EE115 Analog Circuits Introduction

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Outline

- Course logistics
- History of electronics and microelectronics
- Need of analog electronics
- Why is it more challenging to design analog than digital circuitry?
- Why integrated and why CMOS?

Course Information

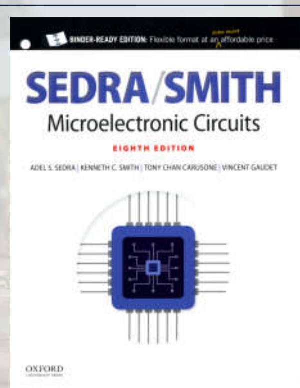
- Lecture
  - Tuesday 8:15-9:55, Thursday (Even week) 8:15-9:55
  - Rm 1D-106 SIST Bldg.
- Instructor
  - Prof. Haoyu Wang
  - Rm 3-530 SIST Bldg., wanghy@shanghaitech.edu.cn
  - Office hours: Friday 3:00pm-5:00pm; other times by appointment
- Recitation:
  - Once every 2 lectures
  - Will be announced by TA in advance

Teaching Assistants

	TA	TA
Recitation & Grader	 Zeyu Wu wuzy12023@shanghaitech	 Taojie Chen chentj2023@shanghaitech
Lab & Project	 Jiashen Yu yujs2022@shanghaitech	 Guanhua Liu liugh2025@shanghaitech

Textbook

- Sedra/Smith, Microelectronic Circuits, 8th edition
  - Oxford University Press
- Minimum reading
  - Assigned sections in the website
- Best to read the relevant sections before lecture
  - Enables meaningful in class discussions



Course Website

- Open website
  - General course info, lecture notes, hw problems
  - https://pearl.shanghaitech.edu.cn/teaching/2025Fall/EE115/
- Discussions
  - QQ group: 797162060

Homework

- Posted in course website & gradescope
- Due one week after it is posted
  - Will be collected in gradescope
  - https://www.gradescope.com/courses/1060659
  - Late homework will be discounted by 20% per day
  - Solution will be discussed in the recitation session
- Be prepared to spend **6-10 hours** to complete
  - Reading, problem solving
- You may discuss homework problems with other students in the class, the TAs, or the instructor.
- **The work you submit for grading must be your own**

gradescope

Grades

- Homework: 15%
  - Lowest score will be dropped from grade calculation
- Lab 20%
  - Led by Teacher LIU Chuang
- Midterm: 20%
- Project 15%
- Final exam: 20%
- Attendance: 5%
- Quiz: 5%
- **Cheating will result in automatic Fail!**

LIU Chuang
SIST 1B-206
liuchuang1@shanghaitech

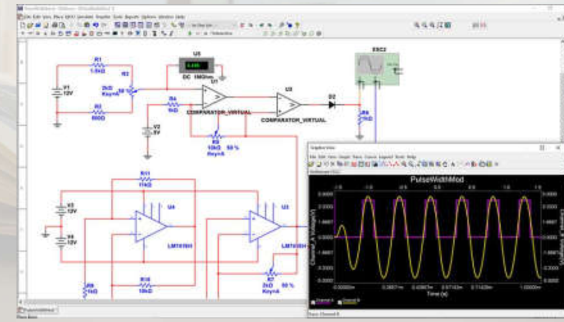
Midterm & Final Exams

- Midterm:
  - 11/6/2025 (Thur.) in class
- Final Exam:
  - 12/23/2025 (Tue.)

