EEC 116 Lecture #13: Future Directions
Alternatives to CMOS
Final Review

Rajeevan Amirtharajah
University of California, Davis
Digital Circuits Beyond CMOS

• Past digital technologies
  – Electromagnetic Relay: mechanical switch controlled by a current; ideal switch but high power and slow
  – Vacuum Tube: three (usually) terminal device, similar to a MOSFET but very high power
  – Bipolar Transistor: high transconductance, but high power, finite input impedance limits fanout

• State-of-the-art digital technology is bulk silicon CMOS
  – Low power, little static power (compared to other technologies)
  – Infinite input impedance allows large fanouts
  – Vast development investment has led to extremely high reliability, high yields, and high performance
Digital Circuits Beyond CMOS

• Modifications on CMOS can extend Moore’s Law
  – Strained silicon: mechanical stress on bulk crystal improves mobility
  – Silicon-on-Insulator: insulating bulk decreases parasitic capacitors, allows tighter integration
  – New materials: low-k interconnect dielectrics, high-k gate dielectrics, metal gates
  – New structures: 3D gates (finFET)

• But what happens when scaling stops?
  – International Technology Roadmap for Semiconductors extends to about 20 nm gate lengths in 2015-2020 time frame
  – Research devices demonstrated down to 5 nm gate lengths
Nanometer Gate Length Bulk FETs

- Still more room at the bottom!
- In 10 nm CMOS, Intel 386 occupies 25 μm x 25 μm
- Fabricated using a combination of lithography and epitaxial growth to define feature sizes
Three Dimensional Transistors: FinFETs

- Channel forms in thin silicon fin
- Gate wraps around fin to control channel formation
- Allows very small channel lengths

Hisamoto, JSSC 2000
Digital Circuits Beyond CMOS

• New devices based on new materials or quantum effects

  – Gallium Arsenide (GaAs) MESFET: high electron mobility but no complementary device and poor oxide isolation

  – Josephson Junctions: superconducting logic and interconnect promises very high speed (THz), but only two terminals inconvenient for circuit design

  – Carbon Nanotube Transistors: carbon nanotube devices demonstrate high carrier mobilities and promise high speed

  – Molecular Electronics: single organic molecules shown to switch states in the lab, but also only two terminals

  – Organic Electronics: semiconducting plastic substrate, enables flexible displays and low cost but offers poor performance
Alternatives to Electronics

- A number of completely different digital technologies
  - Optical Computing: use photons to carry information instead of charge carriers, but no good three terminal nonlinear optical element and difficult integration
  - Quantum Computing: using various atomic-scale structures to store multiple bits simultaneously and operating on them using laws of quantum mechanics allows massive parallelism, but very sensitive to noise
  - Biological Computing: use DNA gene coding and promoter and repressor sites to control synthesis of proteins, which form the digital “signals”

- But can anything replace CMOS?
  - Maybe, but not for a long time
  - Some parts of a system (memory) before others (logic)
Final Exam Review List

Closed Book, Closed Notes, 1 8.5 in. x 11 in. Formula Sheet allowed, both sides, (You may bring a calculator)

- MOS Fabrication (very basics)
- MOS Structure
- Inverter Operation
- CMOS Inverter (Static Characteristics, e.g. VTC)
- CMOS Inverter (Dynamic Characteristics, e.g tpd, etc.)
- Complex Gates
  - DC and Transient characteristics
- Sequential Logic (setup time, etc.)
- Layout
Final Exam Review List

- Pass Transistors
- Memory (DRAM, SRAM, Flash, ROM)
- Low Power Circuits
- Arithmetic Circuits
- Interconnect
- Study all homework and lecture materials
- Study labs
Key Learnings

- Should know what region of operation the transistor is in given the bias voltages at its terminals
- Should know what the PMOS and NMOS $I_d$ vs $V_{ds}$ curves look like
- Be able to identify major points of the VTC for a CMOS Device [$V_{oh}, V_{ol}, V_{ih}, V_{il}, V_m$]
- Need to know how to calculate the total capacitance at the output node (including Miller effect)
- Know the relevant capacitances of a transistor used in transient analysis (i.e. $C_{gs}, C_{gd}, \ldots$).
Key Learnings

• Know how to calculate propagation delay using Req and capacitance load. Be able to derive Req and Cload.
• Know how to find a circuit schematic from layout.
• Know Different Adders and Multipliers
  – Know concepts of how they speed up these arithmetic units
• Memory (different types, SRAM operation)
• Low Power Design techniques (voltage scaling, pipelining, etc.)
• Interconnect basics (resistance, capacitance)
Key Learnings

• Know how to find the Boolean function from a schematic

• Know how to properly size transistors to get the equivalent resistance of a basic inverter

• Know how to size devices

These are here to help focus your study but is not an exhaustive list of what you are responsible for.