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# **New Formats for Music: DVD & SACD**

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# 1. Introduction

The Compact Disc is now 20 years old and, while it is likely to continue for many more years, new formats are now available offering higher quality and additional features, but still on the familiar 12 cm optical disc. These include DVD-Audio, developed by the DVD Forum, and SACD, developed by Philips and Sony. Consumers therefore have a choice of several optical disc formats for their music, which offer higher quality and more features than music downloaded via the Internet.

- The **CD** is still the format of choice for most people. It is compact; the quality is high enough for most and it is most suitable for use in cars and on the move. Enhanced CDs offer additional multimedia content such as videos for playing on a PC.
- **DVD-Video** is becoming more popular for music videos, which offer not just high quality video but also surround sound, neither of which is available on a CD. DVD-Video, however, is not designed as a music carrier and is less suitable for audio-only applications. It also cannot match the quality available from DVD-Audio or SACD.
- **DVD-Audio** is the latest member of the DVD family of pre-recorded optical disc formats and is designed to be the next-generation high-quality audio format. DVD-Audio offers very high quality, surround sound, longer playing times plus additional features that are not available on CDs. DVD-Audio discs can also carry video, like DVD-Video titles, and limited interactivity. Capacity of a single layer DVD-Audio is at least 74 minutes of high quality full surround sound audio. In addition the disc can accommodate the same audio encoded as Dolby Digital for playing on existing DVD-Video players. At the time of writing, the DVD Forum is working on a hybrid version allowing DVD-Audio discs to play on CD players, but in stereo, CD quality only.
- **SACD** (Super Audio CD) also offers high quality audio and optional surround sound but no images, video or interactivity. SACD discs can be hybrid and include a CD audio layer which will play on normal CD players, albeit at CD quality. It is being promoted as the successor to the CD, but playable on the billions of CD players currently available as well as on dedicated SACD players. SACD discs will not play on DVD-Video players unless they are designed to play SACD.

With the increase in penetration of surround sound systems in homes, stimulated by the growth in DVD, more and more consumers will want their music in this format. DVD-Video offers surround sound, using Dolby Digital or DTS audio, DVD-Audio and SACD offer uncompressed high resolution audio as well as surround sound, but only DVD-Audio offers all this plus optional video, stills and other non-audio features as well.

The existence of both DVD-Audio and SACD does create confusion amongst consumers, who may defer purchasing a suitable player until it is clear which format will win. The obvious solution, which is available from a number of manufacturers, is a combination player that plays all the above mentioned formats.

This document describes the formats, their capabilities and differences. At the time of writing it is not totally clear whether one format will win and which one that might be, although with the addition of a hybrid version, DVD-Audio appears to be a front runner.

## 1.1 Requirements for a New High Quality Music Format

An International Steering Committee (ISC), consisting of the IFPI, RIAA and the RIAJ with the major international music companies, produced a set of recommendations as long ago as May 1996:

- Copy protection system with copyright identification to include the ISRC.
- Anti-Piracy Measures to include SID codes.
- Compatible with CD format.
- DVD-Audio discs to carry audio, video and data.
- Conditional Access to additional content on the discs.
- Six audio channels of the highest possible sound quality.
- Accessibility & Disc Functions better than CD players.
- Packaging must not involve a disc caddy.
- Disc durability should be greater than CDs.
- Slide show during audio playback.
- One-sided 12-cm disc is favoured.
- Minimum playing time at maximum quality 74 minutes.

## 1.2 Some History

The development and introduction of DVD-Audio and SACD took several years to complete.

The **DVD-Audio** specification was defined by the DVD Forum and released in 1999, but it took until mid 2000 before players were released and even longer for discs to appear. The delay was due to the need to develop suitable copy protection. All DVD-Audio players also play DVD-Video discs and almost all DVD-Audio discs also play on DVD-Video players.

In the meantime, **DVD-Video** has become an important format for music videos and is encouraging consumers to want their music in surround sound.

**SACD** appeared in 1999 as an audiophile format in stereo only, but in 2001 the first surround sound players and discs appeared. SACD is not approved by the DVD Forum, but was developed by Philips and Sony as a replacement for the CD.

## 1.3 Which Format to Buy?

Consumers who are aware that DVD-Audio and SACD exist are confused and ask which player they should buy.

DVD-Audio discs offer high quality surround sound using a DVD-Audio player and suitable amplifier/speakers. When played in a DVD-Video player the same surround sound experience can be obtained with some loss in quality, which most consumers may not notice.

Consumers will want to be able to play the music that they like and this may determine which player they buy. But consumers who want titles across both formats will need to buy a combi-player that plays DVD-Audios and SACDs.

For audiophiles the choice of DVD-Audio or SACD is one of personal preference, either the way each sound or the titles available. Some consumers have bought players of both formats so that they have a wider choice of titles to choose from. Many consumers will be happy with Dolby Digital or DTS coded audio as found on DVD-Video discs.

## 2. DVD-Audio vs SACD

DVD-Audio and SACD are described in more detail in the following sections. However, there are some major differences in the features and applications of the two formats. Firstly, while both formats are derived from the CD, **DVD-Audio** is a member of the DVD family, and is closely associated with DVD-Video. DVD-Audio offers high resolution, multi-channel audio plus extra content such as video and still images. These discs can also include DVD-ROM content.

**SACD** was designed as a higher resolution audio only format with no extra video or still images and will not play on DVD-Video or DVD-Audio players.

Each format is available in three versions: single layer, dual layer and hybrid. These are listed in Table 1.

**Table 1 DVD-Audio & SACD Disc Formats**

	Single Layer	Dual Layer	Hybrid
CD audio layer	No	No	Yes
DVD-AV layer	4.7 GB Audio + Video	8.5 GB Audio + Video	4.7 GB Audio + Video
SACD layer	4.7 GB Audio only	8.5 GB Audio only	4.7 GB Audio only

Note that a CD audio layer is present only on hybrid versions.

- A **hybrid SACD** comprises a CD layer and a SACD layer.
- A **hybrid DVD-Audio/Video** disc combines DVD-Audio and DVD-Video data on one layer and CD audio data on a second layer.

### 2.1 Features Summary

Table 2 summarises the capabilities of the three formats.

**Table 2 DVD-Video, DVD-Audio & SACD Features Summary**

	DVD-Video	DVD-Audio	SACD
High resolution audio	No	Yes	Yes
Multi-channel audio	Yes	Yes	Yes
Audio coding	DD/DTS/PCM	PCM/MLP	DSD & DST
Max bit rate (Mb/s)	6.144	9.6	-
Video and still images	Yes	Yes	No
Menus & Navigation	Yes	Yes	No
Copy protection	Weak	Strong	Stronger
Plays on DVD-V player	Yes	Yes <sup>1</sup>	No
Plays on DVD-A player	Yes	Yes	No
Plays on CD player	No	Yes (hybrid)	Yes (hybrid)

### 2.2 Audio Coding and Quality

The audio on the three formats is coded differently. DVD-Video uses Dolby Digital and optionally DTS, which are lossy compression formats. DVD-Audio

<sup>1</sup> Most DVD-Audio discs include a DVD-Video section that will play on existing DVD-Video players

uses linear PCM at a much higher resolution than for CD. SACD uses one-bit over-sampled Direct Stream Digital (DSD).

