

Penn State Abington
CMPEN 271
Lecture #2

Digital versus Analog Systems

R. Avanzato © 2017-2018

Topics:

- What is a Digital System?
 - Digital versus Analog
 - CD vs. Phonograph
 - Base 2 number system
-

Video Part 1 of 4 ←

- How is a CD Created?
 - Digitizing an Analog Signal (HW #1A) **Video Part 2 of 4**
 - Advantages of Digital System
-

- HW #1B Digital Answering Machine and Digitizing Signal **Video Part 3 of 4**

- Review Questions **Video Part 4 of 4**

Problem

Assume a friend or relative is convinced that phonograph (turntable) records sound better than digital CD and MP3 players.

“Why is digital better than analog?” the person asks.
Is digital always better than analog?

You have been chosen to represent Penn State in the
“analog versus digital” debate. Be prepared.

What is a digital system?

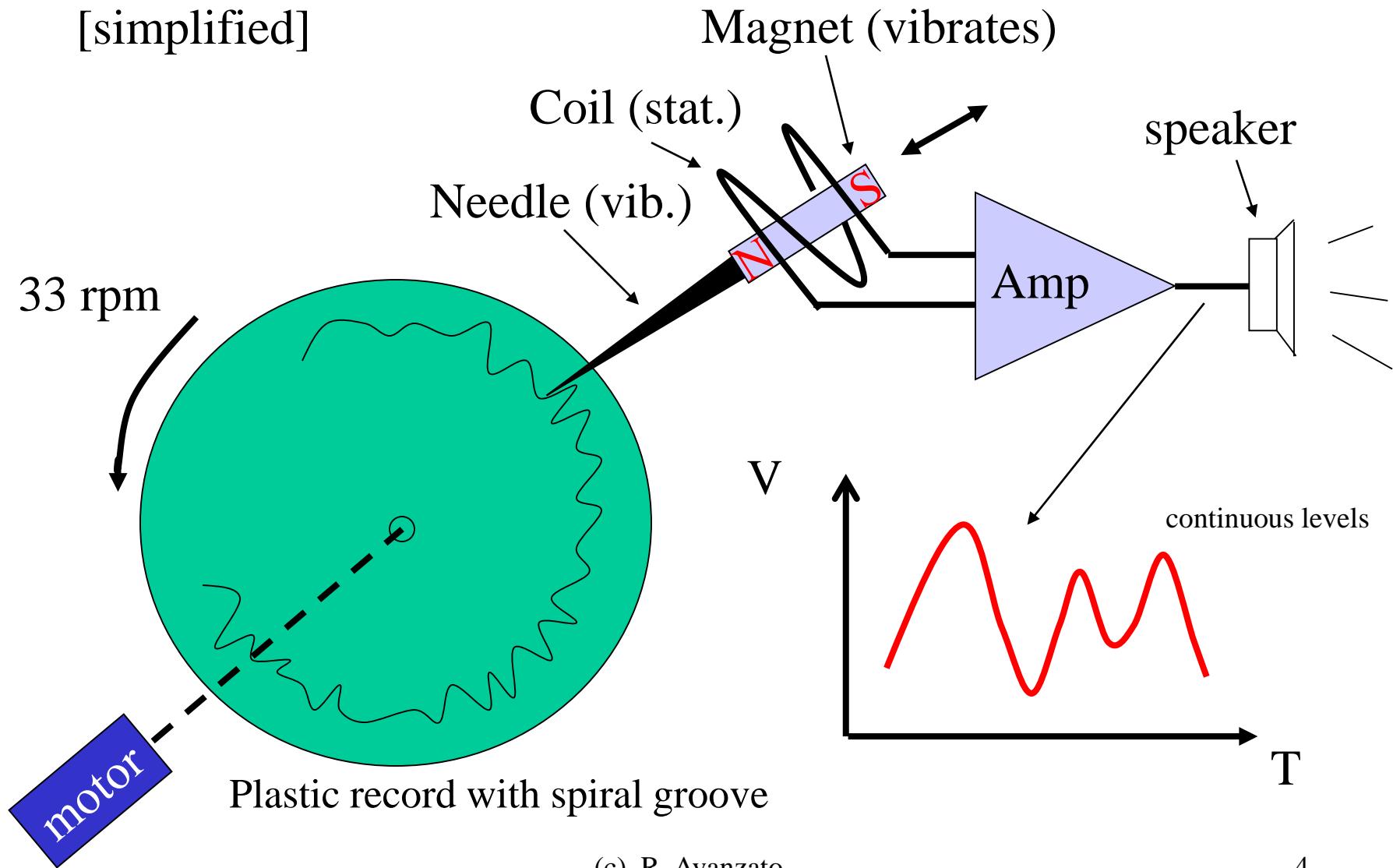
- What is the definition of a digital system?
 - What are some examples of a digital system?
 - What is an analog system?
 - Name examples of an analog system
 - Compare a digital system to analog system
 - What are the advantages and limitations of a digital system?
 - Compare a CD player (digital) with an LP phonograph (analog)
 - Are digital systems always better?
 - Are the following systems analog or digital? Explain
TV, Radio, Microwave, telephone, cassette, DVD,
cell phone, MP3, computer, calculator, etc
-
- Reference: <http://www.howstuffworks.com>
 - Review videos on Edison's phonograph on Youtube. Do search on word "phonograph" Example:
<http://www.youtube.com/watch?v=uAXhclPS3AE>



Ref: Wikipedia

Phonograph (LP)

[simplified]

