Introduction to CD and CD-ROM

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by Graham Sharpless

Southwater Business Park,
Worthing Road, Southwater,
West Sussex, RH13 7YT, UK

Tel: +44 (1403) 739600
Fax: +44 (1403) 732601
FreePhone: 0800 626698

Email: tech@disctronics.com
URL: www.disctronics.com

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Introduction

Compact discs have been so successful they have pushed vinyl discs into the museum and overtaken the compact cassette as the most popular format for audio in the home, in the car and anywhere else where pre-recorded audio is to be found.

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.

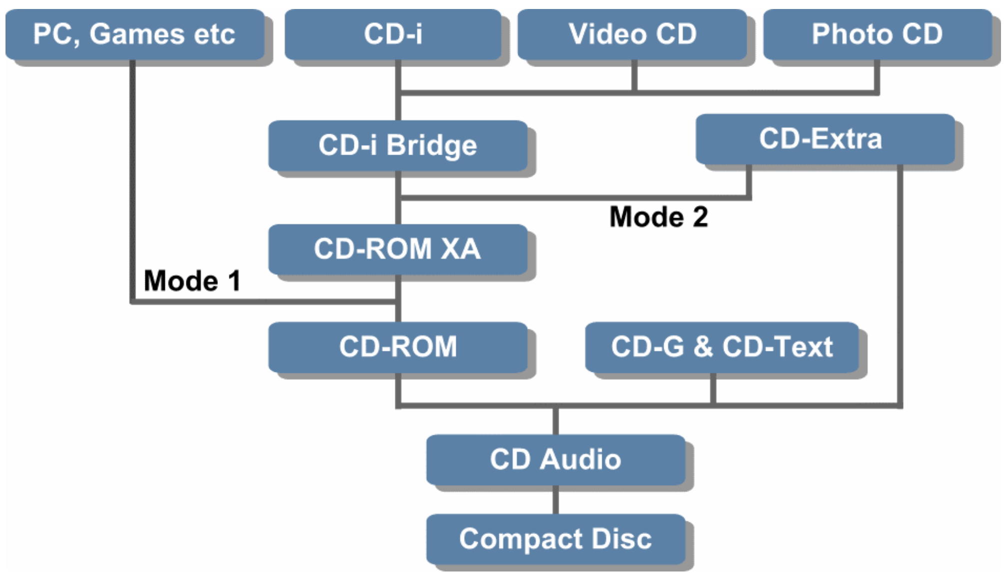
In 1984, the CD-ROM *Yellow Book* specification was published allowing the CD to be used for computer data storage applications. Since then several formats have appeared including CD-ROM XA, CD-I, Enhanced CD and Video CD. These compact discs are physically identical to the audio CD but contain other 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, encyclopaedias and kiosk information systems.

Other new technologies have been developed alongside the CD. One of these, the MPEG-1 video standard, allows 74 minutes of high quality video to be stored on a CD. The Video CD standard uses MPEG-1 for a disc, which, like the audio CD, can be played on a range of different hardware.

The future of the compact disc is now under threat from both the Internet and DVD. However, while CD-ROM sales have started to fall, forecasts indicate that CD Audio sales will continue to grow over the next few years. The Internet is likely to ensure growth of the overall music and software markets and help to increase overall CD and DVD sales.

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 the diagram below and described below.



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

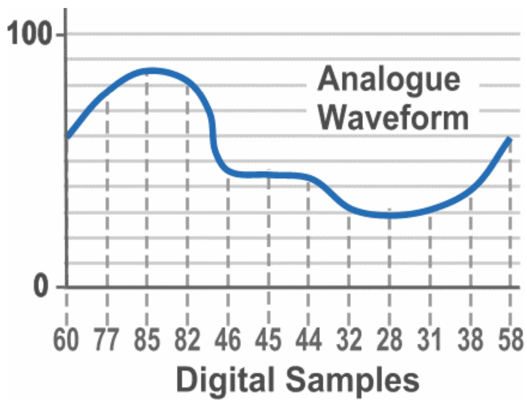
The superior quality of CDs and their compact size is made possible by the use of digital technology combined with laser pickup.

