5. Optical Disks

5.1 Overview

Compact Disc Development

5.2 History

1973   **Video Long Play (VLP) published**

1983   **Compact Disc Digital Audio (CD-DA) – available:**
the Red Book standard

1985   **Compact Disc Read Only Memory (CD-ROM):**
- Yellow Book standard for physical format
- High Sierra Proposal
- ISO 9660 standard for logical file format

1986   **Compact Disc Interactive (CD-I) announcement:**
the Green Book standard

1987   **Digital Video Interactive (DVI): first presentation**

1988   **CD-ROM Extended Architecture (CD-ROM-XA) announcement**

1990   **CD Write Once (CD-WO), CD Magneto-Optical (CD-MO):**
- the Orange Book standard

1996   **Digital Video Disk (DVD)**

5.3 Fundamentals

Pits and Lands

e.g. CD:
$\lambda_1 = 1.6\ \mu m$
$\lambda_2 = 0.6\ \mu m$
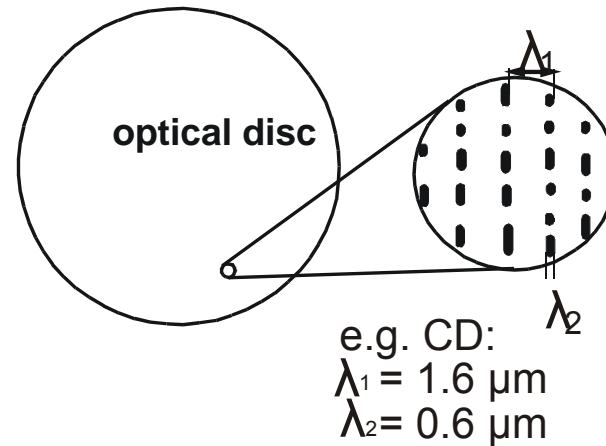
Information is stored in a spiral-shaped track:

- Series of **pits** and **lands** in substrate layer
- Transition from pit to land and from land to pit: '1'
- Between transitions: sequence of '0' s
- 16000 turns/inch (tpi)

Reading: Laser focused onto reflective layer

- **Lands** - almost totally reflect the light
- **Pits** – scatter the light

Reading Data

1,2 mm

Label

protective layer

reflective layer

~0,12 mm

Pit

Land

substrate layer

Laser

Pit

Land

intensity of the reflected beam
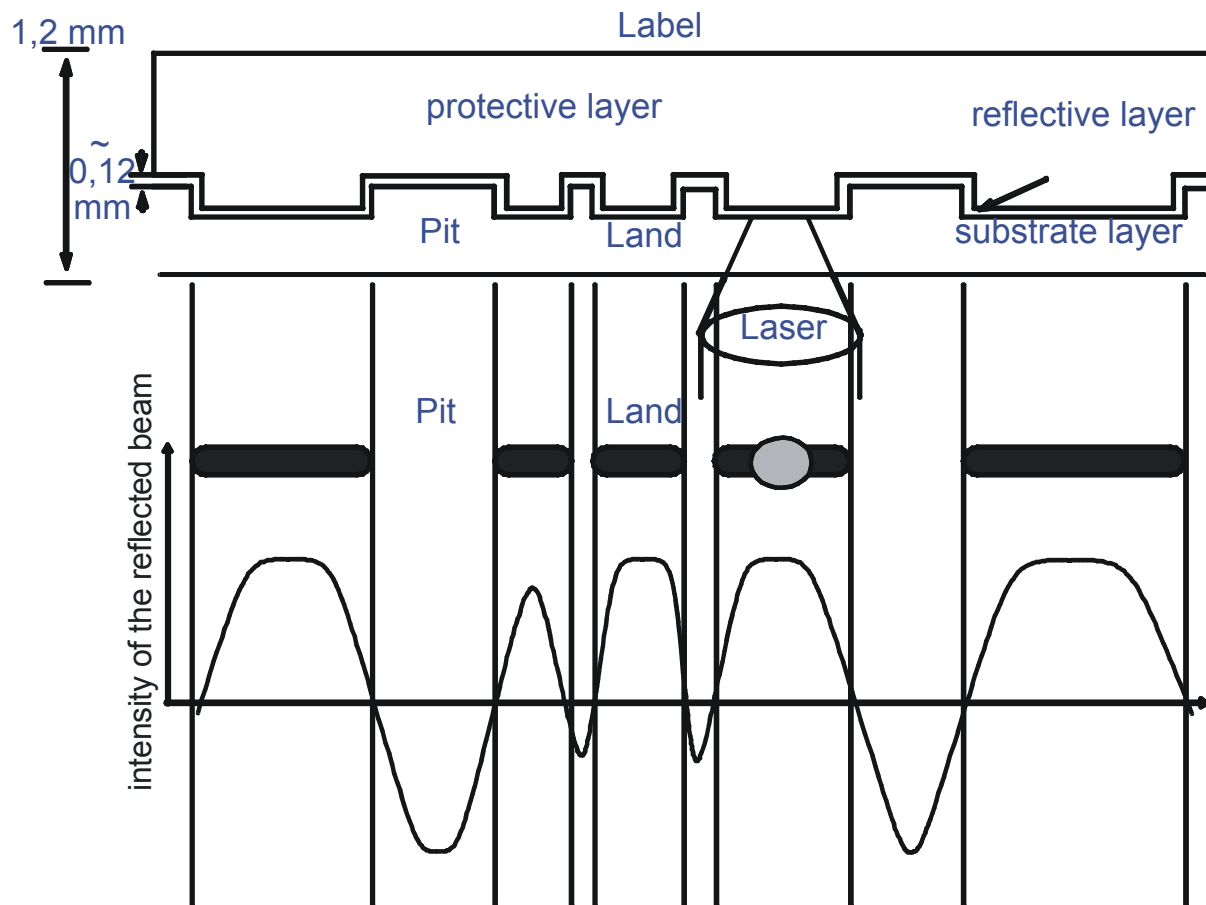
Advantages of Optical Storage Media