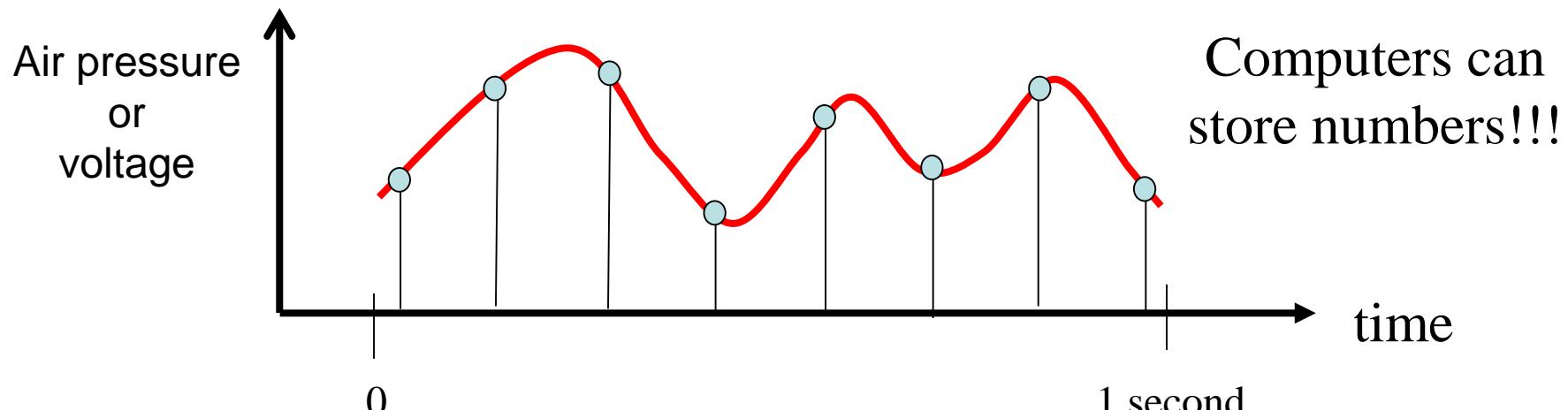
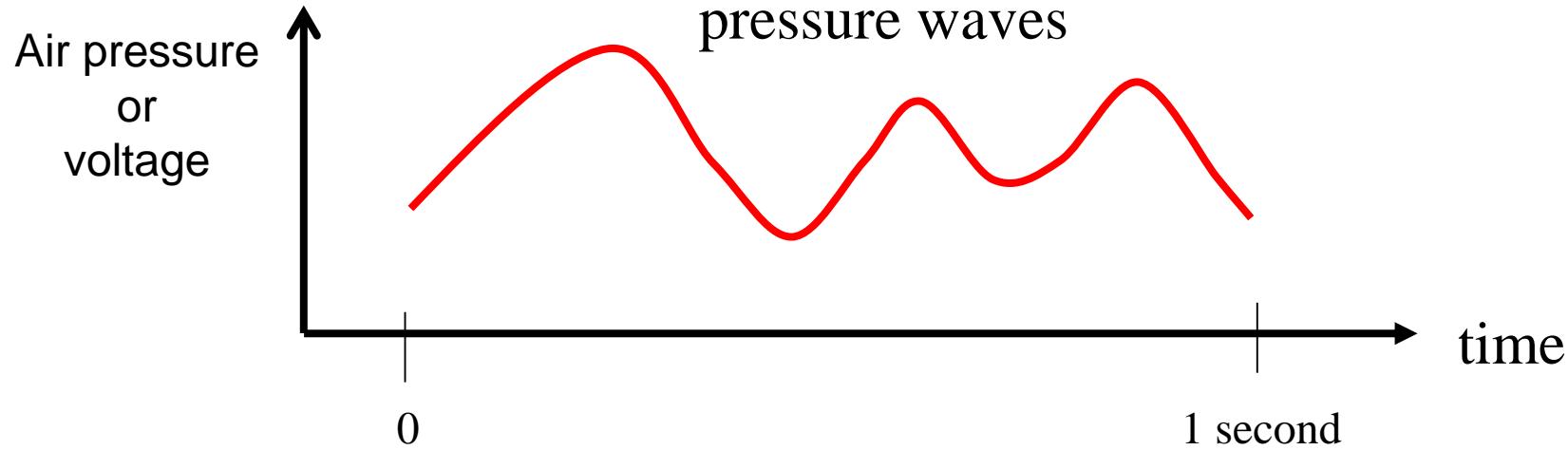


Phonograph Technology (analog)

- Describe how a phonograph (LP) works
- Identify the major components of the phonograph
- What are some of the limitations and disadvantages of the phonograph?
- Ask your parents or grandparents about their experiences with the phonograph? What problems did they experience?
- How does a speaker work?
- Is sound analog?
- What is the velocity of sound? Radio wave?
- How far away was the lightning bolt? (not digital!)