Digital Audio

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.



Digital technology stores samples as numbers. The example here 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).

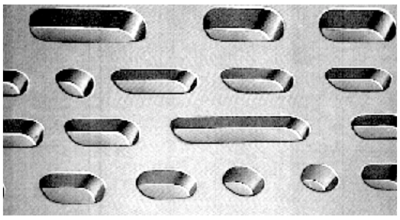
In practice the range of values and sampling rate must be high enough to ensure accurate reproduction of the original analogue waveform. The upper limit for the human ear is about 20kHz so the audio must be sampled at 40,000 times per second or higher (since two samples are required for both halves of 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. This can also be given as 783.216 million bytes, where one byte = 8 bits. To reduce the chance of errors, error correction codes are added to this data, resulting in nearly four times this data actually stored on one CD.

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.

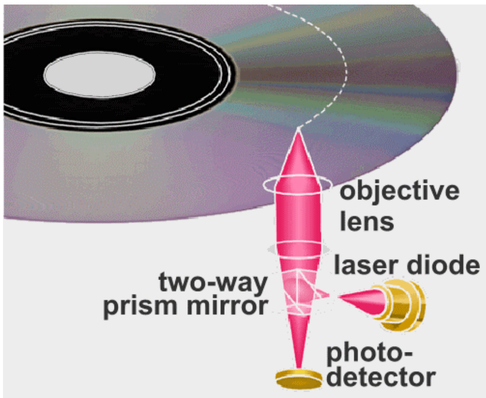
Laser Technology

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 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 mins 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 identical pit sizes and spacing. However, the pits (illustrated above) 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 diagram), 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 radially to follow the pits 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**. 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. When the laser beam falls on a pit very little is reflected. The changing light pattern detected is then converted into a series of zeros and ones, which are then decoded into the original audio or computer data signal.

The main difference between CDs and laserdiscs (apart from the size of disc) is that the CD uses a digital technique where the pits indicate whether a data bit is '0' or '1'. Also laserdiscs can be either CAV (Constant Angular Velocity) or CLV (Constant Linear Velocity), but all CDs use CLV.

Storing Audio on the Compact Disc

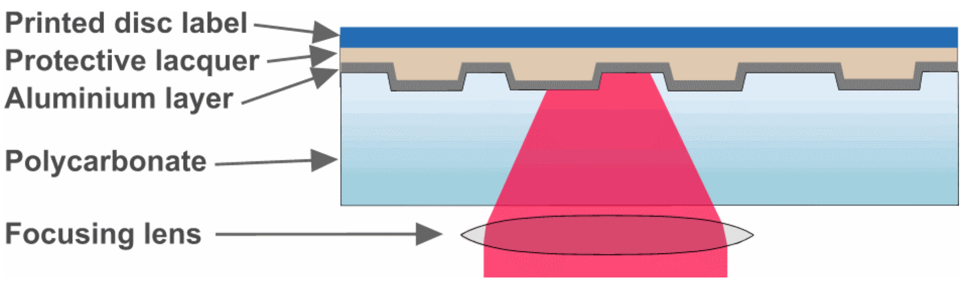
The compact disc was designed to store at least one hour of high quality stereo, digital audio. Philips and Sony worked together on the CD audio specification (known as the *Red Book*). The main features of this specification are listed in the table below.

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
Objective lens numerical aperture:	0.45	

All audio CDs are CLV discs, which means that they are played at a constant velocity of between 1.2 and 1.4 m/s. The rotation speed (rpm) will reduce from the centre to the outside of the disc by a factor of 2.4. This 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.

CD construction

The compact disc comprises a sandwich as shown in the diagram. 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.