### 2.3 Direct Stream Digital (DSD) vs PCM

One of the main differences between DVD-Audio and SACD is that while the former uses PCM (pulse code modulation) to code the audio, SACD uses DSD.



#### PCM coding

PCM (Pulse Code Modulation) has been used for the compact disc for the last 20 years and codes the audio as samples. For the CD, samples are taken at a rate of 44.1 kHz and there are 16-bits per sample for each of the two stereo channels. However, it has been recognised for some time that the CD does not offer a high enough resolution to satisfy audiophiles.

DVD-Audio uses PCM at up to 96 kHz sampling rate (192 kHz for stereo only) and 24 bits per sample, so offering much higher resolution.

#### DSD coding

DSD coding is illustrated in Figure 1, which shows the coding of a sine wave. The DSD bitstream is mostly ones where the sine wave is positive and mostly zeros where it is negative. Any waveform can, in theory, be represented using DSD, which is also called delta-sigma modulation.

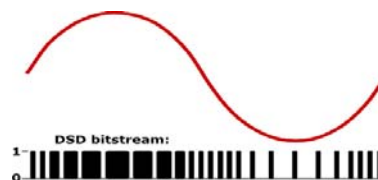


Figure 1 DSD Coding

The width of the DSD 'pulses' are proportional to the value of the waveform at that time; hence this method is also referred to as pulse width modulation (PWM).

DSD uses a bit rate of 2.8224 Mb/s which is 64 times the CD sampling rate of 44.1 kHz and therefore four times the data rate required for each channel of a CD. For low frequencies DSD has a large signal to noise ratio, but above about 10 kHz the noise increases and dynamic range decreases. High frequency noise is one of the criticisms of this method of coding audio.

#### DSD vs PCM encoding and decoding

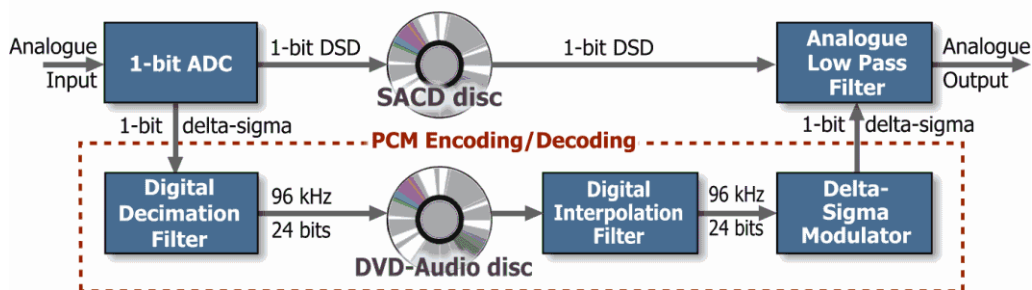


Figure 2 PCM vs DSD Encoding & Decoding

Figure 2 shows the differences between DSD and PCM as implemented by SACD and DVD-Audio respectively. In most digital recording systems, the analogue input is digitised via an analogue to digital converter (ADC) which supplies a 1-bit output at a high bit rate. For SACD this output is DSD at 2.8224 Mb/s and needs no more processing before being stored on an SACD disc. In the player a simple analogue low pass filter is needed to remove the

unwanted high frequency noise. This is a simple and elegant solution, but DSD is difficult to edit without converting to multi-bit PCM.

For PCM and DVD-Audio, the 1-bit delta-sigma output (usually at a higher bit rate than for DSD) is converted to multi-bit PCM (eg at 96kHz and 24 bits) and can then readily be mixed and edited before being stored on the DVD-Audio disc. In the player the PCM is converted to analogue using two more stages than are required for DSD. These include digital interpolation and re-encoding to DSD using a delta-sigma modulator.

### DSD problems

DSD generates noise (which can be filtered out) and is wasteful of bandwidth. A 6-channel recording requires a bandwidth of nearly 17 Mb/s and a 4.7 GB disc would store only 37 minutes. Therefore SACD uses a lossless packing technique (Digital Stream Transfer) to store 74 minutes of audio comprising a 6-channel DSD and a stereo DSD recording with no loss in quality.

DSD is also not easy to edit without converting to PCM, although new hardware is now available to make this easier. One conclusion is that DSD makes digital to analogue conversion easier and, in the past, cheaper, but PCM, at a high enough sampling rate and quantisation, can provide a more reliable and accurate representation of the music. The result is, probably, that both can provide a very high quality level that should be acceptable to most audiophiles.

## 2.4 Multi-Channel and Stereo

DVD-Audio/Video and SACD discs all offer 5.1-channel surround sound, but while most DVD-Audio titles are surround sound, many SACDs are stereo only.

In addition to multi-channel audio there is usually the option to include a stereo mix for users without a surround sound system.

All SACDs contain a separate stereo DSD mix that can be played instead of any multi-channel mix that may be present.

DVD-Audios normally include either a separate stereo mix (which can be included within the MLP encoded main audio file or as a separate file) or the player can down-mix the multi-channel audio to stereo using down-mix coefficients which are stored on the disc with the audio.

## 2.5 Added Extras vs Audio-only

**DVD-Video** discs offer a wide range of features including subtitles, menus, still images and interactivity, which are being used extensively for movie titles and offer additional content possibilities (such as artist photos, biographies, lyrics etc) for music videos.

Most of these features are also available for **DVD-Audio**, which can include slide shows of still images during the playing of the audio, video clips, menus and interactivity. DVD-Audio discs can also be played in an audio-only mode, like CDs, where the TV or other display is not available (eg for in-car applications) or is not required.

**SACD** is an audio-only format and so does not include any added extras.

## 2.6 Compatibility and Hybrid Discs

**Hybrid SACDs** include an optional CD layer, which plays on existing CD players. The independent labels have realised that without a CD layer they are limiting potential sales to a fraction of the music buying public.

**DVD-Audio** discs usually include DVD-Video content. As a result these discs offer multi-channel surround sound on all existing DVD players worldwide. In addition a future hybrid version will also play on CD players.

The introduction of a hybrid version of DVD-Audio and SACD formats does offer a smooth path to high resolution, surround sound audio while maintaining CD compatibility. It is possible for all new releases at some time in the future to use a hybrid format rather than CD. Disc/player compatibility is shown in Table 3.

