IEEE Transactions on Consumer Electronics, Vol. 37, No. 3, AUGUST 1991

HIGH DENSITY MUSE VIDEODISC

Hitoshi Terasaki, Yoichi Tsuchiya, and Osamu Ota
Information & Communication Systems Research Center
Sanyo Electric Co., Ltd.
Gifu, Japan

ABSTRACT

We have developed a MUSE (Multiple Sub-Nyquist Sampling Encoding) videodisc with 60 minutes of playback time per side of CLV disc. The recording density of the disc is doubled as that of NTSC videodisc. A visible laser diode with a wavelength of 670 nm and an objective lens with an N.A. (numerical aperture) of 0.6 are used for playing the disc. As a result, a fine played back image was obtained as reported herein.

1. INTRODUCTION

Recently, high definition television has become the center of attention in consumer electronics. The HDTV systems proposed by NHK (Japan Broadcasting Corporation) is on the market in Japan. The HDTV signal contains about 5 times the information of the conventional NTSC signal. So, the HDTV signal can be recorded on a disc (in the FM format) in a very short time.

2. MUSE VIDEODISC

The MUSE is one of the bandwidth-compression techniques which was developed by NHK Japan for broadcasting via satellite. By this band compression, it was possible to narrow the band to 8.1 MHz. So, it is possible, using the MUSE signal, to record the HDTV signal onto the disc for a long time.

We have developed a high definition videodisc with 30 minutes of playback time per side, using a MUSE signal. Table 1 shows the specifications of the MUSE videodisc. In this disc, the MUSE signal is recorded on FM. In the frequency allocation, the carrier frequency was set to 12.5 MHz for black level and 15.5 MHz for white level. The pilot signal used for the disc rotation in playback is frequency multiplexed into the FM video signal and recorded on the disc. The pilot signal is set to $67.5f_H$ (f_H: horizontal frequency). For the audio signal, two or four channels for broadcasting are time-division multiplexed in the vertical blanking period, and in the CD format the PCM audio signal is frequency-division multiplexed. The recording linear velocity is apploximately double that of the NTSC videodisc. This MUSE videodisc

Table 1. Characteristics of MUSE videodisc

Video signal	MUSE signal	
FM deviation	3 MHz	
Allocation	12.5 ～ 15.5 MHz	
Pilot signal	frequency : 67.5 fH (2.278 MHz)	
Audio signal	(1) Time-division multiplexed PCM (2) Frequency-division multiplexed PCM	
Disc parameter	CLV	CAV
Recording area	55 ～ 145 mm	100 ～ 145 mm
Linear velocity	19 ～ 21 m/s	19 ～ 27 m/s
Track pitch	1.55 ～ 1.7 μm	1.55 ～ 1.7 μm
Playback time	30 min.	15 min.

Manuscript received June 7, 1991

has the same recording density as that of the NTSC videodisc. As a result, the playback time is a maximum of 30 minutes per side.

3. LONGER PLAYBACK TIME

The 30 minute MUSE videodisc is mainly for business use. In order to expand to the consumer electronics markets in the future, it is necessary to achieve at least 60 minutes of playback time per side.

In order to the playback time longer, the recording linear velocity should be slower, and the track pitch should be narrower. In this way, the pits recorded on the disc are made smaller.

In Table 2, the linear velocity, the track pitch and the shortest pit length are shown for each playback time. Because the emphasis for MUSE signal, and frequency multiplexing of the pilot signal and the EFM signal, a frequency higher than 15.5 MHz is actually obtained. Consequently, a pit of less than 0.4 μm in length exists in the 60 minutes MUSE videodisc.

So, for the disc cutting system, the ability to form pits less than 0.4 μm is required. And for the playback system, the ability to detect them is also required.

Table 2. Playback time and shortest pit length

Playback time	Linear velocity	Track pitch	Shortest pit length
30 (min)	19 (m/s)	1.6 (μ m)	0.5 (μ m)
60	14	1.12	0.37
60	13.5	1.16	0.36
60	13	1.2	0.34

4. LASER CUTTING MACHINE

Figure 1 shows the construction of the laser cutting machine. The frequency modulated MUSE signal modulates the Ar (Argon) ion laser beam at the E/O modulator. The modulated laser beam is focused by an objective lens and exposes the photoresists coated on the glass master. The function of the cutting machine is an important factor in the disc mastering process. Table 3 shows the characteristics of the laser cutting machine. To make the pits less than 0.4 μm, an Ar ion laser with a wavelength of 458 nm was used as a light source. And an objective lens with an N.A. of 0.92 was used for the optical head. The recording laser power was 400 mW, and the E/O modulator was used for light modulation.