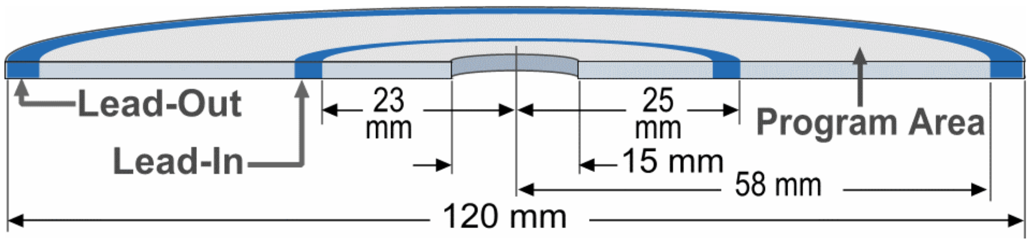


Pits are embossed into the polycarbonate surface by an injection moulding process. The aluminium layer provides a reflective surface, which is protected from corrosion and damage by a lacquer on which a disc label can be printed.

Disc Layout

CDs measure 120mm in diameter with a 15mm diameter centre hole. The audio or computer data is 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.

All audio CDs are played at a constant linear velocity (CLV) of between 1.2 and 1.4 m/s. The angular velocity (rpm) will reduce from the lead-in to the lead-out by a factor of 58/25 = 2.32. This means that pits retain the same geometry wherever they are on the disc and there will be no change in performance across the disc.



The annular space is divided into three main areas:

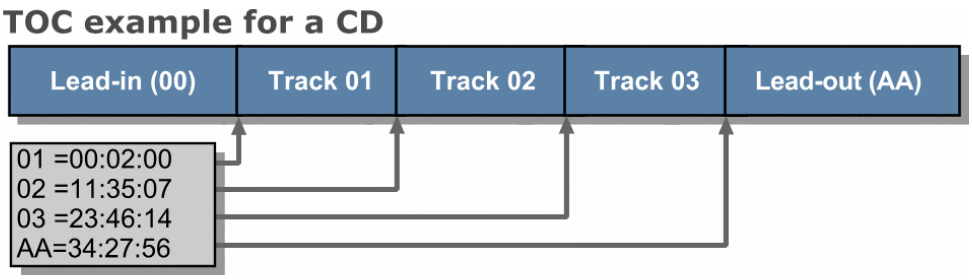
- **Lead-in,** which contains no audio data but does contain other information relating to the audio content. It is used to allow the laser pickup head to follow the pits and synchronise to the audio data before the audio begins
- **Program area,** which contains up to 74 minutes of audio data. This data can be divided into up to 99 tracks each at least 4 seconds in length. A pause of 2 seconds may be inserted between tracks. Audio may be physically divided into tracks, with silence in between, or run continuously between two or more tracks.
- **Lead-out** which contains data silence

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

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 below) 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.



Track start times (but not indexes) are defined in the Table of Contents (see diagram) in the Lead-in area. The TOC comprises absolute times for the start of each track and is used by CD-players to access each track, allowing fast random access to tracks 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.

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, do not usually affect the disc's playability. Therefore the CD specification includes CIRC error correction to compensate for these defects followed by EFM.

