A High-speed and High-density Optical Disk System for Broadcasting Use

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ABSTRACT

NHK is developing high-speed and high-density optical disks with the aim of creating optical disk cameras for HDTV newsgathering. We have constructed two- channel optical-disk experimental equipment using two optical heads. The optical head consists of an objective lens with a numerical aperture (NA) of 0.85, a blue- violet laser with a wavelength of 405 nm, and a high-speed laser driver, and a wideband and low-noise optical detection section. The optical disk's phase-change recording medium has a diameter of 12 cm, a cover-layer thickness of 0.1 mm, and track pitch of 0.32 μm. Recording and playback with this optical disk medium is done using signal processing that combines RLL(1,7) coding and PRML decoding, which are advantageous to high-density, high-speed recording. Linear velocity is fixed at 12 m/second, and the shortest mark length is 0.16 μm (equivalent to a bit length of 0.12 μm, recording density of 17 Gbit/in^2). We achieved a byte error rate (BER) of between10^{-3} and 10^{-4} when recording and playing back a random signal at a data transfer rate of 100 Mbps per channel. The results obtained with this equipment indicate the possibility of recording about 20 minutes of a HDTV signal compressed to 200 Mbps, including overhead.

Keywords: high data-transfer-rate, BER, two optical heads, broadcasting use

INTRODUCTION

In Japan, HDTV digital satellite broadcasting began in December 2000, and digital terrestrial HDTV broadcasting is scheduled to begin in Tokyo, Nagoya, and Osaka in December 2003. In parallel with these developments, NHK is in the process of converting almost all program production to a HDTV format. At present, all program recording and storing is done on videotape. There are about 1.6 million tapes in all increasing at an annual rate of about 40,000 tapes.

Against this background, we have been researching ways of increasing data-transfer-rate and recording capacity in optical disks to facilitate the use of convenient optical disks in broadcasting as well as to make program production more efficient and enable long-term storage. Figure 1 illustrates how optical disks can be used in a broadcasting system. The combined use of optical disks and hard disk drives achieves efficient program production from the news-gathering stage to long-term storage [1,2].

Our first target in achieving such a system is to substitute tape in news-gathering cameras with optical disks. In this paper, we report on a high-speed and high-density optical-disk system for use in HDTV optical-disk cameras.

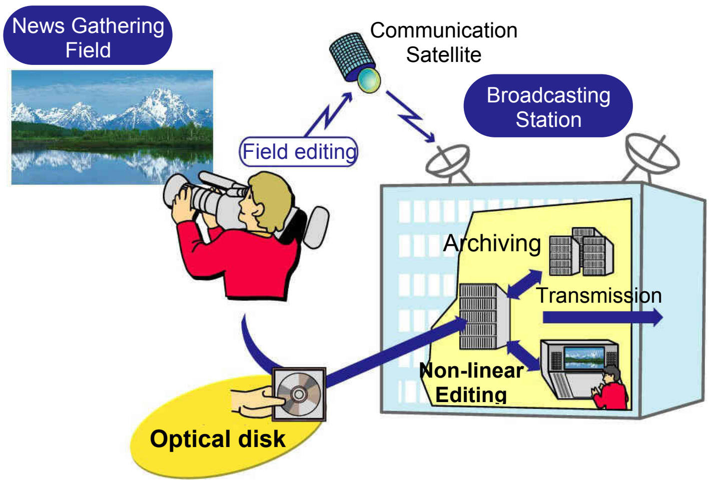


Fig.1 Optical disk system for broadcasting station

PRESENT RECORDING MEDIA AND REQUIREMENTS FOR BROADCASTING USE

Table 1 lists the main specifications of HDTV videotapes presently in use. They all employ either intra-field or intra-frame compression, because these tapes are used for broadcasting purposes. Video rate must therefore be at least 100 Mbps and total recording rate must be near 200 Mbps. Recording time depends on the type of cassette size (S or L).

Table 1: Specifications of digital recording media for HDTV use

Format	D-6	HDD5	HDCAM	DVCPRO HD EX
Video rate (Mbps)	958.5	235.0	140.0	100.0
Compression method	-	Intra-field DCT compression	Intra-field DCT compression	Intra-flame DCT compression
Total rate (Mbps)	1212	301.0	185.0	167.4
Recording time L cassette (min)	64	124	124	124(XL)
Recording time S cassette (min)	8	23	40	-

At NHK, we mainly use HDD5 in the studio and HD-CAM in news-gathering camcorders. Programs produced in the studio must be taped and their final versions recorded, and this requires a recording time of about two hours. In contrast, camcorders used for news-gathering purposes change recording cassettes every scene, which calls for a recording time of at least 20 minutes including credits. The video quality of recording media for broadcasting use must be equivalent to that of news-gathering camcorders presently in use.

