CHAPTER 2

Storage Devices & Its Interfacing
Data Encoding Techniques used in Hard Disk

1) Frequency Modulation (FM)
   - One of the earliest techniques for encoding data for magnetic storage is called Frequency Modulation encoding.
   - Sometimes called Single Density Encoding.
   - Used mostly in Floppy Disk Drives.
   - FM encoding no longer used.
   - In this FM method of data recording a 1 bit is stored as two pulses(one clock pulse and one data pulse.) and 0 bit is stored as a one pulse and one gap or no pulse(1 clock pulse and one “no pulse” to show that it is a 0 bit).
   - A binary digit 1 is stored as two pulses(PP)
   - A binary digit 0 is stored as one pulse and one “no pulse”(PN)
   For example a binary number 1011 will be stored as PP PN PP PP

2) Modified Frequency Modulation (MFM)
   - Modified Frequency Modulation method of data storage, by reducing the number of pulses is able to store more data without any data and synchronisation loss.
   - In MFM recording the 0s and 1s are encoded as given below:
     - 1 is always stored as a no pulse and a pulse (NP)
     - 0 when preceded by another 0 is stored as a pulse and no pulse(PN)
     - 0 when preceded by a 1 is stored as two no pulses (NN)
   - If you store 1001 on the disk surface using the MFM storage method it would be stored as NP NN PN NP
RLL Encoding Scheme

This encoding scheme can be more accurately called as 2,7 RLL encoding because in this scheme in a series or in a running length the minimum number of 0s next to each other is two and the maximum number of 0s together can not be more than seven.

The RLL encoding scheme can store 50 percent more information than MFM encoding scheme on a given surface and it can store three times as much information as the FM encoding schemes.

The Run Length limited name comes from the minimum number (Run Length) and maximum number (Run Limit) of “no pulse” values allowed between two pulses.

<table>
<thead>
<tr>
<th>Data bit</th>
<th>Pulse Encoding</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>NPNN</td>
</tr>
<tr>
<td>11</td>
<td>PNNN</td>
</tr>
<tr>
<td>000</td>
<td>NNNPNN</td>
</tr>
<tr>
<td>010</td>
<td>PNNPNN</td>
</tr>
<tr>
<td>011</td>
<td>NNPNPNN</td>
</tr>
<tr>
<td>0010</td>
<td>NNPNPNNN</td>
</tr>
<tr>
<td>0011</td>
<td>NNNNPNNN</td>
</tr>
</tbody>
</table>

For eg encode a byte 10 0011 00 to proper RLL Signal then the
Bit 10 can be encoded as NPNN
Bit 0011 can be encoded as NNNPNNN
Finally when you look into the table you will find that there is no information given about how to convert the remaining bit 00.
In this type of situation one must remember that the RLL controller is not used to encode single byte of information instead it converts the entire collection of bytes to be sent to the hard drive.
The controller includes bit from the next byte to complete a bit combination that can be encoded. In the above example if the next byte is 10110011 then by adding the first two bit of this byte to the previous bit combination 00, we will get a bit combination given in the table.
00 from last byte and 10 from this byte will give 0010 which can be converted to NNPNPNPNN.
If the last byte of the data contain a bit combination that is not given in the table then the controller adds the excess bits required to encode the byte and encodes it. During the decoding the excess bit is removed from the byte.
To store 10001111 using different data encoding schemes you need
- PP-PN-PN-PP-PP-PP-PP-PP ie total 13 pulses in FM Scheme
- NP-NN-PN-PN-NP-NP-NP-NP-NP ie total 7 pulses in MFM Scheme
- NPNN-NNNNPNNN-PNNN ie total 3 pulses in 2,7 RLL Scheme.

Perpendicular Encoding
- Virtually all hard drives record data using longitudinal recording which stores magnetic bits horizontally across the surface of the media.
- However perpendicular recording which aligns magnetic signals vertically on the media surface has the potential to achieve higher data intensities because vertically oriented magnetic bits use less space than longitudinally stored bits.
A hard disk drive is made up of several physical components
1) Disk platters
2) Read/write heads
3) Head actuator mechanism
4) Spindle motor
5) Logic board
6) Cables and connectors
7) Bezel / Front Plate
8) Air Filter

The platters, spindle motor, heads and head actuator mechanisms usually are contained in a sealed chamber called the hard disk assembly (HDA) and is treated as single components. Other external parts are logic boards, bezels or mounting hardware.
1) Hard Disk Platters (Disks)
   - The platters stores information. It comes in varying sizes like 5.12”, 3.14”, 0.85” etc. The physical size of a drive is expressed as the size of the platters
   - Most hard disk have two or more platters
   - Platters were originally made from an aluminium/magnesium alloy which provides both strength and light weight
   - All modern drives use glass or glass ceramic plates.

