

Optical Storage Technology

Digital Versatile Disc - DVD

Introduction

- CD's limited capacity and slow throughput bit rate made it **unsuitable** for **high bandwidth** or **larger volume** applications such as high quality digital video.
- In 1994, Sony and Philips proposed the **MultiMedia Compact Disc (MMCD)**. In 1995, Toshiba and Time Warner proposed the **Super Density Disc (SD)**.
- A consortium of manufacturers known as The **DVD Forum** was formed to develop the DVD families of formats.
- Several working groups were charged with the development of different formats and aspects within the family.
- The DVD families include **DVD-Video**, **DVD-ROM**, **DVD-R/RW**, **DVD-RAM**, and **DVD-Audio**.

DVD Families

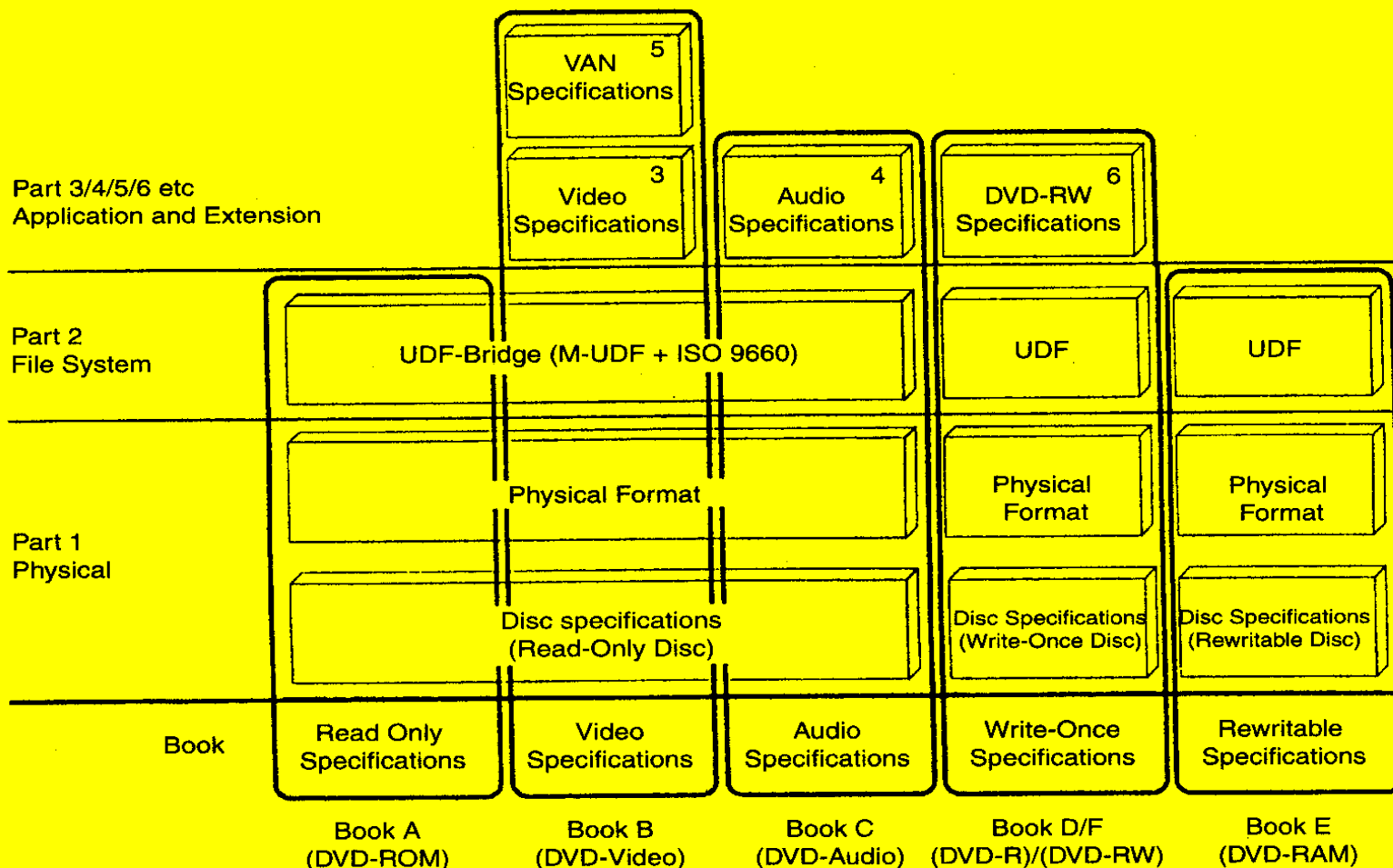


Figure 11.1 The DVD family of specifications includes six books for read only and recordable discs. Some physical and file system attributes are shared, but specific application details are distinct to each specification book.

Introduction

- The DVD file system uses elements of the **UDF**, **ISO 9660** and **ISO 13346** specifications. DVD-Video uses **MPEG** video coding and **Dolby Digital** audio coding, and DVD-Audio uses **multiple types** of coding.
- Whereas the **CD** was designed as an **audio** storage format, **DVD** was designed as an **universal** storage platform.
- The **CD** is also a “**simple**” format designed to work with or without microprocessors in the player. In contrast, **DVD** is based on sophisticated **microprocessor control** to read its file structure and interact with the disc and its content.
- Most importantly, the Red Book **CD** was designed to play back a **continuous stream of data** thus addressing was not needed. In contrast, **DVD** is founded on the premise that all data will be **addressable** and **randomly accessible**.

Improvement of DVD Capacity

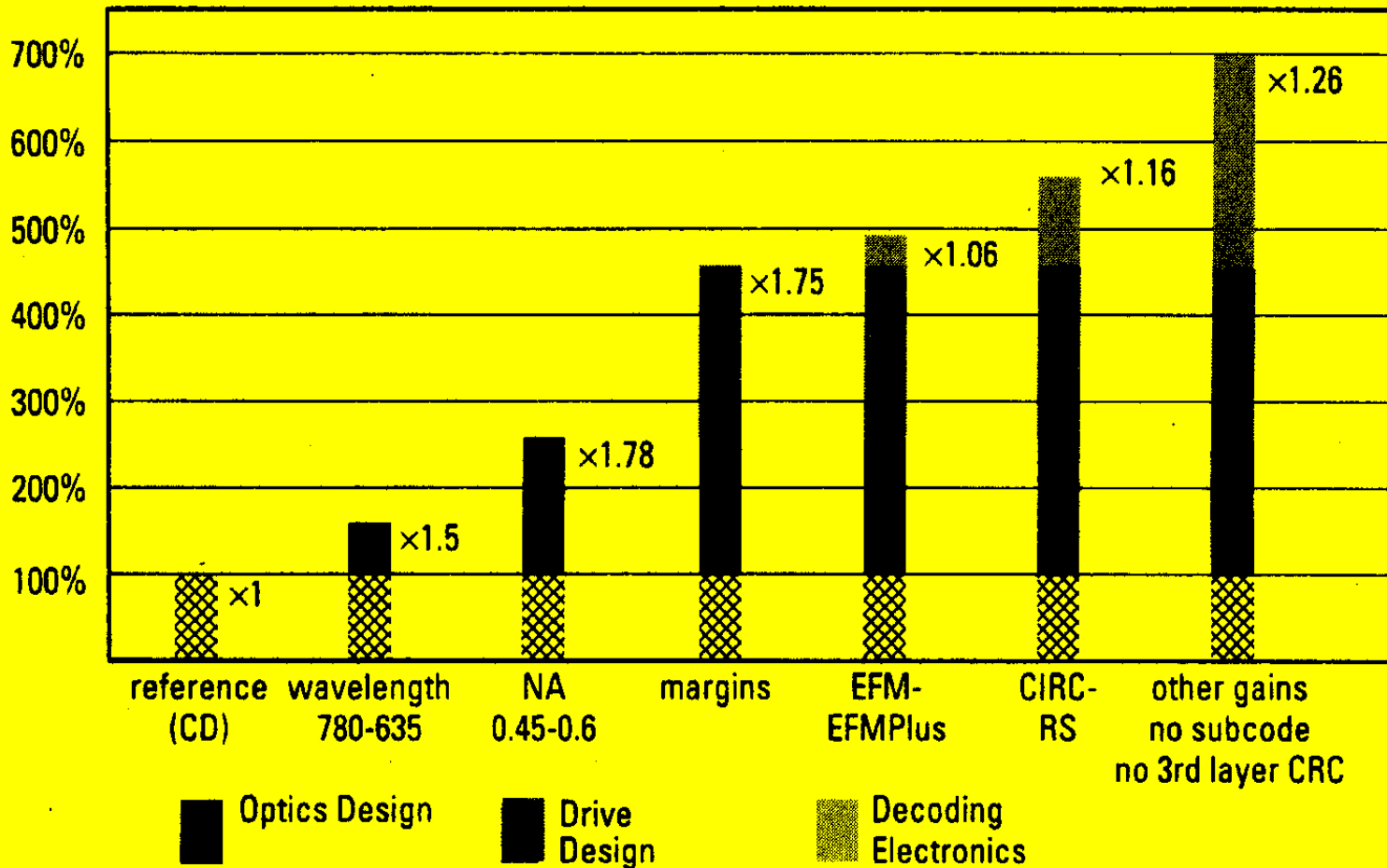
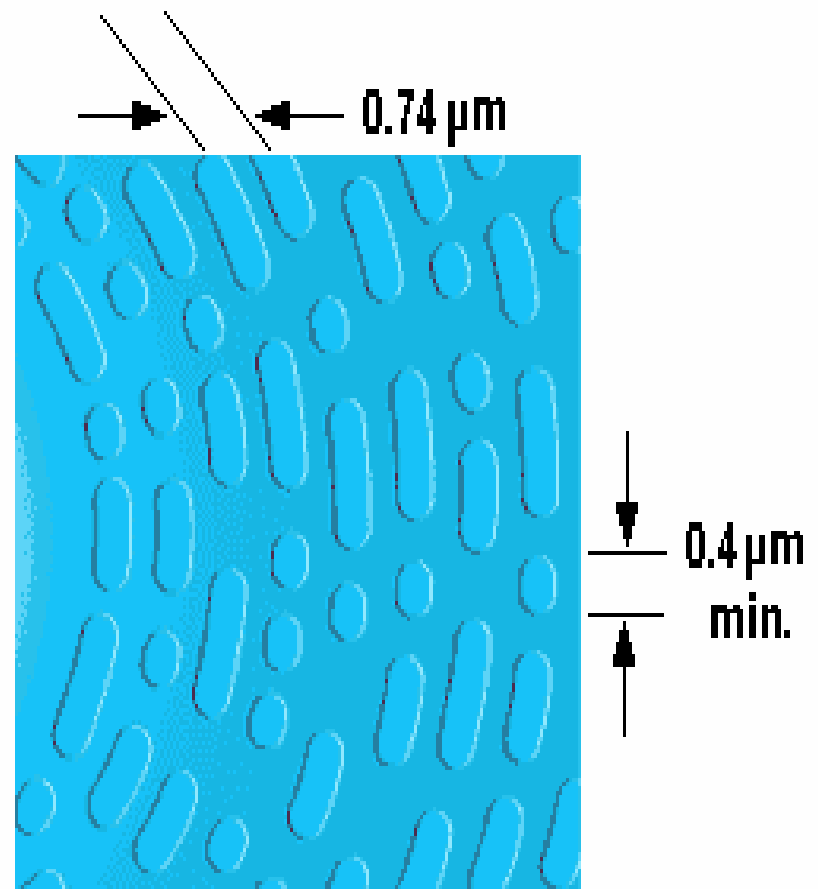
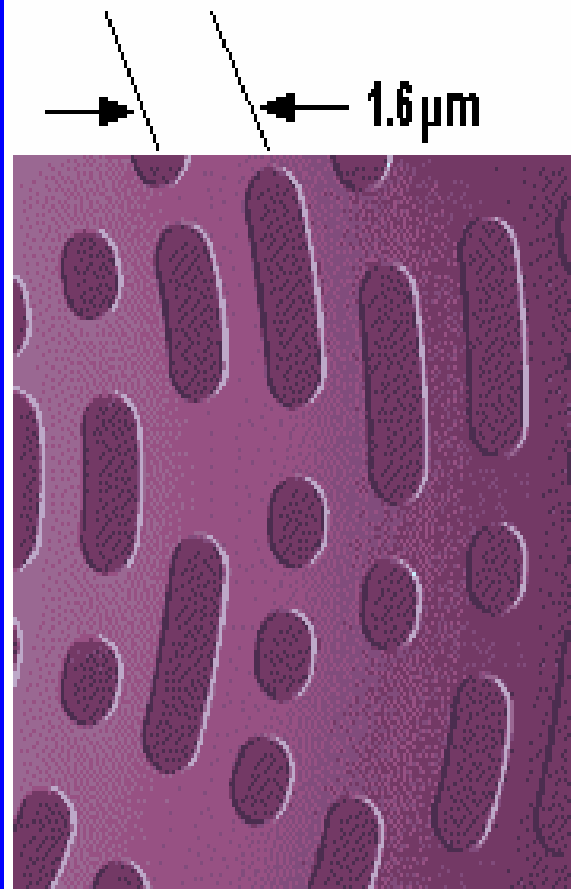


Figure 11.2 DVD disc layers hold seven times the data capacity of CD. This is accomplished through improvements in optics design, improved drive design and precision, and more sophisticated decoding electronics. (*Immink*)

Comparison of CD and DVD



DVD Physical Specifications

- **Part I** defines the **physical specification** and applies to the **DVD-ROM, Audio** and **Video** discs.
- Track pitch : **0.74 mm**
- CLV track velocity : **3.49 m/s** on a **single** layer
3.84 m/s on a **dual** layer
- Min./Max. pit length : 0.40/1.87 μm for single layer
0.44/2.05 μm for dual layer
- Wavelength : both 650 nm and 635 nm are supported
- Numerical aperture (NA) : 0.6
- Capacity : 4.7 Gbytes (measured in multiples of 1000)
4.38 Gbytes (measured in multiples of 1024)
- A DVD disc employs two **0.6 mm substrates**, bonded together with the data layers placed near the internal surface.

Thickness effect

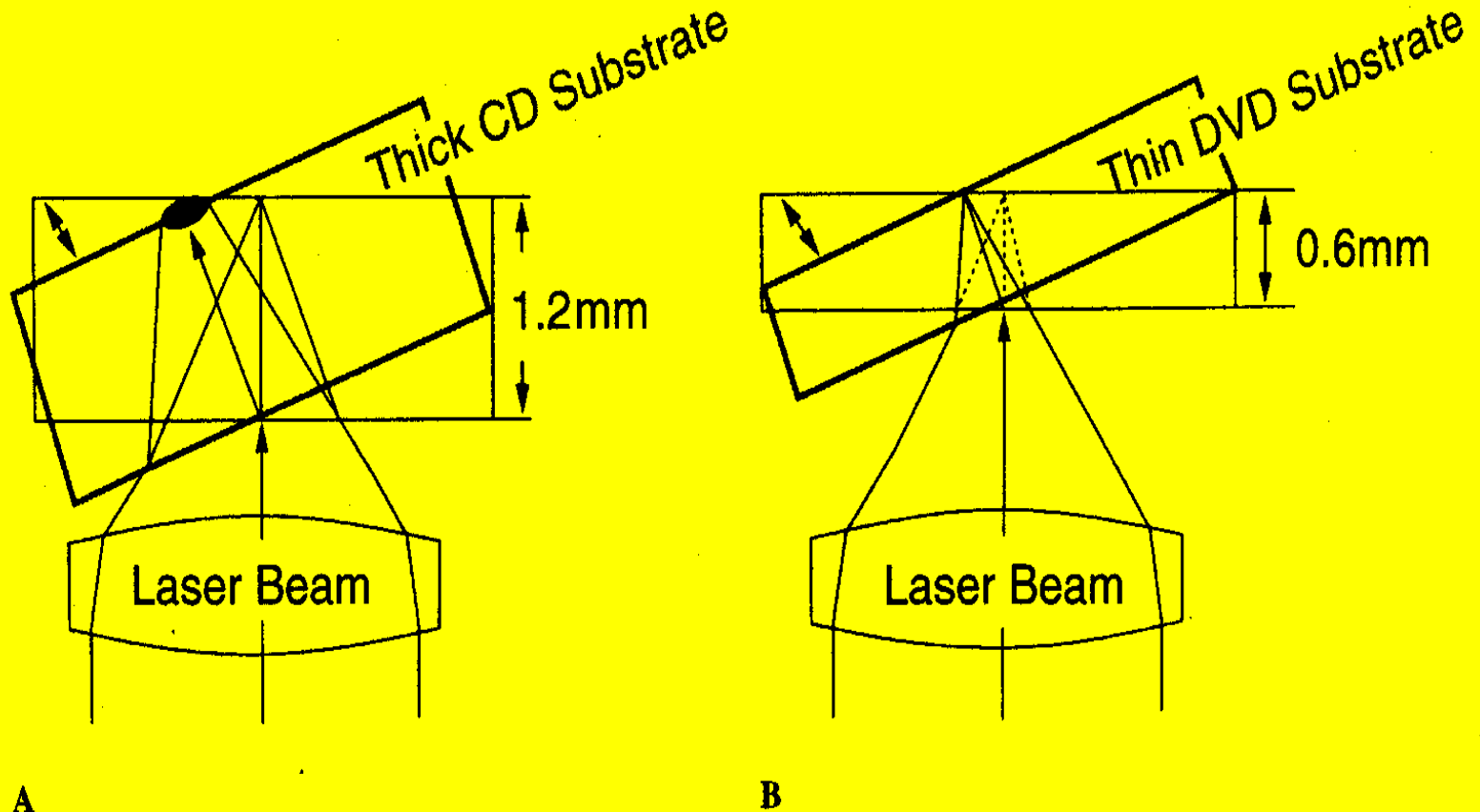
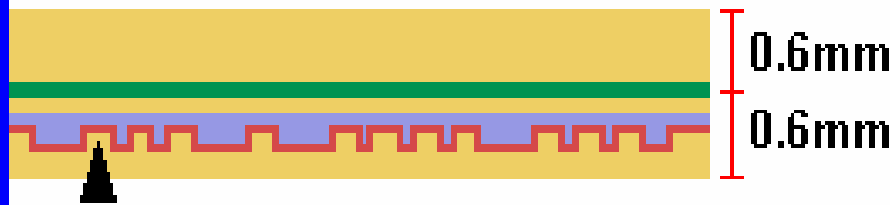


Figure 11.4 The thin (0.6-mm) DVD substrate is less sensitive to tracking and detection errors due to disc tilt. A. Thick CD substrate allows greater deviation. B. Thin DVD substrate has less deviation.

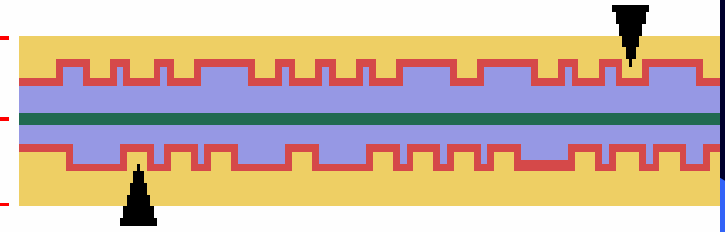
Four Types of DVD Discs

- When the averaged data output bit rate is **4.8 Mbps**, the approximate playing time are : 133, 241, 266, and 482 min.

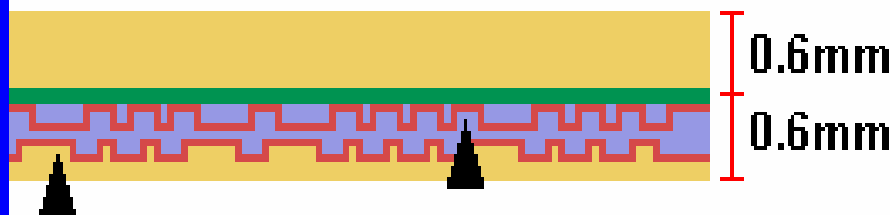
Single-sided, single layer (4.7GB)



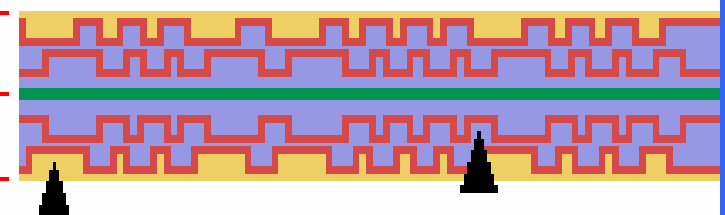
Double-sided, single layer (9.4GB)



Single-sided, double layer (8.5GB)



Double-sided, double layer (17GB)



■ substrate ■ adhesive ■ lacquer ■ reflective layer

DVD Physical Specifications

- For DVD-9 and DVD-18, the dual layers are separated by a **clear resin** and a very thin **semi-transparent** (reflectivity **25 to 40%**) layer of **gold** or **silicon**.
- **Environmental stability** and **playability** performance of the **silicon** semi-reflective layer meets or exceeds that of gold-based disc. However, a **different bonding resin** must be used.
- Because its reflectivity is slightly reduced, as well as signal-to-noise ratio, for reliable playback the embedded layer is formed with a **faster linear velocity**, and thus holds **less data**.
- The maximum **user data bit rate** is **11.08 Mbps**. The maximum **channel bit rate** is **26.16 Mbps**.

