17

DVD Fundamentals

As much as you might like to completely ignore the technical details of DVDs, even the simplest authoring tasks require some knowledge of the file and directory structures, as well as awareness of the available DVD formats. You'll find that the more you get involved in making DVDs, the more useful this knowledge becomes in gaining the results you want. Since this book is designed to serve as a practical guide more than a set of specifications, if you're inclined to delve deeper into the mysteries of DVD, you might want to investigate other references that focus more on the technical aspects of this storage format. One useful place to start is *DVD Demystified* by Jim Taylor, the second edition published in 2001 by McGraw-Hill. Another valuable resource, available online, is the DVD Forum (*www.dvdforum.org*). Outside of exacting engineering applications, these two resources should satisfy most requirements for in-depth DVD technical knowledge.

The latest generation authoring software does a respectable job of shielding the user from many of the intricacies of file formats, encoding, menu structuring, and directory organization. However, if you're well grounded in this kind of information, it is easier to make informed decisions when planning a DVD project. Each of the DVD formats defined in five distinct books—Book A through E—has particular uses. Each format also suits some playback devices better than others or has limitations in terms of playback. Know these limitations and you'll be more capable of creating titles that can be successfully accessed by the widest audience.

This chapter provides a fundamental overview of the DVD layouts and formats and offers technical descriptions of other aspects of DVD technology that should prove useful to developers.

DVD Technology

In the early 1990's, the DVD Consortium (which is now the DVD Forum) set out to increase the storage capabilities of optical discs without altering the physical diameter that had become standardized with the audio compact disc. There were two obvious ways to do this:

- Compress more data within the span of an individual track
- Add additional layers within the disc itself

Since the work of the consortium has been codified as a set of standards, manufacturers have produced a wide array of DVD implementations. The implementations range from single-sided, single-pressed discs to multiple layered DVD-18 discs that store a substantial 17.9 Gigabytes of data.

Commercial DVD-Video discs, which deliver feature films to a prospective audience of 66-million DVD players in the U.S. as of mid-2003 (according to the DVD Entertainment Group), store as much as 17-billion bytes of data on the disc surface. This equates to a storage capability sufficient to handle nine hours of audio and video content (with appropriate compression on a multilayer disc) or 26 times more data than can be stored on an audio CD. The quality of the content surpasses other forms of video storage within the consumer marketplace, providing significantly better quality than the previous standard bearer—the Laserdisc.

The capability of DVDs to handle multichannel audio has led to the creation of *home theater* entertainment systems that position speakers around the viewer and produce a sensation of being in the midst of the onscreen action. Up to six-channel digital sound can be delivered, generally subdivided in this manner:

- Center channel for dialog
- Left channel for music
- Right channel for music
- Left rear channel for effects
- Right rear channel for effects
- Bass channel

Most of the information stored on a DVD-Video disc is in compressed format. MPEG-2 is typically used for the video content and Dolby Digital (AC3) for the audio content. The MPEG-2 digital audio format is also

sometimes used for audio material stored on disc. These compression technologies make it possible to accommodate the prodigious storage capabilities of the media while delivering very high quality audio and video content.

DVD technology was designed from its inception to be backwards compatible with CDs. This presented an immediate technical challenge since the pits embedded in a CD occur at a different level on the disc surface. There are also as many as four possible discrete surfaces embedded within a DVD disc. The read laser in a DVD player must be able to adjust its focus to retrieve data from the various layers.

This technological difficulty was solved through the use of different lenses, including holographic lenses that can simultaneously focus on more than one distance at a time. The built-in backwards compatibility also embraces Video CD 2.0, an earlier format for distributing video material in MPEG-1 format. Video CDs achieved some success in Japan and Europe, but never made significant inroads in the United States.

Increasing Data Capacity

The first step in increasing capacity beyond the audio CD and CD-ROM is to tighten the spiral and reduce the size of the pits used to form the data impressions.

The second technique for increasing the storage capacity is to add additional layers—up to 4 layers total, two on each side of the disc. The laser beam focus is adjusted as necessary to access data on individual levels. Improved optics are required to achieve accurate data reading, as well as a reduction in the wavelength of the laser beam reflected off the disc surface.

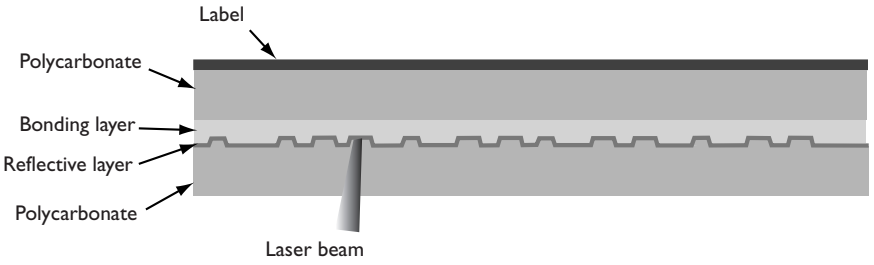
The single-sided, single-layer DVD, as shown in Figure 17 - 1, consists of two 0.6 millimeter polycarbonate substrates that are bonded together to form a disc that is 1.2 millimeters thick. The stamped surface of a single-layer disc is coated with a layer of aluminum through a process called *sputtering*. This aluminum forms the reflective surface upon which the laser beam is used to detect the data pattern. This type of disc has a capacity of 4.7 Gigabytes and is referred to as a DVD-5 disc.

Two methods are typically used to bond the two substrates together:

- Hot-melt method: A thin coat of melted adhesive is spread over each substrate and then the two surfaces are bonded by means of a hydraulic ram. This is the least expensive method of bonding.
- UV method: A thin layer of lacquer is distributed over the disc surface to be bonded, either by rotating the disc or through silk-screening. Ultraviolet light is then applied to harden the lacquer. While this method is more expensive, it forms a bond that is resistant to temperature extremes.

The label surface of this disc can be printed using conventional printing techniques or silk-screening. Impressions molded into the blank substrate can also be used as a substitute for printing a label.

Figure 17 - 1 **Layers within a DVD-5 disc**



A DVD-9 utilizes two separate layers of data. The data layer closest to the laser is composed of a semi-reflective coating that enables the laser to focus on it for data reading or to focus through it to the next higher layer to read the data from the more reflective surface. The capacity of the DVD-9 disc, shown in Figure 17 - 2, is 8.5 Gigabytes.

