10.3 MiniDisc

10.3.1 Introduction and Features of the MiniDisc System

The MiniDisc (MD) system, developed by Sony, offers both digital sound and random access features. In addition to these features, the following three types of MiniDiscs have been developed for various applications:

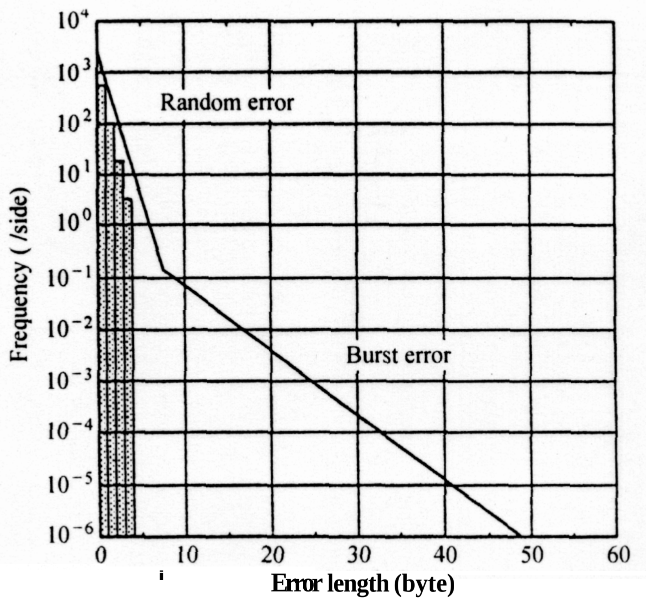


Figure 10.19 Probability of each error length.

1. Playback-only MiniDisc for prerecorded music;
2. Recordable MiniDisc allowing up to 74 minutes of recording time; and
3. Hybrid MiniDisc, a combination with premastered and recordable areas.

The intrinsic recording technology supporting the recordable MiniDisc is the magnetic field direct overwrite method, applied to a consumer product for the first time in the world.

The distinctive features of the MiniDisc are

1. Overwrite function:
2. Maximum 74 min. recording time on a disk only 64mm in diameter, achieved using data compression and high-density recording;
3. Quick random access supported by address information in the wobbled groove; and
4. Disk protection with the cartridge and shutter.

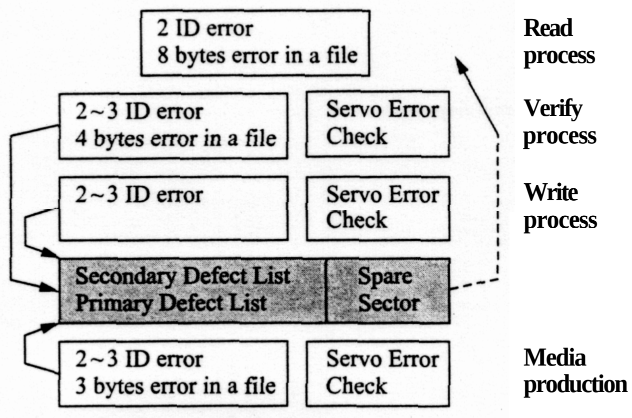


Figure 10.20 Defect management strategies.

Moreover, durability and reliability for the recordable MiniDisc have already been proven with data storage media for computer peripherals, such as the magneto optical disk. Figure 10.21 shows the various MD systems.

10.3.2 System Concept and Specifications

The specifications of the compact disc (CD) were first proposed in 1982, and are described in the so-called "Red Book." Since then, the technological developments for both data and recording applications have been specified in the "Yellow Book" and "Orange Book," respectively. The MiniDisc specifications, which are an extension of these last two books are given in the "Rainbow Book," as shown schematically in Figure 10.22. **A** block diagram and the main specifications are shown in Figure 10.23 and Table 10.5.

10.3.3 Random Access Functions

Figure 10.24 shows the cross section of a playback-only MiniDisc. Both the lead-in area and lead-out area are on the inner and outer circumferences, respectively.

Recordable MiniDiscs are formed with special pre-grooves that cover the entire disc recording area. The pre-grooves enable tracking and spindle servo control operations during both recording and playback, as illustrated in Figure 10.25. These pre-grooves meander slightly at 13.3ms intervals to maintain a specified linear velocity and to create addresses which allow very stable high-speed random access.

In addition to the meandering pre-grooves, a UTOC (User Table of Contents) also contributes to user-friendly quick random access. **As** shown in Figure **10.25,** the lead-in area on the inner circumference of the disk followed by the UTOC area, the program area, and finally the lead-out area similar to the playback-only MiniDisc.

Each sector in the TOC (Table of Contents) in the lead-out and the UTOC is specified as in Table 10.6.

10.3.4 Signal Recording Format

The MiniDisc system uses the popular eight-to-fourteen modulation system (EM) in writing data on a disk and the Cross Interleave Reed–Solomon Code (CIRC) for error

Figure 10.21 Various MD systems.

