Digital Information

Binary Coding
Digital Sampling
CDs and DVDs

Binary Numbers for Digital Representation

- Though we use base-10 for numbers, this isn't the only choice
  - base 2: 1's and 0's only
  - 0 → 00000000 (8-bit)
  - 1 → 00000001 (8-bit)
  - 2 → 00000010 (8-bit)
  - 3 → 00000011 (8-bit) (1 + 2)
  - 4 → 00000100 (8-bit)
  - 127 → 01111111 (8-bit) (1 + 2 + 4 + 8 + 16 + 32 + 64)
- If we want to represent negative numbers, we *could* make up some rule, like:
  - –127 → 11111111 (8-bit): first bit indicates negative

This is one of several representations (esp. for handling negative numbers)

How Binary Works:

- Instead of a 1's place, 10's place, 100's place, etc.
  - which is 10^0 place, 10^1 place, 10^2 place, etc. for base ten
- We have a 1's place, 2's place, 4's place, 8's place…
  - which is 2^0 place, 2^1 place, 2^2 place, 2^3 place, etc. for base 2
- In decimal, when we get to 9, we've run out of digits
  - next number is 10
  - after 9999 is 10000
- In binary, when we get to 1, we've run out of digits
  - next number is 10
  - after 1111 is 10000

Example: Binary to Decimal

- What is 01101011 in decimal?
  - we'll ignore our special rule for negative here: only positive
- By analogy, what does 642 mean?
  - 6 100's plus 4 10's plus two 1's
  - $6\times10^2 + 4\times10^1 + 2\times10^0$
- 01101011 is then:
  - $0\times2^7 + 1\times2^6 + 1\times2^5 + 0\times2^4 + 1\times2^3 + 0\times2^2 + 1\times2^1 + 1\times2^0$
  - $0\times128 + 1\times64 + 1\times32 + 0\times16 + 1\times8 + 0\times4 + 1\times2 + 1\times1$
  - 64 + 32 + 8 + 2 + 1
  - 107

Example: Decimal to Binary

- Let's represent 99 in binary form
- By analogy, in decimal, we don't need any thousand's-place, or hundred's place (these are zero)
  - meaning you could write 99 as 00000000000099
  - 99 is not big enough to need any of the higher places
- We do need 9 10's, then left over with 9
- If in binary, we have a 128's place, 64's place, etc.:
  - then 99 doesn't need a 128: 128 is too big
  - but does need a 64, leaving 35
  - remaining 35 needs a 32, leaving 3
  - remaining 3 does not need a 16, 8, or 4, but does need 2, leaving 1
  - remaining 1 needs one 1 to finish out
- So result is 01100011

How many digits/bits

- 3 decimal digits lets you represent 0–999
  - 1000, or 10^3 possible numbers
- Generally, *N* decimal digits gets you 0–10^N – 1
  - 10^N possibilities
- 3 binary digits gets you 0–7 (2^3 = 8 possibilities)
  - 000, 001, 010, 011, 100, 101, 110, 111
- In general, *N* binary bits gets you 2^N possibilities
- In a similar way, a license plate with a format
  - ABC 123 has (26)×(26)×(26)×(10)×(10)×(10) = 17,576,000 possibilities
  - enough for most states

Adding Binary Numbers

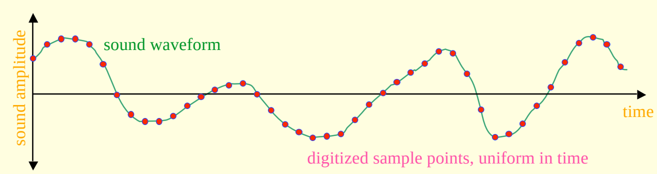
- Same rules apply as for adding decimal numbers:
  - when you exceed the available digits, you "carry" extra digits
- Let's add 46 and 77
  - 00101110 and 01001101

```
     1 1
  00101110   =  2 + 4 + 8 + 32 = 46
+ 01001101   =  1 + 4 + 8 + 64 = 77
-----------
  01111011   = 1 + 2 + 8 + 16 + 32 + 64 = 123
```

- The rules are:
  - 0 + 0 = 00
  - 1 + 0 = 0 + 1 = 01
  - 1 + 1 = 10 (0, carry a 1)
  - 1 + 1 + 1 = 11 (1, carry a 1)

Digital Representation of Analog Quantities

- Sound waveform can be *digitized*
- At uniform time intervals, amplitude of waveform is characterized by an integer number
  - 8-bit (from –127 to 127) (low resolution)
  - 12-bit (from –2047 to 2047)
  - 16-bit (from –32767 to 32767) (high resolution)



Digital Audio Formats

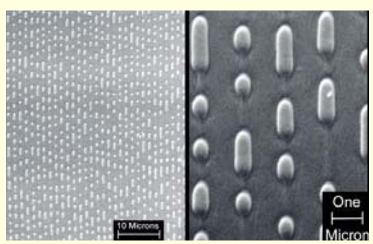
- Must sample at greater than twice the highest frequency you want represented in the sound clip
  - Human hearing sensitive up to 20,000 Hz
  - CDs recorded at 44,100 Hz (44,100 samples/second)
- Must have reasonable resolution (fine-grain)
  - 8-bit has only 42 dB dynamic range (sounds grainy)
  - 16-bit has 84 dB range: CD's at 16-bit
- Stereo is usually desirable (separate waveforms)
- CD's then read $2\times 44{,}100\times 16$ = 1.4 million bits/sec
  - in familiar units: 1411.2 kbits/sec
  - 74-minute disc then contains 6.26 billion bits = 783 MB
  - one second of CD music contains 176 kB of data
  - data CDs use some space for error correction: get 650 MB

All that information on one little disk?!