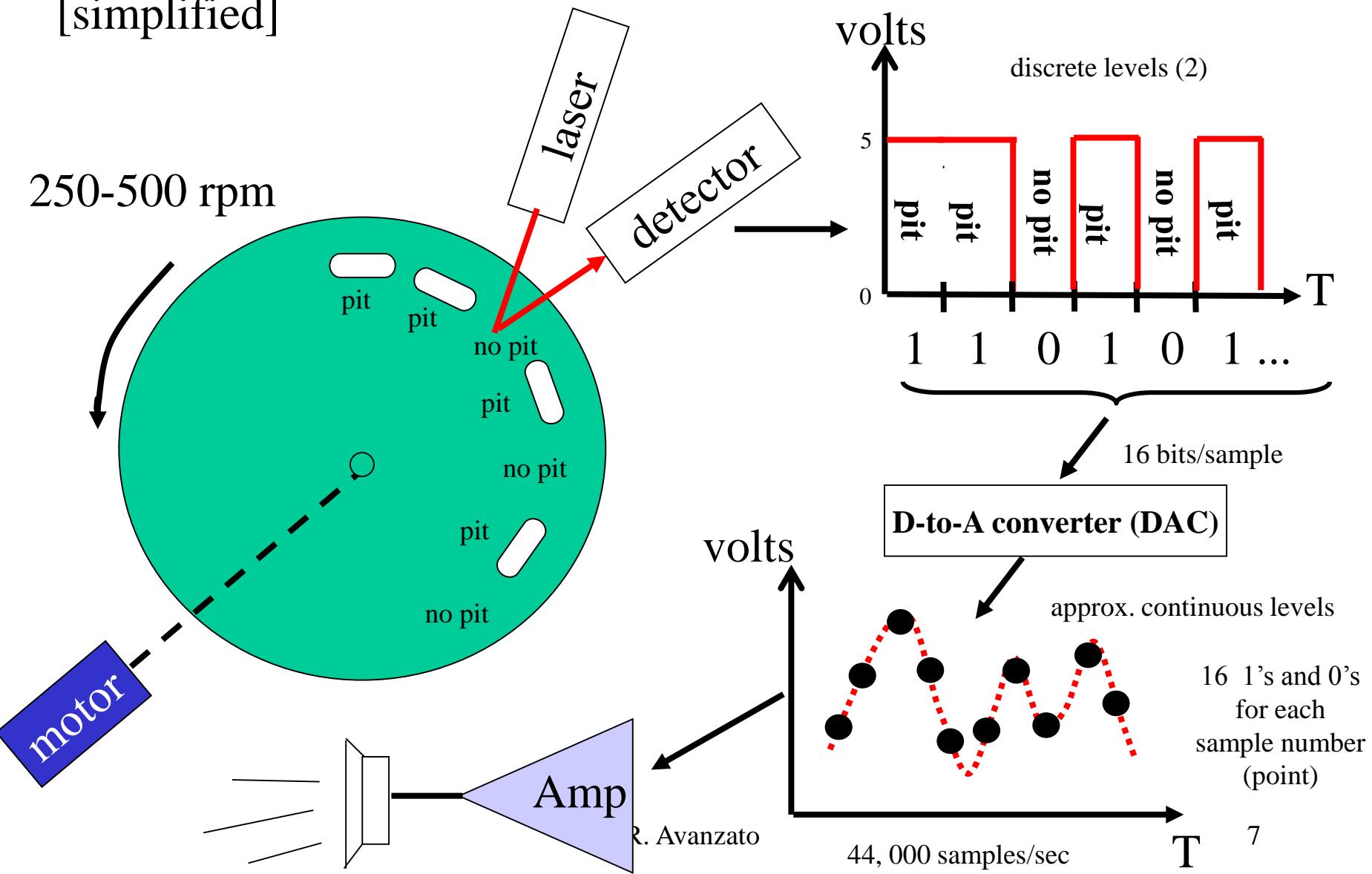
How can we store sound in computer?

Sound (music, voice, noise, etc) is smoothly varying air pressure waves



CD Audio Player

[simplified]



How many bits (pit or no pit) are on a typical CD?

- Assume total playing time of a typical CD = 75 minutes
- Total playing time in seconds = $75 \text{ min} * 60 \text{ sec/min} = 4500 \text{ seconds}$
- Assume sampling frequency for a CD to be 44,000 samples/second
- Sampling frequency is measured in samples/sec or Hertz (Hz)
- A sample is simply a voltage reading at a particular time. It is a number.
- Total # of samples = $44\text{K samples/sec} * 4500 \text{ sec} = \approx 200 * 10^6 \text{ samples}$
- For a CD, the quantization = 16 bits (pits/flats) per sample
- Total # of bits = $200 * 10^6 \text{ samples} * 16 \text{ bits/sample} = \approx 3.2 * 10^9 \text{ bits}$
- Double this # for stereo -- Total # of bits $\approx 6.4 * 10^9 \text{ bits}$
- There are additional bits for error correction and synchronization (ignore)
- By definition --- **8 bits = 1 byte**
- Total # of bytes on a CD $\approx 6.4 * 10^9 \text{ bits} * (1 \text{ byte}/8 \text{ bits}) \approx 800 \text{ MB}$
- Is this consistent with storage of a CD-ROM?
- How many bits per second are read from a CD while playing?
- Note: in reality, the laser scans “bumps” not “pits” (same concept)

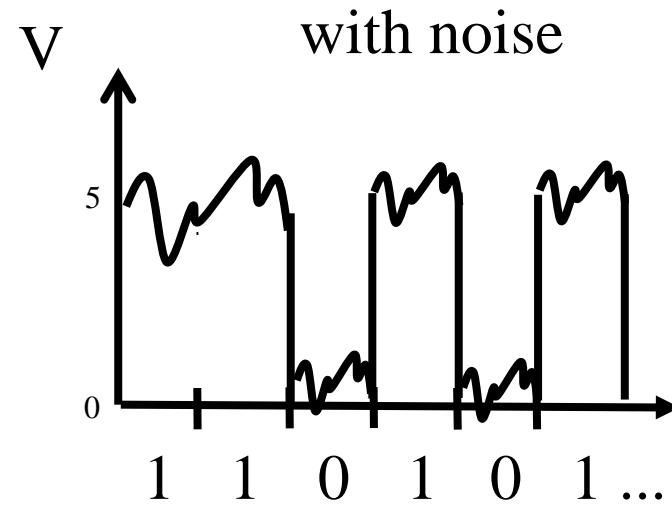
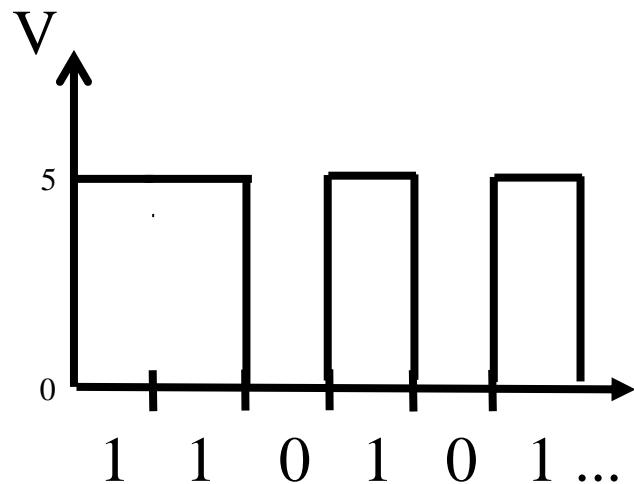
Intro. to Base 2 (Binary) Numbers