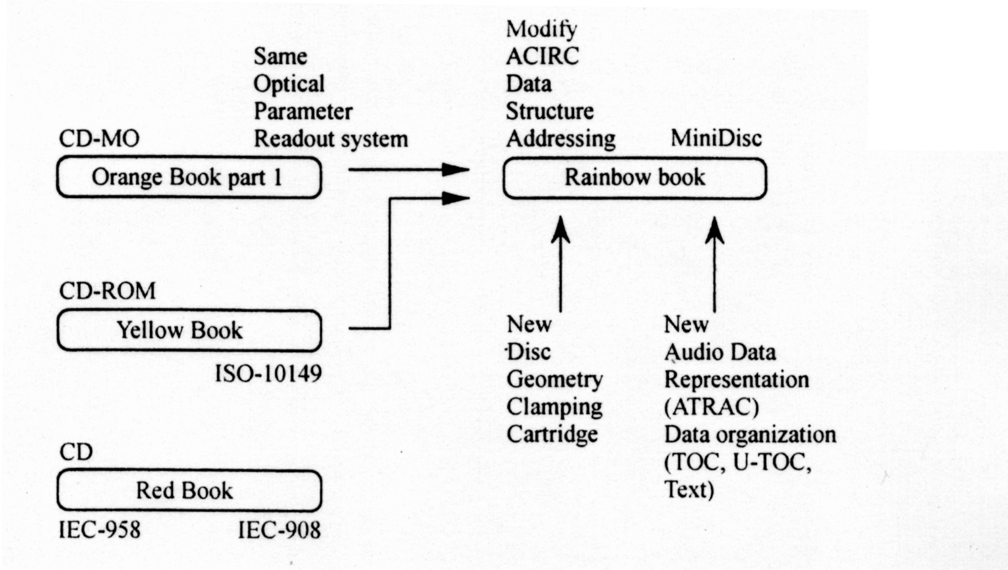


Figure 10.22 Relationships between industrial standards for optical disk products.

correction. Audio data reduced by ATRAC is grouped into blocks for recording in a format very similar to the CD-ROM mode 2 standard, as in Figure 10.26.

The first three sectors of one 36-sector cluster are used as link sectors during recording, with the fourth sector reserved for subdata. In the remaining 32 sectors, the compressed digital data are recorded. When the last sector has been written, error correction data must be written in the first link sector and half of the second sector of the following 36-sector cluster.

TABLE 10.5 MiniDisc Specifications

Major Specifications	
Recording/playback time	74 min (max)
Cartridge size (WHD)	72 x 68 x 5 mm
Disk specifications	
Diameter	64 mm
Thickness	1.2 mm
Diameter (center hole)	11 mm
Diameter (beginning of program)	32 mm
Diameter (beginning of lead-in)	29 mm
Track pitch	1.6 microns
Linear velocity	1.2–14 m/s (CLV)
Signal Format	
Sampling frequency	44.1 kHz
Compression system	ATRAC *1
Modulation system	EFM *2
Error correction system	CIRC *3
Optical Parameters	
Laser wavelength	780 nm
NA	0.45
Recording power	5 mW (max.)
Recording system	Magnetic field modulation

*1 Adaptive transform acoustic coding
*2 Eight to fourteen modulation
*3 Cross interleave Reed–Solomon code

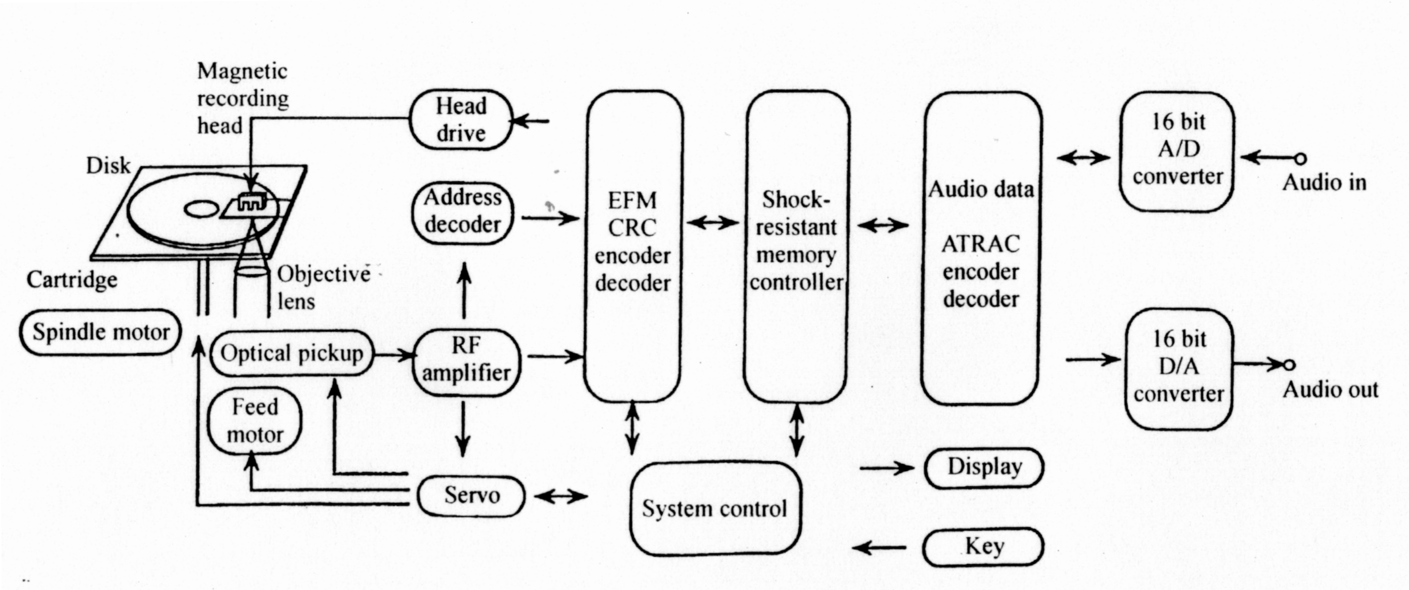


Figure 10.23 Block diagram of MiniDisc system.

