CD, CD-ROM & DVD disc
manufacturing in Texas, USA

Introduction to CD and CD-ROM

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1. Introduction

The compact disc has recently celebrated 20 years since its launch in October 1982. The optical disc format has been very successful in this time and provides a compact and reliable distribution format not just for music but for other applications as well. Even with the introduction of DVD, the CD is still forecast to remain the mainstream format for music for some years to come.

Audio CDs were designed to hold over an hour of high quality stereo audio but current CDs can store up to 80 minutes. The audio is stored in a digital format so that noise, which is often associated with vinyl and cassettes, is virtually non-existent. Under normal use CDs also do not wear out.

In 1984, the CD-ROM *Yellow Book* specification was published allowing the CD to be used for computer data storage applications. Since then several formats have appeared including CD-ROM XA, CD-I, Enhanced CD and Video CD. These compact discs are physically identical to the audio CD but contain other data such as text, images and video as well as or instead of audio. Such multimedia discs use special disc formats tailored to specific hardware such as personal computers and video games machines. Applications for such discs include video games, video on CD, training and encyclopaedias.

The introduction of recordable versions of the CD and the reduction in price of both hardware and recordable media have encouraged consumers to make copies of both CDs and CD-ROMs, not just for their own use but as an alternative to purchasing the legitimate product. This has led games and music companies to make use of various copy protection technologies to reduce the level of home copying and to combat piracy.

Other new technologies have been developed alongside the CD. One of these, the MPEG-1 video standard, allows 74 minutes of medium quality video to be stored on a CD, such as on a Video CD.

The future of the compact disc is now under threat from both the Internet and DVD. CD-ROM sales have started to fall and the growth of CD audio is now being reversed. However, the large number of CD players and CD-ROM drives will ensure that the CD remains in use for many years to come.

1.1 Compact Disc Technologies

The compact disc was developed jointly by Philips and Sony. Philips contributed laser disc experience and Sony digital audio expertise. But there were other necessary technologies that were invented and/or developed several decades before the CD was launched.

- **Pulse Code Modulation** (PCM), which is used to digitally encode the audio on a CD, was invented in 1937 by Alec Reeves while working for STL in London.
- **Error correction codes** that are used in the compact disc were invented by Irving Reed and Gustave Solomon in 1960. Richard Hamming of Bell Labs published information on error correction codes in 1950.
- The **Laser**, which was invented in 1958 by Arthur Schawlow and Charles Townes of Bell Labs.

Without these three technologies the CD would have been impossible. In particular the laser is required as it can be focused to a very small spot size, necessary to enable the capacity required on a 12 cm disc.

1.2 CD Formats

The compact disc supports a range of pre-recorded formats for music, computer data, video, games and other applications. These are illustrated in Figure 1.

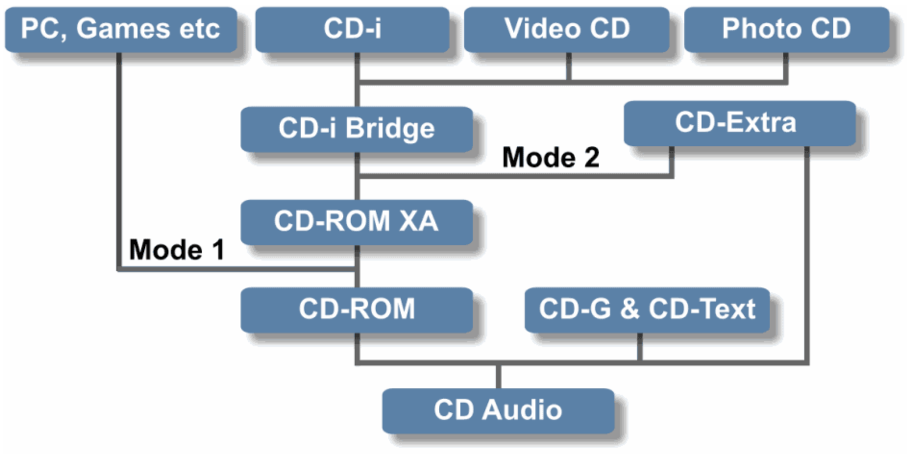


Figure 1 Formats based on the Compact Disc

- **CD Audio** is the original CD format on which all other formats are based. CD Audio discs may also use **CD-Graphics** or **CD-Text**, while **CD-Extra** adds computer data to the audio.
- **CD-ROM** is derived from CD Audio to store computer data for PC games and other applications.
- **CD-ROM XA** is a multimedia version of CD-ROM used as the basis for **CD-i**, **Video CD** and **Photo CD**. **CD-i Bridge** allows the last two formats to play on CD-I players.

2. Compact Disc Digital Audio

The Compact Disc Digital Audio (CD-DA) standard was developed by Philips and Sony and introduced into the market in 1982. Compact Discs are superior to vinyl discs and cassettes in a number of ways:

- Superior sound quality without clicks, hiss or other defects
- Fast random access to any track
- Long-life; compact discs do not wear out
- Compact size: only 12cm in diameter so they take up little storage space

The superior quality of CDs and their compact size are made possible by the use of digital technology combined with laser pickup.

2.1 Digital Audio and Laser Technology

Compact Discs use digital techniques for storing the stereo sound. On vinyl and audiocassettes, the audio waveform is recorded as a direct analogue of the audio waveform. On cassettes this is a magnetic field that varies with the audio signal. On vinyl the groove is modulated with the audio signal. Any imperfections will be heard as noise (hiss) or other defects.

Digital vs Analogue

Using digital technology the audio is stored not as an analogue value but a number representing the amplitude of the audio signal at a particular time.

This number must be accurate to avoid errors that might be introduced. Generally, a digital representation of a changing signal will require much more information than the analogue version. The example in Figure 2 shows the conversion of an analogue waveform (which could be part of an audio signal) to digital by representing each sample by a number (from 0 to 100 in this simple example).

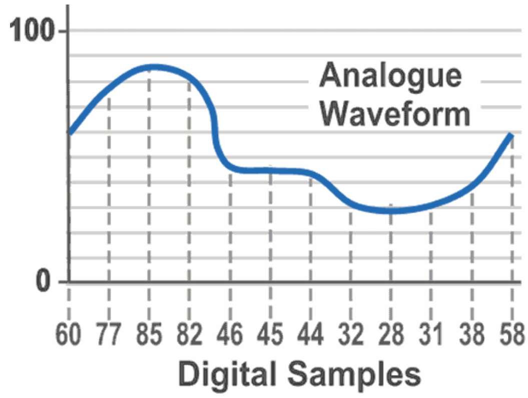


Figure 2 Digital to Analogue Conversion

In practice the range of values and sampling rate must be high enough to ensure accurate reproduction of the original analogue waveform. The upper limit for the human ear is about 20 kHz so the audio must be sampled at 40,000 times per second or higher (since two samples are required for both halves of a sine wave). To reduce distortion and quantisation noise each sample must be represented by at least a 16-bit number giving 65,536 values or levels (0 to 65,535) per sample. This gives a large enough range from the quietest to the loudest sound without any noticeable distortion.

Compact Discs sample the audio 44,100 times per second. The total information needed for 1 second of audio is therefore 44,100 x 2 x 16 = 1,411,200 bits. A bit is a binary digit and has the value 0 or 1. Although longer times are possible, the maximum playing time for all CDs is about 74 minutes to ensure compatibility with earlier CD players. This means that one CD must store 1,411,200 x 74 x 60 = 6,265.728 million bits = 783.216 million bytes, where one byte = 8 bits.

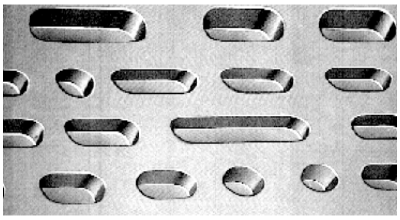
Digital coding allows the use of error correction codes, which are necessary to correct errors resulting from the manufacturing process and minor damage or marks which may occur from handling and use. The result is that the amount of data stored on a CD is nearly four times the data needed to represent the audio only. But this is a small price to pay for a robust format that allows recordings to be played back free of clicks, hiss and other defects associated with analogue media.

CD digital audio should provide the quality needed for all audio applications, but for the purist this is not always enough. For this reason an enhanced format (HDCD) has been introduced and the new DVD-Audio format incorporates new features including higher sampling rate, more bits per sample and multi-channel surround sound.

Laser technology and optical discs

Optical discs such as the CD rely on laser technology to read (and write) the data on discs. The word LASER stands for Light Amplification by Stimulated Emission of Radiation. Lasers generate coherent light, ie light comprising photons with the same wavelength and in-phase. This allows the light beam to be focused to a very small spot size similar to the actual wavelength of the light itself. The minimum **spot diameter** can be calculated as the laser **wavelength** divided by the **numerical aperture** (NA) of the optics used. For CD with a laser wavelength of 780 nm and NA = 0.45, the minimum spot diameter is 780/0.45 nm or 1.73 microns.

