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CD-ROM Drive for Work Station Type Computer Systems

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Compact discs first appeared in October 1982 and helped start the age of digital audio. A standard was made for CD-Read Only Memory (CD-ROM) in 1985 to record computer data instead of music data.
Standardization of the logic format from 1986 to 1988 has brought about an increase of CD-ROM applications in the U.S. The number of CD-ROM drives shipped up to 1990 is estimated at 400,000 to 500,000. The market is expected to expand in the future.
Fujitsu Ten offered a car CD-ROM drive in 1987. Based on this design know-how, Fujitsu Ten has developed the SD-2200, a new CD-ROM drive for computer systems.
This paper describes the features and technology of the SD-2200.

1. Introduction

CD-ROM was standardized by N.V. Philips and Sony under the name of Yellow Book in 1985. This standard is for recording computer data in the audio data area of music CDs standardized by both companies in 1980 (Red Book).

This standard specified only physical format, however, and there was no disc compatibility. CD-ROM was not actually widely used until the High Sierra format (HSF) and logical format standards were established. The HSF standard was established at a conference of major computer manufacturers in 1986. The logical format standard was established by ISO9660, an international standard of HSF, in 1988.

Compatible CD-ROM has since become widely used. The number of CD-ROM drives shipped worldwide up to 1990 is estimated at 400,000 to 500,000. There are now over 3000 CD-ROM software titles.

Since the first CD player for automobiles was developed in 1983, Fujitsu Ten has introduced car CD players, CD-ROM drives, and automatic CD changers to the market.

Fujitsu Ten has used experience gained from the design and production of these automotive products to develop devices for the information equipment field. Fujitsu Ten has been developing CD-ROM drives as computer peripherals and CD-I players as stand-alone multi-media equipment (see article in issue 15 of this magazine).

This paper outlines CD-ROM media and describes the features and major technology of the SD-2200 CD-ROM drive.

2. Outline of CD-ROM

This chapter describes the entire range of CD media and discusses trends.

This chapter also explains the structural characteristics of CD-ROM compared to music CDs.

2.1 Outline of CD media

The term "multimedia" has recently become a popular term. Multimedia refers to using multiple media such as audio, still pictures, and animation instead of representing data only as codes. CD media is an important component of multimedia. This is because CD media can hold a large amount of information and is also suitable for handling audio and image data.

Although CD was originated as a digital audio recording media, it has often been confused with or mistaken for many other types of media.

Figure 1 shows the different types of CD media.

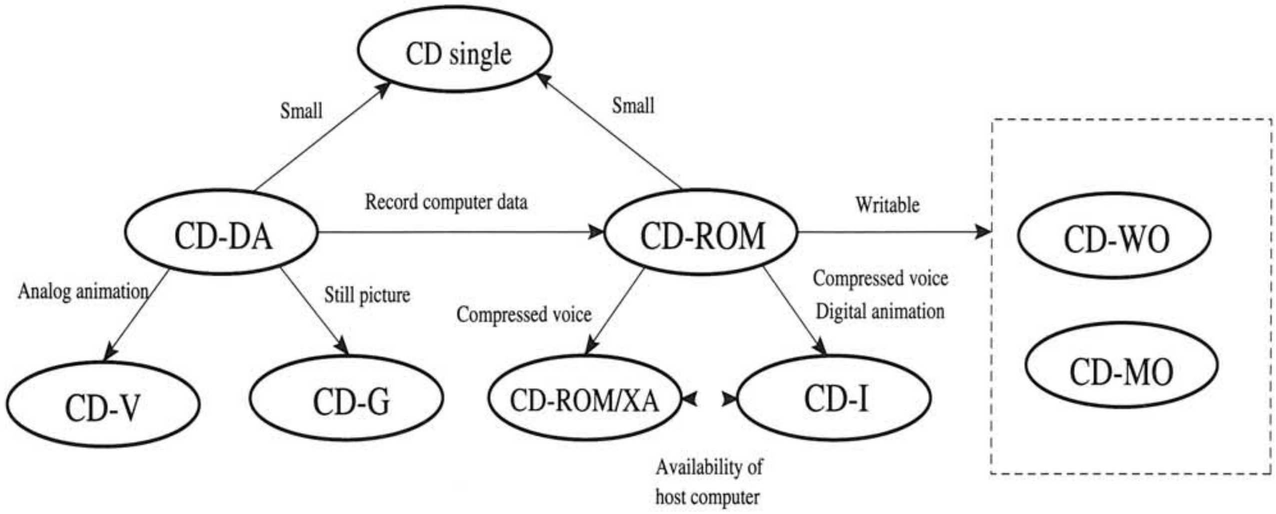


Figure 1. CD media

The basic component of CD media is CD-DA. CD-DA is generally called a compact disc or CD. Although CD-DA refers to music CDs, it is a common nucleus of the physical specifications of all other CD media.

This CD-DA with a disc 8 cm in diameter is called a CD single. It uses the same format as a 12-cm CD. The inertia of a single CD is less than that of a 12-cm CD. A special adapter is required since standard players do not support this size. Recently, 8-cm CD-ROM have also become available.

CD-DA with the function to record still pictures in the subcode area is called CD-Graphics (CD-G). (The subcode area refers to the area where time information is recorded, and is separate from the area where audio data is recorded.) Although CD-G can output audio and still pictures at the same time, ① resolution is low, ② display speed is slow, and ③ image playback hardware is complex. For these reasons, CD-G is used only for sing-along applications (to display the song lyrics). Warner-Pioneer Corporation has recently used this CD-G for music CD, and started sale of software that can display words and graphics. We will pay attention to this trend.

CD-DA with an animation playback function is called CD-Video (CD-V). The disc consists of a video part and audio part. The video part can play back digital audio and analog animation for five minutes. The audio part can play back only digital voice for about 20 minutes. The video part supports the laser disk (LD) standard, and the audio part supports the CD-DA standard. Because CD-V is an incomplete media, playback software is not currently sold. Video single disc (VSD) uses the audio part in the non-recording state for only three seconds and the video part for the remainder. VSD may become more important in the future.

CD-DA with computer data recorded in the audio data area is called CD-ROM. CD-ROM is a read-only media that cannot record data. Recorded data is read to the host computer via the CD-ROM drive. Although the logical data format is standardized by HSF and ISO9660, CD-ROM has is no data compatibility if image and program data varies among models. Because music uses the CD-DA format, data cannot be read while music is played back. Application software simulates concurrent processing of music and data.