TABLE 10.6 Sector Role in TOC/UTOC

TOC	**Generic terms for all subdata**
	Track number, playing time, etc.
	Recording power and recordable time for recordable MD
Sector 0	**Generic terms, start and finish address**
Sector 1	**Disk title, music title and artist**
Sector 2	**Recorded date and time for disk and music**
Sector 3	**Barcord for disk and ISRC for music**
Sector 4	**Disk title, music title, and artist (ISO-8895-1)**

During ATRAC encoding, the audio data are compressed to one-fifth its original volume, and then handled in **424** byte units called "sound groups" with left and right channels allocated 212 bytes each. Eleven of these sound groups are distributed into two sectors. Recorded sound groups in the first sector comprise the left and right channels of five sound groups, plus the left channel of a sixth group, while the right channel of the sixth group and the left and right channels of another five groups are recorded in the second sector. Each of the two sectors can be expressed as $425 \times 5 + 212 \times 1 = 2332$ bytes.

In this manner, 11 sound groups are written per every two sectors in each 32-sector cluster. ATRAC decoding restores the data block to its original volume and time axis, with one sound group becoming equivalent to 512 samples ($512 \times 16 \times 2/8 = 2048$ bytes) for both channels, with a playing time of 11.6ms.

10.3.5 ATRAC Data Compression

MiniDiscs are recorded using Sony's Adaptive Transform Acoustic Coding (ATRAC) system, shown in Figure 10.27, which was designed specifically for high fidelity audio using digital data compression technology. For each block of time, ATRAC analyzes the music signal and determines the sensitivity of each frequency region. The sensitive regions are recorded accurately with very little quantization noise. The remaining regions are recorded less accurately, but since they are not overly sensitive, the quantization error is hardly noticeable. The result is high-fidelity audio in actual listening, recorded at only one-fifth the bit rate, thus enabling ATRAC to allow MiniDiscs up to 74 min of recording and playback time on a disk only 64mm in diameter.

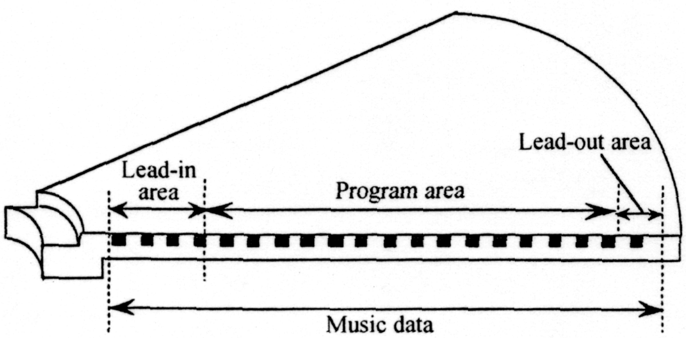


Figure 10.24 Cross section of a playback only MiniDisc.

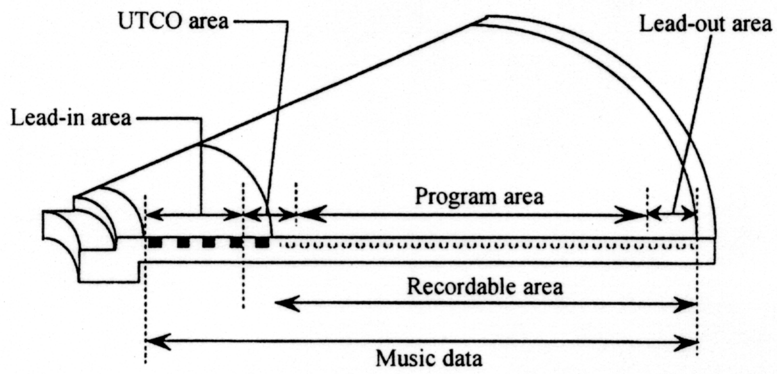
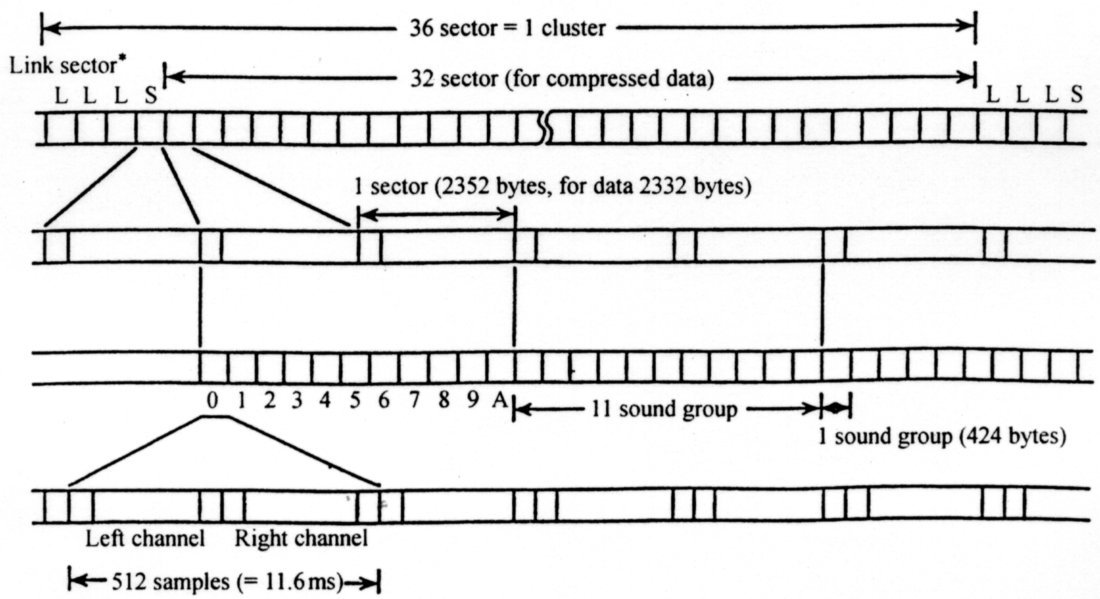
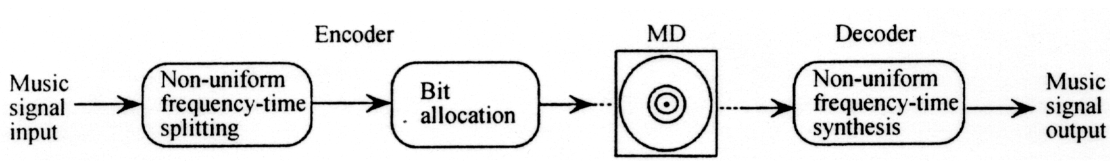


Figure 10.25 Cross section **of** a recordable MiniDisc.