**Table 3 Disc/Player Compatibility**

Disc	Player			
	CD audio	DVD-Video	DVD-Audio	SACD
CD audio	Yes	Yes	Yes	Yes
DVD-Video	No	Yes	Yes <sup>2</sup>	No
DVD-Audio	Yes <sup>3</sup>	Yes <sup>4</sup>	Yes	No
SACD	Yes <sup>3</sup>	No	No	Yes

## 2.7 Copy Protection

Both DVD-Audio and SACD offer copy protection to prevent the audio content being copied to another pressed or recordable disc.

- **DVD-Video** offers only CSS copy protection of the audio and video content.
- **DVD-Audio** uses CPPM, which is stronger than CSS, with watermarking of the audio content. Some players include a digital output via Firewire, but copy protection for this output is or will soon be available.
- **SACD** uses a number of copy protection methods including physical watermarking. As a result SACD discs cannot be read on PCs because the control data in the lead-in is encrypted. SACD players do not include a digital output so it is possible only to access the analogue outputs to make a copy.

<sup>2</sup> If the player is a universal player, as all are at present

<sup>3</sup> For hybrid discs with a CD layer

<sup>4</sup> If the disc contains DVD-Video compatible content

### 3. DVD-Audio and SACD in the Market

Both formats are available on the market, but there are differences in the numbers of titles and players and the way each format is being promoted.

The worldwide SACD catalogue now boasts more than 700 titles. Sony Music, Universal Music and EMI have released SACD titles and more are planned. The number of titles has been a direct result of active promotion by Philips and Sony.

There are around 500 DVD-Audio titles from companies such as Warner Music, EMI, 5.1 Entertainment, Tacet, SurroundedBy, Naxos and others.

A growing number of music titles, meanwhile, are being released on DVD-Video. This format lends itself to the music genre – something that VHS never did – with the result that an increasing percentage of DVD-Video disc sales are now music based.

Industry forecasts show that DVD-Audio player sales will overtake SACD and, if the hybrid DVD-Audio format becomes available, DVD-Audio disc sales are likely to overtake SACD in the next two years. In the meantime, DVD-Video music discs are outselling the other two formats.

#### 3.1 Surround Sound

For the US and Europe, the key selling point for both DVD-Audio and SACD is surround sound. Many SACD discs do not include a CD layer or surround sound. Many labels believe that there is little benefit to all but a very few consumers in offering a stereo only disc and they are therefore including a surround sound mix.

If surround sound is more important than audio quality, DVD-Video could be regarded as providing the features that consumers want, ie high quality video, surround sound and audio quality better than the CD.

#### 3.2 Hardware

DVD-Audio and SACD players started to appear in 2000 and there are now many models available for either format, plus a few that play both.

Early **SACD** players were stereo only, but now all SACD and DVD-Audio players support multi-channel surround sound. DVD-Video players with SACD will play SACDs and the Dolby Digital audio available on most DVD-Audios.

There is a wide selection of DVD-Audio models including single tray players, multi-disc changers, home theatre systems, car audio players, hand-held portables and PC based players. DVD-Audio hardware is affordable for the consumer and is likely to become a standard feature in many players.

#### Combi DVD-Audio/SACD players

Unlike formats such as video tape (where the three competing formats were all physically different) DVD-Audio and SACD are both based on a 12 cm diameter disc using DVD technology. This makes it possible to design players to play all CD and DVD formats, allowing consumers to make a choice of disc based only on the content not on the format. Although combi-players are few in number, it is expected that more will become available in the future. Current combi players are available from Pioneer, Marantz, Onkyo and Apex.

### Home-Theatre-in-a-Box systems

There are now many affordable 'home-theatre-in-a-box' systems comprising a DVD player, surround sound amplifier, 5 satellite speakers and a subwoofer (see Figure 3). A small number of such systems do support either DVD-Audio or SACD and this number is likely to increase in the future.



Figure 3 Home-Theatre-in-a-Box

### Player connections

DVD-Audio and SACD players have 5.1 channel analogue outputs (see Figure 4). These need connecting to a suitable multi-channel amplifier. The digital outputs will carry only Dolby Digital for subsequent decoding.



Figure 4 Audio Connections on Player

### Surround Sound Systems

Instead of large full range speakers, consumers can install small satellite speakers (for the higher frequencies) plus a subwoofer (for the low frequencies). This approach works because the low frequency sounds are non-directional. Tests show that surround sound music will give significantly better results, even on a budget surround sound speaker system, than stereo. Figure 5 below shows a possible loudspeaker placement for a surround sound set up with five satellites (or full frequency range speakers) and a subwoofer.

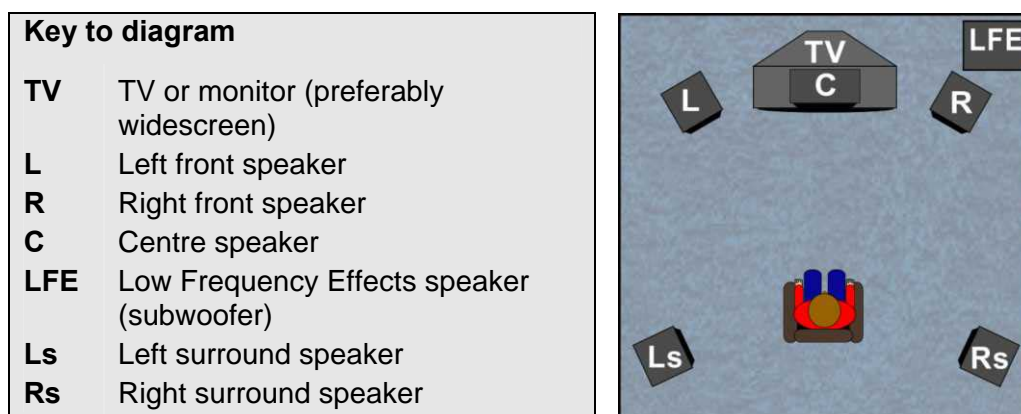


Figure 5 Surround Sound Speaker Placement

The speakers need a suitable surround sound amplifier that provides sufficient power and can handle both full frequency speakers and satellites/subwoofer systems. For the latter the amplifier will need to provide 'bass management' to direct the low frequency components from all five channels (and the .1 LFE channel) to the subwoofer, which is normally self-powered. The amplifier should also allow configuring each channel for position (ie distance from the listener) and balance.

## 4. DVD-Video for Music Videos

DVD-Video was designed as a format for movies and videos, based on recommendations from the Hollywood studios. But it has proved a more successful format than VHS for music videos. This is because the audio quality, even using Dolby Digital, is vastly superior to VHS and it offers higher quality video, extra features and interactivity.

All DVD-Video discs must include audio encoded as Dolby Digital and, optionally, DTS, both of which offer 5.1 channel surround sound.

Other DVD-Video features such as multiple camera angles, subtitles for the lyrics, menus and navigation, still images for artist biographies etc can be used in music videos to give added value for the consumer.

