

An Introduction to DVD-Recordable (DVD-R)

A Technology White Paper

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1 What is DVD Recordable?

1.1 Overview

Simply stated, DVD Recordable (DVD-R) technology allows anyone to create DVD discs at the desktop. Similar in concept to Compact Disc Recordable (CD-R), DVD-R is a Write-Once (WO) medium that can contain any type of information normally stored on mass produced DVD discs - video, audio, images, data files, multimedia programs, and so on. Depending on the type of information recorded, DVD-R discs are usable on any DVD playback device, including DVD-ROM drives and DVD Video players.

In its *introductory* version, a DVD-R disc is able to hold up to 3.95 gigabytes (3.95 billion bytes) of information on each side - six times the capacity of a CD-R disc. Since the DVD format supports two-sided media, a total of 7.9 GB can be stored on such a two-sided DVD-R disc.

Data can be written to or read from a disc at 11.08 megabits per second (Mbps), which is roughly equivalent to nine times the transfer rate of CD-ROM's "1X" speed ("9X" recording). This transfer rate, coupled with DVD-R's capacity, makes it an extremely viable and cost effective (long-term) storage medium.

1.2 Background

DVD-R is an official member of the DVD Forum's family of formats. Its Write-Once characteristics allows users to make their own DVD discs, very similar to how CD-Rs are recorded. As with CD-R, playback compatibility is one of DVD-R's most important attributes - nearly all existing DVD video players and DVD-ROM drives will play one or both of the available disc capacities (3.95 or 4.7 billion bytes). Another key feature is the security inherent in DVD-R's Write-Once nature - **no one can accidentally erase valuable information once it's been recorded**. And because at least one media manufacturer (Pioneer) specifies a 100-year life expectancy of recorded DVD-R discs, the format is well suited for **long term archival** applications.

Until early 2001, DVD-R was used primarily in professional applications such as video authoring and storage of imaging data. For DVD authoring users, DVD-R allows testing and approval of finished titles prior to mass production, and can even be used by some replicators as the final program source in place of DLT tape. In many cases, recorded DVD-R discs are the finished product when only a few discs are needed for deployment in vertical applications such as museums or videowalls in retail stores.

In medical environments, x-rays, CT-scans and ultrasound video images are stored in automated DVD-R archival systems to provide physicians much faster access to information as well as better reliability than tape solutions. In the banking industry, the format is used for storage and retrieval of checks and credit card receipt images generated each day in retail transactions.

1.3 DVD-R Technology

DVD-R is a Write-Once format, meaning that data can be written to a disc and stored without fear of accidental erasure. The fundamental technology employed is similar to that used by CD-R, except that data is written at a much higher rate and density on a DVD-R disc.

DVD-R, like CD-R, uses a *Constant Linear Velocity* (CLV) rotation technique to maximize the storage density on the disc surface. This results in a variable number of revolutions per minute (RPM) as disc writing/reading progresses from one end to the other. Recording *begins* at the **inner** radius and *ends* at the **outer**. Rotation of the disc therefore varies from 1,648 RPM to 648, depending on a record/playback head's position over the surface. The *track pitch*, or the distance from the center of one part of the spiral information "track" to an adjacent part of the track, is 0.8 microns, one-half that of CD-R.

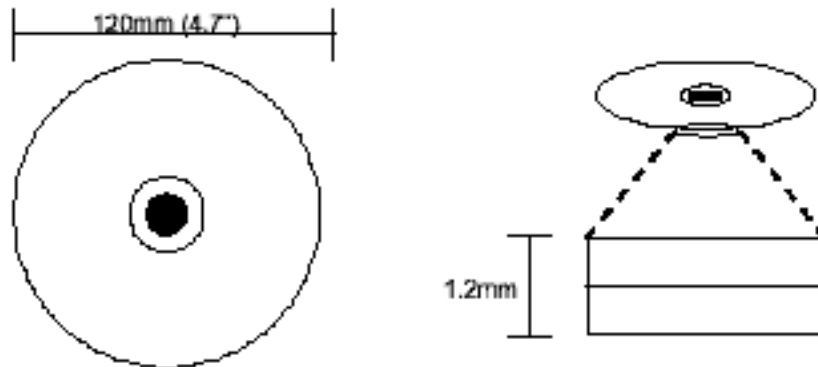


Figure 1: DVD-Recordable Disc Dimensions

To help achieve a sixfold increase in storage density over CD-R, two key components of the writing hardware needed to be altered: the *Wavelength* of the recording laser and the *Numerical Aperture* (n.a.) of the lens that focuses it. In the case of CD-R, an **infrared laser** with a wavelength of 280 nanometers (nm) is employed, while DVD-R uses a **red laser** with a wavelength of 635 nm. At the same time, the numerical aperture of a typical CD-R drive's objective lens is 0.5, while a DVD-R drive uses lenses with an n.a. of 0.6. These factors allow DVD-R discs to record marks as small as 0.44 micron as compared with the minimum 0.834 micron size with CD-R.

