Lecture 25

Multistage Amplifiers (II)

DC VOLTAGE AND CURRENT SOURCES

Outline

1. DC Voltage Sources
2. DC Current Sources and Sinks

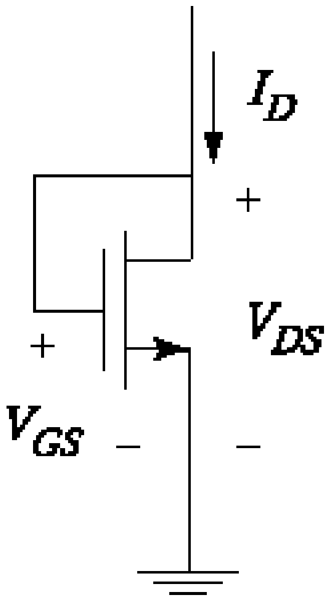
Reading Assignment:
Howe and Sodini, Chapter 9, Sections 9-3-9.4
Final: Monday, May 19, 2009, 9am, Johnson Ice Rink

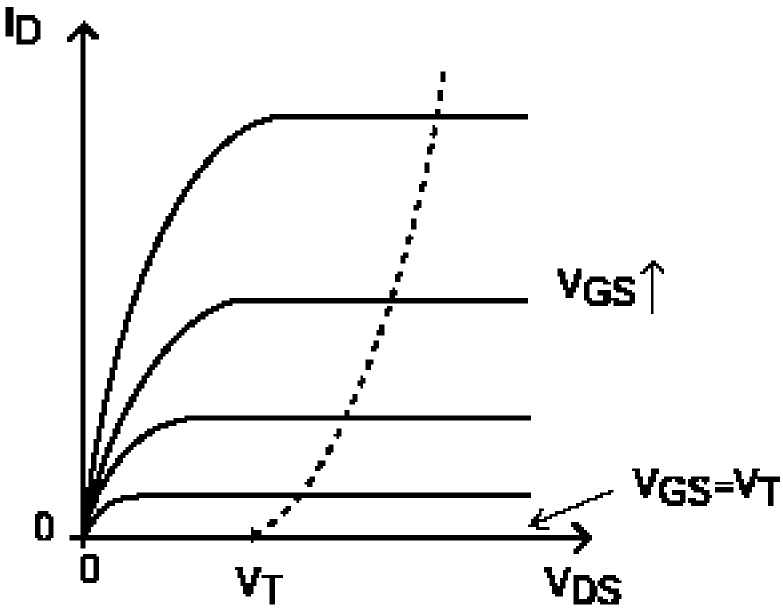
1. DC Voltage Sources

Characteristics of DC Voltage Sources :

- A well controlled output voltage
- Output voltage does not depend on current drawn from source ⇒ ***Low Thevenin Resistance***

Consider a MOSFET connected in "diode configuration"





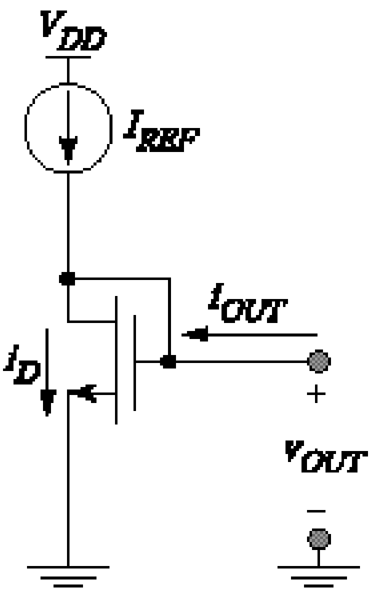
I-V characteristics:

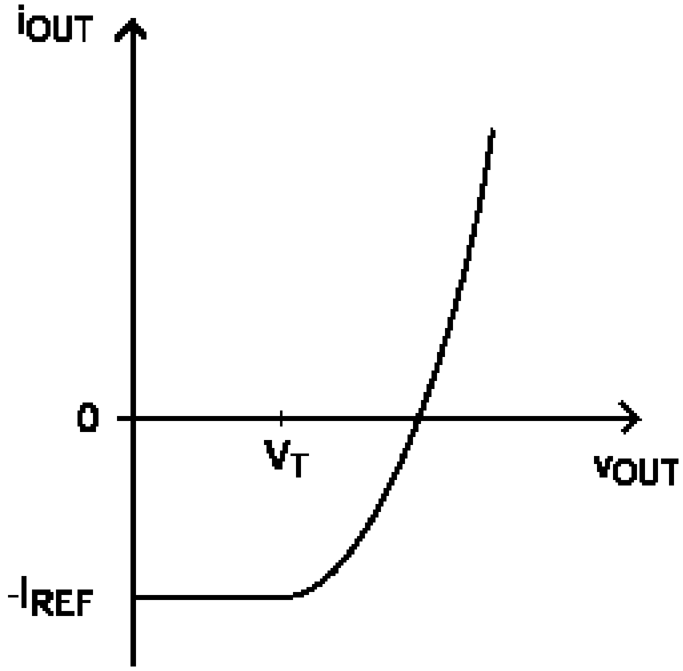
$$I_D = \frac{W}{2L}\mu_n C_{ox}(V_{GS} - V_{Tn})^2 = \frac{W}{2L}\mu_n C_{ox}(V_{DS} - V_{Tn})^2$$

Beyond the threshold voltage, the MOSFET looks like a "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 a value needed to sink current

$$i_D = I_{REF} + i_{OUT} = \frac{W}{2L}\mu_n C_{ox}(v_{OUT} - V_{Tn})^2$$

Then:

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

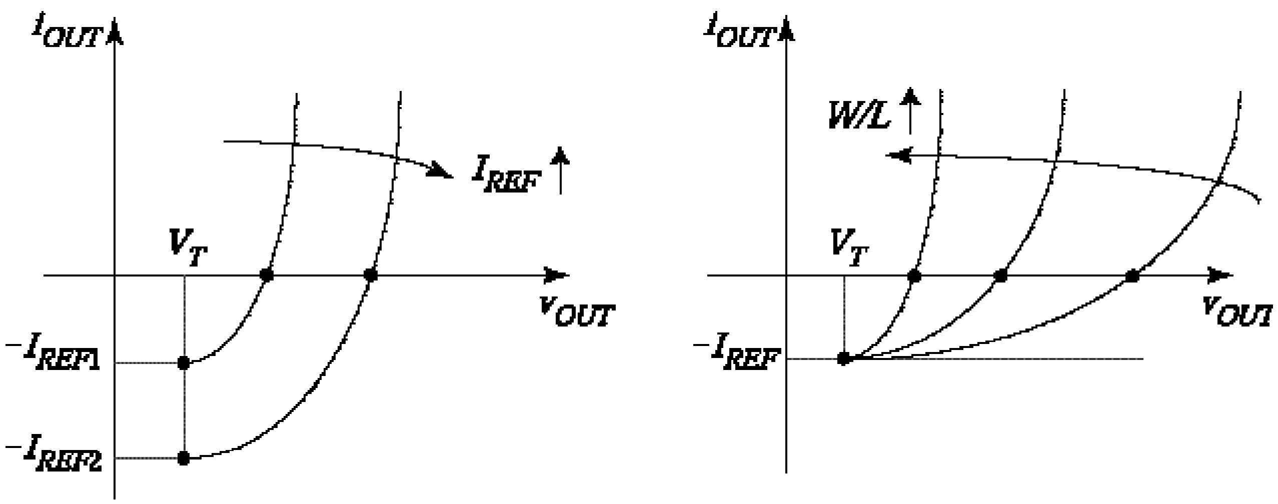
Solving for v_{OUT}:

$$v_{OUT} = V_{Tn} + \sqrt{\frac{I_{REF} + i_{OUT}}{\frac{W}{2L}\mu_n C_{ox}}}$$

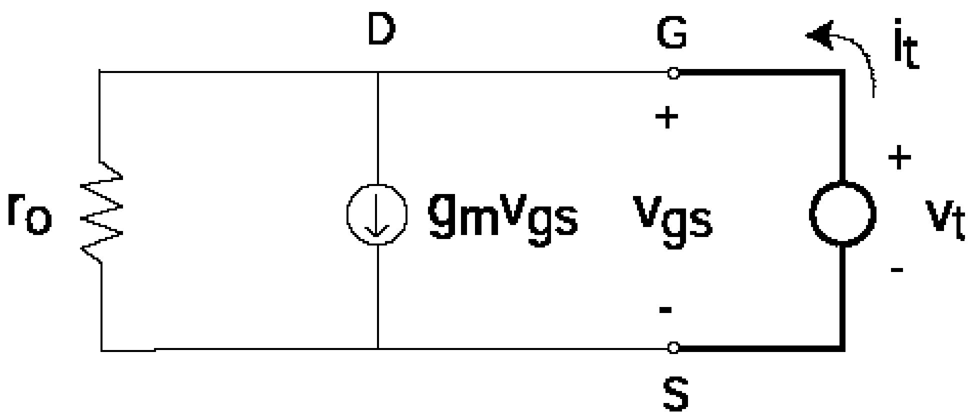
Synthesizing Voltage Sources (contd.)

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

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



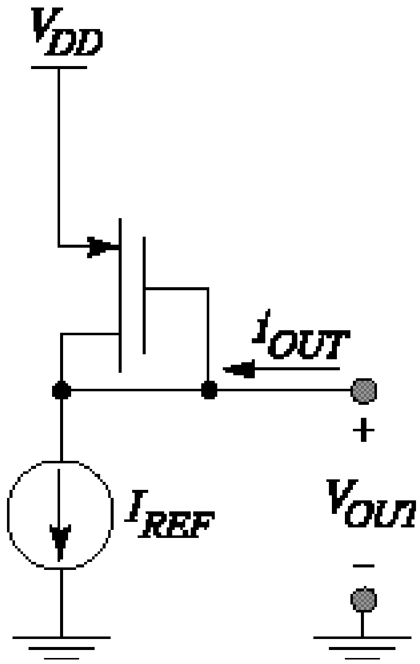
Small Signal Equivalent Circuit Model:



$$R_{out} = \frac{1}{g_m} \| r_o \approx \frac{1}{g_m}$$

R_{out} is small (good!)

PMOS voltage source



Same operation and characteristics as NMOS voltage source. PMOS needs to be larger to attain the same R_{out}.

3. DC Current Sources and Sinks

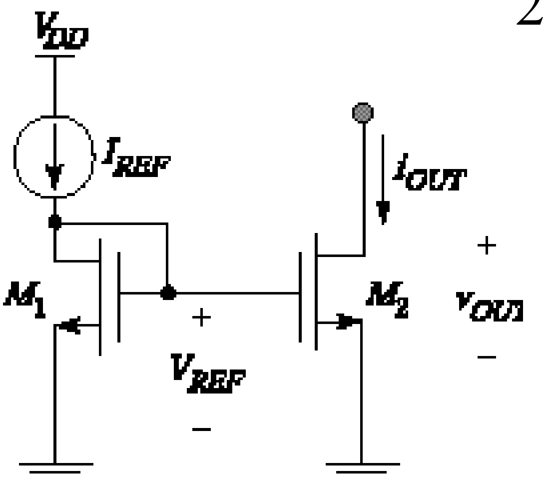
Characteristics of Current Sources

- A well controlled output current
- Supplied current does not depend on output voltage ⇒ ***High Norton Resistance***