CD-ROM that enables concurrent playback by compressing audio data and time-sharing and recording audio and image data alternatively is CD-ROM/XA. CD-ROM/XA uses ISO9660 as the logical data format, and requires CD-ROM hardware and a circuit to expand the compressed audio data. Like CD-ROM, CD-ROM/XA has no compatibility between data items and is hardware-dependent on the host computer. A common library has recently been released to ensure application software compatibility between Fujitsu and Sony. Standardization of the common library will receive greater attention in the future.

CD-Interactive (CD-I) combines the host computer functions to both CD-ROM and CD-ROM/XA. Because image data has been standardized, CD-I can play back still pictures and digital animation and handle CD-DA audio and compressed audio. Because CD-I discs are completely compatible, these disks can be played back on any CD-I player in the world. Manufacturers are developing CD-I and plan to market it from the fall of 1991.

Other types of CD media include CD-Write Once (CD-WO) and CD-Magnetooptical (CD-MO). CD-WO can record data only once and CD-MO can rewrite data any number of times.

CD-ROM can easily handle both audio and image data, and is thus regarded as the first choice for use in multimedia applications. The computer industry has also recognized that CD-ROM has excellent advantages including large capacity, high reliability, reproducibility in large quantities, and low cost. CD-ROM is expected to be widely used in the future.

In the U.S., CD-ROM has been in wide use for the last four or five years. In Japan, however, personal computers and game machines with CD-ROM as the standard have only become popular for the last two or three years. This is also true of the portable CD-ROM players used to read electronic publications. There are indications that CD-ROM will become more widely used in the future.

2.2 CD-ROM configuration

2.2.1 Data configuration

CD-ROM records computer data in the audio data area on music CDs. However, the data configuration is different in terms of data storage media.

Figure 2 shows the differences between the data format for music CDs and CD-ROM.

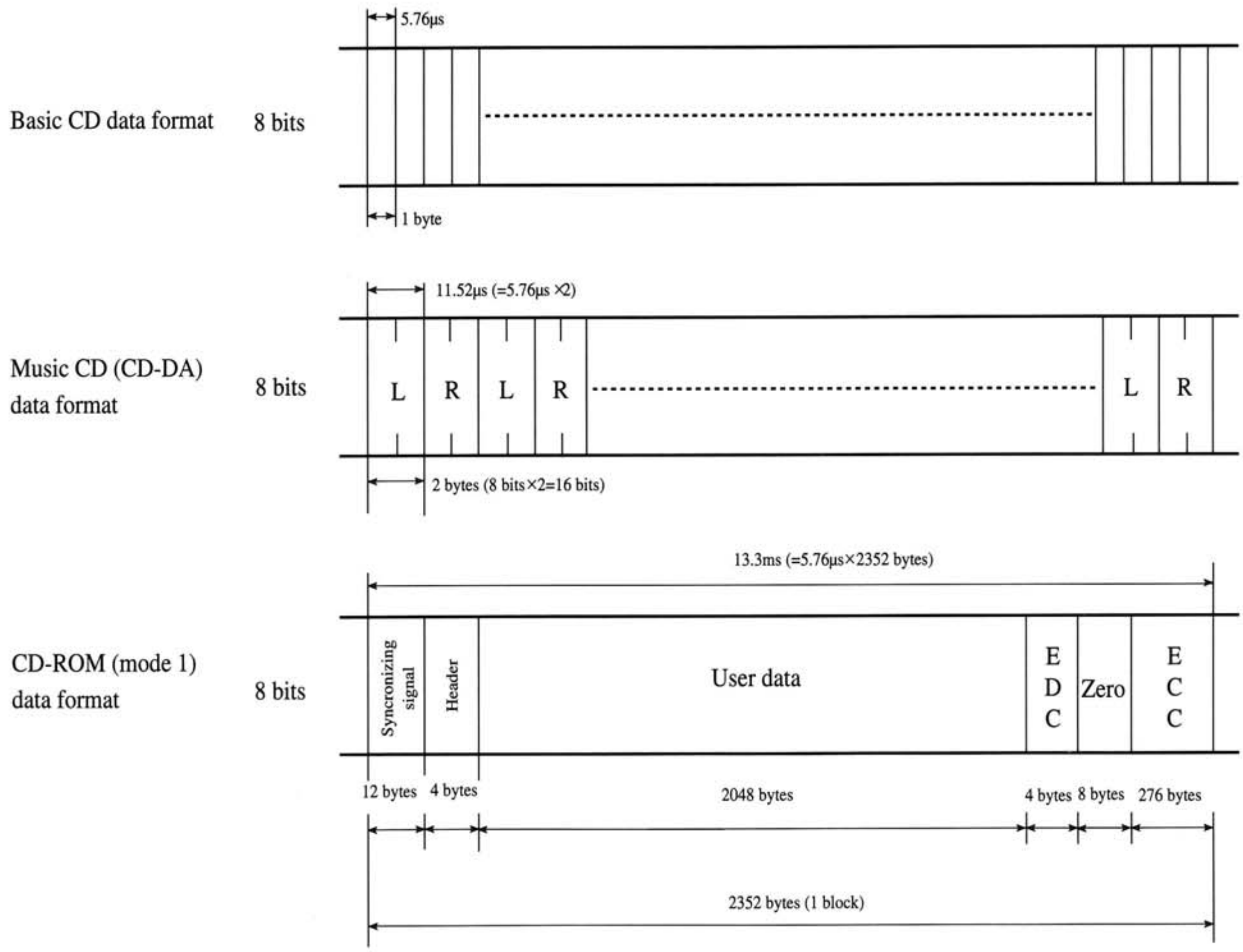


Figure 2. Music CD and CD-ROM data formats

Music CD records two channels (L and R) of 16-bit digital audio data at the sampling frequency of 44.1 kHz.

CD-ROM uses 2352 bytes for 588 sample pairs on this music CD to include the data recording and processing unit (generally called a block). (One sample pair is four bytes for the L and R channels.) The data format depends on the CD-ROM mode. In the most common mode 1, the user data recording capacity in one block is 2048 bytes. The remaining 304 bytes have the following meanings:

① Synchronizing signal [12 bytes] that indicates the beginning of a block
② Header signal [4 bytes] that indicates the user data address (time information) and mode
③ Error detection code (EDC) signal [4 bytes]
④ Zero signal [8 bytes]
⑤ Error correction code (ECC) signal [276 bytes]

CD-ROM records the user data and address in the same area (while music CD records time information in an other area called a subcode area). Because user data and the address matches, data can be accessed exactly. Data reliability can be further improved by using EDC and ECC for error detection and correction.

2.2.2 CD-ROM drive configuration

Music CD player and CD-ROM drive are quite different. Figure 3 shows the block configurations.

