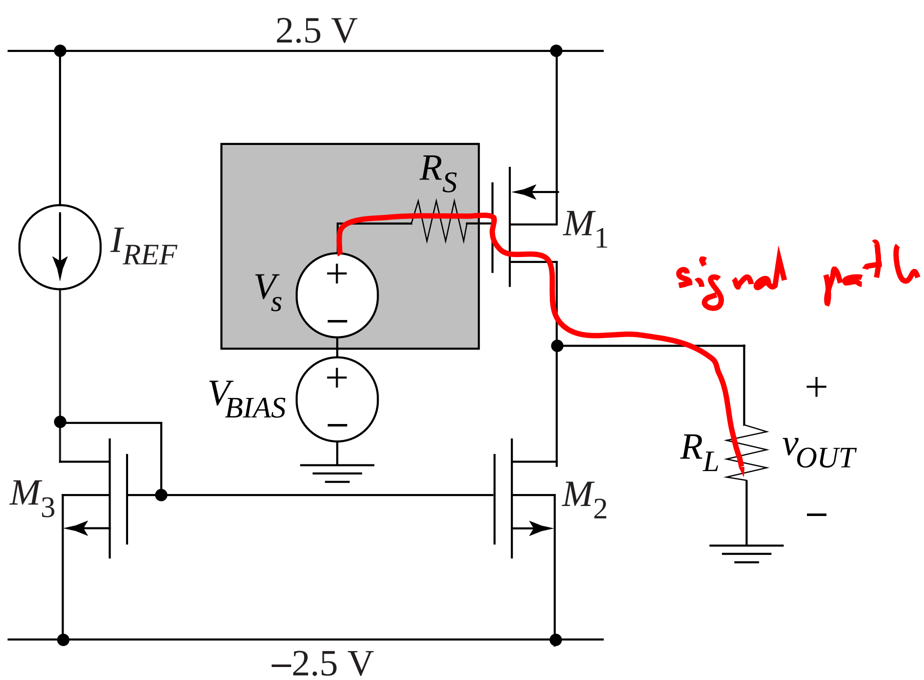
Amp stages: CD

What does it do? voltage buffer



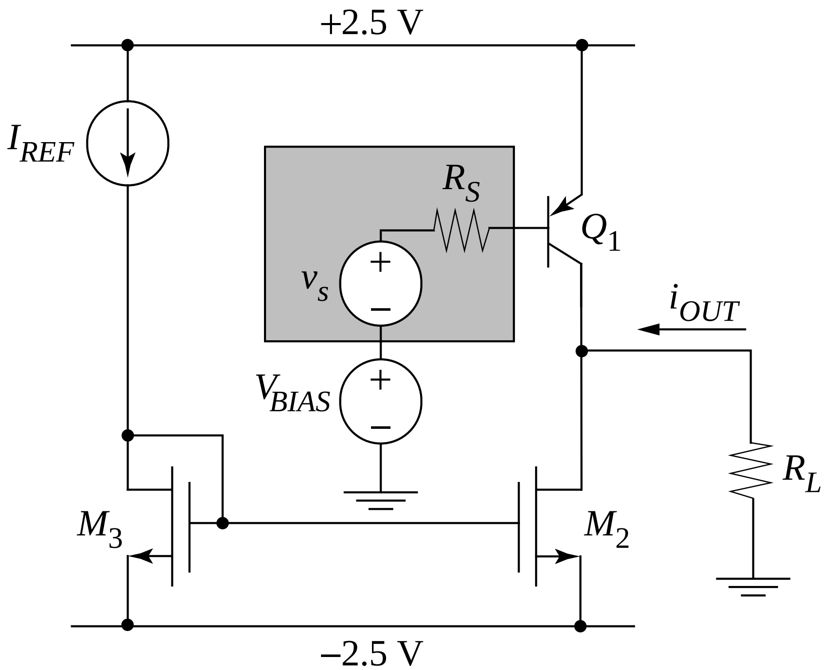
Amp stages:

What does it do?