Connect a voltage source to the gate of another MOSFET

$$I_{OUT} \approx \frac{1}{2}\left(\frac{W}{L}\right)_2 \mu_n C_{ox}(V_{REF} - V_{Tn})^2$$

$$I_{REF} \approx \frac{1}{2}\left(\frac{W}{L}\right)_1 \mu_n C_{ox}(V_{REF} - V_{Tn})^2$$



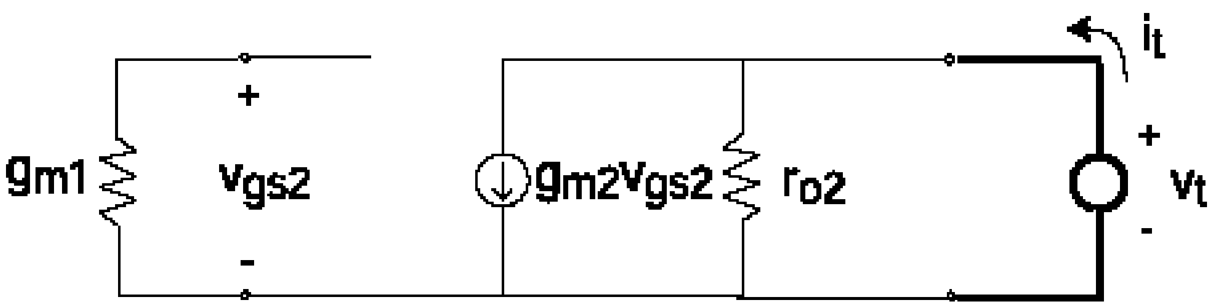
Then: $$I_{OUT} = I_{REF} \frac{\left(\frac{W}{L}\right)_2}{\left(\frac{W}{L}\right)_1}$$

I_{OUT} scales with I_{REF} by W/L ratios of two MOSFETs ⇒ ***Current Mirror Circuit***

Well "matched" transistors important.

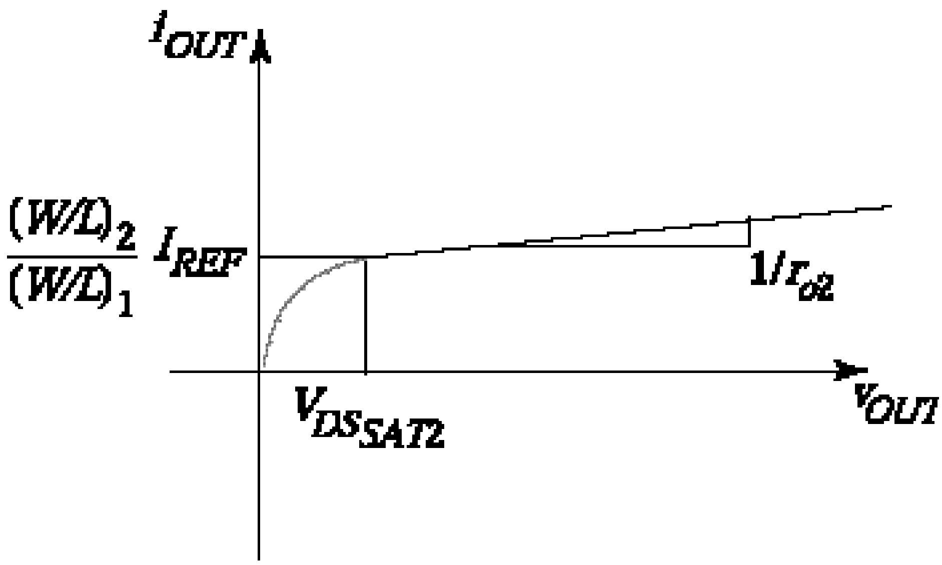
DC Current Sources and Sinks (contd.)