*This becomes a subdata sector in playback-only MiniDiscs

Figure 10.26 MiniDisc data format configuration.



The non-uniform frequency axis and time axis **of** the music signal and drive divided **into** components.

Divided music signal components and allocated bits according to size.

Non-uniform frequency and time components are reconstructed into a music signal.

Figure 10.27 ATRAC operation layout.

10.3.6 Construction of Recordable MiniDisc

Magneto-optical technology is central to the functioning of recordable MiniDiscs. Since a magnetic recording head and a laser are used on opposite sides of the disk, the shutter opens on both sides of the disk, as shown in Figure 10.28.

The construction of the recordable MiniDisc is illustrated in Figure 10.29. The wobbled groove is 1.2 μm wide and λ deep. A 1.6 μm track pitch is specified for the recording track in order to coexist with the address information which is formed by meandering at set intervals of every 13.3 ms. These dimensions have been adopted to satisfy the servo characteristics, in consideration of thermal crosstalk form adjacent tracks, and to gain the maximum C/N.

The design concept behind the MO layers has been reported by Y. Tamada et al. [4]. The current 5.25" and 3.5" MO disks, employ a four-layer structure, and the MiniDisc has also adopted the same layered structure.

10.3.7 Magnetic Field Modulation Overwrite

The recordable MiniDisc is required to realize the same storage density as that of the compact disc, which is 0.85 μm/pit for the 74-min model.

The magnetic field modulation method has certain advantages for this application in terms of system stability and margin between media and drive, compared with the laser modulation recording method. The edge of the marked pattern is determined by the **flux** reversal, and its shape is intrinsically independent of the laser power fluctuation. Moreover, the magnetic field modulation method intrinsically possesses the feature of overwrite recording. In the case of the MiniDisc, the maximum required field modulation frequency is **720** kHz at a linear velocity of 1.2 to 1.4 m/s.

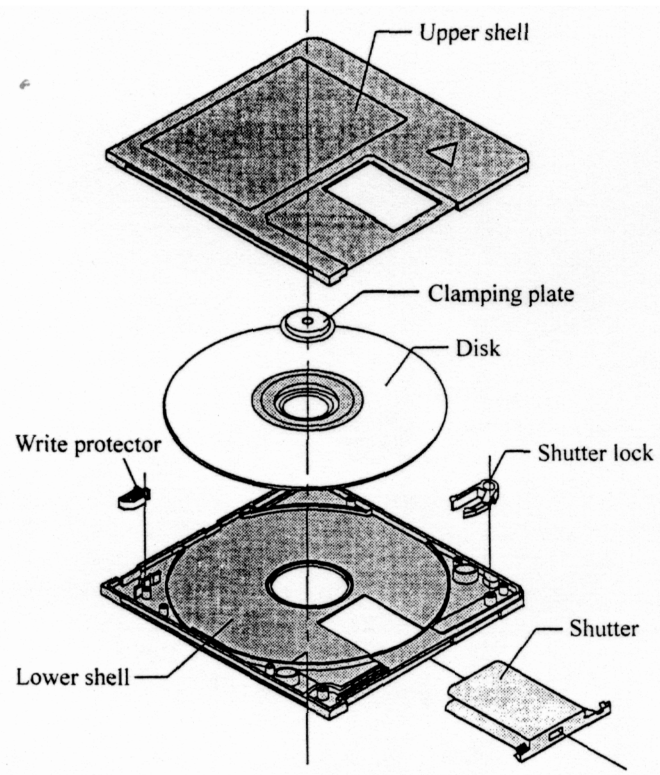


Figure 10.28 Cartridge assemble.

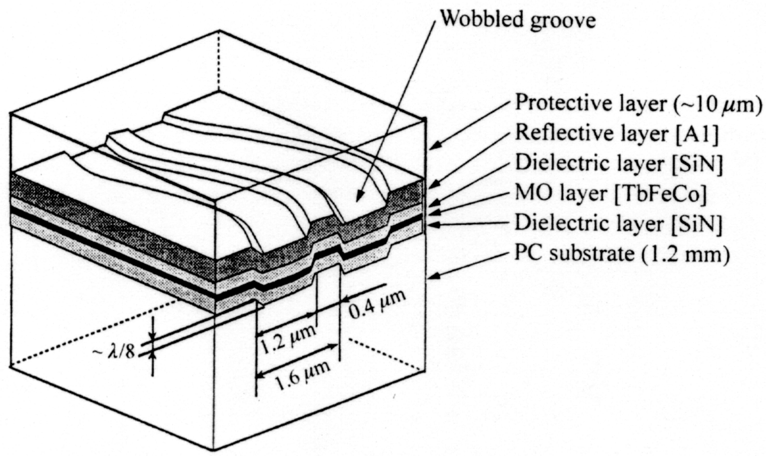


Figure 10.29 Structure of recordable **MiniDisc.**

10.3.8 Magnetic Head for Overwrite

The recording magnetic field for the recordable MiniDisc is required to be over **8** kA/m (100 Oe), and the magnetic head is allowed to contact the disk. In consideration of portability for the MiniDisc system, a contact type has been designed and achieved with the following conditions:

1. Spacing is 150μm;
2. The magnetic field is over **8** kA/m (100 Oe) within ±0.5mm from the center of the core.

Figure 10.30 shows the magnetic field distribution of a recording head at a spacing distance of 150 μm.