The advent of lasers and in particular low cost laser emitting diodes has allowed the compact disc technology to become one of the most successful consumer electronic technologies of all time.



In the late 1960s, Philips developed the laser videodisc, the first such application of the laser for a consumer electronics product. The 30 cm disc was capable of storing up to 60 minutes of analogue video per side. A low power laser was used to read the audio and video information stored in pits (ie minute indentations) in the disc surface. These pits measure about 0.5 microns in width and are arranged in a spiral pattern, like vinyl records.

The Compact Disc uses exactly the same method with similar pit sizes and spacing. However, the pits are used to indicate whether a data bit is '0' or '1'. The length of the pits varies for different sequences of 0s and 1s.

CD players use infra red light emitting diode lasers (see Figure 3), which are compact and low cost, to read the data contained in these pits. The laser diode is mounted on a swivel arm, which can be moved in a radial direction to follow the pits and up and down to keep them in focus. An **objective lens** is used to focus the laser beam on the pits. A **two-way prism mirror** allows the reflected light to pass back to the **photo-detector**.

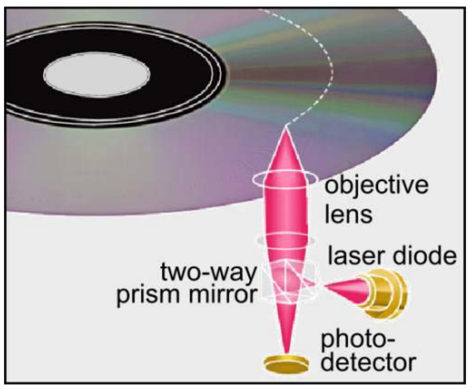


Figure 3 Compact Disc Laser Pickup

When the laser beam falls on a pit the light is scattered and very little is reflected. The changing light pattern detected is then converted into a series of zeros and ones, which are decoded by the player electronics.

Sensitive controls of the radial position of the laser diode and the vertical position of the objective lens are used to ensure that the laser follows the pits accurately, even if the CD is slightly eccentric, due perhaps to the centre hole being slightly off centre. The beam focus can be moved up and down to compensate for the disc being slightly warped.

2.2 CD Audio Specification

The compact disc was designed to store at least one hour of high quality stereo, digital audio. Philips and Sony worked together on the CD audio specification (known as the *Red Book*). The main features of this specification are listed in Table 1.

Table 1 Compact Disc Specification

Parameter	Value	Comments
Disc diameter:	12 cm	8cm also
Disc thickness:	1.2 mm	
Sides:	1	(single side only)
Length of pits:	1 to 3 microns	
Depth of pits:	0.15 microns	
Scanning speed:	1.2 to 1.4 m/s	
Track pitch:	1.6 microns	
Laser wavelength:	780 nm	Infra red laser
Playing time:	74 minutes	Up to 80 minutes possible
Number of tracks:	99 max	Plus up to 99 indexes per track
Channel bit rate:	4.3218 Mb/s	Including modulation & error correction
Number of channels	2	Stereo
Quantization:	16 bits/channel	2's complement
Modulation:	EFM	8 to 14 modulation plus 3 padding bits
Error correction:	CIRC	Cross interleaved Reed Solomon code
Numerical aperture:	0.45	For objective lens

All audio CDs are constant linear velocity (CLV) of between 1.2 and 1.4 m/s, which means that the pits retain the same geometry wherever they are on the disc and there will be no change in performance (including error rate) between the centre and the outside of the disc. Only the angular velocity or revolutions per minute (rpm) will change.

CD construction

The compact disc comprises a sandwich as shown in Figure 4. A 1.2 mm thick polycarbonate substrate containing pits moulded into the upper surface is coated with aluminium, which is then protected by a lacquer on which the disc label is printed. An infrared laser beam is focused on the pits through the clear optical grade polycarbonate plastic.

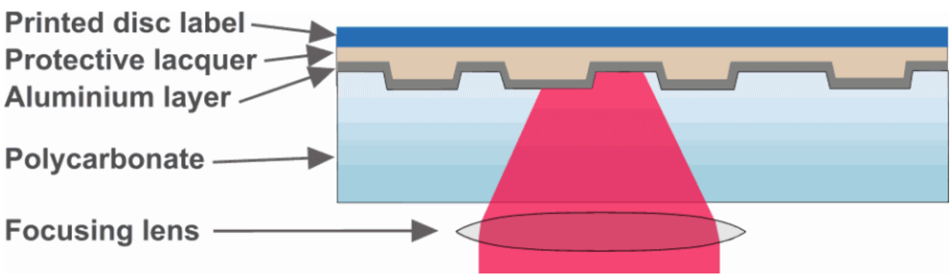


Figure 4 CD Construction

Compact disc layout

CDs measure 120mm in diameter with a 15mm diameter centre hole (see Figure 5). The annular space between the centre hole and outside of the disc is divided into three main areas all containing data:

- **Lead-in,** which starts at radius 23 mm, contains no audio data but does contain other information relating to the audio content. It is used to allow the laser pickup head to follow the pits and synchronise to the audio data before the audio begins
- **Program area,** which starts at radius 25 mm, contains up to 74 minutes of audio data.
- **Lead-out** which starts at or before 58 mm contains digital silence.

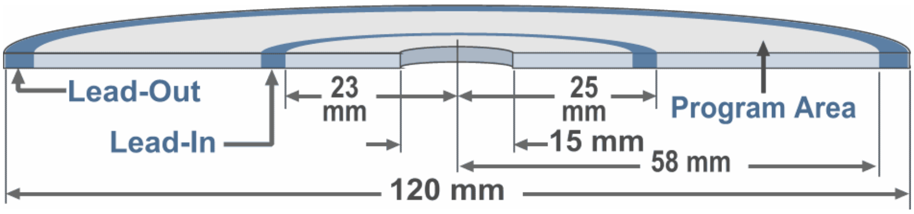


Figure 5 CD Disc Layout

The audio data is therefore stored from radius 25mm (after the lead-in) to radius 58mm maximum where the lead-out starts, the space occupied depending on the playing time.

Since audio CDs are played at a constant linear velocity (CLV), the angular velocity will reduce across the program area by a factor of 58/25 = 2.32.

The disc layout is identical for all types of CD whether for audio or computer data, although the data itself will vary.

CD audio playing time

The playing time of a CD can be calculated from the area of the Program Area, the linear velocity and track pitch. The results are shown in Table 2 for different values of track pitch (1.5 to 1.7 microns) and linear velocity (1.2 to 1.4 m/s). The longest playing time of nearly 80 minutes is achieved by reducing the track pitch to 1.5 microns and the linear velocity to 1.2 m/s, which gives no allowance for tolerances in the manufacturing process.

Table 2 CD Playing Times

	Nominal values	Min Velocity	Min Track pitch	Min values
Start radius (mm)	25	25	25	25
End radius (mm)	58	58	58	58
Linear velocity (m/s)	1.3	1.2	1.3	1.2
Track pitch (microns)	1.6	1.6	1.5	1.5
Playing Time (mins)	**68.9**	**74.7**	**73.5**	**79.7**

Tracks, indexes & table of contents

The Program Area on a CD can be divided into a maximum of 99 tracks, used to separate different items, eg songs, on the disc. Each track must be at least 4 seconds in length and a pause of 2 seconds may be inserted between tracks. Audio may be physically divided into tracks, with silence (pauses) in between, or run continuously between two or more tracks. Any track may be accessed rapidly and tracks may be played in random order. For each track an **ISRC** (see 2.4) must be included to label that track.

Individual tracks are subdivided into indexes. Usually a track will contain two indexes, 0 and 1. Index 0 marks the pause (normally 2 seconds) at the beginning of each track, while index 1 is for the main part of the track. Additional index values (up to 99 in all) may be used where the 99-track limit is inadequate. For example a CD of short audio clips may comprise more than 99 'tracks' by subdividing some tracks into different index values.

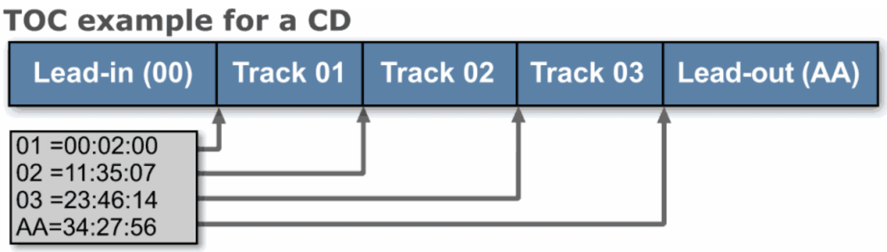


Figure 6 Example of TOC

Track start times (but not indexes) are defined in the Table of Contents (see Figure 6) in the Lead-in area. The TOC comprises absolute times for the start of each track and is used by CD-players to access individual tracks, allowing fast random access and features such as shuffle. The table of contents comprises the timecode for each track (as minutes, seconds and frames) stored three times per track and defines the track type. The last timecode (defined as hexadecimal AA) gives the start of the Lead-out. The Lead-in Area must be long enough to store the TOC for 99 tracks.

