

Understanding the Design of the DVD+RW and DVD+R Disc Format

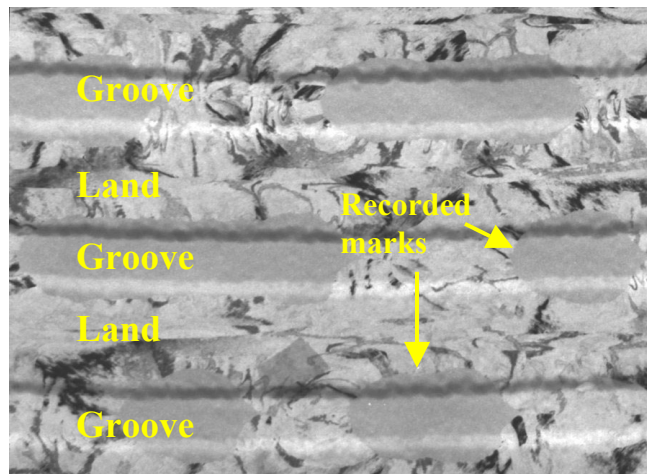
Introduction

The DVD+RW and DVD+R format was designed with 3 main goals; 1) compatibility with past present and future DVD Players and DVD-ROMs, 2) ease of use, and 3) to fully meet the needs of the PCs and Consumer Electronics, enabling true convergence. These goals are attained as a direct result of four major features of the disc format; A) very accurate linking, B) electrical signal compatibility, C) fast reliable detection of location on the disc, and 4) the ability to write in constant angular velocity and constant linear velocity.

Accurate Linkless Editing

The basic concept of linkless editing is that there exist very specific points where writing can both start and stop. If writing starts too early it can destroy the previously recorded data, and if writing starts too late, the data will extend too far and possibly destroy subsequent data. In addition to the need for accuracy for the start of writing, it is important to keep the writing tightly controlled to ensure the length over which the current recording occurs stops at the correct and intended location.

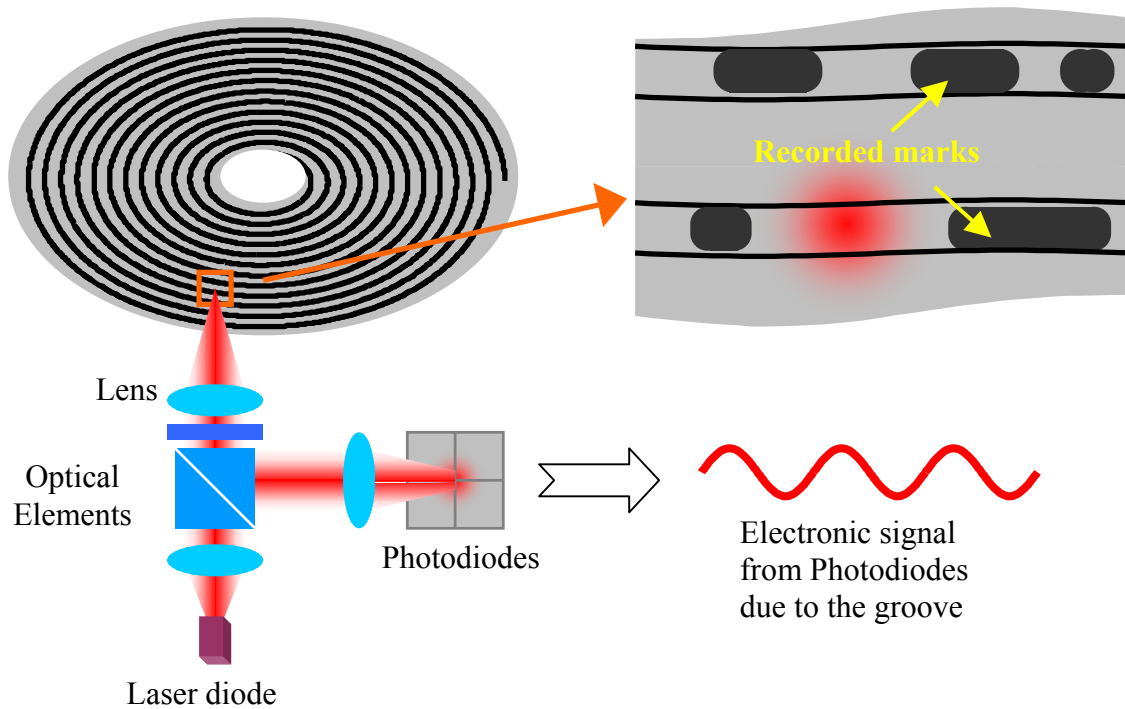
The data on all DVD and CD discs is organized in a single spiral track. In the case of DVD Read-only, the data is a series of pits in the media, while for DVD+RW, there is a single spiral groove where recorded marks are written. The following figure is a picture of a portion of a DVD+RW disc showing the grooves where data is recorded and the lands that separate the grooves.



