EECS 16B
Designing Information Devices and Systems II

Prof. Ali Niknejad and Prof. Kannan Ramchandran

Department of Electrical Engineering and Computer Sciences, UC Berkeley,
niknejad@berkeley.edu

Module 3: CMOS Models and Digital Logic Gates and Applications

EECS 16B

Outline

- Introduction to Transistors

- Simple Transistor Models

- Logic Gates

- Maximum Clock Rates : RC Circuit

- Op-amp settling behavior

- Applications:

  - Analog-to-Digital Conversion (ADC)

  - Digital-to-Analaog Conversion (DAC)
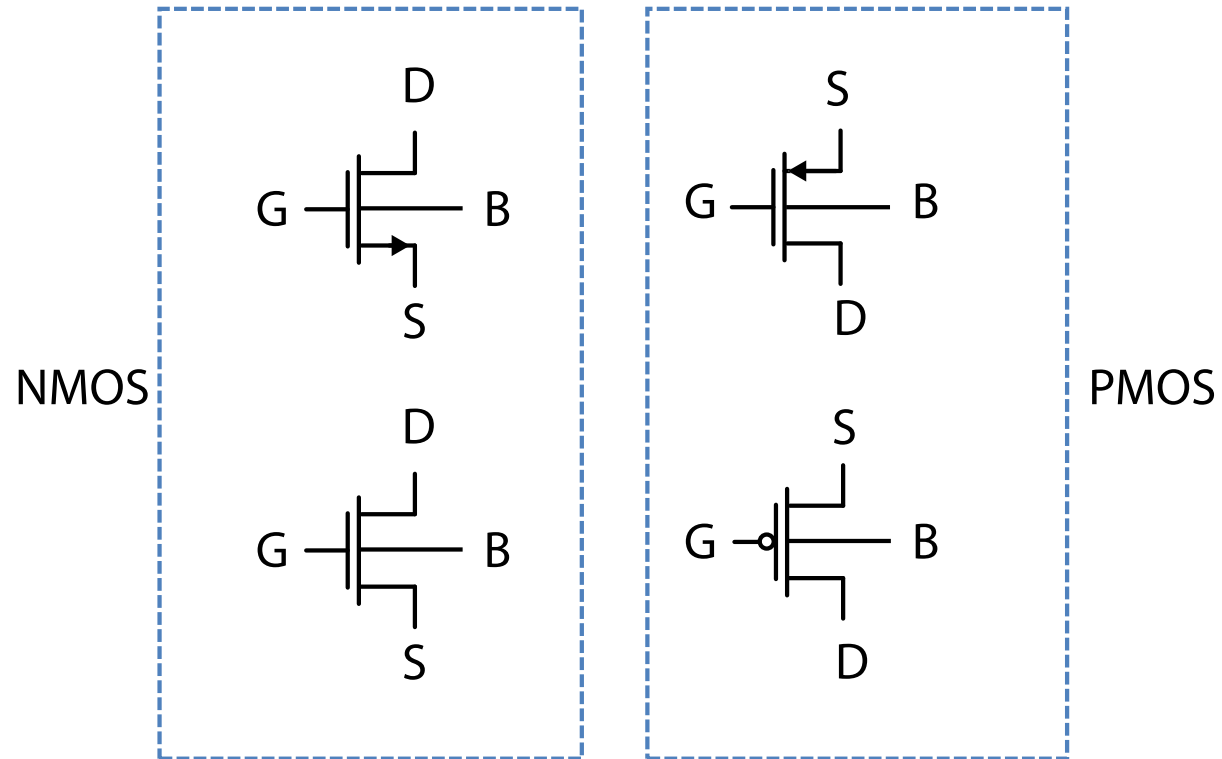
  - Maximum conversion times : RC Circuits !

MOS Capacitor

metal

Gate (n⁺ poly or metal)

p⁺

"Ohmic contact"