The table below highlights the differences between some basic parameters of both media formats:

Parameter	DVD-R	CD-R
Media Type	Write-Once	Write-Once
Wavelength (Recording)	635 - 650 nm	775 - 795 nm
Wavelength (Reading)	635 nm	770 - 830 nm
Recording Power	4 - 11 mW	4 - 8 mW
Numerical Aperture (Recording)	0.60	0.50
Numerical Aperture (Reading)	0.60	0.45
Reflectivity	R _{14H} > 0.5	R _{TOP} > 0.65

Table 1: Basic DVD/CD-R media parameters

Recording on DVD-R discs is accomplished through the use of a *Dye Polymer* recording layer that is **permanently** transformed by a highly focused red laser beam. This dye polymer substance is spin-coated onto a clear polycarbonate substrate that forms one side of the "body" of a complete disc. The substrate is injection molded, and has a microscopic, "pre-groove" spiral track formed onto its surface.

This groove is used by a DVD-R drive to guide the recording laser beam during the writing process, and also contains recorded information after writing is completed. A thin layer of metal is then sputtered onto the recording layer so that a reading laser can be reflected off the disc during playback. A protective layer is then applied to the metal surface, which prepares the side for the bonding process.

These steps are done for each side of a disc that is needed for recording. If only a single recording side is required, then the opposite side can contain a label or some other visible information such as pit art. If both sides are needed for recording, then two recordable sides can be bonded together as depicted in the diagram below. In this case each side must be read directly (by flipping the disc over), as dual layer technology is not currently supported.

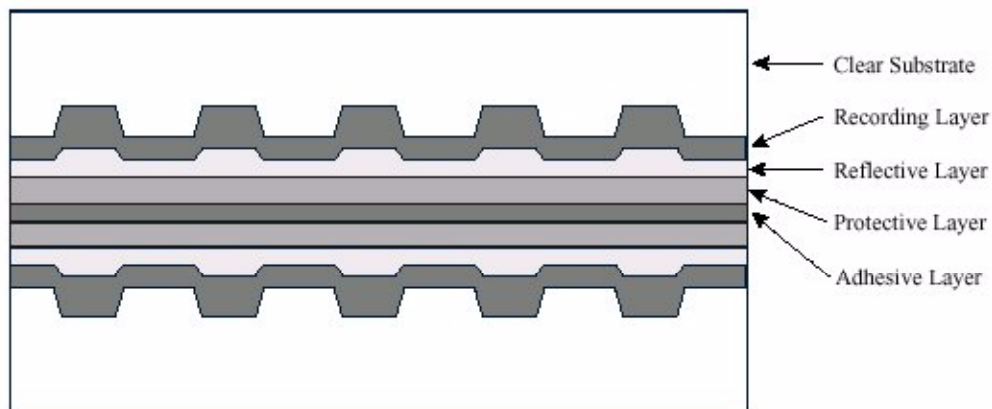


Figure 2: Two-Sided Disc Example (not to scale)

The recording action takes place by momentarily exposing the recording layer to a **high power** (approximately 10 milliwatt) laser beam that is tightly focused onto its surface. As the dye polymer layer is heated, it is permanently altered such that microscopic marks are formed in the pre-groove. These recorded marks differ in length depending on how long the write laser is turned on and off, which is how information is stored on the disc.

The light sensitivity of the recording layer has been tuned to an appropriate wavelength of light so that exposure to ambient light or playback lasers will not damage a recording. Playback occurs by focusing a **lower power** laser of the same approximate wavelength (635 nm) onto the surface of the disc.

The "land" areas between marks are reflective, meaning that most of the light is returned to the player's optical head. Conversely, recorded marks are not very reflective, meaning that very little of the light is returned. This "on-off" pattern is thereby interpreted as the modulated signal, which is then decoded into the original user data by the playback device.