Actual data marks in the picture are barely visible to the human eye, but are still easily detected by a drive's optics and electronics.

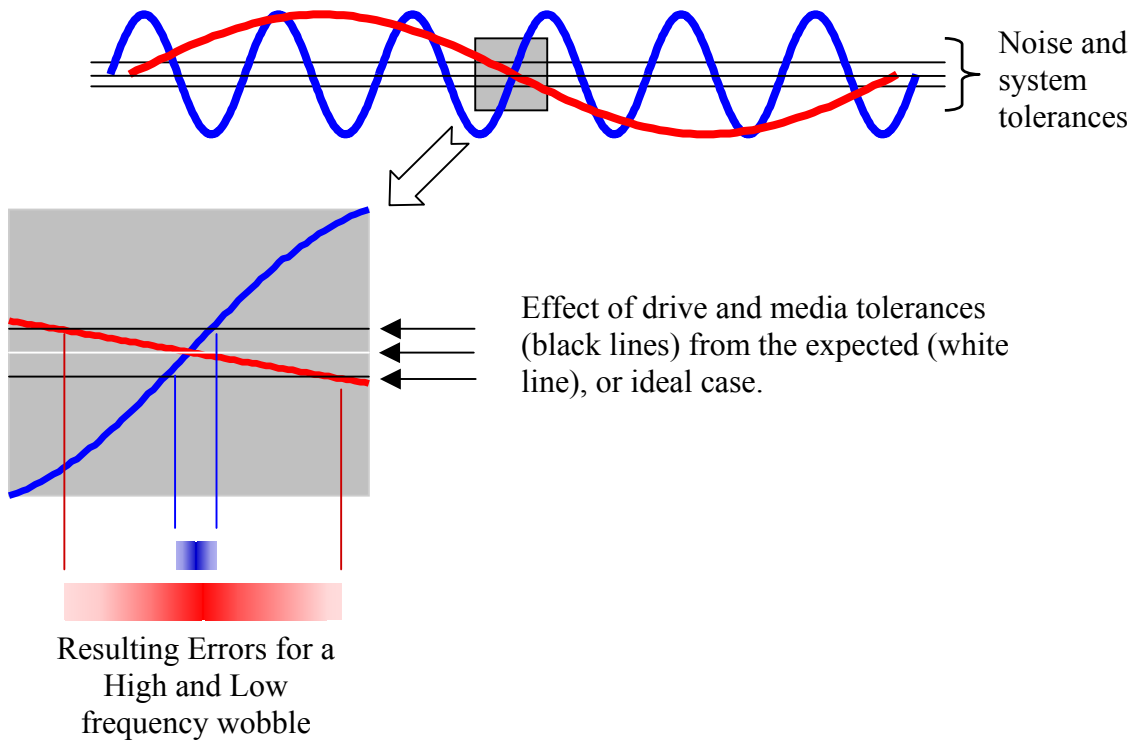
The groove has a slight sinusoidal deviation from the ideal spiral. This sinusoidal deviation is commonly referred to as the "wobble". All recordable DVD and CD have some form of a wobble. This wobble signal is read by the drive optics and electronics,

and used for timing and addressing information and to keep the laser spot positioned on the average center of the groove as shown in the following figure.



