EECS 16B

Designing Information Devices and Systems II

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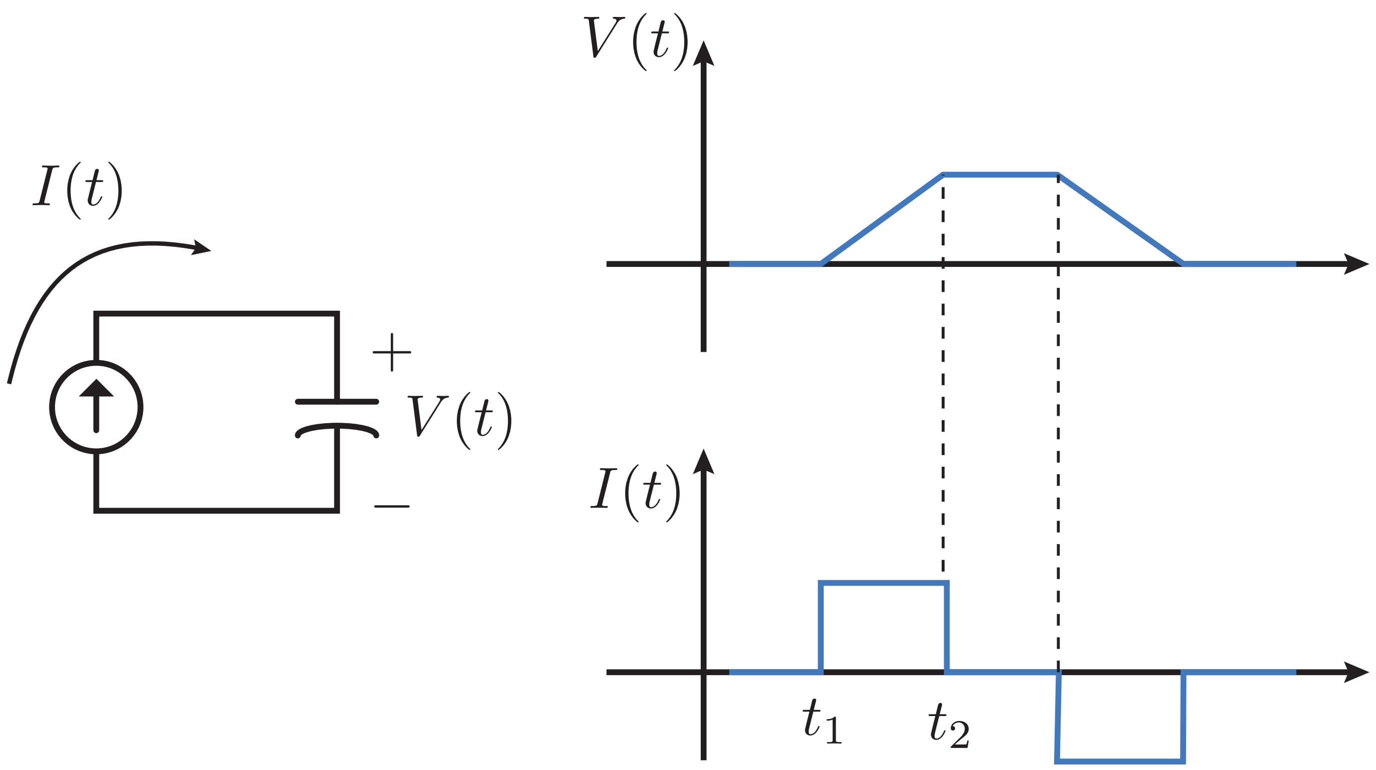
Module 2: RC Circuits, Digital Logic Gates, and Transfer Functions

EECS 16B

RC Circuits

- Solve RC with and without inputs
  - “Natural” response and “forced” response
  - “Moving Average” (Convolution Integral)
- Step Response
- Pulse Response
- Preview: Sinusoidal Steady-State Response
- Low Pass vs High Pass
- Introduction to Transistors

Capacitor Discharge: Linear



Capacitor Discharge

- Water analogy: Rate of outflow is not constant but depends on the height of the water in the tank (the pressure)

RC Circuit

- Can’t solve by “inspection”, need to solve differential equation

RC Solution

- Easy to guess for first-order equation

Capacitor Has “Memory”

- A resistive circuit without capacitors has to memory, the transfer function is instantaneous and if the input goes to zero, the output immediately goes to zero.