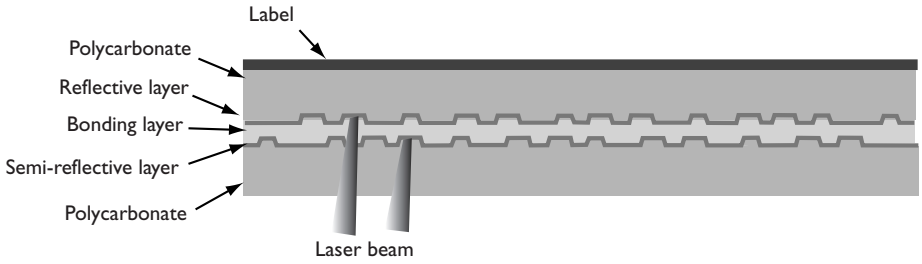
The two substrates of a dual-layer disc are bonded together using one of two methods:

- By means of an optically transparent adhesive film that affixes the layers to each other

- Through a photopolymer material that combines the second layer on top of the first on a single substrate, which is then bonded to the blank substrate

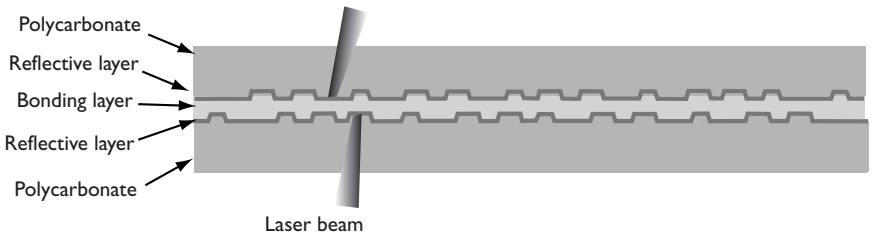
Conventional methods of lithographic printing or screened printing can be used to complete the label.

Figure 17 - 2 **Layers within a DVD-9 disc**



A DVD-10 disc has data on both substrates, using reflective layers on each so that the disc must be physically flipped over in the DVD player or DVD-ROM drive in order to read the data on the second side. This format has a capacity of 9.4 Gigabytes. Since the laser must be directed through both surfaces of the disc, no label is applied to either surface—this is a quick way to recognize this particular format, shown in Figure 17 - 3.

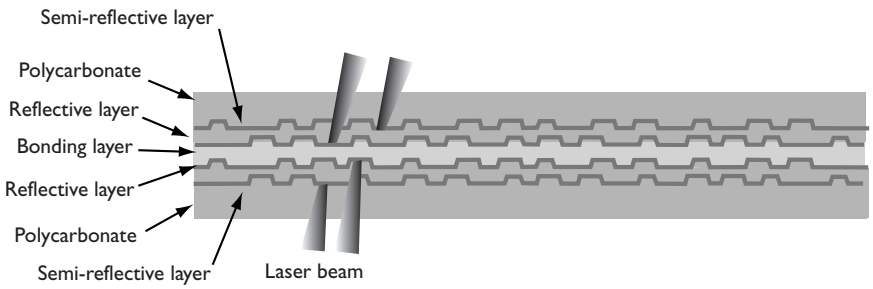
Figure 17 - 3 **Layers within a DVD-10 disc**



The most complex DVD format, and the most expensive to manufacture, is the DVD-18 disc, which includes both dual sides and dual layers, as

shown in Figure 17 - 4. The two layers on each side must be manufactured on a single substrate. One layer is created on a substrate using a conventional stamper to produce the data pattern and then a second stamper creates a data image on a photopolymer material, which is then affixed to the substrate. This same process is followed for the second substrate, which also contains two layers of data, providing a total capacity of 17.9 Gigabytes. As with a DVD-10 disc, this type of disc must be turned over in the player or the DVD-ROM drive in order to access the data on the second side. Similarly, neither surface can be printed with a label, since the surfaces must offer clear access to the laser for data reading.

Figure 17 - 4 **Layers within a DVD-18 disc**



Storing Content on DVD

The addition of new layers to a disc, each with its own microscopic spiral of data, adds to the complexity of manufacturing. For this reason, and the additional costs associated with multilayer disc manufacturing, many commercially released DVD titles utilize only a single layer. This is sufficient to store a typical 135-minute film at a degree of compression that provides a reasonably high quality image. For longer works, or for including multiple movie titles on a single disc, additional layers can be added to the disc to achieve the desired capacity. Approximately 2 Gigabytes of storage is required for each hour of video material compressed with MPEG-2. Title producers can determine the amount of storage needed for a project and then master the disc accordingly.

Unlike a compact disc, which employs a single substrate, a DVD is composed of two 0.6 millimeter substrates that are combined to increase the rigidity. The additional rigidity is also important for the overall disc bal-

ance and for reducing the amount of wobble while the disc is spinning. These are both critical characteristics for ensuring accurate reading of data from the medium.

Reading All Types of Discs

In many ways, the DVD is an extension of the data storage techniques originally perfected for CD-ROMs and CDs, but with its own special characteristics. Just as the vast majority of CD-ROM drives are capable of playing audio CDs, DVD-ROM drives have been designed to be backward compatible with CDs and CD-ROMs. The following table summarizes the similarities and differences between the two types of discs.

Table 2: Comparison of CDs and DVDs

	CD	DVD
Diameter	120 millimeters	120 millimeters
Thickness	1.2 millimeters	1.2 millimeters
Data capacity	680 Megabytes	4700 Megabytes
Layers	1	1, 2, 4
Track pitch	1.6 nanometers	0.74 nanometers
Minimum pit length	0.834 nanometers	0.40 nanometers
Laser wavelength	780 nanometers	640 nanometers

The optical pickup designed for use in a DVD unit is mounted on an arm that positions the laser beneath the disc surface during playback. As you can see from the previous table, the required laser wavelength is different for CDs than it is for DVDs. One technique for handling this difference is to use a twin-laser pickup that features completely separate laser and lens fixtures. If the DVD player or DVD-ROM drive is attempting to read a CD or CD-R, it uses the fixture optimized with a laser wavelength for these media types. For DVDs, DVD-Rs, or DVD-ROMs, the unit employs the laser and lens with the wavelength optimized for DVD media.

A focusing control adjusts the depth of focus to be able to read the individual DVD layers. For a DVD, layer 0 is about 0.55 millimeters above the bottom surface of the disc. The second layer, if present, is another 55 micrometers higher. In comparison, data that is embedded in a CD or CD-ROM appears approximately 1.15 millimeters above the bottom surface of the disc. This difference, as well as the different laser wavelengths

required for reading the data, is the reason that separate lens and laser fixtures must be used for DVD and CD media.

Recordable Forms of DVD

Recordable forms of DVD come in several varieties with varying degrees of compatibility with existing playback equipment. The primary categories are:

- DVD-R—as defined in Book D of the DVD Forum's specifications, this is the write-once form of the media with a standard capacity of 4.7 Gigabytes. The recording surface is a dye layer. Recorded discs are playable in many standard DVD-ROM drives. DVD-R drives can be designed for Authoring or General Use DVD-R media. Authoring media is preferred when masters are being created for replication.
- DVD+R—developed by Sony and Philips outside the purview of the DVD Forum, this format was designed to facilitate wider compatibility of recordable discs with DVD players. The specification for this format is maintained by the DVD+RW Alliance.
- DVD-RW—similar to CD-RW, this approach relies on phase-change technology to support the erasing and rewriting of data. The standard capacity is 4.7 Gigabytes.
- DVD-RAM—defined in Book E of the DVD Forum, this format also uses a phase-change recording layer, which may be single-sided or double-sided. Capacity is 2.6 Gigabytes per side. The RAM stands for Random Access Memory.
- DVD+RW—also developed by the DVD+RW Alliance, this format uses lossless linking technology, a technique that allows the recorder to accurately stop and start data write operations. The media for DVD+RW handles up to 4.7 Gigabytes and offers approximately 1,000 rewrites.