Week	Date	Lectures	Reading Sedra/Smith	HW & Project
1	9/16	**Syllabus**[PDF]; **Lecture 1** Introduction[PDF]	Chapter 1, pp. 1-15	
2	9/23	**Lecture 2** Op-Amp basics[PDF]	Chapter 1, pp. 16-45	
	9/25	**Lecture 3** Ideal Op Amp[PDF]	Chapter 2, pp. 58-82	HW1[PDF] Due date: 10/7/2025
3	9/30	**Lecture 4** Non-ideal Op Amp[PDF]	Chapter 2, pp. 97-116	
4	10/7	**Lecture 5** Semiconductors[PDF]	Chapter 3, pp. 136-149	HW2[PDF] Due date: 10/14/2025
	10/9	**Lecture 6** PN Junction[PDF]	Chapter 3, pp. 150-169	
5	10/14	**Lecture 7** MOSFET[PDF]	Chapter 5, pp. 244-284	HW3[PDF] Due date: 10/21/2025

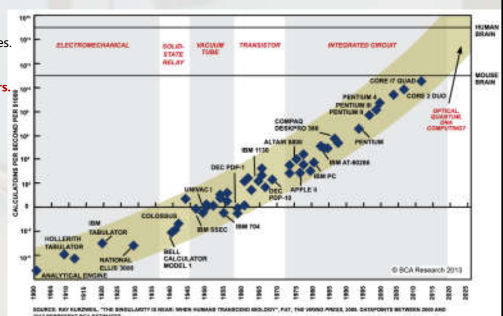
Simulation Software

- SPICE (Simulation Program with Integrated Circuit Emphasis)
  - **Multisim** from National Instruments



Electronics Milestones

- 1874 Braun invents the **solid-state rectifier**.
- 1906 DeForest invents triode **vacuum tube**.
- 1907-27 First radio circuits developed from diodes and triodes.
- 1925 Lilienfeld field-effect device patent filed.
- 1947 Bardeen & Brattain at Bell Lab invent **bipolar transistors.**
- 1952 Commercial bipolar transistor production at TI.
- 1956 Bardeen, Brattain, and Shockley receive Nobel prize.
- 1958 **Integrated circuit** developed by Kilby and Noyce
- 1961 First commercial **IC** from Fairchild Semiconductor
- 1963 IEEE formed from merger or IRE and AIEE
- 1968 First commercial **IC op-amp**
- 1970 One transistor DRAM cell invented by Dennard at IBM.
- 1971 4004 Intel **microprocessor** introduced.
- 1974 8080 microprocessor introduced.
- 1978 First commercial 1-kilobit memory.
- 1984 Megabit memory chip introduced.
- 2000 Alferov, Kilby, and Kromer share Nobel prize

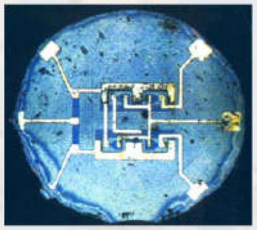


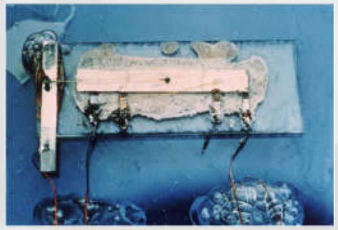
Invention of Transistors - 1947

Bardeen, Shockley, and Brattain at Bell Labs - Brattain and Bardeen invented the **bipolar transistor** in 1947.

The first germanium bipolar transistor. Roughly 50 years later, electronics account for **10% of the world GDP**.

The First Integrated Circuits - 1958





R. N. Noyce
Fairchild Semiconductor
Co-Founder of both Fairchild and Intel (deceased 1990)
Unitary Circuit made of Si

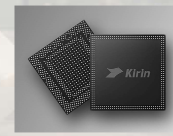
Jack Kilby
Texas Instruments
Invented IC during his first year at TI
(**Nobel Prize** 2000)
Solid Circuit made of Ge

