# Digital Integrated Circuits – EECS 312

http://robertdick.org/eecs312/


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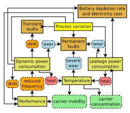
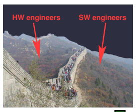
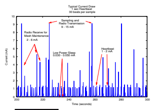
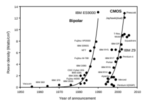
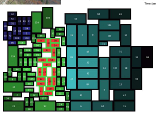





## People

| | |
|---|---|
| Instructor | Robert Dick<br>http://robertdick.org/<br>dickrp@umich.edu |
| Lecture | 1010 DOW<br>Tuesdays and Thursdays, 14:30–16:00 |
| Office hours: | 2417-E EECS<br>Tuesdays and Thursdays, 16:00–17:00<br>plan to extend when demand is high |
| Teaching assistant | Shengshuo Lu<br>Email: luss@umich.edu |
| Discussion | 1303 EECS<br>Fridays, 12:30–13:30 |
| Office Hours | 2725 BBB<br>Mondays, 10:30–12:30<br>Thursdays, 17:30–19:30 |





## 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.

## The line between collaboration and copying I

- 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

J. Rabaey, A. Chandrakasan, and B. Nikolic. *Digital Integrated Circuits: A Design Perspective.*
Prentice-Hall, second edition, 2003.





## Other references

- Ben G. Streetman. *Solid State Electronic Devices.*
  Prentice-Hall, NJ, fifth edition, 2005.
- Andrei Vladimirescu. *The SPICE Book.*
  John Wiley & Sons, second edition, 1994.
- Adel S. Sedra and Kenneth C. Smith. *Spice for Microelectronic Circuits.*
  Harcourt School, third edition, 1991.
- Ivan Sutherland, Robert F. Sproull, and David Harris. *Logical Effort: Designing Fast CMOS Circuits.*
  Morgan Kaufmann, first edition, 1999.





## 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% |

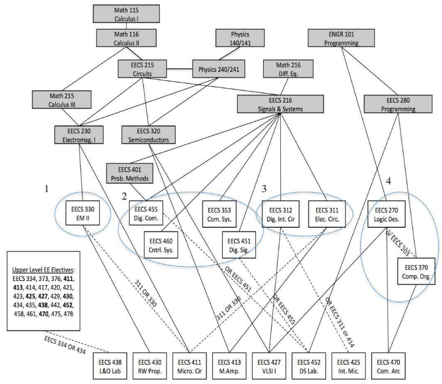
## On lectures and notes

- 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.





## Where EECS 312 fits in one example curriculum








## Integrated circuits are everywhere

Cars, environmental control, computers, communication, etc.






## 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

## What good are ICs?

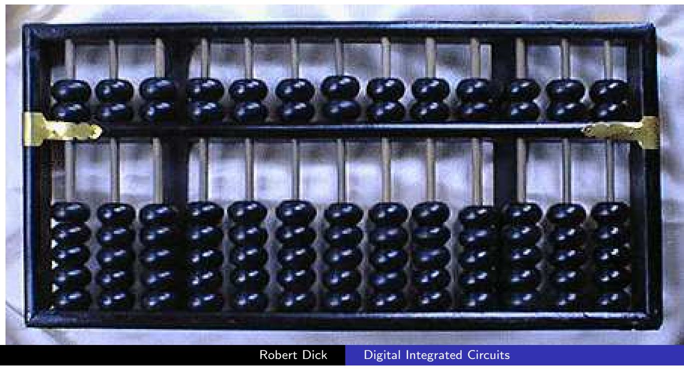
- Are there alternative ways to build digital systems?
- Historical perspective will help.





## Mechanical computational aids

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

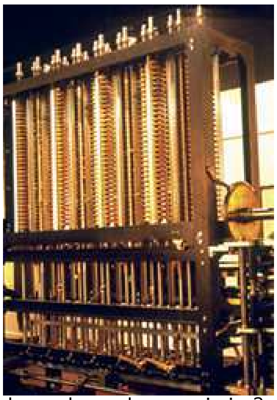






## Mechanical computers

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



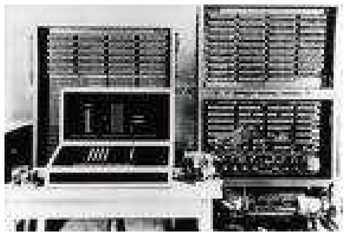
Do mechanical computers necessarily have these characteristics?





## 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

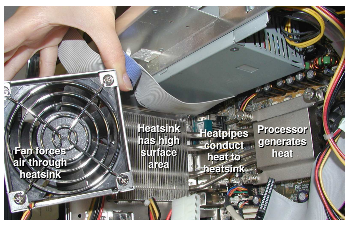
- Electrical numerical integrator and computer
- 1946
- 18,000 vacuum tubes
- 30 tons
- 100 kHz
- Unreliable





## Modern digital computer

- Over 1,000,000,000 transistors
- 1–3 GHz



## Modern embedded digital computer

- Tens of thousands of transistors
- A few MHz
- µW 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!