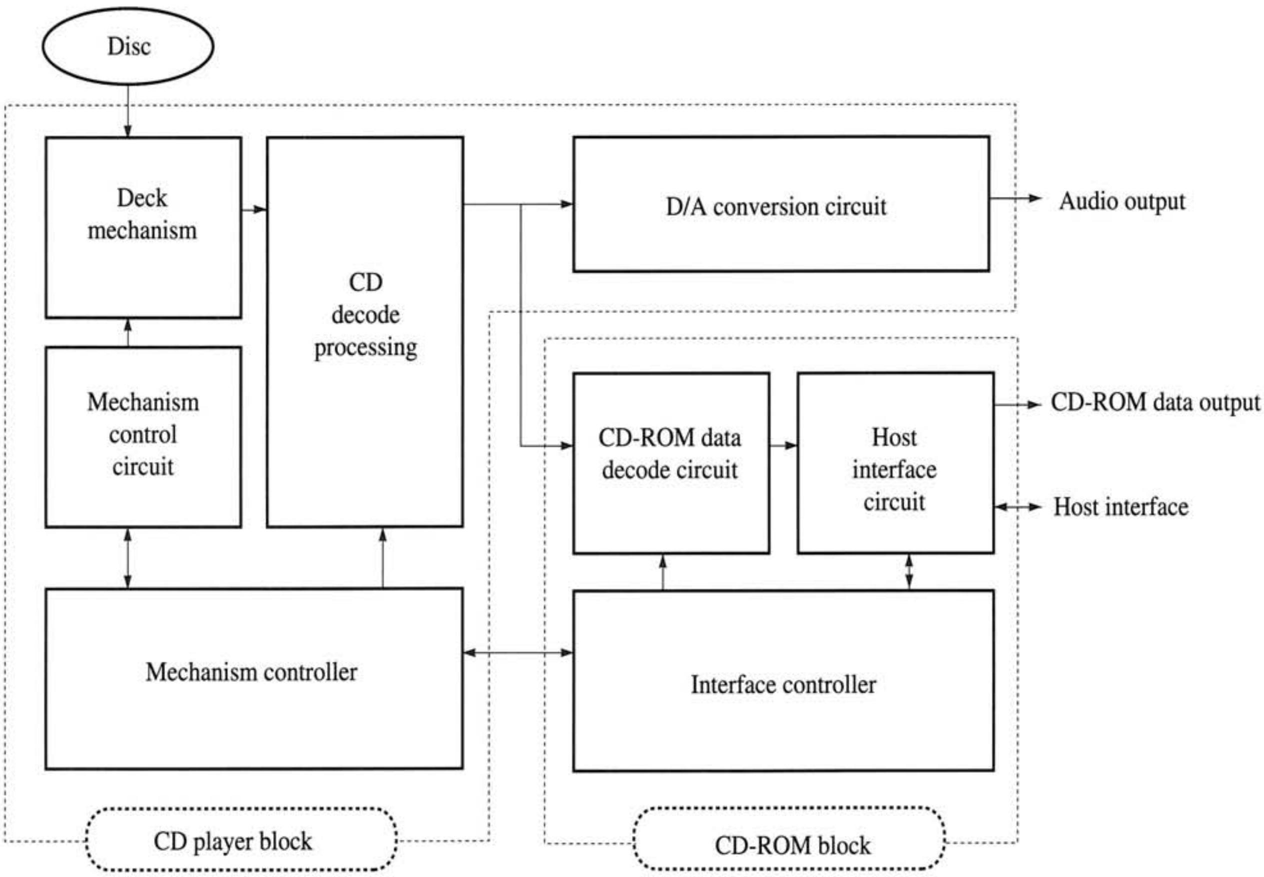


Figure 3. CD-ROM drive block configuration

The CD-ROM drive has a music CD playback block, CD-ROM decoder, and a host interface circuit.

The CD-ROM decoder uses EDC and ECC to correct errors. This is because data reliability is not always fully ensured even if the CD (audio) decode circuit in the music CD playback block corrects errors.

CD was originally designed so that data missing because of disc damage could be corrected by powerful error correction during playback. However, that capability is limited, and missing data sometimes occurs to the extent that it cannot be corrected.

Music CD can use audio continuity to complement missing data from data immediately before and after. The playback sound will be close to the original sound. Because computer data is not continuous like audio data, the CD-ROM drive requires a more powerful error correction method.

The host interface circuit is required for transfer of CD-ROM data to the host computer and communications related to transfer.

The configuration and specifications of this circuit depend on the type of host computer to which it is connected. In stand-alone CD-ROM drives, the Small Computer System Interface (SCSI) is the most common. (See Section 4.3.1.)

For built-in CD-ROM drives, dedicated interfaces specific to particular systems are used taking functions, performance, and cost into account.

3. Objectives and features

This chapter describes the objectives, specifications, and features of the SD-2200 CD-ROM drive developed by Fujitsu Ten.

3.1 Objectives of development

Personal computers and workstations are continuing to become more affordable. In the 1980's, computer manufacturers have promoted higher performance and speed while keeping the cost constant. In the 1990's, computer manufacturers are changing their policies to bring more low-end models to the market or to reduce the price of conventional models.

This trend is also true of peripherals including CD-ROM drives. Cost is being regarded as the most important factor.

The SD-2200 features high performance at a reasonable cost and is designed for use in medium- and low-cost computers.

3.2 Specifications and features

Figures 4 and 5 show the SD-2200 and its block configuration, and Table 1 lists the basic specifications.

The major features are as follows:

① Tray disc loading feature
- Same touch as for a music CD player without using caddy.
- 8-cm disc enables playback without adapter.

② High-speed access
- A linear motor is used for the optical head feeder.

③ Long life
- A brushless motor is used for the disc motor

④ Built-in audio circuit
- A 16-bit digital-analog converter (DAC) with eight times over-sampling is used to ensure high sound quality.

⑤ General-use
- Because the standard SCSI interface is used, dependency on the host computer model is low.
- The compatible mode with non-Fujitsu Ten drives is available to enable playback of 80% of commercially available software products.

⑥ Low cost
- Inexpensive optical music head is used.
- The CD-ROM decoder and SCSI interface circuit use custom LSI chips to reduce the number of components.