Evolution of Electronic Devices

Vacuum Tubes

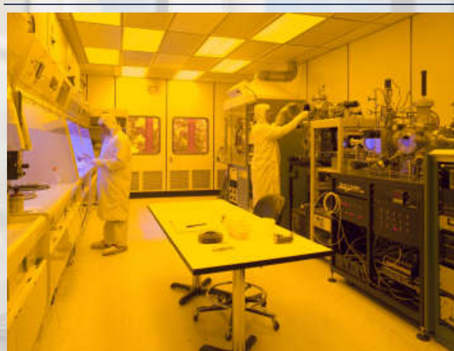
Discrete Transistors

SSI and MSI Integrated Circuits

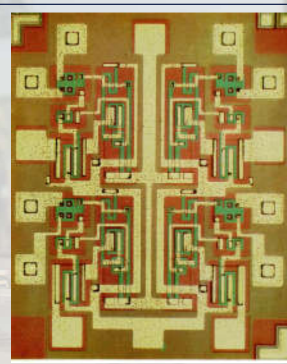


VLSI Surface-Mount Circuits

Semiconductor Device Fabrication



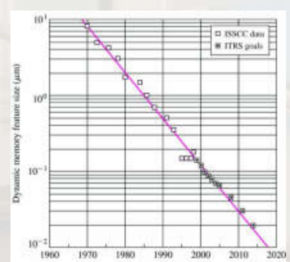
Clean Room

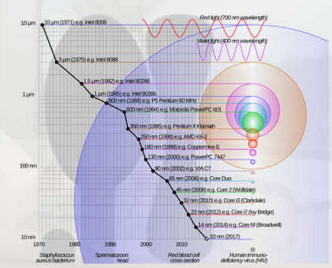


IC micrograph

Device Feature Size

- Feature size reductions enabled by process innovations.
- Smaller features lead to more transistors per unit area and therefore higher density.
- 2020 5nm → 2022 3nm → **2025 2nm**





Moore’s Law

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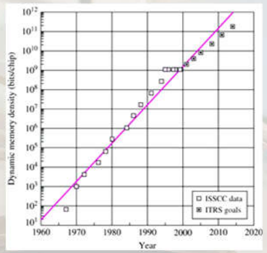
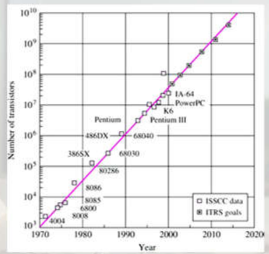
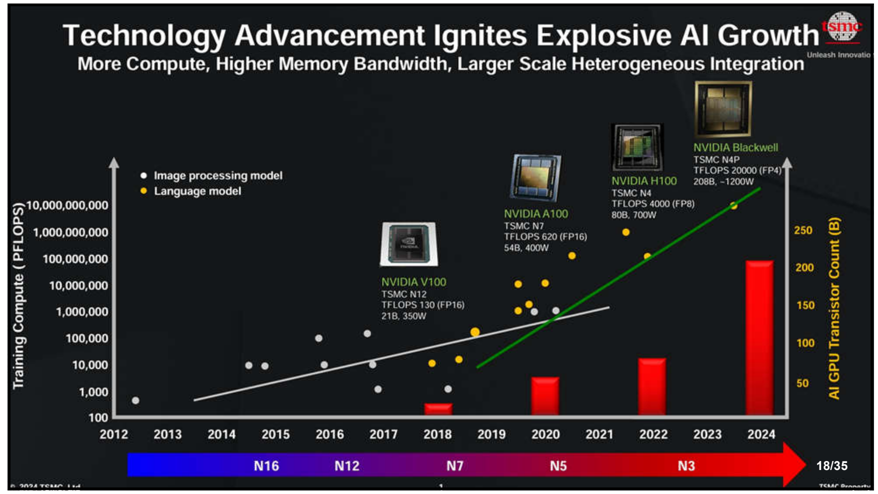
- Number of transistors in an integrated circuit (IC) doubles about every two years.



Memory chip density versus time.



Microprocessor complexity versus time.



Signal Type

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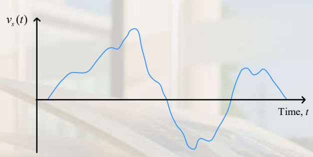
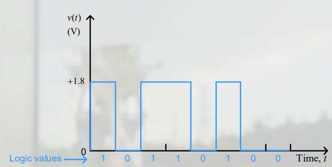
- **Analog** signals take on **continuous** values - typically current or voltage.