2.3 Data Modulation & Error Correction

It is not possible to manufacture CDs where every pit is intact. Small defects in manufacture are permissible and even minor scratches, which can occur with use, should not affect the disc's playability. Therefore the CD specification includes CIRC error correction and EFM.

- A **CIRC** (Cross Interleaved Read-Solomon Code) encoder adds two-dimensional parity information, to correct errors, and also interleaves the data on the disc to protect from burst errors. CIRC corrects error bursts up to 3,500 bits (2.4 mm in length) and compensates for error bursts up to 12,000 bits (8.5 mm) such as caused by minor scratches.

- The **EFM** (Eight to Fourteen) modulation scheme encodes each 8-bit symbol as 14 bits plus 3 merging bits (see below). The EFM data is then used to define the pits on the disc. The merging bits ensure that pit & land lengths are not less than 3 and no more than 11 channel bits. This reduces the effect of jitter and other distortions on the error rate.

CD-ROM discs generally include an extra level of error protection.

Frames and blocks

When converting audio data to the pits stored on the disc, the audio data is divided into groups of 6 samples per channel, ie a total of 192 bits (6 x 2 x 16) or 24 bytes. To this audio data is then added the sub-code channels and CIRC parity data. The resultant frame comprises 36 bytes and 98 such frames are combined to form a block (see Figure 7).

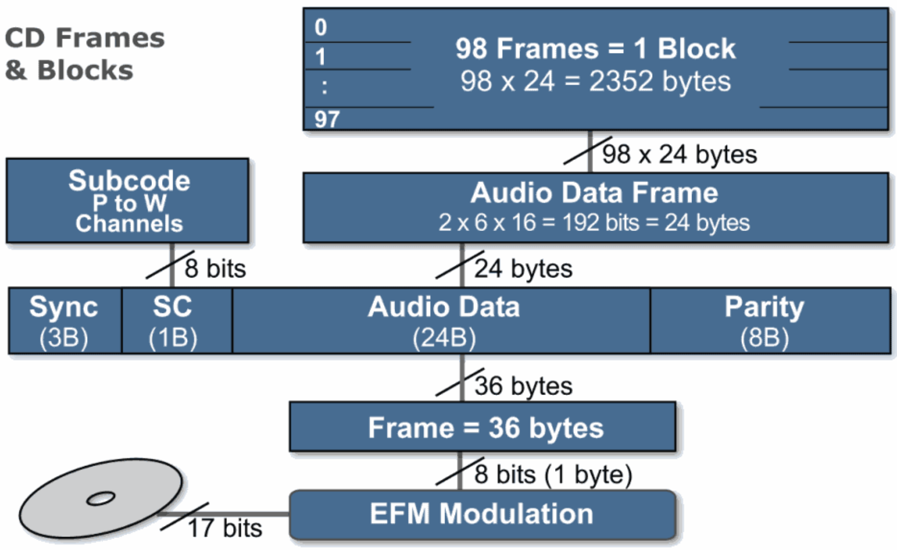


Figure 7 CD Frames and Blocks

Starting from the top, 98 frames are combined to produce a block of audio data, which is 2,352 bytes in length. 75 blocks are read from a CD every second at normal speed. A full 74-minute disc will therefore contain 74 x 60 x 75 = 333,000 blocks.

Each frame comprises the following:

- 3 bytes of sync
- 1 byte of sub-code (SC) data (see 2.4).
- 24 bytes of audio data representing 6 samples for both channels.
- 8 bytes of parity for the CIRC error correction. These are actually interleaved with the audio within the block.

The total of 36 bytes in a frame is stored on disc via an EFM modulator, as described above.

2.4 Sub-code Channels

The eight sub-code bits in each frame represent eight sub-code channels labelled P to W. These are separated from the main channel (audio) data by the decoder and are available for use by CD audio players.

- The **P-channel** simply indicates the start and end of each track by toggling between 0 and 1.
- The **Q-channel** contains the time-codes (minutes, seconds and frames), the Table of Contents (TOC), in the lead-in, track type, catalogue number and ISRC.
- **Channels R to W** are for sub-code graphics (CD-G) and CD TEXT.

Note that there are 98 bytes of sub-code data per block, of which two bytes are used for synchronisation, leaving 96 bytes for the sub-code data. As 75 blocks are read per second from the disc, at normal speed, the sub-code data rate is 7.2 kB/s. Each channel (eg the Q-channel) has a data rate of 7.2 kb/s or 0.9 kB/s. The R to W channels have a combined data rate of 5.4 kB/s. This represents about 3% of the main channel audio data rate of 176.4 kB/s or 1.41 Mb/s.

CD-Graphics

This is an extension to CD-DA (the *Red Book*) to include data for graphics and text, which are contained in the sub-code channels R to W. However it does allow simple graphics and text to be displayed while the music is being played. CD-Graphics data can be in any of the modes defined in Table 3.

Table 3 CD Graphics Modes

Mode	Horizontal	Vertical	Colours
Line-graphics	288	24	2
TV-graphics (CD-G)	288	192	16
Extended-TV-graphics (CD-EG)	288	192	256

One application of CD-G is for Karaoke and there are CD-G Karaoke versions of portable CD hi-fi audio equipment available. They only need a television set to see the graphics and text for the song lyrics and the user has a portable self-contained Karaoke system.

CD-Graphics also defines two additional modes, MIDI and User:

- **MIDI** mode provides a 3.1kb/s maximum data channel for the Musical Instrument Digital Interface (MIDI) data as specified by the International MIDI Association.
- **User** mode is intended for professional applications. The meaning of the data is application specific.

CD TEXT

The R to W channels can also be used for CD TEXT, which allows disc and track related information to be added to standard audio CDs for playback on suitably equipped CD audio players. The CD TEXT information, coded as characters for maximum efficiency, is contained in the R to W sub-code channels in the lead-in and/or program area of a CD.

- **Lead-in area**: text information about the whole disc and individual tracks.
- **Program area**: text information for the current track including track title, composer, performers etc. The CD TEXT data is repeated throughout each track to reduce the delay in retrieving the data.

CD TEXT is compatible with the ITTS (Interactive Text Transmission System) standard. CD TEXT equipped players can provide a range of display formats from one or two line, 20 character display to 21 lines of 40 colour alphanumeric or graphics characters. The specification also allows for future additional data such as JPEG coded images.

Menus are used for the selection of text for display. The main menu lists the available text items, such as album, track titles and artist names. Additional menus may be included before the text itself is displayed. Additional menus may be needed for language selection. In addition to displaying track titles, artists etc, it will be possible to select a track based on the name rather than track number.

In-car use will be important in conjunction with RDS radios, which already display station names and, in some cases, the name of the music being played. This feature will be available for CDs using CD TEXT. Future DAB (Digital Audio Broadcasting), with its CD TEXT compatible text service, will extend the possibilities further.

ISRC

The **ISRC** (International Standard Recording Code) was developed by ISO (International Organisation for Standardisation) as ISO3901:2001 to identify sound and audio-visual recordings. ISRC is a unique identifier of each recording that makes up the album. If a recording is changed in any way it will need a new ISRC, but otherwise will always retain the same ISRC. The ISRC is contained in the sub-code (Q-channel) and comprises 12 characters divided as shown in Table 4.

Table 4 ISRC Fields

Characters	Description
2	Country (eg GB for UK) as defined in ISO 3166-1-Alpha-2
3	Registrant code (eg the producer or owner)
2	Year of reference (actually the last two digits)
5	Designation code (numeric)

The address of the International Agency, which administers the ISRCs is:

International ISRC Agency
IFPI Secretariat
54 Regent Street
London W1B 5RE
United Kingdom

Email: isrc@ifpi.org
Telephone: +44 (0)20 7878 7900
Fax: +44 (0)20 7878 6832
Website: www.ifpi.org/isrc

2.5 CD Audio Enhancements

Audio CDs can be enhanced by adding content related data (CD Extra) or by improving the audio coding (as in HDCD)

Enhanced CD (CD Extra)

CD audio discs can also be Enhanced CDs, which contain two sessions so are multi-session discs. Multi-session capability was originally used for CD-R discs to allow data to be written in several sessions to add or 'modify' data. Each session comprises lead-in, program and lead-out areas (see Figure 8). The first session contains up to 98 audio tracks; the second session contains the CD-ROM track. When played on an audio player, it only 'sees' the first session and so does not try to play the data session, but CD-ROM drives see both sessions and will load any programs contained in the second session.