Early in the design process for the writable form of CD-ROM (CD-RW), progress was hampered by the incompatibility of the rewritable discs with the majority of CD-ROM drives. This problem was overcome by the introduction of the Multiread specification for CD-ROM drives, an extension which ensured that drives certified as MultiRead ready could retrieve data from CD-RW discs.

A similar effort has created a Super MultiRead specification that encompasses the range of recordable forms of DVD, so that the various formats

will be readable in Super MultiRead-certified DVD-ROM drives and players. In general, the latest generation of players and DVD-ROM drives handle the full range of stamped, duplicated, and rewritable media quite well. Older players and drives, however, are unpredictable and much more likely to reject the new recordable formats.

DVD-R for Write-Once Applications

DVD-R media and recorders can produce discs that are suitable for premastering of DVD-ROMs or DVD-Videos, as well as discs intended for data distribution and exchange, document imaging, and archiving. Initially, many replication services required DVD masters to be submitted on the Authoring version of the media, which was the original type of recordable disc designed for professional use. The General Use media, designed for consumer use, is now accepted by some replicators, but, as a whole, the industry still favors Digital Linear Tape (DLT) for submissions. General Use DVD-R hardware and media do not allow data to be written to the lead-in area on the disc, which prevents the use of CSS copy protection. However, another form of copy protection, CPRM, can be used with General Use media.

The specification crafted by Working Group 6 (WG-6) of the DVD Forum includes provisions for single-layer, single-sided media or single-layer, dual-sided media. As with CD-R media, both 12-centimeter and 8-centimeter disc sizes are supported, although the large majority of applications rely on the more common 12-centimeter disc size.

Two polycarbonate substrates—one containing a dye layer and reflective coating and the other blank—are bonded together to produce a 1.2-millimeter thick disc for single-sided DVD-R applications. The first forms of DVD-R media used only cyanine dye, which appears violet on the recording side of the recordable disc.

A spiral pregroove extends from the center of the disc to the outer diameter to act as a guide for the laser during recording. A slight wobble in the pregroove in a pre-established pattern generates a frequency used as a carrier signal; the timing information helps regulate servo motors, tracking of the laser assembly, and focus of the beam. Land pre-pits molded into the substrate provide address information and pre-recorded data, used to initiate write operations.

Pulsed laser beams directed at the dye in the pregroove form impressions by searing variable length marks in the dye surface. These marks, consist-

ing of deformation of the substrate material and bleaching of the dye, serve the same purpose as pits in a pressed DVD disc. Areas in the pregroove that are not exposed to the pulsed laser are interpreted as lands.

DVD-R recording requires a more complex write strategy to establish the appropriate lengths for the pits, which are approximately half the size of those on a CD-R disc. The spacing between the pits and lands within the spiral data pattern is also significantly less than on a CD-R disc. To compensate for the extra precision required during write operations, the laser pulses are very carefully controlled, both in terms of intensity and duration. During recording, the laser is rapidly modulated between the power setting required for writing and the setting used for reading to avoid overheating the media surface and to regulate the size of the mark seared in the dye. A technique known as Optimum Power Calibration (OPC) is used to perform test write operations to a specified calibration area on the recordable media surface and then to read back the test pattern and adjust the laser power settings to match the recorder to the media. Given the extra precision required for recordable operations using DVD-R, this feature becomes a highly desirable addition to any recorder and helps ensure the most consistent results when performing disc recording.

First generation DVD-R media offered capacities of 3.95 Gigabytes and approximately 3.68 Gigabytes of usable space (considering the overhead required for lead-in and lead-out areas and other file system data). The recordable capacity of the second generation DVD-R discs is 4.7 Gigabytes, of which approximately 4.38 Gigabytes is available for data storage.

Data transfer rates for recording DVD discs were initially based on a nominal 1.32 Megabytes per second rate, which is considered 1x speed. At this data transfer rate, completing the recording of a 4.7GB DVD-R disc requires slightly less than an hour. Current generation DVD-R equipment can accelerate the write process using 4x speeds.

DVD-R serves an important role in project prototyping for developers and title producers, since it is designed by definition to be playable in standard DVD players and DVD-ROM drives. Early recorder costs were in the $17,000 range, but as was the case with CD-R equipment, costs have been declining dramatically. Second generation equipment, such as the Pioneer DVD-S201, dropped to the $5000 mark. Authoring caliber DVD-R drives can now be purchased for about half that amount. General Use DVD-R drives can be found for as little as $250. Blank media costs have

dropped from approximately $40 for 4.7GB discs and $35 for 3.95GB discs to about $5 for Authoring media and $1 for General Use media.

Table 3: Differences in Recordable DVD-R Types

Property	Version 1.0	Authoring use	General use
Number of sides	1 or 2	1 or 2	1
Data capacity	3.95GB	4.7GB per side	4.7GB
Recording method	Organic dye layer		
Laser wavelength	635/650nm	635nm	650nm
Minimum pit length	0.44 microns	0.40 microns	0.40 microns
Track pitch	0.80 microns	0.74 microns	0.74 microns
Serialization for CPRM		No	Yes
Pre-recording		No	Yes
Track format	Wobble pre-groove		
Modulation	8/16 modulation		
Error correction	Reed-Solomon Product Code		

Those who followed the development of CD-R technology witnessed the difficulty inherent in maintaining compatibility given the many variables in recordable media, playback equipment, recorders, premastering software, and so on. It took several years for all these varying characteristics to be tamed and controlled in such a way that recorded discs could be freely distributed among the vast majority of CD-ROM drives. A similar evolution is taking place with DVD-R as manufacturers, engineers, and developers refine the tools and techniques used to burn data in discs. Early adopters of this technology faced a variety of trials and tribulations as the compatibility problems were worked out. Today, manufacturers and standards organizations have solved many of the compatibility issues. Users of both DVD-R and DVD+R media can be expected to see compatibility somewhere around 95 percent with DVD players currently being manufactured. Compatibility with earlier players, however, is still a hit and miss affair.

DVD Formats: The Five Books

The Digital Versatile Disc—DVD—suits its name very well. Since the DVD-ROM and DVD-Video specifications were introduced as version 1.0 in 1996, DVDs have become a dominant medium for information storage, both in the entertainment world as a vehicle for distributing feature films and other movies, as well as in the computer world where recordable DVD drives have become standard equipment on many systems. The versatility of this storage medium can be demonstrated by looking at the range of uses, which has led to DVDs exceeding the growth patterns of any previous electronics technology.