Disc manufacturing and playback

- Following **authoring**, disc content is typically imaged on a hard drive disk, then transferred to **Digital Linear Tape (DLT)** for mastering.
- Other media such as **DVD-R** or **Exabyte** maybe used as the delivery medium.
- In DVD mastering, **shorter wavelength** such as blue, ultraviolet, or violet **krypton lasers** must be used in **LBR**.
- It is more difficult to uniformly flow molten polycarbonate into a thinner mold with minimal **stress**. Also it is more difficult to separate the disc from the stamper without **strain**.
- The finer pit structure and geometry of the pits may require injection molding machine with **higher tonnage**.
- Two substrates are bonded together using a **hot-melt adhesive** or **UV-curable** bonding agents.

Dual-layer disc manufacturing - I

(1a) Replicate 1st layer substrate



(1b) Replicate 2nd layer substrate



(2a) Deposit semi-reflective layer



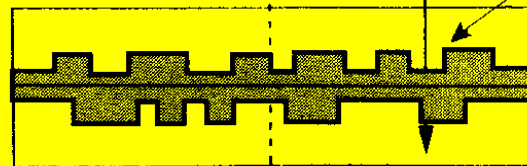
(2b) Deposit fully reflective layer



(3) Put UV hardened bonding resin on substrate



(4) Bond substrates



(5) Harden with UV light

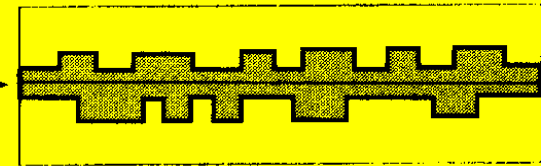


Figure 11.5 Single-sided, dual-layer DVD-9 discs can be manufactured with data layers on two substrates, one with a semi-reflective surface and another with a fully reflective surface.

Dual-layer disc manufacturing - II

(1) Replicate 1st layer substrate



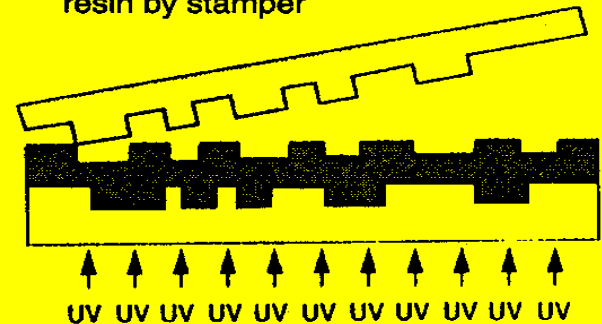
(2) Deposit semi-reflective layer



(3) Put UV hardened resin on substrate



(4) Replicate pits of 2nd layer on resin by stamper



(5) Deposit fully reflective layer



(6) Apply UV hardened resin to form protective layer

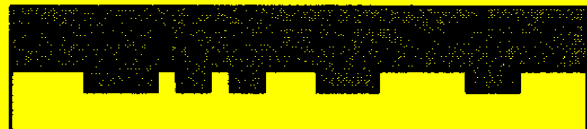


Figure 11.6 Dual-layer substrates can be manufactured by pressing a second data layer into an intermediate resin layer. This technique can be used to produce substrates for single-sided, dual-layer (DVD-9) discs and double-sided, dual-layer (DVD-18) discs.

Requirements for DVD Semireflective Layers

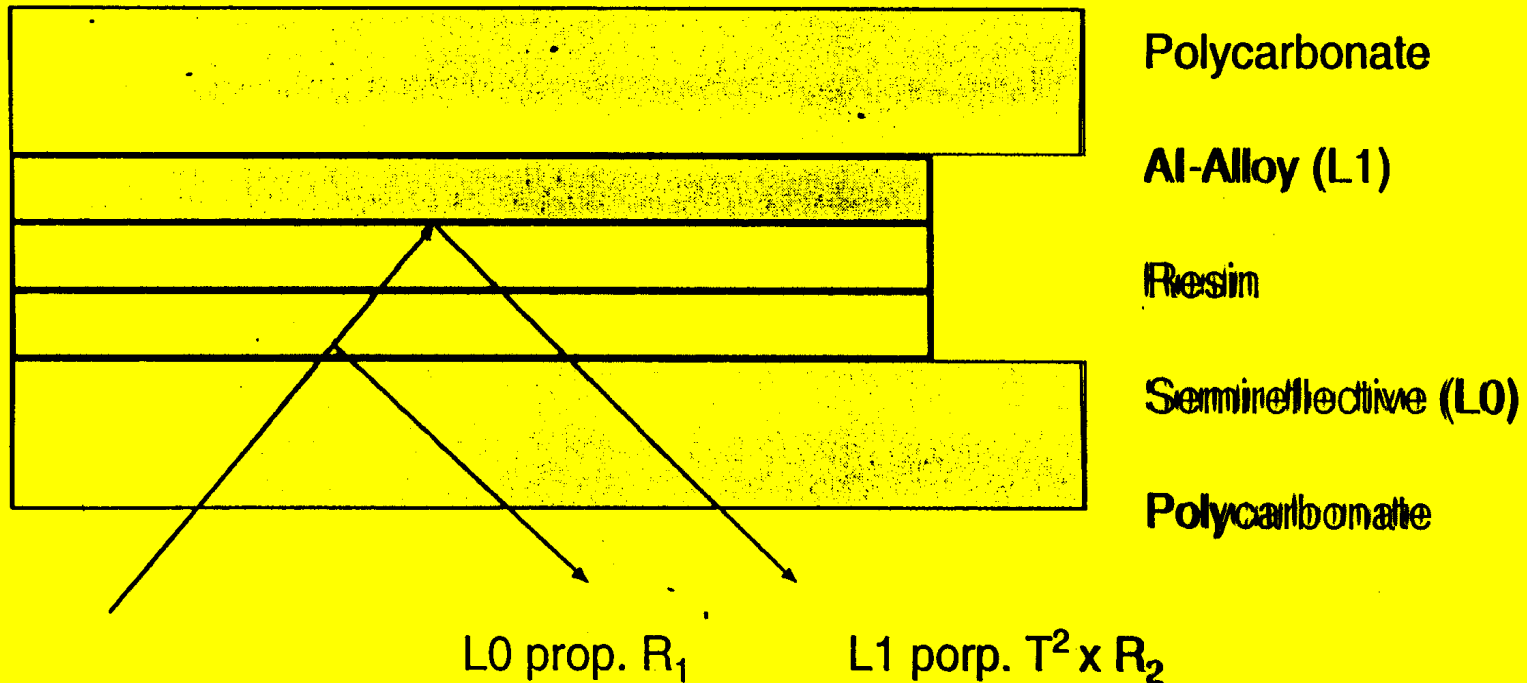
Material requirements:

- **Reflectance: 18 - 30%**
- **High transmittance**
- **UV transparency**
- **Corrosion resistance**
- **Good bondability**

Process requirements:

- **Good uniformity**
- **Low costs**
- **High deposition rate**
- **Good reproducibility**
- **No pit damage**

Dual Layer DVD (DVD 9)

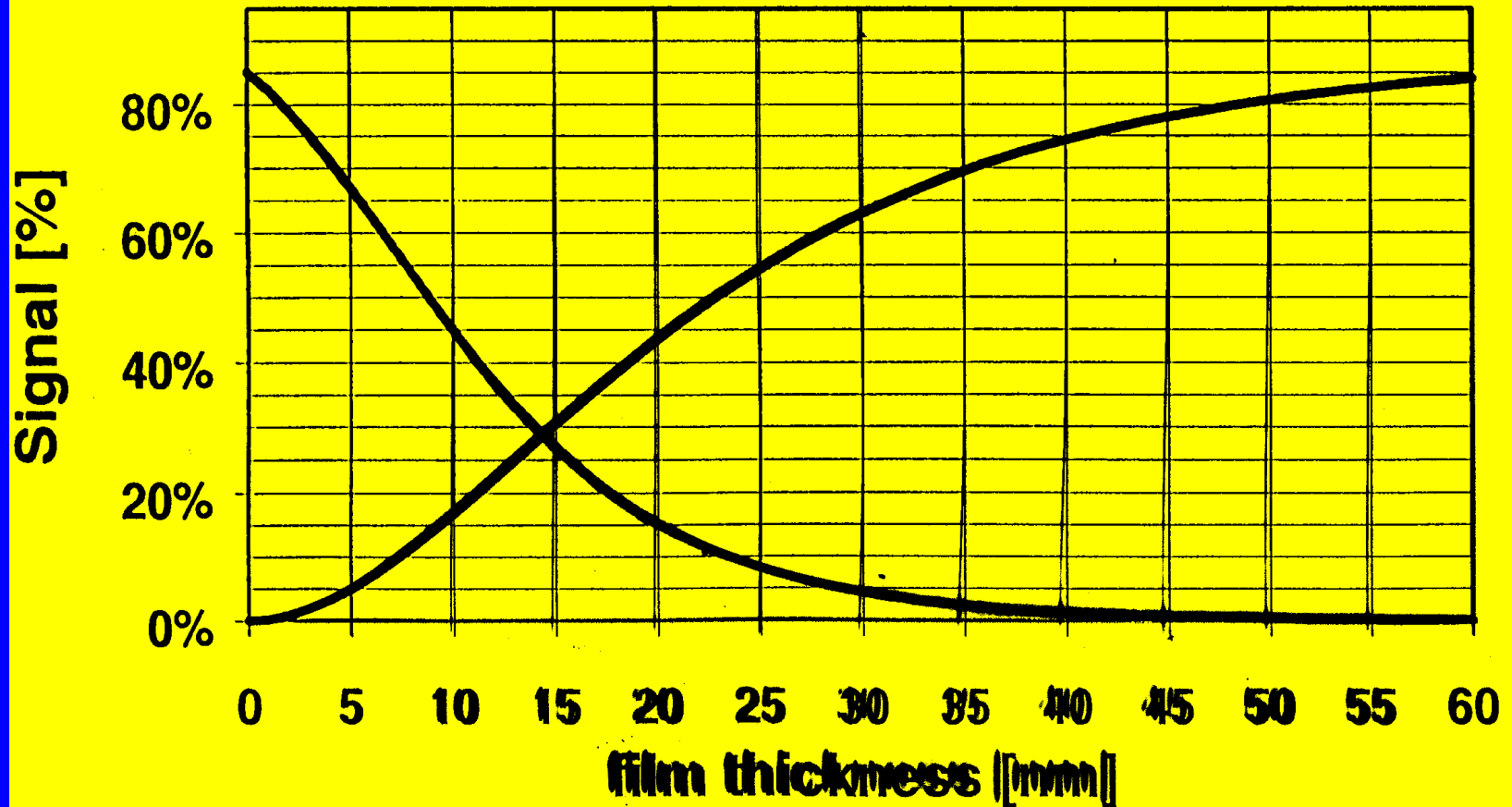


$R_2 = 0.85$ Reflectance of Al within stack $R_1 =$ Reflectance of semireflective layer

$T =$ Transmittance of semireflective layer

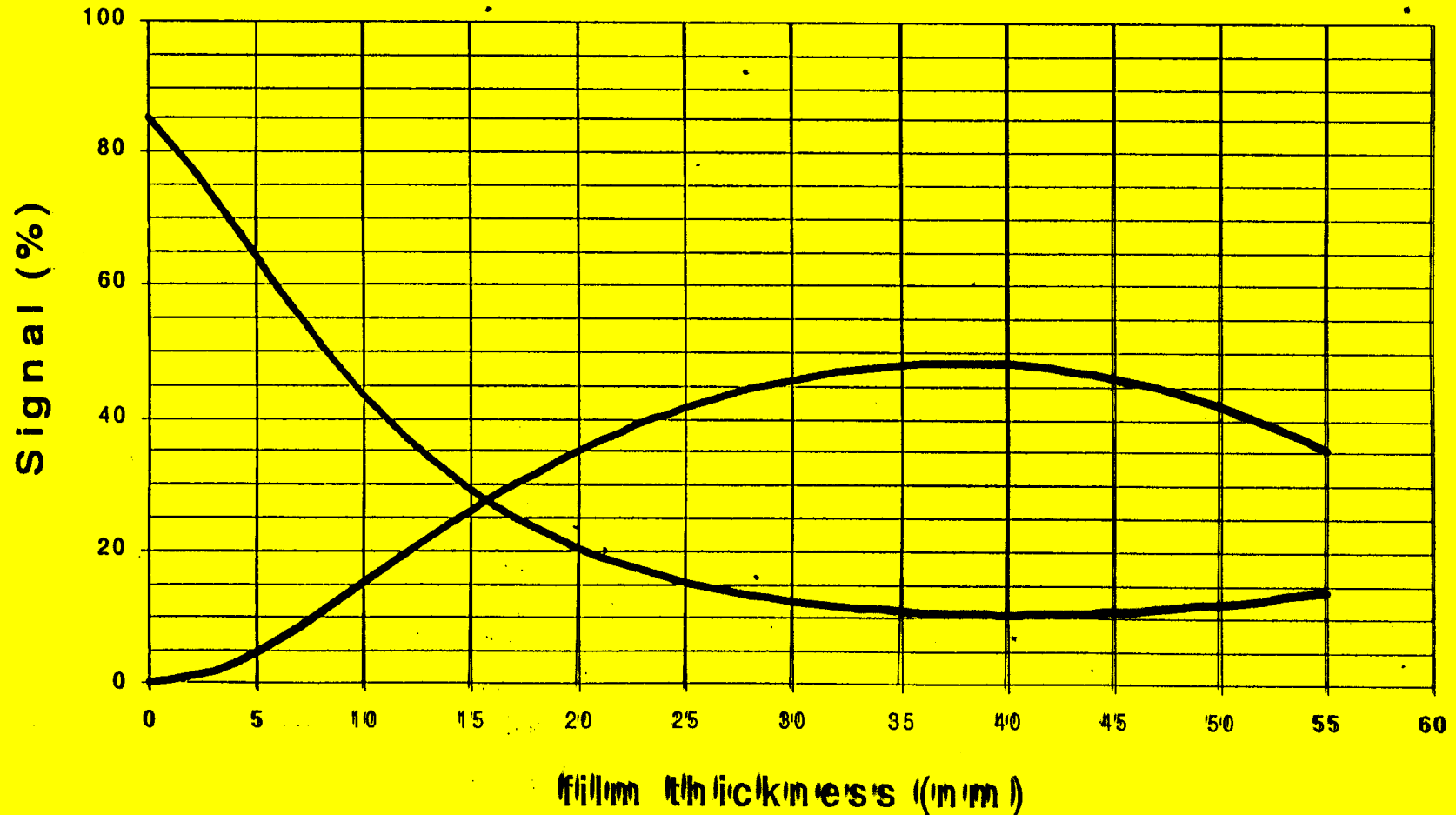
DVD9 Signals depending on L0 thickness (Au)

Signal 0 and Signal 1 at 650 nm



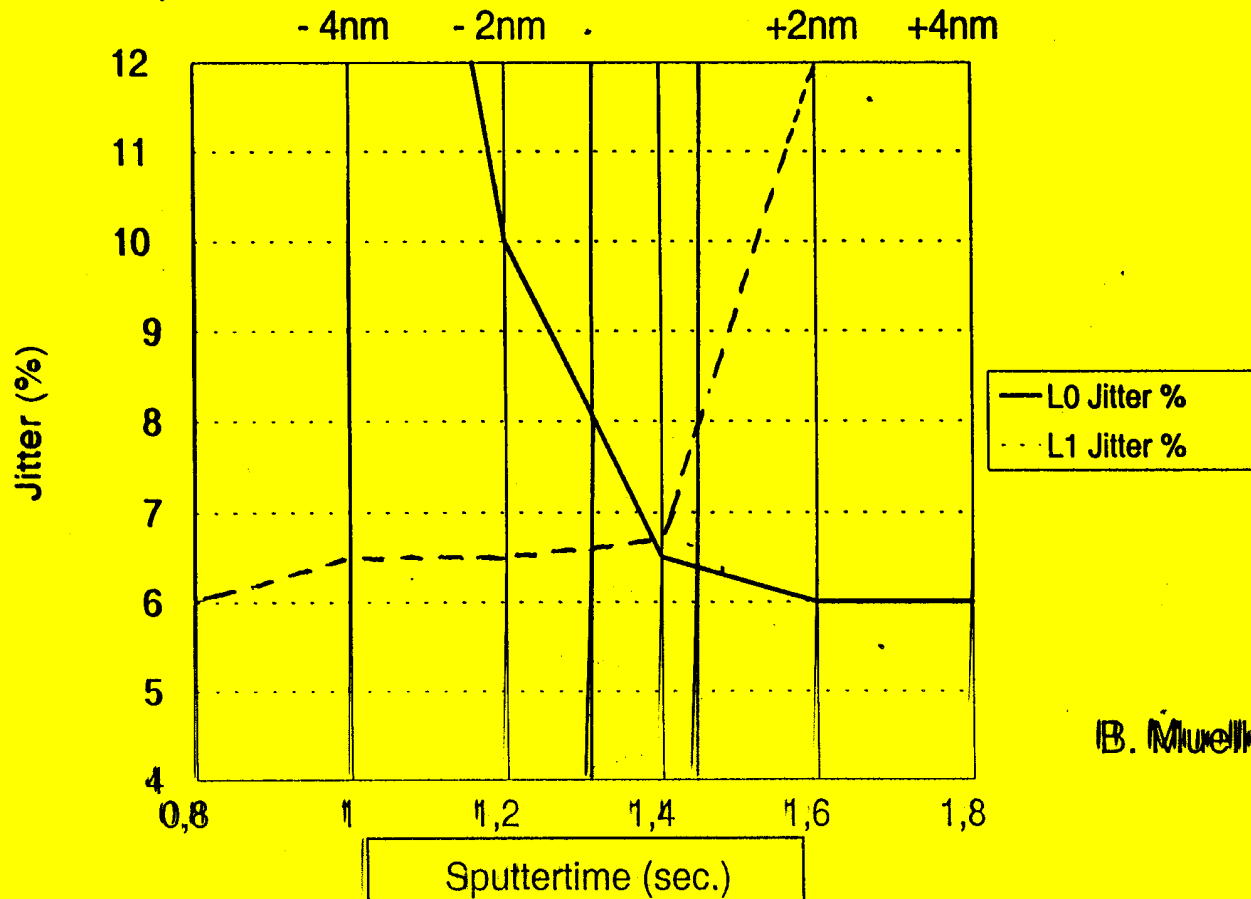
DVD9 Signals depending on L0 thickness (Si)

Signal 0 and Signal 1 at 650nm



DVD 9 Thin Film Challenge:

Jitter Dependence on L0 Layer Uniformity:



B. Mueller; Tape & Disc Aug. 97

Disc manufacturing and playback

- All DVD players can read CD disc with molded plastic pits.