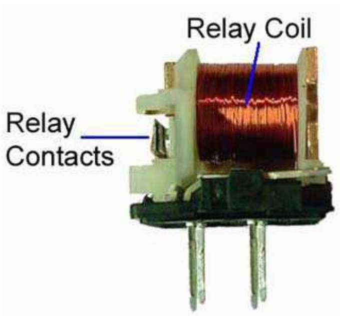




## Electro-mechanical relays

Compared to vacuum tubes,

- large and
- slow.








## Vacuum tubes

Invented in 1915 by Irving Langmuir.
Compared to transistors,

- large,
- slow,
- unreliable, and
- high power.

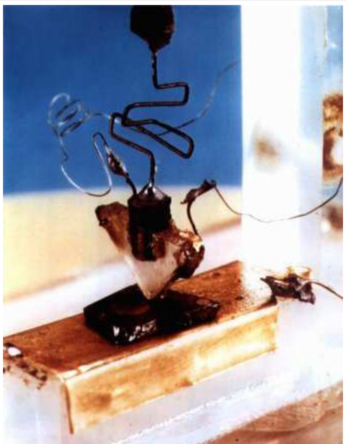




## Discrete transistors

Invented in 1947 by John Bardeen
Compared to integrated transistors,

- large and
- reliable.



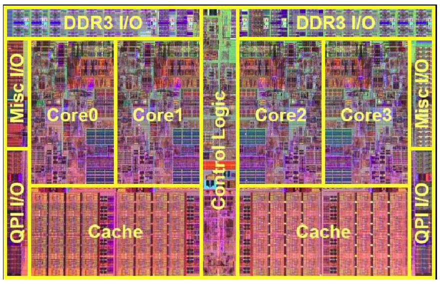




## Integrated circuit

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)



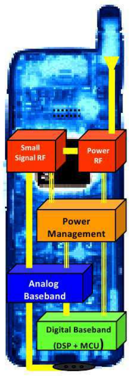

- 731,000,000 transistors.
- 3.6 GHz.
- 45 nm.
- 4 cores.
- 8 MB cache.

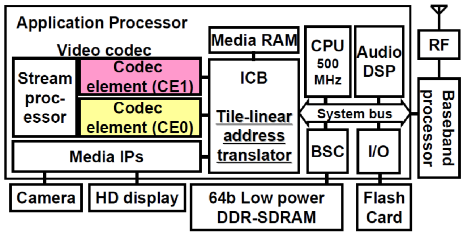
Courtesy of Mark Bohr at Intel.





## Main IC use: embedded systems



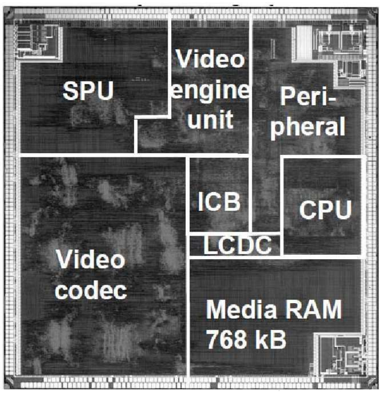




Courtesy of Renesas.





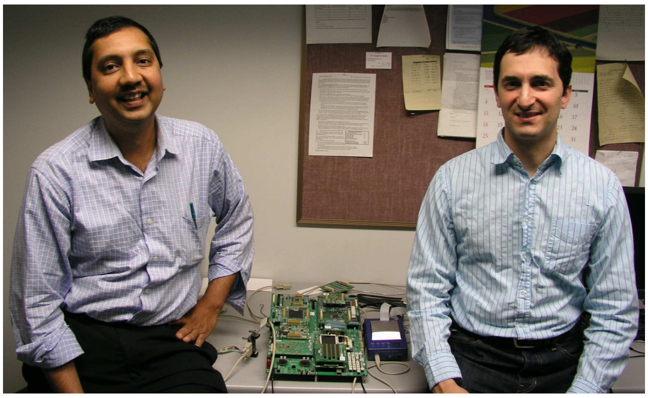
## Cellphone media application chip




Courtesy of Renesas.



## Why "integrated" matters so much for embedded systems





## 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.

## 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

12. Transmission gates
13. Logical effort
14. Dynamic logic
15. Domino logic
16. np-CMOS
17. Interconnect behavior
18. Interconnect design
19. Latches
20. Flip-flops
21. Other sequential elements
22. Scaling and process variation
23. ROM





## 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.





## Homework assignment

- Due 5 September.
- Read the course information handout.
- Read Sections 1.1 and 1.2 in J. Rabaey, A. Chandrakasan, and B. Nikolic. *Digital Integrated Circuits: A Design Perspective.* Prentice-Hall, second edition, 2003.
- 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.