10.3.9 Recording Characteristics and Film Properties

10.3.9.1 Magnetic Characteristics and C/N

The comparison of Kerr loops near the Curie temperature between the recordable MiniDisc *(a)* and conventional MO *(b)* is given in Figure 10.31. Remarkable differences between *(a)* and *(b)* in squareness, and the required minimum magnetic field saturation H_s should be noted.

The temperature dependences of residual θ_K, H_c, and of H_s (saturation field) are shown in Figures 10.32 and 10.33. The difference in H_s between MD and conventional MO is clearly demonstrated. Note that the magnetization of the MiniDisc is easily reversed by a field of less than 8 kA/m (100 Oe), at temperatures near the Curie temperature.

Figure 10.34 shows the magnetic field dependence of the C/N for the conventional MO and MiniDisc. The C/N of the conventional disk at 8kA/m (100 Oe) is not high enough to satisfy MiniDisc specifications and gradually increases with H_{ext} up to 16kA/m, and a C/N of about 49 dB. On the other hand, the C/N of the MiniDisc is much higher even at **a** field **8** kA/m (100 Oe); this value far exceeds the minimum requirement of the MiniDisc system of 46dB.

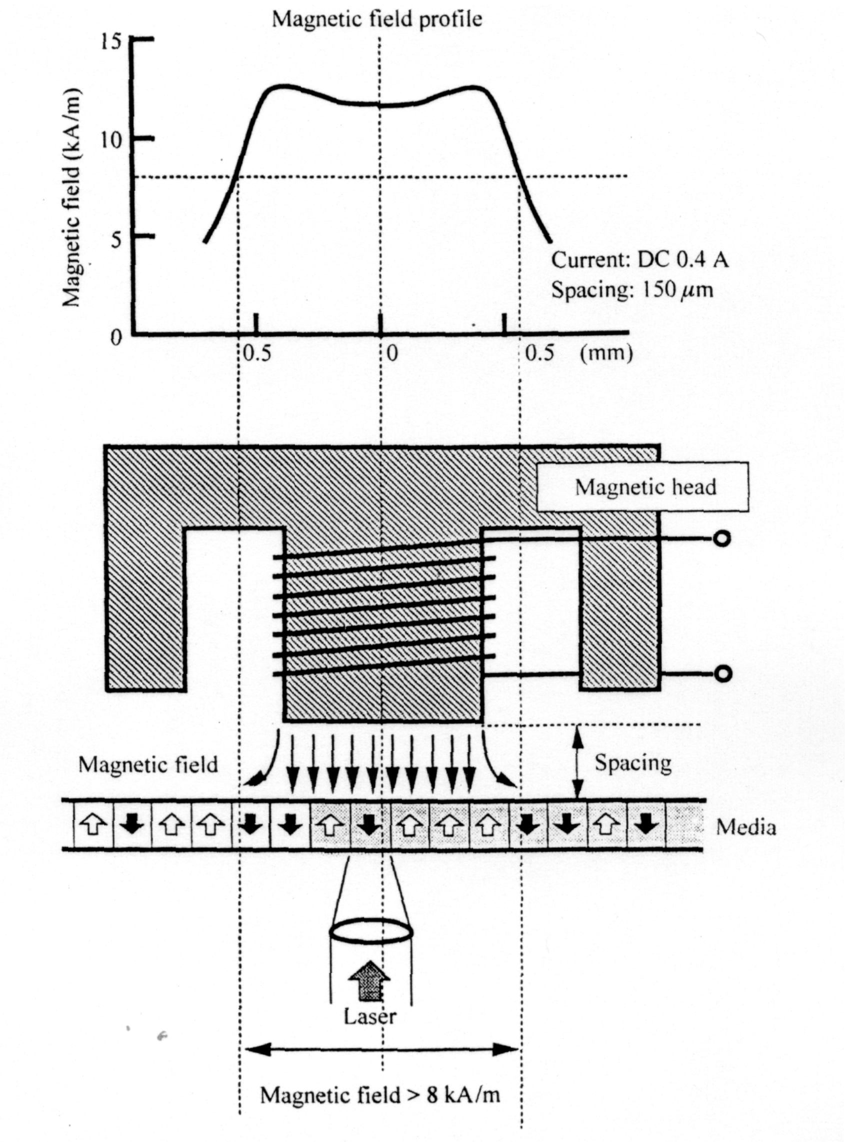


Figure 10.30 Magnetic field profile of a magnetic head.

Figure 10.35 shows the individual trends for the carrier and noise levels. The carrier level of the MiniDisc starts to saturate even at a very low field, and the noise is the dominant factor governing the C/N value in a low field.

10.3.9.2 Power Margin

During actual application, the laser power on a disk may not always be constant, but rather it fluctuates. The fluctuation should be taken into account in an actual drive system recording. For this purpose, the BLER (block error rate) must be less than 3×10^{-2} even when the laser power fluctuates ±20% of its specified values.

