Digital Integrated Circuits – EECS 312

http://robertdick.org/eecs312/

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[Text and diagrams related to digital integrated circuits and semiconductor history and developments.]
Lecture plan

1. Administrative details
2. Context for digital integrated circuit design
3. Course topics
4. Homework assignment
# People

<table>
<thead>
<tr>
<th>Role</th>
<th>Name</th>
<th>Contact Information</th>
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</thead>
<tbody>
<tr>
<td>Instructor</td>
<td>Robert Dick</td>
<td><a href="http://robertdick.org/">http://robertdick.org/</a> <a href="mailto:dickrp@umich.edu">dickrp@umich.edu</a></td>
</tr>
<tr>
<td>Lecture</td>
<td>1010 DOW</td>
<td>Tuesdays and Thursdays, 14:30–16:00</td>
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<tr>
<td>Office hours:</td>
<td>2417-E EECS</td>
<td>Tuesdays and Thursdays, 16:00–17:00</td>
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<td></td>
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<td>plan to extend when demand is high</td>
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<tr>
<td>Teaching assistant</td>
<td>Shengshuo Lu</td>
<td>Email: <a href="mailto:luss@umich.edu">luss@umich.edu</a></td>
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<tr>
<td>Discussion</td>
<td>1303 EECS</td>
<td>Fridays, 12:30–13:30</td>
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<tr>
<td>Office Hours</td>
<td>2725 BBB</td>
<td>Mondays, 10:30–12:30</td>
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<td>Thursdays, 17:30–19:30</td>
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Exams

- **Midterm exam:** 10 October
- **Final exam:** 1:30–3:30 20 December
Purpose of Course and Course Objectives I

- Analyze and design combinational and sequential digital circuits in various logic families.
- Learn trade offs among styles, e.g., noise immunity vs. speed and density vs. static power.
- Teach students to analyze the effect of interconnect parasitics on circuit performance.
- Learn common memory structures (ROM, SRAM, and DRAM) will be described.
- Learn to use SPICE and Cadence schematic capture tools.
- Introduce students to important future trends in large-scale digital circuit design, including manufacturability issues and barriers to device scaling.
Grading and written feedback

- Solutions will be posted.
- Help with assignments and projects available during office hours and discussion sessions.
- I may give you a supplementary reading assignment, but after you have read the required material it is fine to sit in my office doing problems and asking questions when you get stuck.
Grading philosophy

- No fixed number of As, Bs, etc. for the class.
- If the class performs well, there will be more As than average.
- The converse is also true.
- When you help classmates, you needn’t have much concern about undermining your own course grade.
Any student may discuss the problem and design ideas with any other students. However, students are individually responsible for preparing, evaluating, and reporting on their designs.

Share ideas and discuss assignments.

Do not copy the schematics, simulation results, or reports of other students.

If you feel that you must do this, report it openly so credit can be appropriately adjusted (removed).

Continued participation in the course implies that you understand that discussion is fine but claiming credit for copied work is cheating.
Textbook

Other references


Four homework assignments

- A week and a half allowed for each.
- Homework due at the beginning of lecture.
- 5% penalty if late on same day.
- 10% penalty per day for late assignments.
- No credit after assignment covered in class or discussion session.
- Penalty is gradual – avoid all-nighters.
  - The goal is competence, not exhaustion.
- Maximum of two late days per assignment to permit timely release of solutions.
Four laboratory projects and a final project

- Two weeks allowed for each laboratory project.
- Laboratory assignments have 10% per day late penalty.
- Three and a half weeks allowed for the final project.
Grade Weightings

- Midterm exam: 15%
- Final exam: 30%
- Laboratory assignments: 20%
- Final project: 20%
- Homework: 10%
- Research on special topic: 5%
On lectures and notes

- I will use lecture slides and post them.
- However, the slides just provide context and make sure the most important topics are covered.
- I will diverge based on questions and current events.
- Therefore, you should see the on-line lecture notes, and take additional notes in class.
Lecture plan

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Where EECS 312 fits in one example curriculum
Section outline

2. Context for digital integrated circuit design

Digital integrated circuits are everywhere
What is a digital system?
What good are ICs?
How are ICs designed and fabricated?
Integrated circuits are everywhere

Cars, environmental control, computers, communication, etc.
Integrated circuits are everywhere

Cars, environmental control, computers, communication, etc.
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Cars, environmental control, computers, communication, etc.
Section outline

2. Context for digital integrated circuit design
   Digital integrated circuits are everywhere
   What is a digital system?
   What good are ICs?
   How are ICs designed and fabricated?
What is a digital system?

- List possible digital system components on paper.
- List examples of non-digital systems or components.
What distinguishes the two?