We can obtain fine pits of 0.3 μm by using this laser cutting machine.

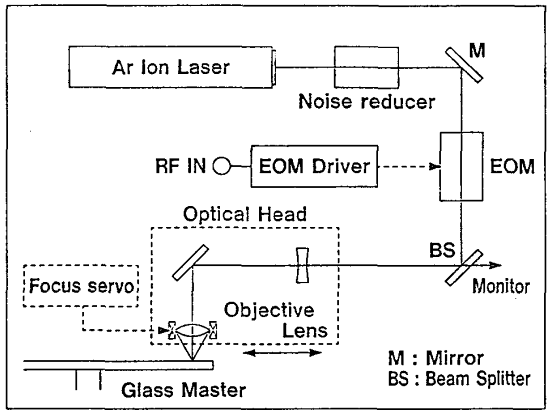


Fig. 1. Construction of laser cutting machine

Table 3. Characteristics of laser cutting machine

Recording Laser	Ar Ion Laser λ = 457.9(nm) Power = 400(mW)
Optical Modulator	E/O Modulator
Objective Lens	NA = 0.92

5. OPTICAL PICK-UP

In the NTSC videodisc player and the 30 minute MUSE videodisc player, a laser diode with a wavelength of 780 nm and an objective lens with an N.A. of 0.5 are used. Under these conditions, the focused beam spot diameter is approximately 1.6 µm. In the 60 minute MUSE videodisc player, to make the pick-up resolution higher, the playback beam spot size should be smaller.

The focused beam spot size is proportional to the wavelength of the beam, and inversely proportional to the N.A. value of the lens. In recent years, a visible laser diode with a wavelength shorter than 780 nm has been developed. So, we employed a visible laser diode as a light source and an objective lens with an N.A. of 0.6.

5.1 Visible laser diode

Compared with conventional laser diode (wavelength = 780 nm), the spot diameter can be small with a visible laser diodes. But, the visible laser diode has a disadvantage in that the aspect ratio of the radiated beam is large. When attempting to focus this elliptic beam by the objective lens, it cannot be focused sufficiently in the direction of $\theta_{\parallel}$. Thus, the beam reform using prisms required focusing of the $\theta_{\parallel}$ direction. After beam radiated from the laser diode is made parallel by the collimating lens, the prisms are inserted to expand the $\theta_{\parallel}$ direction. But, using prisms is unsuitable for mass production because of parts cost and difficulty in optical adjustment.

To overcome these disadvantages, we employed a new visible laser diode developed by SANYO. Which has a low aspect ratio of the radiated beam. Table 4 shows the characteristics of the low aspect ratio type and the normal type visible laser diode. In particular, the radiation angle in the $\theta_{\parallel}$ direction is improved. In using the new visible laser diode without prisms, a focused beam spot of 0.98 µm is obtained with a collimating lens N.A. of 0.18 and objective lens N.A. of 0.6.

Table 4. Visible laser diode and beam spot size

Visible laser diode	low aspect ratio		normal type	
Radiation angle (deg)	$\theta\perp$	$\theta /\!/$	$\theta\perp$	$\theta /\!/$
	30	11	32	8
Spot size (µm)	0.98	0.98	0.98	1.12
Aspect ratio	2.73 : 1		4 : 1	

collimating lens N.A. : 0.18
objective lens N.A. : 0.6

5.2 Frequency characteristics

Figure 2 shows the frequency characteristics of the optical pick-up with a visible laser diode of low aspect ratio. Compared with the 30 minute MUSE videodisc player, the frequency characteristics of the new pick-up are much better.

As described before, in the 60 minute MUSE videodisc, the pits less than 0.4 µm exist. While a pit of 0.4 µm cannot be played back with a pick-up using a wavelength of 780 nm and an N.A. of 0.5, the same pit can be played back with a pick-up using a 670 nm wavelength and an N.A. of 0.6. In this case, we can obtain a 62 dB C/N ratio.