- **Digital** signals appear at **discrete** levels. Usually we use binary signals which utilize only two levels.
- One level is referred to as **logical 1** and **logical 0** is assigned to the other level.

Analog and Digital Signals

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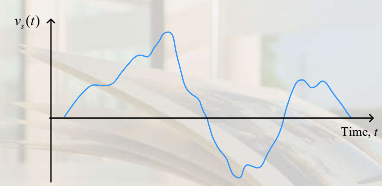
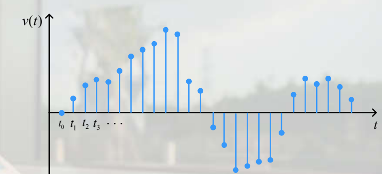
- **Analog** signals are **continuous** in time and voltage or current. (Charge can also be used as a signal conveyor.)

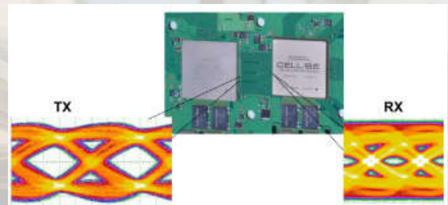




- After **digitization**, the continuous analog signal becomes a set of discrete values, typically separated by fixed time intervals.

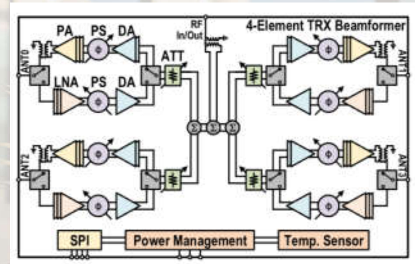
Why Analog?

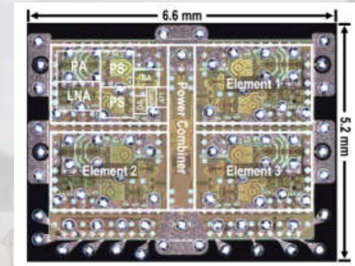
- **The real world is analog**
  - Analog is required to interface to just about anything
  - Even to get two digital chips to talk to each other:



Another Example: RF Transceiver

- Analog needs to provide **gain + filtering** with low noise and distortion

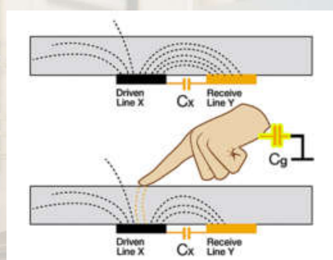


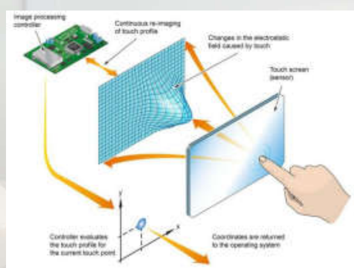


YI et al.: 24–29.5-GHz HIGHLY LINEAR PHASED-ARRAY TRX FRONT-END IN 65-nm CMOS， JSSC 2022.

Capacitive Touch Sensors

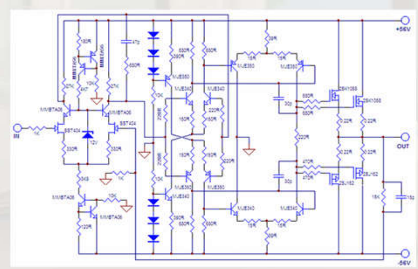
- Similar to communications – analog needed for **signal conditioning**