Since the DVD-ROM and DVD-Video formats were first introduced in 1996, a variety of extended formats have emerged, including several recordable and rewritable types and a DVD-Audio format. Even as the installed base of players continues to grow rapidly, industry leaders are working on a new format to support high-definition video content.

The order in which these standards have been developed follows the sequence of the Books, A through E.

An Evolving Set of Standards

If the DVD standards had been developed logically and methodically by a non-partial committee of neutral participants, we'd probably have a more consistent framework for the growth of DVD. Instead, the standards evolution has been pushed and pulled by groups of electronics manufacturers and entertainment conglomerates, each trying to wield their influence on the process for the gain of their organization. DVD has been pulled and tugged in every conceivable direction by forces representing sometimes diametrically opposed viewpoints.

At this point, the situation for the primary standards is quite stable, although much activity is still going on trying to produce DVDs with audio that can be played in CD players, double-sided hybrid DVD-Audio discs, and other kinds of variations, such as high-definition DVDs. Today, most new DVD-ROM drives will currently read commercially pressed CD-ROMs, as well as CD-R, and many will handle CD-RW as well. DVD players have reached a production volume where the prices have dropped below the $100 mark for entry level units and most of the incompatibilities exhibited by early releases of DVD-Video titles have been eliminated. Consumers, initially wary of the medium from the constant flow of negative information from the press, are purchasing players and DVD-ROM

drives in record numbers. The once sluggish growth curve is now showing record growth patterns. By the middle of 2003, more than 66-million DVD players have been sold in the U.S. and almost 1.8-billion discs have been shipped in North America since the first DVD was sold.

DVD-ROM

The DVD-ROM is the computer data version of the digital versatile disc. As with the transition of the audio CD to CD-ROM, the DVD-ROM includes extended support for error detection and correction to allow it to be successfully applied to computer applications where a missing bit can freeze an application. Unlike the audio CD, however, DVD-ROM is considered the starting point of a succession of standards that includes:

- Book A: DVD-ROM
- Book B: DVD-Video
- Book C: DVD-Audio
- Book D: DVD-R (write-once)
- Book E: DVD-RAM (rewritable)

All of these formats were devised with the goal to create an optical disc format that supported a significantly higher storage capacity than the CD-ROM. From the beginning, the standards bodies involved in developing and refining DVD specifications wanted individual formats to support audio, video, and computer uses, as well as a writable storage format. The five books developed around these objectives.

Data Storage Techniques

DVD-ROM stores data in user sectors, each consisting of 2064 bytes that are organized to support an error correction scheme. Of this total, 16 bytes are reserved for address information, error correction, and copy protection, leaving 2048 bytes for data. Data sectors are structured as 12 individual rows each consisting of 172 bytes. The beginning of each data sector contains 16 bytes of data, subdivided as follows:

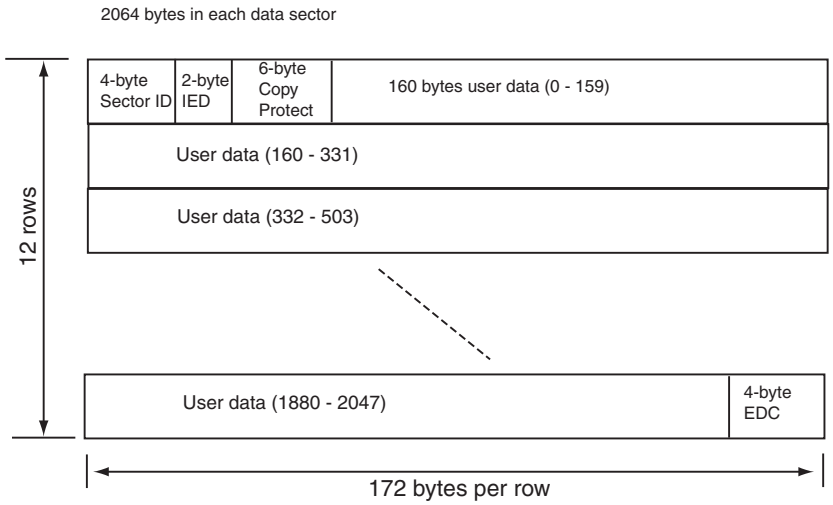
- 4 bytes of identification data representing the sector ID
- 2 bytes of ID error detection data
- 6 bytes of copy protection data

The data sector is concluded with an additional code:

- 4 bytes consisting of an error detection code

The organization of the bytes within a DVD-ROM data sector is shown in Figure 17 - 5.

Figure 17 - 5 **Organization of a DVD-ROM data sector**



Rows of 16 data sectors are interleaved together and structured as blocks for applying error correction codes. A 16-byte Reed-Solomon code is generated for each of the 172 columns within the block. A 10-byte inner-parity Reed-Solomon code is generated for each of the 208 rows of the block. These codes are appended to the data, where they provide a flexible and robust means for detecting read errors within the data.

Through processing by means of 8/16 modulation, each data bytes is doubled to 16 bits, which produces a physical sector size of 4836 bytes. These bytes are generated on the disc surface, row-by-row, as channel data. As with data embedded on a CD-ROM, the Non-Return to Zero Inverted (NRZI) encoded method is used: transitions detected by the laser from a pit to a land are interpreted as binary ones; the absences of transitions are interpreted as binary zeros.

Channel data from the DVD media is transferred at the rate of 26.16M bps, which is then reduced by half by the application of the 16/8 demodulation process, resulting in a rate of 13.08M bps. After the adjusted overhead of error correction, the data transfer rate is a steady 11.08M bps. From the perspective of a DVD-ROM drive, data is transferred in logical units, each unit consisting of 2048 bytes.

UDF

One of the significant additions to the DVD standard is the widespread adoption of the Universal Data Format (UDF) as the means for dealing with files and volumes stored on disc. Although, theoretically, the data regions of a DVD-ROM can contain any type of data, most companies and organizations have followed the lead initiated by OSTA, the Optical Disc Storage Association, and adopted UDF for mapping file and volume structures.

UDF refines a more broad framework constructed by the International Standards Organization in ISO 13346. UDF places limitations on ISO 13346, defining a structure that supports optional multivolume and multipartition divisions on a disc. This allows DVD-ROMs that include filename translations between platforms and support for extended attributes, such as the resource forks, icons, and file/creator types that are familiar to Macintosh users.