DVD-Video singles have also been produced and comprise some video but also up to three tracks without video.

### 4.1 Audio Coding

DVD-Video discs can carry up to 8 streams of audio using a number of non-compressed and compressed audio coding methods. Each audio stream can contain from 2 (stereo) to 6 or 8 (surround sound) channels depending on the source material available. Multi-channel audio will be down-mixed to stereo in players where there is no surround-sound decoder.

#### Audio coding formats

Normally, when used with video, a compressed format will be used. Audio coding formats available for DVD-Video include Dolby Digital, MPEG-1 & MPEG-2, LPCM and DTS. All DVD-Video discs, both for PAL and NTSC regions, must include Dolby Digital mono, stereo or multi-channel audio as a minimum requirement.

- **Dolby Digital** provides up to 5.1-channel surround sound. The coding format is lossy so some of the original audio quality will be lost. Bit rates from 64kb/s (mono) to 448kb/s are available, the highest bit rate being recommended for full 5.1 channel surround sound.
- **MPEG** is an optional audio format for DVD-Video, but is rarely used.
- **Linear PCM (LPCM)** offers up to 8 channels of 48kHz or 96kHz sampling frequency and 16, 20 or 24 bits per sample but not all at the same time. The maximum bit rate is 6.144 Mb/s, but this does not leave enough bandwidth for any associated video.
- **DTS (Digital Theater Systems) Digital Surround** uses compression with a sampling frequency of 48 kHz at up to 20 bits per sample. The data rate can range from 64 kbps to 1.536 Mb/s, with typical rates of 768 and 1536.

### 4.2 Video, Stills and Menus

DVD-Video offers video, still images and menus providing a complete multimedia experience for the consumer. The video features used in some movies are also available and include multiple camera angles (eg for different views of a band which can be selected at will by the consumer) and subtitles in a choice of languages. Still images also use MPEG-2 encoding and can be used on their own or as a menu. The use of menus and still images offers a range of extra features including artist photos and biographies.

## 5. DVD-Audio for High Quality Music

The DVD Forum working group WG4 developed the DVD-Audio specification, which was originally released in March 1999 but it took another year to add copy protection and watermarking. DVD-Audio players have been available in the USA since July 2000 and several of the major music companies and some independents have released several hundred DVD-Audio titles. Most players are also DVD-Video capable and nearly all DVD-Audio discs will also play on DVD-Video players, in full surround sound but using compressed audio.

DVD-Audio is not just a niche format for audiophiles, but could grow into a mass-market format suitable for all music genres. With the penetration of home cinema systems growing rapidly in the USA and Europe, the demand for such a format is likely to increase. Also car manufacturers will exploit the audio-only capabilities by installing DVD-Audio systems in cars, possibly coupled with DVD-based navigation systems. The future addition of a hybrid version, making the discs play on CD players can only help the chances of DVD-Audio becoming the music format of choice. The main features of the DVD-Audio specification include:

- High quality multi-channel audio with copy protection
- DVD-Audio players will play CDs
- A wide range of quality levels and channels allowing flexibility for the content owner
- Extensible to include new technology when available
- Additional added value content including video, stills, text and menus
- User friendly navigation system
- Connection to the Internet for the latest information for that title

### 5.1 Why DVD-Audio is Needed

Some people in the industry have questioned why the DVD-Audio format is needed, since DVD-Video can provide audio, video, stills and navigation. However, while DVD-Video offers multi-channel LPCM audio, the available bit rate is only 6.144 Mb/s compared with DVD-Audio's 9.6Mb/s, which is further enhanced by MLP to offer the maximum sampling rate and quantisation with maximum playing time. DVD-Audio is also designed to play in audio-only players (such as in-car players) and offers slideshows and text that are optimised for audio. Finally DVD-Audio offers CPPM, which is much stronger than CSS for DVD-Video. These differences are summarised in Table 4.

**Table 4 DVD-Audio vs DVD-Video**

Feature	DVD-Audio	DVD-Video	Comments
Audio bit rate (Mb/s)	9.6	6.144	DVD-Audio allows higher quality
MLP compression	YES	NO	For higher quality & playing time
For audio-only players	YES	NO	Important for mobile players
Copy protection	Good	Poor	Required by content owners

For compatibility with existing players, most DVD-Audio titles being released include a DVD-Video compatible zone using Dolby Digital or DTS encoding. This means that each DVD-Audio disc will play in the tens of millions of existing DVD-Video players around the world, although for maximum quality a DVD-Audio player is required.

## 5.2 DVD-Audio Formats

The DVD Forum's WG4 has defined two different versions of the DVD-Audio disc format, one for pure audio applications the other for audio with video. With DVD-Video this gives a total of three formats, which are listed in Table 5.

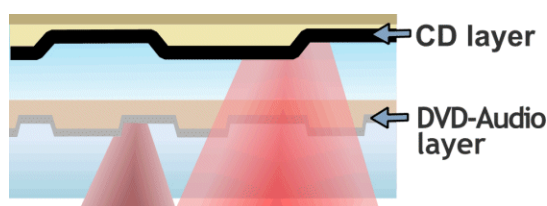
**Table 5 DVD-Audio Disc Formats**

Format	Contents	Will play on
<b>DVD-Audio</b> (no video)	Audio disc with optional text, menus & still pictures but no video	Audio-only, DVD-Audio and Universal players
<b>DVD-Audio</b> (with video)	As DVD-Audio plus a subset of the DVD-Video specification	Universal player and DVD-Video player (video part only)
<b>DVD-Video</b>	Video but no DVD-Audio content	DVD-Video & Universal player
<b>Hybrid</b>	DVD-Audio (and DVD-Video) plus a CD layer.	DVD-Audio (& DVD-Video) & CD players

All DVD-audio discs will also play on audio-only players (such as in-car players) with no display screen, similar to CD audio players. Note that it is recommended that all discs should include a DVD-Video section with audio in Dolby Digital format for compatibility with existing DVD players.

### DVD-Audio disc formats

DVD-Audio discs can be any DVD physical format, ie DVD-5, DVD-9 or DVD-10. In addition the DVD Forum has approved a hybrid DVD-Audio format (Figure 6) to include a CD layer which will play on CD players. However there are a number of obstacles to overcome before this format becomes available.

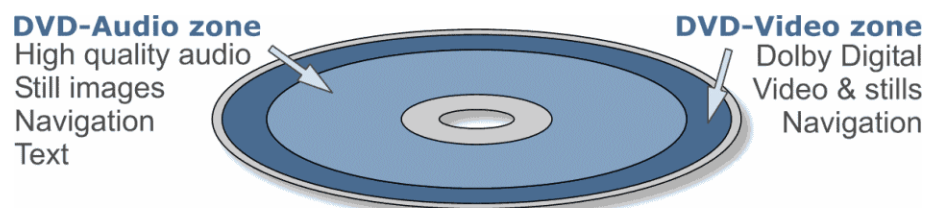


**Figure 6 Hybrid DVD-Audio Disc Format**

- The DVD Forum will need to confirm that such a format is playable not only on CD players but that the DVD content will play on DVD players. Some DVD players look for a CD first so may not see the DVD layer.
- Replication capacity for hybrid SACDs is already inadequate for SACDs, so it will take some time for capacity to increase to a level that will supply demand for hybrid DVD-Audio and SACD discs.