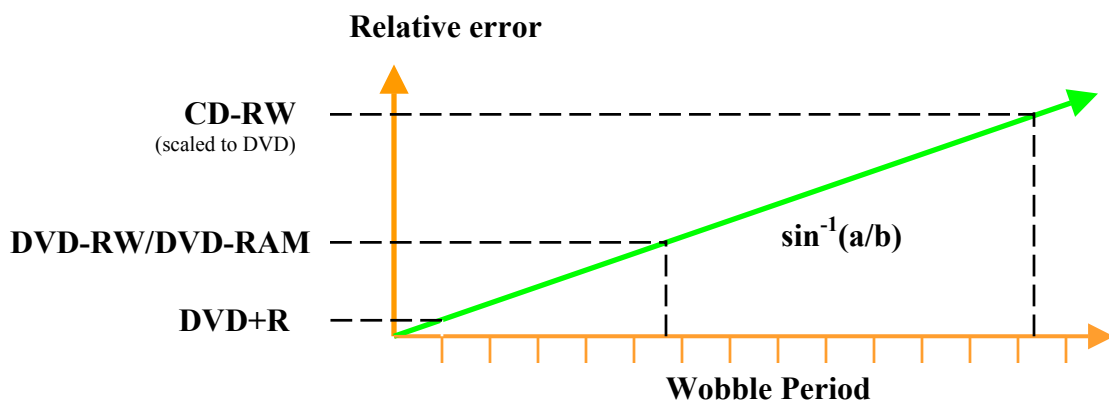
The frequency of the wobble plays a large part in the accuracy of linking. Before illustrating this point, it is important to understand some key elements of drives and media and how it relates to the wobble signal. Drive electronics detect the locations where the wobble signal crosses the average centerline of the wobble, also known as the zero crossing. The design of a format must allow the drive to tolerate minor amounts of off-track, out-of-focus, and disc tilt errors, as well as media and drive noise. Otherwise, the cost of the drive and media would become prohibitive.

The selection of the wobble frequency directly impacts linking accuracy and is primarily a mathematical effect since the slope of a sinusoid at its zero crossing is a function frequency. The following figure attempts to illustrate the effect of two different frequencies due to this effect. The two black lines represent the limits of various tolerances due to noise, off-track and out-of-focus events.



The figure shows that the high frequency wobble (blue sinusoid) has much less error than the lower frequency wobble (red sinusoid). This resulting error represents the amount of noise that directly affects linking accuracy. For exactly this reason, the DVD+RW format uses the highest frequency wobble possible that does not interfere with recorded data.

The amount of error from this effect increases linearly with increasing wobble period (lower wobble frequency) as shown in the following figure.



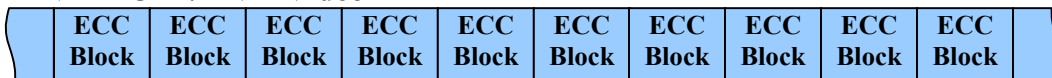
Other factors beyond this affect linking accuracy, both positively and negatively. An example of this is with CD-R/RW, which uses frequency modulation for their addressing that would further worsen the linking accuracy. In general, a high frequency wobble has

better linking accuracy than a low frequency wobble, which is why it was selected for use in the DVD+RW format. For DVD+RW, the physical length of one wobble cycle is the same as the length of two data bytes (~ 4.25 μm). This translates into almost 88,000 wobbles at the outer diameter of the disc or over 2.9 billion total wobble cycles for a 4.7GB DVD+RW or DVD+R disc.

Linkless Editing

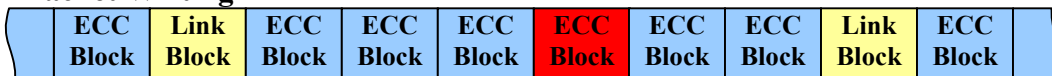
The high frequency wobble enables Linkless Editing because it has extremely high linking accuracy, or said another way, start and stop writing accuracy. To understand the need for this, a description of the DVD Read-only format is necessary. The data in the basic DVD format is organized into blocks of information containing 32 Kbytes of user data plus another 5920 equivalent bytes of error correction data, sync marks and address information. These blocks of information are typically referred to as 32K ECC Blocks or ECC Blocks. In DVD Read-only, ECC Blocks are placed on a disc without any additional area between ECC Blocks as the following figure shows.