2) Read/Write Heads
   - A hard disk drive usually has one read/write head for each platter surface (meaning that each platter has two sets of read/write heads—one for top side and one for bottom side)
   - These heads are connected on a single movement mechanism so heads across the platters in unison.
   - The HDD uses various types of heads for read/write purpose.
     o Ferrite head
     o Metal-In-Gap Head
     o Thin Film Head
     o Magneto Resistive Head
     o Giant Magneto Resistive Head

3) Head Actuator Mechanism
   - This mechanism moves the heads across the disk and positions them accurately above the desired cylinder.
   - Two basic categories are used
     i) Stepper Motor Mechanism
     ii) Voice Coil Actuator
   - Stepper Motor actuators were commonly used on hard drives made during the 1980s and early 1990s with capacities of 100MB or less
   - Floppy disk drives position their head by using a stepper motor actuator
   - All hard disk drives being manufactured today use voice coil actuator.

![Figure 10.8 A stepper motor actuator.](image_url)

Voice Coil Actuator
- The two main types of voice coil positioner mechanisms are
4) Spindle Motor
- The spindle motor spins the platters connected to spindle. The motor is directly connected to the spindle of platters. These platters revolve at exactly 3600 rpm to 1500 rpm. The speed of motor has to be controlled very precisely.
- Normally a feedback loop is employed in the control electronics to monitor the speed. The speed control is fully automatic.

5) Logic Boards
- A disk drive will have a board containing the electronics that control the drive’s spindle and headactuator systems. These are called logic boards.
- They present data to the controller in a planned format.
- They may be removed and replaced to rectify a logic board problem.

6) Cable and Connectors
- Cable and connectors are used to connect HDD to the main computer system.
- All hard drive contains connections for
  - Data/Control interface connector
  - Power connector

7) Bezel/ Front Faceplate
Bezel is the front faceplate provided on most of the hard disk drives.

8) Air Filters
- Nearly all hard disk drives have two air filter. One is called the recirculating filter and the other is called either a barometric or breather filter.
- These filters are permanently sealed inside the drive and are designed never to be changes for the life of the drive.
- A hard disk on a PC system does not circulate air from inside to outside the HDD or vice versa.
- The recirculating filter permanently installed inside HDA is designed to filter only small particles. Scraped off platters during head takeoffs and landings.
Subject: Computer Hardware and Maintenance (17428)

- The HDD is vented through a breather filter element that enables pressure equalization (breathing) between inside and outside of drive HDA in hard disk is sealed but not airtight.

![Air circulation in a hard disk.](image)

Servo Techniques
Three Servo mechanism designs have been used to control voice coil positioners
  - Wedge Servo
  - Embedded Servo
  - Dedicated Servo

The three designs are slightly different but they accomplish the same basic task—They enable head positioner to adjust continuously so it is precisely positioned above a given cylinder on the disk. The main difference between these servo designs is where the gray code information is actually written on the drive.

All servo mechanisms rely on special information ie written to the disk when it is manufactured. This information is usually in the form of special code called gray code—a special binary notational system in which any two adjacent numbers are represented by a code that differs in only one bit place or column position. This system enables the head to easily read the information and quickly determine its precise position.

At the time of manufacture, a special machine called a servo writer writes the servo gray code on the disk.

Wedge Servo:
Early servo controlled drives used a technique called a wedge servo. In these drives, the gray code guidance information is contained in a “wedge: slice of drive in each cylinder immediately preceding the beginning of each track.

The problem is that servo information appears only one time every revolution, which means that the drive often needed several revolutions before it could accurately determine and adjust the head position. Because of these problems the wedge servo was never a popular design it no longer is used in drives.

Embedded Servo
An embedded design writes the servo information before the start of each sector.
This arrangement enables positioner circuits to receive feedback many times in a single revolution making the head positioning much faster and more precise.