## 5.3 Structure of a DVD-Audio Disc

A DVD-Audio disc contains audio, still video and other information on the disc as files (see Figure 7). The DVD-Audio data (in the **AUDIO\_TS** directory) will usually be followed by DVD-Video data (in **VIDEO\_TS**).



**Figure 7 DVD-Audio Disc with DVD-Video Content**

The **DVD-Audio zone** comprises the following files in the AUDIO\_TS directory.

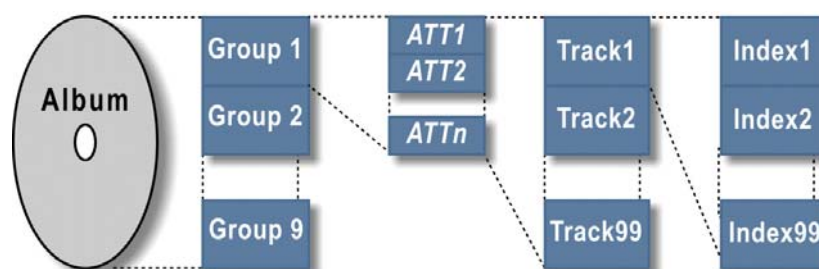
- **SAMG** (Simple Audio Manager) is the equivalent of the CD Table of Contents, allowing playing of tracks on audio-only players.
- **AMG** (Audio Manager) is the table of contents for both the audio and video zones and contains the AMG information and menu.
- **ASVS** (Audio Still Video Set) containing the still images for all audio tracks
- **AOBs** (Audio Objects) containing the audio data.

The audio data comprises a single stream with no other data streams. Therefore it is not possible to interleave audio with other data such as still images. These and other data must be pre-loaded into the player's memory before the audio plays or during pauses, eg between tracks. DVD-Audio discs are not region coded so can be played on any suitable player anywhere.

The **DVD-Video zone** can follow the audio data, and comprises video and other files, which should include the same audio as in the DVD-Audio zone but encoded as Dolby Digital. The video files comply with a subset of the DVD-Video specification, with no multi-angle or seamless branching. Due to bandwidth limitations, it is not possible to store high quality audio and video as part of the same video sequence on a DVD disc. Therefore any video on a DVD-Audio disc will use the existing audio coding specified for DVD-Video, including Dolby Digital, DTS and LPCM.

### Groups and tracks

Each side of a DVD-Audio disc is called an **Album**. Each album can be subdivided into a maximum of **9 Groups**, each Group into **99 Tracks** and each track into **99 Indexes**. This structure is shown in the diagram below.



**Figure 8 DVD-Audio Disc Hierarchy**

For navigation purposes there is an additional layer between Groups and Tracks comprising Audio Titles (**ATTs**). These are logical entities that are used to allocate tracks to Groups. A Group may comprise one or more ATTs and each ATT can link to one or more Tracks. An ATT can be used to play audio tracks only or video content (for video capable players). Note that the ATTs are ignored by audio-only players, which use only the SAMG to play tracks.

## 5.4 Audio Coding

The DVD-Audio specification makes use of a scalable linear PCM multi-channel and stereo encoding format, down-mixing control and optional audio formats. The video objects use the same audio encoding as DVD-Video discs. The audio coding modes for audio and video objects are listed in Table 6. As shown, DVD-Audio offers sampling rates up to 192 kHz for stereo audio and up to 6 channels at 96 kHz maximum for surround sound. Audio bandwidths of up to 96 kHz are therefore possible with signal to noise ratios up to 144 dB.

Table 6 Audio Coding Modes

Parameter	Audio Object	Video Object
Coding mode	LPCM or MLP	LPCM or Dolby Digital
Sampling frequency (kHz)	44.1 to 176.4, 48 to 192	48/96
Bits per sample	16/20/24	16/20/24
Max channels	6 (96 kHz), 2 (176.4/192 kHz)	6 or 8
Max bit rate (Mb/s)	9.6 (for LPCM)	6.144

### Meridian Lossless Packing

To increase the playing time of a DVD-Audio disc to at least 74 minutes per layer for the highest quality and to allow the highest quality for stereo, WG4 has chosen Meridian Lossless Packing (MLP), also referred to as Packed PCM (PPCM). MLP is easy to implement and will not alter the decoded signal in any way. Decoding MLP requires relatively little computing power even for six channels of 24-bit/96 kHz audio.

**But how important is MLP?** DVD-Audio offers a maximum bit rate of 9.6Mb/s, higher than the 6.144Mb/s possible with DVD-Video but not high enough for 6 channels of 24-bit/96kHz audio, which would require a bit rate of 13.8 Mb/s. Using MLP reduces the bit rate to less than half this and increases the playing time from 65 minutes to at least 74 minutes and allows room for extras such as still images, menus, text and video. MLP provides many more features including the possibility to choose the quantisation in one-bit steps. The possible sampling rates, quantisation and numbers of channels for both PCM and MLP audio are shown in Table 7.

Table 7 Possible Sample Rates &amp; Quantisation

Sample rate	Quantisation (bits)	1 ch	2 ch	3 ch	4 ch	5 ch	6 ch
44.1 or 48 kHz	16 to 24	LPCM or MLP					
96 or 88.2 kHz	16	LPCM or MLP					
96 or 88.2 kHz	20 or 24	LPCM or MLP					MLP
176.4 or 192 kHz	16, 20 or 24	MLP	Not possible				

Examples of typical playback times with MLP are shown in Table 8 for high quality stereo, high quality surround sound and CD quality stereo.

Table 8 Example Playback Times Using MLP

Audio combination	Configuration	Playing time Single layer	Playing time Dual layer
2 channels	192kHz, 24bits	120 mins	215 mins
6 channels	96kHz, 24bits	86 mins	156 mins
2 channels	44.1kHz, 16 bits	13 hours	23.6 hours

### Down-mixing

Down-mixing of multi-channel audio to stereo is facilitated by the inclusion of down-mix coefficients to obtain best results. This technique is called **Smart Content** (System Managed Audio Resource Technique). 16 coefficient tables can be re-defined for each Album and the appropriate coefficient table selected from these 16 for each Track. All players must implement down-mixing.

## Channel Groups

The maximum data rate for the audio data is 9.6Mb/s, which means that the sampling frequency for multi-channel audio is limited to 96kHz or less. To make best use of the bandwidth available, multi-channel DVD-Audio can be encoded as two **Channel Groups** with different parameters (ie sampling frequency and quantisations) for each group.