Session 1 (audio)			Session 2 (data)		
Lead-in	Program Area (up to 98 tracks)	Lead-out	Lead-in	Program Area (CD-ROM track)	Lead-out

Figure 8 Enhanced CD Structure

The enhanced CD specification (the *Blue Book*) is based on the multi-session specification with some application specific additions for handling lyrics, titles, video and stills. The main features of such discs are as follows.

- Playable on a wide range of hardware including PCs under Windows 95/98/2000/XP, Macintosh computers, and dedicated CD Extra players.
- **Session one** contains up to 98 tracks of audio data conforming to the Red Book specification.
- **Session two** contains one track of CD-ROM XA (ie Mode 2) sectors and must include certain specified files and directories and use the ISO 9660 file system. For Macintosh compatibility, it is possible to make the data track include HFS as well as ISO9660.

The following directories and files are required in the second session:

- An AUTORUN.INF file in the root directory which meets the Windows Autoplay specification.
- A CDPLUS directory containing general information, lyrics and MIDI data.
- A PICTURES directory containing pictures encoded in both MPEG and other formats.
- An optional DATA directory containing additional data files depending on the application.

HDCD

High Density Compatible Digital (HDCD) is a recording process developed by Pacific Microsonics, which enhances the quality of audio from compact discs. HDCD discs use the least significant bit per channel for additional information to enhance the audio signal without affecting playback of HDCD discs on normal CD audio players. The result is a 20-bit per channel encoding system that is claimed to provide more dynamic range and a very natural sound.

Many HDCD titles are available particularly in the US. Discs can be recognised by the presence of the HDCD logo. For information on titles available see the HDCD website (www.hdcd.com). Special HDCD players are needed to playback HDCD discs by a combination of interpolation plus the use of additional codes to correct for defects in interpolation.

2.6 CD Audio Copy Protection

With the rapid increase in home copying of CDs and piracy, the music companies have started to introduce copy protection for audio CDs. The purpose of the various technologies is to prevent the audio tracks being read by a PC, so that the CD cannot be 'ripped' to hard disk and copies cannot therefore be made.

Most available copy protection systems make use of the differences between CD players and CD-ROM drives. The former stream audio from the CD continuously, while CD-ROM drives read the audio in 'blocks' and need to find the next 'block' of data by using the time-codes in the Q-channel. Also CD-ROM drives will look for the last session on a disc, but CD-Audio players will only read the first session of a multi-session disc.

It is then possible to use these and other characteristics of CD-ROM drives to hide the CD audio tracks from a PC. Another technique is to introduce errors into the audio that are concealed by a CD player but not by a CD-ROM drive when the audio is ripped. A copy will then include 'clicks and pops' when played, but the original CD will not.

Since the audio cannot be played on a PC when hiding is used, most technologies (see Figure 9) include a second session with compressed audio files that will play on a PC. This results in a reduction in the playing time for the Red Book audio tracks of up to 10 per cent.

Figure 9 CD Audio Copy Protection

None of these technologies is 100 per cent effective but the aim is to make it difficult for most consumers to copy a CD. They also do not inhibit analogue copying, but this is less convenient, slow and results in a less than perfect copy. Examples of copy protection technologies are:

- **Macrovision's Cactus Data Shield** available as CDS-100 (single session) and CDS-200 (with compressed audio files in a second session). CDS-200 has been used commercially in over 100 million discs. Midbar Tech developed CDS, but was acquired by Macrovision in December 2002. New products are being introduced in 2003 combining CDS CD audio protection with digital rights management (DRM) technology to control how the compressed files in the CD-ROM session are used.
- **Sony's key2audio** is like CDS-100 in that it does not include compressed audio files. Instead consumers can download the audio files from a website. A new version, **key2audioXSplus,** includes a second session with compressed audio files and additional features including web access. Sony Music has used key2audio to protect over 30 million discs.
- **Sunncomm's MediaCloQ** offers similar protection with compressed audio in the second session. They are using digital rights management built into Microsoft's Windows Media Player 9.

Serial Copy Management System

The Serial Copy Management System (SCMS) is used to control the copying of the content of a CD. Three possible conditions are defined by the SCMS flags contained in the Q-channel:

1. No restrictions
2. Single generation copy
3. No digital copying

The SCMS flags are output from CD players via the **S/PDIF** (Sony/Philips Digital InterFace) which is used to connect to a CD-recorder or other recording hardware. CD-recorders should obey the SCMS flags, inhibiting copying from a second generation copy or where no copying is allowed. SCMS has no affect on analogue copying.

3. Compact Disc Read Only Memory

Since compact discs store audio in a digital format, they are suitable for storing other information that can be represented in a digital form. In 1984, Philips and Sony released the Compact Disc Read Only Memory (CD-ROM) specification, known as the *Yellow Book*. This defines the necessary additions to the Red Book for the storage of computer data. Any computer data can be pre-recorded on a CD-ROM. The specification of a CD-ROM disc is summarised in Table 5.

Table 5 CD-ROM Disc Specification

Parameter	Value	Comments
Data capacity	656 MB	For 74 minutes (688 x 10^6 bytes)
Raw data bitrate	1.41Mbits/s	Includes all bytes in sector
User data rate	150 kB/s	At 1x speed
Block (sector) size	2,352 bytes	
User data per sector	2048	With full error correction
Sector rate	75 sectors/s	At 1x speed reading
Sector Modes	1 or 2	See 3.1
Sector Forms	1 or 2	Mode 2 only

CD-ROM discs are read by CD-ROM drives, which have been standard components of personal computers and some games consoles for a number of years. DVD-ROM drives, which are now replacing CD-ROM drives will also read CD-ROM discs. A CD-ROM has several advantages over other forms of data storage, and a few disadvantages.

- Capacity of a CD-ROM is about 700 MB of data.
- The data on a CD-ROM can be accessed much faster than a tape, but CD-ROMs are slower than hard discs.
- Like audio CDs you cannot write to a pre-recorded CD-ROM but only to recordable versions.

The physical parameters are identical to those defined in the *Red Book*. A CD-ROM is, in appearance, identical to an audio CD. The use of the data it contains is different. While audio CDs can be played at only one speed, CD-ROM drives exist with a range of speed options up to 52 times normal speed. As the speed increases the access time also decreases.

CD-ROM discs differ from CD audio discs in two important ways.

- The data on a CD-ROM disc are divided into sectors, which contain both user data and other data for control and error protection.
- The data on a CD-ROM are contained in files. All CD-ROMs therefore need a file system to enable the computers to access the required file easily and quickly.

3.1 CD-ROM Sectors & Modes

CD-ROM sectors are equivalent to the audio blocks (ie 98 frames) described above. At normal playback speed 75 sectors are read every second. For double speed CD-ROM drives this increases to 150 sectors per second and so on. Sectors may be either Mode 1, used for general computer applications, or

Mode 2, used for CD-i, CD-ROM XA, Video CD and Enhanced CD (see Figure 10).

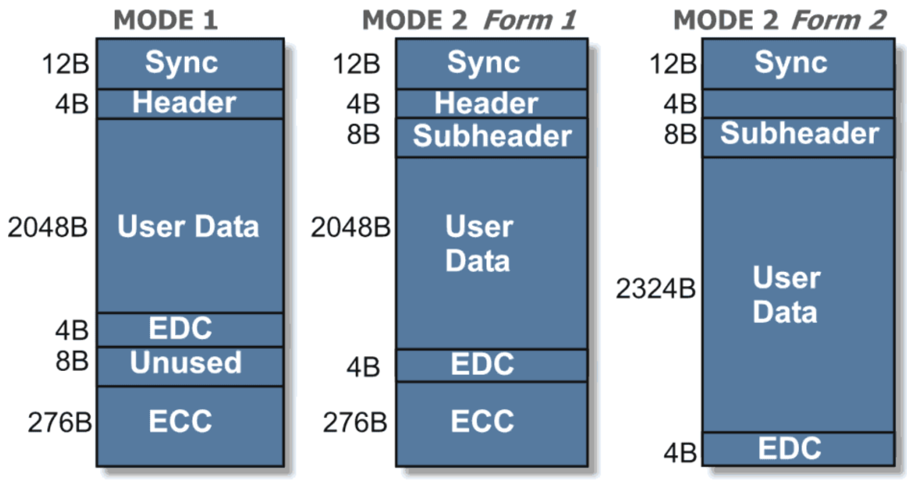


Figure 10 CD-ROM Sectors

- **Mode 1** sectors, as defined in the *Yellow Book*, comprise Sync, Header, 2,048 bytes of User Data, EDC, 8 unused bytes and ECC.
- **Mode 2 Form 1** sectors, as defined in the CD-ROM XA specification, comprise Sync, Header, Subheader, 2,048 bytes of User Data, EDC and ECC.
- **Mode 2 Form 2** sectors, as defined in the CD-ROM XA specification, comprise Sync, Header, Subheader, 2,324 bytes of User Data and EDC but not ECC.