High data density

- 1.66 data bits/μm of track

- Inter-track density: 16000 tpi; compare diskette at 96 tpi

Long term storage

- Insensitive to magnetic/electric interference

- Insensitive to dust, scratches

Low probability of head crashes

- Distance between head and substrate surface > 1 mm

Adequate error correction

- allows handling of many defects

Perception quality

- e.g., each digital music disc is exactly equivalent to the master

5.4 Early Laser Disk

An important precursor of the audio CD.

Laser Disk Characteristics

- Diameter: ~ 30 cm

- Storage of video and audio

- Analog encoding

- High quality of reproduced data

- Storage capacity: ~ 2.6 GBytes

History

- Originally called Video Long Play (VLP)

- 1973 first description in the Philips Technical Review journal

Principles

- Mix of audio and video

- Frequency modulation

- No quantization of pit length

5.5 CD-DA: Compact Disc Digital Audio

Goal

- Storage of audio data

History

- Development of basic technology by Philips

- Cooperation of Philips N.V. and Sony Corporation

- **1983:** CD-DA players and disks available in the market

Physical characteristics

- Diameter: 120 mm

- **Constant linear velocity** (CLV), i.e., number of rotations/s depends on the position of the head

- Track shape: one spiral with approx. 20000 turns (LP: 850 turns)

CD-DA: Characteristics

Audio data rate

- Sampling frequency: 44,100 Hz

- Quantization: 16 bits

- Pulse code modulation (PCM), uniform quantization

- Audio data rate = 1,411,200 bit/s = (~ 1.4 Mbit/s) (stereo)

Quality

- Signal to noise ratio (S/N): ~ 6 dB/bit, 16 bit quantization => S/N exactly 98 dB

- Compare LP, tape: S/N 50-60 dB

Capacity (without error correction data)

- Playback time: maximal 74 min

- Raw capacity =74 min x 1,411,200 bit/s = 6265728000 bit ~ 747 Mbyte

CD-DA: Pits and Lands
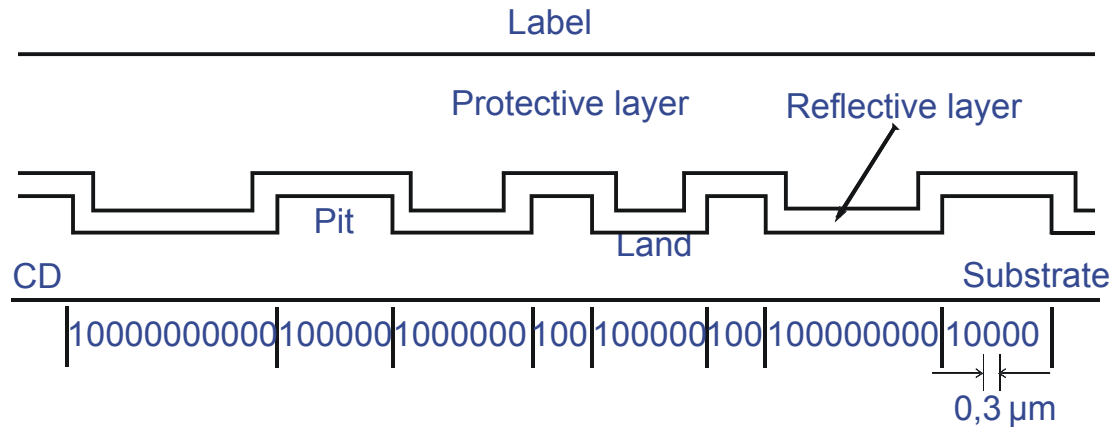
Length of pits and lands: multiples of 0.3 µm

Bit Encoding

- Transition from pit to land or from land to pit encodes a '1'
- Between two transitions: a sequence of '0's

CD-DA: Eight-to-Fourteen Modulation

Restricted laser resolution

- Requires a minimal distance between transitions (pit to land, land to pit): at least two "0"s between two "1"s

Generation (adaptation) of the clock signal is driven by transitions

- Requires a maximal distance between transitions (pit to land, land to pit): not more than 10 consecutive "0"

=> Eight-to-Fourteen Modulation

- An 8 bit data value is encoded using 14 bits
- 267 combinations fulfill the criteria above, 256 are chosen. Criterion: efficient implementation with a small number of gates.

CD-DA: Eight-to-Fourteen Modulation

Example from the code conversion table

data bits	channel bits
00000000	01001000100000
00000001	10000100000000
…	…

But: a concatenation of two independent 14-bit values could lead to a violation of:

- minimum distance of 2 bits between Ones
- maximum distance of 10 bits between Ones
- => three additional *merging (filling) bits* are inserted

CD-DA: Eight-to-Fourteen Modulation Example

Audio Bits	0 0 0 0 0 0 0 0	0 0 0 0 0 0 1
Modulation Bits	0 1 0 0 1 0 0 0 1 0 0 0 0 0	1 0 0 0 0 1 0 0 0 0 0 0 0 0
Filling Bits	0 1 0	1 0 0
Channel Bits	0 1 0 0 1 0 0 1 0 0 0 1 0 0 0 0 0 1 0 0 1 0 0 0 0 1 0 0 0 0 0 0 0	
On the CD-DA	l p p p l l l p p p p l l l l l l p p p l l l l l p p p p p p p p p	