The channel groups can be used for any number of channels from three (L, R and C) upwards. Note that the sampling frequencies and quantisations (bits per sample) used must be as shown in Table 9.

**Table 9 Channel Group Options**

	Channel Group 1	Channel Group 2
<b>Sampling Frequency (kHz)</b>	48/44.1	48/44.1
	96	96 or 48
	88.2kHz	88.2 or 44.1
<b>Bits per sample</b>	16	16
	20 bits	20 or 16
	24 bits	24, 20 or 16 bits

For sampling frequencies of 176.4 and 192 kHz the number of channels is two or less, so only one channel group can be used. Table 10 shows the allowable combinations of channel groups.

**Table 10 Channel Allocation Between Channel Groups**

	Ch0	Ch1	Ch2	Ch3	Ch4	Ch5
1	C					
2	L	R				
3	L	R	S			
4	L	R	Ls	Rs		
5	L	R	Lfe			
6	L	R	Lfe	S		
7	L	R	Lfe	Ls	Rs	
8	L	R	C			
9	L	R	C	S		
10	L	R	C	Ls	Rs	
11	L	R	C	Lfe		
12	L	R	C	Lfe	S	
13	L	R	C	Lfe	Ls	Rs
14	L	R	C	S		
15	L	R	C	Ls	Rs	
16	L	R	C	Lfe		
17	L	R	C	Lfe	S	
18	L	R	C	Lfe	Ls	Rs
19	L	R	Ls	Rs	Lfe	
20	L	R	Ls	Rs	C	
21	L	R	Ls	Rs	C	Lfe
	Channel Group 1				Channel Group 2	

The meaning of the various symbols is shown below:

**L and R:** Left and Right

**C:** Centre

**Lfe:** Low frequency effects

**S:** Surround

**Ls and Rs:** Left and Right surround

## Alternative coding formats

In addition to PCM audio, other optional audio formats are possible including:

- **Dolby Digital** (AC-3), which is the audio encoding format to accompany the video on a DVD-Audio disc
- **MPEG-1** stereo or **MPEG-2** multi-channel audio
- Others such as **DTS**, **SDDS** etc

Audio using any of these coding formats must be in addition to not instead of the normal PCM audio on a DVD-Audio disc.

## 5.5 Content Protection

Digital copy protection and watermarking have been developed for DVD-Audio.

### Digital content protection

Until December 1999, DVD-Audio digital copy protection was to be provided by CSS II. However, the existence of the DeCSS software hack for DVD-Video has meant that a better copy protection was needed for DVD-Audio to prevent a similar occurrence. Content Protection for Pre-recorded Media (CPPM) has been developed by 4C (comprising IBM, Intel, MEI and Toshiba) and uses 56-bit keys, instead of the 40-bit keys used for CSS, and the Cryptomeria Cipher (C2) for content encryption.

It allows for a hacked playback device to be revoked using a Media Key Block (MKB), which contains a very large number of keys. Each licensed decoder model has assigned to it a set of unique device keys that allow it to obtain the Media Key (used to encrypt the audio content) from the MKB stored on each DVD-Audio disc and decrypt the audio content (see Figure 9). Any playback device can be revoked in future discs via the MKB. MKBs are unique for every DVD-Audio title and new MKBs must be used every three months to allow devices to be revoked.

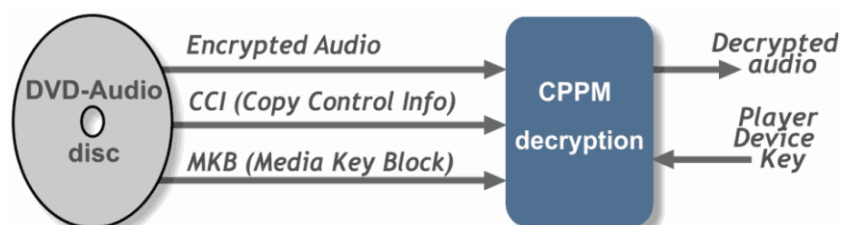


Figure 9 DVD-Audio CPPM Decoding

### Watermarking

The copy protection scheme for DVD-Audio also includes watermarking, needed to identify music tracks and trigger copy protection systems when recording the content supplied as an analogue input. The watermark must remain intact when the content is converted to analogue but not be noticeable in listening tests. Watermarks must provide **transparency** (ie no effect on audio quality), **robustness** (ie be detectable after content processing) and **security** (against forgery).

Verance has created a watermark, which comprises inaudible digital codes embedded into the audio waveform, to meet specifications from the recording industry. It provides both copy protection and content ID and has been used in consumer products since December 1999.

The watermark contains 72-bits of data comprising 4 CCI (Copy Control Information) bits and 8 Usage Identifier bits every 15 seconds plus 60 Content Identifier bits every 30 seconds. This information is used to monitor the distribution and use of the music as well as controlling access to and usage of the content. The embedded watermark travels with the audio content wherever it goes and is claimed to be highly resistant to even the most sophisticated attempts to remove it.

The copy protection features control the usage rules for duplication, such as the number of copies, if any, that can be made. Content identification is achieved by embedding a unique serial number into each piece of audio to allow tracking even when the audio is redistributed by broadcasting or via the Internet.

## 5.6 Additional Content

Additional content can include still pictures, text information, menus & navigation and (optionally) video sequences.

### Still images

Still Images, described as Audio Still Video (ASV), are recorded on disc in a separate file. Each still is an MPEG-2 Intra-frame and can, optionally, be accompanied by a sub-picture for a menu. Up to about 20 still images are pre-loaded into the player's memory before the audio is played or between audio tracks where a mute is acceptable (see Figure 10). This allows the images to be presented either as a slide show or that can be browsed by the user. Transitions for still images include cut, fade, dissolve and wipe. Sub-pictures allow still images to be used as menus or for the display of lyrics etc.

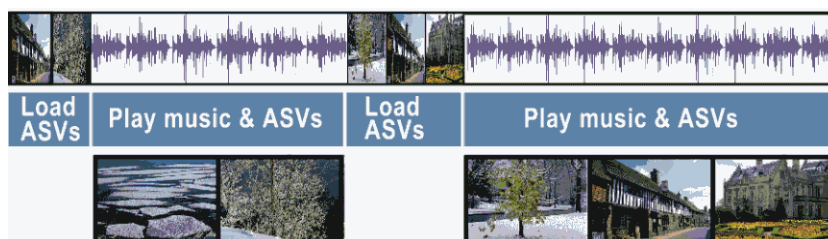


Figure 10 Loading and Playing ASVs

Images are either NTSC or PAL compatible. US players tend not to display PAL images, but most European players will probably be capable of displaying both PAL and NTSC images. Therefore titles for global use should use NTSC images. Also for compatibility with both standard (4:3) and widescreen (16:9) displays, two versions of each image will be required.