Small Signal Equivalent Circuit Model:



$$R_{out2} = r_{o2}$$

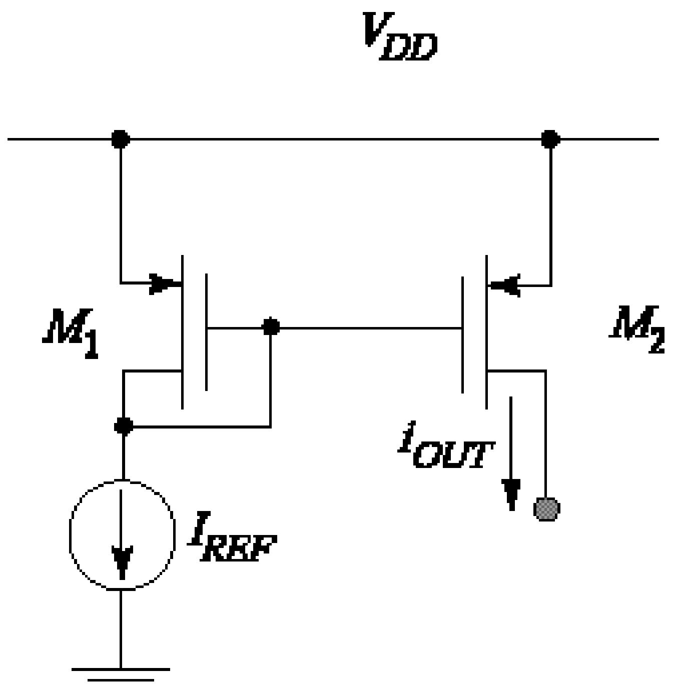
I-V characteristics of NMOS current source:



PMOS Current Source

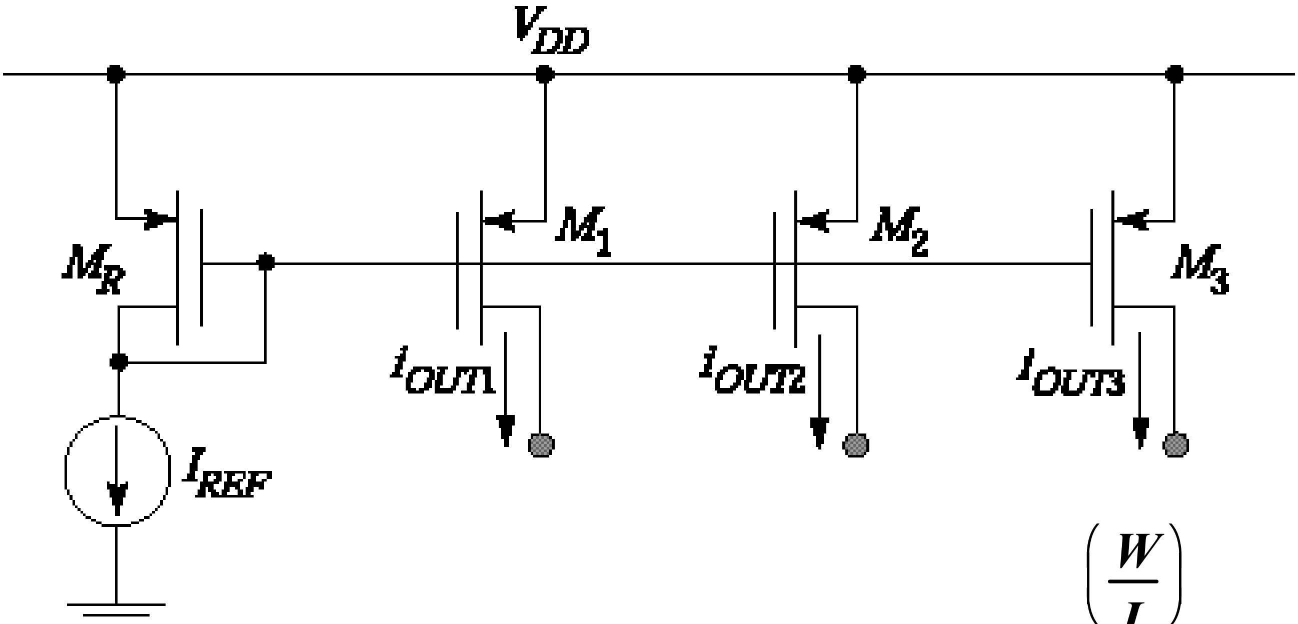
- NMOS current source sinks current to ground
- PMOS current source sources current from positive supply