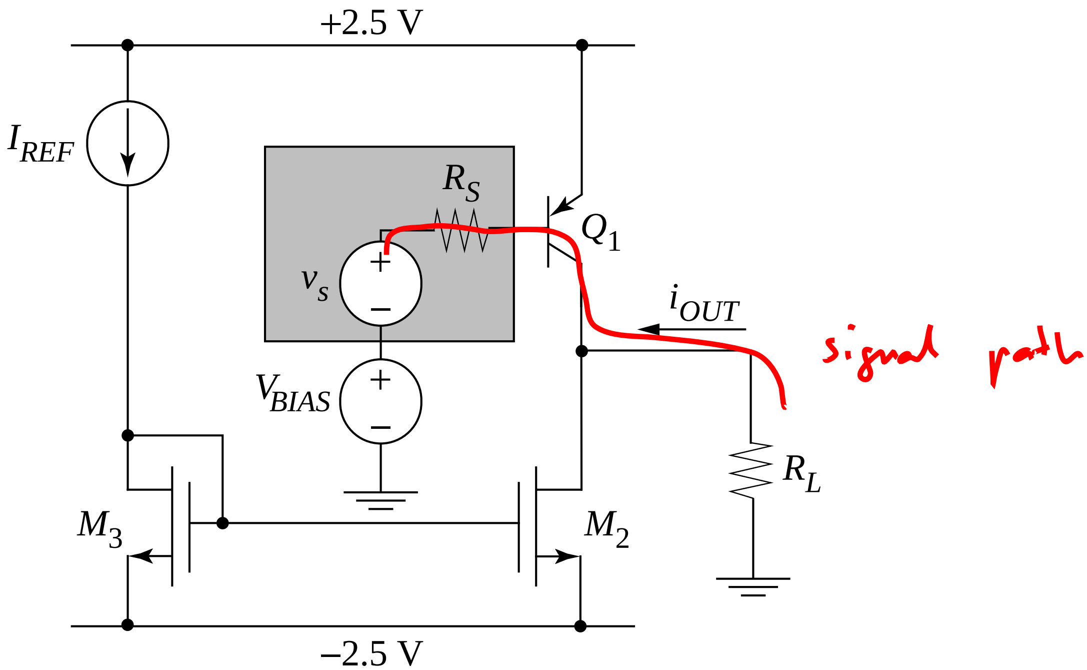
Amp stages: CS

What does it do? transconductance amp.



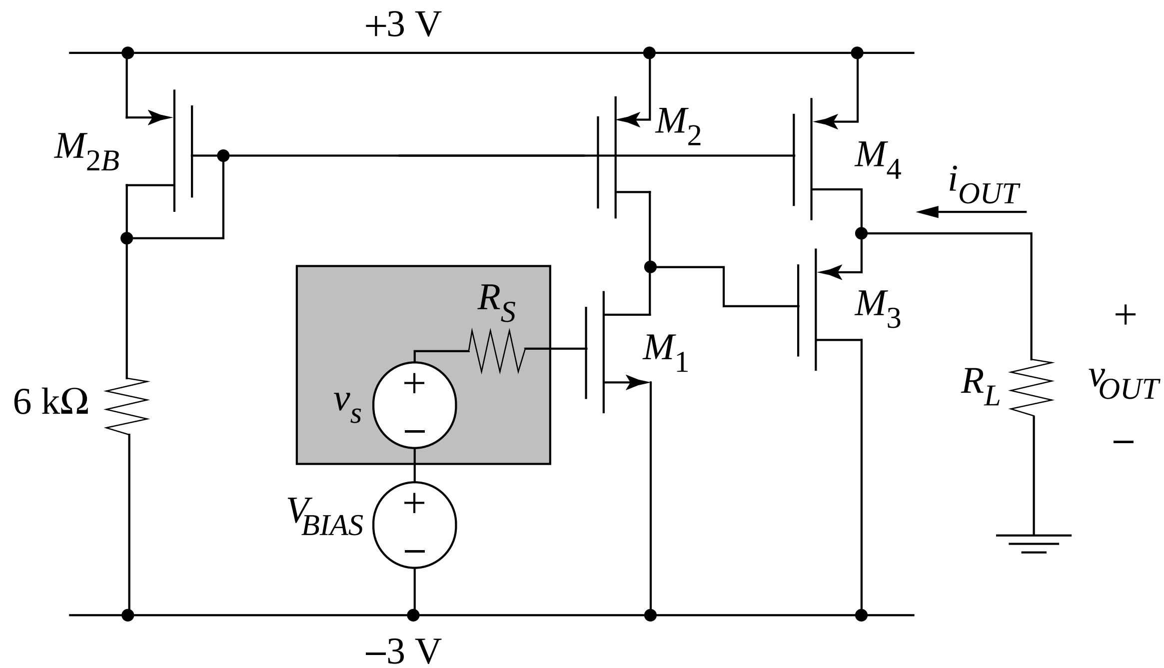
Amp stages:

What does it do?