$$\text{Base 10: } \begin{matrix} 10^2 & 10^1 & 10^0 \\ 3 & 7 & 8 \end{matrix} = 3 * 10^2 + 7 * 10^1 + 8 * 10^0$$

$$\text{Base 2: } \begin{matrix} 2^2 & 2^1 & 2^0 \\ 1 & 0 & 1 \end{matrix} = 1 * 2^2 + 0 * 2^1 + 1 * 2^0 = 5 \text{ (base 10)}$$

- Only 2 allowed symbols in base 2 ----- 0 and 1
- Any number in base 10 can be represented in base 2 (1's and 0's)
- Any number in base 2 can be represented in base 10

Noise Immunity



- Same signal (bits) retrieved (noise removed)
- Noise immunity
- Where does noise (interference) come from?
- Can noise be removed from an analog signal?

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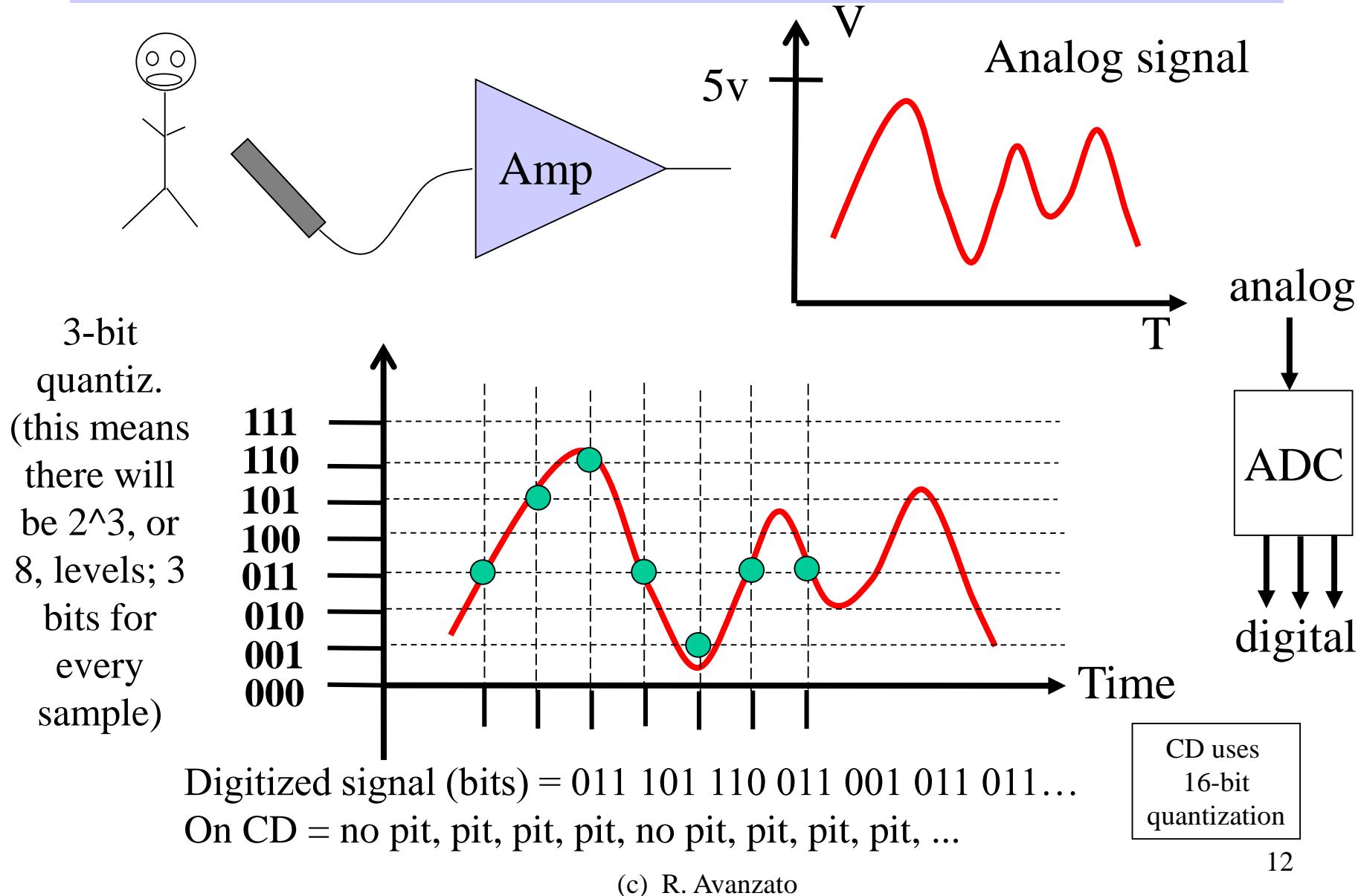
Video Part 1 of 4

