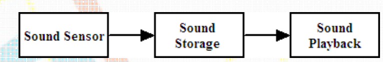
Physics in Entertainment and the Arts

Chapter XXII

Audio/Video Recording and Playback

Audio Recording and Playback

- This diagram shows the basic processes for recording and playing back sound



Sound Sensor

- The basic sound sensor is a microphone
  - which is a transducer
    - A device which converts one type of wave into another
- There are five basic types of microphones
  - carbon (not used much anymore)
  - dynamic
  - ribbon
  - condenser
  - crystal

Microphones

- Carbon
  - A vial of carbon dust connected to a diaphragm
  - Sound waves hitting the diaphragm compress the dust changing its resistance which is turned into an electrical wave
  - Drawback: Carbon microphones need a small current to produce the electrical wave
- Dynamic
  - The same process as a speaker, but in reverse!
    - $F = qvB$

Microphones

- Ribbon
  - A thin conducting ribbon suspended in a magnetic field connected to a diaphragm
  - Sound waves hitting the diaphragm move the ribbon in the field creating an electrical wave
    - $F = qvB$ again

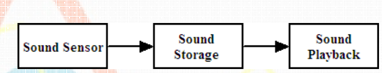
Microphones

- Condenser
  - A capacitor with one parallel plate connected to a diaphragm which can move
  - Sound waves hitting the diaphragm change the capacitance of the capacitor which is turned into an electrical wave
  - Drawback: Condenser microphones need a small battery to provide a voltage across the capacitor

Microphones

- Crystal
  - Certain crystals (called piezoelectric crystals) change their electrical properties as they change shape
  - By attaching a diaphragm, the crystal will create an electrical wave when sound waves hit the diaphragm and compress the crystal
  - Advantage: Can be made very small

Audio Recording and Playback



Sound Storage

- The output of the sound sensor can be directly connected to an amplifier and speaker for immediate enjoyment
- However, normally we want to record the sound for playback at a later time
  - So we must store the sound signals

Sound Storage

- Storing the sound sensor's electrical output can be done in many ways
- Examples
  - grooved disks
  - magnetic tapes
  - compact disks (CD's)
  - solid state devices

Grooved Disks (Records)

- This was the original method
  - Invented in 1877 by Thomas Edison
    - Started with a grooved cylinder
    - Went to a grooved disk in 1889

Grooved Disks (Records)

- The sound vibrations are scratched as bumps and wiggles in the groove on the disk
- The height of the bumps give us the intensity of the sound, the wiggles give us its frequency

Grooved Disks (Records)

- When you playback the disk, a needle connected to magnets follows the groove and moves the magnets back and forth inside wire coils
  - This produces electrical current corresponding to the sound vibrations

- The current is amplified and used to drive a speaker

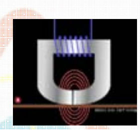
Magnetic Tapes

- This method was invented in 1898
  - Originally used steel wires not plastic tape
- The tape consists of a thin plastic base material coated with ferric oxide powder
  - Ferric oxide contains iron, which is magnetic
- The oxide is normally mixed with a binder to attach it to the plastic

Magnetic Tapes

- The sound wave is recorded on the tape through an electromagnet driven by the sound sensor
- The electromagnet's field varies in time to the sound
  - which magnetizes the iron particles on the tape to match the sound patterns as the tape is pulled past the magnet

Magnetic Tapes



An aside: Magnetic Hard Drives

- Invented in 1950's
- Differences between cassettes and hard drives
  - In a hard disk, the magnetic recording material is layered on an aluminum or glass disk and then polished to mirror smoothness
    - This makes it very durable compared to tape

An aside: Magnetic Hard Drives

- With a tape, you have to fast-forward or reverse to get to any particular point on the tape
  - This can take several minutes with a long tape
- With a hard disk, you can move to any point on the surface of the disk almost instantly

An aside: Magnetic Hard Drives

- In a cassette-tape deck, the read/write head touches the tape directly, eventually wearing out the tape
- In a hard disk, the read/write head "flies" over the disk, never actually touching it
  - This eliminates wear and tear due to friction