Figure 10.36 *(a)* and (b) shows the laser power dependence of C/N, and jitter at 8 kA/m (100 Oe) and BLER, respectively. As the C/N remains more than 46dB and BLER is less than 3×10^{-2} from 3.6 mW to 6.5 mW, this is wide enough for practical

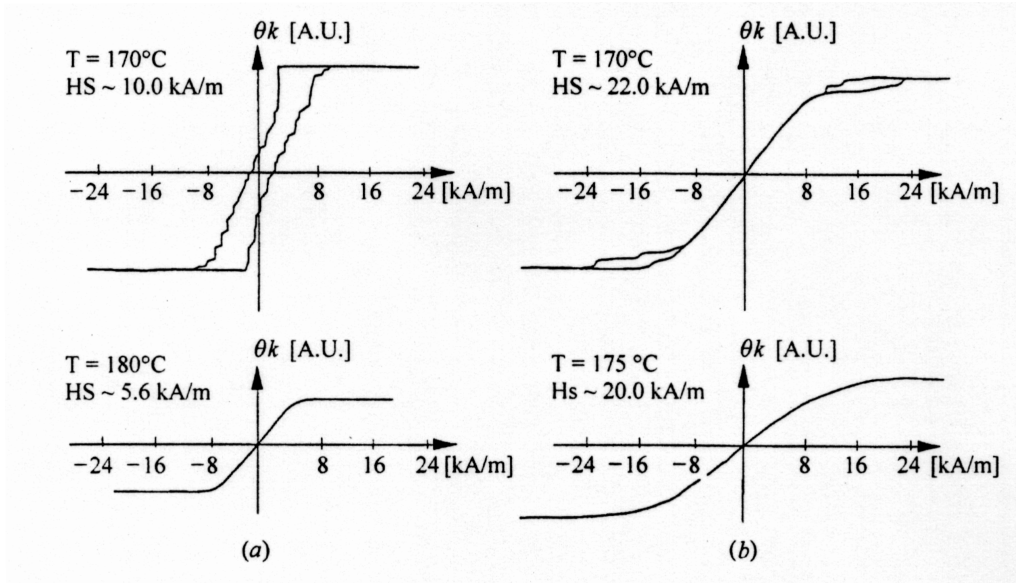


Figure 10.31 Kerr hysteresis loops at **170** and **180°C** for ***(a)*** Recordable MiniDisc ***(b)*** Conventional MO disk on a **glass** substrate with the layers glass/SiN(**110nm)/TbFeCo(250nm)/SiN(350nm)/Al(550nm)**.

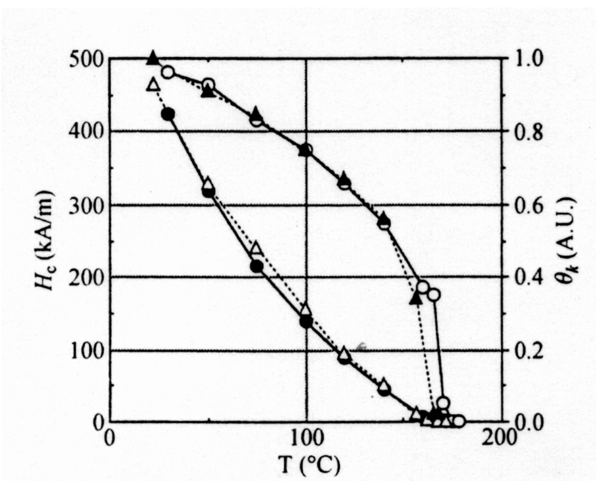


Figure 10.32 Temperature dependence of residual & and H_c.
o MD θ_k ▲: conventional MO θ_k
• MD H_c A: conventional MO H_c

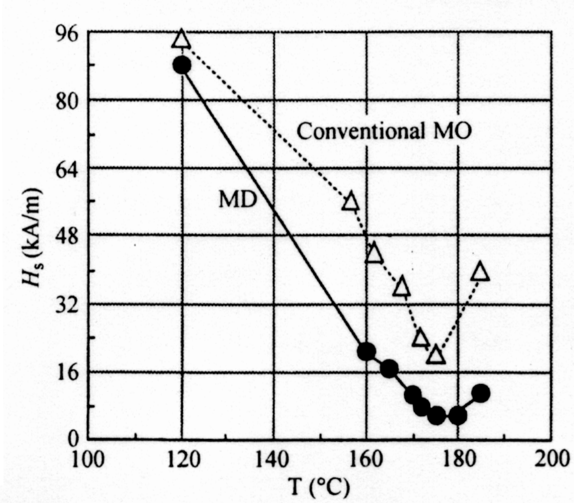


Figure 10.33 Temperature dependence of saturation fields (H_s).

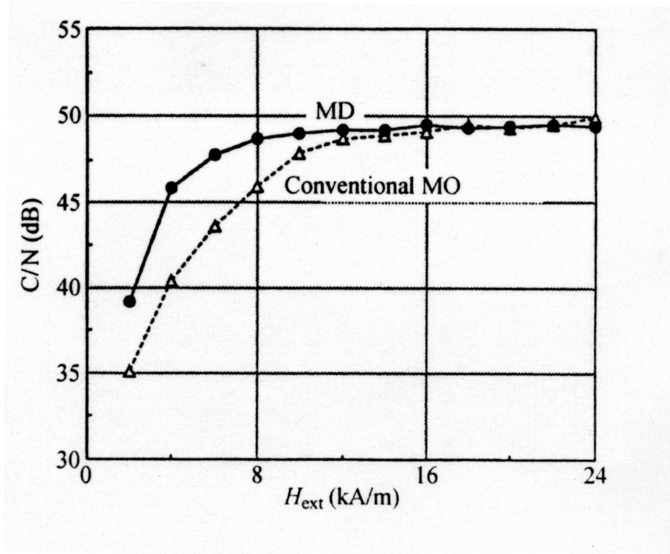


Figure 10.34 Bias field dependence of C/N **for** MD **and conventional** MO v = **1.22m/s, laser power = 4.55 mW, Mark length = 0.85 µm.**

applications. High **BLER** on a low power side is caused by low C/N; on the other hand, **BLER** on a high power side mainly comes from large jitter, due to heat from the adjacent tracks.