Circuit as a System

- Consider inputs (independent voltage/current sources) and outputs (voltages or currents at any node or in any branch of the circuit). Dependent sources are not inputs.

Linear Constant Coefficient Differential Eq.

- Homogenous solution: No inputs. Sometimes called the "natural" solution
- Forced response or a *particular* solution

Superposition

- Equation is linear, so a superposition of solutions is also a solution.

Uniqueness

- Note that for a first-order differential equation, there can be at most one unique solution for the homogenous case

RC Circuit with Inputs

- Now consider an arbitrary source connected to an RC circuit.

Solution with Inputs (Integrating Factor)

Complete Solution

RC Circuits with DC Inputs

Switching Circuits

Step Response

Source Superposition

Pulse Response

Smearing Out Pulses

Reformulation of General Solution

"Moving Average" Interpretation

"Slow Pass" Circuit (Low Pass Filter)

- Suppose a function does not change much on the RC time constant scale

“Fast Pass” Circuit (High Pass)

- Now take the output across the resistor. The transfer function can be written as:

Preview: Sinusoidal Steady State

- Suppose we inject a sinusoidal tone. It's much easier to work with complex exponentials and take the real / imag. part later.

Complex Exponential Solution

Final "Transfer" Function

Why It Worked: Going Around a Circle

- Summing many delayed copies of a complex exponential function still results in a complex exponential. Only magnitude and phase changes.