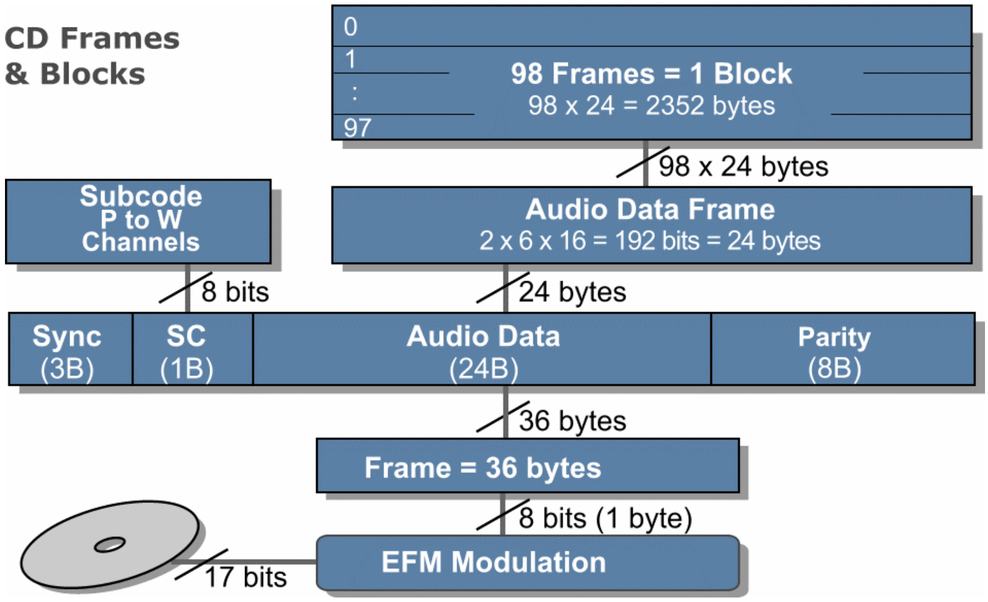
- A **CIRC** (Cross Interleaved Read-Solomon Code) encoder adds two-dimensional parity information, to correct errors, and also interleaves the data on the disc to protect from burst errors. CIRC corrects error bursts up to 3,500 bits (2.4 mm in length) and compensates for error bursts up to 12,000 bits (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. 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 a third 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 as shown below. The resultant frame comprises 36 bytes and 98 frames are combined to form a block.



Starting from the top, 98 frames are combined to produce a block of audio data, which comprises 2,352 bytes. 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 data (see below).
- 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, which converts each 8-bit byte into 14 bits and adds 3 padding bits to ensure that the pits and lands are always at least 3 symbols in length and not more than 11.

Sub-code Channels

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

- The **P-channel** simply indicates the start and end of each track
- The **Q-**channel contains the timecodes (minutes, seconds and frames) the Table of Contents (TOC) (in the lead-in), track type and catalogue number.
- **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. As 75 blocks are read per second from the disc, at normal speed, the sub-code data rate is 7.35 kB/s. Each channel (eg the Q-channel) has a data rate of 7.35 kb/s or 0.92 kB/s. The R to W channels have a data rate of 5.513 kB/s, or about 3.1% 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.

The graphics and text are contained in the sub-code channels R to W, which occupy only about 3% of the capacity of a normal CD. However it does allow graphics and text to be displayed while the music is being played.

The R to W data can be in any of the following modes defined within the sub-code channels.

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 hifi audio equipment available. They only need a television set to see the graphics and text which are the song lyrics and the owner 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 is a more recent addition to the CD audio specification. It 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) to identify sound and audio-visual recordings. It is known as International Standard ISO 3901. 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 independent format it is in. The ISRC is contained in the subcode (Q-channel), is unique to each track and may not be re-used.

Each ISRC comprises 12 characters divided as follows:

Length (chars)	Description
2	Country (eg GB for UK)
3	First owner (allocated by Phonographic Performance Ltd for audio)
2	Year of recording (actually the last two digits)
5	Designation code (assigned by first owner)

In applying the ISRC problems can occur. The following list clarifies some of these:

Example	Result
Re-mix: multiple recordings produced in the same recording session without any change in orchestration, arrangement or artist	new ISRC per recording
Playing time changes	new ISRC
Compilation without editing of individual tracks	same ISRCs
Processing of historical recordings	new ISRCs
Back catalogue	new ISRC for first re-release
Recordings sold, distributed by agent(s)	same ISRCs

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

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

Email: philippa.morrell@ifpi.org
Telephone: +44 (0)20 7878 7900
Fax: +44 (0)20 7878 7950
Website: www.ifpi.org

HDCD

High Density Compatible Digital (HDCD) is a recording process developed by Pacific Microsonics, which enhances the quality of audio from compact discs giving an end result that is more acceptable to audiophiles than standard CD.

HDCD discs use the least significant bit of the 16 bits per channel to encode additional information to enhance the audio signal in a way that has been shown does not affect the playback of HDCD discs on normal CD audio players. The result is a 20-bit per channel encoding system. HDCD 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.

