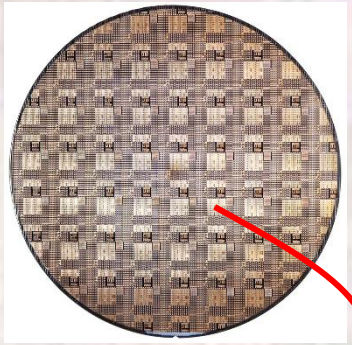
CMOS Transistor Basics

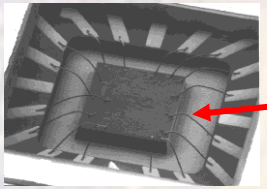
Last updated 1/6/25

CMOS Transistor Basics

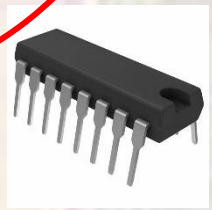
- Integrated Circuit (IC) technology
  - Built on wafers
    - 4" → 12" diameter
    - Multi $B factories
    - Mostly run with automation – few people
      - See videos on website
  - Cut into individual die
  - Packaged into IC 'chips'



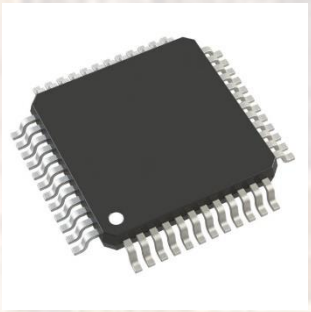
100s to 1000s of die per wafer



die bonded in package



dual inline package



quad flat package

CMOS Transistor Basics

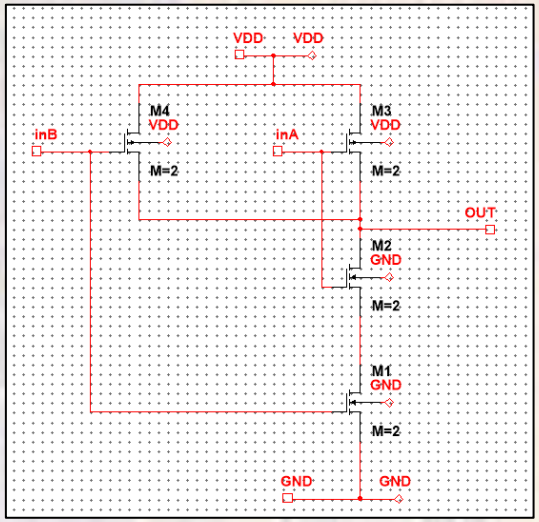
- Semiconductor Component History
  - 1960s
    - Junction Diodes
    - Bipolar Transistors
      - NPN, PNP
  - 1970s
    - N-MOS Transistors
    - P-MOS Transistors
    - C-MOS Transistors
  - 1990s
    - FinFET Transistors
  - 2000s
    - All Around Gate Transistors
  - Continuous shrinking of technology

CMOS Transistor Basics

- Modern Day
  - All modern digital ICs (integrated Circuits) are built on CMOS technology
  - Only exception is very small circuits designed to be backward compatible to earlier Bipolar technologies

Basic Logic Gate (NAND-2)