Header: 4 bytes comprising address (minutes, seconds, sectors) and Mode (1 or 2).

EDC: Error detection code

ECC: Error correction code using CIRC

Subheader: 4 bytes repeated with Form (1 or 2) and content related

The Mode 1 and Mode 2, Form 1 sectors are identical in capacity and error correction. The only difference is the presence of the subheader in the latter. In contrast Mode 2, Form 2 sectors include no error correction, but the increased capacity (2,324 bytes instead of 2,048) is suitable for video or audio data where occasional errors can be masked and do not cause a problem. Mode 2 Form 2 sectors are used by the Video CD format, for example, for video data and by CD-i for audio, still video and moving video data. For other applications and formats either Mode 1 or Mode 2 Form 1 only are used and the subheader is not used.

3.2 Capacity of a CD-ROM

The capacity of a CD-ROM depends on whether it is a Mode 1 CD-ROM or Mode 2 CD-ROM XA. Assuming the maximum size is 76 minutes 30 seconds (as recommended) this means that there are 336,300 sectors on a CD-ROM. From this must be subtracted 166 sectors at the start of track 1 plus a few sectors for the file system, amounting to, say, 200 sectors leaving 336,100 sectors for user data.

- **Mode 1** sectors contain 2048 bytes per sector giving a total capacity of 688,332,800 bytes or 656 MB.

- **Mode 2** sectors contain either 2048 or 2324 bytes per sector so will have a somewhat higher data capacity depending on the mix of the two types of sector.

The above assumes a CD-ROM comprising a single track in a single session. For multiple track/session discs the data capacity will be reduced.

3.3 File Systems

The *Yellow Book* only defines the physical properties of CD-ROM discs and the sector structures. It provides a basic specification for storing computer data on a read-only medium. It does not specify how files, which are fundamental entities for any computer system, are to be stored and accessed.

Therefore, a group of interested parties formed the High Sierra Group and agreed on a proposal for a file system for CD-ROMs. This was then ratified, in a slightly modified form, by the International Standards Organisation as recommendation ISO 9660. ISO 9660 is compatible with MSDOS, for example filenames can be in upper case only with 8 characters plus 3-character extension.

The ISO 9660 file system has limitations so CD-ROM discs can make use of Joliet extensions, for Windows9x and later, and the HFS file system, for Macintosh applications. These are described below.

Joliet

The **Joliet** extension to ISO 9660 was designed to resolve a number of deficiencies in the original ISO 9660 file system particularly when used with Windows9x and later. These include:

- Character Set limited to upper case characters, numbers and underscore.
- File Name Length limited to 8 characters plus three-character extension
- Directory Tree Depth limitations
- Directory Name Format limitations

The Joliet specification uses the secondary volume descriptor (SVD) feature of ISO 9660 to solve the above problems. In order to maintain compatibility with MSDOS the primary volume descriptor and its associated path table meets the ISO 9660 Level 1 specification. The SVD uses a second path table with long filenames for full Windows 95/98/2000/XP compatibility.

Hierarchical File System (HFS)

Other file structures also exist for non-Windows systems, which have particular requirements. The Macintosh Hierarchical File System (HFS) is an example. The features of HFS are summarised below:

- Supports subdirectories (called folders)
- 31 characters maximum per file name.
- Volume names may have a maximum of 27 characters
- HFS files have two forks; a resource fork and a data fork.
- The data fork is used by an application to store the contents of the document.
- The resource fork of a file contains Macintosh resources, which are used by applications to identify the file type and to provide other related data.

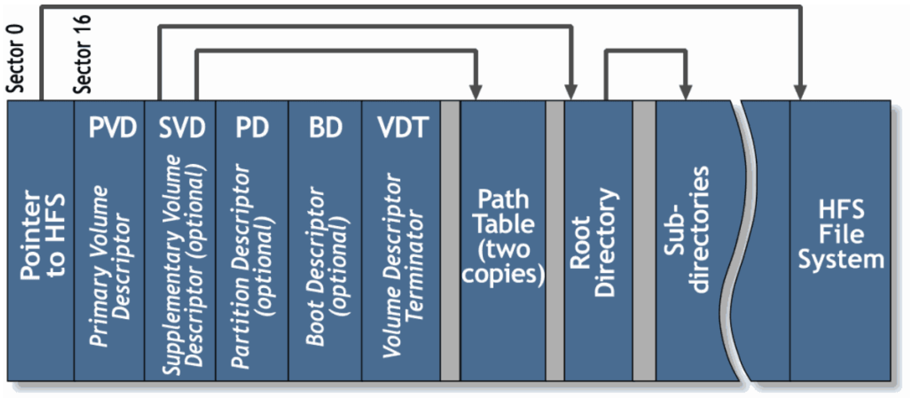


Figure 11 ISO9660 & HFS Hybrid File System

CD-ROM discs can have both ISO 9660/Joliet and HFS file systems and are termed hybrid discs. These are used for software to be run on both Windows PCs and Apple computers. The HFS data is located after the ISO 9660 data and a pointer to the HFS contained in the first 16 sectors (see Figure 11).

3.4 CD-ROM Drives

To read the data from a CD-ROM disc requires a CD-ROM drive as a computer peripheral. The data on a CD-ROM can be accessed much faster than a tape, particularly using the latest high-speed drives (52x is now common). To reduce the maximum angular velocity these faster drives use CAV (constant angular velocity) rather than CLV (constant linear velocity). Therefore the data rate for data near the inside is less than the data rate at the outside of the disc. For example a 40x drive gives a maximum data rate of between 2.8 and 6 MB/s, depending where on the disc the data is being read. Faster drives can create problems so some drives make use of multiple laser beams to increase the data rate without increasing the angular velocity.

CD-ROM drives are designed also to read CD audio discs at the correct speed. Other discs, like Video CDs, which are designed for single speed, are read in bursts to maintain the correct data rate.

3.5 Applications for CD-ROM

When CD-ROMs were first introduced, the main applications were for encyclopaedias and large text databases particularly for the legal profession. CD-ROMs provided a very convenient means of storing and accessing large amounts of text. Later, graphics images were added to the text and then colour photographs, audio and even motion video. Multimedia CD-ROMs had arrived.

With the advent of Microsoft's Windows (particularly the more recent versions), it became much easier to develop titles to exploit the multimedia capabilities of CD-ROM and now almost all CD-ROMs developed for the PC require Windows. Other systems that play CD-ROM discs include Macintosh and Games consoles. Some typical applications for CD-ROM are summarised in the following list:

- **Professional text databases** for legal, medical and other uses.
- **Directories** including telephone directories, yellow pages, shopping catalogues (containing pictures as well as text), directories of printed books and CD-ROM titles.

- **Multimedia Encyclopaedias** containing text database plus photos, graphics, audio clips and video sequences.
- **Games** on CD-ROM are some of the most popular applications.
- **Cover-mount discs** for PC and other magazines with demo versions of programs, clip art, and video.
- **ISP** software including Internet browser software offering free access to the Internet.
- **Computer software** is usually distributed on CD-ROM, or via the Internet.
- **Video CDs** have proved to be popular in China but not in the USA or Europe.

3.6 CD-ROM Copy Protection

Piracy and illegal copying of CD and CD-ROM discs is widespread in most parts of the World. Copy protection systems have been developed for CD-ROM discs. Once such system is SafeDisc, which was developed by C-dilla (now part of Macrovision), a UK-based company. SafeDisc2 is the current version being offered by Macrovision. Another is Sony's SecuROM.

CD-ROM publishers, particularly those of CD-ROM games, face erosion of their revenue by the widespread use of CD-Recorders, distribution of software via the Internet and large-scale piracy. Copy protection systems prevent both individual copying of a CD-ROM (to a CD-R or hard disk) and manufacture of a pirate version.

Most technologies use encryption of the content with the key used to decrypt it 'hidden' on the disc as a digital signature (see Figure 12). A software loader program is added to read the digital signature, extract the key and load and decrypt the main application.

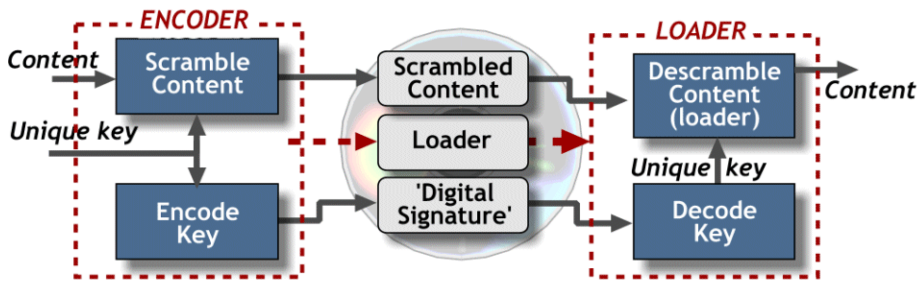


Figure 12 CD-ROM Copy Protection

Implementing copy protection requires premastering (to encrypt the content). The digital signature is added during glass mastering. Modified QA equipment is required to verify the mastering and replication and to measure sample discs. Some technologies add errors to the disc and it is necessary to ensure that these are distinguished from unintentional errors during the QA process.