### Other content

Other content can include:

- **Text** for artists' names, Internet URLs, lyrics etc. Static text information can be used for the overall content while dynamic text is suitable for lyrics that change during the audio presentation.
- **Video clips** follow the DVD-Video specification but certain functions (including multi-story, parental management and region control) are not supported. The audio part of the video may be presented without the video.
- **Menus and navigation** can be included as on DVD-Video discs, but with restrictions. There are only two menu types on a DVD-Audio disc. The

**main menu** providing a full set of commands and the **track level menu** that only allows scrolling forward and back.

## 5.7 DVD-Audio Players

Most DVD-Audio discs will play on existing DVD players, but for best results new hardware is needed. Players types include the following.

- **DVD-Audio, audio-only players**, such as in-car players, that have no display screen and can only play the audio track by track like a CD player.
- **DVD-Audio players**, which are designed to play audio only with simple text displays and, optionally, a video output for slide shows and menus only.
- **Universal players**, which will play both DVD-Audio (including any video) and DVD-Video discs. It is likely that many future DVD-Video players will be universal players. This is because the addition of DVD-Audio capability will not appreciably add to the complexity and cost of the hardware.
- **PCs and Macs** with DVD-ROM drives that can be upgraded

All available DVD-Audio players also play DVD-Video discs. Universal players are available from Apex, Denon, Integra, JVC, Kenwood, Linn, Marantz, Meridian, Panasonic, Onkyo, Pioneer, Thomson and Toshiba. The earliest players were expensive but prices have fallen. In-car players are also becoming available and may represent an important sector of the market. All players will also play CD audio discs. Some players (eg from Pioneer) are designed to play SACD and DVD-Audio discs.

## 5.8 DVD-Audio Titles

Some of the major music companies and some independents started releasing DVD-Audio software from late 2000. Warner Music and 5.1 Entertainment have between them released most titles but other labels such as DTS, Telarc, Hodie, Naxos, AIX and others have also released titles.

By the end of 2002 over 500 titles were available worldwide, with more planned. Most include a DVD-Video zone allowing the audio, in a lower quality, to be played on DVD-Video players. Many titles include added extras to make them more appealing to the consumer. A typical title comprises about 70 to 80 minutes of high quality 5.1 channel music, the same audio in Dolby Digital or DTS coding format, possibly a music video and DVD-ROM content allowing access to the Internet.

The following music companies have released DVD-Audio titles: **AIX Records**, American Gramophone, Audionet, Bad Dog Records, Bison Head Records, Chesky, **Denon**, Divox, **DTS Entertainment**, **EMI**, Ewe, Exton, **5.1 Entertainment Group** (Silverline, Immergent, Electromatrix), Hi-Res Music, Hodie, MDG, Mode Records, Naxos, Nishimura, Peregrina Records, Pioneer Studios, Rhona Classics, Rykodisc, Starkland, Surroundedby, Tacet, Telarc, Victor Entertainment, **Warner** and **Teldec**. Those in bold have been particularly active.

## 6. Super Audio CD

Philips and Sony have developed an alternative format called Super Audio CD or SACD, which uses a different audio coding method, Direct Stream Digital (DSD) and the (optional) use of a hybrid disc format.

SACD is claimed to fully meet the ISC requirements and to provide a format, which is good for another 20 years. SACD offers high quality, multi-channel audio, CD compatibility, copy protection and added features. The main parameters are shown below.

- Up to 100kHz bandwidth
- 120 dB dynamic range
- Full quality for all channels
- Hybrid disc (CD and DVD)
- Watermarking and copy protection
- Text, graphics and video

The SACD specification is contained in the Scarlet Book. SACD discs are DVD discs in that they use the same sector size, error correction and modulation as DVD discs and the same file system (UDF)

### 6.1 Hybrid Disc Format

The hybrid CD/DVD disc format allows the same disc to play on existing audio players as well as Super Audio CD players. This is possible by moulding the CD-Audio pits on the outside of the otherwise blank DVD substrate (see Figure 11) and using a semi-reflective layer for the DVD metallisation, thus allowing the CD-Audio layer to be read by a conventional CD player.

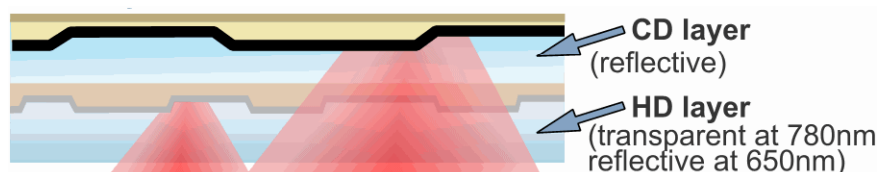


Figure 11 Hybrid SACD Disc Format

The result guarantees that SACD discs play on existing CD players, easing consumer fears of obsolescence. However 'hybrid' discs are more difficult and therefore more expensive to manufacture than CDs.

### 6.2 Copy Protection for SACD

SACD incorporates a layered approach to content protection to give protection against piracy and against consumer copying (see Figure 12).

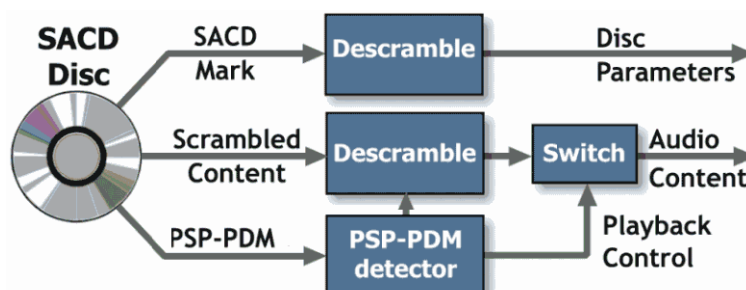


Figure 12 SACD Copy Protection

The layers are:

1. **SACD Mark**, which hides certain disc parameters in the lead-in area by scrambling the data. Drives need this information before they can start

reading the disc. A non-compliant drive will, therefore, not be able to get data from any SACD disc. The consequence of this is that an SACD disc cannot be read using a standard DVD-ROM drive in a PC. Because the data in the lead-in area is scrambled it cannot be read so the PC does not know what the disc is. If it is a hybrid SACD the PC will play the CD layer and ignore the SACD layer.

2. **PSP-PDM**, which is an invisible watermark that is very difficult to write on a recordable disc and can only be mastered with SACD licensed equipment. It involves using Pit Signal Processing (PSP), which modulates the width of pits on the disc. PSP-PDM is used for Playback Control and for content access control as it contains part of the descrambling key.
3. **Scrambled content**, using the SACD synchronous stream cipher, which is optimised to achieve high performance in hardware. It needs a key that is partly hidden in the PSP-PDM on the disc and partly hidden in the player hardware.
4. **Descrambling** algorithm is available in hardware only. The license contract does not allow the algorithm to be made available in software, which would make it too vulnerable for reverse engineering by PC-hackers.