- How is a CD Created?
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 - Advantages of Digital System
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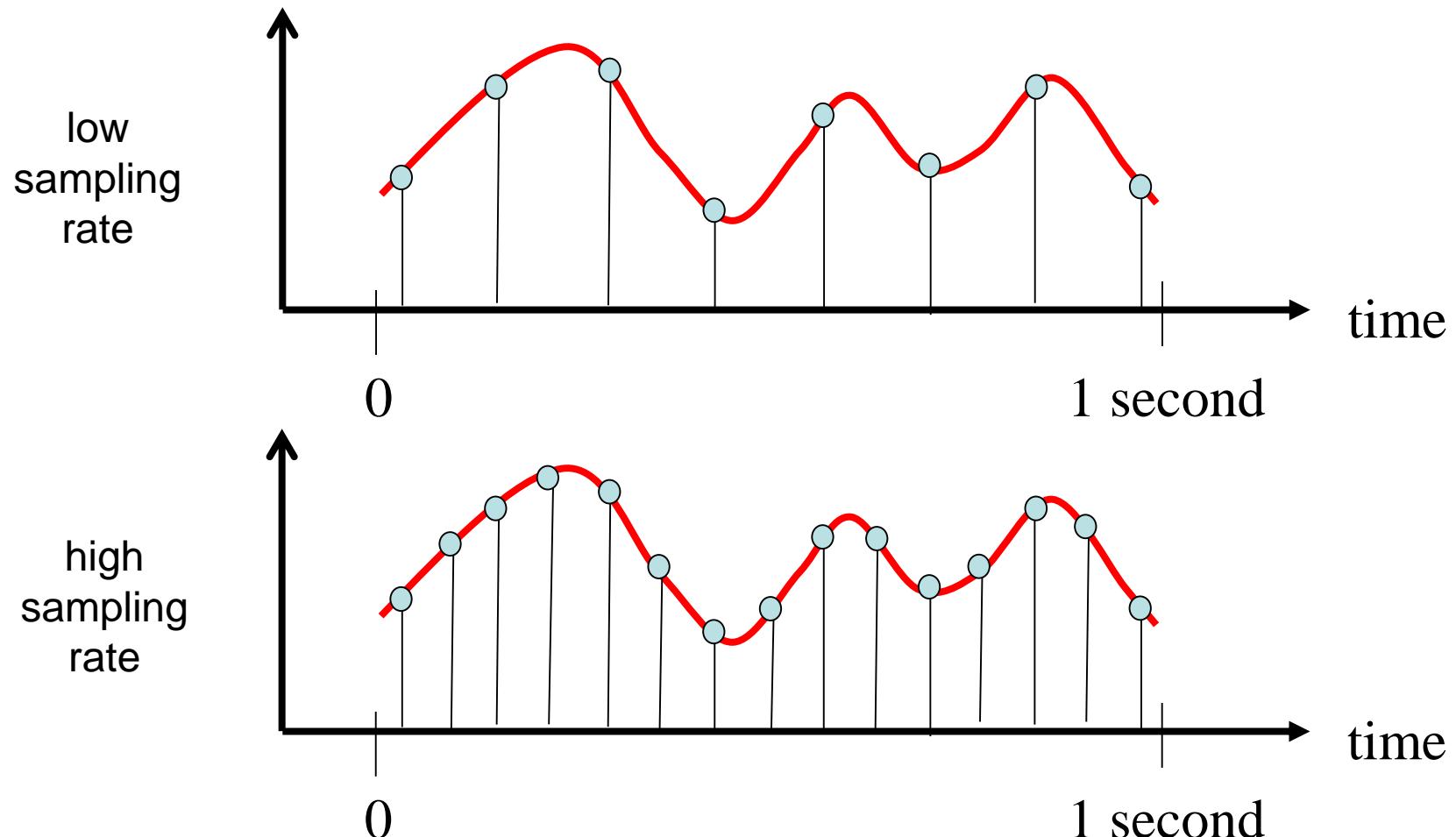
- HW #1B Digital Answering Machine and Digitizing Signal **Video Part 3 of 4**

- Review Questions **Video Part 4 of 4**

How is a CD created?

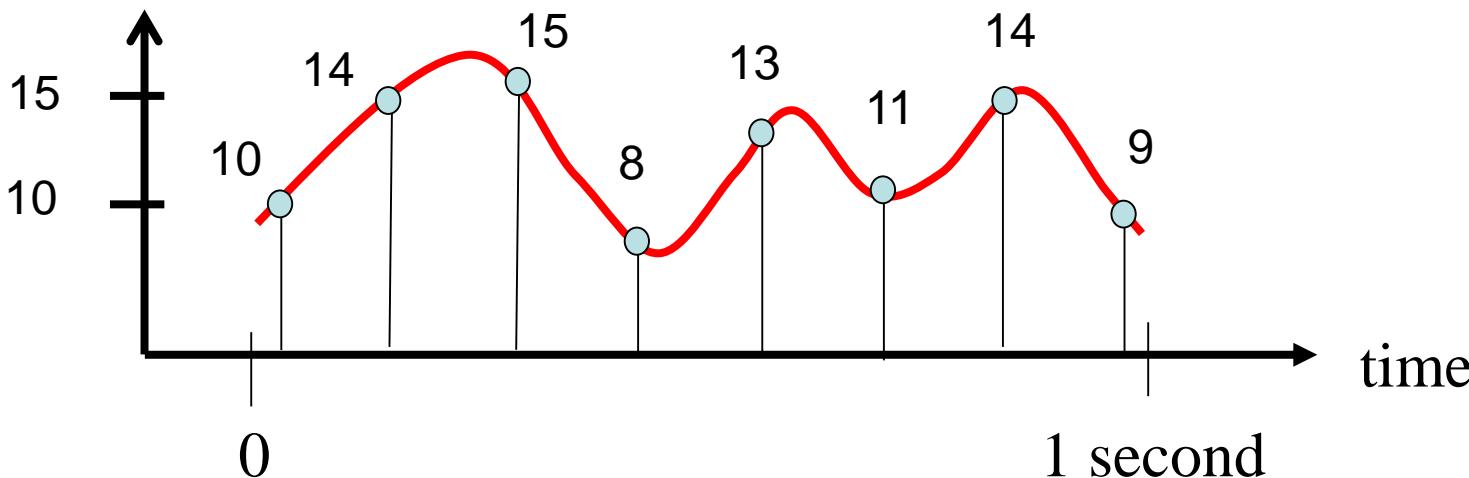


Comparing Sampling Rates



Discussion Question

A digitally recorded song is really a list of numbers (but numbers are stored in binary)