PMOS Current Mirror:



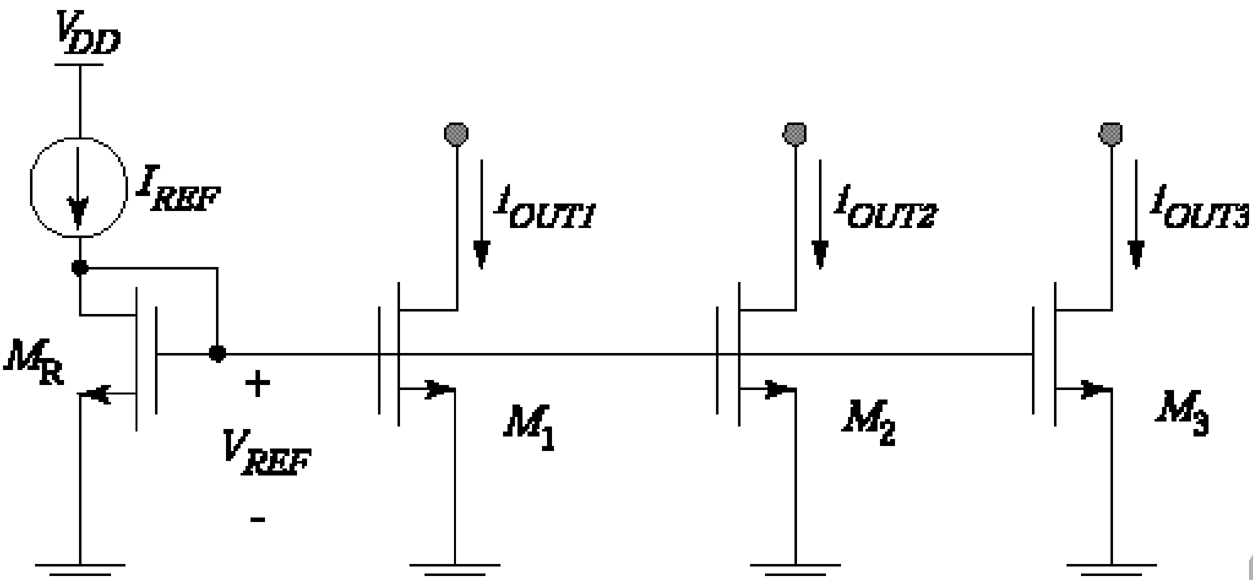
3. Multiple Current Sources

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



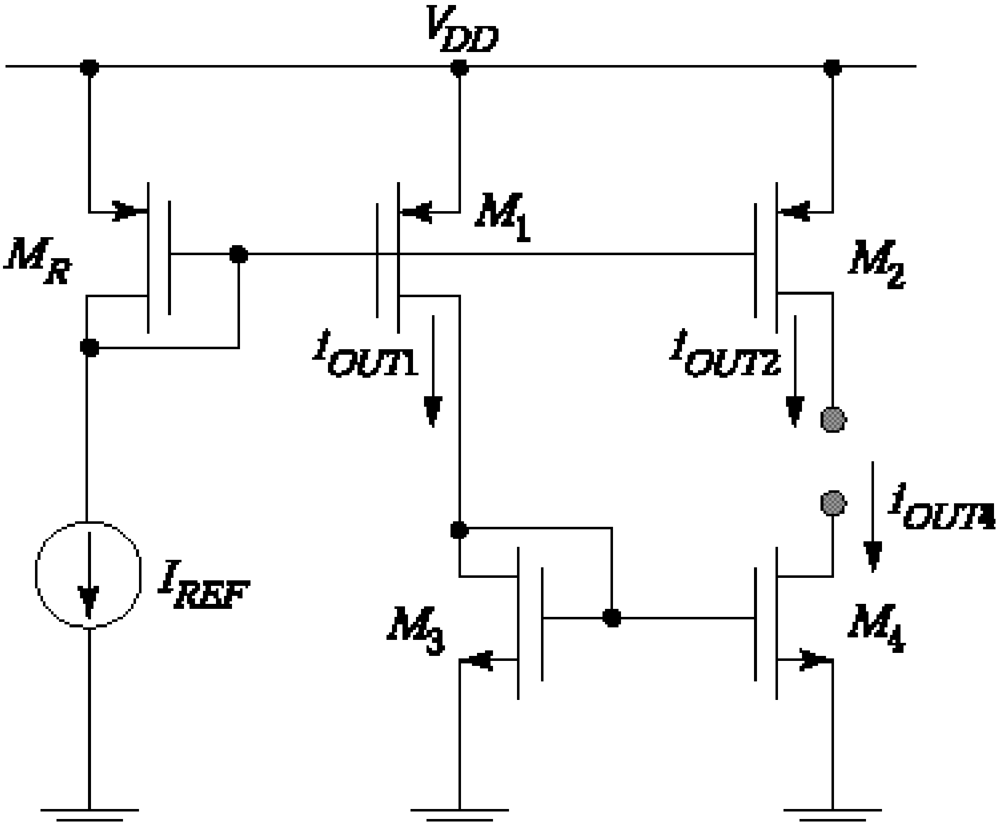
$$I_{OUTn} = I_{REF}\frac{\left(\frac{W}{L}\right)_n}{\left(\frac{W}{L}\right)_R}$$

Similar idea with NMOS current sinks:



Multiple Current Sources and Sinks

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

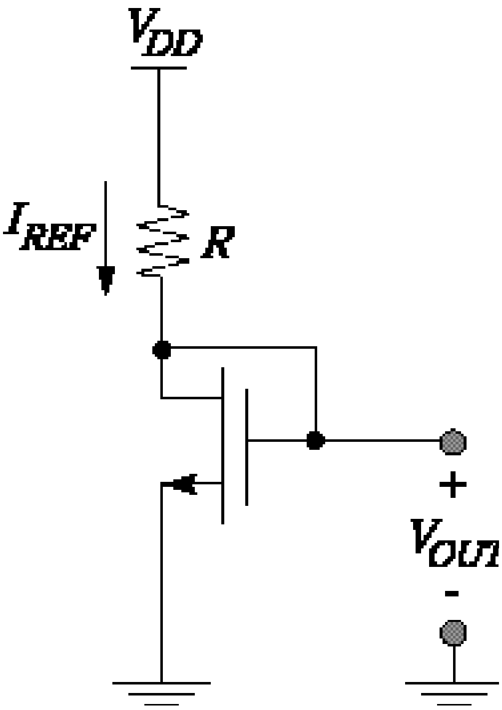


$$I_{OUT1} = I_{REF} \frac{\left(\frac{W}{L}\right)_1}{\left(\frac{W}{L}\right)_R} \qquad I_{OUT2} = I_{REF} \frac{\left(\frac{W}{L}\right)_2}{\left(\frac{W}{L}\right)_R}$$

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

Generating I_{REF}

Simple circuit:



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

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

For large W/L: $$I_{REF} \approx \frac{V_{DD} - V_{Tn}}{R}$$

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

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

What did we learn today?

Summary of Key Concepts

- ***Voltage source*** easily synthesized from **reference *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 can be synthesized from a single current source.
- Voltage and current sources rely on the availability of well "matched" transistors in IC technology.

MIT OpenCourseWare
http://ocw.mit.edu

6.012 Microelectronic Devices and Circuits
Spring 2009

For information about citing these materials or our Terms of Use, visit: http://ocw.mit.edu/terms.