Recording media for broadcasting use must also feature high reliability (no video recording errors) and, news-gathering cameras must be low power consumption.

TARGET PERFORMANCE OF HDTV OPTICAL DISK CAMERAS

To summarize our requirements based on the above discussion, video quality must be good enough to cover all news-gathering camcorders presently in use and recording time must be at least 20 minutes. We therefore established a total rate of 200 Mbps, a recording time of 20 minutes, and a disk capacity (one side) of 23 GB as our design targets.

However, achieving a data transfer rate of 200 Mbps by one channel (one head) presents problems in terms of disk rotation speed, laser-driver response time, power consumption, and noise caused by motor rotation. We therefore opted for a two-channel system that divides this 200 Mbps rate between two channels resulting in a manageable data transfer rate of 100 Mbps per channel.

EXPERIMENTAL DISK EQUIPMENT

To examine the feasibility of the above targets, we constructed 2-head experimental equipment. In this equipment, the two heads are placed 180° apart from each other and controlled independently. Each of these heads uses a 405-nm blue-violet laser and an objective lens with a 0.85 numerical aperture (NA). To give these heads high-speed and high-capacity capabilities, we produced the equipment with a high-rpm air-spindle motor, a wide-band, low-noise amplifier, and a high-speed laser driver, and improved the RIM intensity of the beam profile. Table 2 summarizes these equipment features.

Table 2: Specifications of experimental equipment

Laser wavelength (nm)	405
NA of objective lens	0.85
RIM intensity of laser beam	0.73
Bandwidth of amplifier (MHz)	80
Rising time of laser diode (ns)	0.8
Maximum revolution of spindle (rpm)	12000

With this experimental equipment, we were able to evaluate medium by measuring jitter, and transmission characteristics, and we could measure error rate as well. The equipment was constructed taking the following measurements and simulations into account.

OPTICAL DISK MEDIUM

Table 3 lists the specifications of the recording medium used in this equipment. In fabricating a high-speed phase-change recording medium, it is important to control the crystallization speed and jitter of the phase-change recording material as well as the number of overwrites allowed. Therefore, to understand the behavior of phase-change recording material during high-speed recording, we measured jitter and performed a mark profile simulation.

Table 3 Specifications of optical disk medium

Diameter	120 mm
Substrate thickness	1.1 mm
Cover film thickness	0.1 mm
Track pitch	0.32 µm
Material of recording film	Eutectic phase change material

JITTER MEASUREMENT

Simple repeating patterns were recorded and their jitter was measured. Figure 2 shows the readout signal when recording and playing back a 3T pattern using an N-1 type write strategy. Measurements revealed a jitter of 8.2% at the leading edge and 7.9% at the trailing edge indicating that jitter was larger at the leading edge. Similar behavior was observed when conducting the same kind of experiment for patterns in the range from 4T to 8T, but for the 2T pattern, opposite behavior was observed, i.e., trailing-edge jitter was larger than leading-edge jitter. These results also held true when reversing the direction of rotation or varying tilt, and we next performed a mark profile simulation taking medium characteristics into account.

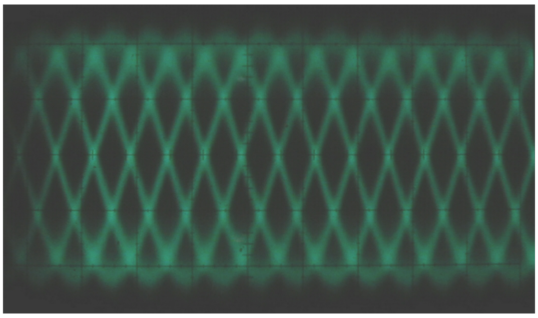


Fig.2 Readout signal of 3T mark

MARK PROFILE SIMULATION

We searched out the main reasons for the above results by performing a mark profile simulation. To perform thermal calculations of the medium, we used three-dimensional thermal calculation equations and evaluated crystallization using the Johnson-Mehl-Avrami equation [3]. Main physical constants for the recording medium and the like were obtained from reference literature [4,5,6].

Specifically, we examined how the mark profile changes with speed of crystallization by varying activation energy in our calculations [7]. Figure 3 shows the results of simulating mark profile in this way. In the figure, 3T-equivalent marks were recorded. Examining these results, we see that recrystallization occurs from the amorphous leading edge as the speed of crystallization increases (as activation energy decreases) and that a recrystallized area appears in the shape of a comet's tail in the leading-edge section.

