Week 5 – Class Notes

Magnetic Storage Media and Digital Audio Tape

6. Magnetic Storage Media

Recording Bandwidth
   The bandwidth of a storage medium measures the range of frequencies it is able to accommodate with an acceptable amplitude loss. For an analog recorder, a bandwidth of 20kHz is suitable because audio frequencies are recorded directly in the tape. A digital recorder, on the other hand, requires a larger much larger bandwidth. Also, the data overhead needed in digital recording greatly increases the recording bandwidth. For example, the bandwidth for a digital recorder can be up to 50 times that of an analog recorder. Large storage capacities are needed as well, even for modest recording times.

Digital Magnetic Media
   Magnetic media is comprised of a substrate (flexible plastic tape or hard plastic) and a thin coat of magnetic material (gamma ferric oxide). The particles of the magnetic material are cigar-shaped and have a magnetic pole structure that exhibit a magnetic field. The orientation of the particles can be changed back and forth. For example, if the media is unrecorded, the magnetic field of the particles has no particular alignment or orientation. In order to record information, an external magnetic field orients the particles magnetic field according to the alignment of the applied field. The particles coercivity, or the strength needed for the magnetic field to change their orientation, exhibits a Gaussian distribution character in which the number of particles oriented depends on the strength of the field. After a certain field strength is applied the number of particles will not change with an increasing field strength, or it is said that saturation has occurred.
   For analog recording, the continuous alignment of the particles magnetic fields represents the magnitude of the recorded signal.

   In digital recording, saturation recording is used to store binary data. A bipolar waveform (pulse or square wave) applied to the tape creates two magnetic states of equal magnitude, but opposite polarity. The write signal is a current signal is a current that changes polarity at transitions in the bitstream. These polarity transitions represent changes between 1's and 0's. Each transition in the recorded polarity causes a flux field in the read head to reverse, generating an output signal that reconstructs the write waveform.
   The physical spacing between transitions determines the recorded bandwidth, while the net magnetic strength recorded on the medium determines the mediums robustness. The more robust a recorded signal is, the less prone to error it is. Saturation recording is considered to provide the greatest possible net variation in domains, thus it is robust.

Digital magnetic recording requires flexible and thin tape, because of the higher track densities and short wavelengths required for precise tape-to-head contact. The higher data density in digital tape is achieved by using particle types that have higher magnetic energy levels. Usually, cobalt is used to increase the ferric oxide particles coercivity.

Intersymbol Interference

Form of distortion generated by closely spaced flux transitions in a magnetic medium. Also known as peak shift. It is generated if the recording systems bandwidth is insufficient or the recording density is too great, this interference between adjacent waveform causes asymmetry in the reproduced waveform. The timing errors introduced causes the reproduction of data to become difficult. Peak shifting can be alleviated by filtering and precompensating the write waveform, however it ultimately dictates the maximum data recording density for the given medium.

Longitudinal Magnetic Recording

In this commonly used recording method, the magnetic particles are aligned along the length of the tape travel. Polarity transitions in the magnetically recorded medium are longitudinal with tape travel. Data increases reduce the recorded wavelength, and as a result data density in limited and intersymbol interference might occur. Higher bandwidths are achieved with higher tape speeds. As a result of higher tape speeds, higher tape consumption and shorter recording times occur. One solution is to use multiple tracks. For example, data from one audio channel can be written to multiple data tracks. Thus, the more tracks available, the greater the data density (measured in kilo-bits per second, kbpi). However, as track width decreases, tape defects become greater. As such, more sophisticated error-correction codes and interleaving techniques must be used. For design purposes, a balance between area density and tape speed must be considered.

Longitudinal magnetic recording techniques inherently limit the linear data density of the medium. This limitation is caused by the number of magnetic particles placed in the coating and by their length and width.