DVD-ROM / DVD Video



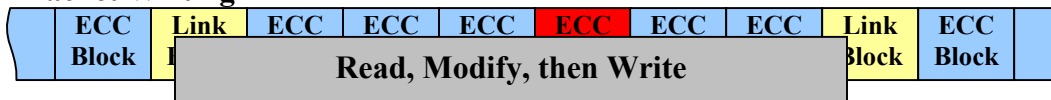
In the past, formats like this would require disc-at-once or track-at-once recording where the entire data set would need to be recorded in a continuous operation. While this works fine for authoring applications, where the data set is prepared on a hard drive and then streamed without interruption to the drive, it is not very conducive for rewritable applications. The old way to handle rewritable media would be to allocate all or part of some ECC Blocks to serve as Link Blocks. Within these Link Blocks are inexact positions where writing starts and stops, called splice points. Here is an example -

Packet Writing



The method used for writing is referred to as Packet Writing. If the red ECC Block in the previous example needs to be overwritten, the drive would first need to read all of the ECC Blocks between the two Link Blocks and then rewrite all of the ECC Blocks plus parts of the Link Blocks back onto the disc.

Packet Writing



There are two types of Packet Writing, Fixed Packets and Variable Packets, which as the names suggests, allows either a fixed number always or different numbers of ECC Blocks between Link Blocks. Variable Packet writing is extremely difficult to use for random

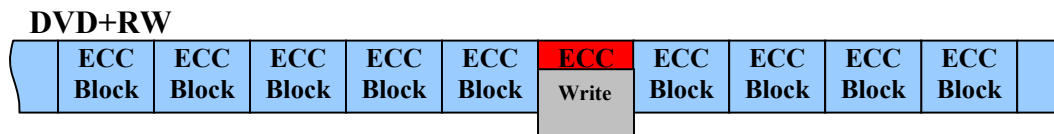
writing, therefore, drag-and-drop applications use Fixed Packet writing for random writing. Unfortunately, Fixed Packet writing has 3 major problems – loss of capacity, slower performance, and lack of compatibility with existing DVD Players and DVD-ROMs.

The previous example used 6 ECC Blocks for every Link Block, which is a capacity reduction of 1/7th (14.3%) of the user capacity. The other problem is that to write one ECC Block, 6 ECC Blocks must be read, then the 6 ECC Blocks and the Link Block must be written to the disc. This is severe performance penalty that can take up to 13 times the length of time it would take to write just the one ECC Block and, at a minimum, 1/6th longer if exactly all 6 ECC Blocks need to be written in the packet. Performance can be improved by reducing the number of ECC Blocks between Link Blocks, but that increases the number of Link Blocks, which further reduces user capacity. Conversely, capacity can be improved by increasing the number ECC Blocks between Link Blocks, but that further reduces performance.

The final issue surrounding packet writing is that, unlike CD-ROMs today, current DVD Players and DVD-ROMs do not understand the concept of Link Blocks, which means they would be assigned a logical sector number (the method used to address user data on discs) even though they are not allowed to contain user data. This is confusing for file systems, which see the Link Blocks as available space, but cannot use. This method is also unusable in DVD Players because it would require splitting up large files into multiple pieces for the file system, forcing the file system to represent the file in multiple extents. Unfortunately, that is currently not a method allowed in DVD Players.

Examples of formats that allow packet writing using Link Blocks include DVD-R and DVD-RW that allow both 2Kbyte and 32Kbyte Link Blocks and CD-R/RW which uses what is effectively a 14 Kbyte Link Block (one 2 Kbyte link block and six additional 2 Kbyte blocks necessary due to the specific ECC scheme used in CD).

DVD+RW has a much more efficient method of writing on the disc. Only the ECC Block or Blocks need be written as illustrated in the following figure using the previous example.