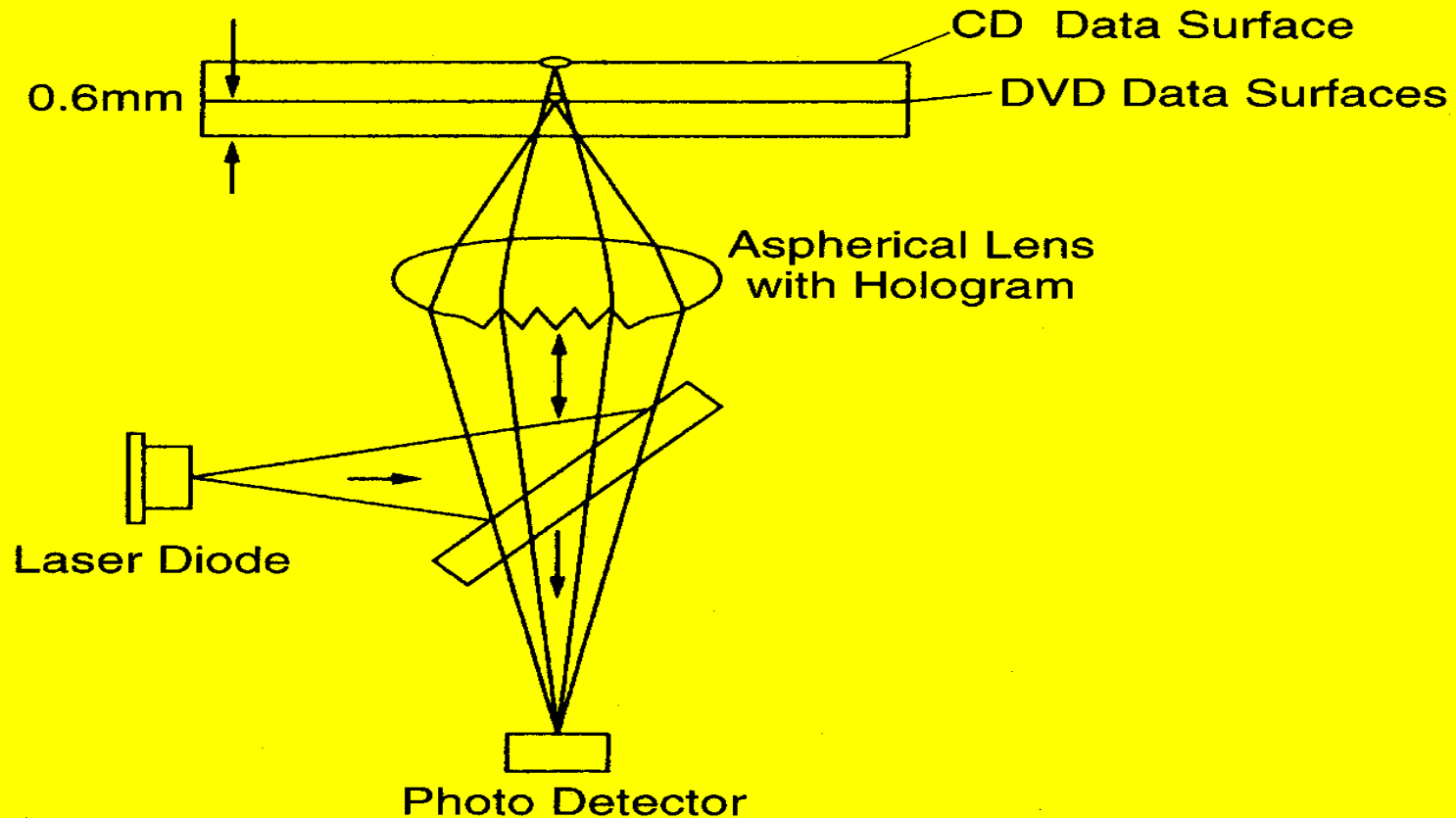


Figure 11.8 A DVD pickup is designed to focus on either CD or DVD data layers. Different focal lengths can be achieved with a variety of techniques including a holographic lens.

Disc manufacturing and playback

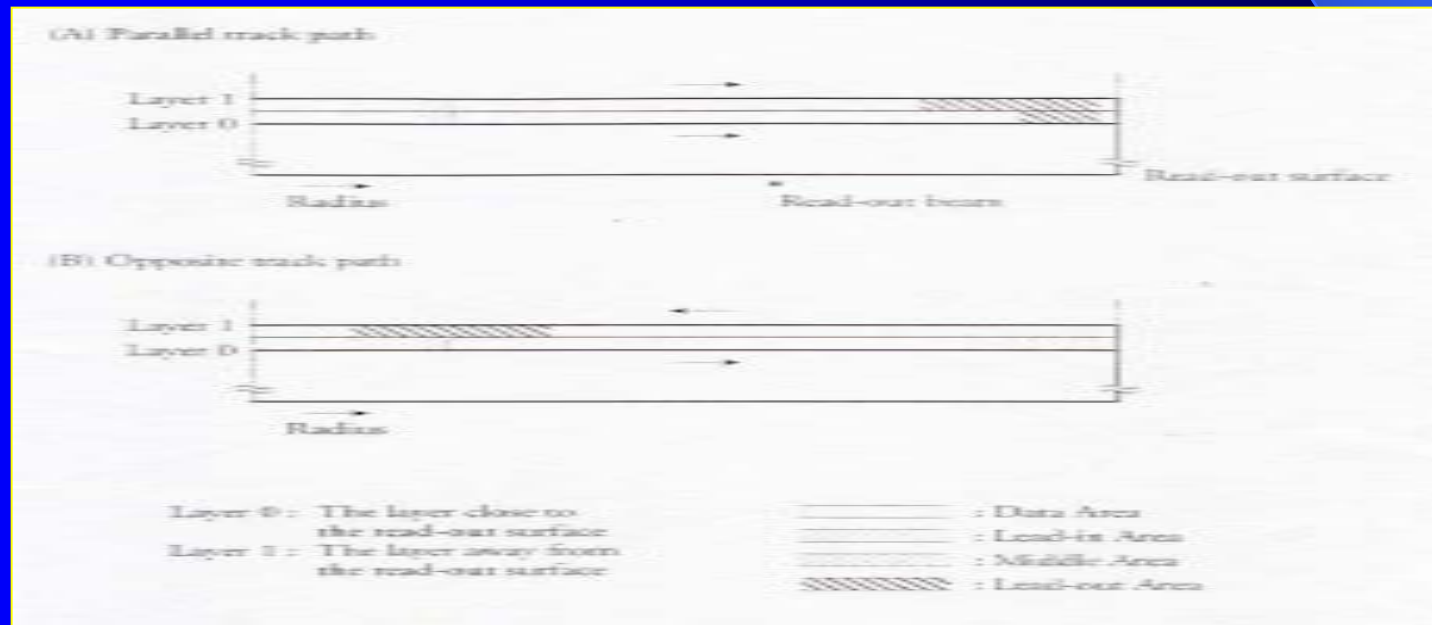
- Playback of **CD-R** discs is **problematic**; the optical response of the **organic dye** recording layer is extremely **wavelength dependent**, with high absorption below a narrow range around 780 nm.
- CD-R compatible DVD pickups are designed with **two discrete optical path at two wavelengths**, or may employ one object lens with **two lasers**.
- In one design, the **numerical aperture** is adjusted by coating the outer circumference with material that is opaque at 780 nm but transparent at 635/650 nm.
- Alternatively, for example, a **dual laser pickup** could mount two objective lenses on a rotating head that placed the appropriate lens in the optical path.

Data Coding

- The **lead-in** area is the innermost area of the Information Area. It consists of the **Initial zone**, **Reference code**, **Buffer zone 1**, **Control data zone**, and **Buffer zone 2**.
- Control data block comprises **16 sectors**; information includes **disc size**, **minimum read-out rate**, **single/dual layer**, **track path**, **disc manufacturing information**, and **copyright**.
- A **Burst Cutting Area (BCA)** is an optional area located inside the lead-in area.
- BCA data can be written by a high-power system such as YAG laser after a disc is manufactured. It comprises a **series of low reflectance stripes** fully extending along the radial direction.

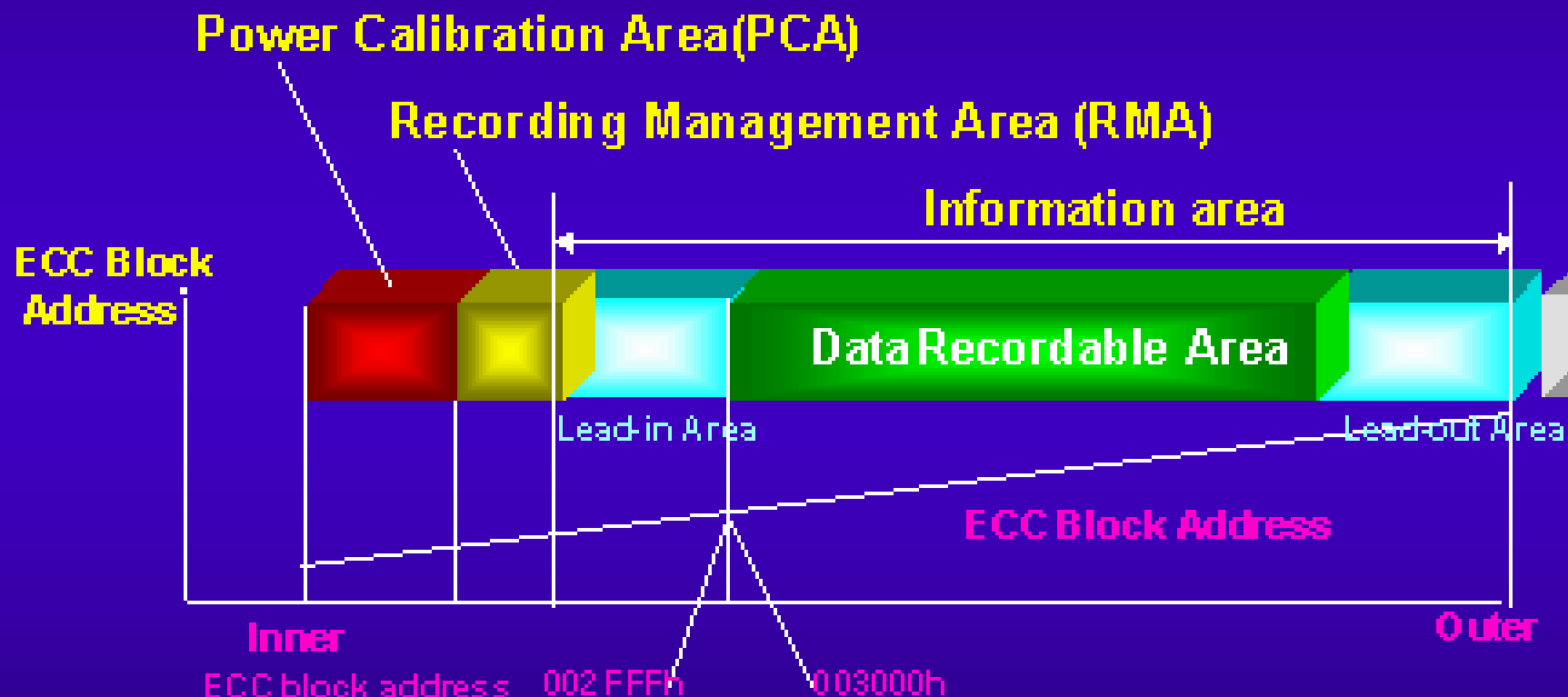
Data Coding

- DVD data is placed on a disc in **physical sectors** that run continuously without gap from the lead-in to the lead-out area. The lead-in area ends at address 02FFFF and data begins at address 030000.
- Two types of dual layer disc are defined: **parallel track** and **opposite track**.





Layout of Physical Sector



Data Coding

- A data sector comprises 2064 bytes, consisting of **2048 bytes** of **main data** and **16 bytes** of **header**.
- The **header** comprises **4 bytes** of **identification (ID)** and **8 bytes** of **other data**, and **4 bytes** of **error detection code (EDC)** data.
- The four bytes of **identification** data contain 1 byte of **sector information** and 3 bytes of **sector number**.
- A **sync code** is added to the head of **every 91 bytes** in the recording sector; in all **52 bytes** of sync code are added.
- After the EDC data is calculated, a **Reed-Solomon Product Code (RS-PC)** is calculated. This code use a combination of two Reed-Solomon codes (C1 and C2) as a product code.
- The two C1 and C2 product codes are **(208,192)** and **(182,172)** in length. The rate of the code is thus 0.872.

Data Coding

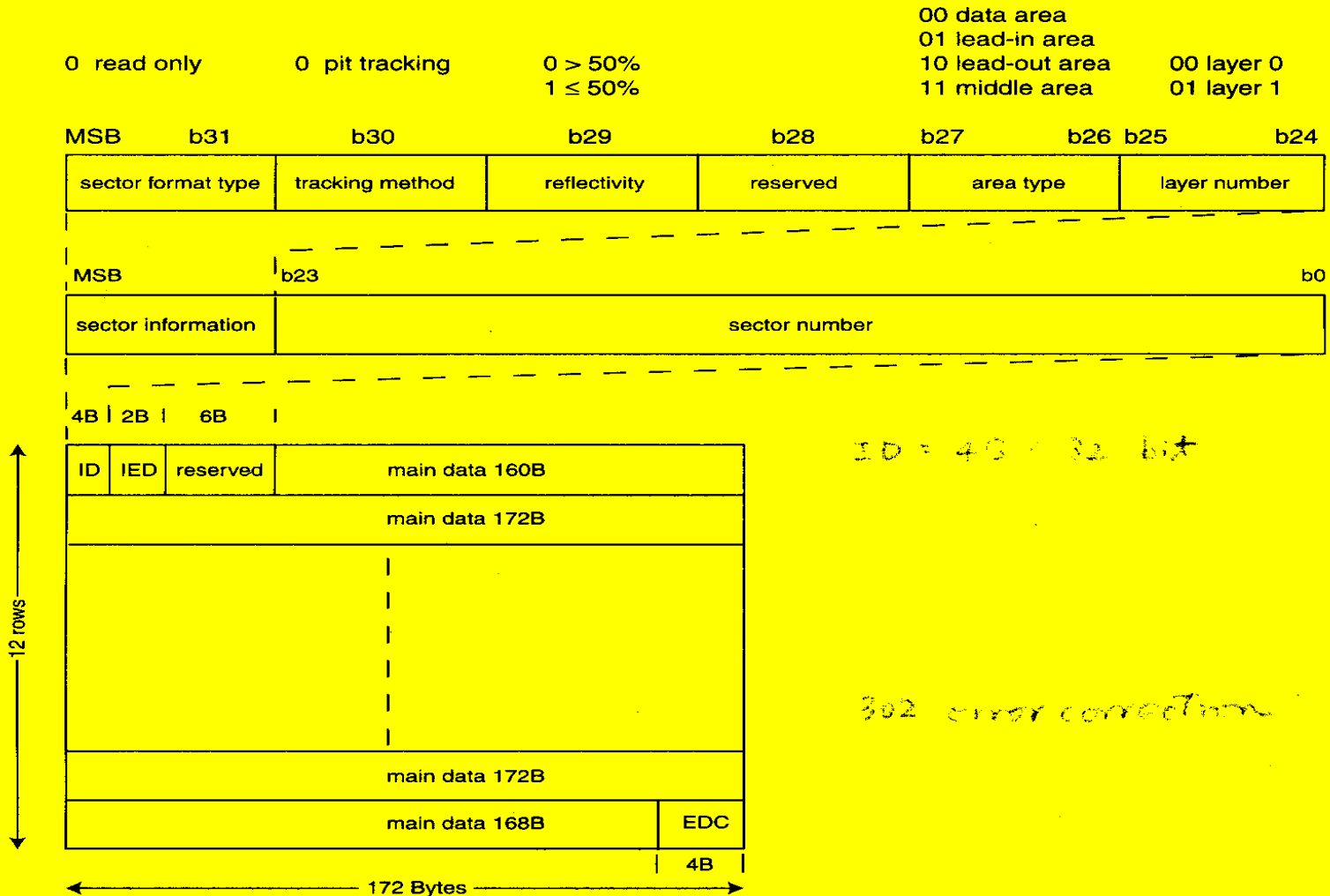


Figure 11.9 DVD data is placed in sectors, each with 2064 bytes of data. Four bytes of ID data contain sector information.

Data Coding

- The superior **RS-PC error correction code** provides **improved overall error protection** compared to a CD.
- Because RS-PC is **more efficient** than CIRC in term of overhead, its use increases data density by **16%**.
- RS-PC is applied to the 2048 bytes of main data, each block providing error correction encoding over **16 data sectors**; **302 bytes** of error correction code are added to each sector.
- An outer code parity **PO** and inner code parity **PI** are added to each sector.
- The initial 2048 bytes of user data is thus increased to **2418 bytes** (**2048 user + 16 header + 302 error correction + 52 sync = 2418**).
- In the DVD format, all disc types use the **same level of error correction**; and error concealment is not used.

Data Coding

- The CIRC code uses a **convlutional structure** that is suited to **long streams of data**. In contrast, the **matrix structure** of the RS-PC code is suited to **small blocks of data**.
- A small disadvantage of an RS-PC code is its **larger memory requirement**.
- In DVD discs, **PI** and **PO error rates** are used.
- **PI error** counts the number of PI rows with any bad symbols.
- **PI failures** are the number of uncorrectable PI rows per ECC block.
- **PO failures** are the number of uncorrectable PO rows per ECC block.
- RS-PC can reduce a random input error of $2 \cdot 10^{-2}$ to a data error rate of 10^{-15} . This is better than CD by a factor of 10.

Data Coding

- Read-only DVD discs use **EFMPlus modulation**.
- It is an **8/16 RLL** code and uses the same minimum (**2**) and maximum (**10**) run length.
- EFM uses 8/14 encoding with 3 merging bits to yield an **8/17 ratio**. EFMPlus provides a **6%** increase in user storage capacity because its coding is more efficient than EFM.
- EFMPlus does **not require merging bits** and uses a more sophisticated **lookup method**.
- When a DVD disc is read, data passes through a **buffer** and then is evaluated by a **navigator/splitter** that separates the bit stream into **video**, **sub-picture**, **audio**, and **navigational information**.
- The video, sub-picture and audio data is **descrambled** and **decoded** in a dedicated **hardware chip** or with software via a computer **CPU**.

Universal Disc Format (UDF)

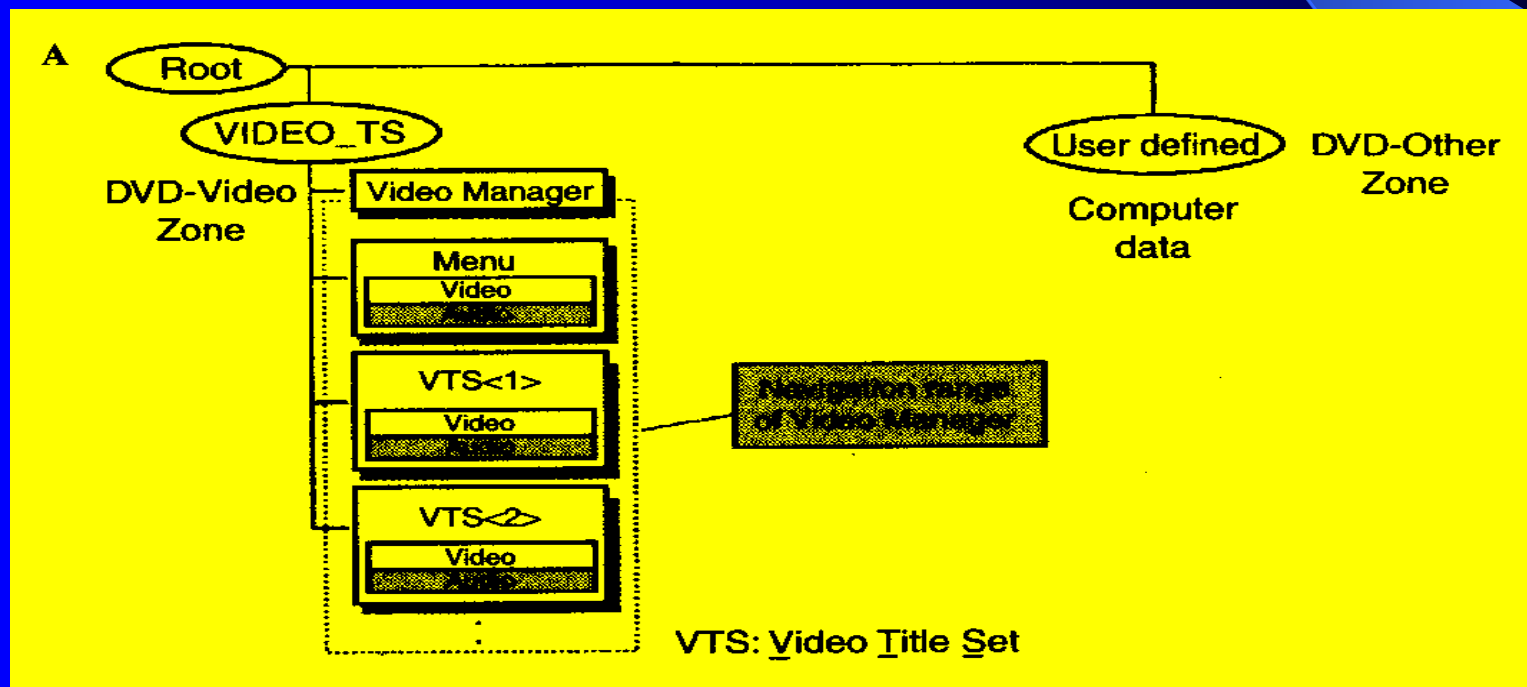
- Read-only DVD discs must use the **Universal Disc Format (UDF)** Bridge for **volume structure** and **file format**.
- The DVD format is unlike CD-Audio that DVD is fundamentally **computer-based** with a file format defined for **all** its applications.
- UDF Bridge defines **data structures** such as volumes, file blocks, sectors, CRC's, paths, records, allocation tables, partitions, and character sets, as well as methods for recording, writing, and other applications.
- It is backward **compatible** to existing **ISO-9660** operating system software; however, a **DVD-Video** or **Audio player** supports **only UDF** and not ISO-9660.

