How Things Work II
(Lecture #25)

Instructor: Gordon D. Cates
Office: Physics 106a, Phone: (434) 924-4792
email: cates@virginia.edu

Course web site available through COD and Toolkit
or at http://people.virginia.edu/~gdc4k/phys106/spring08

March 25, 2008
Announcements

Upcoming readings:

• Make certain you have finished Chapter 12
• Read Chapter 13 through the end of Section 13.1.
  - Read but do not worry too much about the subsection on “Antennas and Tank Circuits”.
• Read Chapter 14 through the end of Section 14.1.
Audio Players

- Miniature computer that supplies the "sound".
- Miniature stereo amplifier that amplifies the sound for your headphones.
From analog to digital:

Amplifier

The ADC "samples" the waveform periodically and records its voltage as a number.

The resulting list of numbers (as illustrated by the plot above) is only an approximation of the original waveform, but it can be quite good.
What determines the quality of the digital recording?

• The number of samples per second.
  - This determines what frequencies or pitches will be reproduced.

• The number of bits per sample.
  - This determines how coarsely you reproduce the size of the waveform each time you sample.
The trade-offs when digitizing: the sampling rate

The waveform on the right is sampled twice as frequently as the waveform on the left.

It turns out that the highest frequency that will be included in your music will be one half of the sampling rate. Example: if you sample at 44,000 Hz, the highest frequency that will be reproduced is 22,000 Hz.
The effect of sampling rate on how something sounds

Sampling less frequently

Sampling more frequently
The effect of sampling rate on how something sounds

Sampling less frequently

Sampling more frequently
The effect of sampling rate on how something sounds

Sampling less frequently

Sampling more frequently
The effect of sampling rate on how something sounds

Sampling less frequently

Sampling more frequently
The effect of sampling rate on how something sounds

Sampling less frequently

Sampling more frequently
The trade-offs when digitizing: the number of bits per sample

Each sample here has many bits per sample. On my computer I believe it is probably 64 bits per sample.

On this plot there are only 3 bits per sample (eight possibilities) plus one additional bit for the sign.
Representing numbers in base-two

10^2 = 100
10^1 = 10
10^0 = 1

So ... 137 = 1x(100) + 3x(10) + 7x(1)

137 (base ten) = 10001001 (base two)

And finally we note that 128 + 8 + 1 = 137
How many possibilities do you get with three bits?

$2^2 = 4$'s column

$2^1 = 2$'s column

$2^0 = 1$'s column

000 (base two) = 0 (base ten)

001 (base two) = 1 (base ten)

010 (base two) = 2 (base ten)

011 (base two) = 3 (base ten)

100 (base two) = 4 (base ten)

101 (base two) = 5 (base ten)

110 (base two) = 6 (base ten)

111 (base two) = 7 (base ten)

8 possibilities
How many possibilities do you get with various numbers of bits?
How many possibilities do you get with various numbers of bits?

3 bits = $2^3$ possibilities = 8 possibilities
How many possibilities do you get with various numbers of bits?

3 bits $= 2^3$ possibilities $= 8$ possibilities

4 bits $= 2^4$ possibilities $= 16$ possibilities
How many possibilities do you get with various numbers of bits?

3 bits  = \(2^3\) possibilities = 8 possibilities

4 bits  = \(2^4\) possibilities = 16 possibilities

8 bits  = \(2^8\) possibilities = 256 possibilities

8 bits is referred to as a “Byte”
How many possibilities do you get with various numbers of bits?

3 bits  = $2^3$ possibilities = 8 possibilities

4 bits  = $2^4$ possibilities = 16 possibilities

8 bits  = $2^8$ possibilities = 256 possibilities

8 bits is referred to as a “Byte”

16 bits  = $2^{16}$ possibilities = 65,536 possibilities
How many possibilities do you get with various numbers of bits?

3 bits = \(2^3\) possibilities = 8 possibilities

4 bits = \(2^4\) possibilities = 16 possibilities

8 bits = \(2^8\) possibilities = 256 possibilities

8 bits is referred to as a “Byte”

16 bits = \(2^{16}\) possibilities = 65,536 possibilities

64 bits = \(2^{64}\) possibilities = 18 million trillion possibilities
Storing a representation of a number that is all 1’s and 0’s is a fairly doable task.

At right is “magnetic core” memory, one of the earliest types of memory that was both cheap and reliable.

Each “ferrite core” (the little doughnuts) would either be magnetized one way, or the other, thus storing a 1 or a 0.

Modern systems use transistors, not unlike the n-channel MOSFET we played with in class that either conducted or didn’t depending on whether we put charge on the gate.
Different types of digital storage

• Volatile storage
  - Random Access Memory or RAM
    • Ferrite-core memory (obsolete).
    • Dynamic RAM or DRAM uses a capacitor and one transistor for each bit stored. It needs to be constantly refreshed.
    • Static RAM or SRAM uses 2-4 transistors per bit that essentially represent a switch that is either on or off.

• Non-Volatile storage
  - Flash memory uses charge on capacitors along with transistors, but charge that is essentially permanently trapped. Memory sticks work this way.
  • Magnetic pole, hard disks, floppies, ...
  • Optical: CD’S, DVD’S
What do we do with all those stored numbers?

- They are used by a separate chip, the central processing unit or CPU.
  - The CPU contains huge numbers of simple circuits, each of which can perform a simple arithmetic or logical operation on digital inputs.
  - The CPU, while containing only a finite number of elements, can perform essentially an infinite number of tasks depending on the list of commands its receives.
  - The list of commands, which is also stored in memory, is the computer program or software. This key concept revolutionized computing, and essentially gave birth to the information age. Prior to this, computers, such as they were, were just glorified adding machines.
Early computers were huge and cumbersome, but still enabled calculations that were otherwise impossible.

- Early on, reconfiguring the function of the CPU's many logic circuits required rewiring.

Shown at right is ENIAC, one of the world's first computers. It was constructed in the 1940's and the first problems run on the computer were related to the development of the hydrogen bomb.
Outline of program in an Ipod

- Fetch segment of Mp3 file from hard disk and place in memory.
- “Decompress” segment and produce list of numbers representing values the waveform each 44,000th of a second.
- Sequentially load the numbers into a “digital-to-analog converter” or DAC.
- Check that controls to Ipod have not been touched.
- Back to the top of program.
Performing logical or arithmetic operations with numbers in binary form

Digital processing is performed by collections of “logic elements” that take one or more inputs and produce an output.

At left is a “Not-And” gate, or a “NAND” gate.

The actual circuit of the NAND gate is shown at right. It requires only that each transistor either be on or off, greatly simplifying requirements on performance.