Another advantage is that every track on the drive has its own positioning information so each head can quickly and efficiently adjust position to compensate for any changes in platter or head dimensions especially for changes due to thermal expansion or physical stress.

Most drives today use an embedded servo to control the positioning system.

**Dedicated Servo**

- A dedicated servo is a design in which the servo information is written continuously throughout the entire track rather than just one per track or at the beginning of each sector.
- Unfortunately if this procedure were used on the entire drive no room would be left for data. For this reason, a dedicated servo uses one side of one of the platters exclusively for the servo positioning information. The team dedicated comes from the fact that this platter side is completely dedicated to the servo information and can’t contain any data.
- When the drive moves the heads to a specific cylinder, the internal drive electronics use the signals received by servo head to determine the position of read/write heads. As the heads move the track counters are read from the dedicated servo surface. When the servo head detects the requested track the actuator stops. The servo electronics then fine tune the position so the heads are precisely above the desired cylinder before any writing is permitted. Although only one head is used for servo tracking the other heads are attached to same rack so that if one head is above the desired cylinder all the others are as well.
- The drawback to a dedicated servo is that dedicating an entire platter surface for servo information is wasteful.

![Diagram of Servo and Embedded Servo](image)
Terms Related to Hard Disk:

- **Track** The read/write area of the hard disk is divided into concentric circles called tracks. The tracks are numbered from zero starting at outside and increasing as you go inside.
- **Sectors** The track in a disk are divided into sectors. Each sector is able to hold 512 bytes of data. The sectors represent are shaped pieces of the track.
- **Cylinder** A cylinder is actually all the tracks that are under read/write heads on a drive at one time.

> [Diagram of hard disk tracks and sectors]

- **Cluster** Cluster is a group of one or more sectors. Cluster is the basic unit in DOS allocated disk space. Cluster sizes is used by DOS.
  - **Disk** Default Cluster Size
    - 5.25" 360 KB 2 sectors(or)1024 bytes
    - 5.25" 1.2 MB 1 sector(0r ) 512 bytes
- **Landing Zone** An unused track on a disk surface that the read/write heads can land on when power is shut off. This is the place that will park the heads.
- **MBR** The MBR or master boot Record contains a small program to load and start the active/bootable partition form the HDD. This area also contains information about all four primary partitions on the HDD their starting sector, ending sector, size etc in a partition table record.
- **Zone Recording** One way to increase the capacity of a hard drive during the low level format is to create more sectors on the disks Outer cylinders than on the inner ones. Because they have a larger circumference the outer cylinders can hold more data. Drives that use zoned recording split the cylinders into...
groups called zones, with each successive zone having more sectors per track as you move outward from the centre of disk.

Write Precompensation

- It is useful for drives using standard track, sector format. Drives using zone bit recording do not require any write pre-compensation.
- The magnetic particles used to write on the disk surface have north and south poles.
- Like poles repel and unlike poles attract.
- In the outer surface of hard disk platter, magnetic particles are far apart to be affected by the attraction and repulsion of magnetic particles.
- In the inner tracks of the disk drive, the density of the magnetic are very high and adjacent particles start to attract and repel.
- This will force to change the information written on the disk.
- To compensate for this shift of data particles due to attraction and repulsion, the drive can write the data apart or closer than the required position.
- The particles will slowly shift to the required position because of attraction and repulsion.
- This process of writing the data closer or farther to compensate for attraction or repulsion of magnetic particles is called Write pre-compensation.
- The cylinder from which this pre-compensation is started is called pre-compensation cylinder. This value will be used by all the cylinders that are towards the centre of the drive.
Interleave and Interleave factor
Although traditionally interleaving was more a controller performance issue than drive issue modern hard disk drives with built-in controllers are fully capable of processing the data as fast as the drive can send it. All modern drives are formatted with no interleave sometimes expressed as 1:1 interleave ratio.
Interleave factor - the number of sectors that pass beneath the read/write heads before the next numbered sector arrives eg 1:3

Formatting The formatting procedures are required before you can write user data to a disk
- Physical or Low Level formatting
- High Level Formatting

Low-Level Formatting (Physical Formatting)
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- During a low level format, the tracks are divided into a specific number of sectors, creating intersector and intertrack gap and recording the sector header and trailer information
- Performed by the manufacturer and cannot be technically performed by end user.

