

## **Lecture 22 - Multistage Amplifiers (II)**

### **DC VOLTAGE AND CURRENT SOURCES**

May 1, 2003

#### **Contents:**

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

#### **Reading assignment:**

Howe and Sodini, Ch. 9, §§9.4

#### **Announcements:**

Athena Office Hours: Thurs 5/1: 8:30-9:30 PM, Sunday  
5/4: 7-9 PM, Athena Cluster 38-370

## Key questions

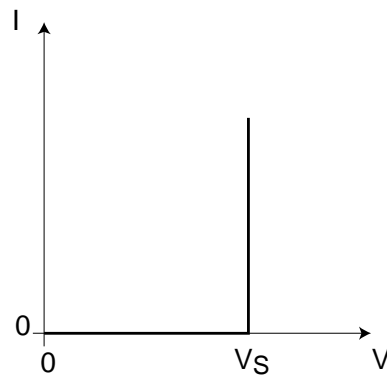
- How does one synthesize voltage and current sources?
- How can this be done in an economic way?

# 1. DC voltage sources

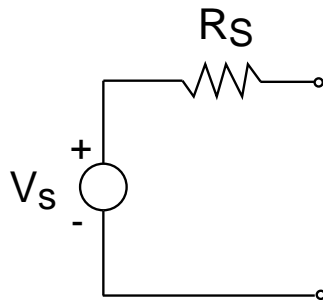
□ Features of voltage source:

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

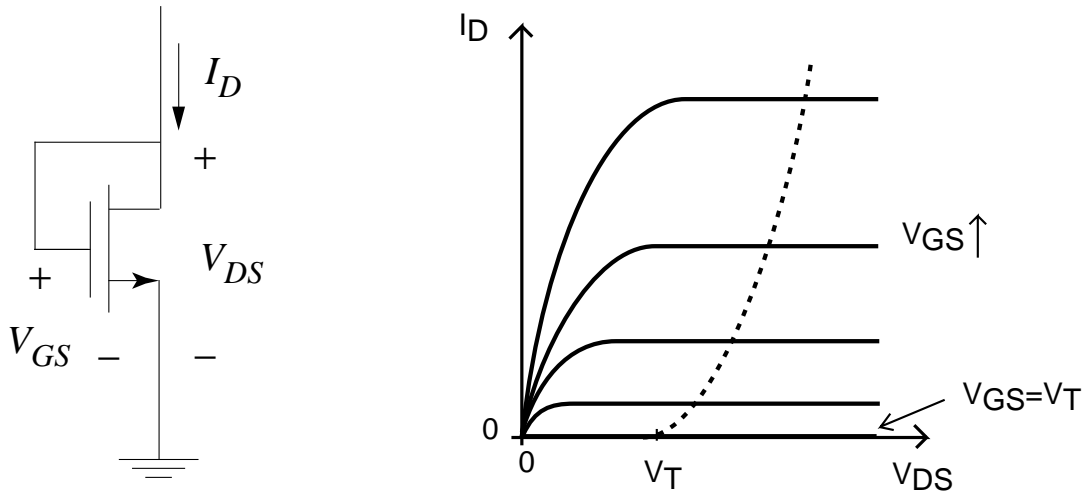
I-V characteristics of ideal voltage source:



Equivalent circuit model of voltage source:



□ Consider MOSFET in "diode configuration":



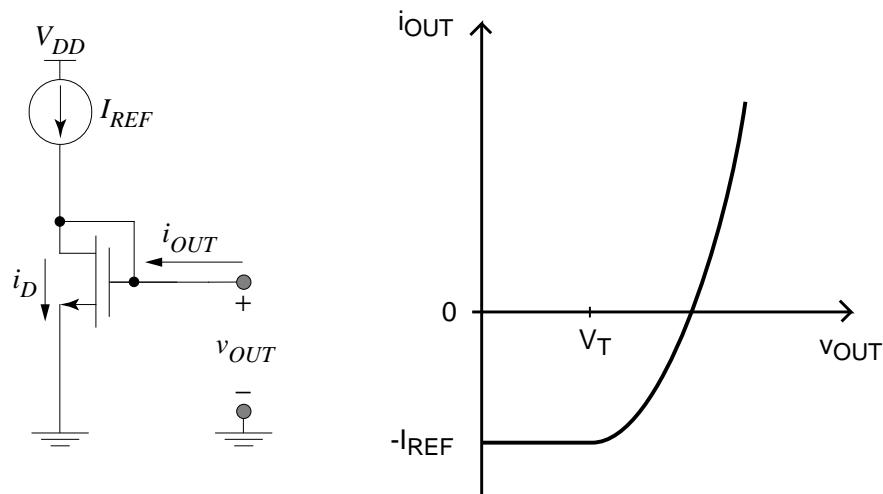
I-V characteristics:

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

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.