Figure 4. SD-2200

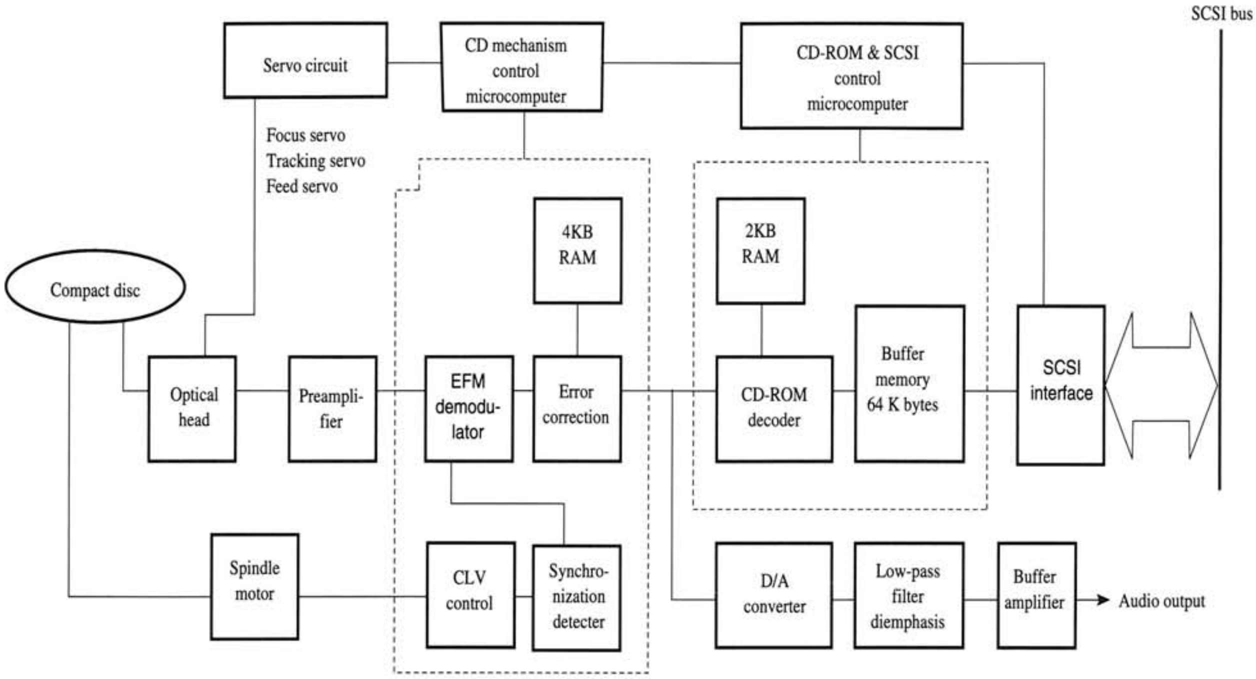


Figure 5. Block configuration

Table 1. Basic specifications

No.	Item	Specifications
1	Disc type	Size: 8/12cm, Type: CD-DA, CD-ROM, CD-V (Music part only)
2	Data format	CD-ROM disc format: YELLOW BOOK MODE 1
3	Error rate	10^{-9} or less
4	Interface	SCSI-2 (command set only)
5	Transfer rate	Up to 640 Kbps (dependent on DMA clock rate of host computer)
6	Buffer RAM	D-RAM 64KB
7	Access time	Full stroke: 0.8 second or less, 1/3 stroke: 0.6 second or less
8	Pickup unit	Disc motor (including drive circuit), optical head, and optical head feeder are held together as a unit.
9	Type	Horizontal stand-alone
10	Insertion and ejection method	Tray motor front loading system
11	Tray ejection amount	135 mm from front panel
12	Motor	Disc motor: Brushless motor, Feed motor: Linear motor
13	Size (W, H, D)	146 × 82.5 × 250 (Full height size)
14	Weight	About 2.4 kg
15	Audio output	Line out output 2 V (50 kilo ohms)
16	Frequency characteristics	20~20,000 Hz 0±2dB
17	S/N	85 dB or more (IHF-A filter, 1 kHz)
18	Distortion factor	0.1% or less (80 kHz LPF, 1 kHz)
19	Separation	75 dB or more (80 kHz LPF, 1 kHz)
20	Optical characteristics	Laser beam wavelength: 760 to 800 nm, Object lense output: 400 μW or less
21	Power supply voltage	12V DC ±5%
22	Current consumption	Disc playback: About 0.7 A disc access: About 1.2 A
23	Temperature	Storage: –30 to 60°C Operation: 5 to 50°C
24	Humidity	Storage: 5 to 85% RH Operation: 15 to 85% RH
25	Vibration	Operation: 0.2 G or more No operation: 2.4 G or more (3 to 60 Hz, sine wave, two-minute sweep, three-direction application)
26	Tilt angle	±10° or less
27	Life	PU, disc motor: 3,000 hours or more Seek: 50,000 cycles or more Insertion and ejection: 20,000 cycles or more

4. Major technology

This chapter describes the major technology (① linear motor-drived optical head feeder, ② access control, and ③ SCSI interface) of the SD-2200.

4.1 Optical head feeder

In the SD-2200, a new deck mechanism for the linear motor feeder has been developed to ensure faster movement of the optical head.

Conventionally, Fujitsu Ten has used the geared feed system for all optical head feeders of CD players and CD-ROM drives.

It was determined that this feeder is not adequate for CD-ROM drives used in computer systems. In the SD-2200, the linear motor system is used. The cost of the linear motor system is higher than that of the geared feeder. The pickup unit of a home CD player (Figure 6) is used to keep the cost relatively low.

As shown in Figure 7, the feeder using the linear motor system starts current in the drive coil on the side of the optical head. It then moves the optical head by electromagnetic force F according to Fleming's left-hand rule.

$$F = niB = ma \quad \ldots\ldots \quad (1)$$

Because mass m of the optical head and magnetic flux density B received from the permanent magnet are constant, when constant current i (number of turns: n) is started in the coil, the optical head obtains constant acceleration a. (Uniformly accelerated motion)

In uniformly accelerated motion, however, the optical head is accelerated so much that it cannot be controlled at long-distance access. The uniformly accelerated motion must be converted to uniform motion to ensure stable feed control. This conversion control is a speed servo.

The speed servo is an automatic control method of feeding back the speed detection signal obtained by the speed sensor. It then moves the optical head at a speed proportional to the given signal voltage. The speed sensor refers to the coil on the side (opposite side of the drive coil) of the optical head. When the optical head moves, the voltage proportional to the movement speed occurs according to Fleming's right-hand rule.

Figure 8 shows the feed servo system including this speed servo.

The optical head feed servo including the speed servo is designed so that the servo band is 1 to 2 Hz. This ensures stability and response.