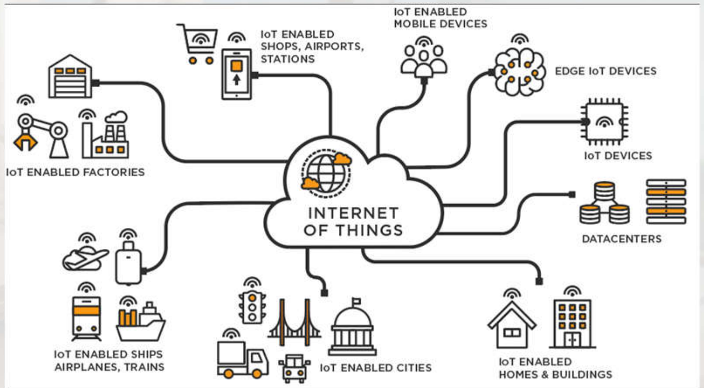
Power Amplifier

- A power amplifier (PA) converts a low-power signal to a higher power one.
  - Audio amplifiers, used to drive loudspeakers and headphones
  - RF power amplifiers, such as those used in the final stage of a transmitter.



HiFi Power Amplifier

Internet of Things (IoT)



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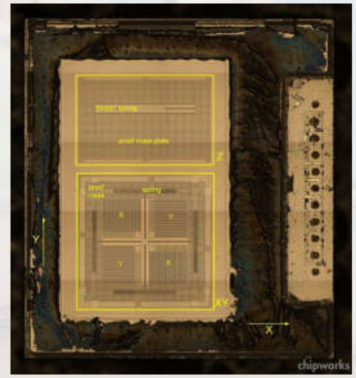
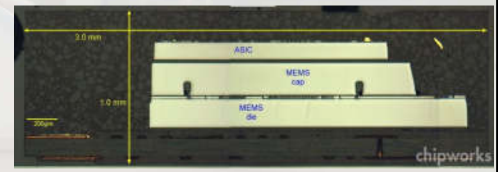
Accelerometer



- ASIC stacked on Microelectromechanical Systems (MEMS)
- Wafer level packaging (WLP) for MEMS
- 2 polysilicon layer surface micromachining process



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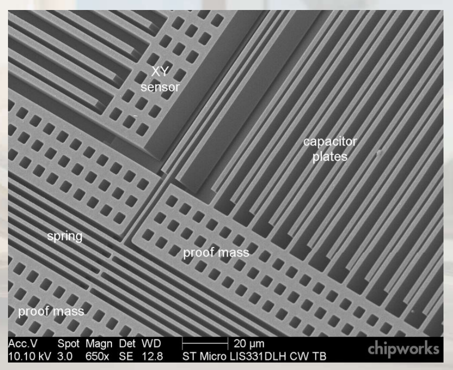
Accelerometer



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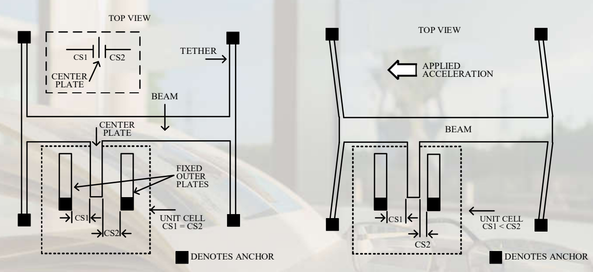
Differential Capacitive Accelerometer



Differential Capacitive Sensing

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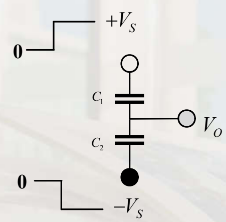

$$C_1 = C\frac{x_o}{x_o+\delta x} \qquad C_2 = C\frac{x_o}{x_o-\delta x}$$

For small displacement:

$$C_1 - C_2 = C\left(\frac{x_o}{x_o+\delta x} - \frac{x_o}{x_o-\delta x}\right)$$