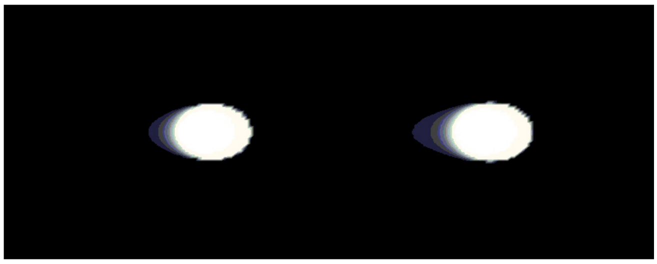
On the other hand, the shape of the trailing edge differs for each value of activation energy although edge position is not greatly different. This phenomenon is particularly evident for high crystallization speeds. The following two methods can be considered in response to this problem.

- Optimize crystallization speed
(near lower limit of crystallization speed at which direct overwrite (DOW) can be performed)

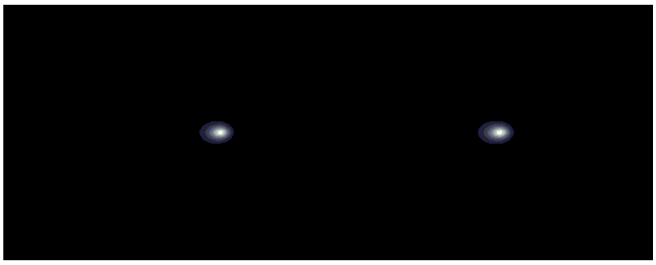
- Make first pulse extremely large and then apply a cooling pulse to prevent recrystallization.

Implementing these methods is hindered, however, by limitations in optical emission time and emission intensity. Nevertheless, we have found that a solution is possible by using laser-driver overshoot characteristics in our calculations in addition to the usual strategy [8]. Furthermore, when recording 2T marks in our experiments, we found that resulting characteristics were opposite those observed when recording other marks as mentioned above. The reason considered for this is that the interval between marks is short and that the thermal diffusion that occurs when recording one mark affects the trailing edge of the previous mark.

(a) Ea=1.72 eV



(b) Ea=1.47 eV



(c) Ea=1.32 eV

Fig.3 Simulation of mark profile for different activation energies

READ CHANNEL

Partial Response Maximum Likelihood (PRML) is a useful technique for achieving playback equalization in high-capacity, high-speed optical disks, and we here apply it as a read channel. Given that the PRML technique can detect playback signals even for very small bit intervals, we recorded a 100 Mbps pseudo-random signal and measured the byte error rate (BER) of the playback signal. Figure 4 shows a block diagram of this measurement scheme.

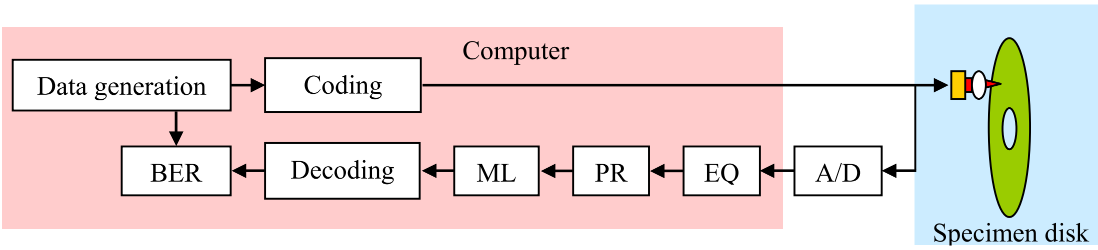


Fig.4 Block diagram of byte-error-rate measurement

In these measurements, the playback signal was passed through an analog/digital converter and then input to a computer where it was subjected to equalizing, partial response (PR) equalization, and Viterbi decoding to produce a digital decoded signal. This signal was then compared with the original pseudo-random signal to measure BER. Figure 5 shows BER versus various PR channels at this time [9]. We tested PR coefficients that looked promising in terms of good BER. As shown in Fig. 5, error rate is smallest for PR(1,1,1).