1.4 Expected Life of DVD-R Media

Since the process of writing and reading data to and from a DVD-R disc is very similar to that used by the CD-R format, the archival life of the two media is expected to be equivalent. This is a key issue when considering the use of DVD-R for archiving applications such as document imaging, medical and graphical, making it highly suitable for mission critical applications.

1.5 Compatibility

As mentioned previously, DVD-R discs will be playable on any destination device that can properly make use of whatever data is written. The diagram below illustrates this:

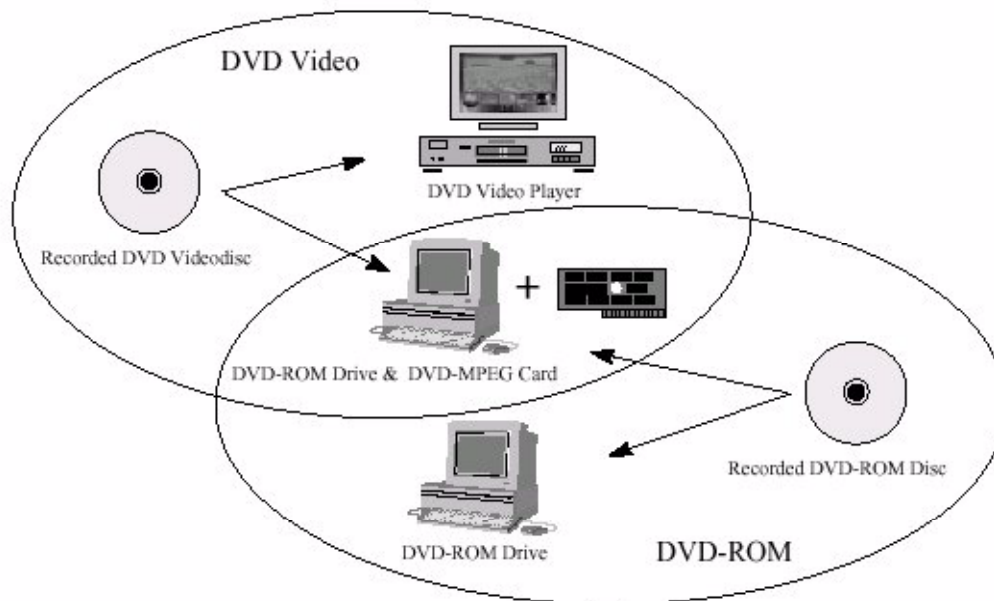


Figure 3: DVD-R Compatibility

Recorded DVD *Videodiscs* can be played on any DVD video player, as well as a computer that is equipped with a DVD-ROM drive, a DVD-compliant MPEG decoder card (or software) and application software that emulates a video player's functions.

A recorded *DVD-R disc* can be read by a computer equipped with a DVD-ROM drive, as well as a computer equipped for DVD video playback as described above. DVD Video components are not necessary, however, if DVD Video material is not accessed or is not present on a disc.

Recorded DVD-R discs support a new file system called "UDF Bridge". This is a hybrid approach that provides both the newer UDF (Universal Disc Format) system as well as the older ISO-9660 system used by the CD-ROM format. This allows DVD discs to be used with computer operating systems that do not have any provision for UDF support.

1.6 Recording Process

The basic recording process for DVD-R discs should be familiar to any user of CD-R technology. Like CD-R, blank DVD-R discs are recorded in a special drive that is controlled by a host computer. The recording process is orchestrated by application software that allows a user to specify which files will be transferred to the disc as well as controlling the actual recording itself.

All DVD discs, recordable or not, must have three basic areas recorded on them: *lead-in*, *user data* and *lead-out*. The lead-in and lead-out areas are boundaries that indicate to a playback device where the inner and outer limits of a recording are respectively. They contain no user accessible information, but are critical to the proper functioning of a disc.

There are two methods of writing a DVD-R disc: *Disc-At-Once* (DAO) and *incremental writing*.

Disc-At-Once, as its name implies, is the process of writing an entire disc's worth of data, to 3.95 GB or 4.7 GB, at one time. Data must be consistently provided by a host computer at a full 11.08 megabits per second during any recording to avoid *buffer underrun* errors. The occurrences of underruns are minimized by the use of a large writing buffer memory in a DVD-R drive; The first generation drive in fact provides a three megabyte buffer that can absorb bit stream interruptions of approximately two seconds in duration.

