Course Overview

EECS 42 – Electronics for Computer Science

- ❑ Introduces “hardware” side of EECS

Course content : (Not precisely in this order)

- ❑ Basic Device and Circuit Ideas
- ❑ Digital Circuits and Logic Delays
- ❑ Physical realization/CMOS
- ❑ Performance limits of CMOS digital circuits

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Analog versus Digital Electronics

- Most (but not all) observables are analog
  think of analog versus digital watches

- But the most convenient way to represent and transmit information electronically is digital
  think of audio recordings

- Analog/Digital and Digital/Analog conversion is essential (and nothing new)
  think of a piano keyboard

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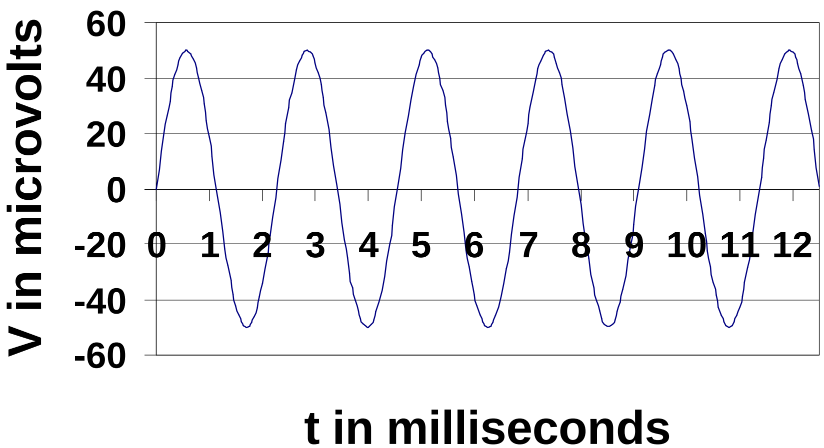
Analog Example:

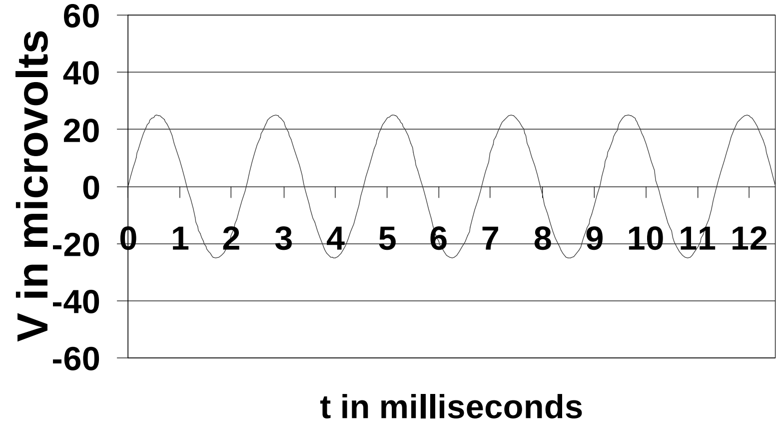
Analog signal (microphone voltage) representing piano key A (440 Hz)..

50 microvolt 440 Hz signal



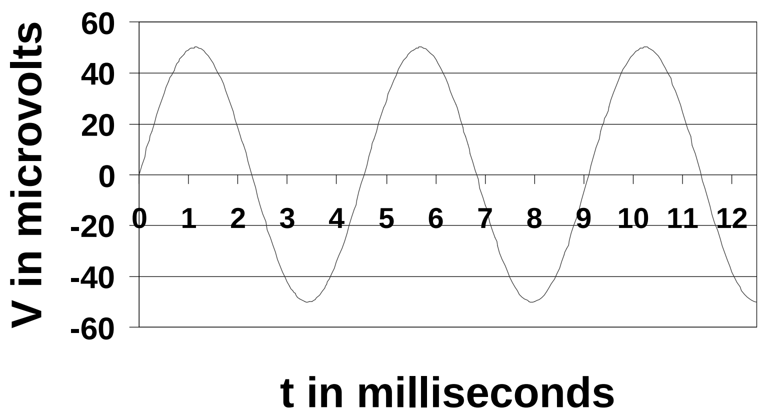
Microphone voltage with normal key stroke

25 microvolt 440 Hz signal



Microphone voltage with soft pedal

50 microvolt 220 Hz signal



Analog signal representing piano A, but one octave below middle A (220 Hz)