Universal Disc Format (UDF)

- A **Sector** is the smallest addressable data file (2048 bytes).
- A **Volume** is a **sector address space**.
- A **Volume Set** is a collection of one or more volumes.
- A **Volume Group** consists of one or more consecutively numbered volumes.
- A **File** is a **set of sectors** with sector number in a **continuously ascending sequence**.
- An **Application** is a program that processes the contents of a file.
- A **Descriptor** contains information about a volume or file.
- The UDF specification was developed by the **Optical Storage Technology Association**.

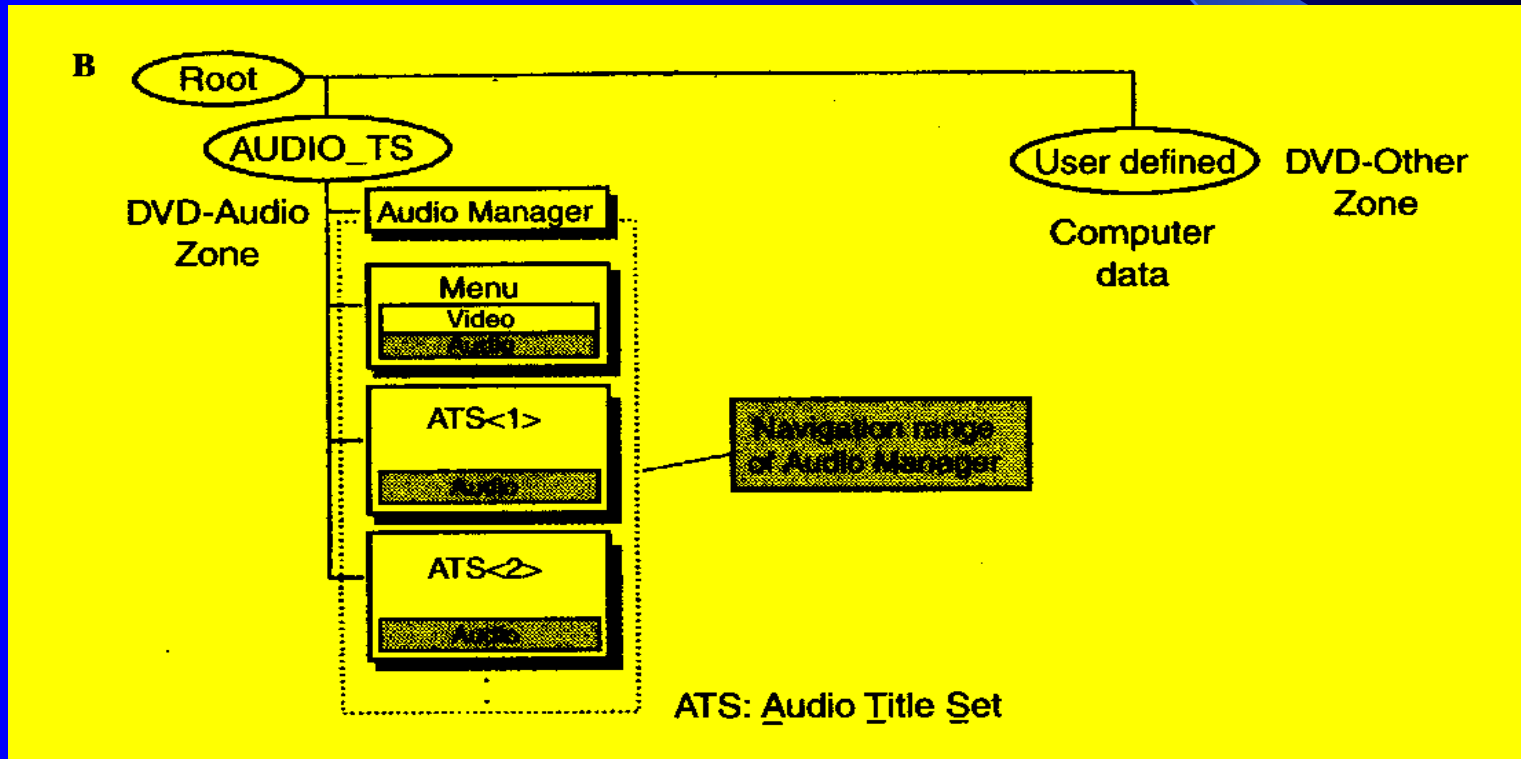
DVD-Video “Video” disc

- A **Video Manager** define file types and organization of both video and audio data.
- **Video Title Set (VTS)** subdirectories contain video and audio data files (such as MPEG-2 video and Dolby Digital audio).



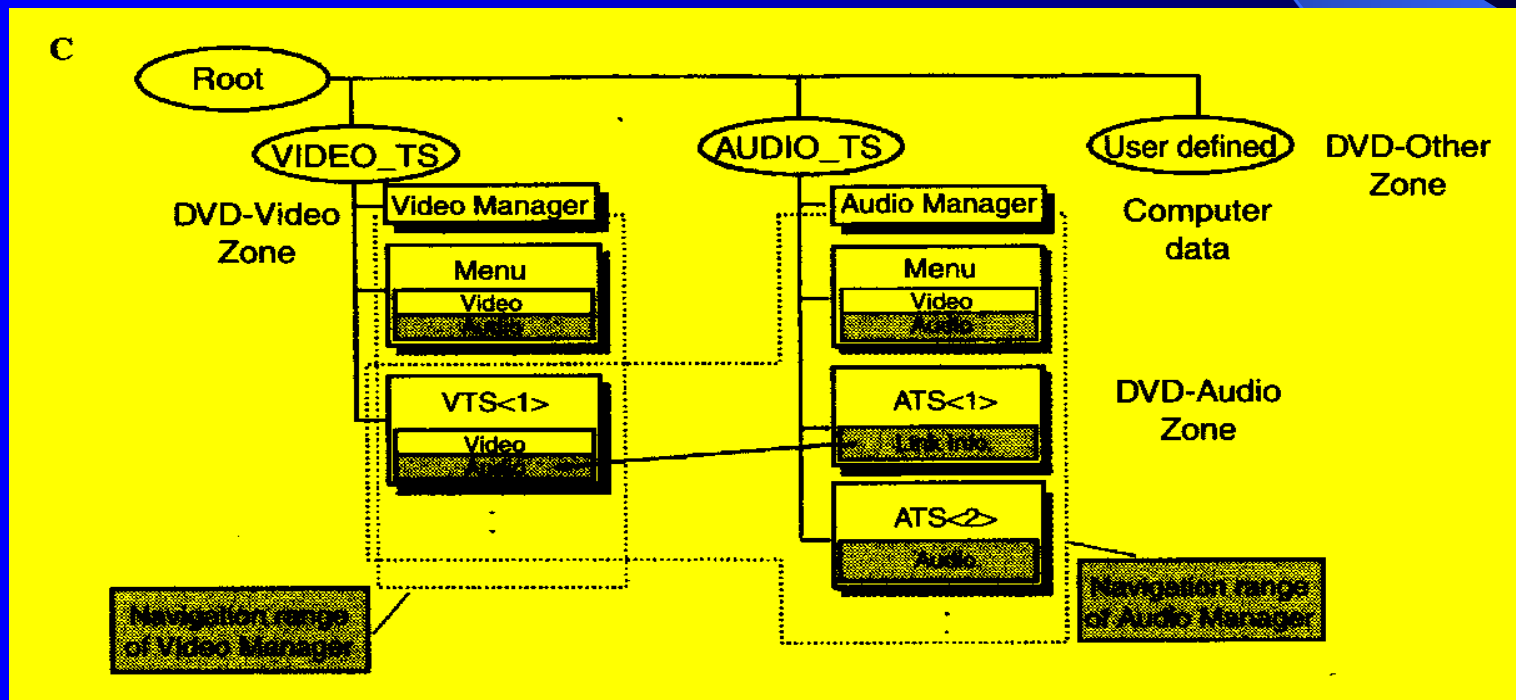
DVD-Audio “Audio only” disc

- Audio data is contained in an **Audio Title Set (ATS)**.
- An **Audio Manager** defines file types and organizes both audio and video data.



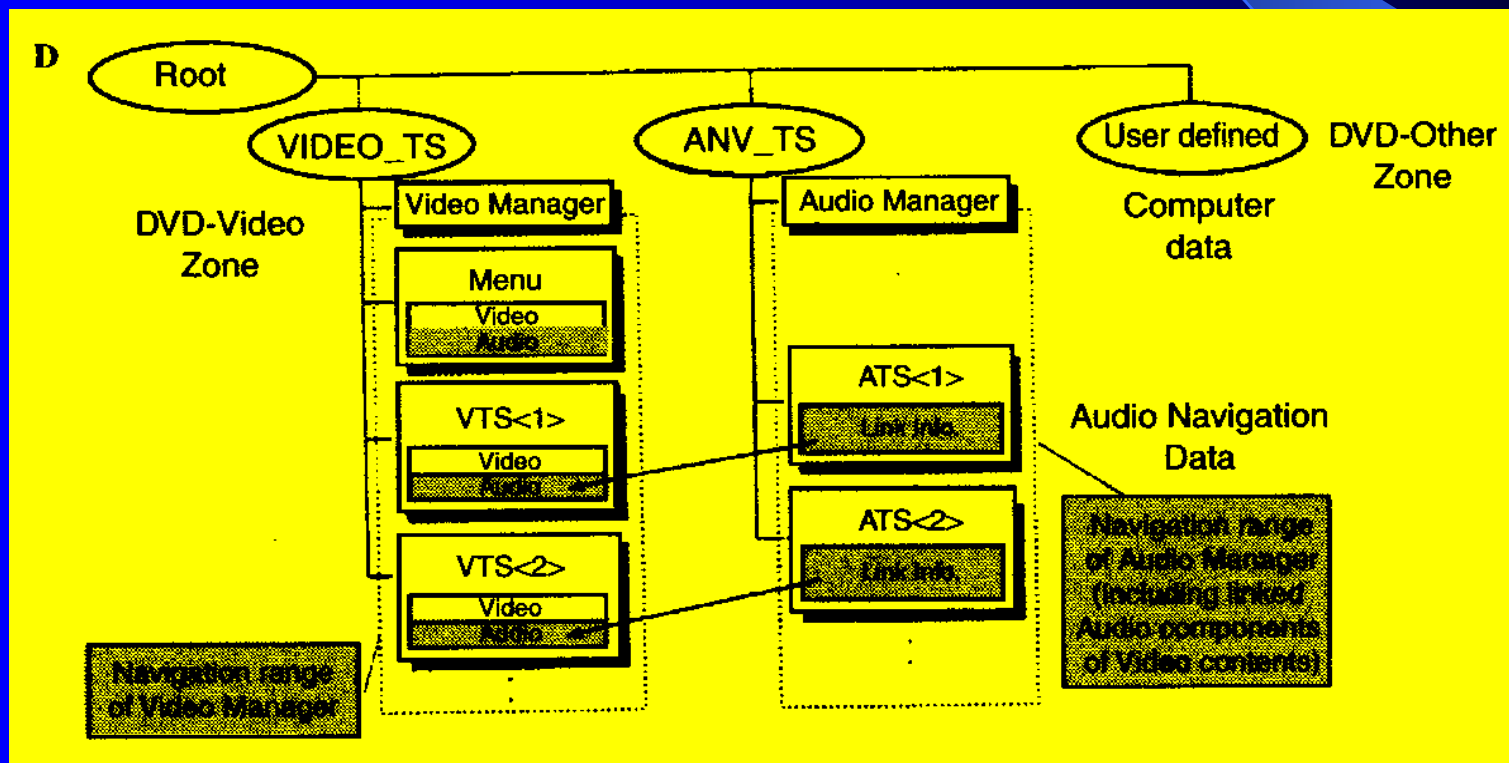
“AV” DVD-Audio disc

- Audio data is contained in an Audio Title Set and video data in a Video Title Set. The **Audio Manager** can control a subset of the DVD-Video data.
- “**Link Info**” shows that a DVD-Audio player can play audio components of video contents.



DVD-Video “AVN” disc

- Audio data is contained in an Audio Title Set and video data in a Video Title Set.
- “Link Info” shows that a DVD-Audio player can play audio components of video contents.



DVD-Video – Video coding

- A movie might be mastered at a video bit rate of **166 Mbps**.
- Although a DVD-Video disc can hold 4.7 Gbytes, it is insufficient to store a feature film.
- The DVD-Video standard uses the **MPEG-2** data compression algorithm to encode its video program.
- It employs the **MPEG-2 Main Profile at Main Level** protocol, also known as **MP@ML**.
- MP@ML yields a high quality pictures that equals that of the professional **CCIR - 601 standard (270 Mbps)**.
- To store **133 minutes** of an audio/video program would imply an **overall reduction** of about **60:1**.
- A NTSC CCIR-601 signal assumes a sampling rate of **858** samples per scan line, **525** lines per frame and **30** frames per second.

DVD-Video – Video coding

- DVD-Video reduces the number of pixels to a **720 by 480** pixel display. The video bit rate is further decreased by **decreasing the word length**.
- Rather than code RGB components, a **YCrCb** representation can be used more efficiently.
- These steps reduce the bit rate by **54%**.
- Movies are shot at **24 frames per second**, whereas DVD-Video is **30 frames per second**. This type of pre-filtering on the input signal may decrease the bit rate by **63%**.
- Although the bit rate may be only **100 Mbps**, it still requires algorithmic compression.
- To place a 133-minute movie on a single-side, single-layer disc, an average compression ratio of **21:1** is needed.

DVD-Video – Video coding

- The MPEG-2 video compression algorithm uses **psycho-visual models** to analyze the video signal to determine how a human viewer will perceive it.
- An important aspect of MPEG-2 coding is its **variable bit rate** (MPEG-1 uses a fixed bit rate).
- MPEG-2 encoders output a **changing bit rate** that reflects the changing degree of **picture complexity** and **coding difficulty**.
- The DVD-Video **maximum** output bit rate is **10.08 Mbps**, and the **average** bit rate is about **3.5 Mbps**.
- The video program is stored as **4:2:0** component video (Y, R-Y, B-Y) with progressive scan, and picture resolution is **720 by 480** pixels.

DVD-Video – Video coding

TABLE 11.1 Summary of the principal characteristics of the DVD-Video format.

Navigation Structure		
Playback control	Information/control file	
Navigation player model (command & user operation)	VMGI (video manager)	
	VTSI (video title set)	
	PGC (program chain)	
	PCI (presentation control information)	
Presentation Structure		
Multiplex system	MPEG2 program stream	
Video	Audio	Subpicture
1 stream	max 8 streams	max 32 streams
MPEG1 & 2 MP@ML	525 system	Run-Length Coded bitmap
Bit rate	AC3, LPCM, (MPEG)	2 bit/pixel
MPEG2 9.8 Mbps	625 system	
MPEG1 1.856 Mbps	MPEG, LPCM, (AC3)	
	AC3	
	fs = 48 kHz	
	max 448 kbps	
	max 5.1 ch surround	
	MPEG1,2	
	fs = 48 kHz	
	max 384/912 kbps	
	max 7.1 ch surround	
	LPCM	
	fs = 48,96 kHz	
	16/20/24 bit	
	max 8 ch	

DVD-Video – Audio coding

- The audio portion of the DVD-Video standard provides both **multi-channel** and **stereo soundtracks**.
- These can be **1 to 8 channels** of **linear PCM**, **1 to 6 channels** of 5.1-channel (5 main channels plus a low-frequency effects channel) of **Dolby Digital (AC-3)**, or **1 to 8 channel** (5.1 or 7.1) of **MPEG-2 AAC audio**.
- Dolby Digital is the standard coding used for multi-channel soundtracks in the U.S. and Canada (Region 1).
- The **Dolby Digital** sampling frequency is **48 kHz**, the **nominal** output bit rate is **384 kbps**, and the **maximum** bit rate is **448 kbps**.
- **MPEG-1** stereo audio is sampled at **48 kHz** with a maximum bit rate of **384 kbps**. **MPEG-2** multi-channel audio is also coded at **48 kHz**; its maximum bit rate is **912 kbps**.

DVD-Video – Audio coding

- For **compatibility**, all movies all carry a redundant **linear PCM** digital stereo soundtrack. These linear PCM audio tracks can employ sampling rate of either **48 or 96 kHz**, and word lengths of **16, 20, or 24 bits**.
- Because up to **8** independent PCM channel are permitted, movie can be released in **eight different languages**.
- LPCM coding can also employ a **dynamic range control** (the same provision as in the DVD-Audio specification).
- The maximum linear PCM bit rate is **6.144 Mbps** on a DVD-Video disc.
- Very generally, a **4.7-Gbyte** disc can hold **133** minutes of program, a **8.5-Gbyte** disc can hold **241** minutes, a **9.4-Gbyte** disc can hold **266** minutes, and a **17-Gbyte** disc can hold **482** minutes.

DVD-Video – Audio coding

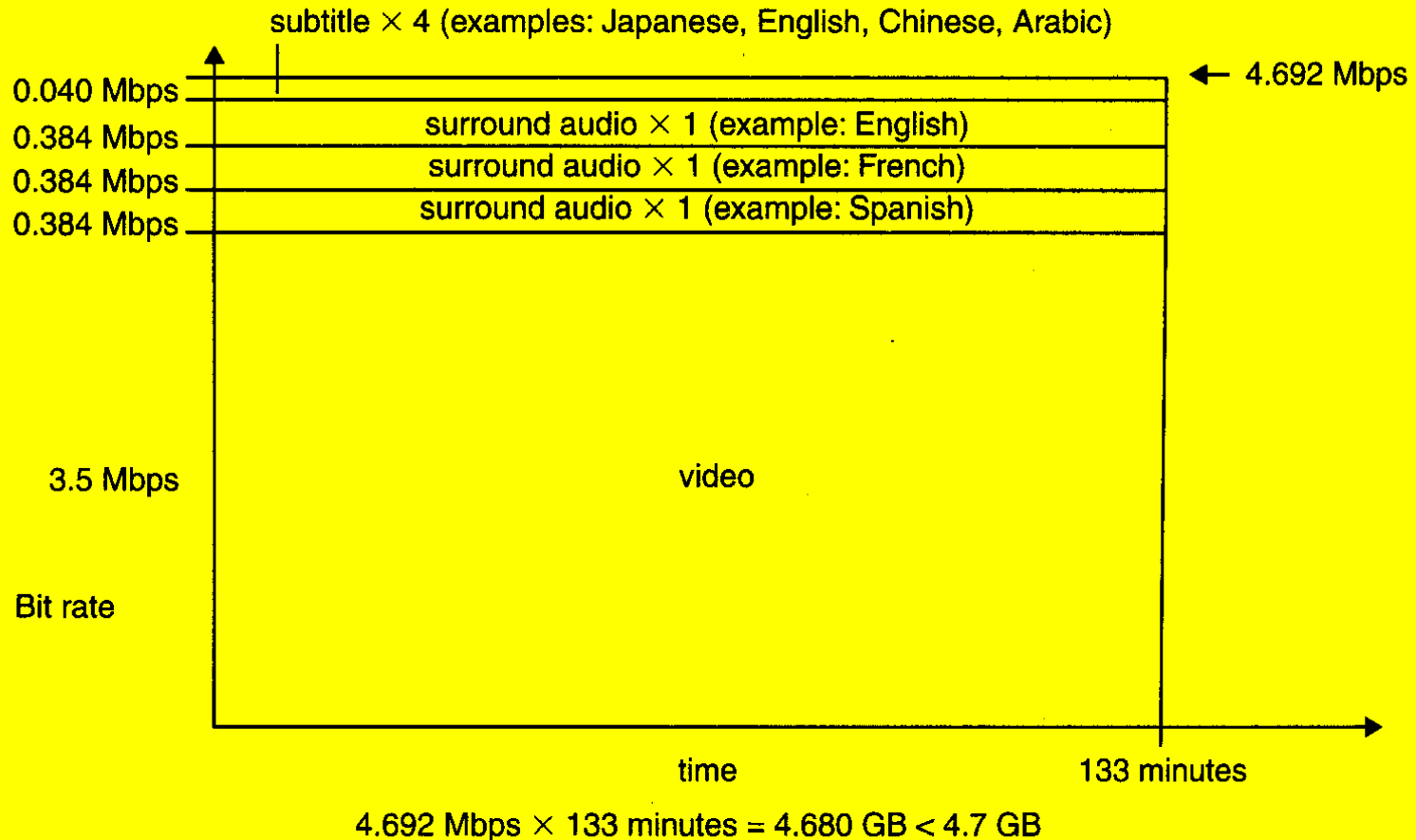


Figure 11.11 An example of how a video program, three audio programs, and four subtitle programs can be placed on a DVD-Video disc, while maintaining an overall capacity requirement of less than 4.7 Gbytes.