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

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

Then:

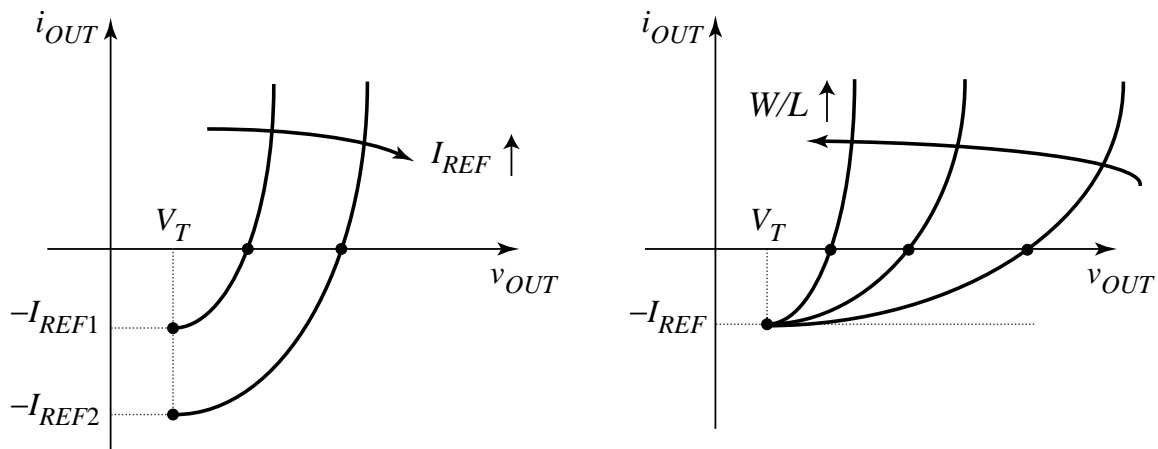
$$i_{OUT} = \frac{W}{2L} \mu C_{ox} (v_{OUT} - V_T)^2 - I_{REF}$$

Solving for  $v_{OUT}$ :

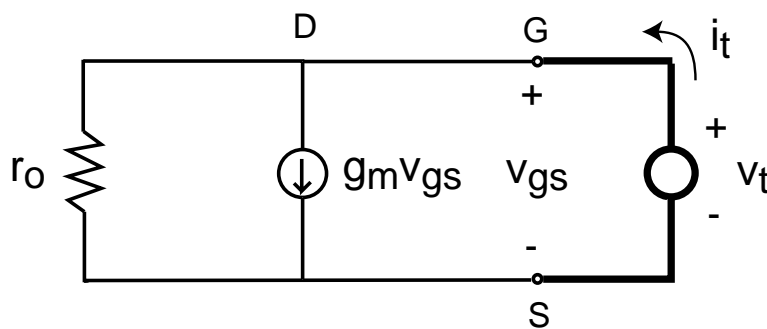
$$v_{OUT} = V_T + \sqrt{\frac{I_{REF} + i_{OUT}}{\frac{W}{2L} \mu C_{ox}}}$$

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

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



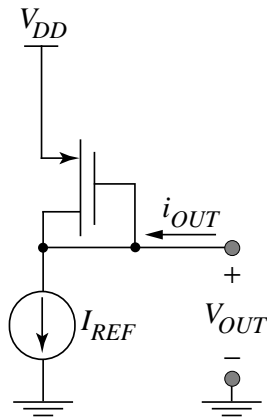
□ Small-signal view of voltage source:



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

$R_{out}$  is small (good!).

□ PMOS voltage source:



Same operation and characteristics as NMOS voltage source.