Within the UDF standard, the following platforms are supported:

- DOS
- OS/2
- MacOS and MacOS X
- Windows 98/NT/2000/XP
- UNIX

The ability to partition discs for different playback equipment makes it possible for manufacturers and title producers to provide content that is specific to a playback platform. In the same manner that Enhanced CDs include both audio content for a standard CD player and computer data for playback in a CD-ROM drive, a DVD disc can have player and computer partitions. The digital video content and a wide range of interactive content can be included in the partition designed for the DVD player; this can include a director's commentary on a film's production issues, alter-

native language editions, and so on. The DVD-ROM partition can include items such as:

- Interactive multimedia content
- Games
- Screen savers
- Links to Web sites where related information about the title is available
- Background information on the cast and crew or design team
- Many other similar kinds of content

Most computer platforms also include some form of video player software for DVD, allowing films to be played on the desktop with the same crisp resolution and fluid playback that you will find on a dedicated player. The key element to making this happen is an MPEG decoder in the playback system, either implemented in hardware or as a standalone software component. Most DVD-ROM drives that are installed as original equipment in new PCs include MPEG decoding hardware as part of the package. If your DVD-ROM drive lacks this hardware, you must obtain a software decoder or you will be unable to play back DVD-Video titles.

Decoders embedded in hardware relieve the playback system processor of the burden of performing the intensive conversion process on the fly, which clearly improves playback performance. Whenever possible, hardware decoding is the preferred approach. The other component necessary to play back DVD-Video content on a PC is that the hardware or software decoder must be able to handle the encryption scheme that is built into DVD-Video discs for copy protection.

DVD-Video

DVD-Video is a specialized form of DVD-ROM that is tailored to the presentation of very high quality audio and video content optimized for set-top players. This is the format that the film studios, video publishers, and consumer electronics manufacturers have been backing as the predominant delivery medium for motion pictures in the new millennium. From a hesitant beginning, the format has caught hold solidly. Given the ongoing backing of so many of the major corporations involved in entertainment and consumer electronics, continuing success is assured.

DVD-Video relies the compression capabilities of MPEG-2 to provide, minimally, 94 minutes of video playback, but up to several hours of playback using the higher capacity formats. MPEG-1 video content can be included on a DVD-Video, but this option is rarely used because of the reduced quality of the compressed video.

The DVD-Video format was devised to support playback on the full range of standard NTSC and PAL television displays using analog data connections, ensuring broad compatibility with the installed television sets around the world. Most current-generation DVD players also include additional digital data connections, including S-Video and optical connections for more advanced televisions that support this form of signal input. The high-definition televisions that are appearing in the market can often take advantage of this digital interface.

Multichannel digital audio support is also an inherent feature of this medium, allowing audio content to be played on standard stereo audio systems, as well as more elaborate home theater systems. Up to eight channels of Dolby Digital audio provide the potential for excellent spatial orientation and rich, full sound to accompany videos.

To achieve the best results for audio works, specialized mastering tools must be used to separate the audio tracks into individual components. If this is not done effectively, the resulting audio performance can exhibit annoying characteristics, such as drifting orientation of the dialog track or poor signal clarity.

File Formats under DVD-Video

A DVD-Video disc can contain data for both playback on a DVD player and additional data content designed for computer playback. Based on the UDF specification, a specific directory is designated to store the video files, VIDEO_TS. An informational file titled VIDEO_TS.IFO must also be present. VIDEO_TS.IFO stores the video manager title set, which contains the contents of the Main Menu that appears when the DVD is mounted in the player.

Other title set information is contained in additional .IFO files and backup copies containing this same information are also maintained. Up to 10 video object block (.VOB) files can be created for each title that appears on the disc; these become the logical divisions by which the disc content can be navigated. Directories and files not intended for use by the

DVD player must be stored after the DVD-V data; these files are typically ignored by the player.

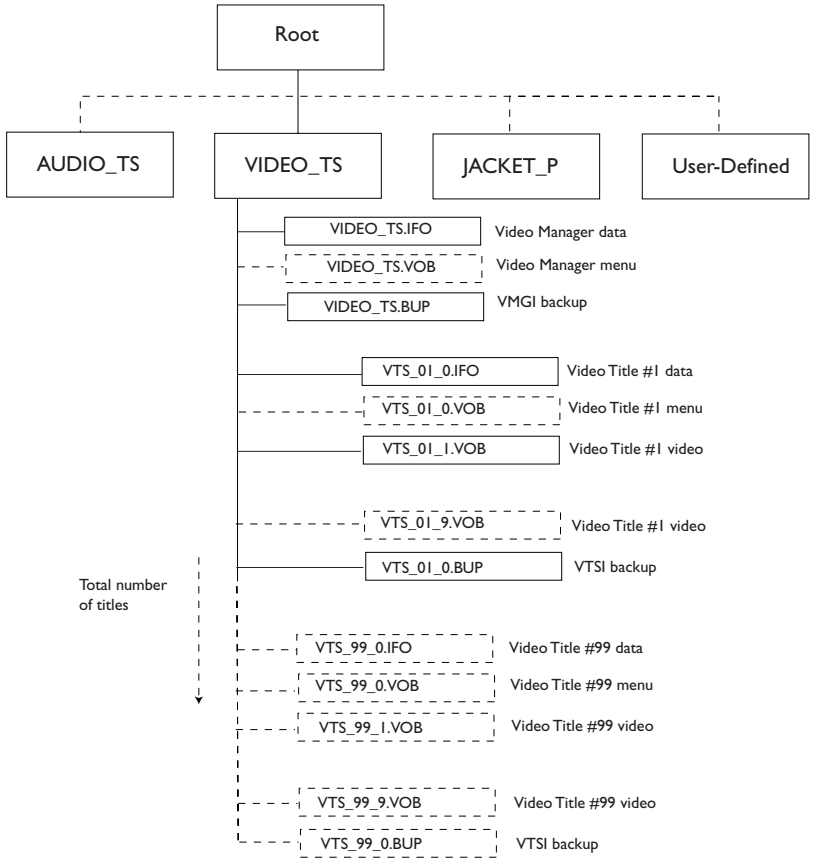
The original UDF standard was modified with an appendix, the MicroUDF, to simplify the recommended requirements that must be met by a DVD player, in the interests of encouraging widespread manufacturing of consumer-level playback equipment.

Appendix 6.9 of the UDF standard includes the following provisions:

- No multisession formats or boot descriptors are permitted on a DVD disc.
- Individual files must be contiguous and smaller than 1 Gigabyte.
- No more than one logical volume, one partition, and one file set can be included on a single-side of a disc.
- DVD players should support UDF in anticipation of ISO 9660 being gradually phased out.
- No more than 8 bits per character should be allocated for file and directory names.
- Aliases can not be used for linking.

The basic file structure used on a DVD-V disc is shown in the following figure.