Problems

- There are several disadvantages with recording sound using grooved disks and magnetic tapes
  - Both media will wear out over time
    - The grooves in the plastic are read out by dragging a sharp metal needle through them (ouch!) which cuts into the plastic every time it is played
    - The tape is scraped by the read head every time it is played back

Problems

- The media are easily damaged
  - Scratches in the tape or disk damage the sound patterns recorded
  - The plastic grooved disks can warp due to heat and humidity
  - The plastic tape is easy to stretch and tangle if it catches in the machinery
- The recordings are not "permanent"
  - If played regularly, they can last ~5 years

Analog Recording

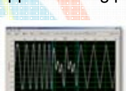
- Both grooved disks and magnetic tapes are examples of analog recordings
- Analog means "continuous"
  - The entire sound wave is recorded
- A problem with analog recording:
  - It's difficult to mass produce!
  - Repeated playing leads to degradation of the original recording

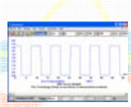
Analog Recording

- This problem can be mostly (not totally) remedied by not recording the sound as an analog (continuous) signal
  - but instead as a digital (non-continuous) signal
- Before we can discuss the remainder of the sound storage methods
  - we have to discuss what digitizing a signal means

Analog to Digital Conversion

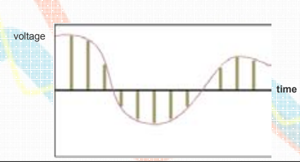
- A/D for short
- The process of converting a continuously varying signal (analog) into a series of approximating pulses (digital)





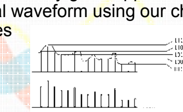
Analog to Digital Conversion

- The A/D process starts by approximating the analog waveform with a series of equally spaced spikes



Analog to Digital Conversion

- The height of each spike is a voltage which is equal to the actual voltage at that particular time
- If we space the spikes close enough, we can get an extremely good approximation of the original waveform using our chain of voltage spikes



Analog to Digital Conversion

- We now encode each spike height as a number
- Example: If the voltage ranges between 0V and 1V, we might break up the range as follows:

0.0V to 0.2V = 0	0.4V to 0.8V = 2
0.2V to 0.4V = 1	0.8V to 1.0V = 3

Analog to Digital Conversion

- So we could approximately represent the analog signal over time as a series of numbers
  - 3120311023221301 for example
- Now comes the tricky part
  - Computers can't recognize any numbers but 0 and 1!
- So we must reduce our sequence to only 0's and 1's

Analog to Digital Conversion

- We do this by converting from the decimal (base-ten) number system to the binary (base-two) number system

0 = 00	2 = 10
1 = 01	3 = 11

These are called 2-bit numbers

Analog to Digital Conversion: An Example

$2^3 = 8 \quad 2^1 = 2$

$$1011 = 1 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 1 \times 2^0 =$$

$2^2 = 4 \quad 2^0 = 1 \qquad 8 + 0 + 2 + 1 = 11$

Analog to Digital Conversion

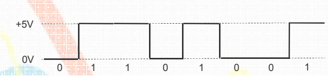
- Older computers use 8-bit numbers; newer ones use 64-bit or even 128-bit numbers
  - Terminology: 8-bits = 1 byte

3 = 0000 0011 in 8-bits

- If we choose a convenient voltage to represent a 0 and a 1, we can send the analog signal as a series of voltage changes

Analog to Digital Conversion

- Example: 0 = 0V, 1 = +5V



- This signal could be represented as an 8-bit pulse train 01101001
  - which equals (in base-ten) the decimal number 69

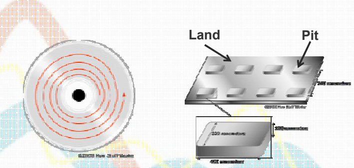
Analog to Digital Conversion

- The computer will now recognize a 0 V pulse as the number "0", and a 5 V pulse as the number "1"
  - and hence can reproduce the series of voltage spikes on its output
- The spikes will be an ***approximation*** to the original sound recorded
  - and can be sent to a speaker to play the sound

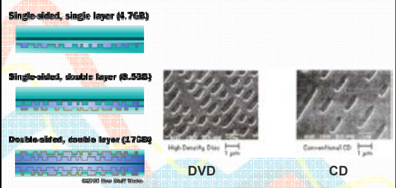
Compact Disks (CD's)