CD-DA: Error Handling

Typical Errors
- Scratches, dust, fingerprints
- „Burst errors"

Two-level Reed-Solomon code with frame interleaving ("Cross Interleaved Reed-Solomon Code"):
- **First level:** byte level, EDC and ECC. Two groups, each with four correction bytes for 24 data bytes:
  - 1st group: correction of single byte errors
  - 2nd group: correction of double byte errors, detection of additional errors
- **Second level: frame interleaving**
  - frame: 588 channel bits for 24 audio data bytes
  - distribution of consecutive data bytes and corresponding ECC bytes over adjacent frames

Error rate: 10^{-8} (~ 1 bit in 100 million bits (!))
- Exact correction of 4000 data bits possible
- 4000 data bits * 0.3 μm/channel bit
- hence: burst errors over 2.5 mm disk surface can be corrected

With interpolation: Up to 12,300 data bits

CD-DA: Frames

Each frame consists of

- **Data**

  - Two groups of 12 audio data bytes each (actual data)

- **Error detection and correction code**

  - Two groups of four "parity" bytes

- **Control&display byte**

  - Together with control&display bytes of other frames it forms the subchannel stream.

  - Example: subchannel byte for track start identification

- **Synchronization pattern**

  - At the start of a frame

  - 12 x "1" + 12 x "0" + 3 merging bits = 27 bits long

CD-DA: Data Streams

Audio bit stream = 1.4112 x 10^6 bit/s

Data bit stream ~ 1.94 x 10^6 bit/s:

- Audio bit stream + "parity" bytes + control&display byte

Channel bit stream ~ 4.32 x 10^6 bit/s:

- Data bit stream + EFM + merging bits + synchronization pattern

  (EFM = eight-to-fourteen modulation)

CD-DA: Areas

Areas

- **Lead-in area**
  - Table of content
  - Pointer to the start of each track
- **Program area**
  - Up to 99 tracks of different lengths
  - Typically, one track contains one song
- **Lead-out area**
  - Helps the device to find the end of the data in case of errors

Random access supported via

- **Tracks**
- **Index points.** Many possible per track, but in most cases only two are used:
  - IP_0: start of track
  - IP_1: start of audio data
  - Track pre-gap: gap between IP_0 and IP_1, typically 2 to 3 s

5.6 CD-ROM: Compact Disc – Read Only Memory

CD-DA provides a suitable means for the handling of typical errors caused by damage or dust. The CD-DA specification became the basis of a **family** of optical storage media.

But not conceived for:

- video (different ECC, EDC scheme required)
- discrete data (error rate too high)
- simultaneous play back of various media

For computers there is a need for storage of:

- Data, audio, compressed audio and video

The Yellow Book CD-ROM Standard

- CD-ROM mode 1: for any data
- CD-ROM mode 2: for compressed audio and video data
- But cannot be combined on a single track

Within a single track:

- Only CD-DA audio or only CD-ROM specific data

Mixed Mode Disc:

- Data tracks at the beginning
- Subsequent tracks for audio data

CD-ROM: Structure

CD
330 000 **blocks**

block
2352 audio bytes
7203 channel bytes

frame, channel bits
588 bit, with
24 audio bytes
$\approx 4,32 * 10^6$ bit/s

EFM
+
merging bits

synchroni--
zation

data bits
$\approx 1,94 * 10^6$ bit/s

control
&
display

CIRC

CIRC

L   L   R   R

audio bits
1,411200 bit/s
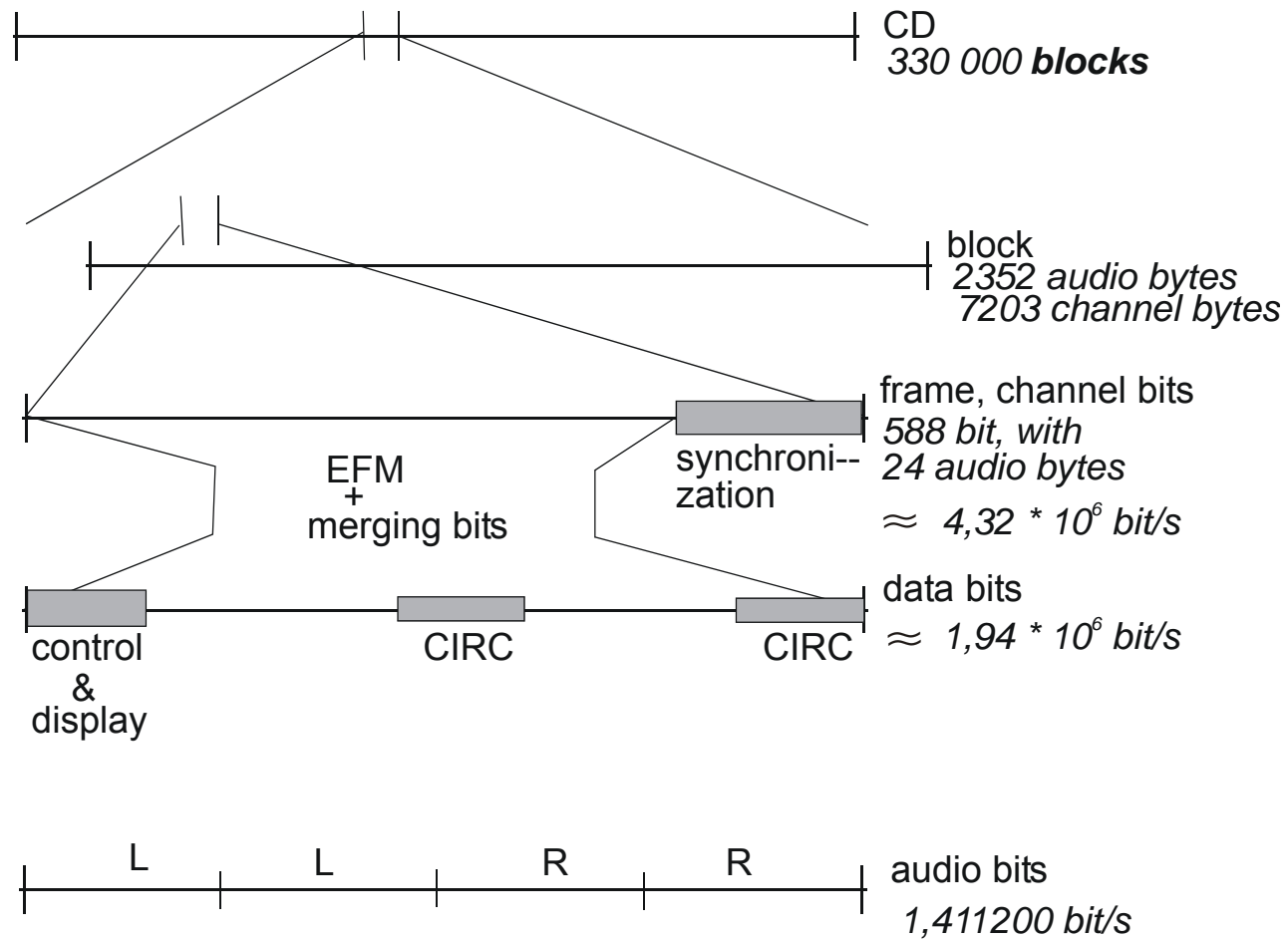
CD-ROM: Structure