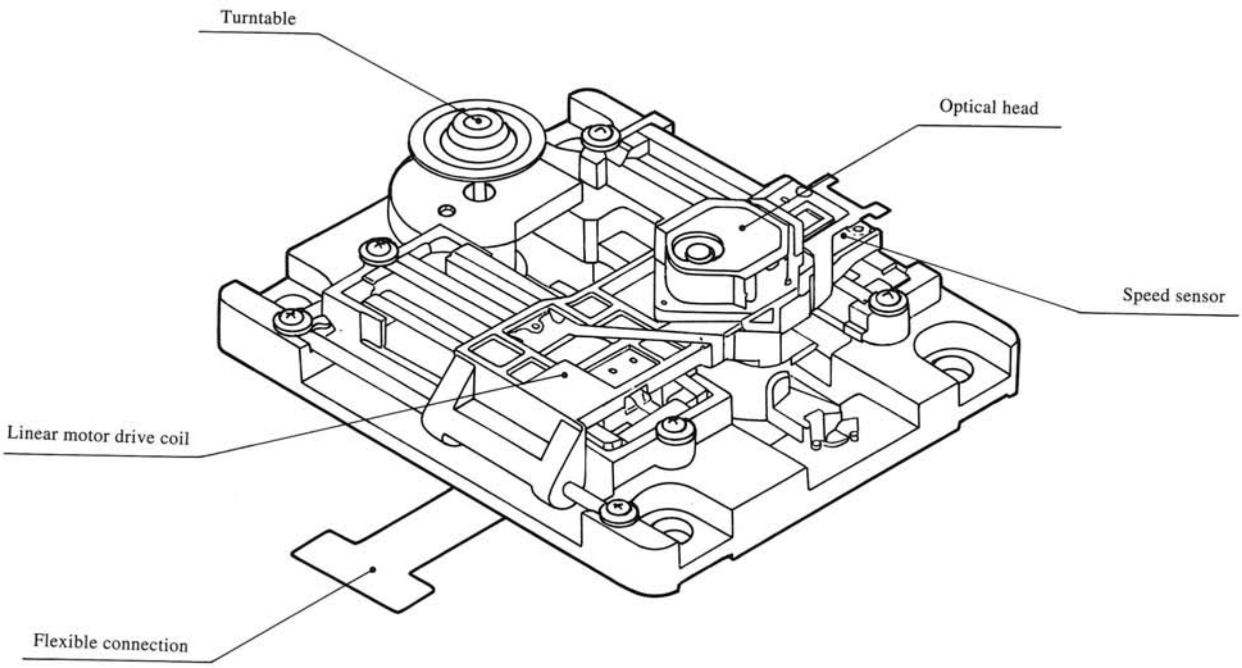


Figure 6. Pickup unit

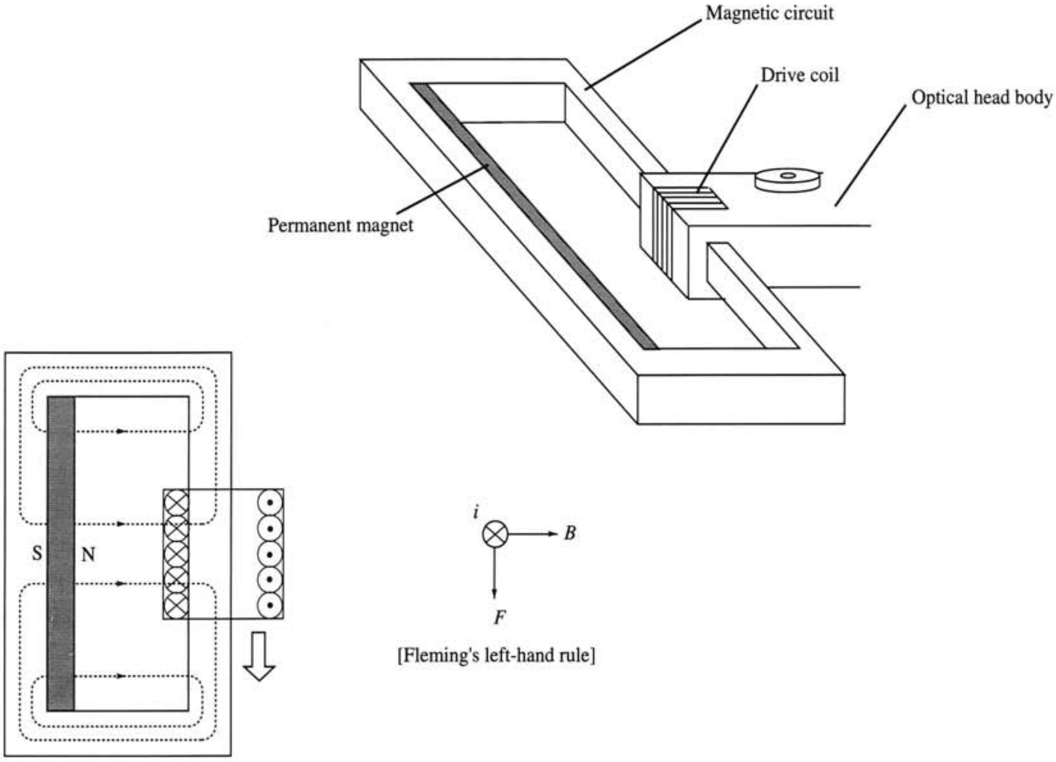
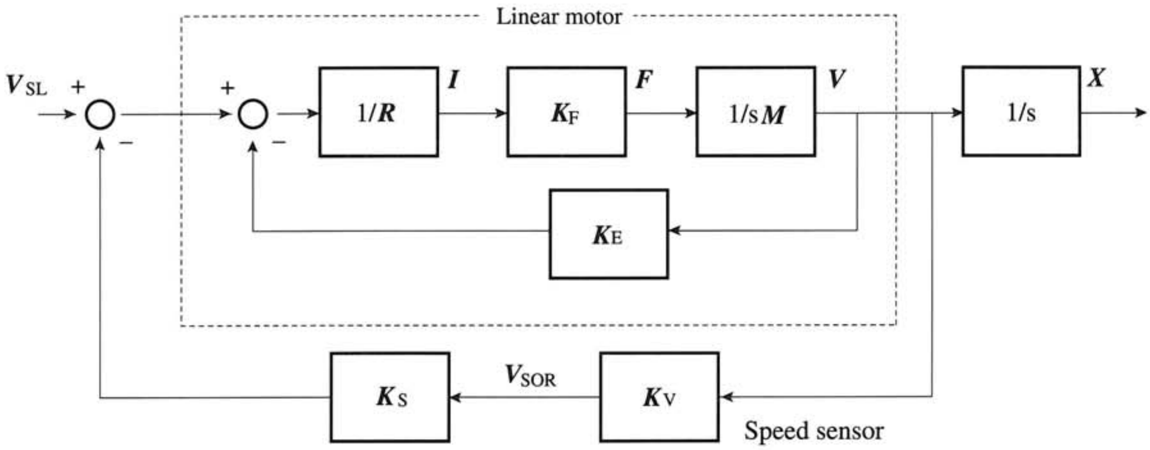