- The binary pulse train can also be recorded as a series of elevation changes above a surface
  - With a zero elevation being a 0 (a "land") and a nonzero elevation being a 1 (a "pit")
- This is how information is recorded on a CD
  - In a spiral track starting from the center

Compact Disks



Compact Disks

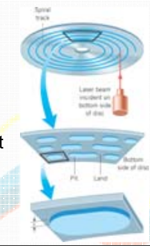


Compact Disks

- Because of the density of information recorded in the spiral track
  - a very precise fine tuned tracking mechanism is needed
- This tracking mechanism must be sharp down to the hundreds of nanometer scale
  - That's the wavelength of visible light!
  - So we use a laser!

Compact Disks

- A laser beam reflecting off the bottom of the disk is used to read the pits and lands
- However, the laser doesn't "see" the lands or pits
  - it "sees" the transitions between them!



Compact Disks

- As the beam sweeps over the edge of a pit
  - part of the beam is on the pit and part on the land
- Each part of the beam has a different path length (PLD ≠ 0)
  - so the beam undergoes destructive or constructive interference depending upon the pattern of data stored on the disk

Compact Disks

- The varying brightness of the reflected beam (due to the interference) is detected by a photocell
  - using the Photoelectric Effect
- The varying brightness is turned into a series of pulses by an A/D converter
  - which goes off to be restored to an approximation of the original sound recorded

Compact Disks

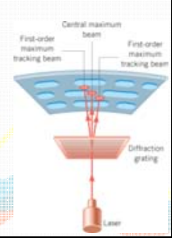
- The data stored on the disk can be considered a thin film
  - where the varying thickness of the film (the pits and the lands) stores the data pattern
- This is all good and well, but since the spiral track is so narrow
  - what happens when the disk heats up and expands by more than the width of the track!

Compact Disks

- Obviously the laser would then be reading the wrong section!
  - So a very accurate tracking mechanism is needed
- More optics to the rescue!

Compact Disks

- Here's what is done…
- The two outer diffracted beams are supposed to stay on the lands and hence remain a constant brightness
  - Only the central beam should vary in brightness



Compact Disks

- If the laser gets off track, the two outer beams will start to reflect off the pits on an adjacent track or the current track
  - and start to vary in brightness!
- A separate photocell will detect this
  - and adjust the laser's path to compensate
    - This is called negative feedback

Compact Disks

- This method can keep the laser on a track just a couple of hundred nanometers wide
  - About 500 times smaller than a typical human hair!

Solid State Devices

- Solid state devices are those that have no moving parts
  - There's nothing to wear out!
- These storage devices record the digital signal in a series of electronic components called EEPROM's
  - Electronically Erasable Programmable Read Only Memory

Solid State Devices

- EEPROM's (a type of "flash memory") are an electrical 2-D grid of cells
  - each containing two transistors at the intersection of each grid line
- Each transistor pair can store electrons for a very long time (but not forever!)
  - A certain number of stored electrons equals a "1", less than that equals a "0"

Solid State Devices

- Because solid state devices have no moving parts
  - they can be made extremely small and shock-resistant
- MP3 players, Ipods, Iphones, etc… all use solid state devices for storage of digital data

Solid State Devices

- Storing the sound wave digital patterns "simply" requires the A/D converter to add the appropriate number of electrons to the appropriate grid intersection
- Playing back the sound pattern "simply" requires the counting of the electrons in each grid intersection and creating the appropriately sized voltage spike

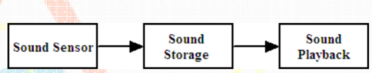
Storage Comparisons

- Analog sound pattern storage
  - Advantages
    - The entire waveform is stored yielding a more accurate reproduction
    - The storage media are cheap
    - Equipment to create original recordings is cheap
  - Disadvantages
    - The media wear out quickly and lose accuracy
    - Mass production is limited by this loss of accuracy

Storage Comparisons

- Digital sound pattern storage
  - Advantages
    - Media last a long time (Nothing lasts forever!)
    - Mass production is not limited by media wear
  - Disadvantages
    - Only an approximation to the original sound pattern is stored
    - Equipment to create original recordings is expensive
    - The storage media are more expensive

Audio Recording and Playback



Sound Playback

- Sound playback from either analog or digital storage is the same
- Two types of transducers are used:
  - speakers
    - woofers
    - tweeters
    - midrange
  - headphones

Sound Playback

- There are lots of types of speakers and headphones
  - but most have the same basics as the microphones discussed earlier
- Interestingly, you can use a microphone as a speaker and vice versa
  - although not as efficiently!