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. The CD-ROM disc is therefore like a pre-recorded floppy disk with a very large capacity. Any computer data can be pre-recorded on a CD-ROM. The specification of a CD-ROM disc is summarised in the table below.

Parameter	Value	Comments
Data capacity	682 Mbytes	Assuming 74 minutes
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 below
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. It can hold nearly 700 megabytes (MB) of data, the equivalent of nearly 500 high-density floppy disks. 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.

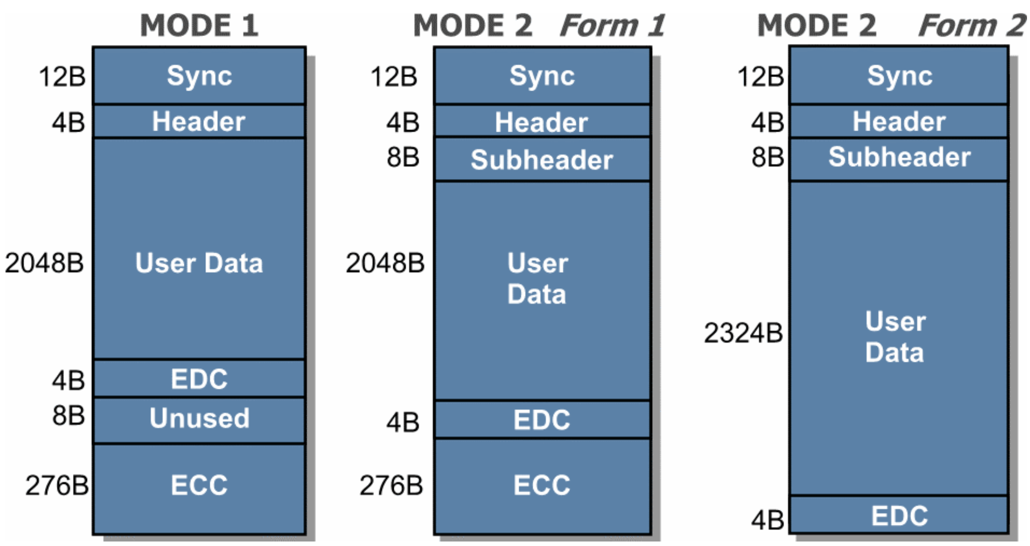
The physical parameters are identical to those defined in the *Red Book*. A CD-ROM is, in appearance, identical to an audio CD. The use of the data it contains is different. While audio CDs can be played at only one speed, CD-ROM drives exist with a range of speed options up to 50 times normal speed or even more. As the speed increases the access time also decreases.

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

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

CD-ROM Sectors & Modes

CD-ROM sectors are equivalent to the audio blocks (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 diagram below).



- **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 data.

The Mode 1 and Mode 2, Form 1 sectors are identical in capacity and error correction. The only difference is the presence of the sub-header 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 eg video data where occasional errors can be masked and do not cause a problem. The Video CD format, for example, uses Mode 2, Form 2 sectors for video data.

CD-ROM File Structures

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 structure 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 **Joliet** specification was designed to resolve a number of deficiencies in the original ISO 9660 file system particularly when used with Windows95. 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 supplementary 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 compatibility.

Other file structures also exist for non-MSDOS 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.

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.

CD-ROM Drives

To read the data from a CD-ROM disc requires a CD-ROM drive as a computer peripheral. This can provide nearly 700 megabytes (MB) of read-only data storage on removable media, the equivalent of nearly 500 high-density floppy disks.

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 drives 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.

CD-ROM Applications

When CD-ROMs were first introduced, the main applications were for 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, 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, Games consoles and CD-i. 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), directory 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** are popular in China but not in the USA or Europe.

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.

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 such as SafeDisc prevent both individual copying of a CD-ROM (to a CD-R or hard disk) and manufacture of a pirate version. SafeDisc2 uses a unique authentication technology that prevents re-mastering of CD-ROM titles and unauthorized copies. It comprises three key features:

- A digital signature that cannot be copied to CD-R or be re-mastered.
- An encrypted wrapper protecting the content.