All copy protection systems are subject to the effort of hackers to break the copy protection and allow games, in particular, to be copied and illegally distributed. Fortunately it is possible to upgrade the copy protection system for subsequent titles to keep one step ahead of the hackers. Games generally have a short life, often being replaced by a new version within months, so the copy protection must remain effective for a relatively short period of time.

4. CD-ROM and CD-ROM XA Formats

The different CD-ROM based formats are listed in Table 6.

Table 6 CD-ROM & CD-ROM XA Formats

Format name	Mode(s)	File structure	Comments
Windows CD-ROM	1 or 2	ISO 9660 or Joliet	Most common format
Mac CD-ROM	1	HFS	Based on Mac operating system
CD-i	2	ISO 9660+	Superset of ISO 9660.
CD-ROM XA	2	ISO 9660 or Joliet	Combines CD-ROM and CD-i
Video CD	2	ISO 9660	A CD-i Bridge format
Photo CD	2	ISO 9660	A CD-i Bridge format
Enhanced CD	2	ISO 9660 or Joliet	Multi-session audio + data

4.1 Windows and Mac CD-ROM Formats

The most common CD-ROM format uses Mode 1 sectors and ISO 9660/Joliet file system for Windows PCs and other platforms. Windows is also capable of reading Mode 2 CD-ROM XA discs, but Mode 1 is suitable for virtually all purposes.

Mac CD-ROMs use Mode 1 and the HFS (Hierarchical File Structure) instead of ISO 9660 and are less common.

Hybrid CD-ROMs contain both the ISO 9660 and HFS file systems so they can be read by both platforms. Hybrid CD-ROMs will normally contain two versions of executable files (Windows and Mac versions) but it is possible for both platforms to use common data files such as video, graphics and audio.

4.2 CD-ROM XA

CD-ROM XA (for eXtended Architecture) discs contain Mode 2 sectors and were designed to allow audio and other data to be interleaved and read simultaneously. This avoids the need to load images first and then play CD audio tracks (a technique used in the early days of CD-ROM multimedia).

The CD-ROM XA specification also defines certain image and audio formats, including graphics formats, which are compatible with both PC and CD-I formats and audio, which is ADPCM (Adaptive Delta Pulse Code Modulation), which is also defined for CD-i. But this part of the CD-ROM XA specification is now obsolete.

However three application formats are based on the use of Mode 2 sectors, which are described in the CD-ROM XA specification. These are Photo CD, Video CD and CD EXTRA. CD-i also uses mode 2 sectors and shares some commonality with CD-ROM XA; for example both use ADPCM audio. Only Video CD and CD EXTRA are currently in use, but these do not use the coding formats defined in the CD-ROM XA specification.

4.3 CD-I Bridge

CD-I Bridge is a Philips/Sony specification for discs intended to play on CD-i players and other platforms such as the PC. The main features are:

- Discs conform to the CD-ROM XA specification.

- ISO 9660 file system so that discs can be read on CD-i players and PCs.
- Mandatory CD-i application program stored in the CDI directory. However as CD-i is now obsolete this is an academic requirement.
- Audio data coding, including ADPCM and MPEG and still image data coding for compatibility with CD-i and CD-ROM XA. These are now obsolete.
- Multi-session disc structure including sector addressing and volume space.
- CD-i related data for CD-i players, but this is now obsolete.

Examples of CD-I Bridge formats are:

- **CD-Interactive** (CD-i), an almost obsolete multimedia format.
- **Photo CD** for storing photo files on a CD in a range of resolutions.
- **Video CD** for up to 74 minutes of video using MPEG-1.
- **Super Video CD** offering higher quality MPEG-2 video.

Only the last two are current formats, which are used mainly in parts of Asia.

4.4 CD-interactive (CD-i)

CD-i is a multimedia system originally intended for the home, but is now obsolete apart from very limited education and training applications. The CD-i specification (the *Green Book*) describes the disc layout, file structure (based on ISO 9660), data encoding formats and the architecture of the hardware and its operating system used to play CD-i discs.

CD-i discs comprise mode 2 form 1 and 2 sectors. Each sector contains data of only one type: audio, video (still and motion) or other data. CD-i players are based on the Motorola 68000 processor with memory, two-plane video decoder (plus optional MPEG) with visual effects, audio processor, non-volatile memory and user interface. CD-RTOS is the real-time operating system designed for CD-i. It allows multi-tasking and facilitates event-driven programming.

4.5 Photo CD

Kodak announced Photo CD in 1990 and launched it in the summer of 1992. Photo CD discs contain photographic images in a range of image resolutions to suit a wide variety of applications as listed in Table 7 and described below.

Table 7 Photo CD Formats

Format	Max size (pixels)	No images	Application
Photo CD Master	2048 x 3072	100	Consumer 35mm films
Pro Photo CD Master	4096 x 6144	25 to 100	Professional
Photo CD Portfolio	512 x 768 or 1024 x 1536	up to 700	Interactive presentations
Photo CD Catalogue	512 x 768	up to 6,000	Catalogues
Print Photo CD	2048 x 3072	100	Printing industry

Photo CD discs are CD-I Bridge discs and therefore comprise Mode 2 sectors and include a CD-I application.

- **Photo CD Master** discs can each hold about 100 high-resolution images, or four 24- exposure rolls of 35mm film. These discs can be Orange Book multi-session CD-Rs allowing photos to be recorded to the disc in more than one session. The discs offer image resolutions from thumbnails (to facilitate selecting the required picture for viewing) up to 2048 x 3072 pixels used for making prints.

- **Pro Photo CD Master** is used by professionals to store images from the larger film formats including 120, 70 mm, and 4 x 5-inch, as well as 35 mm. Pro Photo CD includes Base*64 (4096 x 6144 pixels) to the resolutions stored on a Photo CD Master disc. The Pro disc format also offers security features such as ownership and copyright notices.
- **Photo CD Portfolio** discs allow interactive sound-and-picture presentations to be created for playback on TV or computers. Because the highest resolutions are not required on this format, users have more space available for other content, such as audio and graphics. A Portfolio disc can be played on a Photo CD player, a CD-i player or a computer equipped with a CD ROM drive and suitable Software.
- **Photo CD Catalogue** discs are designed for organisations that want to store large numbers (up to 6,000) of images on a disc and distribute these images widely, such as mail-order retailers, tourism associations, or art galleries. The low resolution images cannot be used to make photo-quality prints.
- **Print Photo CD** has been optimised for customers in the printing industry and allows three kinds of image data:
    1. 16*base Photo CD Image Pac files (see Image Pacs) accessible in the same way as conventional Photo CD images.
    2. Platform-independent CMYK format based on the TIFF/IT file to allow graphics files to be easily shared among systems from different manufacturers
    3. Vendor-specific data to allow Print Photo CD discs to accommodate all the resources necessary for production.

Photo CD Image Pacs

Images are stored using the PhotoYCC encoding format, developed by Kodak, which stores data at up to six levels of resolution in Image Pac files.

Table 8 Photo CD Image Pacs

Base	Size (Hor x Vert)	Comment
x 64	4096 x 6144	Pro Photo CD only
x 16	2048 x 3072	Print size
x 4	1024 x 1536	HDTV resolution
x 1	512 x 768	TV resolution
/ 4	256 x 384	Thumbnail
/ 16	128 x 192	Thumbnail

Picture CD

Picture CD is an alternative format to Photo CD for consumers. The format does not include as many resolutions or options as Photo CD, but is used for storing photos which have been scanned from film following processing.

The following table compares Photo CD and Picture CD.

	Picture CD	Photo CD
Application	pictures from film with a PC	high-quality professional and commercial
Resolution	1024 x 1536	128 x 192 up to 2048 x 3072
File format	JPEG	Image Pac
Quantity	Single roll of film	Multiple films up to 100 images
Film type	APS or 35 mm	35 mm to 4 x 5
Hardware	PCs, Macs, some DVD players*	PCs, Macs, Photo CD players, CD-i players

* An increasing number of DVD players will read and display JPEG photos from a CD-ROM or CD-R disc as a slideshow. This includes not just Picture CDs but any CD that contains JPEG images.

4.6 Video CD

Video CDs contain MPEG audio and video for mainly linear video applications. Video CDs are CD-ROM XA discs designed also to play on CD-i players and any other hardware that will decode MPEG-1 data. Super Video CD (SVCD) format was developed for China and offers MPEG-2 video for higher quality. Super Video CD and Video CD version 2.0 are compared in Table 9.