Sound Playback

- The three types of speakers listed are optimized in their construction
  - to reproduce sound more accurately in certain frequency ranges
- Woofers are used for the low frequency range (the "bass")
  - Their large size is able to handle the large amplitude slower oscillating waves

Sound Playback

- Tweeters are used for the highest frequency range (the "treble")
  - Their small size is able to handle the lower amplitude faster oscillating waves
- Midrange speakers handle waves not covered by the other two
  - Mostly the human voice range of frequencies

Sound Playback

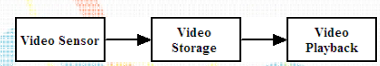
- Good quality speakers are a combination of one of each of these types
  - all connected together

Woofer Tweeter Midrange

Sound Playback

Video Recording and Playback

- This diagram shows the basic processes for recording and playing back video



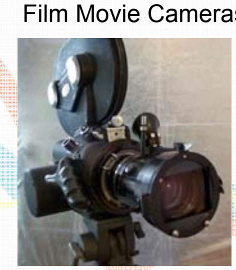
Light Sensors

- There are two basic types of light sensors used for recording video
  - film movie cameras
  - digital movie cameras
- Since we are concentrating on video, we'll ignore still photography

Film Movie Cameras

- In a film movie camera, a motor drives a continuous strip of film past a shutter at about 24 frames per second
- The shutter opens and closes once for each frame exposing the film beneath
- This creates a series of pictures on the film strip that will appear to be moving when played back at the same speed

Film Movie Cameras



Digital Movie Cameras

- A digital movie camera (or camcorder) uses a charge-coupled device (CCD) to record the “impact” of photons
  - via the Photoelectric Effect
- A single CCD pixel (made up of many atoms) will eject electrons when struck by photons
  - # electrons proportional to # photons

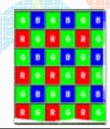
Digital Movie Cameras

- Many pixels make up a CCD array

- The electrons are shifted out of the CCD array electronically and sequentially in time
  - and used to form the picture after appropriate A/D conversion

Digital Movie Cameras

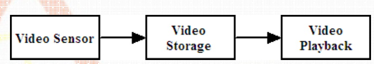
- Color info is provided by using appropriate filters (RGB) on the input photons in a grid pattern



Movie Cameras

- Note that neither of these movie camera types produce a analog (continuous) wave recording of the video
- No one has been able to create a device yet that can do this!
  - Even high speed cameras have a set frame rate

Video Recording and Playback



Video Storage

- The film from a film movie camera is the actual storage mechanism
  - As long as the film is stored correctly, it will last decades

***Not* stored correctly!!**

Video Storage

- The digital output from a digital movie camera can be stored in several ways
  - magnetic tapes
  - digital video disks (DVD’s)

Magnetic Tapes

- Storing video images via magnetic tape is similar to that of sound storage
  - except way more intricate and precise

VHS tape – Video Home System

Digital Video Disks

- Storing video images via DVD is similar to that of sound storage via CD
  - except way more intricate and precise

CD **DVD**

Video Recording and Playback

Video Playback

- Film playback
  - film projector
  - movie screen
- Magnetic tape playback
  - video cassette recorder (VCR)
  - television
- DVD playback
  - DVD player
  - television or computer

Film Projectors

VCR's

DVD Players

Televisions

- There are three basic types of television displays
  - cathode ray tube display (CRT)
  - liquid crystal display (LCD)
  - plasma display
- Projection displays are basically just a type of movie projector
  - without the film!