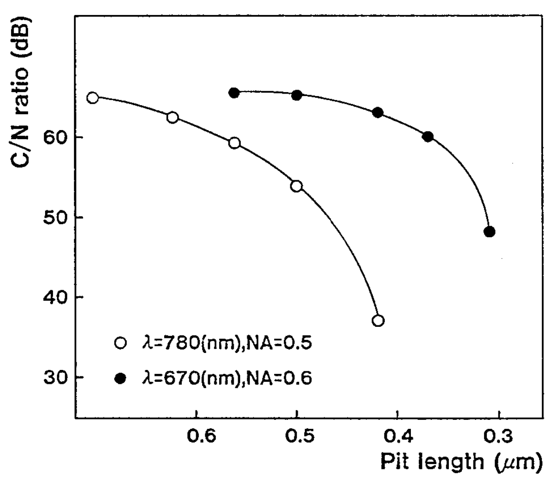


Fig. 2. Frequency characteristics

6. DISC PARAMETERS

Next, we studied the disc parameters for a playback time of 60 minutes.

6.1 Track pitch

As the playback time becomes longer, the track pitch must be narrower. Figure 3 shows the relations between S/N ratio of the playedback image and the track pitch for 30 and 60 minute disc and pick-up. As the track pitch is made narrower, the S/N ratio decreases, bacause the crosstalk noise from the adjoining tracks increases. For this reason, the track pitch should be narrowed to minimize the incidence of crosstalk noise. The crosstalk noise, of course, depends on the beam spot size while playing the disc, too. As shown in Figure 3, in the 60 minutes disc and pick-up, when the track pitch is more than 1.1 μm, the S/N ratio is over 42.5 dB, and no crosstalk noise can generally be observed in the played back image.

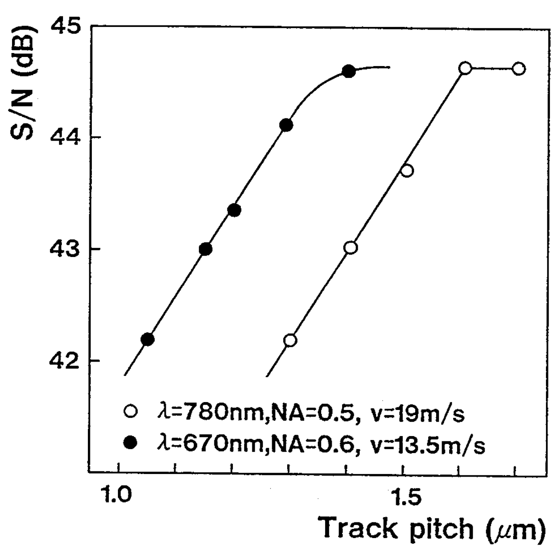


Fig. 3. S/N vs. track pitch

6.2 Linear velocity

Of course, the S/N ratio of the played back video signal also depends on the recording or playing linear velocity. The relations are shown in figure 4. These data were obtained by using a pick-up with a wavelength of 670 nm and an N.A. of 0.6. The linear velocity should be set as fast as possible. However, the high linear velocity causes the track pitch to be narrower, because the disc recording area is restricted between a 55 and 145 mm radius. So, it is necessary to make the linear velocity fast within the allowable track pitch range. From the study of the track pitch as described before, we set the track pitch to 1.12 μm, and the linear velocity to 14 m/s.

These conditions enabled us to get 60 minutes of playback time per side, and a 43 dB S/N ratio was obtained.

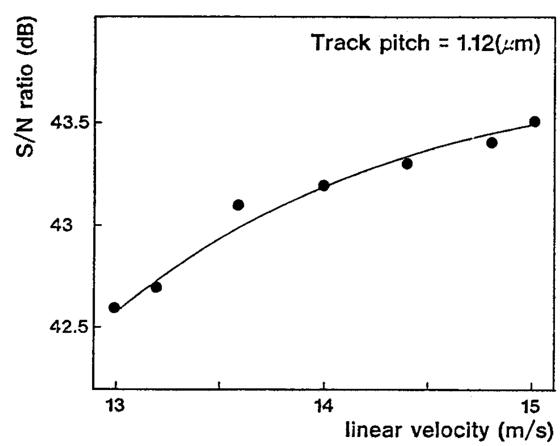


Fig. 4. S/N vs. linear velocity

7. RECORDING CONDITIONS

7.1 Frequency allocation

To improve the S/N ratio, we looked at the carrier frequency.

