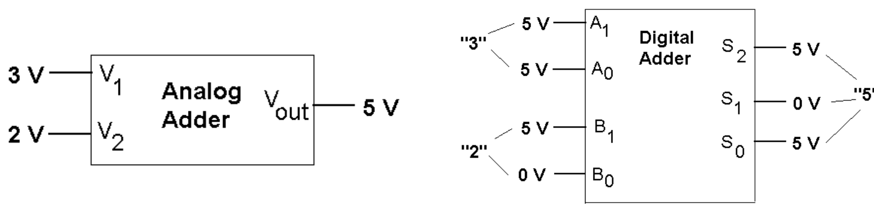
Lecture #1

OUTLINE

- Course overview
- Introduction: integrated circuits
- Analog *vs.* digital signals



Course Overview

EECS 40:

- **One of five EECS core courses (with 20, 61A, 61B, and 61C)**
  - introduces "hardware" side of EECS
  - prerequisite for EE105, EE130, EE141, EE150
- **Prerequisites: Math 1B, Physics 7B**

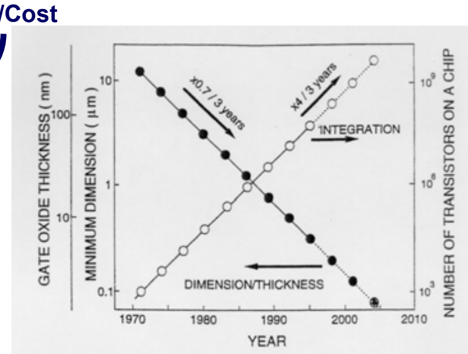
Course content:

- **Electric circuits**
- **Integrated-circuit devices and technology**
- **CMOS digital integrated circuits**

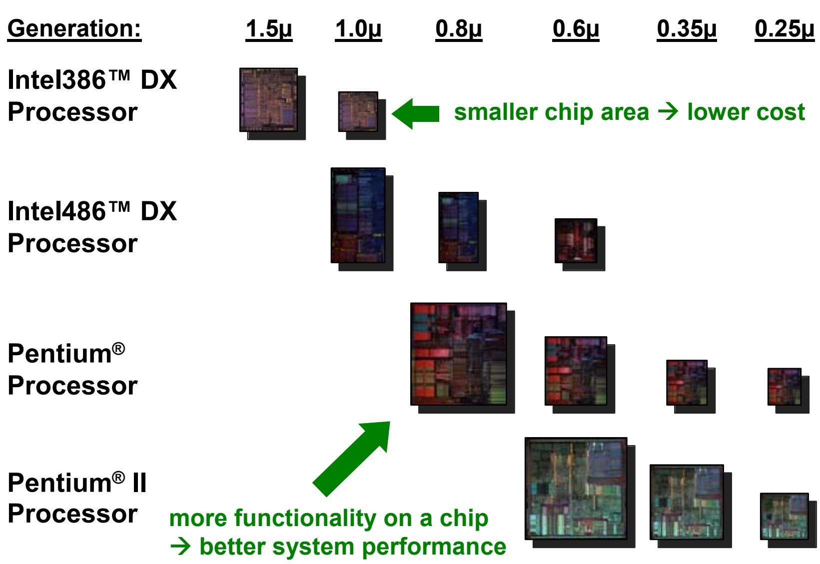
IC Technology Advancement

"Moore's Law": # of transistors/chip doubles every 1.5-2 years

– achieved through miniaturization



Benefit of Transistor Scaling



Analog *vs.* Digital Signals

- **Most** (but not all) **observables are analog**

  think of analog vs. digital watches

but the most convenient way to represent & transmit information electronically is to use digital signals

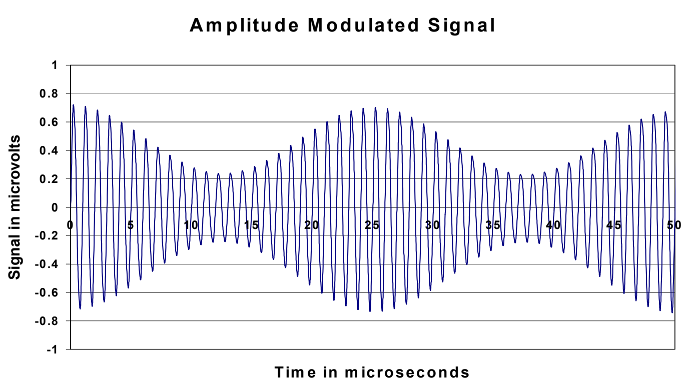
think of telephony

→ Analog-to-digital & digital-to-analog conversion is essential (and nothing new)

think of a piano keyboard

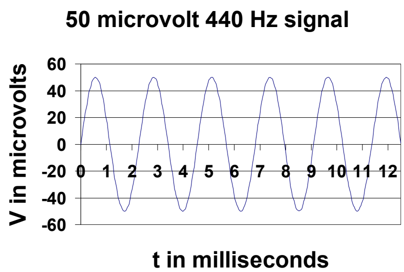
Analog Signals

- may have direct relationship to information presented
- in simple cases, are waveforms of information *vs.* time
- in more complex cases, may have information modulated on a carrier, *e.g.* AM or FM radio