The DVD+RW format is able to write this way because of the high frequency wobble that makes possible extremely accurate linking and requires no need for Link Blocks. This capability in DVD+RW eliminates the need for additional linking strategies as found in DVD-R, DVD-RW, and CD-R/RW, simplifying software design and creating a single consistent write method.

Electrical Signal Compatibility with DVD Read-only

The electrical signals derived from the recorded marks in DVD+R and DVD+RW must meet the same specifications as the electrical signals derived from the pits in a DVD

Read-only disc to maximize compatibility. The following table lists the specifications for single layer DVD Read-only (SL DVD-RO), as well as dual layer DVD Read-only, DVD+R and DVD+RW.

| | SL DVD-RO | DL DVD-RO | DVD+R | DVD+RW |
|-----------------------------|--|----------------|--|----------------|
| Laser wavelength | 645 nanometers – 660 nanometers | | | |
| Numeric Aperture | 0.60 | | | |
| Reflectivity | 45%-85% | 18%-30% | 45%-85% | 18%-30% |
| Modulation | ≥ 0.15 | | | |
| | ≥ 0.60 | | | |
| DPD tracking | $0.5 \leq x \leq 1.1$ at 0.1 μm offset | | | |
| Tangential push-pull | $0 \leq x \leq 0.9$ | | | |
| Asymmetry | $-0.5 \leq x \leq +0.15$ | | | |
| Track cross signal | ≥ 0.10 | | | |
| Jitter | ≤ 8% | | ≤ 9% | |
| Substrate thickness | 0.60 mm ± 30 μm | | 0.60 mm ± 20 μm | |
| Radial deviation | ≤ 0.8° | | ≤ 0.7° | |

Most values are the same or tighter for DVD+RW and DVD+R than DVD Read-only except for reflectivity and jitter. Jitter describes the amount of variation that the edges of pits or written marks of the data. Drives are typically designed to handle up to ~15% jitter, which is much greater than the amount allowed on the disc. This is because drives must account for other tolerances, including some amount of defocus, or being slightly off track, or the disc tilted slightly, etc. This is often referred to as the system margin, which includes tolerances for both the drive and media.

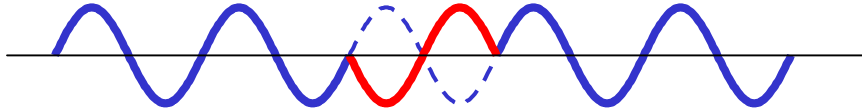
Disc manufacturing is not perfect and can vary from disc to disc and within the same disc. This includes variations in the thickness of the polycarbonate (plastic) substrate of the disc or the amount of radial deviation (tilt) of the disc. Note that while the specification for the jitter value for DVD Read-only is approximately 11% better than the values for DVD+RW and DVD+R, the values for thickness variation and radial deviation for DVD Read-only are worse by 50% and 14%, respectively. This gives an equivalent amount of system margin for DVD+RW and DVD+R as DVD Read-only, and therefore, does not impact compatibility with DVD Players and DVD-ROMs.

The overall reflectivity for DVD+R is the same as single layer DVD Read-only, while the reflectivity for DVD+RW is the same as a dual layer DVD Read-only disc. This means that all DVD products should have the necessary electronics to handle DVD+RW.

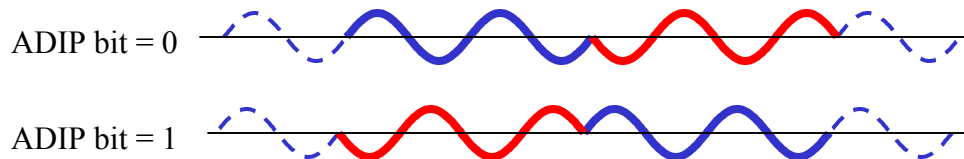
Fast, Reliable Physical Addressing

All recordable discs have some form of addressing used by a drive to determine disc location. DVD+RW chose to require a fast, reliable addressing method that also was readable, before, during and after writing. Additionally, the addressing method takes into account the DVD+RW disc does not require a cartridge and was designed to robustly handle dust and other surface defects. The DVD+RW wobble addressing is called ADIP (Address In Pre-groove).