Fine granularity for random access

- Tracks and Index Points not sufficient
- Structure with a higher resolution: the **block**
- Blocks contain a fixed number of frames

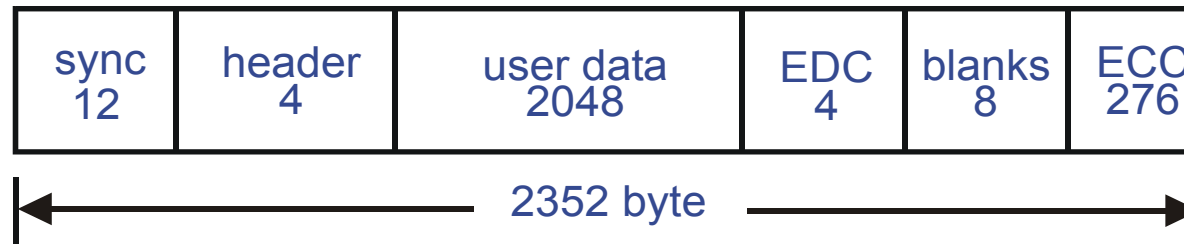**Disk structure**

- 1 block = 32 frames
- 75 blocks/s (for a single-speed CD-ROM)
- 1411200 bit/s / 75 blocks/s / 8 bits/byte = 2352 bytes/block

Allows for

- Random access
- Better EDC, ECC

CD-ROM Mode 1

sync 12	header 4	user data 2048	EDC 4	blanks 8	ECC 276

←———————————————— 2352 byte ————————————————→

1 block = 2352 bytes:

- Header bytes include minutes, seconds, block number, mode
- Error rate = 10^{-12}

Capacity:

- Max. 74 min x 60 s/min x 75 block/s = 333000 blocks
- 333000 blocks/CD ~ 650 MByte (user data)

Data rate:

- 2048 byte/block x 75 block/ s ~150 KByte/s (single-speed)

Used by most CD-ROM applications, but

- simultaneous reading of audio and other data in CD-ROM mode 1 not possible

CD-ROM Mode 2

sync 12	header 4	user data 2336

$\longleftarrow$ 2352 byte $\longrightarrow$

Capacity:

- 333000 blocks x 2336 bytes/block
  = 777888000 bytes ~ 741.85 MByte

Data rate:

- 2336 byte/block x 75 block/s = 171 KByte/s (single-speed)

CD-ROM: Average Access Time

Time to position a block/sector

- **Synchronization time:** Adapt internal clock to disc signal
  - milliseconds
- **Seek time:** Adaptation of laser to radius
  - about 100 ms
- **Rotational delay** (for constant linear velocity):
  - Wait for disk sector within the current rotation
  - Adapt disk speed
  - For 40 x CD devices (with 9000 rotations per minute) ~ 6.3 ms

Access time (also) depends on

- actual and desired position of the head (distance)
- cache strategies of the device

The actual average access time may be about 100 ms (with data caching).

CD-ROM: File System

Original (early) CD-ROM
- No logical file format
- No directory specification

High-Sierra Proposal
- Developed by a group of industry representatives
- This initial file system later lead to ISO 9660

ISO 9660 file standard
- Directory tree: information about files
- Path table: List of all directories and direct access to files at any level
- File interleaving

First track
- 16 blocks (sectors 0 to 15): system area
- Volume descriptors in subsequent blocks with e.g. the length of file system

Logical block size
- Between 512 bytes and 2048 bytes (in steps of 2^i)
- Blocks of 512 bytes, 1024 bytes, and 2048 bytes are used
- Files begin at logical block start

5.7 CD-ROM/XA: CD-ROM Extended Architecture

History

- Philips N.V., Sony and Microsoft (announcement in 1988)
- An extension of the Yellow Book standard