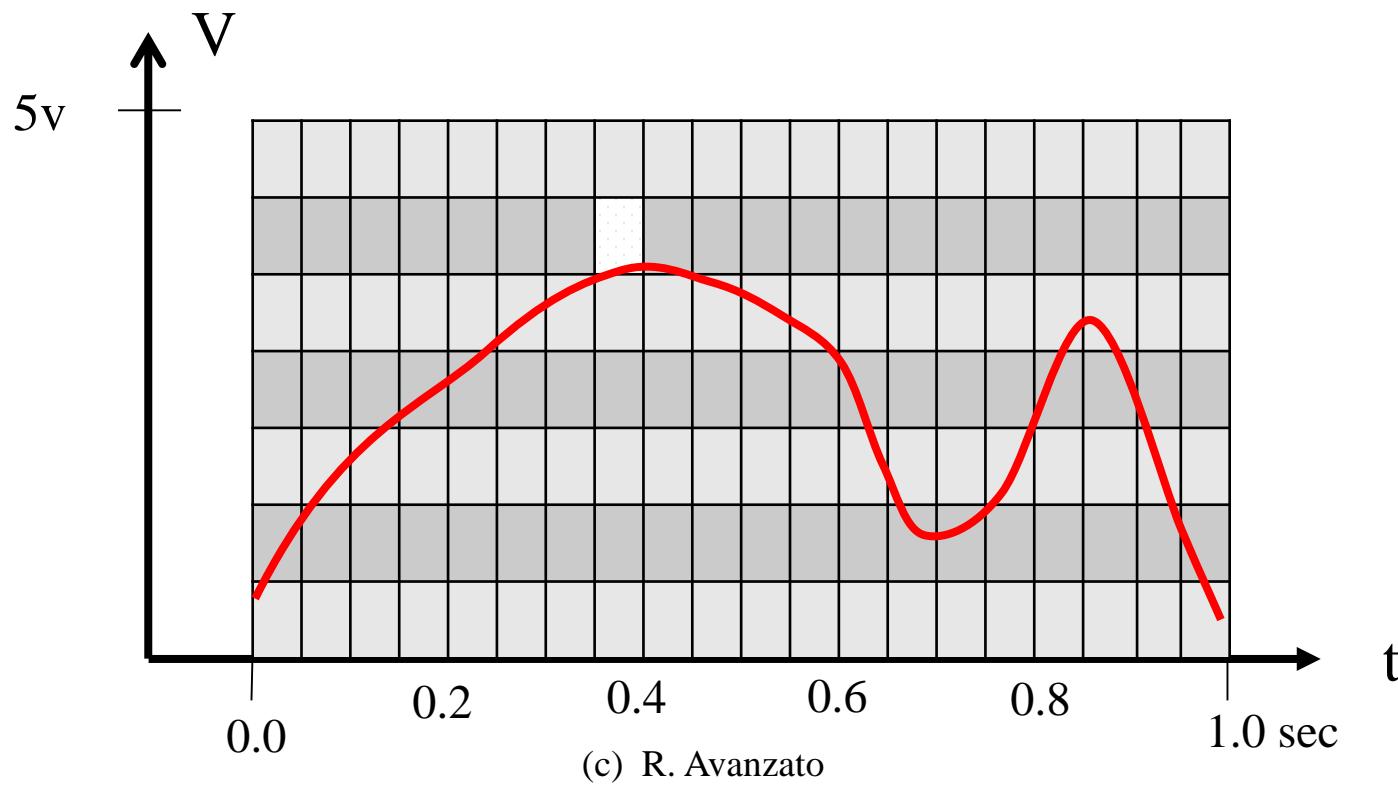
| <u>List of numbers</u> |
|------------------------|
| 10 |
| 14 |
| 15 |
| 8 |
| 13 |
| 11 |
| 14 |
| 9 |
| etc |

What do the numbers represent? Where is time?
Compare sampling concept to a video/movie

Each number may require 8 bits or more.
(depends on quantization)