DVD+RW addressing uses what is referred to as phase-modulated wobble addressing. Certain wobbles are shifted in phase so as to be inverted. The following figure shows this more clearly, where the blue line represents the normal wobble phase and the red wobble is inverted.



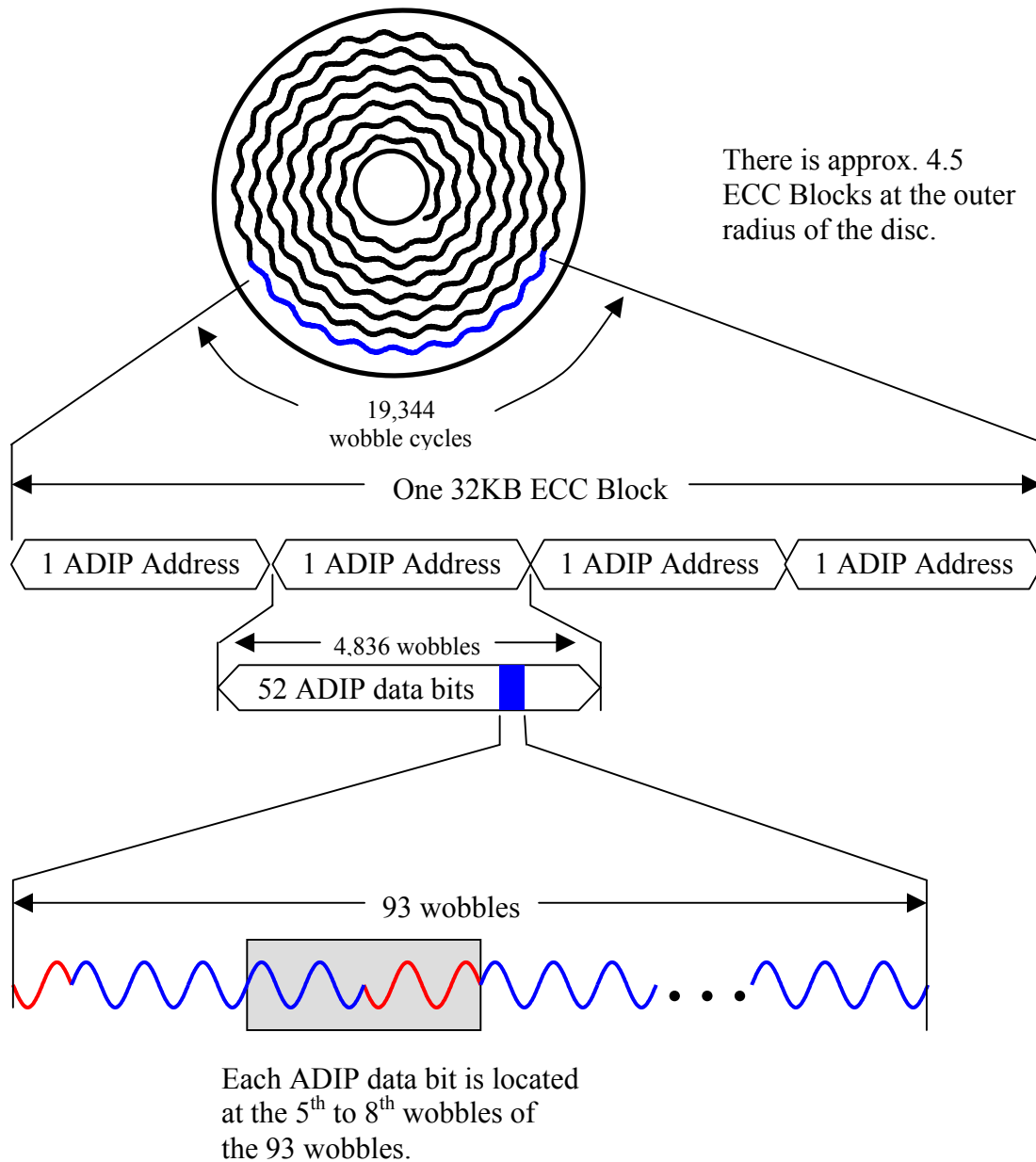
The actual pattern used to determine a “1” or a “0” consists of 4 consecutive wobbles, either 2 normal phase wobbles followed by 2 inverted wobbles or 2 inverted wobbles followed by 2 normal phase to indicate a data “0” and “1”, respectively.