DVD-Video – Playback Features

- The DVD-Video format supports up to **32 channel** of **sub-picture** information. Sub-picture are generally used for **captions, sub-title** or **other text**.
- **Hybrid DVD-Video discs** may contain a movie that is playable in a dedicated DVD-Video player and a DVD-ROM-enable PC.
- The DVD-Video specification (part 5) also describes a **hybrid video-audio disc**. Because it contains “ **video audio navigation** “ information, **VAN** disc can also be played on DVD-Audio player.
- A **DVD-Video player** is used to play video program from **DVD-Video** and **VAN** disc, as well as the video content on an **AV type DVD-Audio** disc. It can also play **audio CDs** (not all player can play CD-R discs).

DVD-Video – Playback Features

- Movies can be coded to play **different versions**, **skipping** potentially offensive scenes or using **alternate scenes** and **dialogue tracks**.
- DVD-Video also supports both **normal (4:3)** and **widescreen (16:9)** aspect ratio.
- Other features include chapter division, forward and reverse scanning, up to **nine camera angles** and **interactive story lines**.
- Digital audio data stored at a **96 kHz sampling rate** is not output through a player's digital audio output; it is **downsampled to 48 kHz**.
- **Regional codes** on discs are **optional**; circuitry is **mandatory** on players.

DVD-Video – Playback Features

- There are **six** geographic regions :
 1. Canada and the United States and its territories.
 2. Japan, Europe, South Africa, and the Middle East.
 3. Southeast and East Asia including Hong Kong.
 4. Australia, New Zealand, Pacific Islands, Central America, Mexico, South America, and the Caribbean.
 5. Former Soviet Union, Indian Subcontinent, Africa, North Korea, and Mongolia.
 6. People's Republic of China
 7. Reserved
 8. International non-theatrical venues such as airplane, cruise ships, etc..

DVD-Video – Copy Protection

- The **Content Scrambling system (CSS)** copy protection is standard in DVD-Video discs.
- With CSS, content is **self-protecting**; that is, content cannot be digitally copied because **software keys** needed to decrypt the data are missing in any copy.
- Other copy protection is needed to prevent **digital-to-analog** copying. **Macrovision copy protection** is employed.
- The CSS system scrambles data **during encoding** and then uses **authentication** to verify that the player's decoder is authorized to descramble the data.
- CSS features two copy protection methods.
- “ **Content Scrambled DVD** ” method is designed for DVD-Video players.

DVD-Video – Copy Protection

- Content providers must select two encryption “ **keys** ” – one **disc key** and one **title key** – jointly used to encrypt the data prior to storage on a DVD-Video disc.
- Copies made from the output digital stream **cannot** be **descrambled** because any subsequent decoders will not be able to retrieve the encryption keys and use them to descramble the data.
- The second “ **Bus Authentication and Encryption** ” method is designed for use in the **computer** environment, where encrypted **128-bit keys** must be transmitted from a DVD-Video discs across a computer bus to decryption software.
- An **authentication key** is used in addition to the disc and title keys.
- This method is more sophisticated.

DVD-Video – Copy Protection

- The **Macrovision** system is used to prevent digital-to-analog copying. This system uses **automatic gain control (AGC)** and **Colorstrip** method.
- The **AGC portion** is to cause a VCR to record a **weak, noisy, and unstable signal**.
- The **Colorstrip** method creates **horizontal strips** in a copy.
- CSS technology is used primarily by the **motion picture industry**. Importantly, CSS does **not protect** other types of data such as **software programs**.
- Manufacturers who want to accommodate playback of CSS-coded titles may apply for a license, and place CSS decoders in their products.

DVD-Video – Developer's Summary

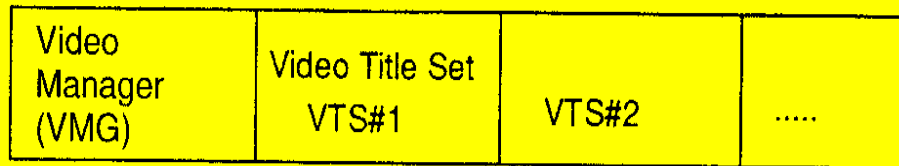
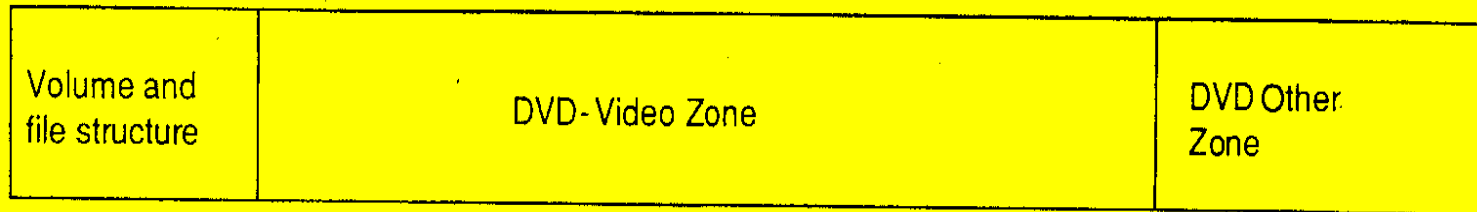
- Part 3 DVD-Video format adheres to Part 1 and Part 2 of the DVD specification. It employs the UDF file format.
- **Part 3** specifically defines how the user can access disc contents (**Navigation**) and how the video data itself is structured (**Video Objects**).
- Part 3 defines a video disc for moving pictures. The **Presentation data** structure complies with the **MPEG-1** and **MPEG-2** specification.
- The Volume Space of a DVD-Video disc consists of the **Volume** and **File structure**, a single **DVD-Video zone**, and **DVD-Other zone**.
- **DVD-Video zone** : one **Video Manager (VMG)** and one or more **Video Title Sets (VTS)**. The VMG is the **table of contents** for all VTS.

DVD-Video – Developer's Summary

- The VMG contains a **menu** for disc title, text data, etc.
- A VTS contains a menu for **title chapter**, **language** for audio/sub-picture, **playback control information (PGCI)**, and audio-video **VOBS data**.
- A Video Object Set (VOBS) is a collection of Video Objects that hold **presentation data** such as video, audio, or sub-picture data.
- A Title consists of one or more **Program Chains (PGC)** each containing **Program Chain Information** and **VOBs**.
- **PGCI** is the **Navigation Data** used to control presentation of the PGC and order of cell play back.
- Titles with **multiple PGCs** permit branching, multiple story lines, etc.

DVD-Video – Developer's Summary

Disc Image



Menu for disc
Title

Text Data

Menu for title
Chapter

Language for audio/subpicture
Playback control information
PGCI
AV data
VOBS

Figure 11.12 The DVD-Video data structure can be viewed as a disc image with the DVD-Video zone holding the Video Manager and Video Title Sets. DVD-Audio follows the same structure.

DVD-Video – Developer's Summary

- A Video zone also contains **Navigation Data** (playback control) and **Presentation Data** (the video program to be play back).
- The **Navigation Manager** handles navigation data to contro playback, interpret user actions, and determine how the Presentation Engine should play back Presentation Data.
- Presentation Data consists of Video Objects (VOB).
- Navigation data allows the users to access disc contents. Content provider can use this data to code **branching** and **interactivity**.
- There are four types : **Video Manager Information (VMGI)**, **Video Title Set Information (VTSI)**, **Presentation Control Information (PCI)**, and **Data Search Information (DSI)**.

DVD-Video – Developer's Summary

- **VMGI** described in VMG describes information in the VIDEO_TS directory.
- **VTSI** described in VTS describes information for one or more Video Titles and the Video Title Set Menu.
- **PCI** described in the Video Object Set (VOBS) along with Presentation data
- **DSI** is dispersed in the VOBS along with Presentation data. DSI is the Navigation information used to search and seamlessly play back the VOB Unit (VOBU).
- The maximum total stream bit rate is **10.08 Mbps**.
 - **Video** stream (max. 1) has a max. transfer rate of **9.80 Mbps**
 - **Audio** stream (max. 8) has a max. transfer rate of **6.14 Mbps**
 - **Sub-picture** stream (max. 32) has a max. transfer rate of **3.36 Mbps**.

DVD-Video – Developer's Summary

TABLE 11.1 Summary of the principal characteristics of the DVD-Video format.

Navigation Structure		
Playback control	Information/control file	
Navigation player model (command & user operation)	VMGI (video manager)	
	VTSI (video title set)	
	PGC (program chain)	
	PCI (presentation control information)	
Presentation Structure		
Multiplex system	MPEG2 program stream	
Video	Audio	Subpicture
1 stream	max 8 streams	max 32 streams
MPEG1 & 2 MP@ML	525 system	Run-Length Coded bitmap
Bit rate	AC3, LPCM, (MPEG)	2 bit/pixel
MPEG2 9.8 Mbps	625 system	
MPEG1 1.856 Mbps	MPEG, LPCM, (AC3)	
	AC3	
	fs = 48 kHz	
	max 448 kbps	
	max 5.1 ch surround	
	MPEG1,2	
	fs = 48 kHz	
	max 384/912 kbps	
	max 7.1 ch surround	
	LPCM	
	fs = 48,96 kHz	
	16/20/24 bit	
	max 8 ch	

DVD-Audio

- A high-quality audio storage format that provides a **wide variety of channels, sampling frequencies, word lengths** and other features.
- The DVD-Audio **version 1.0 specification** was finalized in **February 1999**. DVD-Audio products were introduced in **early 2000**.
- DVD-Audio's maximum bit rate of **9.6 Mbps** (DVD-Video's maximum bit rate is 6.144 Mbps) increases its abilities.
- DVD-Audio also provides for **lossless data compression** of audio. This option allows storage of over **74 minutes** of high quality multi-channel music on a single disc.
- Two types of DVD-Audio disc : **Audio-Only** disc and **Audio with Video (AV)** disc.

Coding and channel options

TABLE 11.2 The DVD-Audio specification supports a variety of coding methods, each with many possible recording parameters. Some examples are shown here.

Audio coding	Sample rate (kHz)	Word length	Number of channels
LPCM	192	16, 20, 24	2
	176.4	16, 20, 24	2
	96	16, 20, 24	1 to 6
	88.2	16, 20, 24	1 to 6
	48	16, 20, 24	1 to 6
	44.1	16, 20, 24	1 to 6
MLP	192/176.4	16, 20, 24	2
MLP	96, 88.2, 48, 44.1	16, 20, 24	1 to 6
Dolby Digital	48	16, 20, 24	1 to 6
DTS	48/96	16, 20, 24	1 to 6

MLP : Meridian Lossless Packing

Coding and channel options

- **Linear PCM (LPCM)** tracks are **mandatory** on all disc.
- All DVD-Audio players must support **MLP decoding**.
- DVD-Audio is a “ **scalable** ” format; that is , its specification provides considerable **flexibility** for content providers.
- The use of **MLP lossless compression** increases playing times as well. Very approximately, it gives about a **1.85:1** compression ratio.
- The use of high sampling rates such as **96** and **192 kHz** may seem **unnecessary**. In rare cases, a person may be able to hear frequencies to **24 or 26 kHz**, far below the cutoff frequencies of 48 and 96 kHz. In most cases, high frequency hearing response is below **20 kHz**.
- In theory, a high sampling rate may improve **spatial imaging**.

Example of coding methods

TABLE 11.3 Examples of coding methods and recording parameters and resulting playing times per disc layer (DVD-5).

Audio coding	Sample rate (kHz)	Word length	Number of channels	Approx play time (min)
LPCM	192	24	2	65
	192	20	2	78
	96	24	2	129
	96	20	6	52
	48	24	6	86
	44.1	16	2	422
MLP	192	24	2	117
	192	20	2	141
	96	24	2	234
	96	20	2	282
	48	24	2	468
	44.1	16	2	764
Dolby Digital	48	24	6	1550
DTS	48	24	6	425

Channel Groups

When priority of sound quality is given to front L, R channels

When priority of sound quality is given to front L, R, C channels

When priority of sound quality is given to corner L, R, Ls, Rs channels

	ch0	ch1	ch2	ch3	ch4	ch5
1	C					
2	L	R				
3	L	R	S			
4	L	R	Ls	Rs		
5	L	R	Ls			
6	L	R	Ls	S		
7	L	R	Ls	Ls	Rs	
8	L	R	C			
9	L	R	C	S		
10	L	R	C	Ls	Rs	
11	L	R	C	Ls		
12	L	R	C	Ls	S	
13	L	R	C	Ls	Ls	Rs
14	L	R	C	S		
15	L	R	C	Ls	Rs	
16	L	R	C	Ls		
17	L	R	C	Ls	S	
18	L	R	C	Ls	Ls	Rs
19	L	R	Ls	Rs	Ls	
20	L	R	Ls	Rs	C	
21	L	R	Ls	Rs	C	Ls

L- left front
R- right front
C- center front
Ls- left surround
Rs- right surround

Channel Group 1

Channel Group 2

Channel Groups

TABLE 11.5 The Channel Groups are scalable. The sampling frequency and word lengths of CG1 must be greater than or equal to those of CG2.

	Channel Group 1	Channel Group 2
Sampling frequency	48 kHz	48 kHz
	96 kHz	96 or 48 kHz
	192 kHz*	192, 96 or 48 kHz
	44.1 kHz	44.1 kHz
	88.2 kHz	88.2 or 44.1 kHz
	176.4 kHz*	176.4, 88.2 or 44.1 kHz
Word length	16 bits	16 bits
	20 bits	20 or 16 bits
	24 bits	24, 20 or 16 bits

*More than two channels coded with MLP.

Coding and channel options

TABLE 11.6 Examples of multichannel LPCM channel configurations with multiple sampling rates, showing bit rate and playing time (on single-layer/dual layer discs). A. 5.1-channels coded at 48 kHz/96 kHz. B. 5.0-channels coded at 48 kHz/96 kHz.

A. 48 kHz/96 kHz, 5.1 channels			B. 48 kHz/96 kHz, 5 channels		
Configuration	Bit rate [Mbps]	Playback Time [min]*	Configuration	Bit rate [Mbps]	Playback Time [min]*
48kHz-24bit-6ch	6.912	86/156	48kHz-24bit-5ch	5.760	103/187
96kHz-16bit-6ch	9.216	64/117	96kHz-16bit-5ch	7.680	77/140
96k-20b-2ch & 48k-20b-4ch	7.680	77/140	96k-24b-2ch & 48k-20b-3ch	7.488	79/144
96k-24b-2ch & 48k-24b-4ch	9.216	64/117	96k-24b-2ch & 48k-24b-3ch	8.064	73/134
96k-24b-2ch & 48k-20b-4ch	8.448	70/128	96k-24b-2ch & 96k-16b-3ch	9.216	64/117
96k-16b-3ch & 48k-16b-3ch	6.912	86/156	96k-20b-3ch & 48k-20b-2ch	7.680	77/140
96k-20b-3ch & 48k-16b-3ch	8.064	73/134	96k-20b-3ch & 96k-16b-2ch	8.832	67/122
96k-20b-3ch & 48k-20b-3ch	8.640	68/125	96k-24b-3ch & 48k-20b-2ch	8.832	67/122
96k-24b-3ch & 48k-16b-3ch	9.216	64/117	96k-24b-3ch & 48k-24b-2ch	9.216	64/117
96k-20b-4ch & 48k-16b-2ch	9.216	64/117	96k-20b-4ch & 48k-20b-1ch	8.640	68/125
			96k-20b-4ch & 96k-16b-1ch	9.216	64/117

*Playback time [min]: single layer-single side/dual layer-single side.

Coding and channel options

- DVD-Audio discs can employ the **SMART** (System Managed Audio Resource Technique) feature with LPCM tracks.
- SMART provides **automatic down-mixing** so that a multi-channel audio program can be mixed down to **two channels** by the player during playback and thus replayed over a **stereo playback system**.
- Full motion video can be added to a DVD-Audio disc (an **AV** disc). Several **restrictions** apply : (1) there is a maximum of **two audio streams** at least one of which must be **LPCM** and the LPCM stream is limited to six channel with restricted channel assignments. (2) there is **no multi-story, multi-angle**, parental control or **region control** features. (3) **Dolby Digital** is mandatory in the DVD-Video portion.

Disc contents

Album (Volume)

Group 1					Group 2				
					Group : 1- 9				
Track 1	Track 2	Track 3	Track 4	Track 1	Track 2		
					Track : 1- 99				
Index 1	Index 2	Index 3						
Index : 1- 99									

* Index is available only for Audio Only content

DVD Audio-Only Disc

Group 1	North Rim	#1	#2	time
Track 1	North Kaibab	48k/20b/5ch	48k/20b/2ch	4:00
Track 2	Thunder River	48k/20b/5ch	48k/20b/2ch	4:30
Track 3	Clear Creek	96k/20b/3ch& 48k/20b/3ch		5:10
Track 4	Widforss	96k/20b/3ch& 48k/20b/3ch		4:00
Track 5	Nankoweap	96k/24b/2ch		3:50
Group1 total time				21:30
Group 2	South Rim	#1	#2	time
Track 1	South Kaibab	48k/24b/2ch	MPEG 5.1ch	4:20
Track 2	Bright Angel	96k/24b/2ch	MPEG 5.1ch	5:00
Group2 total time				9:20
Visual Menu is available for U-Player.				Album total time 30:50

Figure 11.15 An example of the artwork for an “audio-only” DVD-Audio disc, showing two groups with a total of seven tracks.

AV DVD Audio Disc

Group 1	Zion	#1	#2	time
Track 1	Hidden Canyon	48k/20b/2ch	48k/20b/5ch	4:00
Track 2	Lower West Rim	48k/20b/2ch	48k/20b/5ch	4:30
Track 3	Emerald Pools	96k/20b/3ch& 48k/20b/3ch		5:10
Track 4	Observation Point	96k/20b/3ch& 48k/20b/3ch		4:00
Track 5	Angels Landing	96k/24b/2ch		3:50
Track 6	Weeping Rock<with Video>	48k/16bit/2ch	AC-3 5.1ch	4:40
Track 7	Kolob Arch <with Video>	48k/16bit/2ch	AC-3 5.1ch	3:10
Album total time				29:20

Video component of Track 6,7 is not presented by A-Player.

Visual Menu is available for U-Player.

Figure 11.16 An example of the artwork for an “AV” DVD-Audio disc, showing one group with seven tracks.

Compatibility

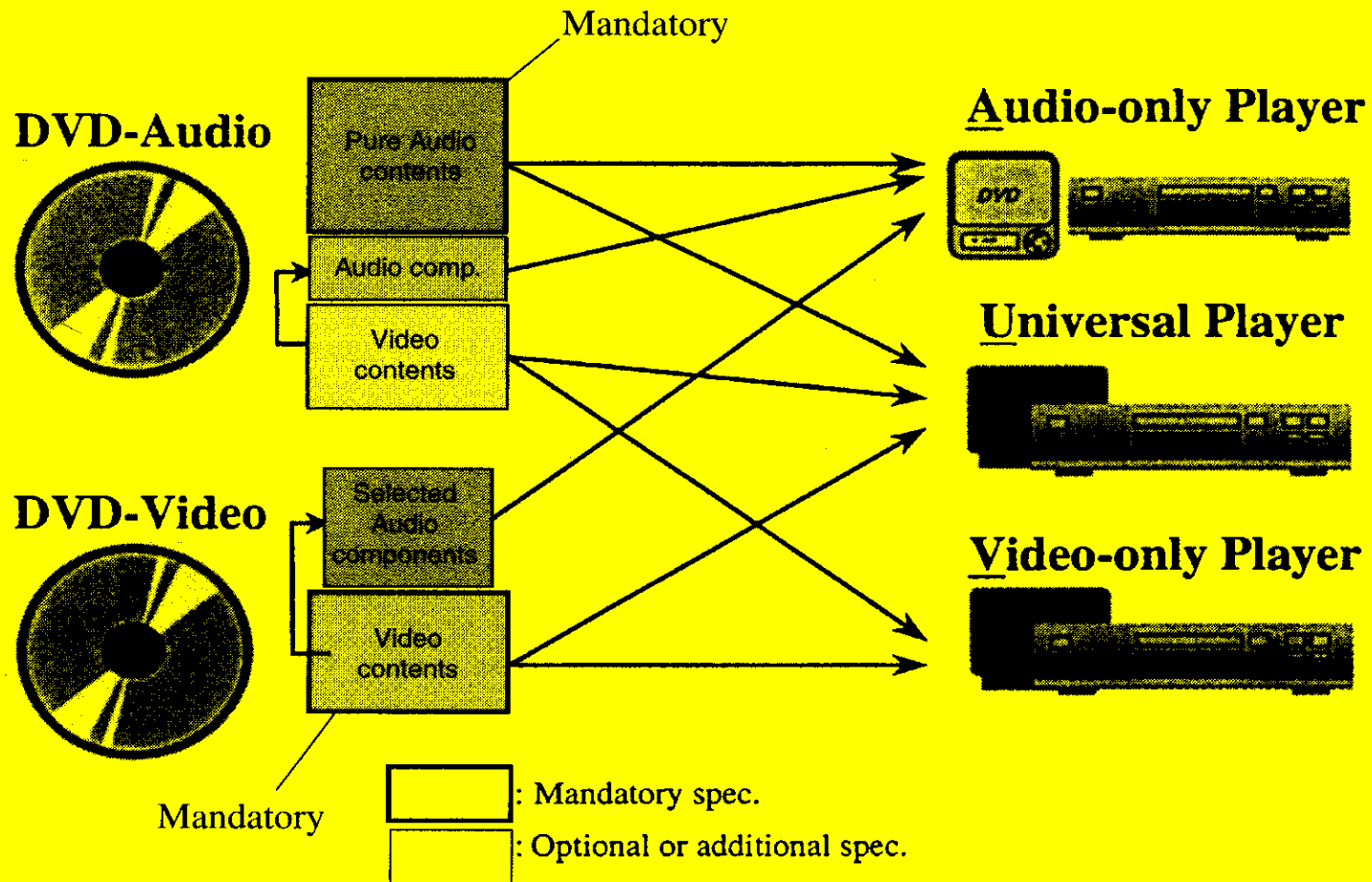


Figure 11.17 Some compatibility exists between DVD-Audio and DVD-Video discs, and the three types of players: A-players, U-players, and V-players.