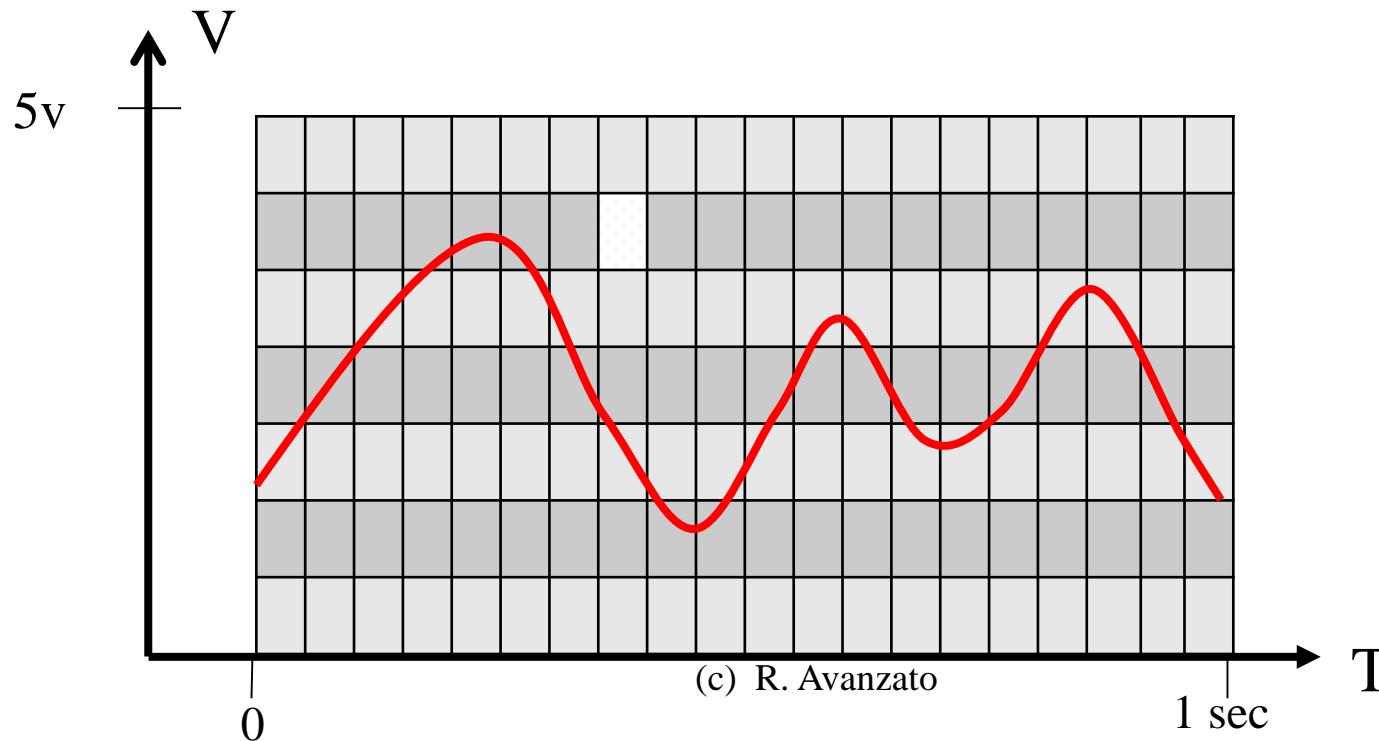
Practice: Digitize an Analog Signal

- Let sampling frequency = 5 Hz (5 samples per second). Try others
- Let quantization = 3 bits/sample . Try others.
- Digitize signal from $t=0$ sec to $t=1$ sec only.
- Generate a stream of 1's and 0's as output.
- How many total bits will be generated (in 1 second)?
- Hint: Draw a grid (draw evenly-spaced vertical lines and horizontal lines).
- Hint: See previous slide “How is a CD Created?” for an example.



HW#1A: Digitize an Analog Signal

- Let sampling frequency = 10Hz (10 samples per second)
- Let quantization = 2 bits/sample
- Digitize signal from $t=0$ sec to $t=1$ sec only.
- Generate a stream of 1's and 0's as output.
- How many total bits will be generated (in one second)?
- Hint: Draw a grid (use evenly-spaced vertical lines and horizontal lines).
- Hint: See previous slide “How is a CD Created?” for an example.



(c) R. Avanzato

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Definition of a Digital System

Digital System = processes and stores information represented in **discrete** levels (2 or more levels).

Analog System = processes and stores information represented as **continuous** range of values

Questions:

- 1) Is a binary system (2 levels) a digital system? Is a digital system always binary?
- 2) Is the real world analog or digital?

Advantages of a Digital System

- Noise Immunity
- Easier to design digital circuits
- Digital systems can be programmed (using software)
- Easier to duplicate digital circuits (consistent performance)
- Can miniaturize digital circuits more easily than analog
- Digitized information (music, photos, videos, ebooks, etc.)
can be reproduced (copied) with no loss of quality.

Digital System Review-1

- What is a digital system?
- Name examples of digital systems?
- What is digital communication? Give examples.
- What are advantages of a digital system over an analog system?
- Where are the 1's and 0's in a digital system? Explain.
- What is a bit? How are bits represented?
- What is a byte?
- What is ADC? Explain inputs & outputs
- What is DAC? Explain inputs & outputs
- What is sampling frequency? Units?
- What is quantization (resolution)? Units?
- What are the pros and cons of high sampling frequency and quantization?
- How is digital information stored on a flash drive, harddrive?
- Is the speedometer in your car analog or digital?

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and Digitizing Signal
-
- Review Questions **Video Part 4 of 4**

HW#1B: Design of a Digital Answering Machine

Design Problem: (Part 1.) You are an engineer at a company planning the design and manufacture of a digital answering machine. Given a sampling rate of 12KHz and a quantization of 8 bits, how much memory (MBytes) is required to store 20 minutes of conversation? What size memory chip (in MBytes) is appropriate? (Recall that memory chip sizes are available in powers of 2. For example, 2KB, 4KB, 8KB,2MB, 4MB, 8MB, 16MB, 32MB, ...2GB, 4GB, 8GB, 16GB, etc.) **Must show all steps of the calculation.**

(Part 2) If your manager says the overall total cost for the memory chips is too high, what would you recommend to reduce costs (or needed capacity) of memory chips? What questions would you ask? (Include 3 suggestions)

What you should know...

- Know definition of key terms: analog system, digital system, ADC, DAC, sampling frequency, sample, quantization, resolution, bits, byte.
- Be able to identify examples of analog and digital systems.
- Be able to compare a phonograph (analog) system with a CD(digital) system.
- Be able to list and explain the advantages of a digital system over an analog system.
- Be able to compute the number of bits and bytes required to store a digitized signal given the sampling frequency and the quantization
- Be able to graphically digitize an arbitrary analog signal given the sampling frequency and quantization.
- Understand how an arbitrary base 10 number can be represented as a binary base 2 number (1's and 0's)
- Be able to compute the number of bits and bytes required to store a digital image given the number of pixels and the color depth.