Figure 17 - 6 **File Structure for DVD-V**



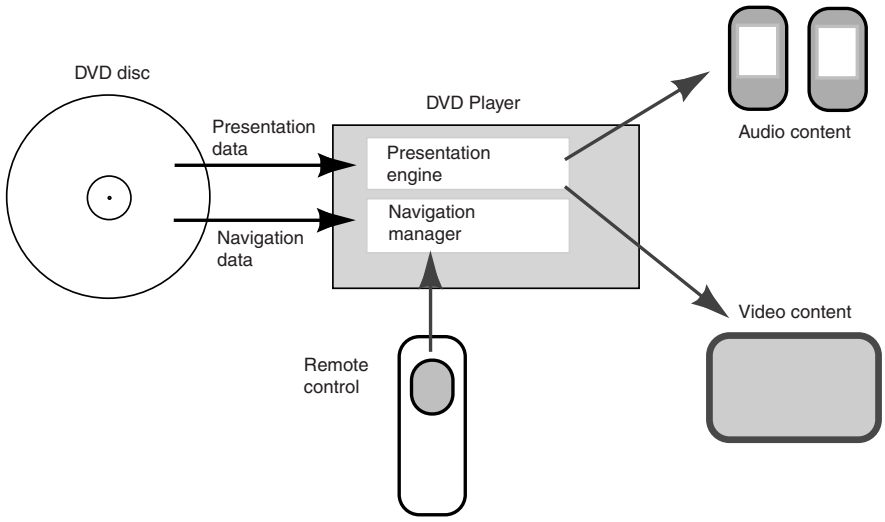
Navigating DVD-V Content

Unlike linear systems for video playback, such as film or videotape, DVD offers random access to the content on disc. Once is a disc is inserted in a player, a main menu can be accessed, which guides the user through the various types of content available on the disc. This may include a chapter view of a movie (allowing the viewer to jump to a particular point in a film), production information in video form, still images, audio content, interviews with directors and cast, and so on.

This type of content is handled by a presentation engine and a navigation engine contained in the player. This provides the equivalent to a com-

puter user interface to the viewer, allowing someone to control the selection of the different elements for playback or to activate certain features available on the DVD. For example, a user might select an audio commentary to be played at the same time the video is being presented.

Figure 17 - 7 **Navigation and presentation engines**



The actual content on the discs, from the perspective of the user interface, consists of:

- *Titles*, which may be films, videos, or album material
- *Parts of titles*, which may be chapters or individual songs

Each DVD can contain up to 99 discrete titles. Each title can be further subdivided into 10 chapters. For example, a disc containing the three-part television miniseries Stephen King's *Storm of the Century* might contain an individual title for each part and then 8 chapters within each title, allowing selection of any part of the series within 12 to 15 minute increments.

Optionally, a DVD can contain only a single title. For more complex projects, titles can also be nested within other titles and each title can have its own title menu. Viewers navigate between the various options using a remote control that features directional arrow keys and a select

button, as well as the usual assortment of controls that one might find on a VCR remote, such as pause, scan, forward, back, and so on.

A presentation can include many different optional features that are handled by the navigation manager. For example, a project might incorporate a second camera angle that could be enabled through the menu to allow viewing of the content from a different perspective. Subtitles can be included for display when viewing foreign films. If any of these kinds of features are not required, the DVD author simply bypasses them within the authoring application.

Authoring for DVD-V

Authoring tools available for creating DVD-V content range from simple consumer-oriented applications for creating DVDs of family events to expensive, multi-featured professional-caliber tools. As both hardware and software tailored for creating DVDs has become less expensive, the trend has been towards an overall reduction in the cost of tools. Very sophisticated DVD authoring applications, such as Apple DVD Studio Pro v2.0 and Sony Vegas Video+DVD, can be purchased for less than $1000.

Encoders for producing MPEG-2 video range in price from software-only solutions suitable for both home and professional applications to elaborate standalone hardware systems with high-speed processors. Hardware approaches can deliver consistent, high quality video at rates that support industrial and commercial applications. More exacting video compression, however, is often performed using software encoders, which can be used to encode difficult variations in video frames by adjusting parameters and extending compression time. Many authoring packages include a built-in MPEG-2 encoder that can prepare raw video content prior to burning a DVD-R or DVD+R disc.

DVD-Audio

DVD-Audio is being positioned as a replacement for CD-DA (Compact Disc - Digital Audio), though the launch of players and titles has been slowed by a number of issues and acceptance by consumers has been much more gradual than for DVD-Video. DVD-Audio provides a minimum of 74 minutes of high-resolution Surround Sound. This format also supports a number of extended features, such as video content and simple interactivity. DVD-Audio discs support 5.1 channel Dolby Digital audio content, enabling fully equipped home entertainment systems with multiple speakers designed for enjoying DVD-Video sound to play back DVD-Audio discs at an equivalent level of quality.

As it stands, the DVD-Audio standard provides several significant enhancements over audio delivered via CD:

- Multichannel audio: the availability of 5.1 channels supports surround sound, encoded as Dolby Digital or MPEG-2 audio data
- Higher sampling rates: digital audio content can be sampled at rates up to 96K bps, producing greater frequency response
- Larger sample sizes: dedicating more bits to the sample sizes provides extended dynamic range and increased depth-of-field
- Display of album titles, lyrics, artist's names, and song titles during playback

The format for DVD-Audio includes the capability of including a DVD-Video sector. This approach makes it possible to create a high-capacity DVD equivalent to an Enhanced CD, with the audio material supplemented by video material and URLs that could be linked during playback in a DVD-ROM player. Another way of looking at it is that DVD-Audio combines the features of three separate DVD formats: combining audio, video, and computer data within a single framework. Most DVD-Audio players are also capable of playing DVD-Video content and most DVD-Video players can play back DVD-Audio discs. A number of major music companies, as well as some enterprising independents, have released titles on DVD-Audio discs and [as of late 2003] there are more than 1000 titles in the market.

The Working Group 4 (WG-4) of the DVD Forum continues to refine the DVD-Audio standard, but the fundamental elements of this standard have at reached the point where player manufacturers have felt confident enough to design and engineer the playback equipment. A fair amount of research and development is still taking place to try to design alternative formats, such as Super Audio CD (SACD), which includes layers that permit playback in CD players at CD quality. The high-quality audio (and optional surround sound content), however, require specially equipped DVD-Video players compatible with SACD.

Authoring of DVD-Audio content requires both a different set of tools and a different mindset for the development community. The abundant storage capabilities encourage titles that include not only audio, but video clips and computer data as well. However, as has been the case with Enhanced CDs, the extra costs associated with this type of development may limit the number of titles that include bonus content and extras. Dif-

ferent hardware and software tools are required to be able to record and mix the audio for 5.1 channel playback. The potential, however, for DVD-Audio is enormous. Audiophiles and music lovers looking for a way to experience more rich and vibrant sound, with the added benefit of audio and video content, should eventually be won over by the advantages of the format as more types of playback equipment and a greater selection of titles reach the marketplace.