Copy Protection

- The DVD-Audio format uses an optional content protection framework employing **encryption** and **embedded watermark technology**.
- The **encryption** used in DVD-Audio can allow **two-channel CD-quality** real time copying along with the **IEC-958** interface.
- The **encryption** in DVD-Audio can allow **two-channel** and **multi-channel, CD-quality and higher quality, high speed copying** along with the **IEEE 1394 interface**.
- The **watermark** is designed to identify content through **unencrypted digital links**.
- The watermark operates similarly to **SCMS (Serial Copy Management System)** in the digital domain, but it operates in the analog domain or unencrypted digital domain.

Copy Protection

- A **copy-permit** is the **default status**; when a copy is made the embedded watermark signal is **updated** to mark the copy as a second-generation source.
- The watermark can also identify the **manufacturer, artist, copyright holder** and other characteristics.
- The encryption and watermarking technologies are separate and independent.
- As with DVD-Video, copy protected DVD-Audio discs can only be played on **licensed players**.

Developer's Summary

- A DVD-Audio zone contains one **Audio Manager (AMG)** and one or more **Audio Title Sets (ATS)**.
- The Audio Manager Information Management Table (AMGI_MAT) is a table that describes the **size** of the AMG and AMGI, **starting addresses** of information in the AMG, etc.
- The Audio Title Search Pointer Table (ATSPT) is a table with **search information** for **Audio titles**.
- The Audio Only Title Search Pointer Table (AOOTSPT) is a table that contains **search information** of **Audio Only Titles**.
- The Audio Manager Menu PGCI Unit Table (AMMPGIUT) is a table that describes the **audio menu**.
- The Audio Text Data Manager (ATDM) contains information such as **album**, **group** and **track name**.

Developer's Summary

AMG

Table of contents for all Audio Title Sets (ATs) and all Video Title Sets (VTs)

AMGI

AMGI_MAT

Audio Manager Information Management Table

BACKUP

ATSPT

Audio Title Search Pointer Table

AOTSPT

Audio Only Title Search Pointer Table

AMMPGCIUT

Audio Manager Menu PGCI Unit Table

ATDM

Audio Text Data Manager

Developer's Summary

ATS

Define the Audio Only Titles (AOTTS)

ATSI

ATSI_MAT

Audio Title Set Information
Management Table

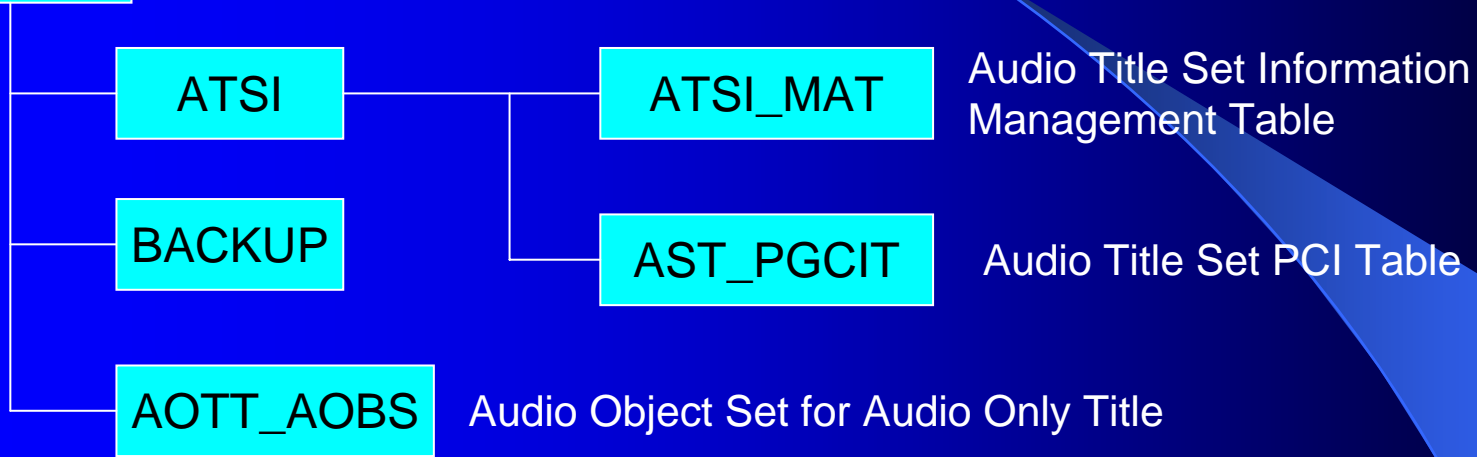
BACKUP

AST_PGCIT

Audio Title Set PCI Table

AOTT_AOBS

Audio Object Set for Audio Only Title



Developer's Summary

- The **ATSI** contains the **Navigation Data** needed to play back every ATT in the ATS and provides information to support User Operation.
- The ATSI_MAT describes the **size** and **starting addresses** of ATS and ATSI, as well as attributes.
- The ATSI_MAT also describes the **coefficients** to **mix down** the audio data from multi-channel to two-channel.
- The ATS_PGCIT is the **Navigation Data** to control the presentation of the Audio Title Set Program Chain.
- The AOTT_AOB contains the presentation data that are **audio**, **Real-Time Information (RTI) data** and **still picture data**.
- The AOTT_AOB uses three types of packs : **Audio pack**, **Real-Time Information pack**, and **Still Picture pack**.

Developer's Summary

- The maximum length of a pack is **2048 bytes**.
- The maximum total transfer rate of all streams is 10.08 Mbps.
- The maximum transfer rate of the audio stream is 9.6 Mbps.
- The maximum video transfer rate for still picture is 9.8 Mbps.
- An AOTT_AOB **Audio pack** has up to **2013** bytes of user data. An AOTT_AOB **Real-Time Information pack** has up to **2015** user bytes. An AOTT_AOB **Still Picture pack** has up to **2025** user bytes.
- Part 4 **navigation parameters** are classified as **General Parameters (GPRM)** and **System Parameters (SPRM)**.
- There are **16** GPRMs to memorize the user's operation, there are **24** SPRMs for player settings.

Data Compression

- The **Meridian Lossless Packing (MLP)** is the first lossless algorithm for wide scale audio use.
- Generally, the **lower the probability** of occurrence of an event, the **greater the information** it contains.
- The average amount of information occurring over time is called **entropy**, denoted as H .
- When each event has the **same probability** of occurrence, **entropy is maximum**, denoted as H_{\max} .
- **Redundancy** in a signal is obtained by : $1 - (H / H_{\max})$.
- **Adding** redundancy **increases** the **data rate**; **decreasing** redundancy **decreases** the **rate**; this is **data compression**, or **lossless coding**.
- **Entropy** determines the **average number of bits** needed to convey a digital signal.

Entropy Coding

- Entropy (or Huffman) coding derived by David Huffman uses **probability of occurrence** to code a message.
- Samples that occur **most often** are assigned the **shortest** codewords; samples that occur **less frequently** are assigned **longer** codewords.
- The compression is lossless because **no information is lost** the process is **completely reversible**.
- The **Morse telegraph code** is a simple entropy code.
- It is an entropy code based on **prefixes**. To code the most frequent characters with the shortest codewords, the code uses a **non-duplicating prefixed system** so that the shortest codewords cannot form the beginning of a longer word.
- Ex : 110 and 11011 cannot both be codewords.

Entropy Coding

- The success of the code is gauged by calculating its **average code length**; it is the summation of each codeword length multiplied by its frequency of occurrence.
- Data compression algorithms require greater processing complexity with the attendant coding delay; generally compression ratios of **1.5:1 to 3.5:1** are possible.

Train status	Probability	Tree	Huffman code	Train status
On-time	0.5		0	On-time
Late	0.35		10	Late
Early	0.125		110	Early
Wrecked	0.025		111	Wrecked

Figure 11.18 A Huffman code is based on a nonduplicating prefix, assigning the shorter code-words to the more frequently occurring events. If trains were usually on-time, this code would be particularly efficient.

Audio Data Compression

- Lossless compression can be used to **increase effective storage capacity**, while not affecting signal integrity.
- Any compression method must **observe** a system's **maximum bit rate**, and ensure that the **threshold** is **never exceeded** even during low-redundancy (hard to compress) passages.

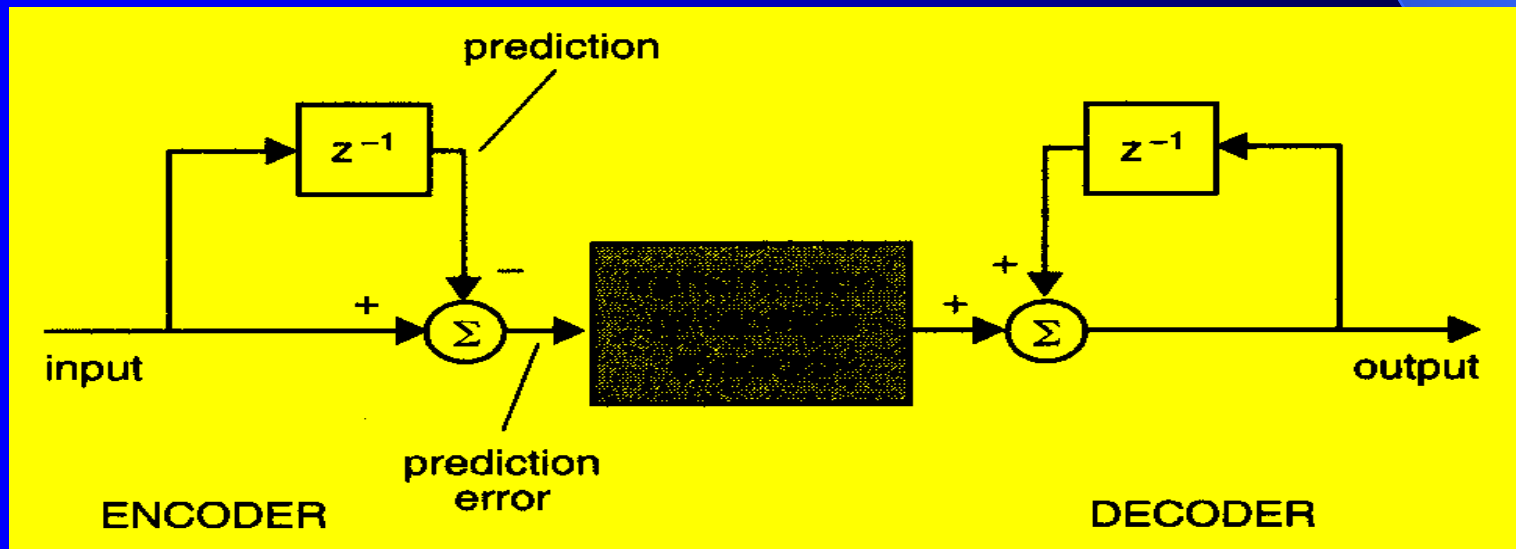
Sample no.	Binary value
1	00000000010000110000
2	00000000011000010000
3	00000000011001100000
4	00000000010011110000
5	00000000001000110000
6	11111111111011100000
7	11111111101111010000
8	11111111100111110000
9	11111111100110100000
10	11111111101100010000
11	11111111110111010000
12	00000000000100100000

(Craven and Gerzon).

TABLE 11.7 Twelve samples taken from a 20-bit audio file, showing limited dynamic range and resolution. In this case, simple data compression techniques can be applied to achieve a 60% decrease in file size.

Audio Data Compression

- A **predictive strategy** can yield greater coding efficiency.
- In the previous example, the 16-bit numbers have decimal values of +67, +97, +102, +79, +35, -18, -67, -97, -102, -79, 35 and +18. the differences between successive samples are +30, +5, -23, -44, -53, -49, -30, -5, +23, +44 and +53.
- This coding can be achieved with a simple predictive encode-decode strategy.



Audio Data Compression

- The goal of a prediction coder is to **predict the next sample** as accurately as possible, and thus minimize the number of bits needed to transmit the prediction error.
- To provide greater efficiency, the **1-sample delay element** in the predictor coder can be replaced by more advanced **general prediction filters**.
- An n -th order predictor yields a transfer function of $(1 - Z^{-1})^n$. **$n = 4$** is optimal.
- However, the high frequency component of the quantization **noise is increased** by higher-order predictors, thus a value of **$n = 3$** is probably the limit for audio signals.
- More successful coding can be achieved with more sophisticated prediction filters using, for example, **non-integer-coefficient filters** in the prediction loop.

Audio Data Compression

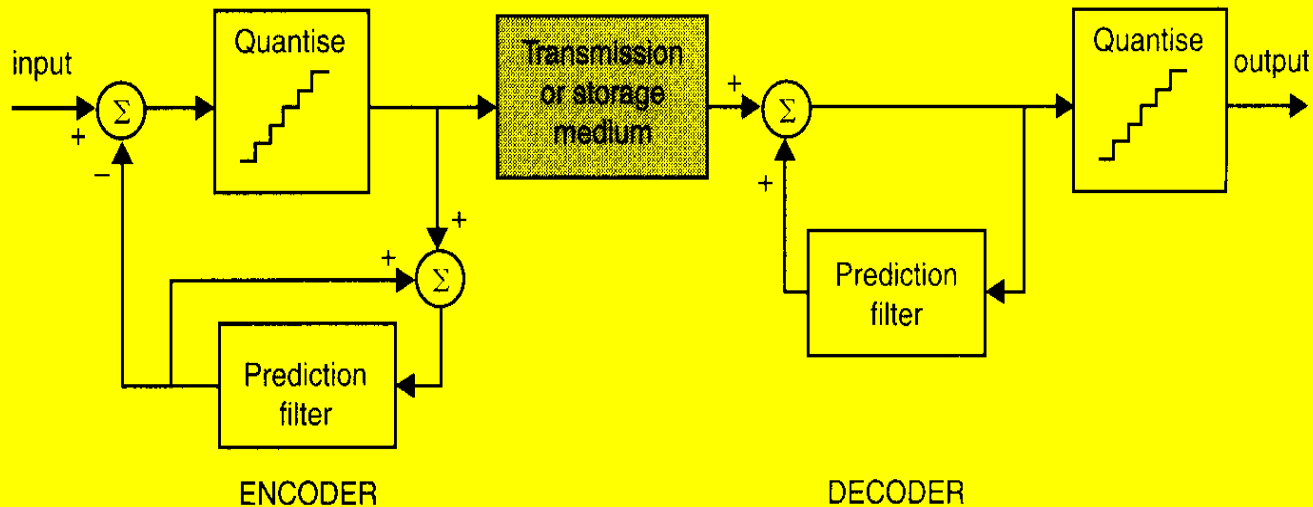


Figure 11.20 Noninteger-coefficient filters can be used in a prediction encoder/decoder. The prediction signal is quantized to an integer number of LSB steps. (*Craven and Gerson*)

Meridian Lossless Packing (MLP)

- **Meridian Lossless Packing (MLP)** is an audio coding algorithm used to achieve **lossless data compression**, primarily for the DVD-Audio format.
- All DVD-Audio **players must support** MLP decoding, but the use of MLP on **discs** is **optional** for content providers.
- MLP supports **all** of the DVD-Audio **sampling frequencies** and MLP quantization may be selected for **16 to 24 bits** in 1 bit steps.
- The degree of compression varies according to the nature of the music data itself. Generally, more compression is achieved with **higher sampling rate** and **more channels**.
- MLP allows **6-channel 96-kHz/24-bit** recordings; it may achieve **38% to 52%** of bandwidth reduction, reducing bandwidth from original 13.824 Mbps to 6.6 to 8.6 Mbps.

Meridian Lossless Packing (MLP)

- MLP does **not discard data** during coding; instead, it “**packs**” the data **more efficiently**. It can ensure that the output signal is exactly the same as the input signal.
- The MLP encoder inserts proprietary **check data** into the bit stream; the decoder uses this check data to verify bit-for-bit accuracy.
- MLP uses full **CRCC (Cyclic Redundancy Check Code)** checking and **minor transmission errors** are recovered in less than **2 ms**. Full recovery from **burst errors** can occur within **10 to 30 ms**.
- **Interpolation** may be used to prevent clicks or pops in the audio program.

Meridian Lossless Packing (MLP)

- In MLP encoder, a **lossless matrixing technique** is used to optimize the data in **each channel**.
- The signal in each channel is then **de-correlated** using a separate predictor for each channel.
- The de-correlated audio signal is further encoded with **Huffman coding** to more efficiently code the most likely occurring successive values in the bit stream.
- Multiple data streams are **interleaved**. Then the stream is **packetized for fixed or variable data rate**.
- An MLP **transcoder** can re-packetize a fixed-rate bit stream into a variable-rate stream, and vice versa.