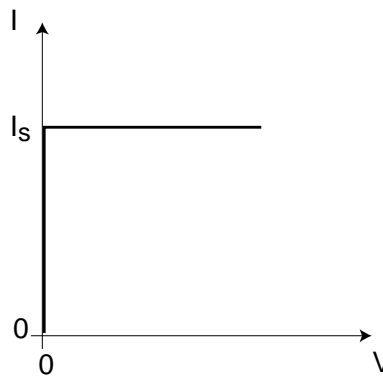
PMOS needs to be bigger to attain same  $R_{out}$ .

## 2. DC current sources and sinks

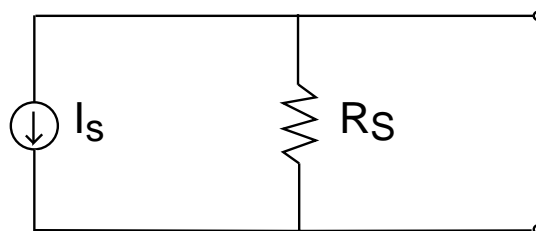
□ Features of current source:

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

I-V characteristics of ideal current source:

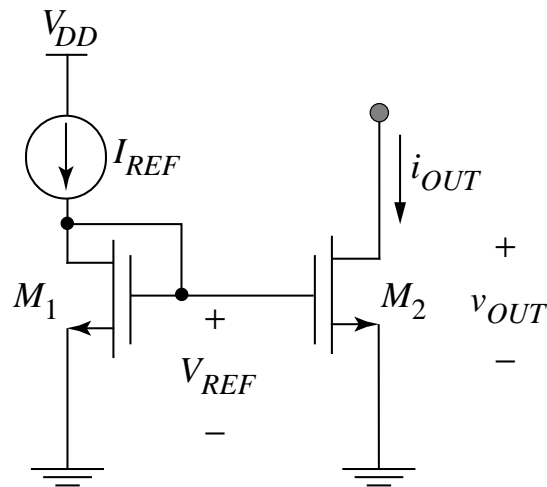


Equivalent circuit model of current source:





□ Connect voltage source to another MOSFET:



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

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

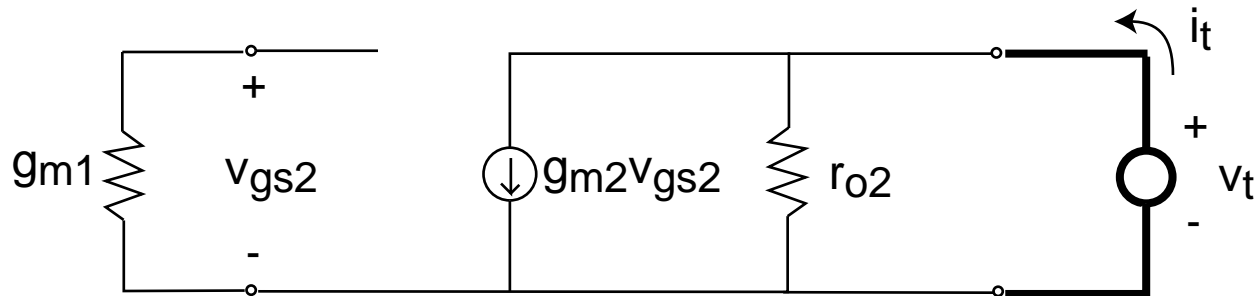
Then:

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

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

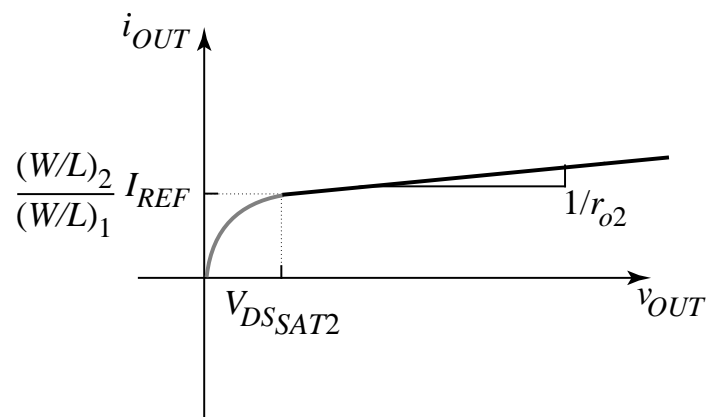
Well "matched" transistors important.