DVD-R

If you want to burn a DVD disc designed for the widest possible playback, including current DVD players and DVD-ROM drives, DVD-R is the best choice. DVD-R is the write-once member of the writable family tree. The other rewritable formats currently lag behind with a number of compatibility issues that can create problems with some playback equipment. The DVD Forum maintains the DVD-R standard, while a competing organization, the DVD+RW Alliance has introduced DVD+R, which currently also has a very high degree of compatibility with more modern DVD players.

The DVD Forum has defined two individual categories in the DVD-R Book version 1.9 to accommodate different uses of DVD-R:

- DVD-R for Authoring: utilizes a laser wavelength for writing of 635 nanometers. This variation is designed for authoring only.
- DVD-R for General: utilizes a laser wavelength for writing of 650 nanometers, suitable for write operations intended for general uses.

Depending on the selection of recordable media, a DVD-R can handle up to 3.95GB or 4.7GB of data per side. Double-sided media boost the ultimate recording capacity to 9.4GB per disc.

The extra capacity of a DVD-R disc derives from the use of a red laser with a 635 or 650nm wavelength and an objective lens with a numerical aperture of 0.6. The smallest recorded mark possible on a CD-R disc is 0.834 micrometers, while DVD-R pits can be as small as 0.4 micrometers. This results in an increase of almost seven times the data density of the DVD-R disc over what can be stored on CD-R media.

The track pitch—the distance between two adjacent tracks on the spiral of data—is also much tighter for DVD-R than CD-R: 0.74 microns for the 4.7GB media and 0.8 microns for the 3.95GB media. All of these fac-

tors—the laser wavelength, pit size, track pitch—make it possible to achieve the high storage capacities available on DVD-R.

Playback Compatibility

DVD-R drives offer the advantage of broad playback compatibility, which includes most of the playback equipment available for DVD format discs. Discs can be recorded in either DVD-V or DVD-ROM format.

A properly recorded DVD-Video disc produced on a DVD-R machine can be played on:

- Most standalone DVD-Video players
- DVD-ROM drives installed in a host computer as long as they are equipped with either a hardware-based MPEG decoder or a software decoder that performs the same function

DVD-ROM discs that are recorded on a DVD-R drive can generally be played back on:

- A DVD-ROM drive installed in a host computer, without built-in MPEG decoding
- A DVD-ROM drive installed in a host computer with either hardware or software MPEG decoding (if access to DVD-Video material is required)

Both MPEG-1 and MPEG-2 decoders are available in both hardware and software implementations. The earlier MPEG-1 encoding method was first introduced for storing video content on CD-ROM. Commercial Video CDs, including movie titles, were introduced in the market shortly after multimedia CD-ROMs became popular. The Video CD format fared more successfully in Europe and Japan than in the U.S. Many DVD players can also play back Video CDs, if you happen to have any of the released titles in your collection. Most MPEG-2 decoders can handle both the MPEG-2 and MPEG-1 data formats.

File System for DVD-ROM

As described earlier in the chapter, the file system for DVD discs is much different than the fragmented system that was designed for CD-ROMs as they evolved and grew to encompass many different types of data formats. Instead, the more unified UDF structure was applied to all types of DVD discs and this file system is suitable for all forms of content and any type

of file format designed for storage on optical disc. It is also designed to be adaptable to all the major computer operating systems.

To maintain backwards compatibility with earlier computers and operating systems that are not designed to read UDF, the UDF Bridge file system was designed. UDF Bridge is a hybrid system that includes support for discs recorded using the original ISO-9660 file system that originated with CD-ROMs. UDF Bridge also provides full support for discs containing files structured under UDF, as well.

UDF Bridge maintains an important optical disc convention that has been followed ever since the Yellow Book CD-ROM format was introduced as a means of extending the compact disc to include computer data, as well as audio data. Computer-based playback devices and decoders, as much as possible, have been designed to read all earlier formats. CD-ROM drives were designed to read audio CDs. DVD-ROM drives, from the beginning, were equipped to be able to manage CD-ROM playback. The UDF Bridge format makes it possible to provide backwards compatibility with ISO 9660-based readers while also offering the benefits of the UDF structure.

In comparison, playback devices targeted for the entertainment industry and consumer use, such as audio CD players and DVD playback equipment, usually only accommodate a single format. The Enhanced CD format was designed as a hybrid format—containing both audio and computer data. This allows CD players to play the audio present on the compact disc, while the computer data files could only be read if the disc were inserted in a PC CD-ROM drive. Similarly, DVD-Video discs often contain content designed for the PC, which is essentially ignored by the DVD playback equipment. The additional data only becomes available if you insert the disc in a DVD-ROM drive. A file folder labeled ROM is recognized as the storage receptacle for content designed for computer playback.

Writing to DVD-R Media

Anyone familiar with CD recording applications and equipment will recognize the very close parallels to DVD-R write operations. The recording process is handled by an application running on the host computer connected to the DVD-R unit. For example, Roxio Easy CD Creator 5 is such an application. The application lets the person doing the recording select the files and organize them for the write operation. The application then

manages the actual recording process, controlling the DVD recorder until the write operation is complete.

Disc-at-Once

Like CD-R discs, DVD-R discs can be fully written in one complete operation—known as Disc-at-Once—or written incrementally over several individual sessions. Unlike CD-R discs, however, data written to DVD-R discs occurs in a slightly different sequence. The recording application first produces a lead-in area, followed by user data area, followed by a lead-out area. The lead-in and lead-out areas contain information that allows the DVD player or DVD-ROM drive to properly access the full range of data. These same two areas also appear on commercially pressed DVD disc—they are essential to playback. The user data, sandwiched in between these two regions, can vary from a 32Kb block—the minimum amount of data that can be recorded—up to the maximum capacity of the recordable media: 4.7GB.

In comparison, CD-R discs are written in a different sequence. The user data regions are recorded first. Next comes the lead-in area and the table of contents. The write operation is concluded typically by writing the lead-out area.

Write Operations

During write operations, the host computer must be able to deliver the data at 11.08 Megabits per second to prevent any interruptions in the data pattern being recorded to disc. Buffering is used in the DVD-R drive to compensate for any interruptions in the flow of data.

When incremental write operations are being performed, the complete file system data is not available until all of the individual writes have been finished, so the disc must be finalized before it can be read in any device other than another DVD-R drive. Finalization calculates and records the data contained in the lead-in and lead-out areas and then records this information to disc. Once a disc has been finalized, it can be read by other DVD playback devices. No further data can be recorded after a disc has been finalized.

At the recording speeds of the current generation of 4x equipment, a 4.7GB disc can be recorded in about 15 minutes.

Uses for DVD-R

The lowering costs of DVD-R recorders may persuade many corporate and individual users who are looking for archival storage or backup applications, even if they have no intention of producing discs for commercial

replication. This category of users may also find a viable solution in the rewritable formats discussed in the next section.