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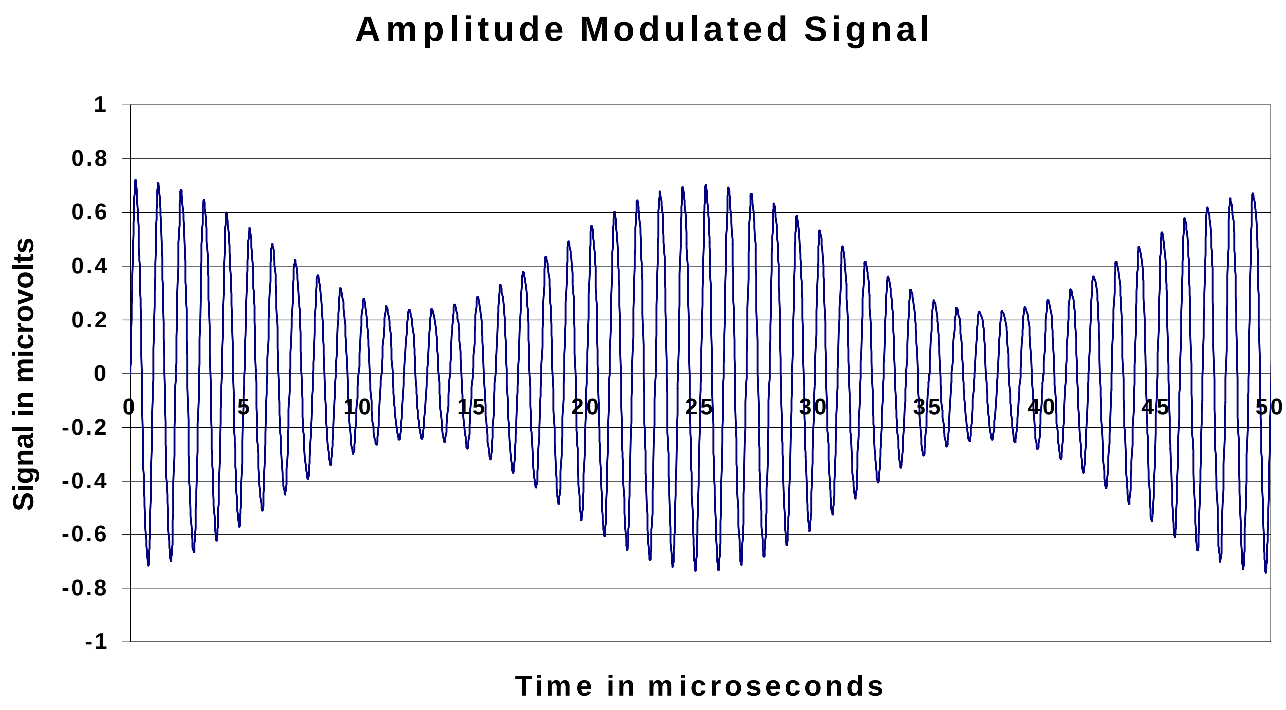
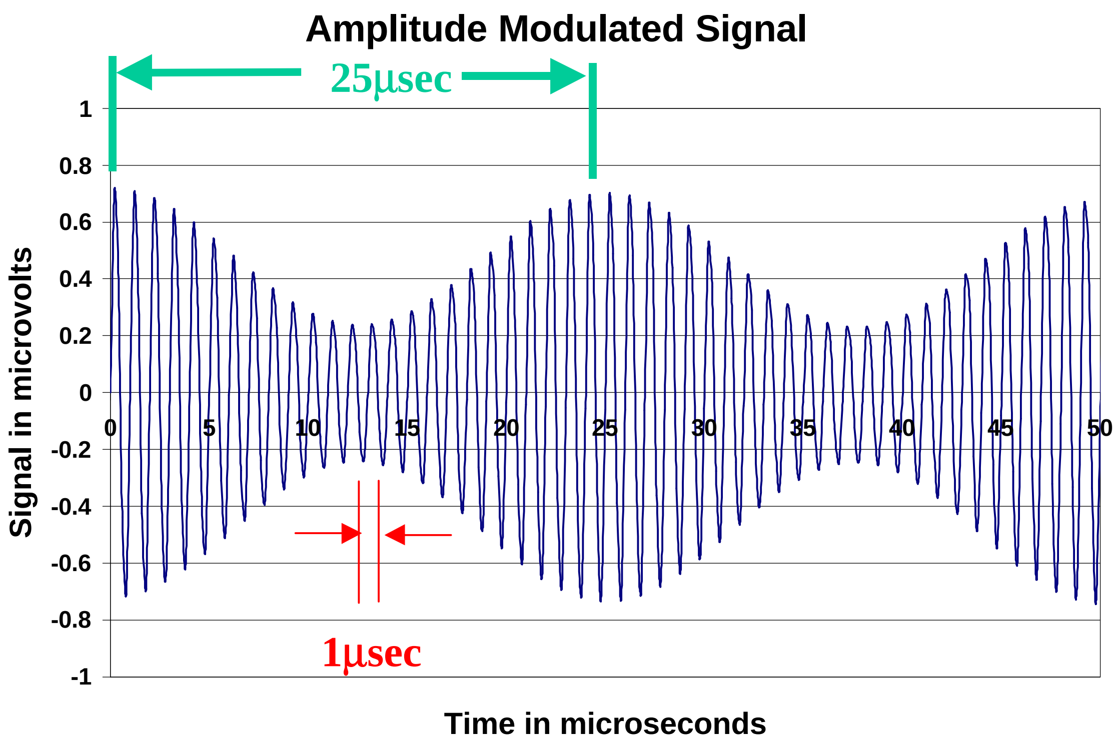
Analog Signals

- May have very physical relationship to information presented
- In the simplest, are direct waveforms of information vs time
- In more complex cases, may have information modulated on a carrier as in AM or FM radio



1000 KHZ AM radio station signal (analog)



Parameters of sin waves:

Period (time to repeat)

Frequency (1/period)

Phase

Amplitude

Note: The period of the carrier is 1µsec * (that is, the frequency is 1MHz)
The period of the modulation is 25µsec (that is, the frequency is 40kHz)
The amplitude of the modulation is about 50% of the maximum possible

What is the equation of this waveform (just for fun)??