Body (p-type)
Semiconductor
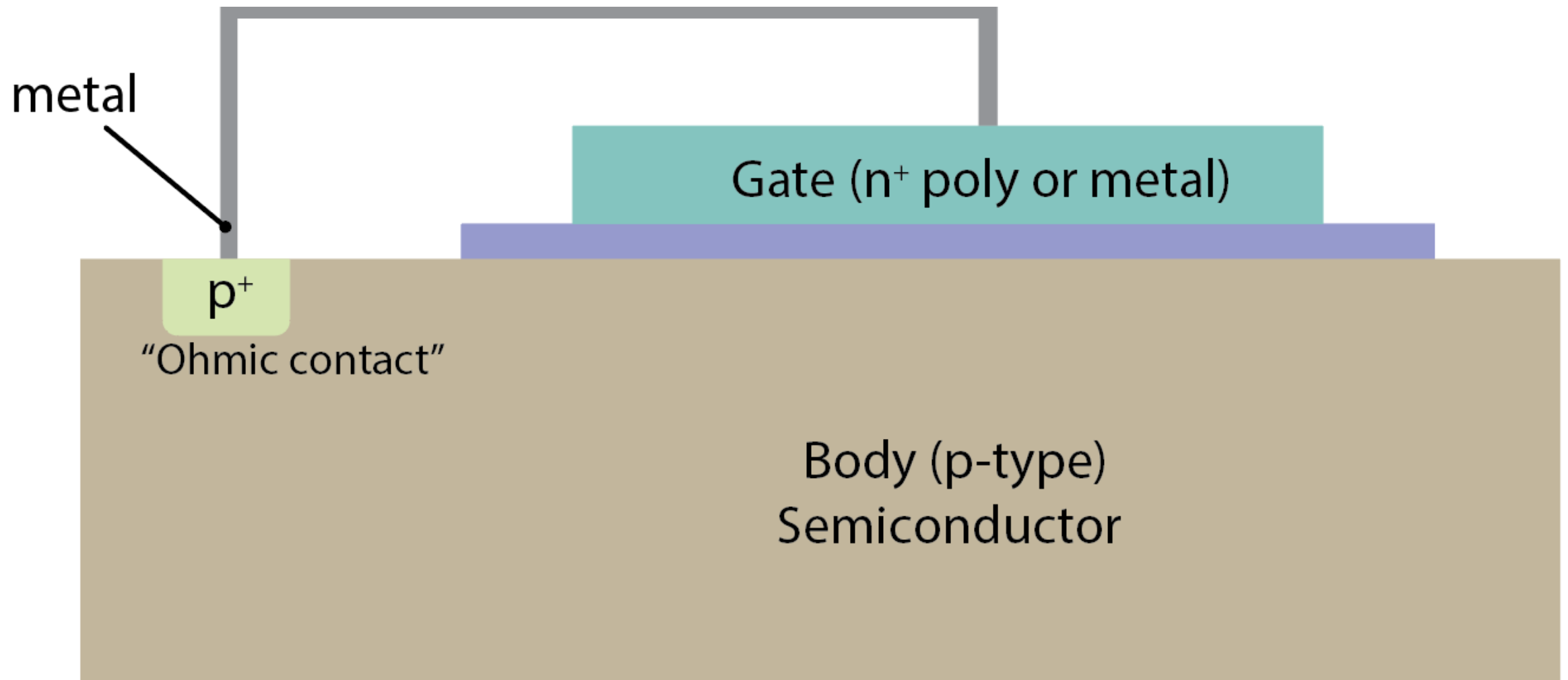
Preview: Transistor
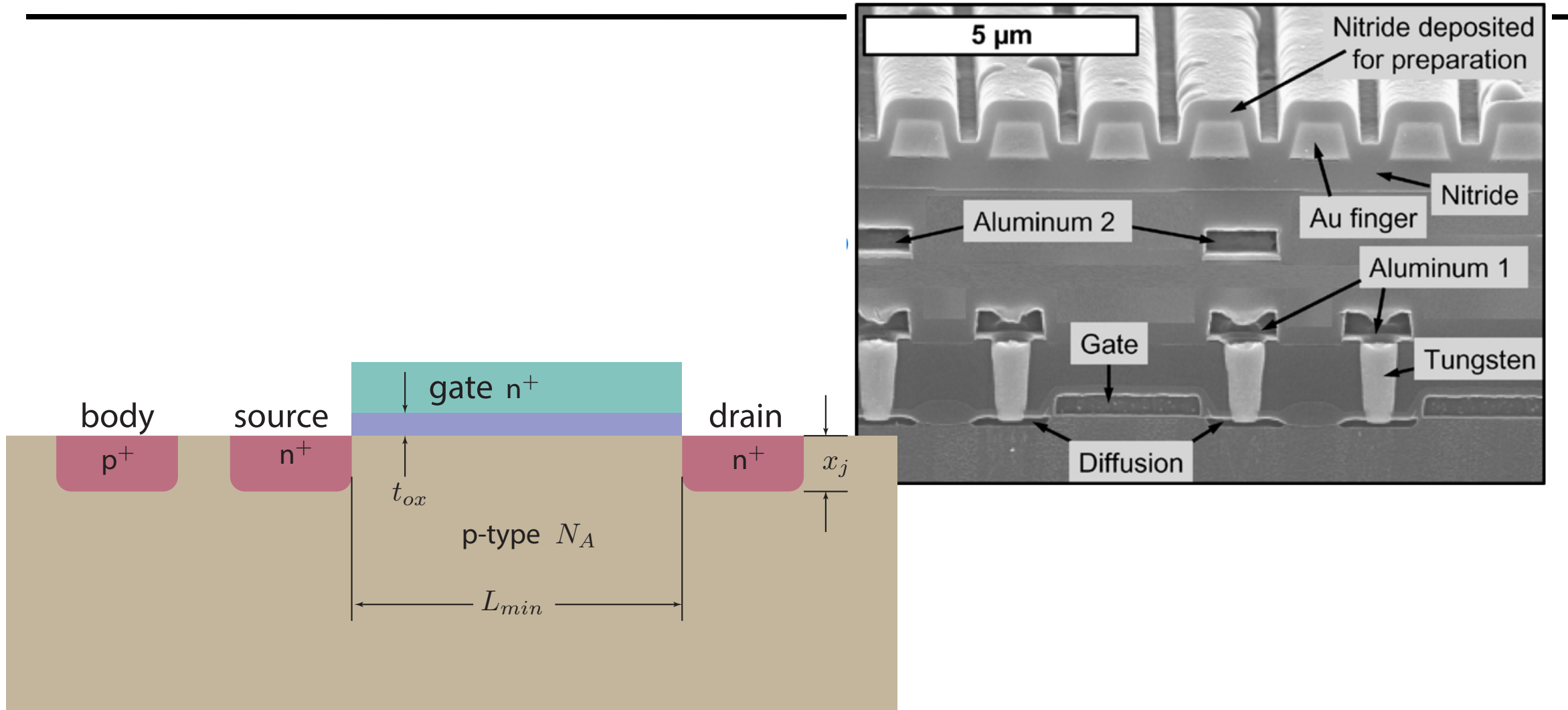
MOS Transistor Schematic