Four wobble cycles represent a (relatively) large feature size, to indicate each ADIP data bit. This makes each bit less sensitive to defects and conditions that arise while writing the data. Additionally, each of these 4 wobble cycle ADIP bit is separated by 89 wobbles, which makes adjacent ADIP bits less likely to be damaged by the same defect.

Two more factors make the DVD+RW wobble addressing even more reliable, redundancy and error correction. Each ADIP word consists of 52 bits, but only 32 bits contain address and auxiliary information. The remaining 20 bits are additional error correction bits. And finally, there are 4 ADIP addresses for every ECC Block, and remember that an ECC Block is the smallest writable amount for all recordable DVD.

The following figure is a schematic representation of the ADIP addressing system.



Other addressing methods were considered for the DVD+RW format, but rejected for various reasons. Frequency modulation of the wobble, used in CD-R/RW was not used as it would lead to less accurate linking and make it more difficult to keep the clock used for writing coupled directly to the wobble. Any pre-embossed headers, including ones similar to DVD-RAM could not be used as it violates one of the main tenets of DVD+RW – compatibility. Another common method used is called Land Pre-Pit (LPP) and used in DVD-R and DVD-RW. These LPPs are less than 0.5 μm in size, which compared to the DVD+RW phase modulated wobbles (just over 17 μm in length) are more susceptible to defects, have less focus and disc tilt tolerance, and more difficult to read during and after writing the disc. Based on these factors, the phase-modulated ADIP system was deemed the best choice for the DVD+RW format.

Constant Angular Writing

The DVD+RW format needed to address the needs of the IT or PC industry as well as the Consumer Electronics (CE) industry. Typical CE applications only require a constant data rate, which equates to reading and writing a disc using Constant Linear Velocity. In CLV mode, the disc is spinning fast when the laser is focused at the inner diameter of the disc. As the position of the laser moves towards the outer diameter of the disc, the disc rotation rate decreases. This is, typically, not a concern for CE devices, which stream content to/from the disc in a linear fashion.

The PC industry has more and varying needs than the CE space. PC drives are often expected to randomly write at different locations (radii) on the disc. In the CLV mode, if the laser must write at 2 different radii on the disc, the rotation rate of the disc must settle to the correct speed before writing. For some applications, such as disc authoring and backup, this is acceptable. However, some applications, such as random writing of small files, this degrades performance. For this and other reasons, a Constant Angular Velocity (CAV) mode is allowed. In CAV mode, the disc always rotates at the same rate, and the data rate (the speed at which data is written to the disc) increases from the inner diameter to the outer diameter. The longest operation in seeking is usually the time it takes to change the rotation rate of the disc. By eliminating that factor, performance can increase for some operations. Another impact of a CLV mode is in power consumption, as the operation of increasing or decreasing the rotation rate consumes more power than maintaining the same rotation rate. It is conceivable that applications dependent on batteries (such as laptops) will find the CAV mode advantageous.

The 1st generation of DVD+RW and DVD+R were designed for writing at speeds from 1X (1.385 Mbytes/sec) to 2.4X. Subsequent DVD+RW and DVD+R specifications will continue to include a CAV mode. It should be noted that in the case of 1X to 2.4X format, it is possible to write the disc in CLV mode at any single speed between 1X and 2.4X, inclusive.

Summary

The DVD+RW format was designed to meet the needs of the CE and PC markets. The format was designed to maximize compatibility, usability, reliability, and flexibility. The DVD+RW / DVD+R format creates a viable scenario for a single format, which meets the needs of all customers.