Meridian Lossless Packing (MLP)

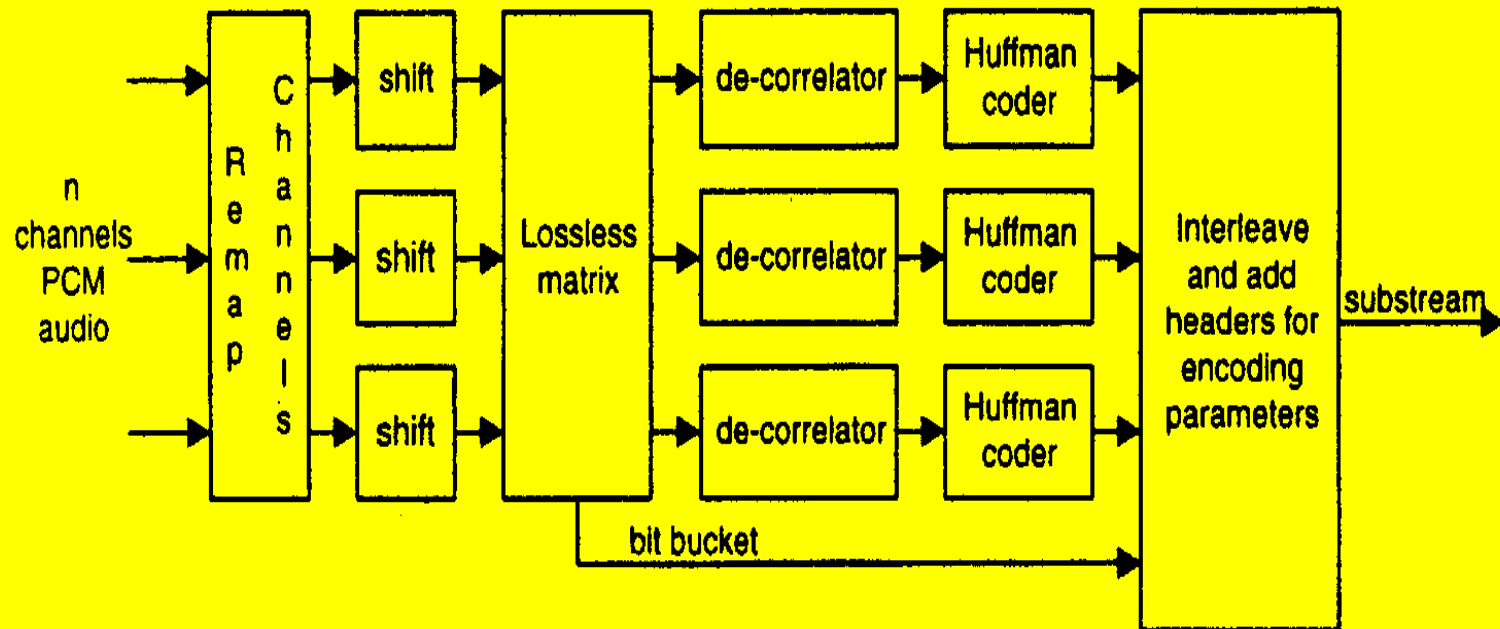


Figure 11.21 An example of a MLP encoder showing a lossless matrix, de-correlators and Huffman coders. (*Stuart*)

Other DVD Disc Formats

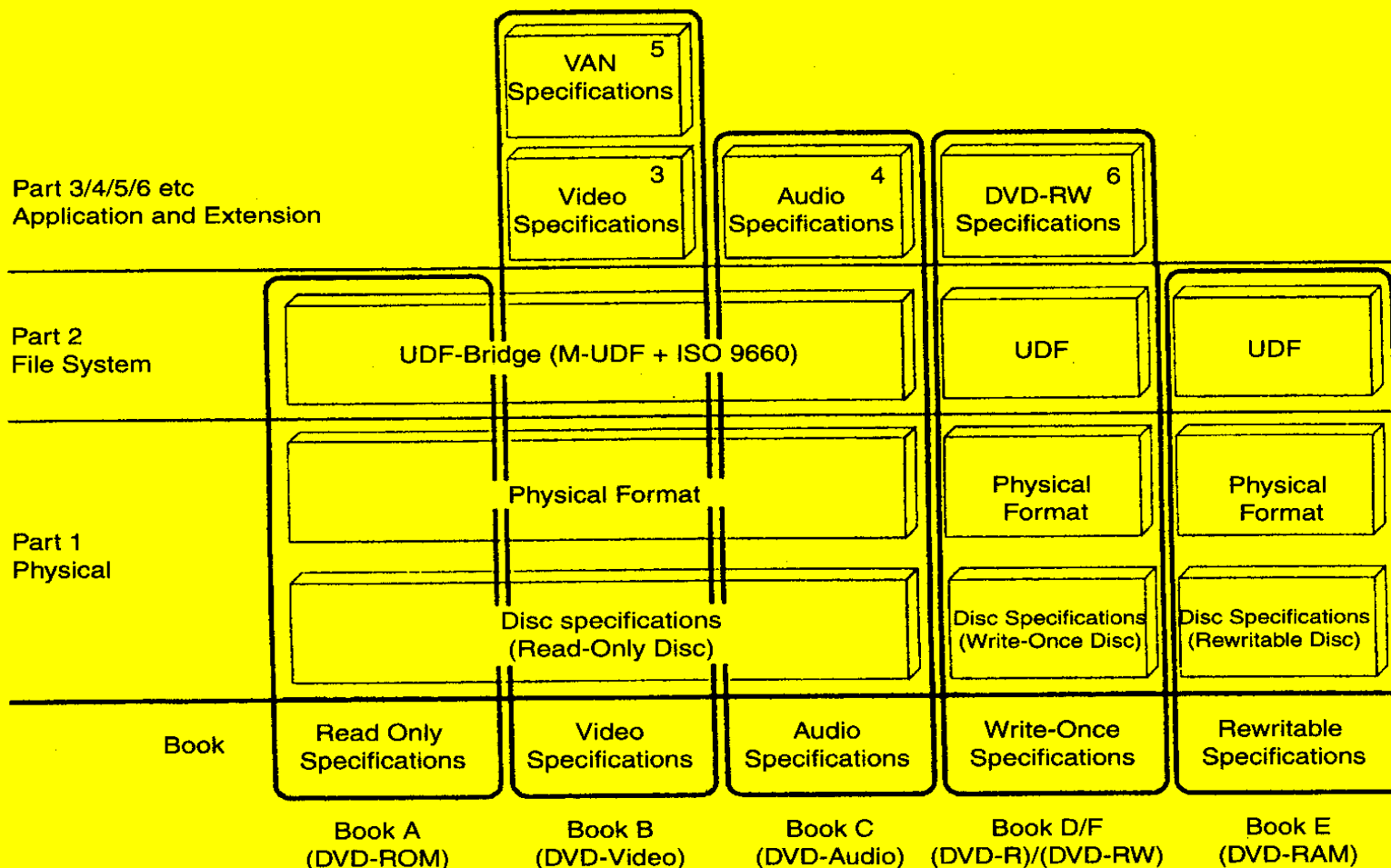


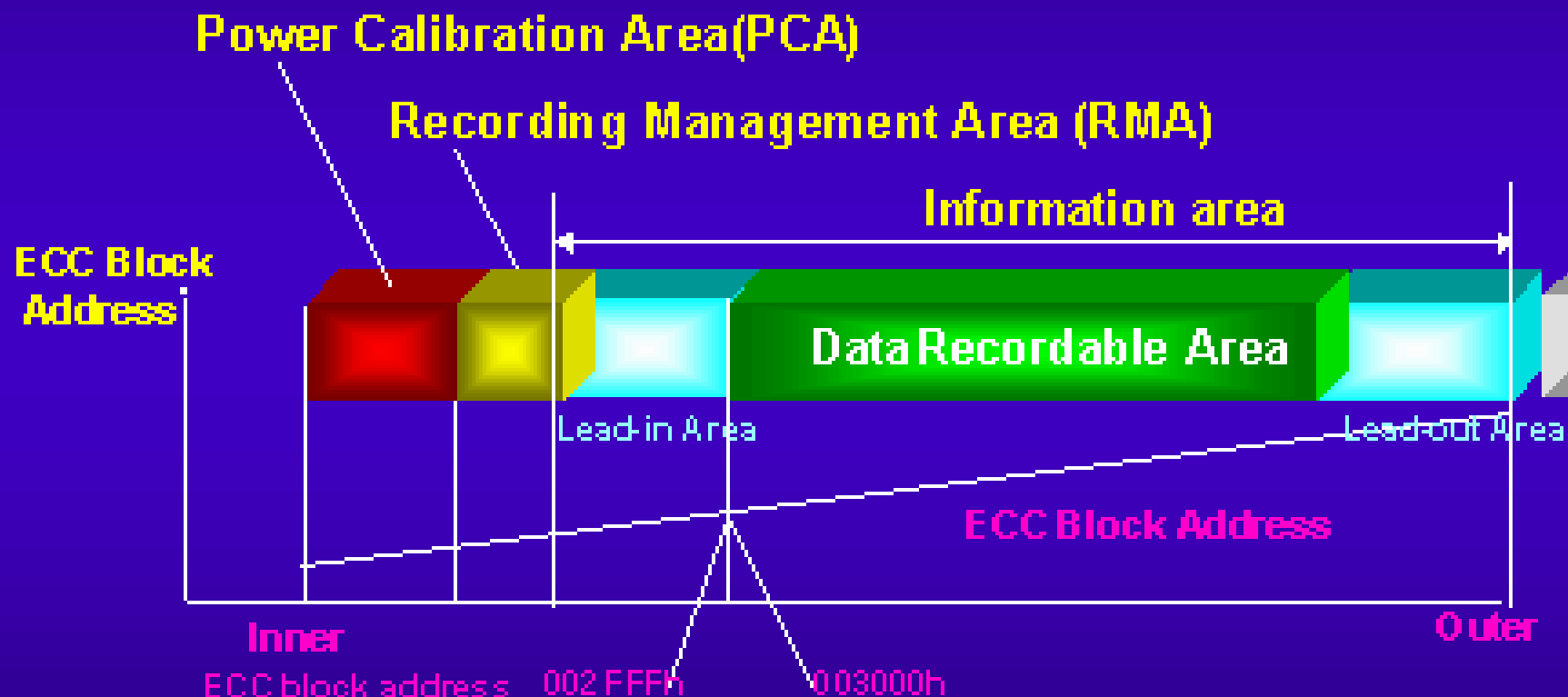
Figure 11.1 The DVD family of specifications includes six books for read only and recordable discs. Some physical and file system attributes are shared, but specific application details are distinct to each specification book.

DVD-R

- DVD-R discs contain a **Power Calibration Area (PCA)** for testing laser power.
- A **Recording Management Area (RMA)** stores **calibration information, disc contents and recording locations and remaining capacity information, and recorder and disc identifiers for copy protection.**
- The PCA can hold **7088** different calibrations, and RMA can hold OPC information as many as **four** different recorders.
- The remainder of the disc comprises the Information Area including the Lead-in, Data Recording Area and Lead-out.
- DVD-R discs use a **CLV wobbled pregroove** to generate a carrier signal used for **motor control, tracking and focus.**
- DVD-R discs use **pits and lands** (known as **land pre-pits**) molded into land areas between grooves to encode the **ATIP address and pre-recorded signal.**



Layout of Physical Sector

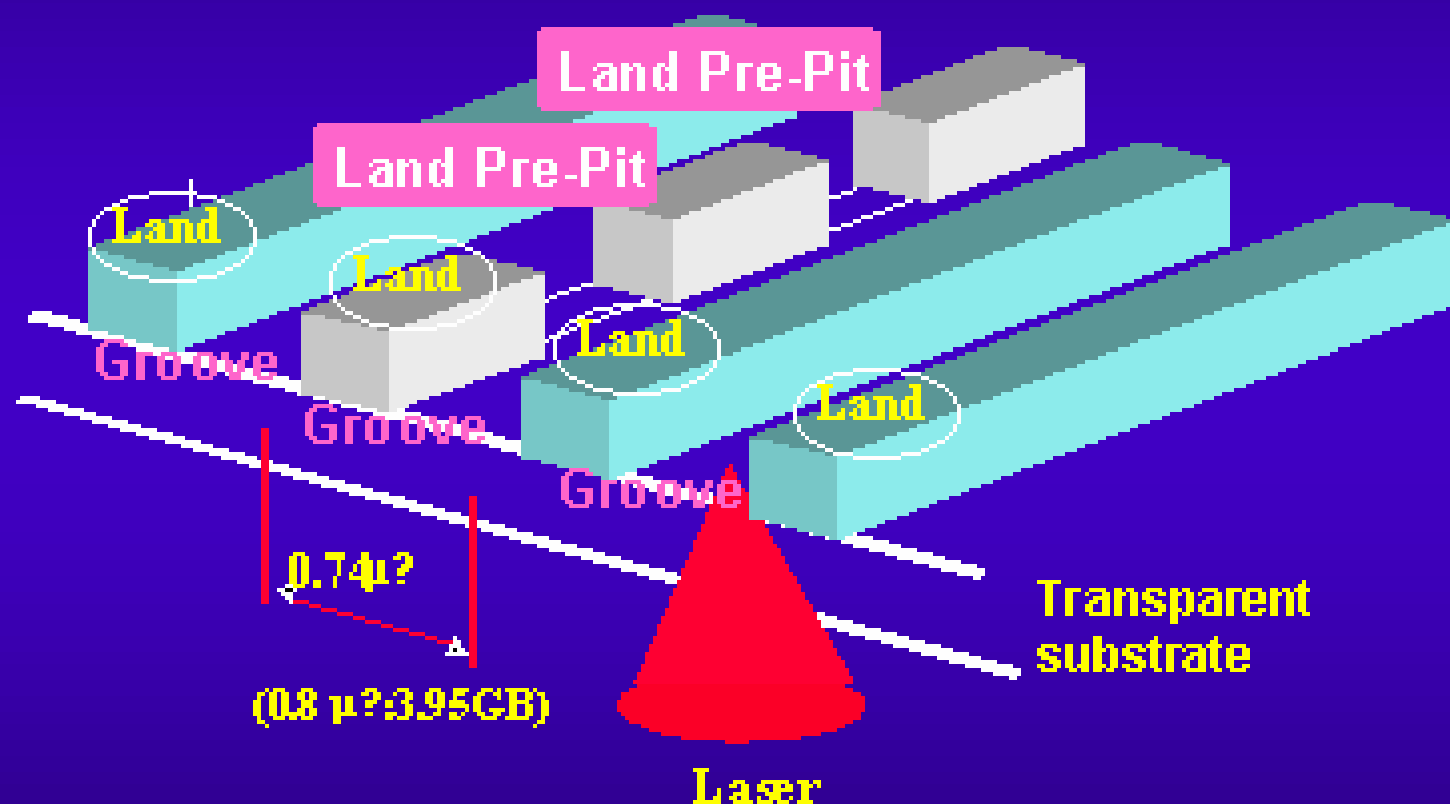


DVD-R

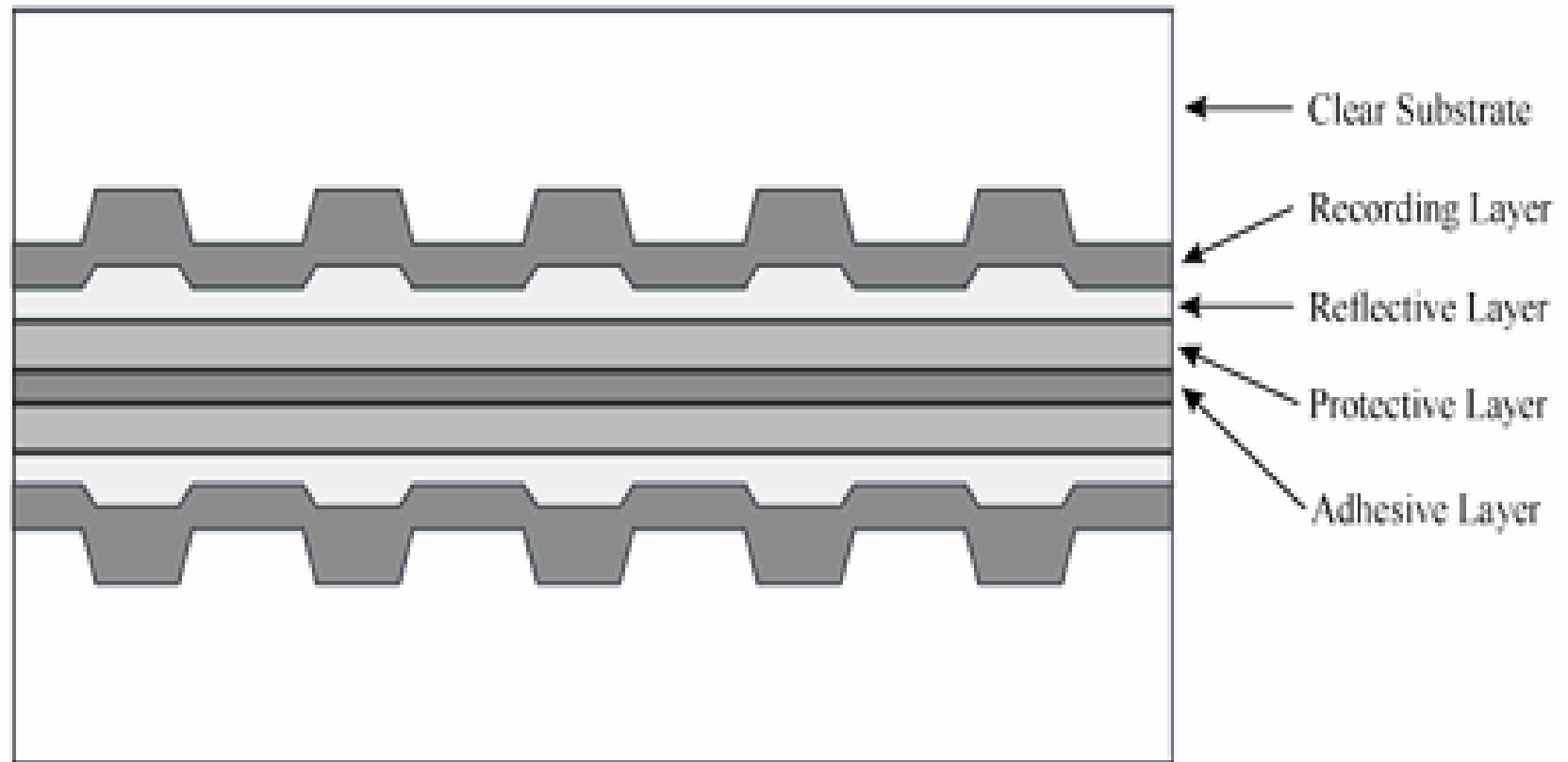
- DVD-R discs use pits and lands (**land pre-pits**) molded into land area between grooves.
- The reading laser tracks the pregroove, but the light shines on the **pre-pits** peripherally to create a **secondary signal** that can be extracted from the main signal.
- Disc manufacturers can optionally place a **write strategy code** in the **lead-in pre-pits** to modify the player's write strategy.
- A **cyanine dye** recording layer may be used, with a **635- or 650-nm** laser.
- Both **sequential** (**Disc-at-once**) and **incremental** writing can be performed.
- DVD-R is used primarily for **professional authoring** and **testing** of DVD titles.



Outline of DVD-R disc



DVD-R



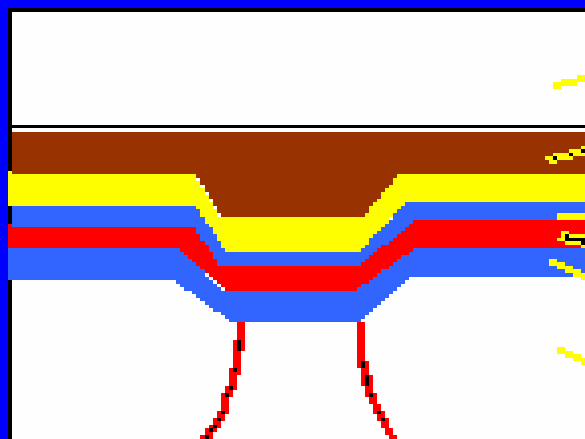
Two-Sided Disc Example
(Not to Scale)

DVD-RW

- DVD-RW allows **rewriting** of data; the specification is essentially an extension to the DVD-R format.
- Discs use a **phase-change** recording mechanism and a **multi-layer** disc structure.
- Unlike dye-polymer technologies, phase-change recording is **not wavelength specific**.
- DVD-RW is particularly used for **sequential writing**, as in **mastering applications**.
- DVD-RW is **not** intended for **general purpose data storage** and **distribution**.