- Anti-hacking software that prevents the compromise of its security features.

Publishers who decide to use SafeDisc will need to license the technology from Macrovision. SafeDisc's main features are:

- Exceptional level of protection from hacking based on several years of experience and research into copy protection systems.
- Compatible with over 98% of CD-ROM drives in use. SafeDisc is transparent to the user.
- Any hacking of one particular title cannot lead to a generic hack.
- Technology continuously being enhanced and improved to keep ahead of potential hackers.
- Approved by Philips as compatible with the Yellow Book specification.
- SafeDisc supports multiple disc games, patch upgrades and network play.
- SafeDisc supports Windows 95 and Windows 98 but not DOS, CD-ROM XA discs or Macintosh titles. Windows NT will be supported in 1999.
- Executables must use 32 bit code.

During glass mastering a unique authentication signature (watermark) is added. SafeDisc adds software to the disc to read the signature and use it to authenticate the disc. Executable files are decrypted in real-time, preventing access to the decrypted version.

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.

CD-ROM Formats

There are a number of different CD-ROM based formats in use. These may be divided according to how the data is formatted on the disc and to their use. Although they all comply with the *Yellow Book*, the way sectors (ie frames) are formatted and used is different.

The various formats may also be divided into two categories according to their use.

- **Generic** disc formats are designed for use with a wide range of hardware. Examples are CD Extra and Video CD.
- **Proprietary** disc formats are designed for a specific hardware platform. Examples are PC and Mac CD-ROMs. Such discs will offer maximum functionality but can be played successfully only on the hardware for which they were designed.

These various formats are listed below together with the recordable CD formats for completeness.

Format name	Mode(s)	File structure	Comments
PC CD-ROM	mode 1 or 2	ISO 9660 or Joliet	Most common format
Mac CD-ROM	mode 1	HFS	Based on Mac operating system
CD-i	mode 2	ISO 9660+	Superset of ISO 9660.
CD-ROM XA	mode 2	ISO 9660	Combines CD-ROM and CD-i
Video CD	mode 2	ISO 9660	A CD-i Bridge format
Enhanced CD	mode 2	ISO 9660	Multi-session audio + data
CD-R	any	any	Write once CD Recordable
CD-RW	any	any	CD Re-Writable

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:

- The graphics formats include 256 colour modes, which are compatible with PC formats and CD-i.
- The audio used is ADPCM (Adaptive Delta Pulse Code Modulation), which is also defined for CD-i.

The CD-ROM XA format has not been successful in itself but there are three important formats based on it: 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.

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. It comprises:

- Disc format defining CD-I Bridge discs as conforming to the CD-ROM XA specification.
- Data retrieval structure as per ISO 9660.
- A CD-i application program, which is mandatory and stored in the CDI directory.
- Audio data coding, which includes ADPCM and MPEG.
- Video data coding for compatibility with CD-i and CD-ROM XA.
- Multi-session disc structure including sector addressing and volume space.
- CD-i related data since all CD-i players must be able to read CD-i Bridge data

Examples of CD-I Bridge formats are:

- CD-Interactive (CD-i), an almost obsolete format developed by Philips for multimedia edutainment
- Photo CD for storing photo files on a CD in a range of resolutions suitable for display and printing, now rarely used
- Video CD for up to 74 minutes of video using MPEG-1 plus menus and playlists

- Super Video CD offering higher quality MPEG-2 video.

CD-interactive (CD-i)

CD-i is defined in the *Green Book*. It is a multimedia system originally intended for the home, but now used for limited education and training applications. 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.

Video CD

Video CDs are defined in the *White Book*. They 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. Special purpose designed Video CD players have been developed in the Far East for which the Super Video CD (SVCD) format was developed with MPEG-2 video for higher quality. A full-length movie can be stored on disc this way in a quality similar to DVD but on three discs not one. Super Video CD and video CD version 2.0 are compared in the table below.