There can also be an optional **Visible Watermark**, which is a 'hologram-like' image that can optionally be placed on the signal side of an SACD disc, using pit signal processing, but with the pit width modulation synchronised so that a pattern can be written. As in the case of bank notes, this mark can be used to indicate to the consumer that the disc is an official product.

### 6.3 SACD Players

SACD players are available from Philips, Sony, Sharp and others. Sony has started adding SACD capability to most of its DVD players including those priced at under \$250. Most SACD players are also DVD players.

Pioneer and a few other manufacturers have released players that will play DVD-Video, DVD-Audio and SACD discs.

### 6.4 SACD Titles

There are over 700 SACD titles available, but few are in surround sound.

- Sony Music titles are mostly stereo and non-hybrid, although Sony has now started producing hybrid discs, having been convinced that that is the way to go. Probably about half of all SACD titles are from Sony Music.
- Universal Music has committed to producing 200 SACD titles in the next year or so, all of which will be hybrid discs.
- EMI/Virgin has released some SACD titles.

About 30 or so independent music companies have released SACD titles. In particular Abkco launched 22 titles of the Rolling Stones in August 2002. Other independents with SACD titles include Academy of Sound & Vision, Albany Records UK, Analogue Productions, Audio Quest, BIS, CCn'C, Challenge, Channel Classics, Chesky, Delos, Digital Music Products, First Impression Music, Fone, Heads Up, Hyperion, Linn Records, Lyrinx, Mobile Fidelity Sound Lab, Octavia, Omega, Opus 3, Pentatone Classics, Red Rose SACD Club, Telarc, Venus Records, Waterlily Acoustics and Zomba (now part of BMG).

## 7. Producing DVD-Audio and SACD Discs

DVD-Audio and SACD titles need different processes and tools for pre-mastering and manufacturing.

### 7.1 Production Tools and Studios

High resolution, multi-channel surround sound recordings require new tools for recording, editing and pre-mastering.

Recording and editing tools for PCM have been available for some time, but the resolution required for DVD-Audio (ie 96 kHz and 24 bits) has been supported only in the last few years.

DSD, although not as new as Philips and Sony claim, has not been supported at all until fairly recently and even now there are few tools and even fewer that support surround sound. Processing DSD is difficult and hardware for this purpose is only now becoming available, but at a higher price.

DVD-Audio authoring requires complex tools similar to DVD-Video authoring, but with additional features to support DVD-Audio.

Suitable tools for some or all of these functions are available from a number of sources.

- **Sonic Solutions** provides a range of tools for DVD-Audio mixing, editing and authoring.
- **SaDiE** also offers a simpler DVD-Audio authoring system to complement their multi-channel editing systems, plus a SACD pre-mastering system.
- **Sony** has recently announced D-MAP, a range of new compact DSD signal processing modules.
- **Philips** has announced the development of the Direct Stream Digital Interchange File Format (DSDIFF).

Other manufacturers of DSD production tools include Merging Technologies, Genex, dCS and Tascam.

Some studios are beginning to adopt DSD as a recording and mastering medium for SACD and CD production. Philips/Sony's Super Bit Mapping Direct technology can be used to convert DSD to PCM for CD.

### 7.2 Authoring DVD-Audio Titles

DVD-Audio discs can include multimedia content which needs authoring in a similar way to a DVD-Video title.

- Firstly, a DVD-Audio title will comprise the PCM or MLP audio divided into Groups and Tracks so that an audio-only player can navigate the audio.
- Authoring is needed to add the still images, video, text and menus plus the navigation and interactivity.
- Thirdly the DVD-Video content (Dolby Digital, images, video etc) needs adding for compatibility with DVD-Video players.
- Finally a disc image is created from the content ready for glass mastering and replication.

Some titles are authored for double-sided DVD-10 discs with the DVD-Audio content on one side and the DVD-Video content on the other. This simplifies the authoring process, but is less than ideal for the consumer.

## 7.3 Manufacturing DVD-Audio and SACD Discs

### Mastering DVD-Audio and SACD

The glass mastering process is identical to DVD-ROM and DVD-Video except that the CSS copy protection is replaced by DVD-Audio copy protection (CPPM). The replicator is responsible for obtaining the necessary license and equipment for implementing CPPM copy protection.

SACDs can be mastered on the same laser beam recorders used for DVDs, with some minor modifications to accommodate the content protection. In particular the Pit Signal Processing (PSP) involves modulating the power of the laser, so that as the beam intensity increases so does the size of the spot used to write the pits. At the same time the length of the pits are modified to compensate for the varying spot size to ensure that the correct pit lengths are retained. Philips rents the encoders to replicators rather than selling them to ensure that they cannot end up in the hands of non-licensees.

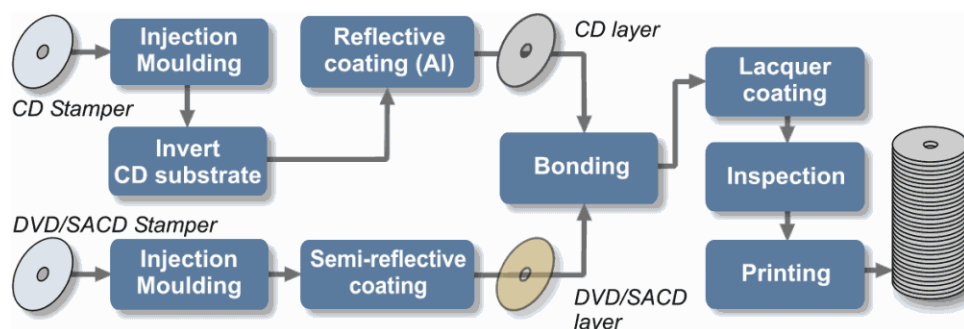
### Replicating DVD-Audio and SACD discs

Non-hybrid discs can be replicated on any DVD replication line.

For hybrid DVD/SACD discs, which contain a CD layer, a modified DVD-9 line is required comprising the following additional or modified processes.

- A CD mould for the CD layer.
- An extra station to flip the layer 1 substrate, which contains the CD layer.
- Alternative to polycarbonate to reduce disc warping.
- A new or modified metalliser for the DVD/SACD semi-reflective layer.
- Lacquer coating stage, which is used for CDs.
- Modified inspection equipment.

The processes required are illustrated in Figure 13.



**Figure 13 Hybrid DVD/SACD Replication**

There are very few replication lines in the world that can replicate hybrid DVD/SACD discs, but more are due to be installed during 2003. The decision by the DVD Forum to allow a hybrid DVD-Audio disc (subject to trials being successful) will create additional demand for such lines.