**Goal: Simultaneous transfer of various media data**

- Based on CD-ROM mode 2, ISO 9660, CD-I
- Interleaving of blocks of different media within the same track
- Definition of a new type of track used for:
  - compressed audio (ADPCM) and video data
  - images, text, programs
- Distinction between two block formats: **Form 1**, **Form 2**

XA: Extended Architecture

Drawbacks

- Compatibility to audio and video compression?
    - For some media only reference to other standards
    - MPEG audio not compatible (MPEG does not use ADPCM)
- Interleaved storage of data of different types in the same track:
    - Requires special disc layout
    - Requires effective interleaving with a choice of the suitable audio level
    - Complex application development

CD-ROM/XA (Mode 2) Form 1

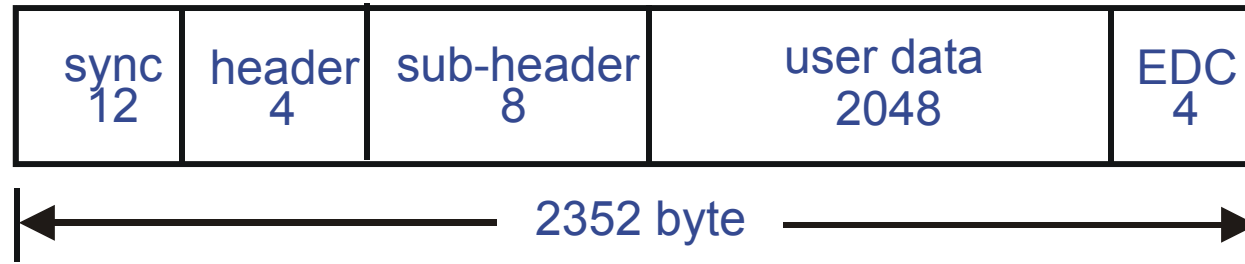| sync 12	header 4	sub-header 8	user data 2048	EDC 4	ECC 276

← 2352 byte →
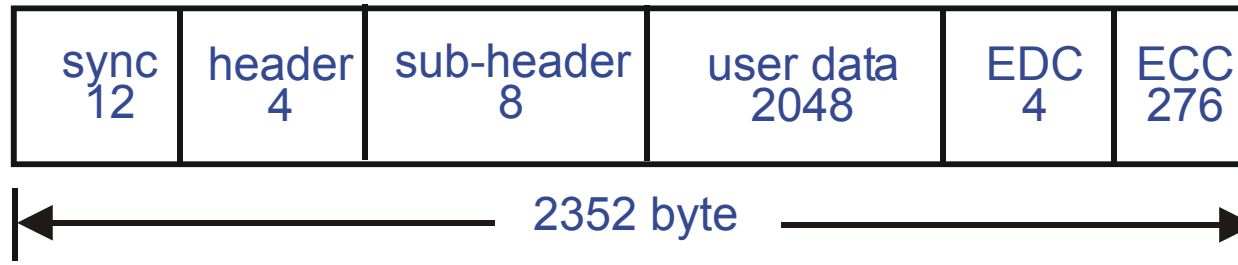
Subheader:

- Specification of CD-ROM Mode 2 XA Format type
- 8 bytes long

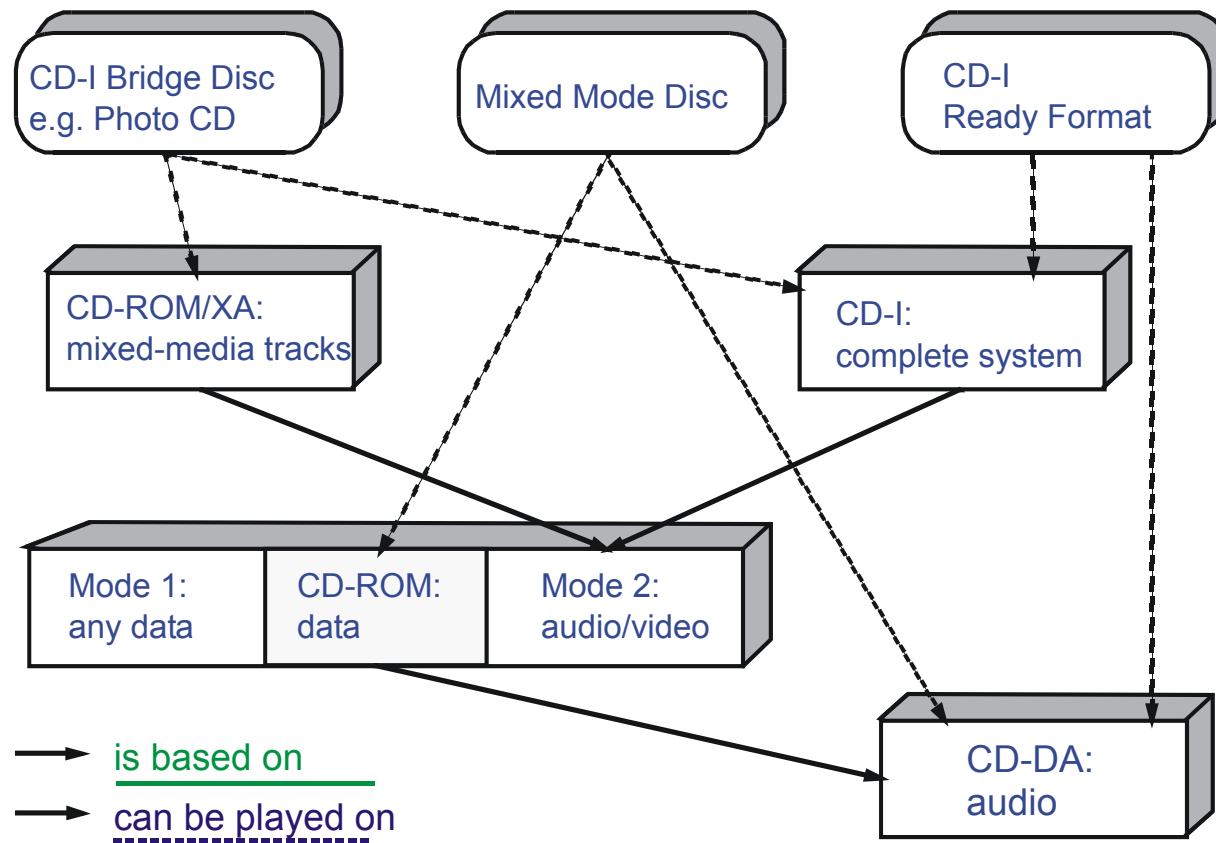**Improved error handling** for text and program data with 4 bytes for error detection and 276 bytes for error correction.