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.

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. *White Book* Video CDs are characterised by the use of multiple tracks. Video CD ver 2.0 uses constant bit rate encoding (CBR).

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.

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 (optionally followed by audio tracks) 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.

Video CD Directories and Files

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

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. Players from China will play SVCDs and also players from Philips, Toshiba and Samsung.
- Most PCs will play Video CDs and SVCDs using suitable software decoders.

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. The producer of such discs can get the benefits from two titles but only needs to produce one. The user with only a CD audio player will be unaware of the data content, while the user with a CD-ROM drive in a PC will be able to play the audio and use the data content. Applications include the addition of video or sleeve notes with graphics/photos plus more interactive and esoteric applications.

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. This problem is recognised and one solution hides the data in an extended pause before track 1, where the audio starts. This seems to work on most players but is not an ideal solution.

Enhanced CD (CD Extra)

Enhanced CDs are a type of mixed mode CD developed by Philips and Sony in conjunction with Microsoft and Apple. Often referred to as CD EXTRA these discs contain two sessions, each of which comprise lead-in, program and lead-out areas. The first session contains up to 98 audio tracks; the second session contains the data track. When played on an audio player, it only sees the first session and so does not try to play the data session. The specification (the *Blue Book*) is based on the multi-session pressed disc specification with some application specific additions for handling lyrics, titles and stills.

The main features of such discs are as follows.

- Playable on a wide range of hardware including PCs under Windows 95/98, Macintosh computers, and dedicated CD Plus 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.

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.

DDCD

Double Density CD 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 will be available in read-only, write-once and re-writable versions. It is intended only for data storage not for CD audio. The following table compares DDCD with CD-ROM.

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

Manufacturing Compact Discs

Manufacturing compact discs involves three distinct sets of processes, pre-mastering, mastering and replication. In addition quality assurance is essential to ensure that discs meet the specifications. Finished discs, that have passed QA inspection, are then printed and packaged. Finally more and more customers are demanding a range of fulfilment services for the finished disc. These are summarised below.

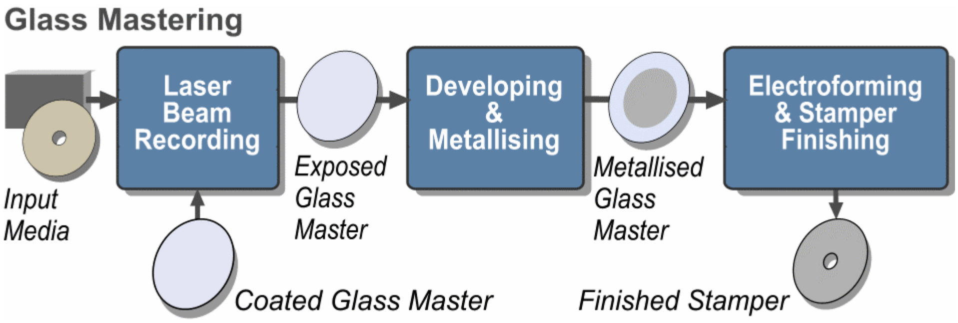
Premastering CDs

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. No one tool is capable of pre-mastering all formats.

- **CD Audio** premastering comprises audio editing and compilation, PQ encoding, audio transfer and sample rate conversion. While U-matic tapes were standard at one time, CD-Rs and Exabyte tape are now more popular formats for delivered content that needs premastering.
- **CD-ROM** premastering can include formatting to ISO 9660/Joliet, Mac HFS and hybrid ISO9660/Mac HFS, CD EXTRA premastering and virus checking.