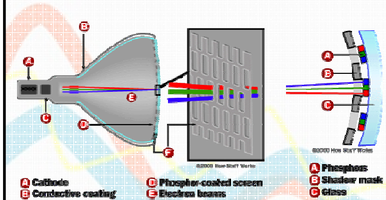
Cathode Ray Tubes

- Cathode ray tubes create their images by firing high speed electrons at a phosphor coated screen
  - The impacting electrons excite the phosphor atoms which give off light when they return to their ground states
- The image is created by varying the intensity of the electron beam as it is scanned across the face of the screen
  - by using electric and magnetic fields! F = qvB

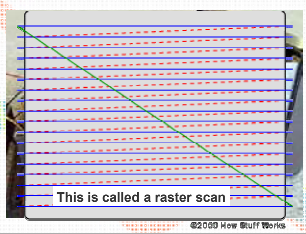
Cathode Ray Tubes

- Colors are created by using three beams and three types of phosphors (Red, Green and Blue) in a pixel grid pattern
- The three phosphor types can be impacted with electrons of varying energies to form any color!

Cathode Ray Tubes



Cathode Ray Tubes



Cathode Ray Tubes

Liquid Crystal Displays

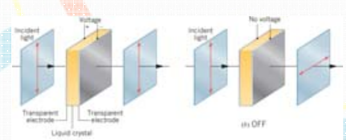
- Liquid crystal displays (LCD's) use polarized light to create their images
- Some common types of liquid crystals
  - lecithin, DNA, cellulose, cholesterol esters, gangliosids, paraffins, and graphite

Liquid Crystal Displays

- A liquid crystal will normally rotate the plane of polarized light by 90º
- But when a voltage is applied to it, the polarizing effect is removed!

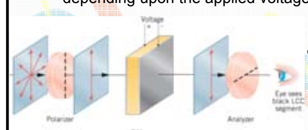
Liquid Crystal Displays

- An LCD pixel consists of a sandwich of crystal between two transparent electrodes



Liquid Crystal Displays

- An LCD pixel, when used in tandem with a set of polarizers
  - can be made to appear light or dark depending upon the applied voltage



Turn the voltage off and you would see a white LCD segment

Liquid Crystal Displays

- An actual LCD display is an array of LCD pixels on top of a light source
- Color displays are made by grouping the pixels in three's
  - and placing a R or G or B filter in front of each pixel
  - This allows you to make any color you want!
    - Just like a TV screen

Liquid Crystal Displays

Plasma Displays

- Plasma displays work like little fluorescent lights
  - but instead of mercury vapor laced with neon gas we use xenon vapor laced with neon gas
- The xenon gas gives off a much more saturated light than the mercury
  - yielding a much sharper image

Plasma Displays

- The xenon and neon gas is contained in hundreds of thousands of tiny cells positioned between two plates of glass
- Three cells are combined into one pixel
  - Each pixel has three different phosphors (R, B, and G!) to create all the colors

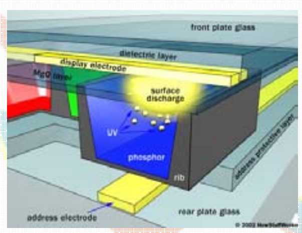
Plasma Displays

- A pixel is energized by applying a voltage across the cells which release electrons into the gas
- These electrons excite the xenon gas which gives off UV photons when it decays back to the ground state

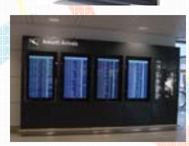
Plasma Displays

- The UV photons are absorbed by the phosphors which are then excited
- When the phosphors decay back to the ground state they give off visible light
  - of the appropriate color!

Plasma Displays



Plasma Displays



Analog vs Digital vs HDTV

- Analog signals
  - Advantage: cheap
  - Disadvantages
    - poorer sound and picture quality
    - large bandwidth (one channel per signal)
    - lower resolution

Analog vs Digital vs HDTV

- Digital signals
  - Advantages
    - better sound and picture quality
    - smaller bandwidth (multiple channels per signal)
    - higher resolution
  - Disadvantage: all or nothing
    - You either receive the signal or not, you don't get a partial signal as in analog

Analog vs Digital vs HDTV

- High Definition signals
  - Advantages
    - best sound and picture quality
    - highest resolution
  - Disadvantage: all or nothing
    - You either receive the signal or not, you don't get a partial signal as in analog