CD-ROM/XA (Mode 2) Form 2

sync 12	header 4	sub-header 8	user data 2048	EDC 4

← 2352 byte →

- Storage of compressed data (incl. audio, video)

- Only 4 bytes for error detection, no error correction

- 13% more data bytes

5.8   Further CD-ROM-based Developments

CD-I Bridge Disc
e.g. Photo CD

Mixed Mode Disc

CD-I
Ready Format

CD-ROM/XA:
mixed-media tracks

CD-I:
complete system

Mode 1: any data	CD-ROM: data	Mode 2: audio/video

CD-DA:
audio

→ is based on

→ can be played on

Overview of Further Developments

Further standards

- Directly based on the CD-ROM mode 2 standard
- CD-ROM/XA
    - allows for mode 1 and mode 2 blocks in the same track
- CD-I (CD Interactive)
    - a complete multimedia system

Compatibility formats

Formats that can be played on multiple players

- **CD-I Bridge Disc:** CD-ROM/XA and CD-I players
- **Mixed Mode Disc:** CD-ROM and CD-DA players
- **CD-I Ready Format:** CD-I and CD-DA players

Photo Compact Disc: Example of a CD Bridge Disc

Purpose: Storage of photos of high quality

History

- Eastman Kodak and N.V. Philips Company
- **1990** announcement of the Kodak Photo CD system

Characteristics

- Based on CD Write Once (CD-WO)
- Readable with:
  - Photo CD players
  - CD-I players
  - CD-ROM/XA players
- Can be written with Special Photo CD writers and CD-WO writers

Capabilities

- New professional and private application areas
- Simultaneous display of several images
- Image editing

Photo Compact Disc: ImagePac

Production

- Photos are taken with conventional cameras
- Digitized with 8 bits for the luminance component and 8 bits for each of the two chrominance components
- Written on CD

Image resolution of a Photo CD:

type of image	compr./uncompr.	number of lines	number of columns
base/16	uncompressed	128	192
base/14	uncompressed	256	384
base	uncompressed	512	768
4base	compressed	1024	1536
16base	compressed	2048	3072
64-Base	compressed	4.096	6.144

Per photo

- ImagePac at five different resolutions: hierarchical coding
- About 3 to 6 MByte storage per ImagePac

5.9   CD-WO: Compact Disc Write Once

Defined in the Orange Book Standard Part II

A "raw" CD-WO has:

- a pre-grooved track
- an absorption layer between the substrate and the reflective layer

Recording: an irreversible change of the reflection characteristics by heating up the absorption layer ("burning")

The CD-WO can be played in CD-DA players.