Vertical Magnetic Recording

Vertical, or perpendicular, recording is a technique designed to provide high-density data recording. In VR the medium is magnetized perpendicularly to the surface, instead of along the surface. The particles are placed vertically in the magnetic medium. Thinner particles, improve the length-to-thickness ratio (due to their size), yield a greater recording density and increase the magnetic strength of the medium. As a result, higher densities are more robust and allow for short wavelength recording. Ultimately, the recording density is dictated by the particles thickness. Higher densities do allow for thinner recording media and higher media coercivity.

Stationary Head Tape Recorders
  Commonly used in analog audio tape recorders. They offer design simplicity and low cost, long head life, and compact and rugged construction. However, they are limited by the density of storage required, and lack of random data access. Stationary head tape recorders have been replaced by newer technologies such as rotary head digital storage and hard-disk drives.
  Stationary head recorders offer editing via physical splicing, punch-in and punch-out, and record and playback of separate channels for synchronous recording (features used in multichannel recording).

Rotary Head Tape Recorders
  Rotary head recorders allow for great amounts of data storage capacity. Because they have narrow track width and high head-to-tape speed rotary head design, the recording density is increased while the tape consumption is kept low. Rotary tape heads were originally used in video tape recording. Audio sub-frame editing has to be precise, thus specific digital audio editors have been developed to replace standard video editors. Professional and consumer video recorders use rotary head transport, as well as DAT and modular digital multitrack recorders.

Hard-disk Drives
  Magnetic hard-disk storage offers efficient storage and the ability of random data access. Using a large memory buffer, data can be located in any number of hard disks and assembled into a final form. Feature-wise, hard-disks can store many gigabytes of data, are low cost, small sized, and are removable. For audio editing applications they are ideal since they offer fast data access times and random data access.

Some information math:
  1 Kbyte (KB) = 1024 bytes
  1 Mbyte (MB) = 1024 kbytes
  1 audio sample (16-bit, 44.1 kHz) = 2 bytes
  Mbyte (for one channel) = sf x bits / sample x time

Hard disks, unlike analog tape, do not observe silences by only recording the parts themselves.

  Most hard disks are non-removable so that cost is reduced, design of medium is simplified, and allows for increased storage capacity. The medium is comprised by a series of disks, made out of rigid aluminum alloy, stacked on a common spindle. The disks are coated on top and bottom with a magnetic material and an undercoat. Alternatively, metallic disks can be electroplated with a magnetic recording layer. These thin-disks, because of their closer data spacing, provide greater data density and faster track access. Also, thin-film disks are more durable than conventional oxide disks because their data surface is harder; this helps them resist head crashes.

Data on the disk surface is configured in concentric data tracks. Each track comprises one disk circumference for a given head position. Most drives segment data tracks into arcs know as sectors. A particular physical address within a sector, known as a block, in identified by a cylinder (positioner address), head (surface address), and sector (rotational angle address). Hard disks currently use MFM coding, as well as other codes, for greater storage density.

Data can be output either in serial or parallel; the later provides faster data transfer rates. Overall, hard disks should provide a sustained transfer rate of 5-20 Mbytes/sec and access time of 5 ms. A rotational speed of 7200-15000 rpm is recommended for most audio applications. In any case, RAM buffers are used to provide a continuous flow of output data.
Hard disk drives can be connected to the host computer via SCSI, IDE (ATA), Firewire, USB, EIDE (ATA-2), and Ultra ATA (ATA-3, Ultra DMA) connections.

ATA – satisfactory performance, low price.
SCSI-2, -3 – fast and robust performance. Multiple drive connection to a single SCSI bus.

The transfer rate of a hard disk is faster than that required for a digital audio channel. During playback, the drive delivers bursts of data to the output buffer that in turn steadily delivers output data.
High performance systems use a Redundant Array of Independent Disks (RAID) controller; RAID level 0 is used in audio/video applications. Level 0 configurations use disk mirroring, writing blocks of each file to multiple drives, to achieve fast throughput.

Disk defragmentation or optimization, is useful because it places data into continuous sections for faster access. Most disk editing is done through an edit decision list in which in/out and other edit points are saved as data addresses. This allows for nondestructive editing. Original data can be backed up to another medium, or a finished recording can be output using the edit list.
Finally, because of its low cost and high capacity, hard-disk drives are largely responsible for the wide integration of digital audio/video production with the computer environment.