$$= C\frac{-2x_o\delta x}{x_o^2-\delta x^2} \cong -C\frac{2}{x_o}\delta x$$

$$C_1 + C_2 \cong 2C$$

$$V_o \cong -\frac{\delta x}{x_o}V_S$$

$$V_o = -V_S + \frac{C_1}{C_1+C_2}\cdot 2V_S = \frac{C_1-C_2}{C_1+C_2}V_S$$

Output voltage ∝ displacement

ADXL Block Diagram – Open Loop

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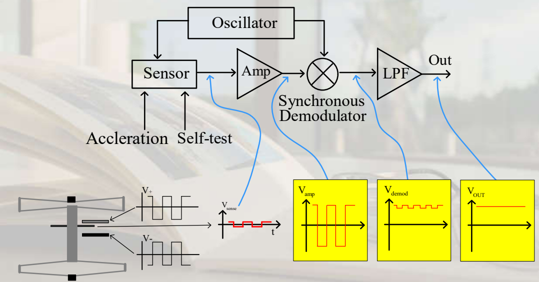
- Minimum detectable capacitance change: 20 aF (aF = 10^{-18}F)
- Minimum detectable displacement: 0.02 nm (1/5 of hydrogen atom)



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Analog is more challenging than digital

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- Digital entails primarily ONE trade-off: speed and power
- Analog face **multiple trade-offs** including **speed, power, gain, precision**, etc.
- Analog is significantly more **sensitive** to noise, crosstalk, and other interferences than digital.
- **Second-order effects** in devices influence more to analog than digital.
- Almost **zero automation** in analog, meaning every device needs to be hand-crafted.

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Why CMOS?

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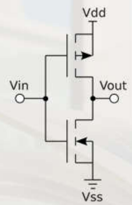
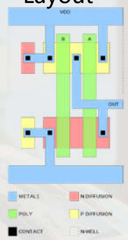
- Size of a transistor, gate length, has been **scaled down** from 25 μm in 1960 to **2 nm in 2025**.
- **MOSFETs** was patented in early 1930s far before the invention of **bipolar transistors**; technology becomes practical later in early 1960s. Yet, only n-type MOSFETs were produced. CMOS becomes available in mid-1960s.
- CMOS dissipates **power** only during switching and requires very few devices in contrast to bipolar.
- However, **MOSFETs** were slower and noisier than **biopolar**; i.e., g_m of MOSFETs << g_m of BJT
- **Scalability and speed** of CMOS has championed for past 30 years !

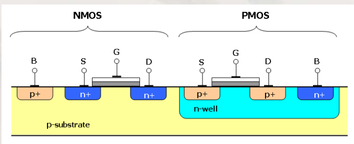
CMOS Circuit

Inverter

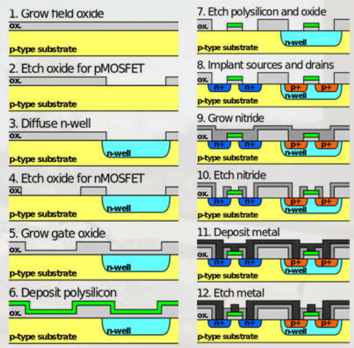


Layout

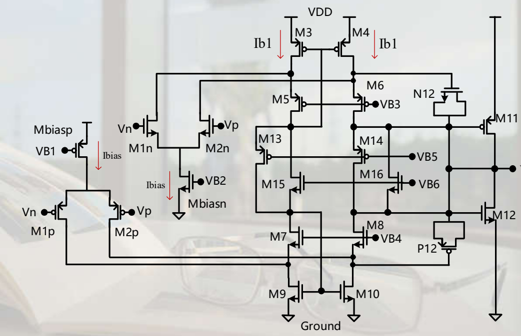




Process Flow



What You Will Learn in EE115



ShanghaiTech Circuit Courses

- Electric Circuits
- **Analog Circuits**
- Digital Circuits
- Analog Integrated Circuits I
- Digital Integrated Circuits I
- Power Electronics
- Advanced Analog Integrated Circuits (graduate course)
- Advanced Digital Integrated Circuits (graduate course)
- Radio Frequency Integrate Circuits (graduate course)