CD-WO: Sessions

Disc layout with several sessions

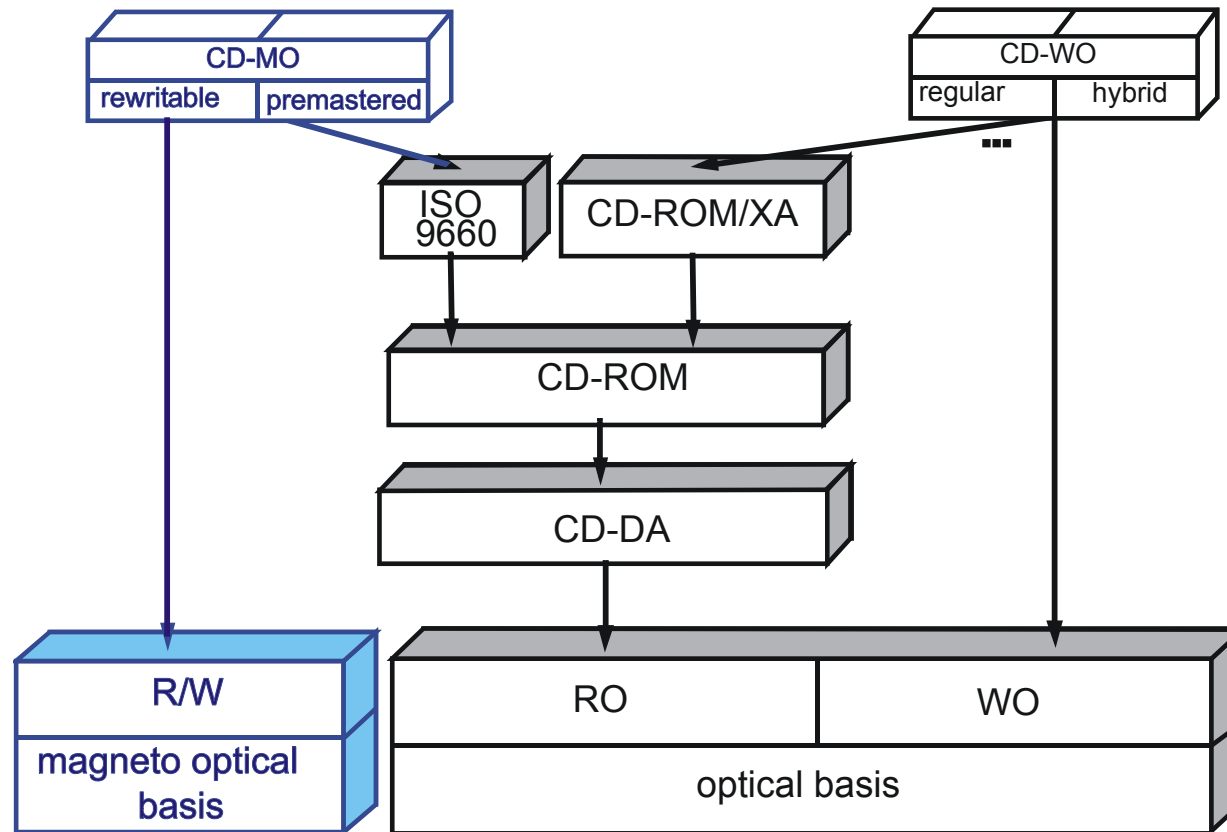| lead in	information	lead out	lead in	information	lead out	...
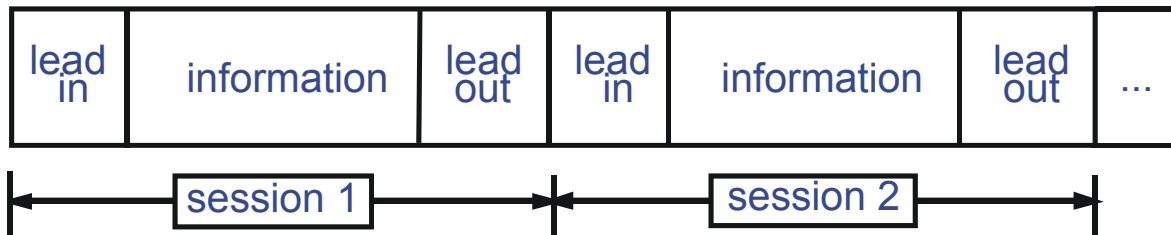
|← session 1 →|← session 2 →|

Sessions

- Burning can be done in several sessions each with:
  - Lead-in part
  - Data part
  - Lead-out part
- Maximum: 99 sessions

Note

- CD players older than 1992 can only read the first session
- Regular CD-WO: only one session
- Hybrid CD-WO: several sessions

5.10 CD-MO: Compact Disc Magneto Optical

CD-MO: Features and Principles

Definition in the Orange Book Standard Part I
- High capacity (double-sided): about 650 MByte
- Data transfer rate: about 1.2 Mbit/s

Features
- write data
- read data
- erase data
- rewrite data

Principles of the magneto-optical technique
- Write:
  - Heat up the blocks
  - Apply about 10 x the magnetic field of the earth
  - Polarization of single elements
- Erase:
  - Use a constant magnetic field
  - Simultaneously heat up the block
- Read:
  - Polarization of light is influenced by magnetic characteristics

5.11 VCD and SVCD: Video CD and Super Video CD

VCD special implementation of CD-ROM/XA

• designed to store MPEG-1 video CD-ROM Mode 2 (Form 2)

sync 12	header 4	sub-header 8	user data 2324	EDC 4

← 2352 bytes →
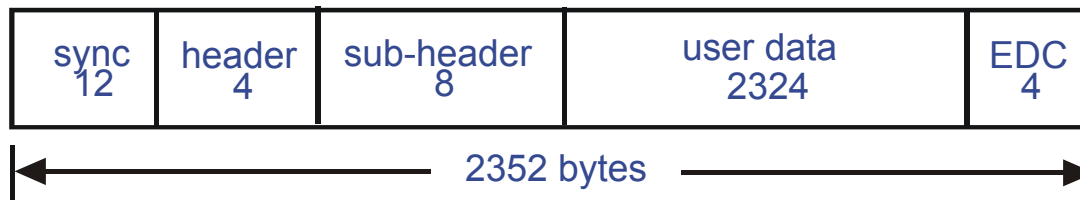
VCD: Video Quality

• MPEG-1 video

• resolution

    * 352x240 (NTSC)

    * 352x288 (PAL)

Usage

• personal computer with a CD-ROM/ XA drive

•stand-alone VideoCD players are also available

History - Versions

White Book specification

• announced by JVC, Philips, SONY and Matsushita in July 1993

1993	**Video CD (VCD version 1.1)** • White Book Standard
1995	**Video CD Version 2.0**
1998	**Super Video-CD (SVCD)**
appr. 2001	**Video CD (VCD Version 3.0)**

Further similar formats

• VCD-ROM (1997)

• VCD-Internet (1997)

• China Video Disc

• High-Quality Video CD (HQ-VCD)

SVCD: Super Video CD

Origin

- DVD licenses caused problems in China
  - * China developped „Chaoji VCD"
- Philips and China joint efforts later and developped Super Video CD

Video

- usually DVD-compatible MPEG-2 format
- or sometimes high-bitrate MPEG-1
- resolution
  - * 480 x 576 (PAL)
  - * 480 x 480 (NTSC)

SVCD comprises

- 35 - 60 minutes of video
- 2 tracks of audio
- 4 selectable subtitles

5.12 DVD: Digital Video Disk

Also known as: „Digital Versatile Disk"

Goal: to create a new optical medium to store an entire high-quality digi-tal movie on a disk.