High level Formatting
- During the high level format, the operating system writes the structures necessary for managing files and data on the disk. For eg. FAT partitions have a Volume Boot Sector (VBS), two copies of a File Allocation Table (FAT) and a root directory on each formatted logical drive. These data structures enable the operating system to manage the space on the disk, keep track of files and even manage defective areas so they do not cause problems.

Partitioning
- Creating a partition on a hard disk drive enables it to support file systems each in its own partition. Three common file systems are used by PC operating today:

FAT (File Allocation Table)
- Developed by Microsoft for MS-DOS, MS-Windows 95,98, Me
- FAT located in MBR sector of bootable disk
- 2 Important Functions of FAT:
  1) contains allocation information (in the form of linked list)
  2) Indicate which allocation units are free.
- It is simple and reliable. Two identical copies of FAT are used.

Structure of FAT

<table>
<thead>
<tr>
<th>Partition Boot Sector</th>
<th>FAT 1</th>
<th>FAT 2 (Duplicate)</th>
<th>Root Folder</th>
<th>Other Folders and All Files</th>
</tr>
</thead>
</table>

FAT 12:-
- Uses 12 bit binary number to hold cluster Number
- Max 4086 Clusters are possible
- Suitable for small size disk e.g. 16 MB

FAT 16:-
- Uses 16 bit binary number to hold cluster
- Max 65526 Clusters are possible
- Used for HD of size 16 MB to 2048 MB (2 GB)

FAT 32:-
- Most popular and nearest FAT supported by Windows 95,98, Me, 2000
- From 32 bits -28 bits is cluster number and 4 bits are recovered.
- It permits 268 Millions of clusters i.e. HD size of 2 TB

NTFS (New Technology File System)

Structure

<table>
<thead>
<tr>
<th>Partition Boot Sector</th>
<th>Master File Table</th>
<th>System File</th>
<th>File Area</th>
</tr>
</thead>
</table>

- NTFS provides better performance, security compatibility and extendibility than FAT
- Read, Search, Write, Recovery are done fast.
Subject: Computer Hardware and Maintenance (17428)

- Master File Table (MFT) contain information about all files and folders. First file on NTFS volume.
- Partition Boot Sector Start at Sector 0 to 16. First Info on an NTFS volume.

Features:
1. It allows you to encrypt files and automatically decrypt them as they are read.
2. Supports long file names up to 255 characters
3. Supports file size up to 2 TB
4. For keeping track of clusters it uses a B-tree directory
5. Reliable file system as compared to FAT
6. Allows large partition sizes i.e more than 4 GB
7. Built-in file compression facility
8. Improved security and access control deciding who can perform what sorts of operations on various data within the file system

**NTFS vs FAT**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>NTFS</th>
<th>FAT32</th>
<th>FAT16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Volume Size</td>
<td>2TB</td>
<td>32GB for all OS, 2TB for some OS</td>
<td>2GB for all OS, 4GB for some OS</td>
</tr>
<tr>
<td>Max Files on Volume</td>
<td>Nearly Unlimited</td>
<td>4194304</td>
<td>65536</td>
</tr>
<tr>
<td>Max File Size</td>
<td>Limit Only by Volume Size</td>
<td>4GB minus 2 Bytes</td>
<td>2GB (Limit Only by Volume Size)</td>
</tr>
<tr>
<td>Max Clusters Number</td>
<td>Nearly Unlimited</td>
<td>4177918</td>
<td>65520</td>
</tr>
<tr>
<td>Max File Name Length</td>
<td>Up to 255</td>
<td>Up to 255</td>
<td>Standard - 8.3 Extended - up to 255</td>
</tr>
<tr>
<td>System Records Mirror</td>
<td>MFT Mirror File</td>
<td>Second Copy of FAT</td>
<td>Second Copy of FAT</td>
</tr>
<tr>
<td>Built-In Security</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Recoverability</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Performance</td>
<td>Low on small volumes/High on Large</td>
<td>High on small volumes/Low on large</td>
<td>Highest on small volumes/Low on large</td>
</tr>
<tr>
<td>Disk Space Economy</td>
<td>Max</td>
<td>Average</td>
<td>Minimal on large volumes</td>
</tr>
<tr>
<td>Fault Tolerance</td>
<td>Max</td>
<td>Minimal</td>
<td>Average</td>
</tr>
</tbody>
</table>

HDD Interface Types

Compiled By: Ms. M.S Karande (Information Technology Dept)   Page 13 of 19
Interfacing means connecting the hard disk drive to the main computer system.