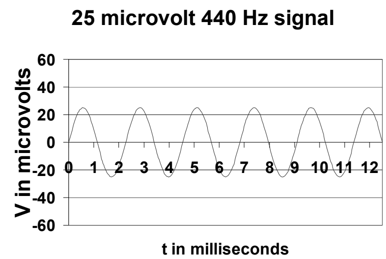


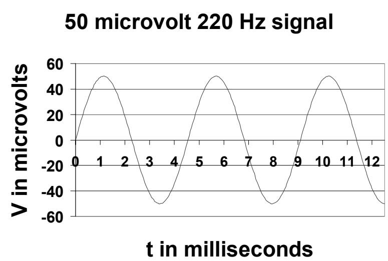
Analog Signal Example: Microphone Voltage

Voltage with normal piano key stroke



Voltage with soft pedal applied





Analog signal representing piano key A, below middle C (220 Hz)

Digital Signal Representations

Binary numbers can be used to represent any quantity.

We generally have to agree on some sort of "code", and the dynamic range of the signal in order to know the form and the number of binary digits ("bits") required.

Example 1: Voltage signal with maximum value 2 Volts

- Binary two (**10**) could represent a 2 Volt signal.
- To encode the signal to an accuracy of 1 part in 64 (1.5% precision), 6 binary digits ("bits") are needed

Example 2: Sine wave signal of known frequency and maximum amplitude 50 μV; 1 μV "resolution" needed.

Example 2 (continued)

Possible digital representation for the sine wave signal:

Analog representation: Amplitude in μV	**Digital representation:** Binary number
1	000001
2	000010
3	000011
4	000100
5	000101
8	001000
16	010000
32	100000
50	**110010**
63	111111

Why Digital?

(For example, why CDROM audio *vs.* vinyl recordings?)

- Digital signals can be transmitted, received, amplified, and re-transmitted with no degradation.
- Digital information is easily and inexpensively stored (in RAM, ROM, *etc.*), with arbitrary accuracy.
- Complex logical functions are easily expressed as binary functions (*e.g.* in control applications).
- Digital signals are easy to manipulate (as we shall see).

Digital Representations of Logical Functions

Digital signals offer an easy way to perform logical functions, using Boolean algebra.

- Variables have two possible values: **"true"** or **"false"**
  - usually represented by **1** and **0**, respectively.

All modern control systems use this approach.

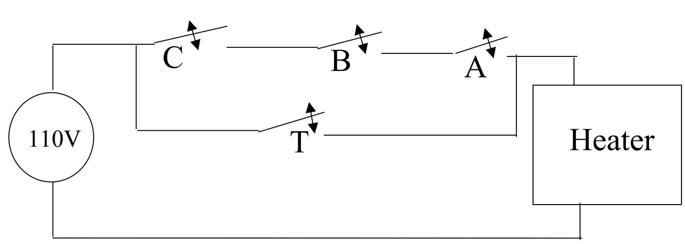
<u>Example</u>: Hot tub controller with the following algorithm

Turn on the heater if the temperature is less than desired ($T < T_{set}$) ***and*** the motor is on ***and*** the key switch to activate the hot tub is closed. Suppose there is also a "test switch" which can be used to activate the heater.

Hot Tub Controller Example

- Series-connected switches:
  - A = thermostatic switch
  - B = relay, closed if motor is on
  - C = key switch
- Test switch T used to bypass switches A, B, and C

<u>Simple Schematic Diagram of Possible Circuit</u>



“Truth Table” for Hot Tub Controller

A	B	C	T	H
0	0	0	0	0
0	0	1	0	0
0	1	0	0	0
0	1	1	0	0
1	0	0	0	0
1	0	1	0	0
1	1	0	0	0
1	1	1	0	1
0	0	0	1	1
0	0	1	1	1
0	1	0	1	1
0	1	1	1	1
1	0	0	1	1
1	0	1	1	1
1	1	0	1	1
1	1	1	1	1

Notation for Logical Expressions

Basic logical functions:

AND: “dot” Example: $X = A \cdot B$

OR: “+ sign” Example: $Y = A+B$

NOT: “bar over symbol” Example: $Z = \overline{A}$

- **Any logical expression can be constructed using these basic logical functions**

Additional logical functions:

Inverted AND = NAND: $\overline{AB}$ (only 0 when A and $B=1$)

Inverted OR = NOR: $\overline{A+B}$ (only 1 when $A=B=0$)

Exclusive OR: $A \oplus B$ (only 1 when A, B differ)

i.e., $A+B$ **except** $A \cdot B$

The most frequently used logical functions are implemented as electronic building blocks called “gates” in integrated circuits

Hot Tub Controller Example (cont'd)

First define logical values:

- closed switch = "true", *i.e.* boolean **1**
- open switch = "false", *i.e.* boolean **0**

Logical Statement:
Heater is on (H = 1) if A and B and C are 1, or if T is 1.

Logical Expression:
H=**1** if (A **and** B **and** C are **1) or (**T is **1)**

Boolean Expression:
$H = (A \cdot B \cdot C) + T$

Summary

Attributes of digital electronic systems:

1. Ability to represent real quantities by coding information in digital form
2. Ability to control a system by manipulation and evaluation of binary variables using Boolean algebra