Table 9 Video CD vs SVCD

Parameter	Video CD ver 2.0	Super Video CD
Playing time:	74 minutes	35 to 70 mins+
Data rate:	150 kBytes/s (1x speed)	300 kBytes/s (2x speed)
Video:	MPEG-1 1.15 Mb/s CBR*	MPEG-2 2.6 Mb/s average VBR*
Resolution:	352 x 240 (NTSC) 352 x 280 (PAL/SECAM)	480 x 480 (NTSC) 480 x 576 (PAL/SECAM)
Audio:	MPEG-1 stereo CBR* optional CD audio tracks	2 streams MPEG stereo VBR* optional 5.1 channel
Interaction:	Menus, Playlists	More interactivity
Subtitles:	Closed captions	Overlay graphics (4 selectable channels)

*Note that CBR = Constant Bit Rate and VBR = Variable Bit Rate.

Video CD uses MPEG-1 and CBR encoding for 74 minutes of VHS quality video on a disc. **Super VCD** allows a full-length movie to be stored on two or three discs. Multi-disc players can give near-seamless, uninterrupted playback of movies using this format. The use of MPEG-2 VBR (variable bit rate) video encoding, as used for DVD-Video, gives improved quality without an unacceptable reduction in playing time.

Video CD Tracks

White Book Video CDs are characterised by the use of multiple Tracks (see Figure 13).

Track 1	Track 2	Track 3		Track N
CD-i app, Playlists etc	MPEG data	MPEG data		MPEG data

Figure 13 Video CD Disc Structure

Track 1 contains the following data:

- CD-i application program.
- Track information for Karaoke or music videos (optional)
- Entry point addresses
- Playlists
- MPEG stills

Tracks 2 upwards are used for the MPEG video data files, which also can contain the scan table information and closed caption data in the user data area. A Video CD disc must therefore contain at least two tracks. The MPEG video files only are contained in Mode 2, Form 2 sectors. Optional CD audio tracks can be added after the last MPEG track.

Video CD Directories and Files

Most files on a Video CD disc have predefined filenames and are located in specific directories as shown in Table 10.

Table 10 Video CD Directories and Files

Directory	Files	Comments
VCD	INFO.VCD ENTRIES.VCD PSD.VCD LOT.VCD	Album and disc identification Entry point list for up to 500 entries Optional Play Sequence Descriptor Optional List ID Offset file
MPEGAV	AVSEQnn.DAT	MPEG files (one per track)
CDDA	AUDIOnn.DAT	CD Audio files (one per track)
SEGMENT	ITEMnnn.DAT	Segment play items (one per segment)
KARAOKE	KARINFO.xxx	Optional Karaoke information files
EXT	PSD_X.VCD LOT_X.VCD SCANDATA.DAT CAPTnn.DAT	Optional extended version of PSD.VCD Optional extended version of LOT.VCD Optional list of I-frame addresses Optional Closed Caption data (one per track)
CDI	(undefined)	CD-i program and data files

Video CD Players

A number of different types of hardware are capable of playing Video CD discs.

- Dedicated VCD players are manufactured and sold mainly in China, where the format has become extremely popular.
- CD-i players with MPEG decoders are capable of playing Video CDs but not SVCDs.
- DVD-Video players will, mostly, play Video CDs, but not all will play SVCDs.
- Most PCs will play Video CDs and SVCDs using suitable software decoders.

4.7 Mixed Mode CD-ROM

Mixed mode is a term to describe a disc with tracks of more than one type. In particular, a disc with one data track (mode 1) followed by up to 98 audio tracks. Such discs can be played on normal audio CD players, avoiding the first track. One of the problems that have inhibited the widespread use of mixed mode discs is that some early CD players will try to read a data track with possibly disastrous consequences. One early mixed mode title was called "Don't Play Track One" perhaps to remind the user of the potential dangers.

The solution that is now in widespread use is the Enhanced CD format, described under the section on CD audio above.

4.8 Recordable and Other CD Formats

Several recordable and re-writable versions of the CD are available or have been developed and an increased capacity pre-recorded version has been defined.

CD-R

CD-Recordables are defined in the *Orange Book,* which specifies both write-once and re-writable discs. They are used to produce small quantities of discs as a lower cost alternative to mastering and pressing.

CD-Rs are recorded according to the *Orange Book* and can be multi-session. This allows data to be recorded at different times. Each session is like a different disc with its own lead-in, program area and lead-out. As a new session is recorded to a data disc, an updated file structure (to ISO 9660) is recorded in the last session. For example, when a file on CD-R is updated the new version is stored in the latest session. The file structure in this session will be used to access all files on the disc, so that only the latest version will be accessible.

CD-R discs have become very popular since the late 90s and two versions now exist.

- **Data CD-R** discs for storing data and to be read by CD-ROM drives on PCs. These discs can be used for recording PCM audio using PC-based CD-Recorders.
- **Audio CD-R** discs for use with the new audio CD-Recorders. These are significantly more expensive than data discs to inhibit their use for making illegal copies of pre-recorded CDs.

CD-RW

CD-RW discs are re-writable, are also defined in the *Orange Book* and have the same capacity as CD-R discs. CD-RW discs generally cannot be played on CD-ROM drives unless they are MultiRead drives, ie are capable of reading multiple formats. CD-RW discs need to be formatted to act as a re-writable device for computer use.

High Capacity Recordable Disc System

Philips has released a provisional specification for a high capacity version of the CD-R, known as HC-R. HC-R discs are write-once and have a capacity of 98 minutes, 29 seconds and 74 frames on a single session 12 cm disc. This extra capacity is achieved by reducing the track pitch to 1.28 microns and scanning velocity to 1.13 m/s.

Double Density CD

Double Density CD (DDCD) is a new CD format released by Philips and Sony as the Purple Book. DDCD is a 12cm (or 8cm) disc, offers twice the capacity of CD and can be available in read-only, write-once and re-writable versions. It is intended only for data storage not for CD audio. Table 11 compares DDCD and HC-R with CD-ROM.

Table 11 DDCD vs CD-ROM Parameters

Parameter	DDCD	HC-R	CD-ROM/CD-R
Capacity (GB)	1.3	0.83	0.65
Sides:	1	1	1
Start diameter program area (mm):	48	49.4 min	50
Min Length of pits (microns):	0.7	0.9	1
Scanning speed (m/s):	0.9 (1x)	1.13 min	1.3
Track pitch (microns):	1.2	1.28 min	1.6
Laser wavelength (nm):	780	780	780
Modulation:	EFM	EFM	EFM
Error correction:	CIRC	CIRC	CIRC
Objective lens NA:	0.5 to 0.55	0.45	0.45

The pre-recorded DDCD is therefore very much like a CD-ROM disc but with reduced pit geometry, higher numerical aperture (NA) and an improved error protection scheme. DDCD-R and DDCD-RW versions have also been defined in the Purple Book, which was released by Philips in July 2000 as version 0.5.

5. Manufacturing Compact Discs

Manufacturing compact discs involves pre-mastering, mastering and replication. In addition quality assurance is essential to ensure that discs meet the specifications. These are summarised below.

5.1 Premastering CDs

Compact Discs of any format need to be pre-mastered before being manufactured. Audio pre-mastering is the simplest while some formats require complex processes.

- **CD Audio** premastering comprises audio editing and compilation, PQ encoding, audio transfer and sample rate conversion. Enhanced CD premastering involves adding the CD-ROM content to the audio tracks.
- **CD-ROM** premastering can include formatting to ISO 9660/Joliet, Mac HFS and hybrid ISO9660/Mac HFS, CD EXTRA premastering and virus checking.
- **Copy protection,** particularly for CD-ROM, requires a premastering stage for encrypting the content prior to glass mastering.

5.2 CD Mastering

CD and CD-ROM mastering comprises glass mastering and electroforming, illustrated in Figure 14.

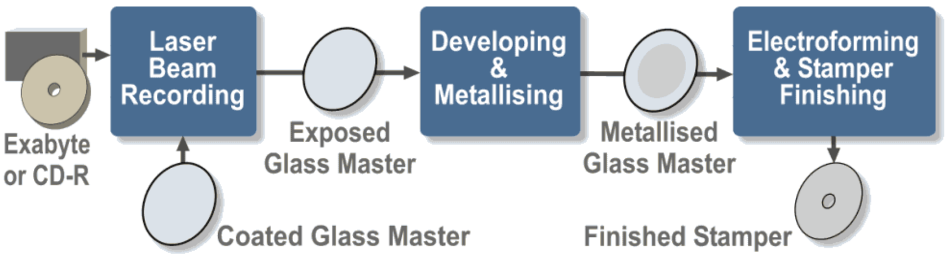


Figure 14 CD Glass Mastering

Source data eg on exabyte or CD-R is used to modulate the laser in a laser beam recorder thus exposing a coated glass master where the pits are to be on the final CD. The glass master is then metallised and stampers produced by electroforming. Copy protection is implemented at this stage.