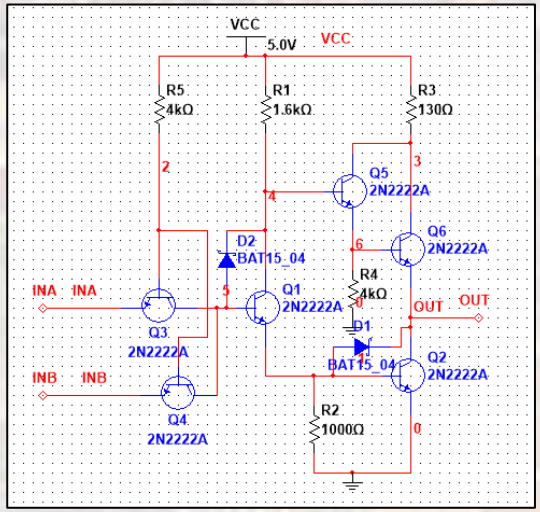
CMOS



4 transistors

Small, low power

Bipolar



6 transistors
2 diodes
5 resistors

Large, high power

CMOS Transistor Basics

- CMOS
  - Complimentary Metal Oxide Semiconductor
    - Integrated Circuit technology
  - Dominates digital circuit design
    - Small
    - No DC power
  - Many variations
    - Referenced by generation: 1um, 100nm, 10nm, 7nm, 5nm, …
    - Shrinking sizes lead to more ‘stuff’ in a fixed area
  - 2 primary devices (complimentary)
    - N-Channel (NMOS, N-type)
    - P-Channel (PMOS, P-Type)

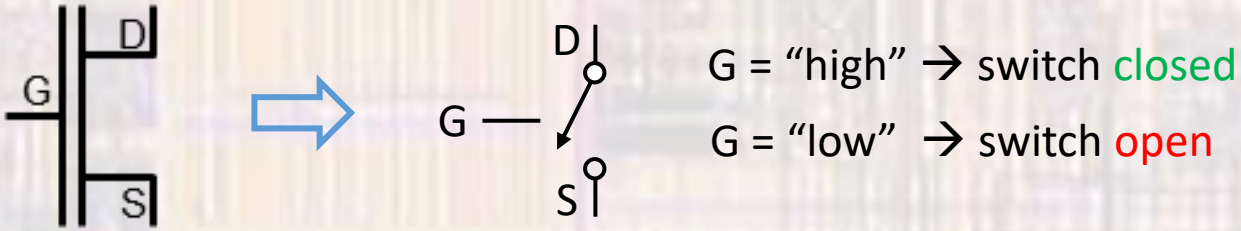
CMOS Transistor Basics

- N-Channel (NMOS, N-type)
  - Primary current carrier – electrons
  - 4(3) terminals
    - Gate – control
    - Drain/Source – current flow
    - Body – fixed connection for digital designs

digital version

CMOS Transistor Basics

- N-Channel (NMOS, N-type)
  - Full transistor characteristics very complicated
  - 2 Levels of abstraction
    - Ideal Switch



CMOS Transistor Basics

- N-Channel (NMOS, N-type)
  - Full transistor characteristics very complicated
  - 2 Levels of abstraction
    - Complex Switch

G = “high” → R small

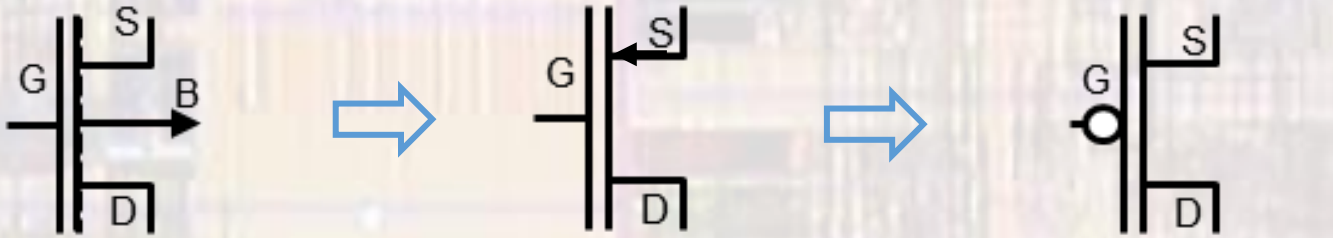
G = “low” → R large

R ↓ as transistor size ↑

C ↑ as transistor size ↑

CMOS Transistor Basics

- P-Channel (PMOS, P-type)
  - Primary current carrier – holes (positive charge)
  - 4(3) terminals
    - Gate – control
    - Drain/Source – current flow
    - Body – fixed connection for digital designs