10.3.10 Reliability and Durability

Sufficient reliability has been designed into the MiniDisc as in the case for the conventional MO disk. Figure **10.37** shows no change in **BLER** when the same area has been repeatedly recorded a million times over. The MiniDisc system allows for the magnetic head to contact the disk. To obtain sufficient durability for this interfacing, the recordable MiniDisc has a lubricating feature on the overcoat layer, which covers the sensitive layers and faces the magnetic head. The magnetic head has been specially designed to reduce the friction. Figure 10.38 shows changes in friction when the head continuously contacts the same track, under various circumstances. This gives evidence that. the durability for contact is sufficient for practical applications.

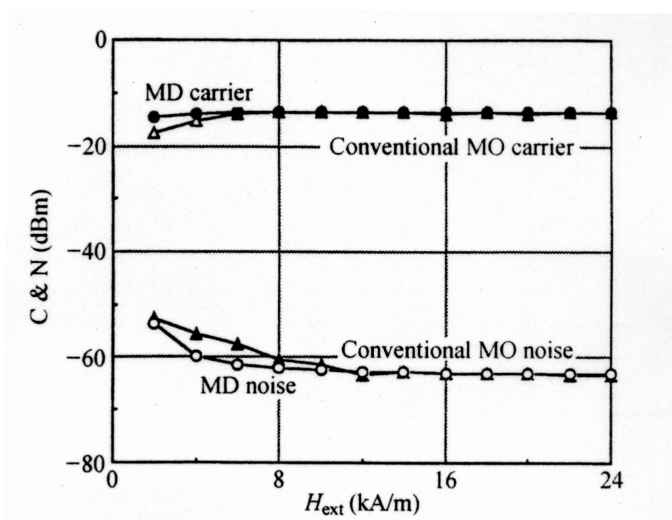
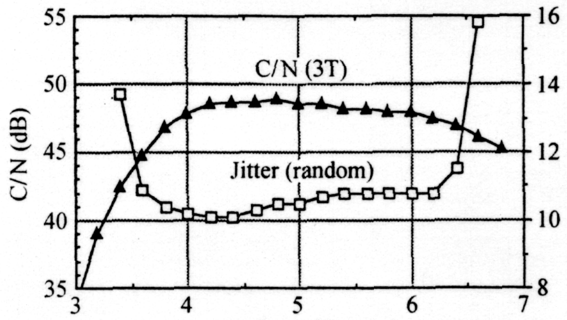
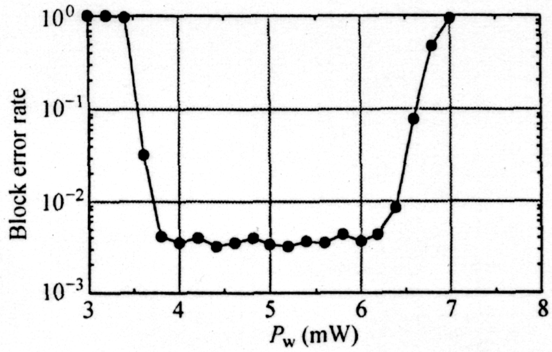


Figure 10.35 Bias field dependence of carrier and noise v = **1.22m/s, laser power = 4.55 mW, mark length = 0.85 µm.**



(*a*)



(*b*)

Figure 10.36 (*a*) The laser power dependence of C/N and jitter $v = 1.22\,m/s$, $H_{ext} = 8\,kA/m$, C/N mark length = 0.85 μm. (*b*) The laser power dependence of block error rate $v = 1.22\,m/s$, $H_{ext} = 8\,kA/m$.

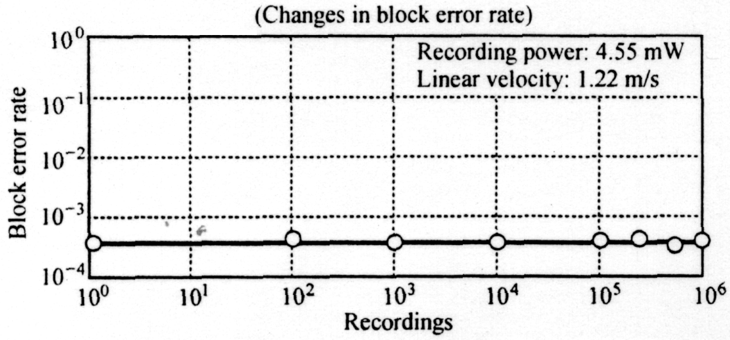


Figure 10.37 Durability in repeated recordings.

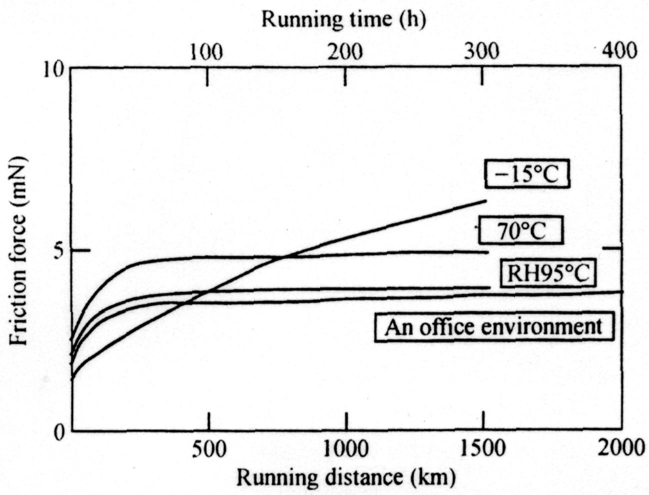


Figure 10.38 Friction force of a magnetic head.