Answer: V (in microvolts) = $[.5 + .25 \cos(2\pi \times 40 \times 10^3\, t)] \times \sin(2\pi \times 10^6\, t)$

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Digital Signal Representations
(Analog to Digital Conversion)

By using binary numbers we can represent any quantity. For example a binary two (**10**) could represent a 2 Volt signal. But 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 minimum number of bits.

Example: We want to encode to an accuracy of one part in 64 (i.e. 1.5% precision). It takes 6 binary digits (or "bits") to represent any number 0 to 63.

Example: Possible digital representation for a pure sine wave of known frequency. We must choose maximum value and "resolution" or "error," then we can encode the numbers. Suppose we want 1μV accuracy of amplitude with maximum amplitude of 50μV, We could use a simple pure binary code with 6 bits of information. (Why 6 bits…. What if we only use 5?)

Answer: with 5 binary digits we can represent only 32 values

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Digital Signal Representations

Example: Possible digital representation for the sine wave signals, and highlighting our maximum possible 50μV sine wave

Amplitude in μV		Binary representation
1		000001
2		000010
3	?	000011
4	?	000100
5		000101
etc.		
8		001000
16		010000
32		100000
50 (= 32+16+2)		**110010**
63		111111

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Digital Representations of Logical Functions

Digital signals also offer an effective way to execute logic. The formalism for performing logic with binary variables is called *Switching Algebra* or *Boolean Algebra.*

In switching algebra we have only **"true"** and **"false"** conditions, usually represented by binary **1** and **0**, respectively. Thus stating that "A is true" and "B is false" is equivalent to stating A=1 and B=0.

The utility of switching algebra is that we can perform elaborate logical operations with simple Boolean arithmetic. All modern control systems are digital, utilizing this approach.

Thus digital electronics combines two important properties: 1) The ability to represent real functions by coding the information in digital form, and 2) The ability to control a system by a process of manipulation and evaluation of digital variables using switching algebra.

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So Why Digital?

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

- Digital signals can be transmitted, received, amplified, and re-transmitted with no degradation.
- Binary numbers are a natural method of expressing logical variables.
- Complex logical functions are easily expressed as binary functions (e.g., in control applications).
- Digital signals are easy to manipulate (as we shall see).
- With digital representation, we can achieve arbitrary levels of "dynamic range," that is, the ratio of the largest possible signal to the smallest than can be distinguished above the background noise
- Digital information is easily and inexpensively stored (in RAM, ROM, EPROM, etc.), again with arbitrary accuracy.

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Are Voltages in a Digital Circuit “0’s” and “1’s” ?

(For example, in a RAM or Microprocessor)

- Well, on a static basis we represent “0” by some voltage range (say 0 to 0.1V). And on a static basis we represent “1” by another voltage range (say 1.5 to 2.0V).
- So if nothing is changing, most of the nodes are at logical zero or one.
- But we are in a hurry to get the answer, so when the circuit is active we actually evaluate the logical state before it reaches the static value (just like the press evaluates the outcome of the election before all the votes are in). We are really dealing with analog information.
- Moreover in lots of circuits (such as RAMs) there are places where the signals are much smaller than the official logic assignments. These signals are amplified in linear (or nonlinear) fashion, a classical analog operation.
- If you use a modem connection to the internet, you are sending analog information to represent digital (to sneak by the bandwidth filters).

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Are Voltages in a Digital Circuit “0’s” and “1’s” ?
(continued)

Clever encoding methods (as opposed to simple digital representation) can lead to cost, size, and performance advantages:

Example: Telephone Dialing

- 1950: “Pulse dialing” Six pulses represented 6, etc.
- Improvement: “Tone dialing” Each number represented by a combination of tones (tones that are within the limited frequency bandwidth of telephones.
- Analog modem technology: Uses combination of amplitude and phase modulation to represent digital information. This is done because the telephone lines are filtered to stop all frequencies above 2kHz. Sending simple pulses would limit us to a few Kbits/sec maximum.

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So what should a computer scientist know about electronics ?

(Impossible to answer, but…)

- Knowing something about physical nature of information (voltages and currents) can be useful in understanding what goes in and out of a computer, memory, radio, etc
- Knowing something about the electronic devices (e.g. CMOS) can be useful in understanding the restrictions on size, weight and performance of working systems.
- Learning enough electronics to be able to carry out simple performance and power calculations can be useful understanding the limits of actual physical hardware.

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