5.3 CD Replication

CD replication includes moulding, metallising, lacquering, printing and packing. The first three stages (see Figure 15) are implemented by an inline system that includes one or two moulding machines.

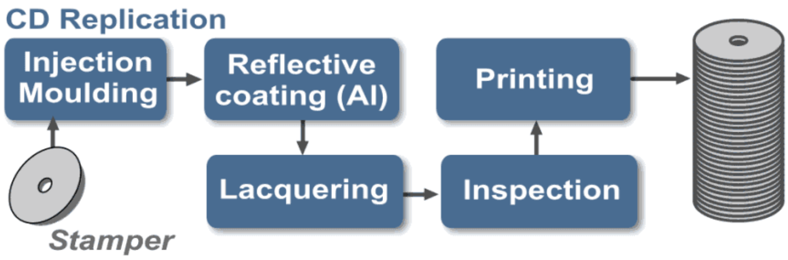


Figure 15 CD Replication

6. The CD Books

The CD Books are mostly coloured and known by their colours. These are summarised below for CD Audio, CD-ROM and CD Recordable.

6.1 CD Audio Books

The CD Audio books comprise the original Red Book (plus the additions for Subcode Channels R-W and CD-Text) and the Blue Book. The Red Book is also available as the international standard, **ISO/IEC 60908**, and is available in English and French from the International Electrotechnical Commission (IEC), www.iec.ch.

Red Book

The Red Book describes the physical properties of the compact disc and the digital audio encoding. It comprises:

- Audio specification for 16-bit PCM.
- Disc specification, including physical parameters.
- Optical stylus and parameters.
- Deviations and block error rate.
- Modulation system and error correction.
- Control and display system (ie sub-code channels) & CD Graphics

The current versions of the Red Book and extensions are listed in Table 12.

Table 12 Red Book Versions & Extensions

Format	Version	Date	Comments
CD Audio	-	May 1999	Red Book
Subcode/Control & Display System	-	Nov 1991	Extension to Red Book for CD Graphics
CD Text	1.0	Sep 1996	Extension to Red Book

Blue Book - Enhanced CD

The Blue Book defines the Enhanced Music CD (also known as CD Extra) specification for multisession pressed disc (ie not recordable) comprising audio and data sessions. These discs are intended to be played on any CD audio player, on PCs and on future custom designed players. It comprises:

- Disc specification and data format for the two sessions (audio and data).
- Directory structure (to ISO 9660) including the directories for CD Extra information, pictures and data. It also defines the format of the CD Plus information files, picture file formats and other codes and file formats.
- MPEG still picture data format.

The latest version of the Blue Book is version 1.0, issued in December 1995.

6.2 CD-ROM and CD-ROM XA Books

The formats based on the CD-ROM are contained in the Yellow Book (CD-ROM), White Book (Video CD) and Green Book (CD-i). In addition there are non-coloured books for multisession CDs and Photo CD. The Yellow Book is also available as the international standard, **ISO/IEC 10149**, and is available in English from the International Electrotechnical Commission (IEC), www.iec.ch.

Yellow Book - CD-ROM

The Yellow Book comprises the CD-ROM specification plus an extension for CD-ROM XA. The Yellow Book for **CD-ROM** was written in 1984 and last updated in May 1999 to describe the extension of CD to store computer data and comprises the following:

- Disc specification, optical stylus parameters, modulation and error correction and control & display system (from Red Book)
- Digital data structure, which describes the sector structure and the ECC and EDC for a CD-ROM disc.

CD-ROM XA Book

As a separate extension to the Yellow Book, the **CD-ROM XA** specification ("SYSTEM DESCRIPTION CD-ROM XA") comprises the following:

- Disc format including Q channel and sector structure using Mode 2 sectors.
- Data retrieval structure based on ISO 9660 including file interleaving which is not available for Mode 1 data.
- Audio and graphics encoding (now obsolete)

The CD-ROM XA book was last updated in May 1991.

White Book - Video CD

The White Book was written by Philips, Sony, Matsushita and JVC. The original version was for Karaoke CD as a replacement for the ageing VHD videodisc systems used in many Karaoke bars in Japan. It defines the Video CD specification and comprises:

- Disc format including use of tracks, Video CD information area, segment play item area, audio/video tracks and CD-DA tracks.
- Data Retrieval Structure, compatible with ISO 9660.
- MPEG audio/video track encoding.
- Segment play item encoding for video sequences, stills and CD-DA tracks.
- Play sequence descriptors for pre-programmed sequences.
- Scan data (for fast forward/reverse) and closed captions.
- Examples of play sequences and playback control.

The various Video CD formats and enhancements are listed in Table 13.

Table 13 Video CD Formats

Format	Version	Date	Comments
Karaoke CD	1.0	1993	Original VCD for Karaoke
Video CD	2.0	Apr 1995	Current Video CD specification
Internet	1.0	Apr 1997	Extension for linking to websites
Super Video CD	1.0	May 1999	Higher quality video using MPEG-2

Green Book

The Green Book defines the CD-i disc format, which is a real-time interactive system delivering video, still images and audio together with full user interactivity. The Green Book comprises the following:

- Disc layout and Mode 2 sector format.
- File structure (based on ISO 9660).
- Data encoding formats for audio, still images and video.
- Hardware architecture.
- Operating system used to play CD-i discs.

The latest version was released in May 1994.

Photo CD Book

Photo CD has been specified by Kodak and Philips based on the CD-i Bridge specification. It comprises the following:

- General Disc format including example of program area layout, index table, volume descriptor, data area, subcode Q-channel skew, CD-DA clips and microcontroller readable sectors.
- Data retrieval structures including directory structure, the INFO.PCD file and microcontroller readable sectors system.
- Image data coding including a description of image coding and image packs.
- ADPCM files for simultaneous playback of audio and images by interleaving.
- Playback program system including playlist files.

The Photo CD book was last updated in December 1994.

Multisession CD

The multisession CD specification for pressed discs is a Philips/Sony standard (actually yellow in colour) defining discs which have two or more sessions but are pre-recorded (pressed) and not recordable.

The only pressed multisession disc format currently defined is the Enhanced Music CD, defined in the **Blue Book**.

The latest version of the Multisession CD book (Version 1.0, December 1995) defines the following:

- Data Format (including Sector Layout, Table of Contents, Program Area of each session and Lead-Out Area of each session).
- Data Retrieval Structure ie the ISO 9660 file system.

6.3 CD Recordable and Re-writable

There are two versions of the CD that can be written to CD-R and CD-RW, both defined in the Orange Book. A third version (using Magneto Optical technology is no longer in use).

Orange Book Part II – CD-R

Part II of the Orange Book is in two volumes:

- **Volume 1** defines recording speeds of up to 4 times nominal CD speed. The latest version is Volume 1, Version 3.1, dated December 1998.
- **Volume 2** defines recording speeds up to 48 times nominal CD speed. The latest version is 1.2, dated April 2002.

Both volumes contain the following sections:

- Disc specification for unrecorded and recorded discs.
- Pre-groove modulation.
- Data organization including linking.
- Multi-session and hybrid discs.
- Recommendations for measurement of reflectivity, power control etc.

The Orange Book does not contain information on the application for a CD-R disc, which can be used to store data from any of the pre-recorded CD formats defined in the books listed above.

Orange Book Part III – CD-RW

The Orange Book Part III defines the CD-ReWriteable format, which can be written to, erased and overwritten with new data. CD-RW discs have a lower reflectivity than a pre-recorded CD, so they must be played back on CD-RW enabled CD players. Part III is in three volumes.

- **Volume 1** defines recording speeds of up to 4 times nominal CD speed. The latest version is Orange Book Part III: CD-RW, Volume 1, Version 2.0, dated August 1998).
- **Volume 2** (High Speed) defines linear recording speeds between 4x and 10x nominal CD speed. The latest version is 1.1, dated June 2001).
- **Volume 3** (Ultra Speed) defines linear recording speeds between 8x and 24x nominal CD speed. The latest version is 1.0, dated September 2002.

CD-RW discs can contain data for any CD-based format, although as mentioned above they will not play back on all CD hardware.

6.4 Contact Details for CD Books

These Books are obtainable from either of the addresses below:

Philips Intellectual Property & Standards, Email: info.licensing@philips.com
URL: www.licensing.philips.com

Building WAH, Prof Holstlaan 6,
5656 AA Eindhoven
or P.O. Box 220 5600 AE Eindhoven
The Netherlands
Fax: +31-40-2732113

Building SFF 8, Glaslaan 2,
5616 LW Eindhoven
or P.O. Box 80002, 5600 JB Eindhoven
The Netherlands