- Small-signal view of current source:



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

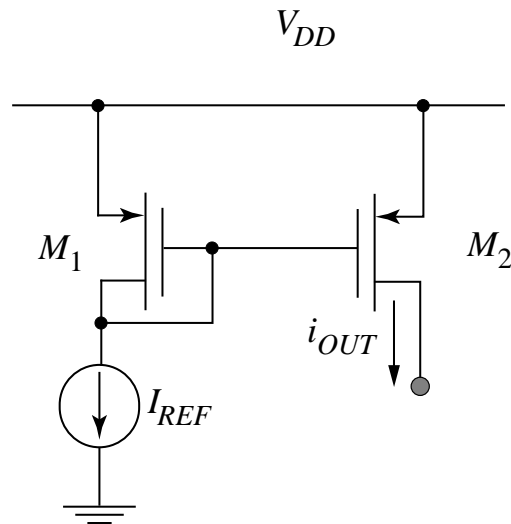
I-V characteristics of NMOS current source:



□ PMOS current source

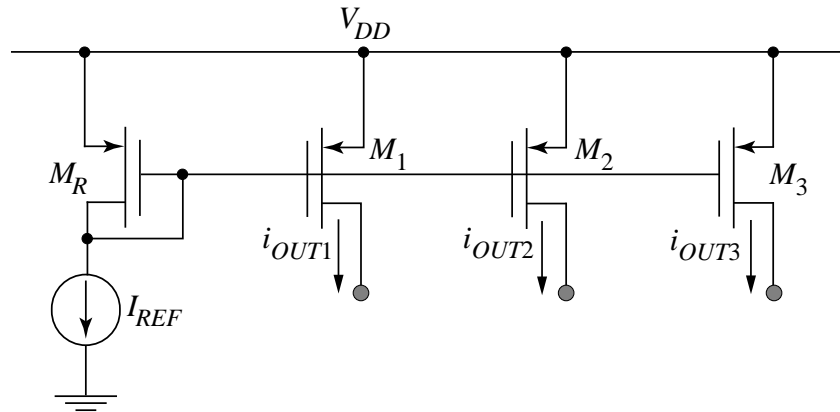
- NMOS current source *sinks* current to ground.
- PMOS current source *sources* current from positive supply.

PMOS current mirror:



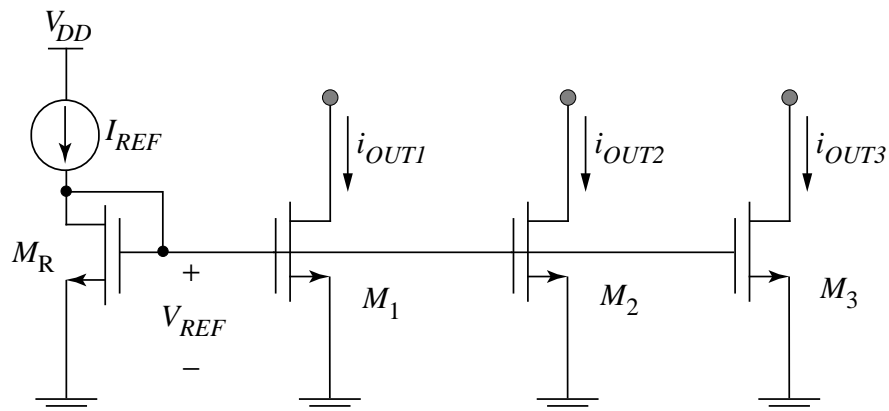
## □ Multiple current sources

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



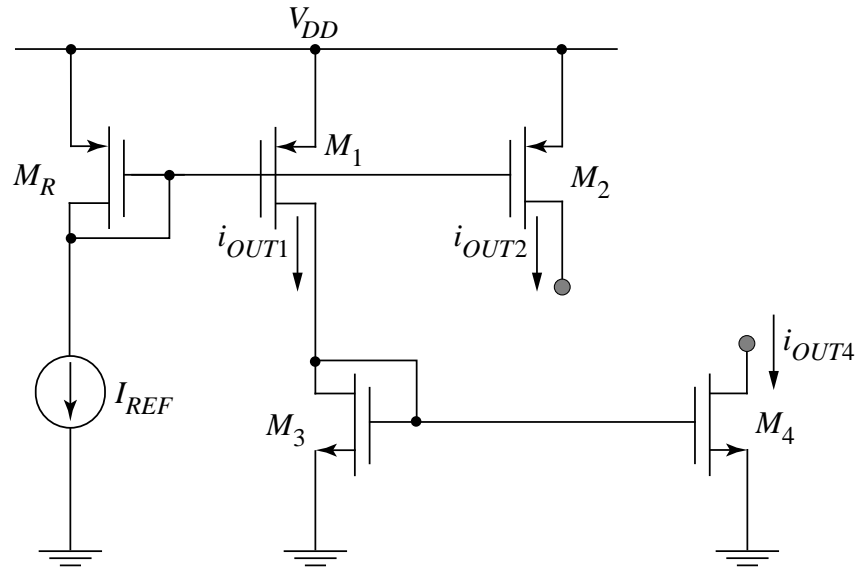
$$I_{OUTn} = I_{REF} \frac{\left(\frac{W}{L}\right)_n}{\left(\frac{W}{L}\right)_R}$$

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:



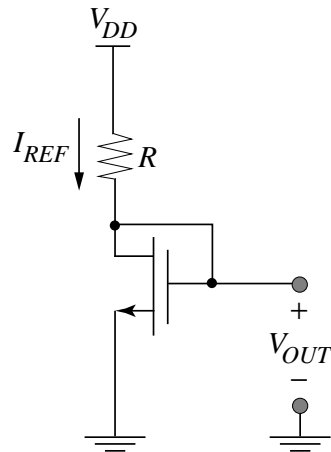
$$I_{OUT1} = I_{REF} \frac{\left(\frac{W}{L}\right)_1}{\left(\frac{W}{L}\right)_R}$$

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

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

□ 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:

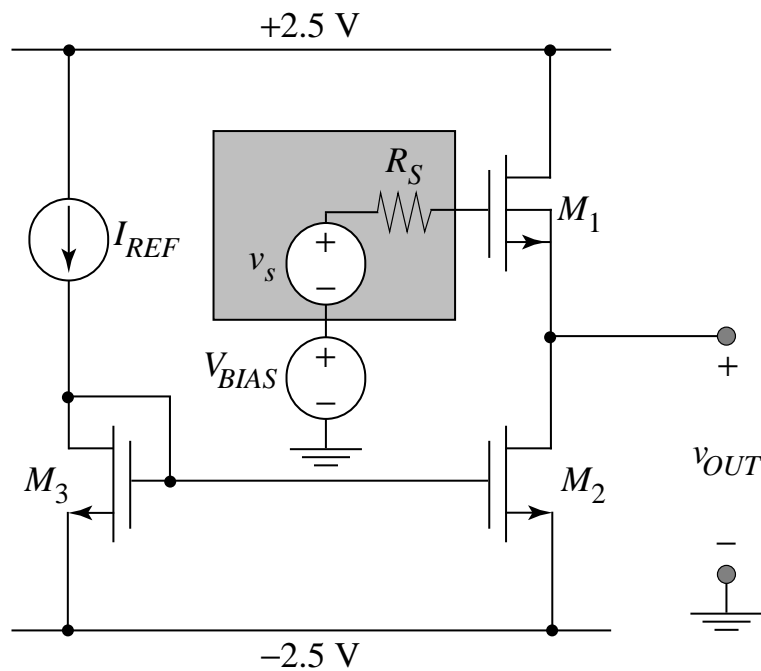
- $V_{DD}$  also affects  $I_{REF}$ .

- $V_T$  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.