digital version

CMOS Transistor Basics

- P-Channel (PMOS, P-type)
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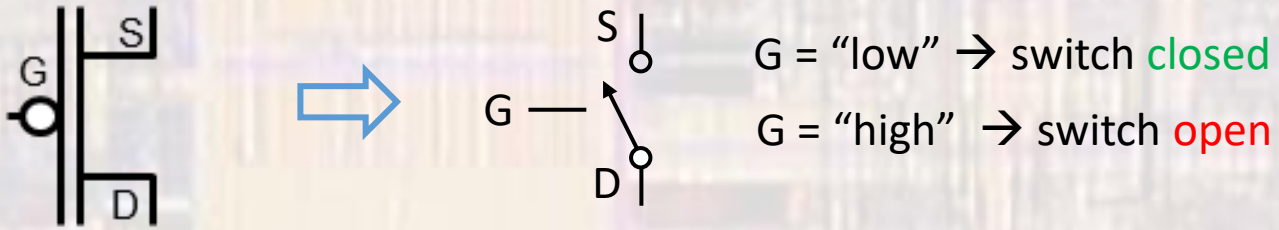
  - 2 Levels of abstraction
    - Ideal Switch



CMOS Transistor Basics

- P-Channel (PMOS, P-type)
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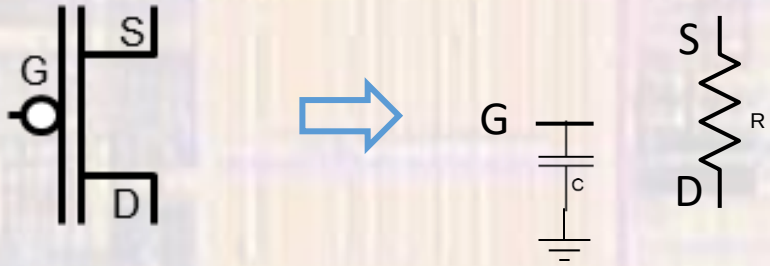


G = “low” → R small

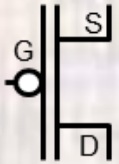
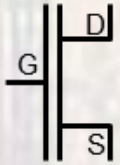
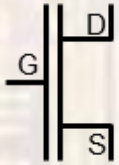
G = “high” → R large

R ↓ as transistor size ↑

C ↑ as transistor size ↑

CMOS Transistor Basics

- Complimentary
  - For the same Gate value
    - One is on and the other is off

	G = "high"	G = "low"
PMOS	 open	 closed (shorted)
NMOS	 closed (shorted)	 open

CMOS Transistor Basics

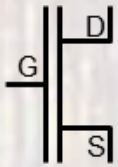
- A little more detail
  - NMOS devices do not turn on (close/short) until the gate voltage reaches a small positive voltage
  - Threshold voltage - Vt_N
    - 0.7v for 3.3V systems
    - 0.45v for 1.2V systems
  - PMOS devices do not turn on (close/short) until the gate voltage reaches a small voltage below V_{DD}
  - Threshold voltage - Vt_P
    - 2.7v for 3.3V systems
    - 0.75v for 1.2V systems

CMOS Transistor Basics

- Digital Iconography
  - In digital circuits, a ○ (bubble) indicates opposite (inverted) operation
    - The NMOS is ON when the gate is high → active high
    - The PMOS is ON when the gate is low → active low → ○

PMOS

NMOS



CMOS Transistor Basics

- CMOS Transistor Parameters
  - Gate terminal
    - Looks like a capacitor to ground
  - S/D terminals
    - Look like a variable value resistor between S/D
  - Size
    - Large transistors
      - Larger gate capacitance
      - Smaller resistance values
    - Small transistors
      - Smaller gate capacitance
      - Larger resistance values
    - P vs. N
      - Same gate capacitance for the same size
      - P is weaker than N for a given size
        - R_{ON-P} 2x to 3x R_{ON-N}