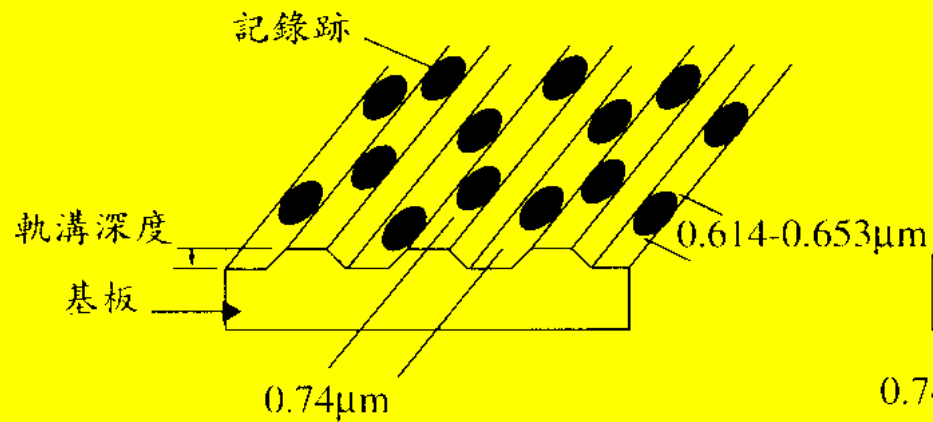
Disc structure



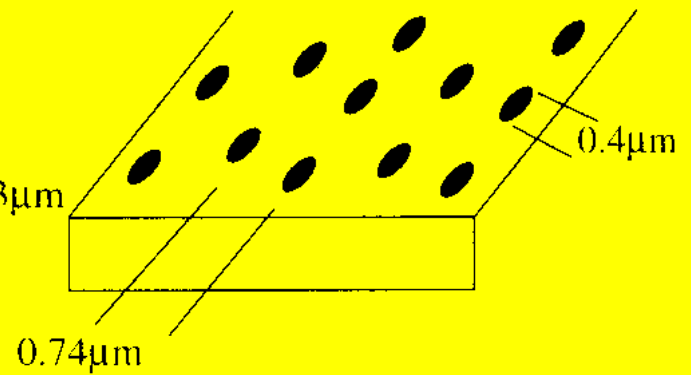
Laser beam

Polycarbonate
2P resin
Al-Alloy
ZnS-SiO₂
Ag-In-Te-Sb
ZnS-SiO₂
Polycarbonate

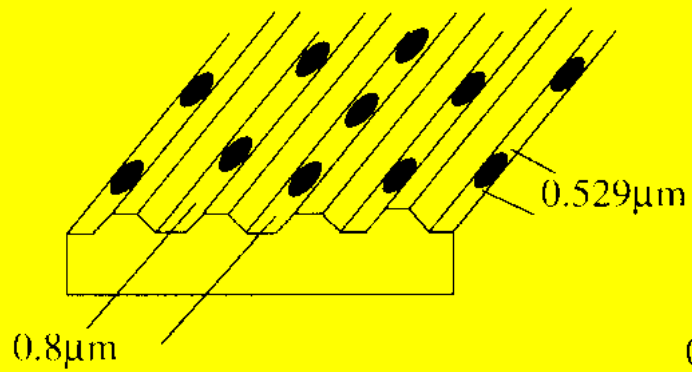
(a) 2.6GB DVD-RAM



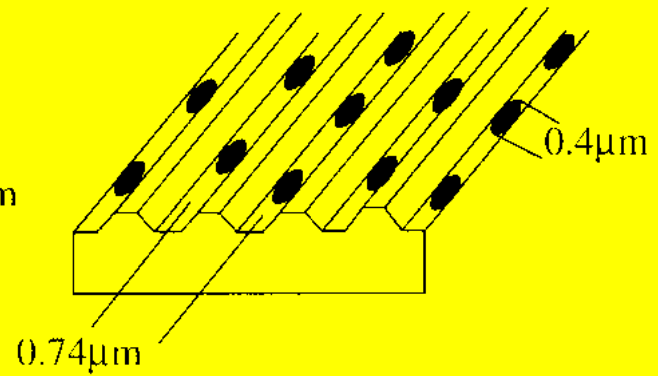
(b) 4.7GB DVD-ROM



(c) 3.0GB DVD+RW



(d) 4.7GB DVD-RW

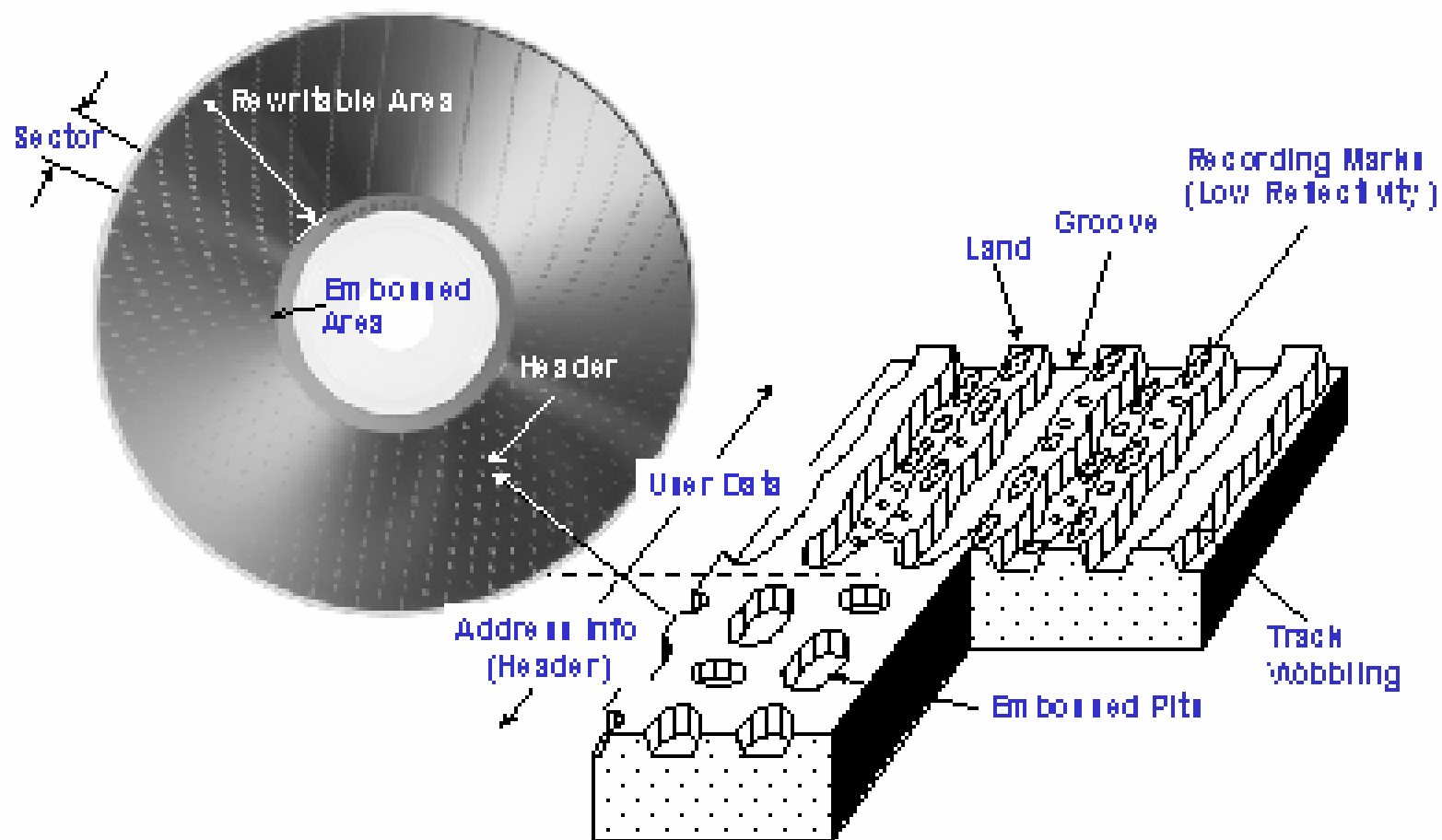


DVD-RAM

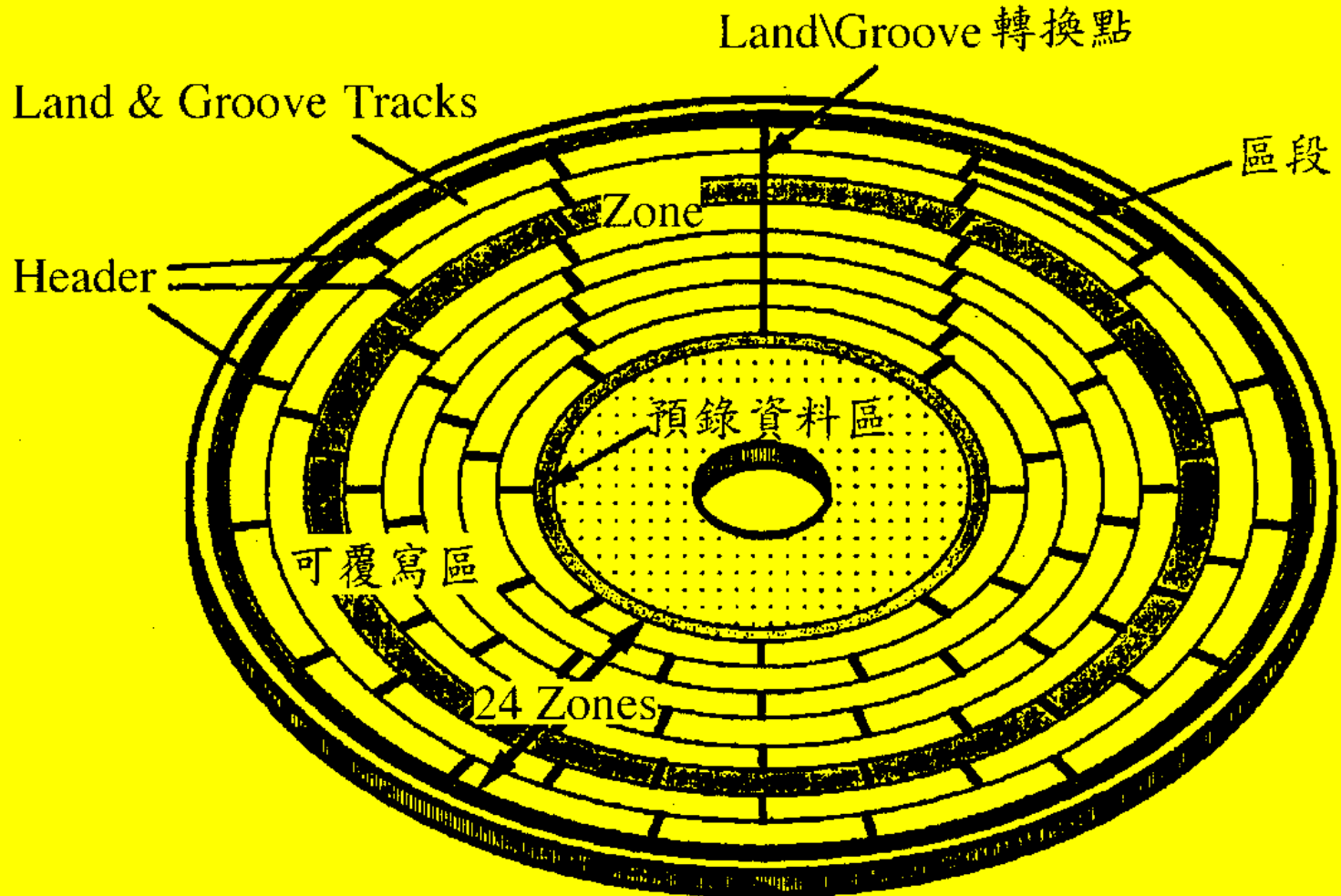
- DVD-RAM uses a **phase-change** recording mechanism and a wobbled **land and groove** disc design.
- This technique doubles disc capacity, but **deep grooves** with **steep walls** are needed to **avoid crosstalk** interference between adjacent data.
- **Servo** must be employed to **switch** the pickup's focus **between** the **groove** and **land** area on each revolution.
- Discs also contain **pre-embossed pit areas** to provide **addressing header information** and **zone constant linear velocity (ZCLV)** rotational control.
- There are total of **24** recording zones across the disc.
- These features enable DVD-RAM to be used as a true **random access, non-sequential** medium.



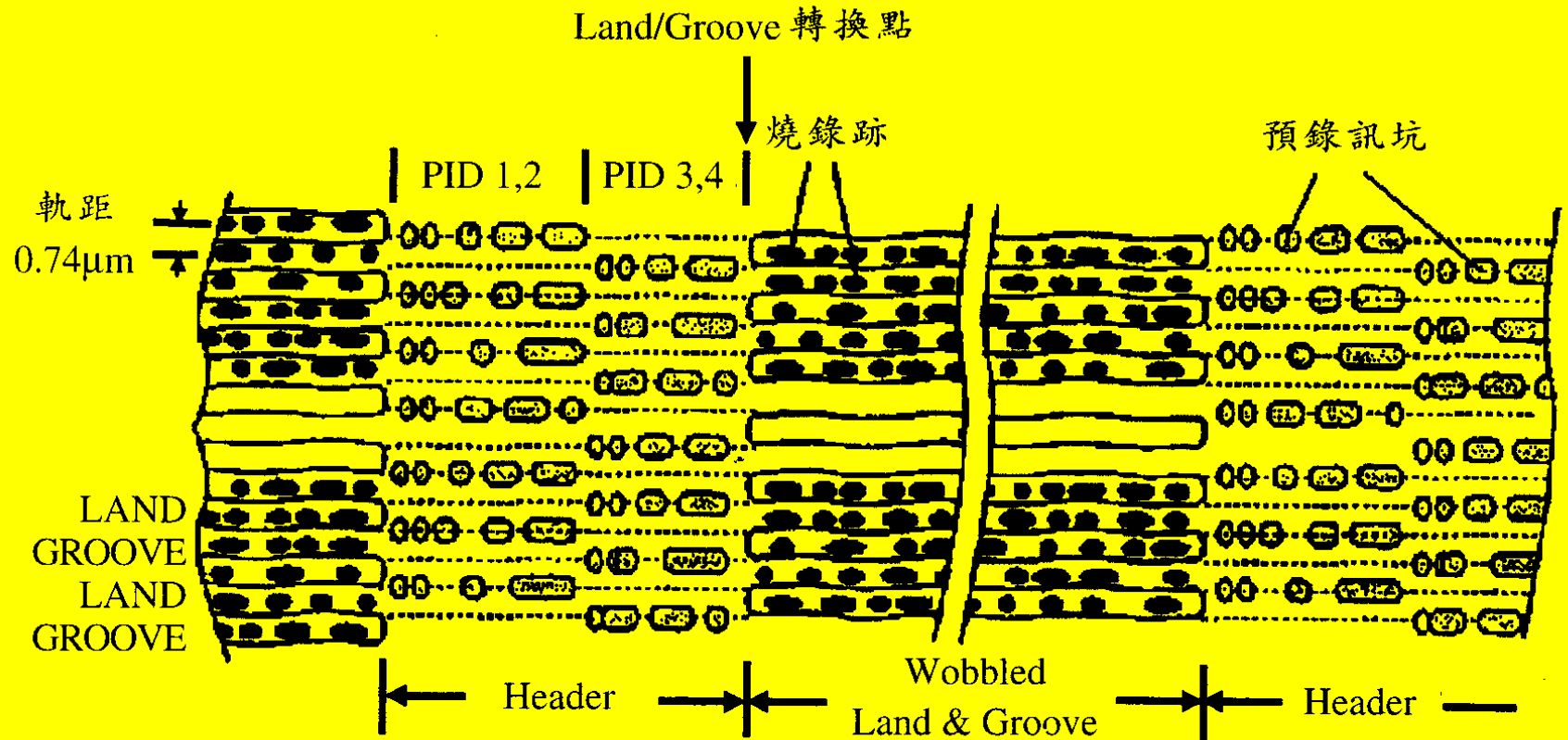
DVD-RAM Disc Outline



DVD-RAM - appearance



DVD-RAM - Header

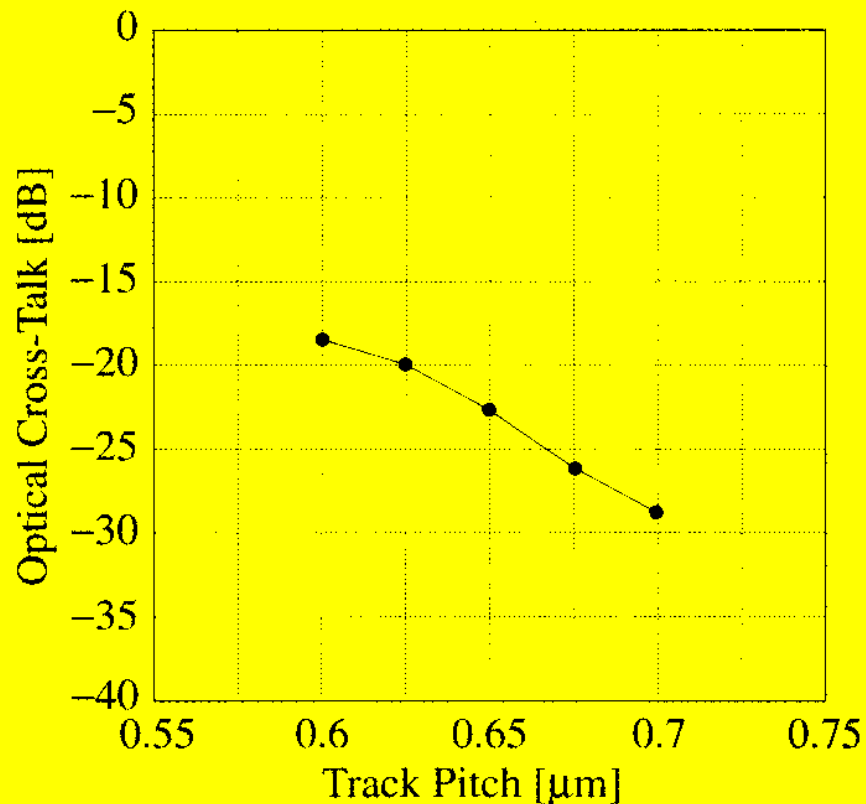


DVD-RAM

- Problem : **Cross – Talk & degradation of recording material**

► 圖四

軌面與軌溝同時記錄，軌間距對光學串號關係圖(Philips)



DVD-RAM

UV Resin
Al- Alloy
ZnS-SiO ₂
Ge-Sb-Te
Ge-N
ZnS-SiO ₂
PC基板

Matsushita

UV Resin
Al- Alloy
M-M _x O _y
ZnS-SiO ₂
Ge-Sb-Te
ZnS-SiO ₂
PC基板

Hitachi

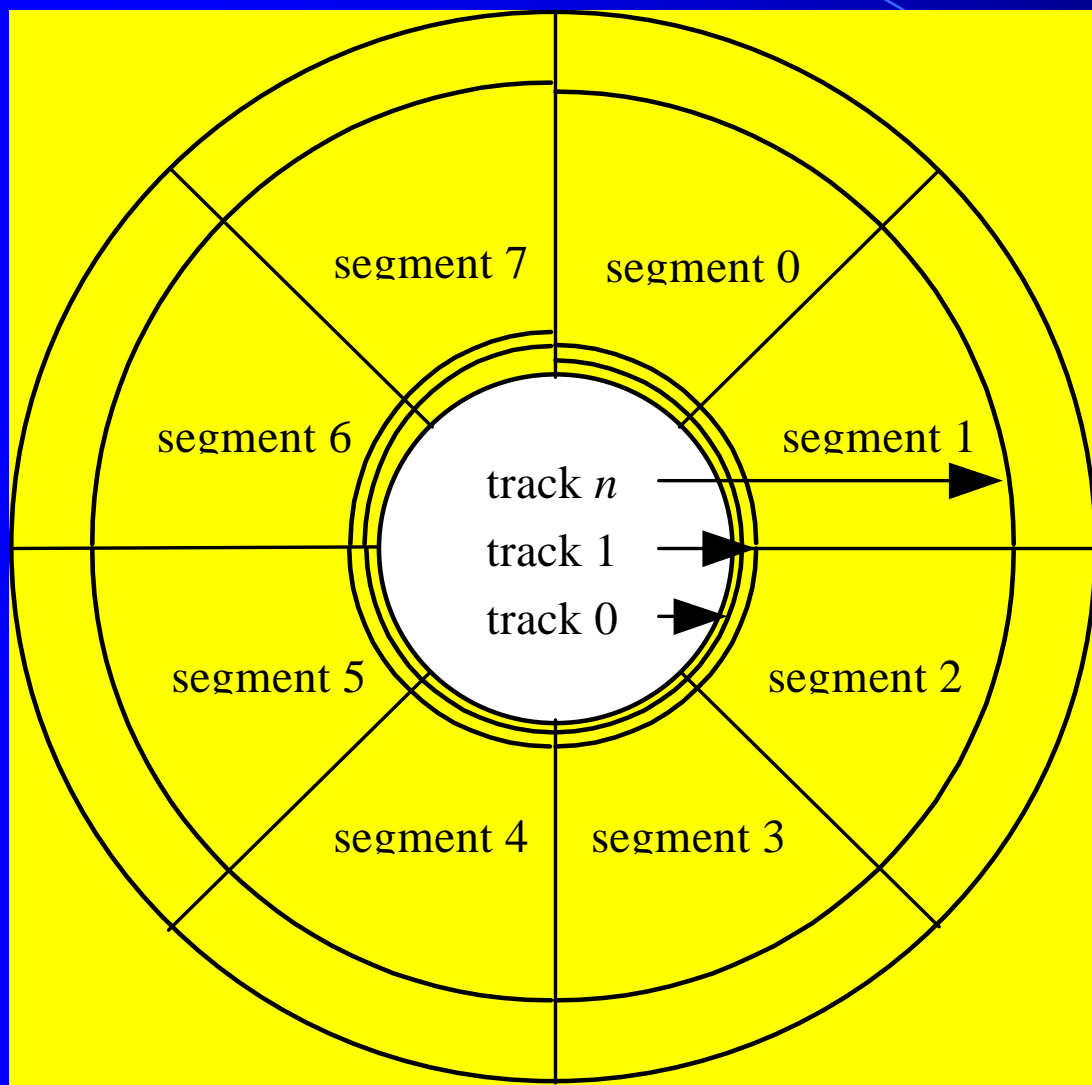
UV Resin
Al- Alloy
ZnS-SiO ₂
Ge-Sb-Te
ZnS-SiO ₂
SiO ₂
ZnS-SiO ₂
PC基板

NEC

DVD+RW

- DVD+RW is another rewritable format using **phase-change** media, a **wobble pregroove**, and **CLV or CAV** rotation, for either raw data transfer or fast data access.
- Both **sequential** and **random access** recording are supported.
- Wobbled pre-groove with
 - ✓ **Address in Pre-groove** (ADIP)
 - ✓ CAV wobble with **frequency modulation** center frequency 57.6 kHz at 20 Hz
 - ✓ **Biphase-Mark encoding**
 - ✓ **8 segments** (addresses) per rotation
 - ✓ **96 Alternating Fine Clock Marks** per rotation (AFCM)

DVD+RW



UV Resin

Al- Alloy

ZnS-SiO₂

SiC

Ge-Sb-Te

SiC

ZnS-SiO₂

PC基板

Philips