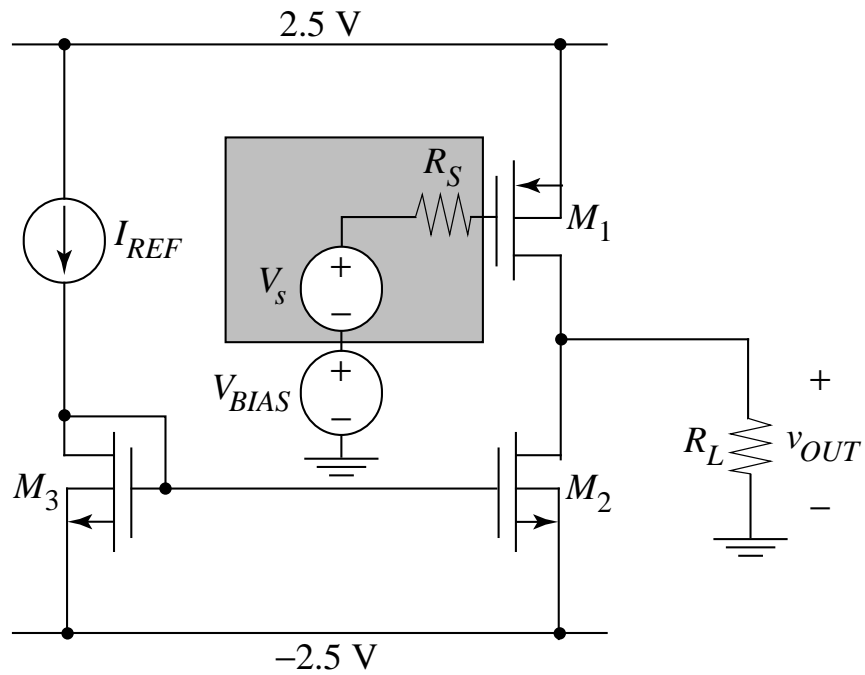
□ Can now understand more complex circuits.

Examples:



Amp stages:

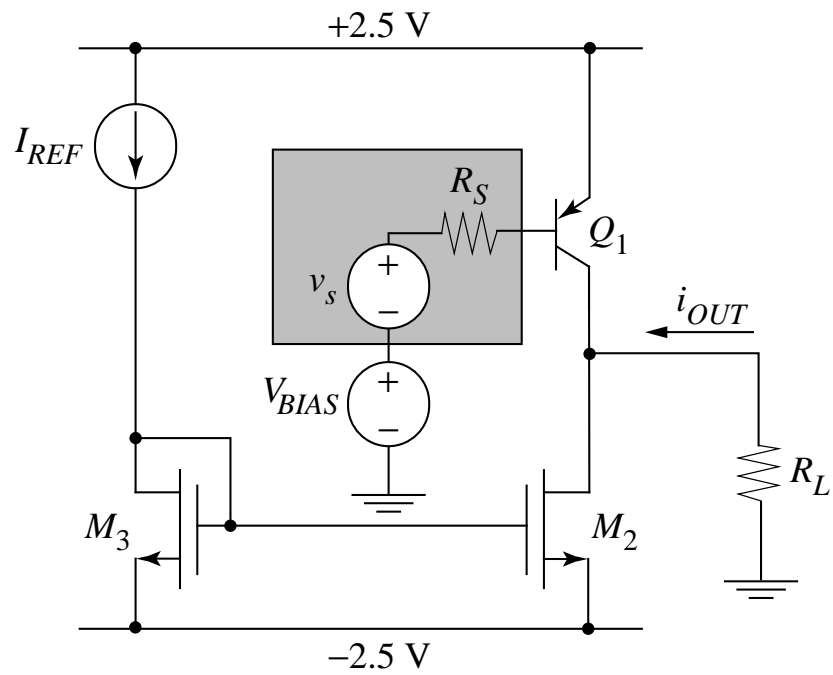
What does it do?



Amp stages:

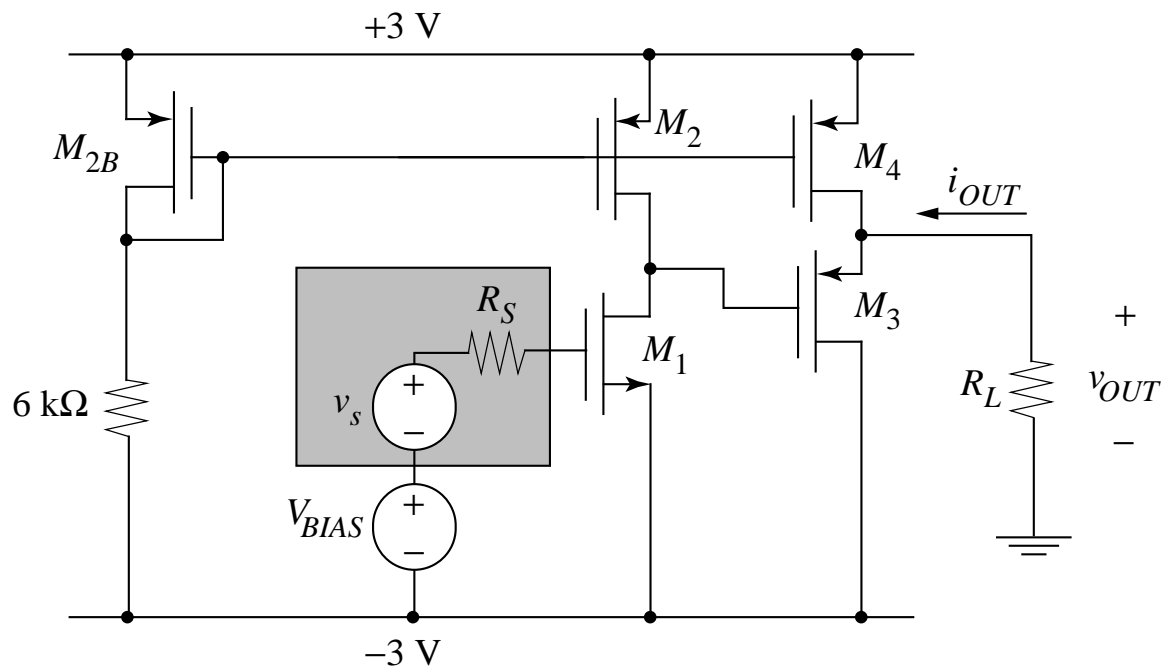
What does it do?





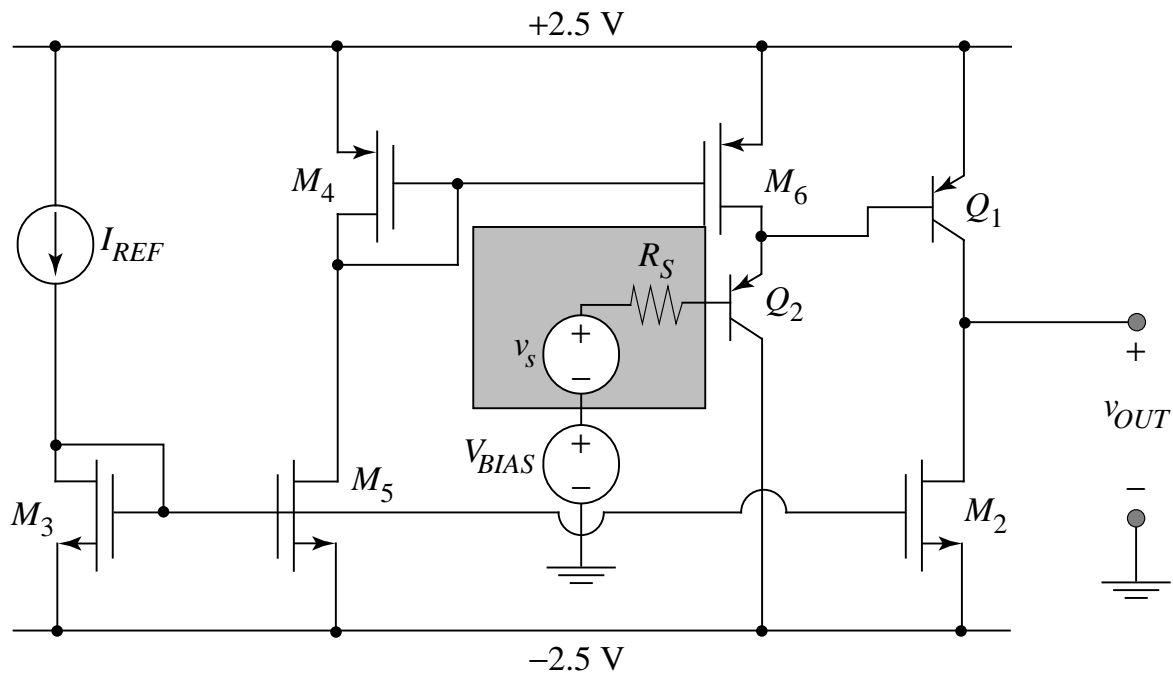
Amp stages:

What does it do?



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Amp stages:

What does it do?

## 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.