NMOS

PMOS

Toy Physical Model of Transistor

- If we charge up the MOS capacitor, we create a channel that allows current to flow from the source to drain (electron flow)

- If the voltage at the gate is not sufficient to pass a threshold, the path is too resistive and we model it as an open circuit.

Transistors Have Polarity

- You can build two kinds of transistors, ones that use electron flow to establish current and another that uses "holes" (positive charges with about twice the mass of electrons).

- Holes are legitimate quasi-particles that represent electrons moving among the various bonding states (valence band) in a crystal

Transistor As Switch

Transistor I-V Curve

- Constant current and "switch" region

Switch On-Resistance

Switch Gate Capacitance

Switch Off Capacitance

Transistor as a Transconductor

- The channel conductivity is modulated by the gate voltage.

- What's a circuit element that has this property?

CMOS Inverter

Logic Gates
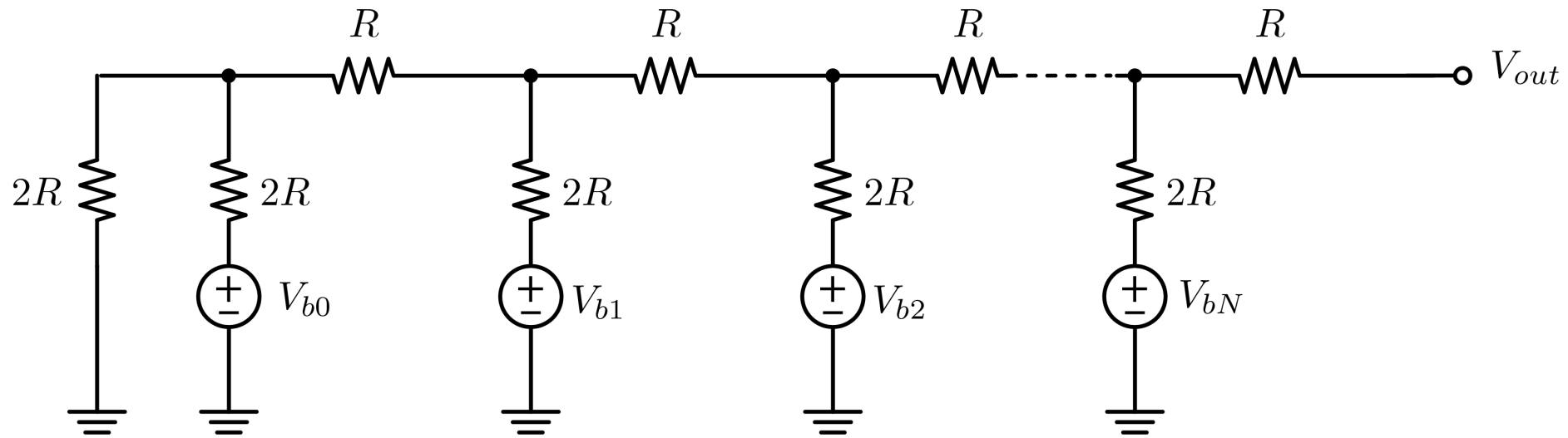
Differential Equations for Inverter