Digital Audio Tape (DAT)
  In DAT format, the audio signal is recorded and played back using helical tape storage. This technique provides the wide recording bandwidth needed for PCM storage. This format supports 32 , 44.1, and 48 kHz sampling frequencies, although in some models 96 kHz can be supported. Also, DAT format facilitates a wide dynamic range, low distortion, and high signal-to-noise ratio.

DAT Tape Cassette
  DAT tapes can record up to 2 hours of audio on about 60m of tape. Greater recording times (4-6 hrs) can be achieved by slowing the tape speed, reducing the sampling frequency, reducing the hub diameter, or using thinner tape. Blank tapes have a high-coercivity metal particle oxide coating.
  Every DAT tape has four recognition holes, located in standard positions. These holes are used to identify the type of cassette inserted. The first three holes form a code with four states defined for tape thickness and track pitch. The fourth hole identifies a prerecorded, or non-prerecorded tape. To prevent accidental erasure, DAT tapes contain a safety tab on one end.

DAT Modes

DAT Hardware Design
  The DAT format is a proprietary design. This technology borrows from both rotary-head video recorders and the CD. The tremendous data density recorded to tape necessitates a number of sophisticated recording techniques for track format. Modulation code and error correction are integral in determining the systems performance.
  DAT recorders use circuitry that is similar to that of a CD player, and employ a number of digital circuit elements such as ADC, DAC, modulators/demodulators, and error-correction.
  The helical scan system requires that time compression is used so that the continuous input analog signal is separated into discrete fields prior to recording, then to rejoin them upon playback with time expansion to form a continuous output signal. At the recording stage, the output of a buffer memory is clocked faster than the input data is entered, in order to achieve time compression. Subcode is added to the bitstream, and the data is converted from parallel to serial data. Eight-to-ten modulation is used to encode the digital signal and aid the recording to the magnetic tape.
  During playback, the transitions on the tape induce a signal in the head that regenerates the record waveform. Track-finding and adjusting signals are derived from the tape. Eight-to-ten de-modulation is performed and the data is returned to a parallel bitstream. Subcode data is separated and is used for operator an servo control. De-interleaving is done in order to accomplish error-correction, and finally the signal is output through the DAC as an analog signal.

Track Format
   The rotary head used in DAT recording produces diagonal tracks at an angle of ~6.5º from the horizontal. Data is recorded over helical scan track pairs, one track per head. In addition, the tape contains two additional longitudinal areas at the edge of the tape used as protection for the scan tracks. Each track is divide into a series of data fields. PCM audio data constitutes the majority of data on a track and is recorded at the center of the track.
   However, substantial fields are allocated to subcode, automatic track following (ATF), and other items such as PLL (phase -locking the data in the field, provides location), inter-block

gap (IBG, used to ensure full overwriting of old tracks and prevent interference between data areas).

The scan-track pattern is designed so that data needed for control purposes, such as subcode, can be read during high-speed search. During high-speed shuttling, track following is not engaged, the head crosses over many data tracks. Synchronization data, subcode, timecode, as well as PCM data can be read, thus audio data bursts can be retrieved and played.

The recorded area is distinguished from a blank section of tape with no recorded signal, even if the recorded are has no audio signal. The track format is always encoded on the tape even if no signal is present, unlike blank area. If these sections are mixed in tape, search operations might be slowed.

Azimuth Recording

In this type of recording, tracks are adjacently recorded to one another, without any spacing; thus, increasing the data density. With this system, the drum head pairs are angled differently from each other with respect to the tape, thus creates two track types (A and B). This reduces the crosstalk between adjacent tracks, eliminates the need for a guardband between tracks, and allows for high-density recording.

Automatic Track Following

Track correction allows for a good quality playback of the signal. Each track scan contains two bursts of an automatic track following (ATF) tracking signal; it controls the capstan to ensure correct tracking.