Figure 7. Principle of feed operation using a linear motor



V_{SL}: Applied voltage
V_{SOR}: Speed sensor output voltage
V: Pick-up movement speed
X: Pick up position
R: Coil resistance
K_F: Thrust resistance
M: Motor mass
K_E: Servo voltage constant
K_V: Speed sensor power generation constant
K_S: Feedback amplifier

Figure 8. Block diagram of feed servo system including the speed servo

4.2 Access control

Figure 9 shows the CD-ROM access procedure.

CD-ROM records data at constant linear velocity to increase recording density. This rotation control is called continuous linear velocity (CLV) control.

Consequently, CD-ROM is accessed slower than other media (floppy disk, hard disk, and magnetooptical disk) whose rotation is controled at constant angular velocity (continuous angle velocity (CAV)).

The reasons are as follows:

① The number of rotations differs between the inner and outer cylinders of the disc. The number of disk rotations must be set to the proper value for each access.

② Because the amount of data per cylinder is different for each cylinder, calculation up to the target address is complex. Access cannot often be terminated by one jump.

③ Rotational delay is not constant. (The outermost cylinder with slow rotation velocity requires up to 270 ms.)

In view of the problem in ② , the flexible and precise access control system was developed to improve access time in the SD-2200.

Table 2 and Figure 10 give a comparison between access control for conventional models and for the SD-2200.

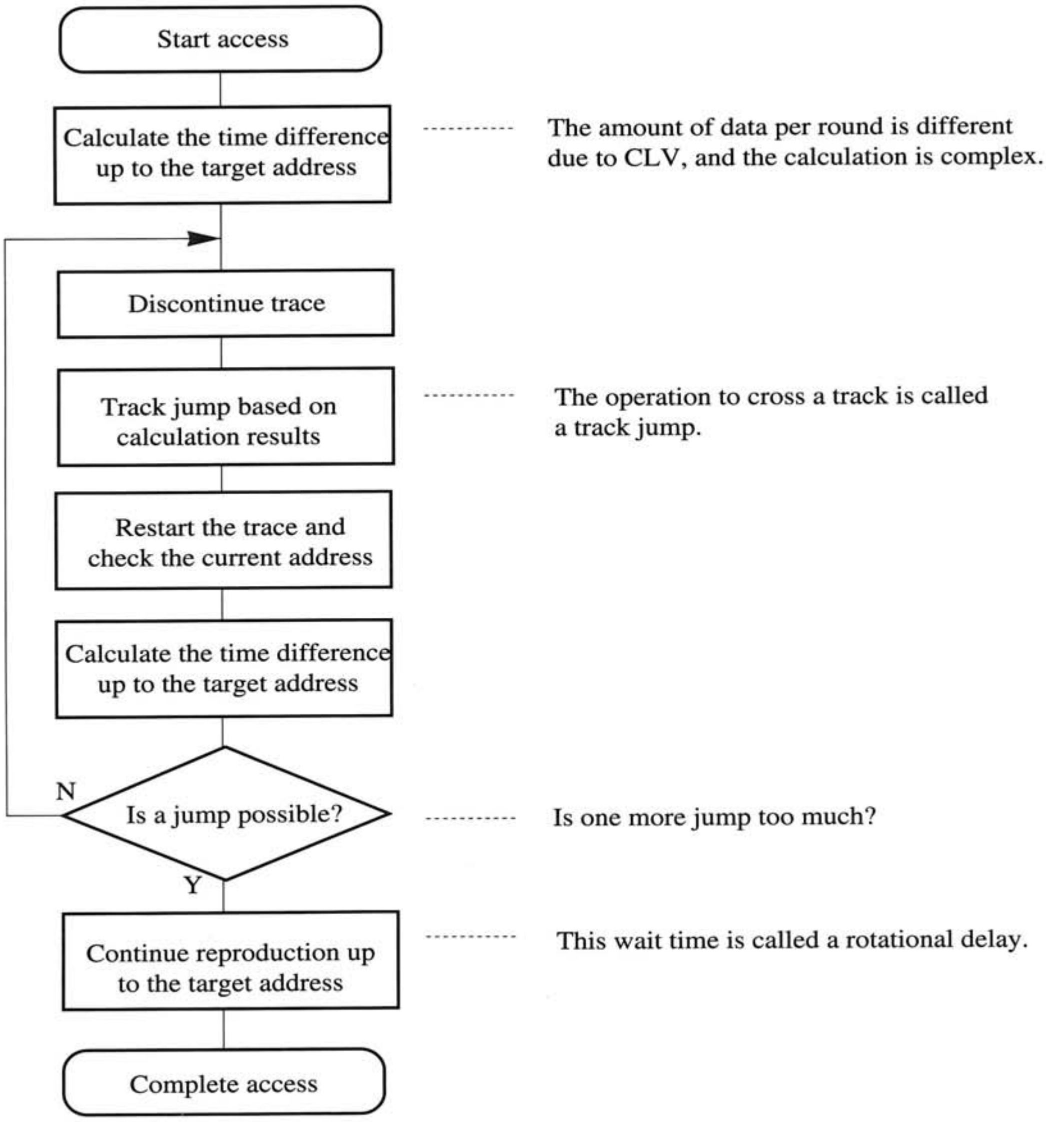


Figure 9. CD-ROM access procedure

Table 2. Optimized access control

No.	Item	Access control for conventional models	Access control for the SD-2200
1	Number of jumps	Fixed	Variable
2	Accuracy of jump	Variations in disc, deck, and circuit causes a large error due to time control.	Because the number of tracks crossed at a jump is counted, the jump is fairly accurate.
3	Calculation of number of jumps to target	Rough estimation from difference between target time and current time (set experimentally)	The number of required track jumps up to the target address is calculated every time (a program refers to the result table).