- How are “digital” components built?
- This course sits between the analog world and the digital view we would like to superimpose on it to simplify design. It bridges physics and computation.
- You will learn the fundamentals of designing digital integrated circuits from individual transistors.
Example digital systems

- Combinational systems
- Sequential systems
- Instruction processors
- Reconfigurable logic
Section outline

2. Context for digital integrated circuit design
   Digital integrated circuits are everywhere
   What is a digital system?
   What good are ICs?
   How are ICs designed and fabricated?
What good are ICs?

- Are there alternative ways to build digital systems?
- Historical perspective will help.
Mechanical computational aids

- 500 BC–1940 AD
- Advantages: required limited intellectual capital investment
- Disadvantages: manual
Mechanical computers

- Babbage difference engine
- 1822
- 4,000 components
- Three tons
- 31 digits
- Advantages: Automatic
- Disadvantages: Slow, expensive, inflexible, big

Do mechanical computers necessarily have these characteristics?
Programmable, electro-mechanical computers

- Konrad Zuse’s Z3
- 1941
- Floating point
- Relay-based
- Zuse also designed a high-level programming language, Plankalkül
- 5–10 Hz
- Turing complete, i.e., can simulate a universal Turing machine – a computer that can run different programs.
Electronic computer

- Electrical numerical integrator and computer
- 1946
- 18,000 vacuum tubes
- 30 tons
- 100 kHz
- Unreliable
Modern digital computer

- Over 1,000,000,000 transistors
- 1–3 GHz
## Modern embedded digital computer

- Tens of thousands of transistors
- A few MHz
- $\mu$W when sleeping
- As big as a fingernail
- Smart enough to save kids from SIDS or keep bridges from falling down?
What changed?

- **Intellectual and physical capital:** Without today’s computers, building tomorrow’s computers would be impossible.
- **Architecture:** Caches, out-of-order execution, multi-processors.
- **Devices!**
Electro-mechanical relays

Compared to vacuum tubes,
- large and
- slow.
Inventor in 1915 by Irving Langmuir.

Compared to transistors,
- large,
- slow,
- unreliable, and
- high power.
Discrete transistors

Invented in 1947 by John Bardeen
Compared to integrated transistors,
  • large and
  • reliable.
Integrated circuit

Independently invented in 1959 by Jack Kilby and Robert Noyce.

Allows a lot of transistors to be packed into a small space – and that makes all the difference in the world.
Intel Nehalem Microprocessor (2009)

- 731,000,000 transistors.
- 3.6 GHz.
- 45 nm.
- 4 cores.
- 8 MB cache.

Courtesy of Mark Bohr at Intel.
Main IC use: embedded systems

Courtesy of Renesas.
Cellphone media application chip

![Cellphone media application chip](image)

Courtesy of Renesas.
Why “integrated” matters so much for embedded systems
2. Context for digital integrated circuit design
   Digital integrated circuits are everywhere
   What is a digital system?
   What good are ICs?
   How are ICs designed and fabricated?
How are ICs designed and fabricated?

Goal of the course: Understand how to use individual devices to build
- combinational logic,
- sequential logic, and
- complex architectures based on combinational and sequential components
under constraints on
- reliability,
- performance,
- design time,
- testing cost,
- area, and
- power consumption.
Trends

- Embedded.
- Multicore.
- Power density.
- Scaling limits.
Lecture plan

1. Administrative details

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3. Course topics

4. Homework assignment
Course topics I

1. Course overview and administrative details
2. Context for digital integrated circuit design
3. Transistor static behavior
4. Transistor dynamic behavior
5. Fabrication
6. SPICE models
7. CMOS inverters
8. Inverter dynamic behavior
9. Inverter power consumption
10. CMOS gates
11. Pass transistor logic
# Course topics II

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<tr>
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<tr>
<td>12</td>
<td>Transmission gates</td>
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<td>13</td>
<td>Logical effort</td>
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<td>14</td>
<td>Dynamic logic</td>
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<td>Domino logic</td>
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<td>np-CMOS</td>
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<td>Latches</td>
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<td>20</td>
<td>Flip-flops</td>
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<td>Other sequential elements</td>
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<td>Scaling and process variation</td>
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<tr>
<td>23</td>
<td>ROM</td>
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Course topics III

24 SRAM
25 DRAM
26 Future trends
Upcoming topics

5 September:
- Overview and history of integrated circuits.
- Integrated circuits in the context of digital system design.
- Transistor static behavior.
Lecture plan

1. Administrative details

2. Context for digital integrated circuit design

3. Course topics

4. Homework assignment
Homework assignment

- Due 5 September.
- Read the course information handout.
- List specific integrated circuit related topics you are interested in that you would like to see covered in the course
  - E.g., “Why use multicore processors instead of just making unicore processors faster?”

Email this to me at dickrp@umich.edu.