DVD-R Disc-At-Once writing is performed such that the lead-in, user data area and lead-out areas are all written sequentially. This differs from CD-R Disc-At-Once writing, where the data area is written first, followed by the lead-in and lead-out areas.

DAO recording is likely to be used when authoring video programs due to the large size of theatrical film releases. It can also be used for multimedia or other titles intended for publishing, as these works are normally assembled on hard drives prior to testing them on DVD optical discs. This also applies for long-term data storage (archival) applications, since at a certain moment in time data will be fixated and recorded in one action to the long-term storage medium.

Incremental writing will also be supported by the DVD-R format. This is very similar in concept to the packet writing technology that has recently been introduced for CD-R. Incremental writing will allow a user to add files directly to a DVD-R disc one recording at a time instead of requiring that all files be accumulated on a hard disk prior to writing as with the DAO method. The minimum recording size must be at least 32 kilobytes, (even if the file to be recorded is smaller) as this is the minimum error correction code (ECC) block size for DVD.

Obviously, a disc that is being written to incrementally cannot be considered a complete volume until the final information has been stored or the disc capacity has been reached. The lead-in and lead-out boundary areas therefore cannot be written until either of these two events occur.

Such an "unfinalized" disc (one without lead-in, lead-out and complete file system data) can only be read by a DVD-R drive until this process can be completed. After finalization, a disc can then be read by a destination playback device, but can no longer have data added to it.

1.6.1 Time to Record One Disc

A complete 1st generation 3.95 GB disc side is written in approximately 50 minutes in a DAO recording, regardless of the data that will be contained. Even variable bit rate MPEG video data is recorded at the full 11.08 megabits per second rate, as illustrated below:

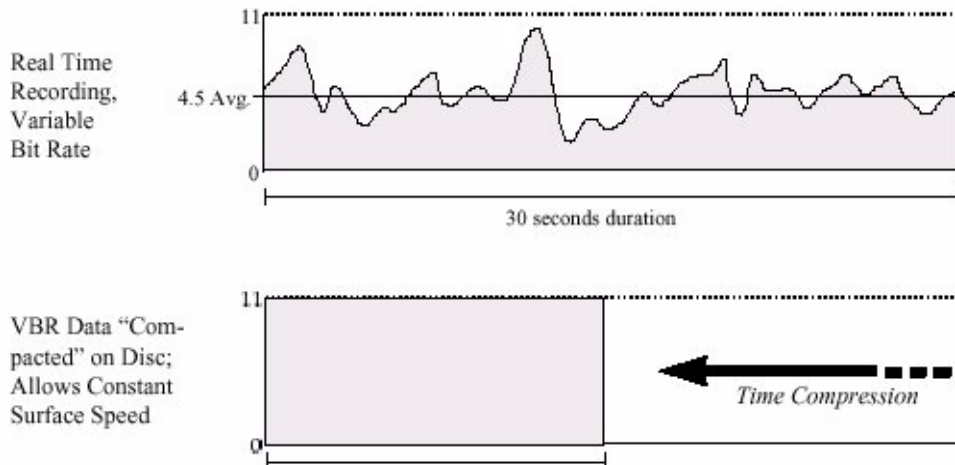


Figure 4: Constant surface speed recording

Upon playback, a video player accomplishes the necessary bit rate variation with a buffering technique as illustrated below:

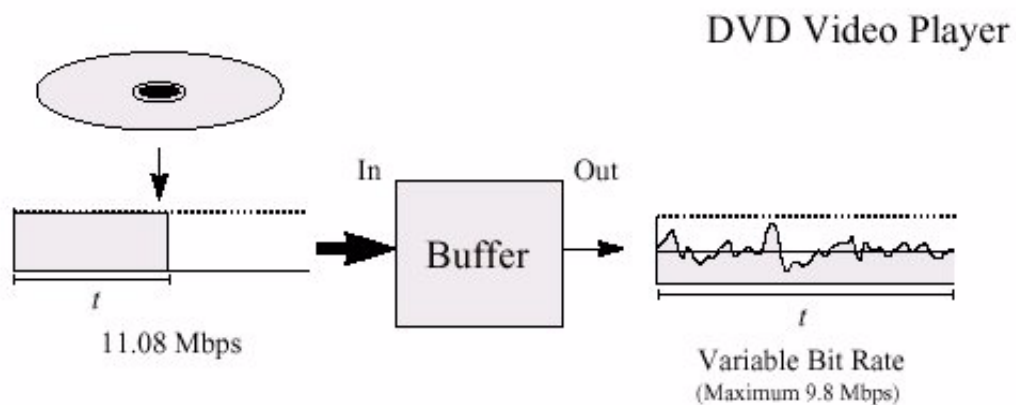


Figure 5: Variable Bit Rate Playback

As these illustrations show, all information, video or otherwise, is written at the full 11.08 Mbps data rate, with playback equipment providing any necessary time base adjustments.