1) PATA Parallel Advanced Technology Attachment (IDE)
IDE stands for integrated Drive/Device Electronics In ST-506/412 interfaces the controller card was with the expansion slot and the drive was connected through cables.

**Features**
- Proven and reliable technology integration
- Upto 133 MB/s interface transfer rate
- PATA allows cable lengths upto 18 inches (46 cms)
- Designed for desktop PCs and Notebook PCs with usage in entry servers and consumer electronics as well
- PATA is based on the original IBM PC ISA bus

2) SCSI (pronounces as scuzzy) Small Computer System Interface

This interface is not a drive level interface but it a system level interface.
SCSI is not a controller for a single device.
SCSI interface is used in high end configurations
IDE is used in low end configuration

**Features**
- Fast and wide Data Path
- Supports upto 7 peripheral Devices such as CD-Rom, scanner that can attach to a single SCSI port
- Faster than the average parallel interface
- It will allow data transfer upto 100 MB/s to 160 MB/s
- SCSI is now plug and play in nature such as automatic SCSI ID assigning and termination

3) SATA (Serial Advanced Technology Attachment)

- Is a computer bus primarily designed for transfer of data between a computer and mass storage devices such as hard disk drives and optical drives.

**Features**
- SATA is better more efficient interface than the dated PATA standard.
- It supports hot swapping
- Serial ATA uses only 7 conductors while PATA uses 40.
- Data Transfers at the rate of 1.5 Gbit/s, 3 Gbit/s and 6 Gbit/s
CD ROM-Construction and Recording

-Can be connected to the computer via an IDE(ATA), SCSI, SATA, firewire or USB interface
-1x CDROM gives a data transfer rate of 150 KB/s

Construction of CDROM Drive

The drive consists of the following:

1. TurnTable (Servo Motor) The turn table spins the disc at a variable rate of speed depending on where the data is located.
2. A tracking mechanism Moves the laser assembly so that the laser’s beam can follow the spiral track. It has to be able to move the laser beam at micron resolutions.
3. LASER beam The CDROM drive measures reflections from the laser beam which guided along the length of the track. The laser light bounces back into a light sensing detector that sees the beam when the tightly focused laser beam reflects off a land. However, when the beam encounters a pit no laser light is reflected into this detector.
   A sensor detects a change in reflection when it encounters a transition from a pit to land or land to pit. Each transition is read as 1 and the lack of transition is read as 0. These interruptions in light reflections are decoded into music, text or pictures.
4. Optical Head It shines a laser on the disk surface then travels to the location of the data. After the optical head finds the data, it positions itself within the spiral tracks and refocuses to read the data.
   The optical head is composed of 3 main parts. These enable the optical head to read data on disc. They are
   a. Laser Diode
   b. Lens
   c. Photo Detector
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a. Laser Diode An infra red laser diode emits a beam of light onto a reflecting mirror. This mirror which is part of overall head assembly of the drive reflects this light through a lens which focuses on a particular point on the disc. Depending on where the light was focused appropriate intensity of light is then reflected back to a photodetector which transforms this light intensity into electrical energy. Based on the charge data is encoded and decoded for processing.

b. Lens The optical head assembly of the CDROM drive usually called a lens or a pickup traverses a path from the inside of the disc to the outside which is made up of concentric circles.

c. Photodetector It contains different photodiodes (sensors that sense light and intensity and convert it into an electrical signal) and reads the laser reflections from the disc. These photodiodes ensure that the laser beam is focused and is correctly following the disc’s spiral track.

Working of CD-ROM Drive

![Diagram of CD-ROM Drive Components]

**Figure 13.3** Typical components inside a CD-ROM drive.

1. The laser diode emits a low-energy infra red beam towards the reflecting mirror.
2. The servo motor positions the beam onto the correct track on the CD ROM by moving the reflecting mirror.
3. When the beam hits the disc, its reflected light is gathered and focused through the first lens beneath the platter, bounce off the mirror and sent towards the beam splitter.
4. The beam splitter directs the returning laser light towards another focusing lens.
5. The last lens direct the light beam to a photo detector and convert the light into electric impulses.
6. These incoming impulses are decoded by the microprocessor and sent along to the host computer as data.
Recording of CDROM Drive
- EFM (Eight to Fourteen Modulation) is an encoding technique used by CDs and provides a way of countering errors by encoding a byte into 2 bytes.
- Using EFM data is broken into 8 bit blocks (bytes)
- Each 8 bit block is translated into a corresponding 14 bit codeword using a predefined lookup table.