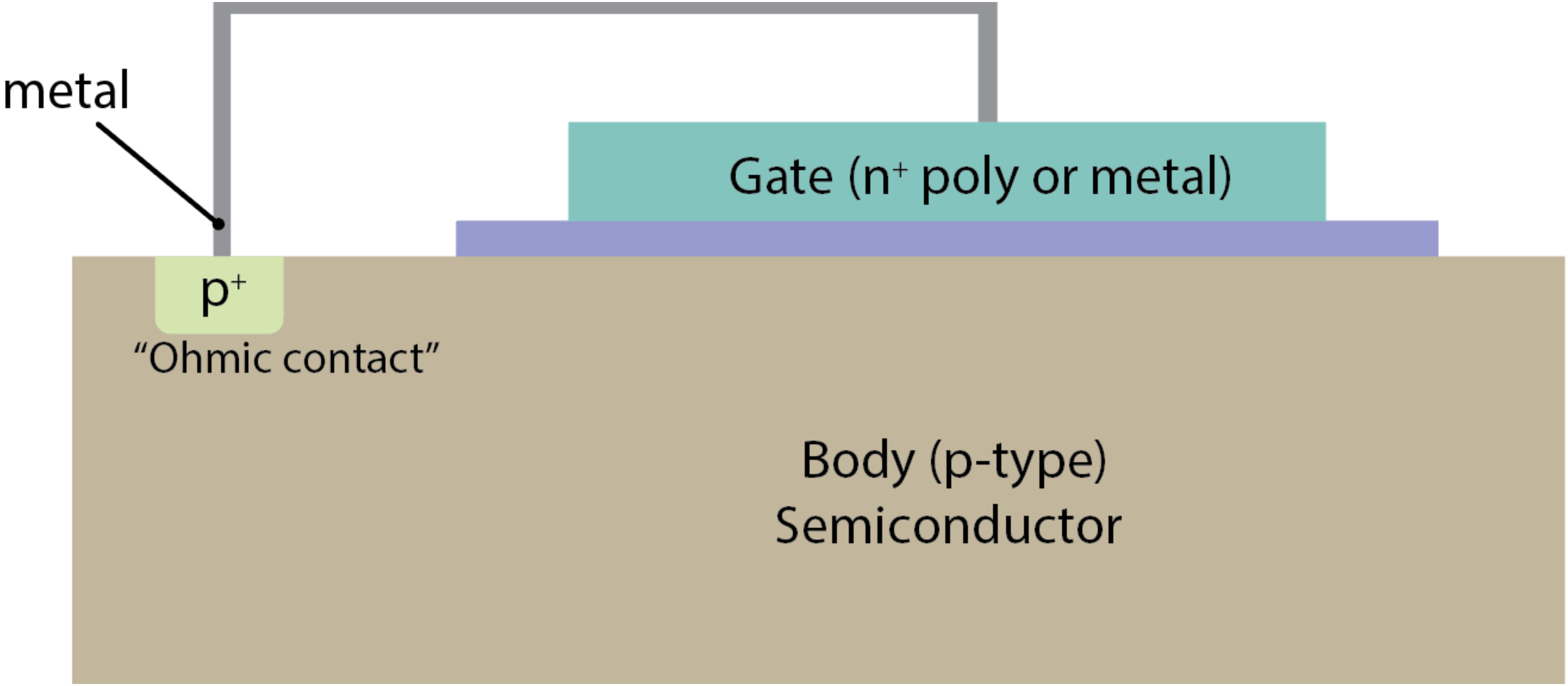
"Natural" Eigenfunction Solution

Low Pass for Sinusoidal Inputs

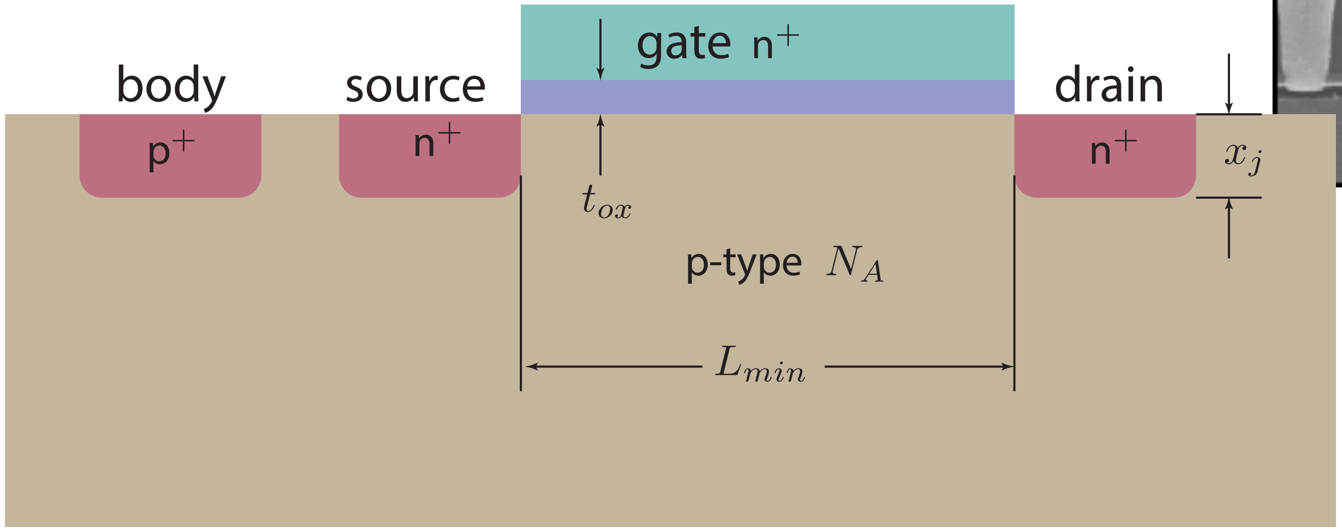
Application: Filtering out Noise

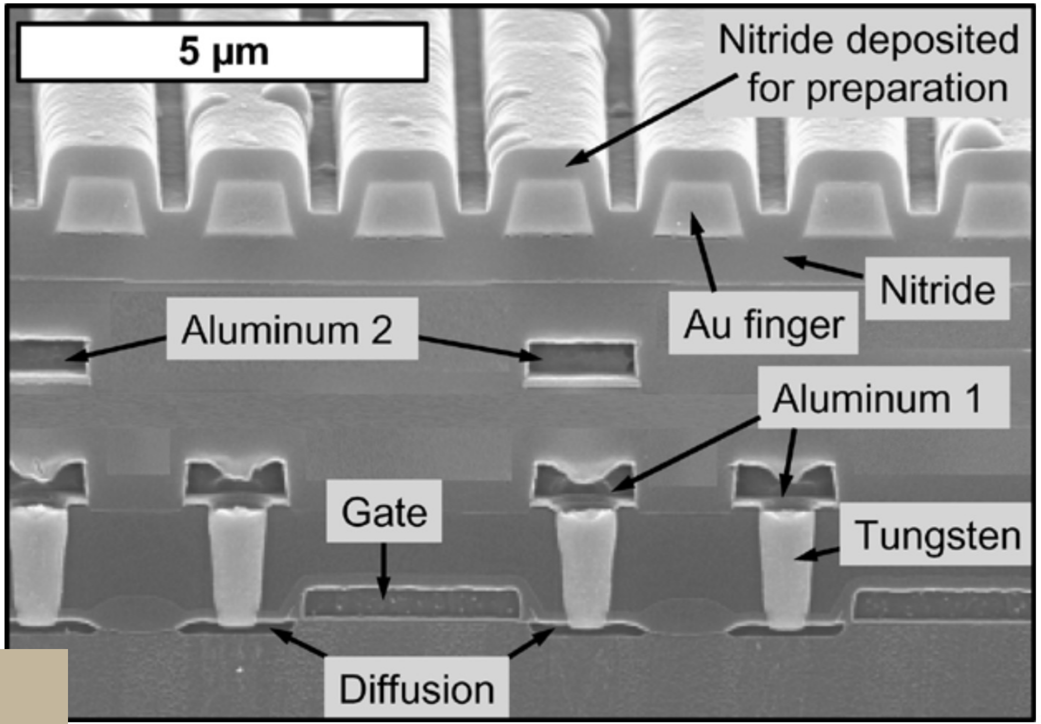
- Listen to an audio signal and note that while speech and music has a lot of distinct tones, noise is random, with many high pitched and low-pitched parts.
- What if we use a “low pass” filter to get rid of high-pitched parts?