2 DVD-R Applications

DVD-R's relatively low cost per megabyte, coupled with its physical storage efficiency and the portability of its recording equipment makes the medium applicable to a large variety of uses in virtually all industries.

There are three fundamental applications anticipated for DVD-R:

- **Testing and development**
- **Distribution**
- **Long-term storage (Archiving)**

2.1 Testing and development

Many DVD applications utilize replicated read-only discs that are mass produced and distributed to a large number of users. Preparation of the content that will be published can be a complex and time consuming process that must be completed accurately to avoid errors or functional defects. Compared to the cost of the mastering and set-up efforts required to replicate only one disc, DVD-R provides a far more cost effective method of testing content prior to mass production. A single low cost disc can be quickly written and tested in a representative destination device (video player or ROM drive).

In fact, multiple test discs may be required throughout the development process, as published titles are often the collaborative effort of many people. As a result, DVD-R can make a significant contribution to the cost reduction of publishing efforts.

2.2 Distribution

Small scale distribution of DVD content can be aided by DVD-R's low cost media and the relative portability of the recording equipment. As in the testing example above, mastering and replication expenses can be prohibitive when only a single disc or very small quantity is required. DVD-R allows discs to be recorded at the desktop or (small) office level, which can result in very quick turnaround and significantly lower cost. It is also possible that service providers could offer recording services to end users that require small production runs.

Some users may not be comfortable with sending sensitive data files or other work in progress to an outside facility for replication, so the ability to maintain continuous control of this information can be crucial. This is particularly true with classified data maintained by Government agencies. Complete confidentiality is afforded by DVD-R because it can easily be maintained as an in-house process.

2.3 Long-term storage (Archiving)

DVD-R is expected to provide archival lifetimes that are comparable to CD-R. For this reason, the format is suitable for long-term archival of any information that can be stored digitally. This includes image data, film and video archives, or any other media that are susceptible to deterioration over time.

Since DVD discs are dimensionally identical to the CD family of discs, they have the advantage of being compatible with existing smartDAX mechanisms. This will allow automated retrieval of recorded DVD-R volumes in networked environments, with a sixfold increase in storage density as compared with CD-R technology.

As an example, a 100 disc smartDAX would contain a total of 470 gigabytes, or 0.47 terabytes. If 50 kilobyte image files are written on every disc, a total of 7.7 million images could be stored and retrieved in a compact device.

3 Recent and Future Developments

The initial data capacity of DVD-R media was 3.95 GB. Recently this has been increased to 4.7 GB, resulting in higher capacity and even more cost effective long-term data storage. This has not been a trivial task, as higher density recordings can only be accomplished by decreasing track pitch from 0.8 to 0.74 microns, as well as decreasing the minimum recorded mark size from 0.44 to 0.40 microns. There have been many challenges that needed to be solved, including excessive jitter of recorded data that is exacerbated by disc tilt (unflatness) when these parameters are reached using existing materials.

To increase compatibility with other (competing) DVD and CD standards some manufacturers have announced drives that would either be able to write both CD-R(W) and DVD-R media (Pioneer) or write both DVD-R and DVD-RAM media (Panasonic).

Over time, improvements have been made to the writing technology. This resulted in two different writing technologies (in terms of laser beam wavelength) and DVD-R media formats. These issues are covered in the following chapter.

4 DVD-R Authoring vs. General Media

4.1 What's the difference?

There are now two different types of DVD Recordable (DVD-R) media: DVD-R for Authoring (DVD-R(A)) and DVD-R for General (DVD-R(G)). It is important to understand how these two formats differ, and just as importantly, how they are alike. In a nutshell, it's important to match the correct type of DVD-R media with specific DVD-R recorders, but after recording, either type can be used for playback on any playback device that supports DVD-R.