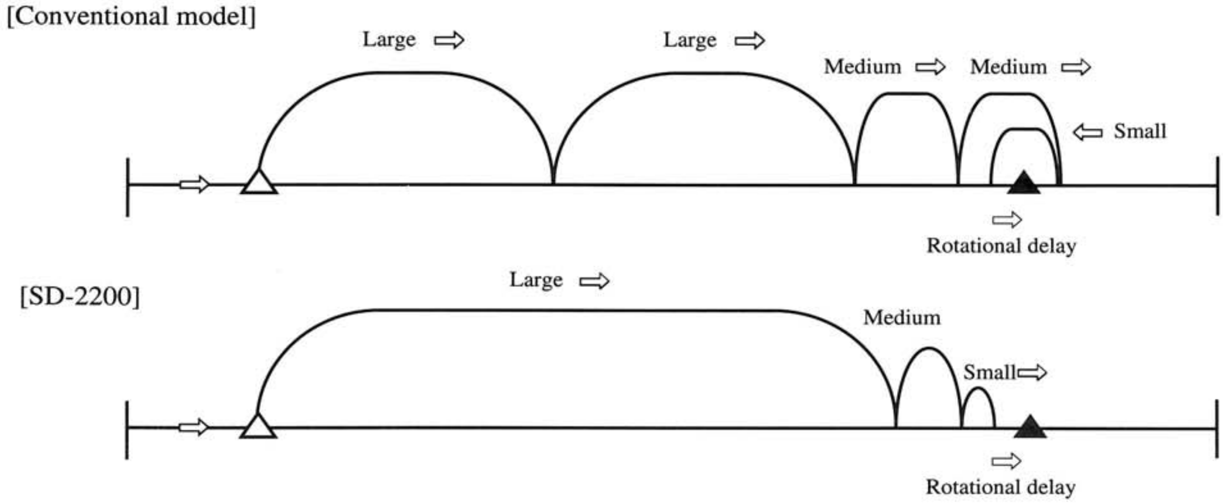


Figure 10. Comparison of access control (search from Δ to ▲)

This control system enabled the SD-2200 to provide access performance of 0.8 second for full stroke access and 0.6 second for 1/3 stroke access. This means that the access speed of the SD-2200 is six times faster than that of conventional Fujitsu Ten models.

Figure 11 compares this access time with a non-Fujitsu Ten product.

CD-ROM access time is not defined clearly. Access time varies among companies and cannot be directly compared. Table 3 lists various access time measurement conditions of different companies. They are converted to compare with Fujitsu Ten's measurement conditions ((a): full stroke, (d): 1/3 stroke), or the access time is actually measured for comparison with Fujitsu Ten's products.

Figure 11 indicates that the SD-2200 has the same access performance as non-Fujitsu Ten products.

4.3 Host interfaces

4.3.1 SCSI interface

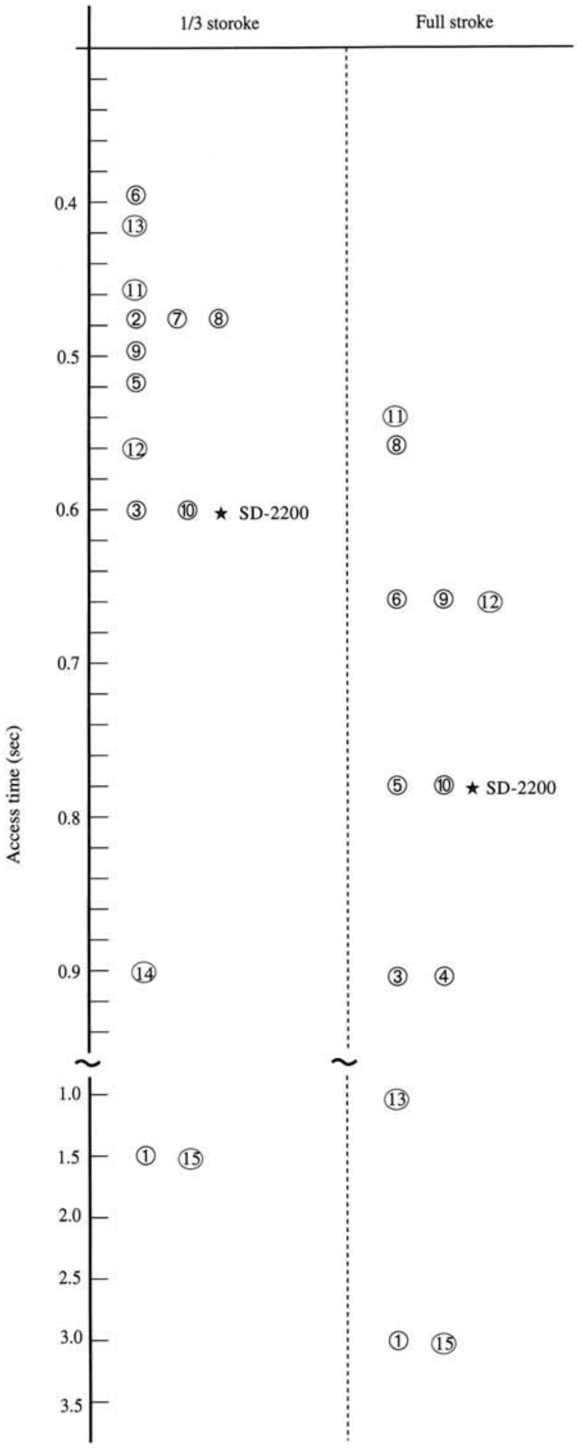
The SD-2200 uses a SCSI interface for the host computer.

SCSI is the standard established by the American National Standard for Information Systems (ANSI) in 1986. SCSI specifies the interfaces between devices in small systems such as personal computers. Many manufacturers use SCSI, the industry standard for CD-ROM drives.

The SCSI interface enables daisy-chain connection of up to eight devices including the host computer, and allows communication between these devices without host computer intervention.

The following devices can be connected and have command sets specific to device groups:

① Direct access devices (hard disk drive etc.)



Notes:

1. The SD-2200 is compared with 15 models of nine companies.
2. Fujitsu Ten measurement conditions are used as a reference. Data for models that do not satisfy the conditions is converted for comparison (see Table 3).

Figure 11. Comparison of access time

② Sequential access devices (magnetic tape unit etc.)
③ Printers
④ Processors (personal computer etc.)
⑤ Single-write multiple-read devices (WO disk drive etc.)
⑥ Read-only direct access devices (CD-ROM drive etc.)

Typical devices that use the SCSI interface include the hard disk drive. Because the hard disk drive uses the SCSI interface, its dependency on the host computer is extremely low. A hard disk drive can be connected to almost any host computer by simply modifying the software.

Many manufacturers also use the SCSI interface for stand-alone CD-ROM drives to obtain the same benefits as for hard disk drive.