MOS Capacitor

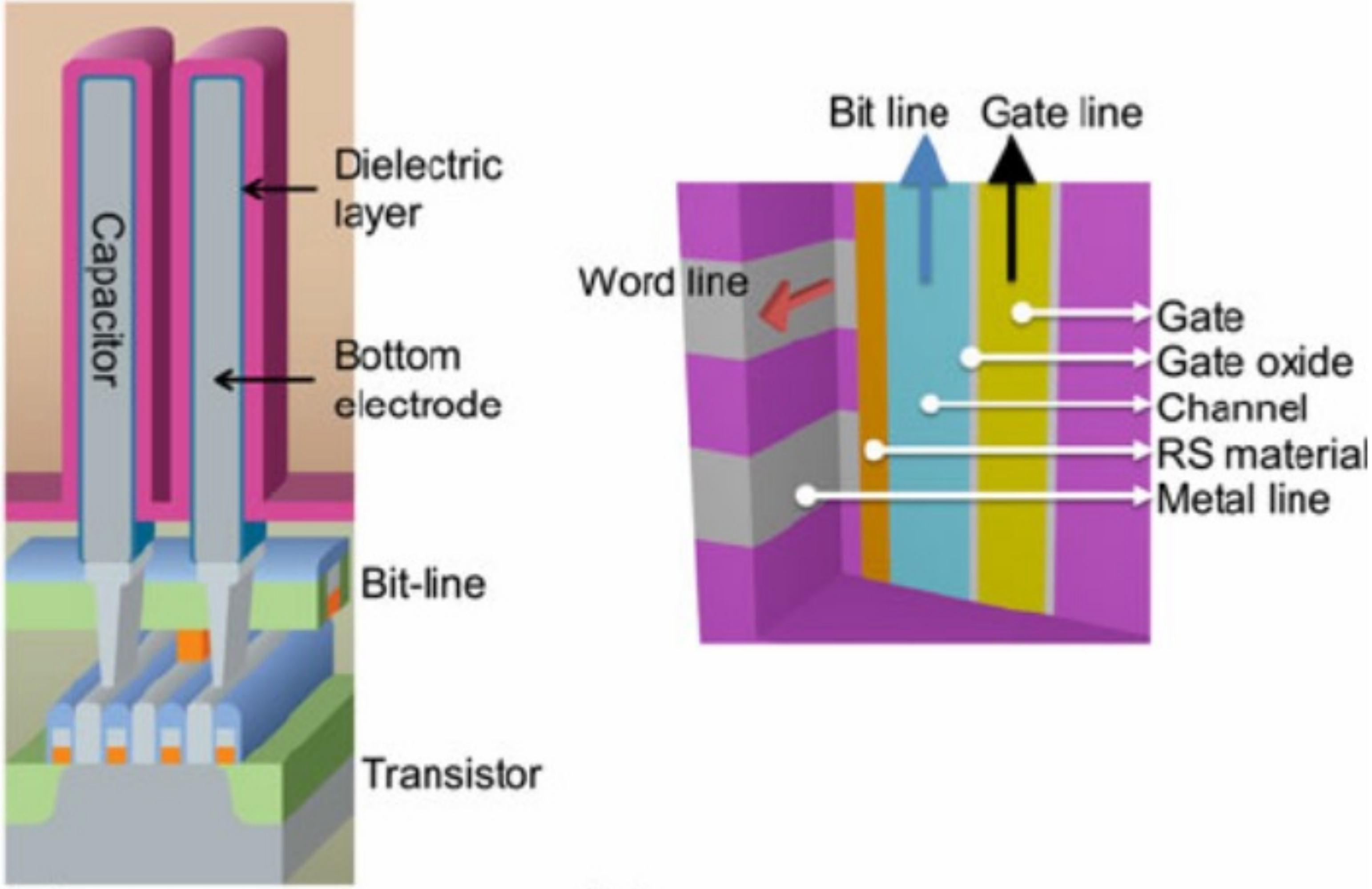


Preview: Transistor



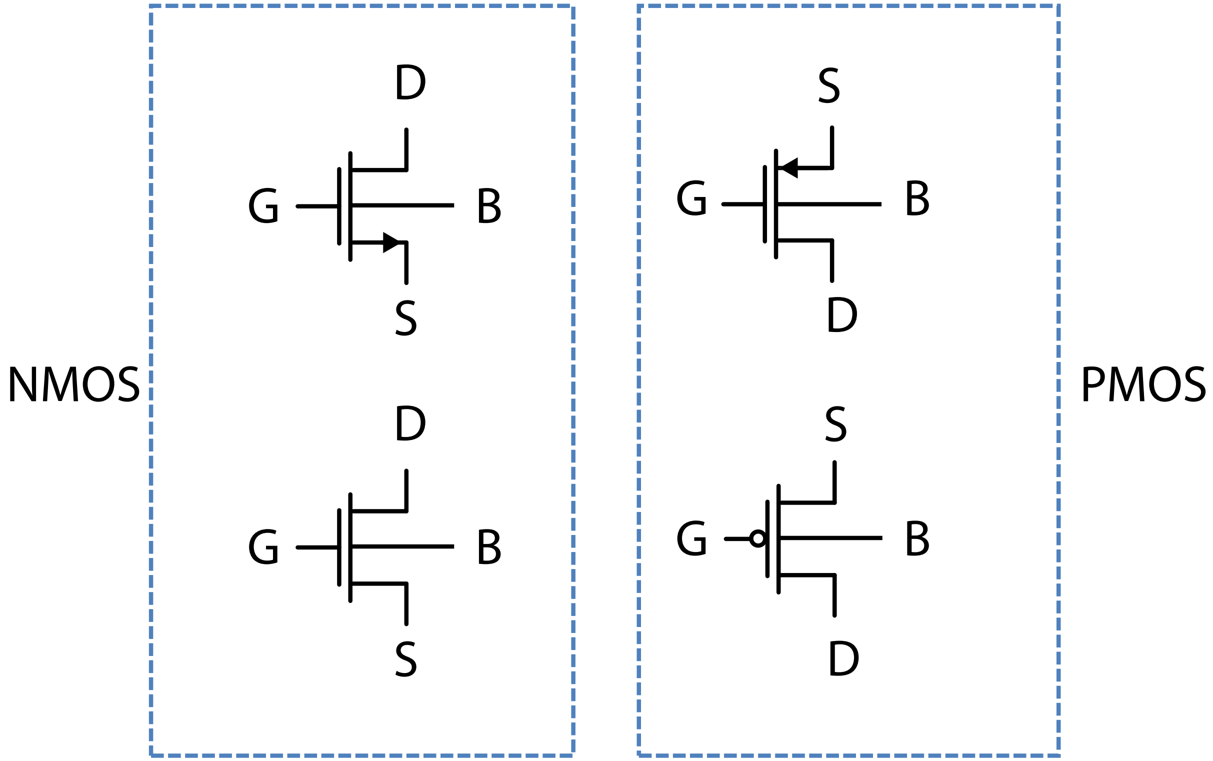


DRAM



https://www.researchgate.net/figure/Schematic-diagrams-of-a-DRAM-cells-which-consist-of-a-cell-transistor-and-capacitor_fig1_258797946

MOS Transistor Schematic



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 as a Transconductor

- The channel conductivity is modulated by the gate voltage.
- What's a circuit element that has this property?

Op-Amp Model with RC