TABLE 10.7 Rewritable MD-Data Specifications

Format	User area (radius)	mm	**16–30.5**
	Sector size (mode **4)**	bytes/sector	**2048**
	Configuration of track		Spiral
	Track pitch	**μm**	**1.6**
	Direction of rotation		CCW (seen **from** optics side)
Mechanical characteristics	Outer diameter of disk	mm	**64**
	Cartridge dimension **(W/R/H)**	mm	**72 x 68 x 5**
	Substrate thickness	mm	**1.2**
Read/write conditions	Nominal write magnetic field strength	kA/m	**8–24**
	Carrier-to-noise ratio	dB	**>46**
	Block error rate		$< 3 \times 10^{-3}$
Recording capacity		MB	**140**
Reliability	Read cycle		$> 10^6$
	Write/read cycle (rewritable)		$> 10^6$

10.3.11 Future Applications

The recordable MiniDisc and MiniDisc system represents the world's first implementation of magnetic field modulation overwrite in a consumer product. This technology will find further use in a data storage model, the MD DATA, which has a storage capacity of 140MB with the same 64mm diameter disk. Specifications are shown in Table 10.7. Moreover, this technology has been introduced into the Digital Audio Master Disc for application in professional recording studios. Recording densities for the Master Disc are presented in Table 10.8, comparing these with the MiniDisc. It has been possible to raise the resolution potential by setting the optical head to NA **0.5,** and wavelength to 780 nm. As a result, the recording density of the Master Disc is 20% greater than the 74 min version of the MiniDisc, in addition to using **2–7** modulation. Figure 10.39 offers a comparison of recording densities for different magneto-optical disks.

In summary, the technology for magnetic field modulation has been realized with overwrite features for both consumer and professional applications, and for audio entertainment as well **as** data storage.

TABLE 10.8 Recording Densities for MASTER DISC and MD Format

	MASTER DISC	MD **(74** min.)
Disk format		
Modulation system	**2–7 RLL**	EFM
Track pitch	**1.55** μm	**1.6** μm
Smallest pit length	**0.78** μm	**0.847** μm
Optical pickup		
Numerical aperture of lens (NA)	**0.50**	**0.45**
Laser wavelength	**7.80** nm	**780** nm
Comparison of recording densities		

$$\frac{\text{MASTER DISC}}{\text{MD}} = \frac{1/2}{8/17} \times \frac{1/1.55}{1/1.60} \times \frac{1/0.785}{1/0.847} = 1.18$$

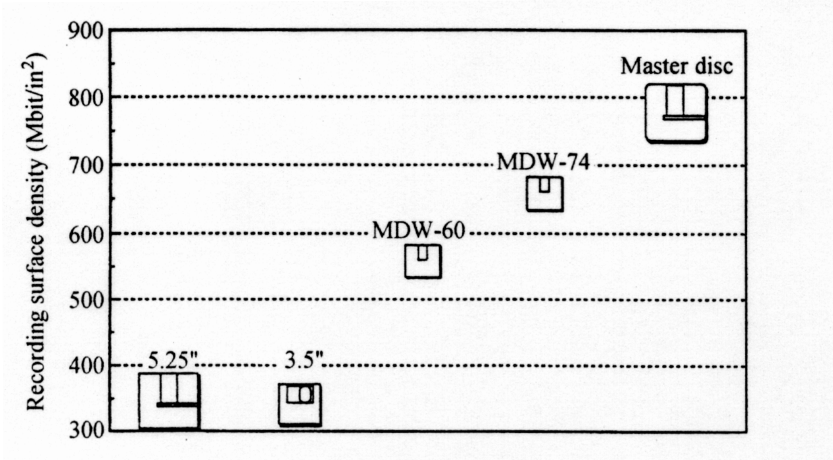


Figure ***10.39*** Comparison **of** MO disk recording densities.

10.4 FUTURE PROSPECTS

10.4.1 Overview of Magneto-Optical Disks

As stated in Section **10.3,** magneto-optical disks have the added feature of direct over-writing by the magnetic field modulation technique.

The characterization of magneto-optical disks in comparison with other rewritable media is already discussed in Chapter 1, but a brief review is given here.

Figure 10.40 shows how the areal recording density among the major recording media has been changing over time. Although the magneto-optical disk is still superior in areal recording density, its performance in a complete system is generally inferior to

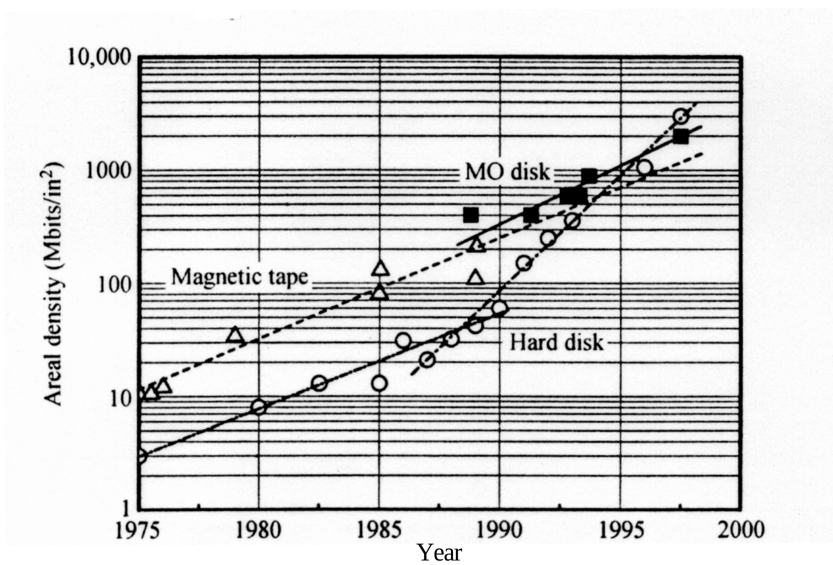


Figure 10.40 Progress in areal recording density which has been commercially achieved for three major data storage media. The magnetic hard disk has experienced a rapid rate of improvement compared with magnetic tape and magneto-optical disk media. One key factor **is** the "fixed" nature of the hard disk. The other media, in contrast, must support removability and interchangeability.