Homework #1 (check due date)

- **Part 1A**: Digitize Analog Signal from previous slide; include plot with grid; generate series of 1's and 0's. (10 pts)
- **Part 1B**: Digital Answering Machine from previous slide (include any calculations). (10 pts)
- Submit each solution part in a **separate Word document** (or PPT) to Canvas into HW#1A Dropbox and HW#1B Dropbox.
- **Include header** with course name, student name, homework number, title, date, and brief description of HW (do this for all homeworks; otherwise grade penalties)
- **Individual effort** – not team
- **Collaboration** is allowed (and encouraged), but no copying is permitted
- **Ask instructor** if you have any questions.
- **Submit on time** to avoid late penalties

Required Readings

- www.howstuffworks.com
 1. How do Bits and Bytes Work
 2. How do CDs Work
 3. How do Analog and Digital Recordings Work
- Above 3 articles are required readings. Please ask instructor if you have any questions.
- Hint: When you want to read an article on **HowStuffWorks** website → press the **Print Version** button first (but do not print). This displays the article in a format which is easier to read and is contained on one page (and also the advertisements are removed)
- It is recommended that you **take some notes** to summarize key ideas in these articles. Also, write down any questions that you might want to ask the instructor in class or by email.

Summary

- A vinyl LP and phonograph system is an example of an analog system. Sound signals are stored as continuous values as grooves.
- A CD is a digital system and stores sound waves (and other information) in a digital format using two discrete symbols → "pits" and "flats"
- The sampling rate (or sampling frequency) is the number of samples per second. Each sample is a numeric value on a waveform. For example, the sampling rate for CD quality sound is 44,000 samples per second (or 44KHz)
- Determining the sampling rate depends on the how fast the signal is changing.
- The quantization is the number of bits per sample. Generally quantization is between 8 and 20 bits/sample.
- If quantization is 3 bits, then there are (2^3) 8 levels on the vertical scale (amplitude).; if quantization is 4 bits, there are (2^4) 16 levels, etc.)
- Any number or numeric quantity can be expressed in base 2 as a sequence of 1's and 0's.
- One advantage of a digital system over an analog system is noise immunity. Other advantages include ease of fabrication, reliability, less mechanical parts, and precision.
- The disadvantage of digital systems is that the real world is analog. So, for the example of a digital sound system, one needs an analog-to-digital converter (ADC) to get analog sound into the digital system, and one needs a digital-to-analog converter (DAC) to convert the digital signals into analog so humans can hear the sound.

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- Review Questions

Video Part 4 of 4 ←

Sample Questions

1. A digital system represents information in

- a) discreet levels b) discrete levels
- c) a continuous range of values d) variables

2. An analog system represents information in

- a) discreet b) discrete levels
- c) a continuous range of values d) variables

3. Sampling frequency is expressed in what units?

- a) bits b) voltage c) Hertz d) number of bits/sample

4. The term "quantization" refers to the

- a) number of bits per sample b) number of samples per second
- c) number of bits in a byte d) number of samples per bit

Sample Questions

5. Which of the following systems is analog?

- a) audio cassette b) HDTV c) CD player d) computer

6. What is the quantization for an audio CD?

- a) 16KHz b) 44.4KHz c) 16 bits d) 8 bits

7. The approximate sampling frequency of an audio CD is

- a) 16KHz c) 8 bits d) 16 bits d) 44KHz

8. The bits on a CD are physically represented as

- a) charge b) magnetic field orientation
- c) voltage d) pits/no pits

Sample Questions

9. An 8-bit analog-to-digital converter (ADC) divides the input voltage into how many discrete levels?

- a) 8
- b) 16
- c) 256
- d) 128

10. Approximately how long does it take for light to travel 1 foot?

- a) 1 nanosecond
- b) 1 millisecond
- c) 1 microsecond
- d) 1 sec

11. What is the approximate speed of sound?

- a) 1000 feet per second
- b) 1 billion feet per second
- c) 1 million feet per second
- d) 186,000 feet per second

Sample Questions

12. If a digital system uses a quantization of 8 bits and a sampling frequency of 10Hz, then what is total number of bytes stored in 2 seconds?

- a) 20 bits
- b) 20 bytes
- c) 80 bytes
- d) 80 bits
- e) 160 bytes

13. If a digital system uses a quantization of 16 bits and a sampling frequency of 1KHz, then what is total number of bytes stored in 1 second?

- a) 2000 bits
- b) 2000 bytes
- c) 16 bytes
- d) 16,000 bits
- e) 160 bytes

Sample Questions

16. If a digital system uses a quantization of 16 bits and a sampling frequency of 1KHz, then what is total number of bits stored in 1 second?

- a) 2000 bits
- b) 16 bytes
- c) 16000 bits
- d) 16000 bytes
- e) 160 bytes

17. If the sampling frequency is doubled for an analog to digital recording system, then the number of bits stored in 1 sec will increase by a factor of..

- a) 2
- b) 4
- c) 8
- d) 16
- e) 1

18. If the quantization is doubled from 8 bits/sample to 16 bits/sample for a analog to digital recording system, then the number of bits stored in 1 sec will increase by a factor of..

- a) 1
- b) 4
- c) 8
- d) 16
- e) 2

Sample Questions

19. One of the key advantages of a digital system over an analog system is
- a) voltage
 - b) price
 - c) power
 - d) noise immunity
20. If the sampling frequency of a digital recording system is increased, then
- a) quality increases
 - b) quality decreases
 - c) storage requirements decrease