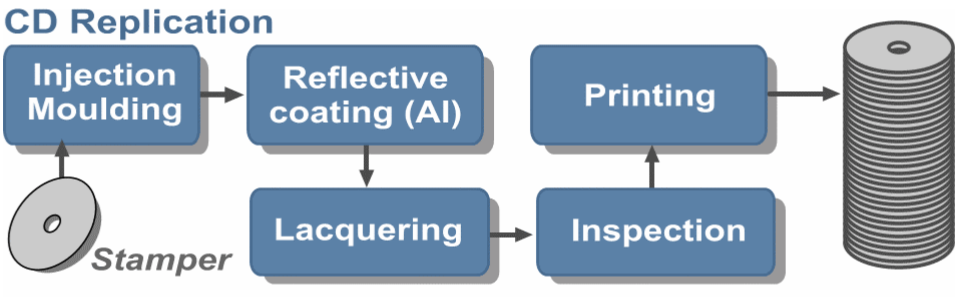
CD Mastering

CD mastering comprises glass mastering and electroforming, illustrated in the diagram below:



CD Replication

CD Replication includes moulding, metallising, lacquering, printing and packing. The first three stages are carried out by an inline system that comprises one or two moulding machines plus downstream equipment.



Fulfilment

Replication of CDs must now be complemented by a wide range of fulfilment services including the following.

- **Automated packing** in all standard packages to meet the most demanding requirements.
- **Bespoke packaging solutions** including the design and differentiation of customers' products.
- **Secure warehousing** monitored by round the clock security and CCTV.

- **Full 'pick and pack' service** using computerised inventory control for same-day shipment.
- **Distribution** and shipping service to all major world destinations
- **State-of-the-art logistics** and order tracking capabilities.
- **Mailing services** from individual units upwards.
- **E-commerce solutions** including website design & implementation, financial transactions and order processing.

Disctronics

Disctronics is one of the largest independent CD and DVD disc manufacturers, with plants in the USA and Europe offering a total capacity of 1 million CD and 100 thousand DVD discs every day, seven days a week. The company has replication plants in the UK, France, Italy and Texas, plus sales offices in Paris and Los Angeles as well as a rapidly growing fulfilment division in the UK. We offer CD & DVD premastering, mastering, copy protection, on-line order tracking, replication, fulfilment, CD cards, custom CDs and e-commerce services for the music, software and home video industries. Disctronics is ISO 9002 registered, accredited by IRMA, ELSPA and FACT and is a founder member of IODRA.

Disctronics thrives on offering the best service to our customers. In addition to our disc replication and fulfilment services, we also provide information and advice to our customers where and when they need it. This is particularly important for new technologies such as DVD where even the most experienced are still learning.

For more information on CD, CD-ROM and DVD replication email **sales@disctronics.com** or visit our website **www.disctronics.com.**

Disctronics Manufacturing (UK) Ltd Southwater Business Park, Worthing Road, Southwater, West Sussex, RH13 7YT, UK	**Tel:** +44 (1403) 739600 **Fax:** +44 (1403) 733786 **FreePhone:** 0800 626698 **Email**: sales@disctronics.com **URL**: www.disctronics.com
Disctronics Fulfilment Services Focal Point, Fleming Way, Crawley, West Sussex, RH10 2JY, UK.	**Tel**: +44 1293 590400 **Fax**: +44 1293 590471 **E-mail**: dfs@disctronics.com
Disctronics Texas Inc 2800 Summit Avenue, Plano, Dallas, Texas 75074, USA	**Tel**: +1 972 881 8800 **Fax**: +1 972 881 8500 **Email**: sales@discusa.com **URL**: www.discusa.com
Disctronics France 24, rue Evariste Galois, BP 35, F-81 001 ALBI Cedex, France 5-7, rue de l'Admiral Courbet, F-94 160 SAINT MANDE, France	**Tel:** +33 5 63 78 22 50 **Fax**:+33 5 63 78 22 55 **E-mail**: jgiraud@disctronics.com **Tel:** +33 1.53.66.15.40 **Fax**: +33 1.53.66.15.50 **E-mail**: cmadsen@disctronics.com
Disctronics Italia SpA Via Rossini, 4 20067 Tribiano, Milano, Italy	**Tel**: +39 02 90621.1 **Fax**: +39 02 90630564 **Email**: atricomi@disctronics.com