Formats
- single-sided single-layer
- single-sided double-layer: laser must switch focus to read both layers
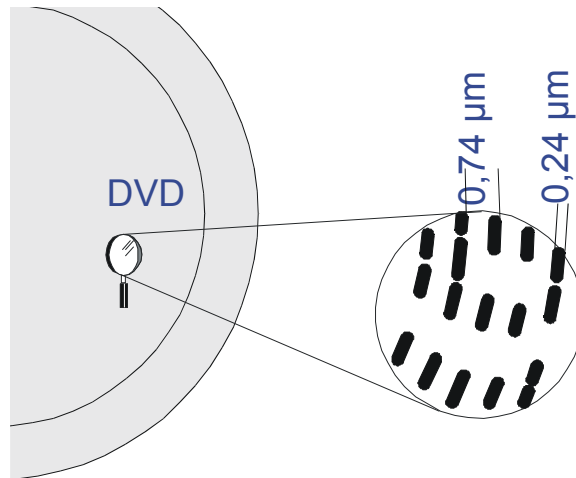- double-sided: disk must be flipped over to read both sides

Under discussion: smaller DVDs
- Diameter of 8 cm (instead of 12 cm)

Video quality
- resolution: 700 x 480
- MPEG-2 compression used

DVD - Technical Overview

DVD

0,74 µm

0,24 µm

CD-like optical storage medium
• same physical size as CD => allows for backward compatibility of reading devices
Capacity considerably higher than CD:
• pits and lands shorter
• tracks narrower
EFM PLUS error correction scheme
• more robust than the CD scheme
• maps 8 bits of data to 16 bits of encoded signal, no need for *merging bits*

A Comparison of CD and DVD

	CD	DVD
Media diameter	120 mm	120 mm
Media thickness	1,2 mm	1,2 mm
Wavelength of laser light	780 nm (infrared)	650 and 635 nm (red)
Track distance	1,6 µm	0,74 µm
Min. pit / land length	0,83 µm	0,4 µm
Data layers	1	1 or 2
Sides	1	1 or 2
Capacity	ca. 650 MB	ca. 4.38 GB (SLSS) ca. 7.95 GB (DLSS) ca. 8.75 GB (SLDS) ca. 15.9 GB (DLDS)
Video data rate	ca. 1,5 Mbit/s	1-10 Mbit/s (var.)
Video compression standard	MPEG-1	MPEG-2
Video capacity	ca. 1 h	between 2 and 8 h (depending on format)
Sound tracks	2-channel MPEG audio	2-channel PCM 5.1-chanel AC-3 optional: up to 8 data streams
Subtitles	-	up to 32 languages

DVD: Physical Disk Configurations

Name	Diameter (cm)	Sides	Layers per side	Capacity (GB)	Remarks
DVD-5	12	SS	SL	4,38	>2 h video
DVD-9	12	SS	DL	7,95	ca. 4 h video
DVD-10	12	DS	SL	8,75	ca. 4.5 h video
DVD-18	12	DS	DL	15,9	> 8 h video
DVD-1*	8	SS	SL	1,36	ca. 1/2 h video
DVD-2*	8	SS	DL	2,48	ca. 1.3 h video
DVD-3*	8	DS2	SL	2,72	ca. 1.4 h video
DVD-4*	8	DS	DL	4,95	ca. 2.5 h video
DVD-R	12	SS	SL	3,68	
DVD-R	12	DS	SL	7,38	
DVD-R	8	SS	SL	1,15	
DVD-R	8	DS	SL	2,3	
DVD-RAM	12	SS	SL	2,4	
DVD-RAM	12	DS	SL	4,8	

DVD: Variants

DVD-ROM: *DVD Read Only Memory*

- Basic DVD specification
- read only mode

Application formats

Specification of how to place audio and video on a DVD

- **DVD Video**
    - * MPEG-2
    - * Video:
        - * resolution: 720 x 480
    - * Audio:
        - * up to 8 Dolby audio streams
        - * MPEG-2 multi-channel Audio (MPEG-1 Layer 2 audio) or
        - * linear PCM
- **DVD Audio**
    - * multi-channel audio
    - * higher quality PCM audio

DVD: Variants of Recordable Types

Write Once:

• **DVD-R (G):** DVD Recordable General

    * general version: different wavelength 635 nanometer (instead of 650), one or

      two sides, no content protection

• **DVD-R (A):** DVD Recordable Authoring

    * authoring version: 650 nm, single side only, with content protection

Write Many:

All may have 4,37 Gbyte in the versions since 2002.

• **DVD-RW**   DVD Recordable (should be „DVD Rewritable")

    * constant linear velocity CLV, appr. 1.000 rewrites

• **DVD-RAM** DVD Rewritable (should be „DVD Random-Access Mem.")

    * constant angular velocity CAV, appr. 1.000.000 rewrites

• **DVD+RW**   DVD

    * CLV or CAV, appr. 1.000 rewrites

Read only and write once

• **DVD PROM**

    * part ist „read only", rest many be written once

DVD: Variants

DVD Read Only Specification (DVD-ROM, Book A):

- Storage medium with high capacity, successor of the CD-ROM

DVD Video Specification (DVD-Video, Book B):

- Special application of the DVD for the distribution of "linear" video streams

DVD Audio Specification (DVD-Audio, Book C):

- Special application of the DVD for the distribution of pure audio data, similar to the CD-DA

DVD Recordable Specification (DVD-R, Book D):

- Variant of the DVD that allows to record once

DVD Rewriteable Specification (DVD-RW, Buch E):

- Variant of the DVD that allows to record several times. Also called DVD-RAM (Random Access Memory)