- CDs are truly marvels of technology
- Data density: 6.26 billion bits over πR^2 area
  - R = 60 mm = 60,000 μm → A = 11 billion μm^2
  - 0.55 bits per micron-squared: 1.34 micron square per bit
- Bits arranged in spiral pattern from center out
  - Outer 40 mm / 1.34 micron → 30,000 wraps
  - 74 minutes = 4440 seconds → 6–7 revolutions per second
- Bits ⇔ Pits pressed into aluminum foil
  - Pit → digital 0; No pit → digital 1

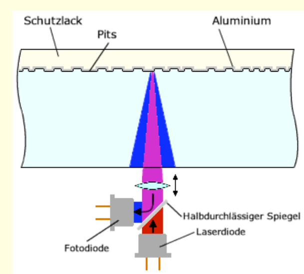
Arrangement on the CD

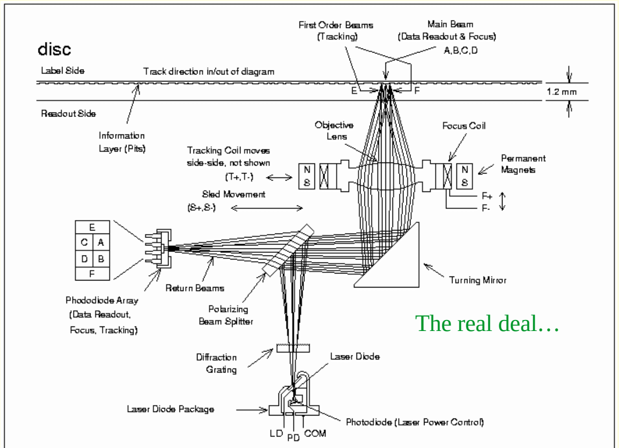
- Pits are arranged in long spiral, starting at center and spiraling outward toward edge
- Are pits bits? Are non-pits bits?



Read-out Mechanism

- Laser focuses onto pit surface
- Reflected light collected by photodiode (light sensor)
- Intensity of light interpreted as bit value of zero or one
- Separate side beams ensure tracking
  - "ride" between adjacent tracks on spiral
- polarizing beamsplitter separates outgoing from incoming light





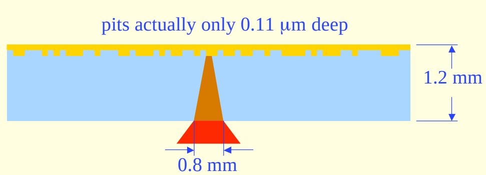
Sony KSS361A Optical Pickup Organization

Optical Requirements

- Pits are *small*!
  - micron size; laser wavelength is 0.78 μm
- Cannot (quantum-mechanically) focus laser smaller than its wavelength
  - and have to work real hard to come close

Noise Immunity

- Can scan ahead (array of detectors)
  - Build up multiple-reads of same block
- Hardly affected by dust/scratches on surface
  - beam is 0.5–1 mm in diameter as it encounters disk
  - most of beam sees around dust or scratch



Why All the Fuss? Why Go Digital?

- Sound, images are inherently analog:
  - sound is continuously variable pressure amplitude
  - light is represented by a continuum of wavelengths and brightnesses
- But reproduction of these with high fidelity would require precision recording, precision equipment
  - exact height of ridges in vinyl record groove critical
  - exact signal strength of radio wave determines brightness of pixel on TV screen
  - device-dependent interpretation (tuning) subject to variation
- Digital information means unambiguous data
  - CD pit is either there or it isn't
  - Electronically handled as 0V or 5V: easy to distinguish
  - everybody has access to the full-precision information

DVD Technology

- DVDs make many leaps beyond CD technology:
  - 0.65 μm laser: the better to see you with
    - smaller pits→greater data density
  - can be double-sided
  - double layer in some cases (4 layers altogether)
  - data compression
- Density of pits up 4 times, plus 4 surfaces
  - holds 16 times as much as CD
- Data compression extremely important for DVDs
  - avoids redundant coding of repetitive information (e.g., still scenes, backdrops, even music waveforms)

Data Compression

- Two types: *lossless* and *lossy*
- Lossless examples
  - zipped computer files, GIF images, stuffit
  - can *completely* recover error-free version of original
  - toy example: 00010001000100010001000100010001
    - notice 0001 appears 8 times
    - *could* represent as 10000001, where first 4 bits indicate number of times repeated, second four is repeated pattern
    - compresses 32 bits into 8, or 4:1 compression ratio
- Lossy examples
  - JPEG, MP3, MPEG
  - look/sound okay, mostly by cheating
  - ignoring information they eye/ear is not adept at noticing
  - irrecoverable errors introduced into data

Audio Compression

- Imagine a perfect sine wave
  - could represent this as lots of samples (many bits)
  - or could represent as frequency and amplitude (few bits)
- MP3 recipe
  - break into short bits (576 samples)
    - shorter (192) when something abrupt is happening
  - characterize frequencies and amplitudes present
  - represent as fewer numbers of bits
  - if one frequency dominates, can ignore the rest
    - ear's limitation allows us to do this
  - achieve compression of about 11:1

References & Assignments

- References:
  - How CDs work: http://electronics.howstuffworks.com/cd.htm
  - DVDs: http://electronics.howstuffworks.com/dvd.htm
  - MP3: http://computer.howstuffworks.com/mp3.htm
  - also: http://en.wikipedia.org/wiki/Mp3
  - http://computer.howstuffworks.com/file-compression.htm
  - iPod: http://electronics.howstuffworks.com/ipod.htm
- Assignments
  - HW4, due 5/11: 11.E.16, 11.E.19, 12.E.13, 12.E.14, 12.E.15, 12.E.16, 12.E.17; plus 6 additional required questions accessed through assignments page on website