CD-ROM is equivalent to the device in ⑥ of the SCSI standard. However, audio playback commands are specific to CD-ROM. Manufacturer-specific commands (called vendor unique commands which are permitted in the SCSI standard) are now being used. This means that CD-ROM drives have much lower compatibility than hard disk drives.

For these reasons, ANSI is proceeding with standardization of the extended interface called SCSI-2. (This standard will be established in 1991 and is currently under final discussion.) In SCSI-2, command sets related to CD-ROM will also be provided. Standardization of these command sets will significantly improve compatibility.

SD-2200 ensures future compatibility by using the command sets for the SCSI-2 CD-ROM drive.

Table 4 lists the SD-2200-supported commands.

4.3.2 Compatibility with non-Fujitsu Ten products

Future compatibility is ensured by using the SCSI-2 command sets. SCSI-2 is still under discussion, however, and CD-ROM software using SCSI-2 commands is not yet commercially available.

The SD-2200 also supports vendor unique commands for non-Fujitsu Ten products so that most commercially available software can be used.

Figure 12 shows the market shares for CD-ROM drives by manufacturer.

The SD-2200 already supports vendor unique commands for Toshiba and NEC drives, and will also support

Table 3. Access time measurement condition

Classification		Measurement condition	Rotational delay	Conversion to Fujitsu Ten's measurement condition
Full stroke	(a)	Average time when CD-ROM is accessed for 0 to 60 minutes	Included	Fujitsu Ten's condition
	(b)	Average time when CD-ROM is accessed for 0 to 60 minutes	Not included	100 ms is added.
	(c)	Full stroke access although whether it is (a) or (b) is unknown (only maximum access time is described)	Unknown	Measured and determined at Fujitsu Ten
1/3 stroke	(d)	Average time when CD-ROM is accessed for 15 to 35 minutes	Included	Fujitsu Ten's condition
	(e)	Average time when CD-ROM is accessed for 15 to 35 minutes	Not included	100 ms is added.
	(f)	Average time when CD-ROM is accessed at random	Unknown	Measured and determined at Fujitsu Ten
	(g)	1/3 stroke access although whether it is (d), (e), or (f) is unknown (only the average access time is described)	Unknown	Measured and determined at Fujitsu Ten

Table 4. Support commands

Code	Type (*1)	Name	Drive operation
00h	O	TEST UNIT READY	Checks whether the drive is operable.
01h	O	REZERO UNIT	Returns the optical head to the origin.
03h	M	REQUEST SENSE	Returns sense data.
08h	O	READ (6)	Transfers data only for the specified number of blocks from the next address to the specified one.
0Bh	O	SEEK (6)	Seeks the specified address.
12h	M	INQUIRY	Returns INQUIRY data.
1Ah	O	MODE SENSE (6)	Returns MODE SENSE data.
1Bh	O	START/STOP UNIT	Starts or stops the drive.
25h	M	READ CD-ROM CAPACITY	Returns the capacity of CD-ROM data.
28h	M	READ (10)	Transfers data only for the specified number of blocks from the specified address.
2Bh	O	SEEK (10)	Seeks the specified address.
42h	O	READ SUB-CHANNEL	Returns subcode and audio output state data at the specified address.
43h	O	READ TOC	Returns TOC information.
44h	O	READ HEADER	Returns the header at the specified address.
45h	O	PLAY AUDIO (10)	Outputs audio only for the specified number of frames from the specified address.
48h	O	PLAY AUDIO TRACK/INDEX	Outputs audio from the specified start address to the end address.
48h	O	PAUSE/RESUME	Pauses at the current address or releases pause.
A8h	O	READ (12)	Transfers data only for the specified number of blocks from the specified address.

*1 M: Mandatory O: Option

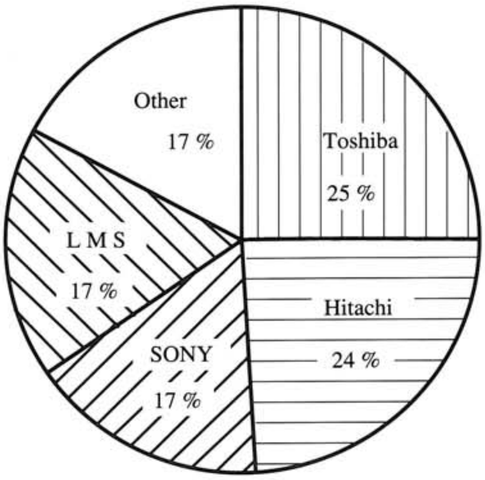


Figure 12. CD-ROM drive market share (1989 shipment)

the ones for Hitachi and SONY in the future. This will enable the SD-2200 to run about 80% of commercially available CD-ROM software.

The SD-2200 is thus a good general use CD-ROM drive.

5. Future problems

The SD-2200 is a stand-alone CD-ROM drive that has excellent performance and is inexpensive.

However, the SD-2200 does not provide deal access time. Section 4.2 describes three problems: (① improved response for disc rotation velocity, ② optimized track jump, and ③ shortened rotational delay). Fujitsu Ten is planning to solve problems ① and ③ in the near future.

Development of smaller drives for the next model is underway. In addition to the stand-alone SD-2200, internal drives (Installed inside the main unit of the computer) are required.

The height of the SD-2200 conforms to the industry standard of full height (H = 82.6 mm). For CD-ROM drives installed inside the computer equipment demand for half-height (H = 41.3 mm) models is expected to increase. To meet these market needs, Fujitsu Ten will also offer minimum half-height drives containing the SCSI interface as a separate product.

6. Conclusion

Fujitsu Ten has responded to users in the marketplace. CD-ROM is required for multimedia computer systems.

CD-ROM is only being used for storing electronic publications such as dictionaries and encyclopedias at present. Other specialized applications include large data bases used for customized data retrieval systems. CD-ROM has not yet been used on a large scale for multimedia applications. It seems unclear what can be done to change this situation.

CD-ROM has begun to be used by game machines and electronic stationery. These new products are expected to stimulate the CD-ROM market.

The market for CD-ROM including that for computer systems will be developed. CD system media such as CD-ROM/XA, CD-I, CD-WO, and CD-MO, and magnetooptical disks are expected to develop in parallel with CD-ROM.

Fujitsu Ten will attempt to keep up with the market and continue developing timely products.

Hajime Matoba

Entered the company in 1982. He has been engaged in the development and design of CD-ROM, and currently works in the Data Processing Engineering Department, 2nd Audio Products Division.

Keiichi Suzuki

Entered the company in 1975. He has been engaged in the development car audio CD-ROM, and is now the Data Processing Engineering Department, 2nd Audio Products Division.