Eight-to-Ten Modulation

This modulation group code provides efficient operation in the azimuth recording system. 8/10 code is designed to eliminate DC content and reduce the low-frequency content of the generated code. Also, it facilitates overwriting, and supports high-data density. 8/10 code generates a 10-bit channel word from an 8-bit information word. The encoded words are written in NRZI modulation code.

DAT Error Correction

Tape wear caused by the constant contact with the rotating heads requires a rather sophisticated error correction system. In addition, tape is prone to manufacturing defects and environmental factor. DAT is designed to correct random and burst errors; the former caused by crosstalk from an adjacent track, traces of an imperfectly erased signal, or mechanical instability; the latter from dropouts caused by dust or scratches on the tape, or head clogging. Because DAT error correction must permit editing, data cannot be interleaved over many tracks and is limited to only a pair of tracks. In this way, new data can be recorded over the old.

To facilitate error correction, Reed-Solomon codes are used to form across a data array. Each data track is split into two halves, one for left and right channels. In addition, data for each channel is interleaved into even and odd data blocks, one for each head. Interleaving guards against burst errors caused by a dirty head, so that in this case only half of each channel's samples are lost. Tape defects, however, can cause losses on both channels, but only even or odd samples would be lost simultaneously.

Serial Copy Management System

SCMS circuitry is used on consumer DAT recorders to prevent multiple-generation digital copying of protected material. Audio data output from a player via S/PDIF is accompanied by copy protection and generation information. During playback, the player examines the ID-6 on tape and outputs the appropriate C-bit (bit 2), L-bit (bit 15), and category code for a DAT machine in its bistream. The recorder examines the received C-, L- bits, and category code, and if recording is permitted, it writes the appropriate SCMS code to its tape.

SCMS is stored into two PCM-ID subcode bits identified as ID-6, within the main ID data area. For example, if the ID-6 is set to 00 (C-bit set to 1, L-bit set to 0), no copy protection is asserted for that portion of the tape. If ID-6 is set to 10, the data is copied and becomes copy protected (both C-, L-bits set to 0). if ID-6 is set to 11, the data is original and copy protected (C-bit is set to 0, L-bit se to 1).

When the C-bit is set to 0 (copyright protection asserted), the recorder will not record the input, except if the signal is original and contains an allowed category code, or when the signal contains an unidentified category code (one generation copying permitted), or when the product is not capable of transmitting copyright information (two generations of copying are allowed).

On the other hand, if the C-bit is set to 1 (no copyright protection), an unlimited generation of copies can be generated.

Prerecorded DAT

DAT machines can playback prerecorded DAT tapes, however, this DAT format differs from the recording format in which the tracks can be wider. Also, the metal particle used is different .

Professional DAT

Although the DAT format was originally introduced as a consumer product, is has many applications in the professional recording industry. Curiously enough, it was not a successful consumer format and found more acceptance in the professional field (audio and video).

Professional DAT recorders are similar to consumer ones, but they differ in that they have a four-head format. A read-after-write function provides off-tape audio monitoring during recording or dubbing. In editing, either the recorder of player can be monitored. Audio data and timecode can be recorded simultaneously in assemble more or individually in the insert mode.

Professional digital audio recorders are interconnected via AES3 (or AES/EBU) serial transmission interface. AES3 has a data capacity of 192 kbps without compression for two-channels.

DAT Timecode

The original consumer DAT format did not support timecode, however a SMPTE timecode signal can be encoded with a data rate of 2.4 kbps. As a solution, the Pro-DAT format was created. This format modifies the consumer running time to form a new time pack. By using frame rate conversion algorithms, the incoming time code (at any rate) is converted to Pro-DAT timecode. The standard DAT frame rate of 33.33 frames/sec is not compatible with timecode rates (24, 25, 29.97, and 30 frames/sec). In theory, any type of timecode can be converted to Pro-DAT timecode.

In addition, an SMPTE/EBU timecode reader/generator enables the recorder to operate synchronously with an external video synchronization signal.