4.2 Key points

Key points of this chapter are:

- There are two types of DVD-R media:
 - DVD-R for Authoring (**635 nm** wavelength recording sensitivity: DVD-R(A))
 - DVD-R for General (**650 nm** wavelength recording sensitivity: DVD-R(G))
- Each type of DVD-R disc **must** be recorded on the proper drive (see chart below).
- Both types of DVD-R media can be played equally well on any DVD video player or DVD-ROM drive that supports DVD-R playback. Playback devices do not care which type of DVD-R media was used for recording.
- DVD-R for Authoring media can be recorded only on Pioneer DVR-S201 and DVR-S101 (3.95 GB only) recorders.
- DVD-R for General media can be recorded on Pioneer DVR-A03 and DVR-103 (OEM) drives, DVR-2000 set top video recorders, as well as on Panasonic's DVD-R SW-9501-S/T drives. More devices have been announced by several manufacturers.
- Either type of DVD-R disc can contain any type of information, including authored DVD video titles.
- CSS encrypted video programs cannot be stored on either type of DVD-R media.

DVD-R Recorder	DVD-R Media		Write Capacity	
	General	Authoring	3.95 GB	4.7 GB
Panasonic SW-9501-S/T	✓	✗	✗	✓
Pioneer DVR-S101	✗	✓	✓	✗
Pioneer DVR-S201	✗	✓	✓	✓
Pioneer DVR-A03, DVR-103	✓	✗	✗	✓
Pioneer DVR-2000	✓	✗	✗	✓

Table 2: Supported Media and Write Capacity

4.3 Two Formats for Two Markets

During this initial three-year period, the underlying technology of these professional applications employed 635 nanometer (nm) lasers for writing information to 3.95 and 4.7 GB DVD-R discs. This technology has allowed DVD-R products to become vital and dependable components of many DVD authoring suites and archival systems around the world. To support consumer applications for DVD-R, the DVD Forum determined that another type of DVD-R media was necessary. The newest member of the DVD-R family uses a recording wavelength of 650nm, and discs are recorded on different drives than the existing 635nm format. This new format is called "DVD-R for General - DVD-R(G)",

because it is aimed at a broad base of applications. Meanwhile, the existing 635nm format has been renamed "DVD-R for Authoring - DVD-R(A)" to reflect its use in professional applications.

Why are there two formats? The key reason for the introduction of DVD-R for General media is that it contains content protection measures that make it physically impossible to make bit-for-bit copies of CSS encrypted entertainment titles.

Meanwhile, the 4.7 GB Authoring media specification has introduced a new and unique feature that is potentially quite valuable to professional users: the Cutting Master Format (CMF). CMF allows 4.7 GB Authoring media to be used as a direct replacement for DLT master tapes when submitting a title for replication, thus saving valuable time in the final authoring stage. This is accomplished by using a portion of the DVD-R disc's leadin area to store the DDP (Disc Description Protocol) header information normally used on DLT master tapes. The CMF capability is one reason why it is anticipated that Authoring drives and media will continue to be utilized in the professional DVD (Video Mastering) environment; General media does not accommodate this feature.

4.4 Compatibility

4.4.1 Recording Compatibility

The two types of DVD-R media use different recording laser wavelengths, which means that the proper type of media must be recorded in the corresponding type of DVD-R drive. Authoring media must be recorded in either a Pioneer DVR-S 101 (3.95 GB only) drive or a Pioneer DVR-S201 (both capacities) drive, and General media must be recorded in a General drive such as the Pioneer DVR-A03, DVR-2000 video set top recorder or the Panasonic SW-9501-S/T. It is expected that future drives, including those from other manufacturers, will most likely be General type drives.