DVD (Digital Versatile/Video Disc)
- Optional storage media for storing data
- Uses primary for movies softwares and data backup purpose
- DVD holds about 7 times more data than CD Data
  DVDs can store more data than CDs for a few reasons:
  • Higher-density data storage
  • Less overhead, more area
  • Multi-layer storage
### Comparison of CD and DVD

<table>
<thead>
<tr>
<th>Parameter</th>
<th>CD</th>
<th>DVD</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sides</td>
<td>1</td>
<td>1 or 2</td>
<td></td>
</tr>
<tr>
<td>Layers</td>
<td>1</td>
<td>1 or 2</td>
<td></td>
</tr>
<tr>
<td>Capacity (GB)</td>
<td>0.68 GB</td>
<td>4.7-17 GB</td>
<td></td>
</tr>
<tr>
<td>Track pitch(µ)</td>
<td>1.6</td>
<td>0.74</td>
<td></td>
</tr>
<tr>
<td>Minimum pit length(µ)</td>
<td>0.83</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Wavelength(nm)</td>
<td>780</td>
<td>650</td>
<td>Of laser diode pickup</td>
</tr>
<tr>
<td>Tracks</td>
<td>Yes</td>
<td>No</td>
<td>DVD uses files not tracks</td>
</tr>
</tbody>
</table>

### DVD physical disc formats

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Format</th>
<th>Capacity</th>
<th>Layers</th>
<th>Sides</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DVD 5</td>
<td>4.7 GB</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>DVD 9</td>
<td>8.54 GB</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>DVD 10</td>
<td>9.4 GB</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>DVD 18</td>
<td>17.08 GB</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

![Diagram of CD track geometry](image)

**e 13.2** Pit, land, and track geometry on a CD.
Blu–Ray Disc

- **Blu ray also known as Blu-ray Disc (BD)** is a next generation optical disc format jointly developed by members of the **Blu-ray Disc Association (BDA)** – a group of the world’s leading consumer electronics, personal computer and media manufactures (including Apple, Dell, Hitachi, HP, JVC, LG, Mitsubishi, Panasonic, Pioneer, Philips, Samsung, Sharp, Sony, TDK and Thomson).
- The format was developed to enable recording, rewriting and playback of High Definition Video (HD) as well as storing large amounts of data.
- The format offers more than five times the storage capacity of traditional DVDs and can hold up to 25 GB on a single layer disc and 50 GB on a dual layer disc.
- A blue laser is used to read the media. Blue light has a shorter wavelength than red used by previous technologies. This makes it possible to read data with greater precision.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity (Single Layer)</td>
<td>23.3 GB/25 GB/27 GB</td>
<td>Tracking Pitch</td>
<td>0.32µm</td>
</tr>
<tr>
<td>Capacity (Dual Layer)</td>
<td>46.6 GB/50 GB/54 GB</td>
<td>Shortest pit length</td>
<td>0.160/0.149/0.138 µm</td>
</tr>
<tr>
<td>Laser Wave Length</td>
<td>405 nm (blue-violet)</td>
<td>Recording Density</td>
<td>16.8/18.0/19.5 Gb/sq.in</td>
</tr>
<tr>
<td>Lens Numerical Aperture</td>
<td>0.85</td>
<td>Data transfer Rate</td>
<td>36 Mbps</td>
</tr>
<tr>
<td>Disc Diameter</td>
<td>120 mm</td>
<td>Recording format</td>
<td>Phase Change Recording</td>
</tr>
<tr>
<td>Disc thickness</td>
<td>1.2 mm</td>
<td>Tracking format</td>
<td>Groove Recording</td>
</tr>
<tr>
<td>Optical Protection Layer</td>
<td>0.1 mm</td>
<td>Video Format</td>
<td>MPEG2</td>
</tr>
</tbody>
</table>