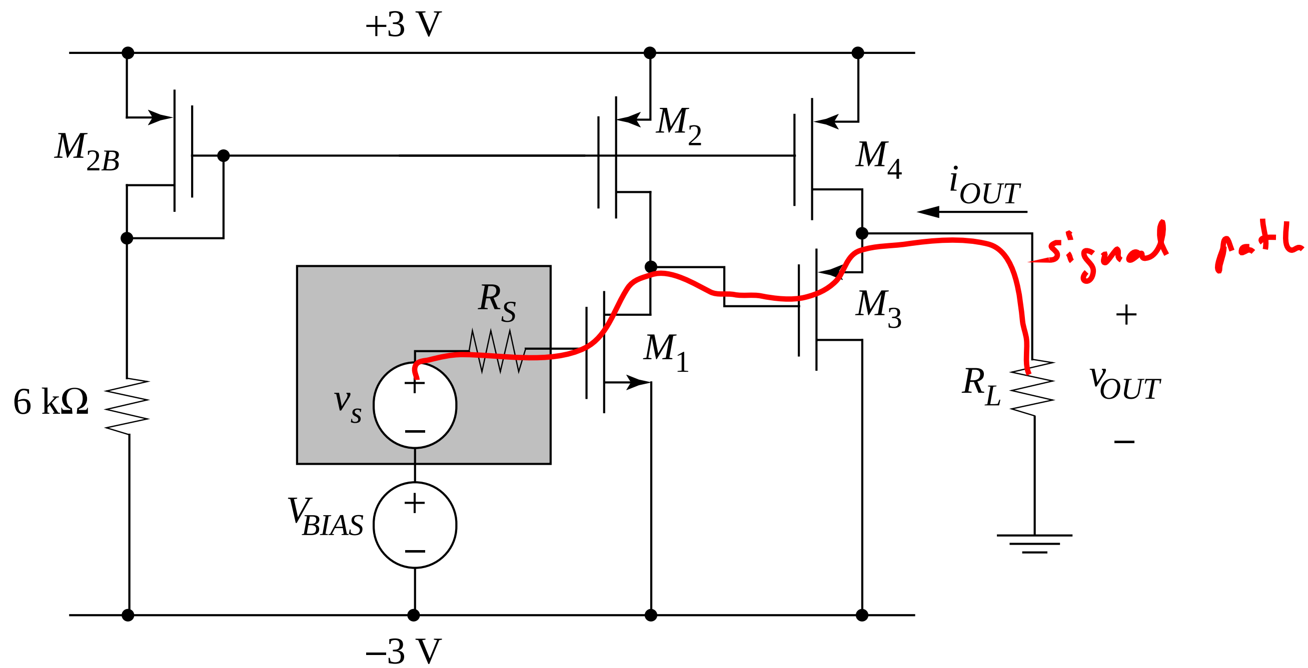
Amp stages: CE

What does it do? transconductance amp.



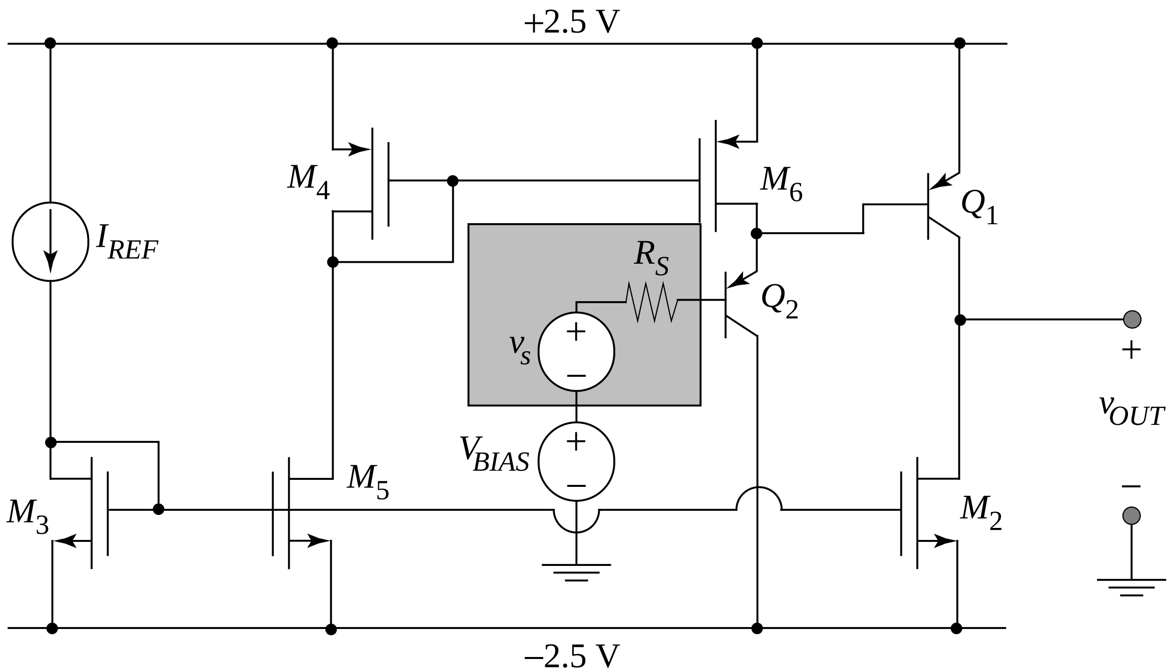
Amp stages:

What does it do?



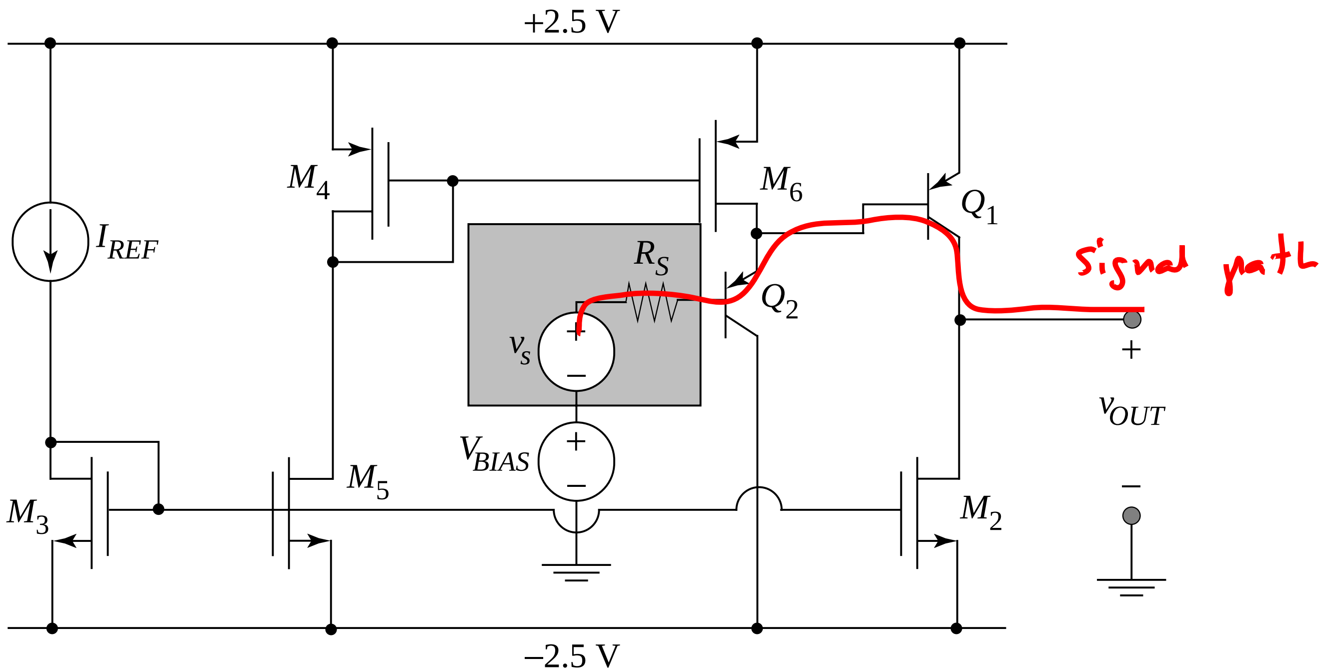
Amp stages: CS + CD

What does it do? voltage amp.



Amp stages:

What does it do?



Amp stages: CC + CE

What does it do? Voltage amp. for signal source with high R_s

Key conclusions

- Voltage source easily synthesized from current source using MOSFET in diode configuration.
- Current source easily synthesized from current source using *current mirror* circuit.
- Multiple current sources and sinks with different magnitudes of current can be synthesized from a single current source.
- Voltage and current sources rely on availability of well "matched" transistors in IC technology.