I-V Curve Again

Op-Amp Model with RC
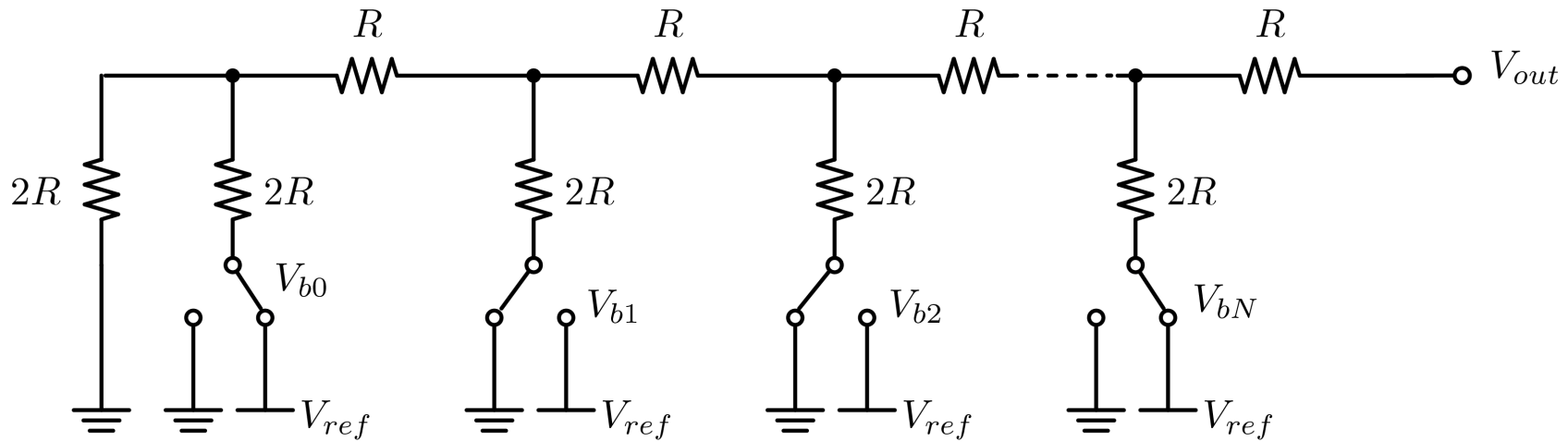
Amplifier Settling Time

Applications

R-2R Ladder Digital-to-Analog Converter

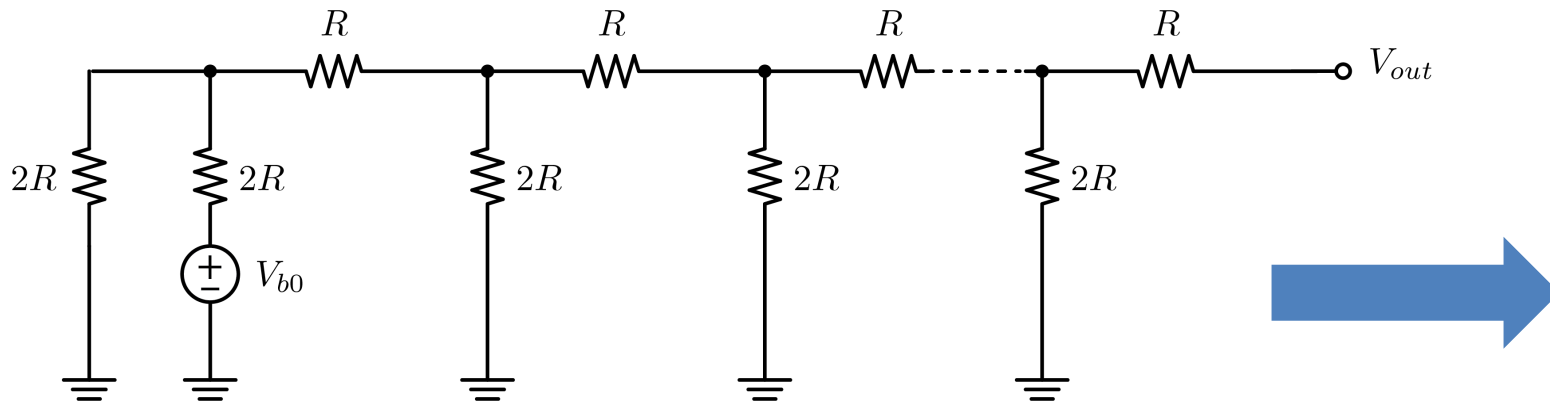How to set all these "digital" voltages?