The broad compatibility of DVD-R makes it a medium well suited for high-volume data distribution, particularly in situations where there is little control over the playback devices that will be used to read the discs. DVD-Video discs made using DVD-R media will be readable in the vast majority of DVD players, as well as those DVD-ROM drives equipped with the required decoding hardware. DVD-ROM discs produced using DVD-R equipment should be readable in all DVD-ROM drives.

Authoring Use

DVD-R for Authoring is the medium of choice for testing and development work, where developers must confirm operation on a range of target playback equipment before releasing a title to a replication facility for mass manufacturing. To avoid costly errors when a DVD title is being authored, DVD-R lets developers and testing firms produce discs that can than be run in standard playback equipment—either a DVD player or DVD-ROM drive. Any inaccuracies or problems with the playback can be detected and corrected before a disc get submitted for mass replication.

Presentations

Producing DVD discs for presentations, particularly presentations destined for portable DVD player playback, represents another ideal use for this medium. The interactive capabilities of the DVD-Video format make it possible to author presentations that are similar to full interactive multimedia applications.

Archiving

Certain archival applications, such as storing image data, audio material, motion pictures, and so on, favor the write-once characteristics of DVD-R. Archivists who want to record data and then ensure that it is not altered can rely on the properties of DVD-R media to protect their stored file contents. The estimated 100-year plus lifespan of the DVD-R discs also provides assurance that long-term archiving can be accomplished safely using this form of optical recording. For archival operations where data must be available for near-line access, DVD-ROM jukeboxes provide a means of storing extremely large quantities of data for convenient access. For example, a 100-disc DVD-ROM jukebox can handle close to a half-terabyte (470GB) of information.

For shorter term archiving and storage, the rewritable storage options provided by DVD-RAM, discussed in a following section, may provide a better alternative.

The DVD+R Alternative

DVD+R is another write-once format that has established a strong presence in the industry. The specification was forged by the DVD+RW Alliance. This alliance, composed of industry leaders such as HP, Philips, Ricoh, Sony, Yamaha, Dell, and Thomson, offers widespread playback compatbility with DVD-ROM drives and DVD players. With a baseline write speed of 2.4x, DVD+R can complete the writing of a DVD disc several minutes faster than a conventional 2x recorder. This format is essentially equivalent to the DVD-R General Use version.

DVD-RAM

The DVD-RAM format was the first of the rewritable DVD formats to reach the market. DVD-RAM drives are less expensive than DVD-R Authoring Use equipment, primarily because they use phase-change technology for storing data rather than the method used by DVD-R, which employs an organic dye to record laser impressions on disc.

The phase-change technology—which is an amalgam of the technologies used in magneto-optical cartridges, CD-RW, and PD devices—is also the reason that discs created on a DVD-RAM drive cannot be read in the typical DVD-ROM drive or DVD player. This significant drawback limits the utility of this particular storage method, but advances in player technology may overcome the limitation, much in the same way that early CD-RW discs could only be read in CD-RW players. Now, MultiRead-compatible players can handle CD-RW discs and CD-R discs with equal ease. Similar advances may make DVD-RAM discs more widely compatible.

Data patterns written to a DVD-RAM disc are recorded to a thin film that is sensitive to laser light. The DVD-RAM write laser strikes the film surface and converts the material from a crystalline state to an amorphous state. The reflectivity of these two different states is different enough that it serves to identify bit patterns. The disc surface can be "erased" by applying a different intensity laser burst. The energy from this burst converts the film from the amorphous state back to the original crystalline state.

DVD-RAM discs employ the same kind of modulation and error-correction codes that are used for DVD-Video and DVD-ROM. This characteristic should help ensure broadened future compatibility for this media type. Both single-sided and dual-sided media are available. Each side of a version 1 DVD-RAM disc has a capacity of 2.6GB. Version 2 DVD-RAM implementations doubled this to 4.7GB per side. In most regards, the physical discs have the same dimensions as DVD-R discs, but both single-

sided and double-sided discs are housed in cartridges for use. Clock data is embedded in a wobble pattern integrated into the tracks, also offering a means by which address signals can be identified by the drive.

Uses for DVD-RAM

The primary appeal of DVD-RAM is inexpensive, flexible, abundant storage—this benefit comes at the loss of compatibility with the majority of players and drives in the market.

DVD-RAM is well suited to these kinds of uses:

- Short or long-term storage of press-quality images, digital audio files, digital video files, or other similar kinds of content requiring large amounts of storage space
- Local periodic backup and temporary archiving of network files, personal hard disks, organizational files, and so on
- Exchange of large-volume files between parties with similar equipment (compatible DVD-RAM drives)
- Nearline storage of mission-critical data that is important to an organization's operation, but cannot be concisely stored on the network
- Network-resident storage for periodic system backup or personal workstation archiving, through thin server technologies

As the DVD-RAM technologies matures and the adoption of the Super MultiRead standard makes it possible to exchange disc cartridges more freely, this format should continue to provide a flexible, inexpensive storage medium that provides a high degree of utility.

Re-Recordable Formats

DVD-RAM was first on the scene with a form of DVD storage that could be rewritten hundreds of times. Two additional formats, DVD-RW and DVD+RW, have emerged to offer a reusable medium that can be re-recorded up to 1000 times.

DVD-RW

Officially sanctioned by the DVD Forum, DVD-RW offers up to 4.7GB of storage on a cartridge-free medium that can be played back on many existing DVD players and drives. DVD-RW discs are frequently used for home and consumer applications, such as editing of home movies and

storage of digital photographs and music files. The optical properties of a DVD-RW disc are similar to a commercial DVD-9 disc.

DVD+RW Introduced as a faster, less expensive alternative to DVD-RW, the DVD+RW format enjoys widespread industry support and some additional features that improve start-and-stop recording. A technology known as lossless linking simplifies the mechanics of performing write operations and replacing 32KB data blocks during rewrites. Compatibility with current generation players and drives is nearly equal to DVD-RW, providing a good value and a high measure of data integrity through a defect management scheme that verifies the accuracy of data written to disc and read back.

Summary

The evolution of the DVD standards in many ways mirrors the course of CD-ROM and recordable CD development, but there are also some clear advantages to the way data storage has been handled on DVD. The format is far more flexible when it comes to embedded different data types onto disc, without the necessity for creating individual formats for each of the individual data types (as can be seen on CD-ROM with Video CDs, Photo CDs, CD-PROM, CD-ROM XA, and so on). The UDF standard also intelligently handles most of the key cross-platform issues, making DVDs less prone to the kind of file translation issues and file system concerns that have complicated CD-ROM delivery. The backwards compatibility with CD-ROMs and audio CDs, which is a requisite feature of most drives and players, also makes DVD the logical successor to the CDs as the ideal portable data storage medium. The newer recordable formats also make it exceptionally easy for developers, programmers, and filmmakers to generate content that can be played back on many different machines, including mainstream consumer DVD players. Delivering movies, multimedia content, games, high-resolution photographs, digital audio, and other content on DVD has become an extraordinarily useful vehicle for communicators in many different fields.