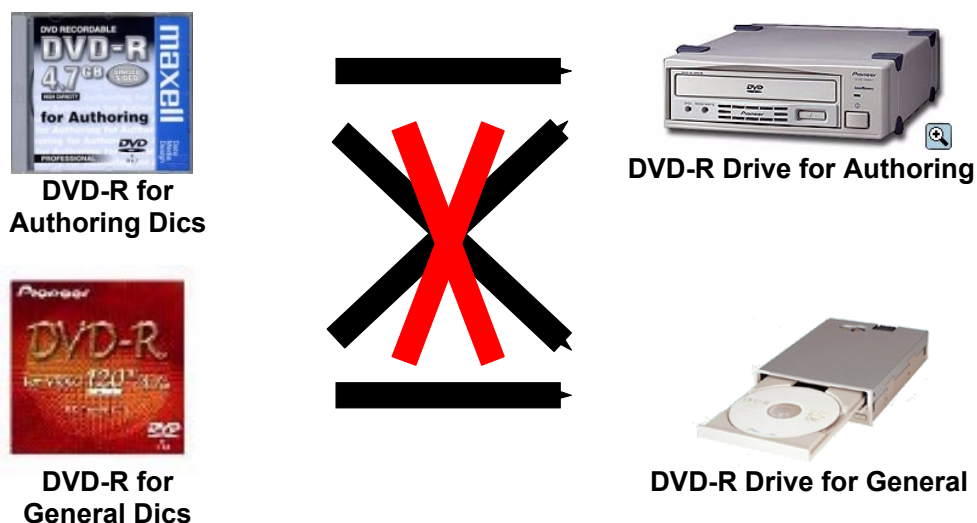


Figure 6: Authoring vs. General Recording Compatibility

4.4.2 Playback Compatibility

For playback, there is no compatibility consideration. Both Authoring and General DVD-R media can be played back equally well in any DVD video player or DVD-ROM drive that supports DVD-R (most existing models).

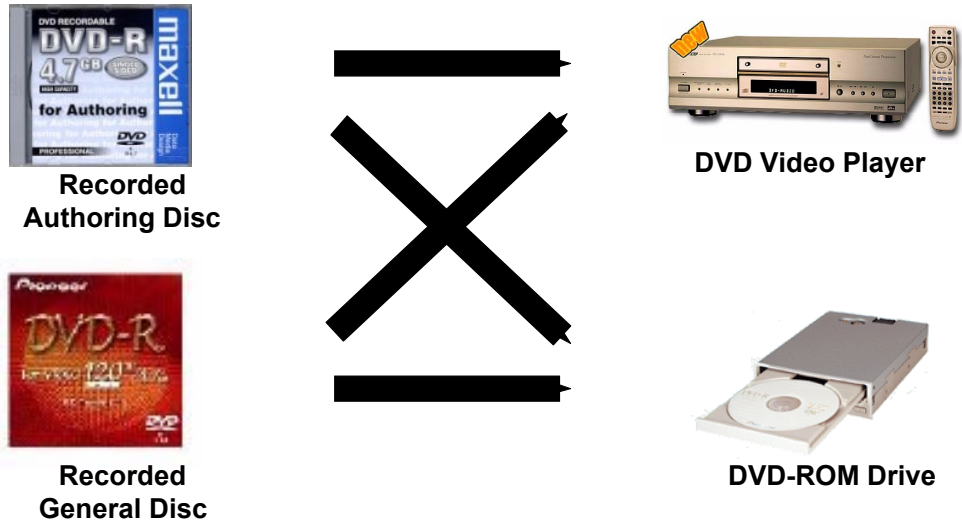


Figure 7: Authoring vs. General Playback Compatibility

5 Conclusion

In essence, DVD-R technology can be thought of as an enormous "bit bucket". Any kind of digital data can be stored on DVD-R discs, such as high quality video databases, document images, audio recordings, multimedia titles, and so on. The format's high capacity and data transfer rate has the potential to expand existing CD- R applications in two dimensions: faster information flow/higher quality, as well as significantly more of it on each volume.

DVD Recordable will provide users with a powerful new tool that has applications in nearly every industry. It is believed that DVD-R will become an indispensable medium that can be counted upon to store and deliver digital information reliably, inexpensively and over a long period of time. It is our sincere hope that DVD-R will enable new archival markets and applications for DVD technology.

Future developments acknowledge the statements made by the manufacturers that optical technology will provide both *backwards-* (CD/DVD - Pioneer) and *intercompatibility* (DVD-R(OM)/DVD-RAM - Panasonic), safeguarding investments for a lifetime.

References

- See also
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 - ECMA-119: Volume and File Structure of CDROM for Information Interchange
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 - ECMA-TR/71: DVD Read-Only Disk File System Specifications
 - ECMA-267: 120mm DVD - Read-Only Disk
 - ECMA-279: 80mm (1,23 GB per side) and 120mm (3,95 GB per side) DVD-Recordable Disk (DVD-R)
 - OSTA Standards (<http://www.osta.org>)
 - Universal Disk Format Specification - Revision 1.02
 - Universal Disk Format Specification - Revision 1.50
 - Universal Disk Format Specification - Revision 2.00
 - Universal Disk Format Specification - Revision 2.01
 - Pioneer DVD White Papers