Switches

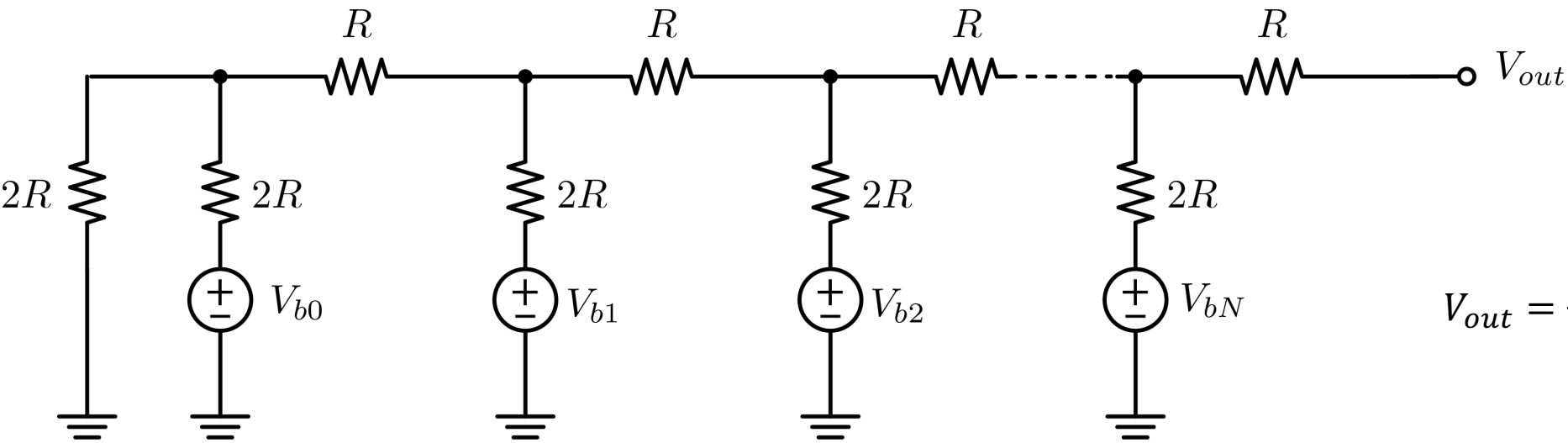# CMOS Gates

Remember Superposition and Equivalence?

R-2R Ladder Digital-to-Analog Converter

Use superposition: Start with first voltage source:

R-2R Ladder Digital-to-Analog Converter

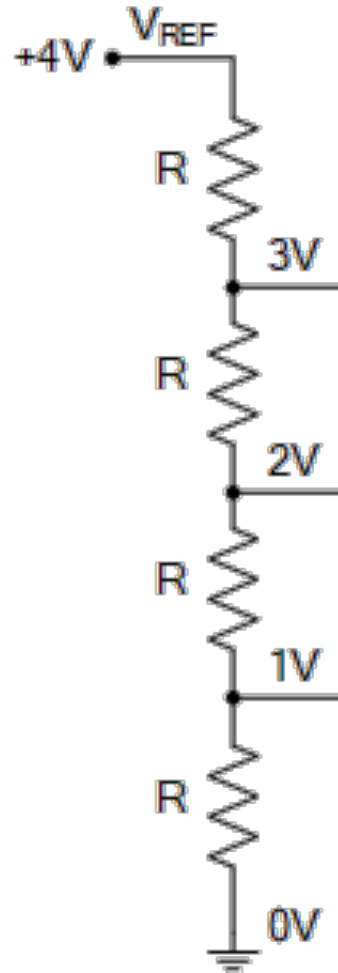Adding all contributions from the sources

$$V_{out} = \frac{V_{b0}}{2^N} + \frac{V_{b1}}{2^{N-1}} + \cdots + \frac{V_{bN}}{2}$$

How fast can we "convert"?

Analog to Digital Conversion

Say we want to convert an analog signal to a 2 bit digital signal → 4 levels

Lab 2: SAR (Successive Approximation Resistor) ADC