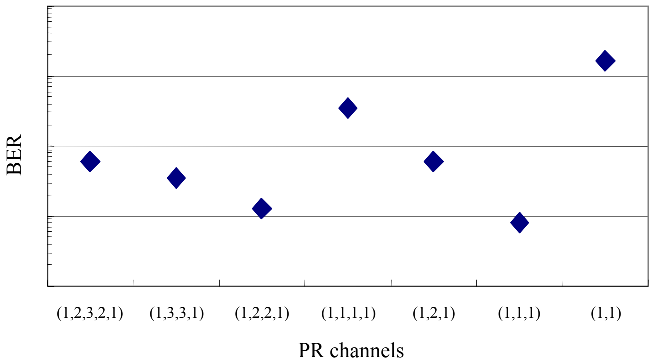


Fig.5 BER versus various PR channels

WIDEBAND AND LOW-NOISE PRE-AMPLIFIER FOR DETECTOR

One problem in high-speed recording and playback is band broadening in signal processing. Band broadening can degrade the SNR since that portion of noise that was traditionally eliminated by a low-pass filter (LPF) now makes a large contribution to overall noise. In response to this problem, we developed a wideband and low-noise preamplifier so that SNR becomes a medium limit [10].

Achieving a 100-Mbps data transfer rate by RLL(1,7) coding requires a band of at least 37.5 MHz in the optical detecting system that converts light returned from the optical disk to an electrical signal. The amplifier that we constructed for this equipment features low noise of 1.2 pA/√Hz at 37.5 MHz with a bandwidth of 80 MHz.

HIGH-SPEED SERVO SYSTEM

To achieve a high-rotation speed, we have proposed a high-speed servo system that combines feedback (FB) control with feed-forward (FF) control. This system has been shown to reduce residual tracking error to a level far below that of the conventional FB control system [11].

We also constructed a prototype high-speed optical beam positioning control apparatus using a high-speed digital processor (DSP). It was confirmed that the residual tracing error could be kept to within the acceptable rage required for 100 Mbps signal recording.

MEASUREMENT OF BYTE ERROR RATE

Under the conditions described above, we measured BER in our experimental 2-head optical disk system having a data transfer rate of 100 Mbps per head. Table 4 and Fig. 6 show experimental parameter and a block diagram of this measurement scheme, respectively.

First, to check medium characteristics, we examined the readout eye patterns shown in Fig. 7 when recording a pseudo-random signal. Jitter value at this time was under 10% for the signals of both heads, and we measured BER in this state and while using PR(1,1,1) as described above. Error rate was found to range from 10^{-3} to 10^{-4} without error-correction processing. This value of error rate is not a problem in practice and confirms the feasibility of a 200 Mbps system.

Table 4: Experimental parameter

Linear velocity (m/s)	12
Channel clock (MHz)	150
Modulation code	1,7 RLL
Bit length (µm)	0.12
Write strategy	N-1 type

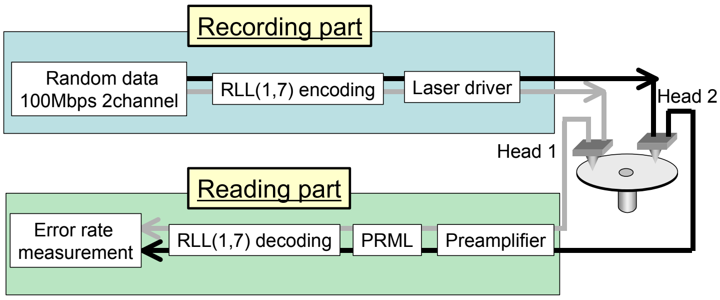


Fig.6 Block diagram of byte-error-rate measurement in experimental system

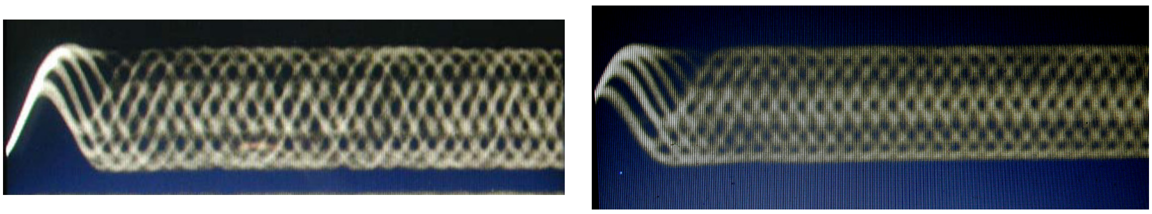


Fig.7 Readout eye patterns from each head

CONCLUSION

We have constructed two-channel optical disk experimental equipment and media having a high data transfer rate and high recording density (17 Gbit/in^2). We obtained a BER low enough to allow practical application. The results of testing this equipment indicate the possibility of recording about 20 minutes of a HDTV signal compressed to 200 Mbps. The optical disk has great potential for use in the production of TV programs and for their long-term archiving in the fast approaching digital broadcasting era. We plan to initially use optical disks for the broadcast of news programming on a trial basis and then to introduce their use in other types of programming.

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