In the 30 minute MUSE videodisc, we have set the carrier frequency to 12.5 MHz for black level and 15.5 MHz for white level. With this frequency allocation, the shortest pit is not easy to read, because the pick-up's frequency characteristics start to drop suddenly in this pit length. Therefore, as shown in table 5, we set the carrier frequency in the 60 minute MUSE videodisc to 11.5 MHz for black level and 14.5 MHz for white level. With this allocation, the shortest pit length is about 0.4 μm, and a C/N ratio of more than 60 dB is obtained.

As a result, the S/N ratio of the played back video signal improved to 44 dB, and no influences on the lower carrier frequency on the played back image were observed.

Table 5. Carrier frequency

Playback time (min.)	60	
Carrier frequency (MHz)	14	13
Allocation (MHz)	12.5~15.5	11.5~14.5
S/N (dB)	43	44

7.2 Frequency multiplexed PCM audio

In the 60 minute MUSE videodisc, as in the 30 minute MUSE videodisc, the EFM signal is frequency multiplexed below the pilot carrier frequency.

The pit length is greatly affected by the frequency multiplexing of EFM signal. So in the 60 minute MUSE videodisc, frequency multiplexing becomes very difficult compared with the 30 minute MUSE videodisc. If the multiplexing level is too high, the pits are made even smaller. And if the multiplexing level is too low, the S/N ratio of the playedback EFM signal lowers, and the error rate of the audio signal at demodulation increases. Figure 5 shows the correlation between the block error rate and the multiplexing level for a non-modulated FM carrier. When the multiplexing level is set to -27 dB for the FM carrier, the block error rate is 2×10^{-2}. At this error rate, no practical problems occurs at all.

With the time division multiplexed audio signal, the error rate is also low.

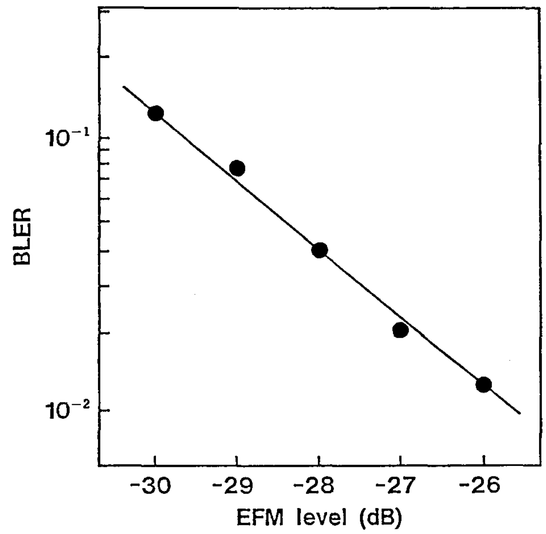


Fig. 5. BLER vs. multiplexing level

8. SPECIFICATIONS

Putting all that we described together, the characteristics of the 60 minute MUSE videodisc and optical pick-up are shown on Table 6.

9. CONCLUSIONS

We have developed a high density MUSE videodisc with a playback time of 60 minutes per side, by developing a recording and playback system, through the optimization of

Table 6. Caracteristics of disc and pick-up

Video signal	MUSE signal
Audio signal	Time-division multiplexed PCM
	Frequency-division multiplexed PCM
Carrier Frequency	13 MHz
FM deviation	3 MHz
Disc diameter	300 mm
Recording area	55~145 mm
Linear velocity	14 m/sec
Track pitch	1.12 μm
Playback time	60 min
Wavelength	670 nm
Objective Lens NA	0.6

recording conditions and by reexamining disc parameters.

Using these techniques, the fine played back image with an S/N of 44 dB was obtained.

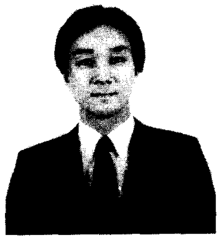
Two kinds of audio signals are recorded, frequency-division multiplexed PCM and time-division multiplexed PCM. In both systems, a low error rate which presents no practical problem was obtained.

10. REFERENCES

1. Y.Ninomiya, Y.Otsuka, and Y.Izumi, "Single Channel HDTV Broadcast System - the MUSE", NHK Laboratory Note, No.304, Sept.1984.
2. T.Hioki, T.Toyama, Y.Morita, H.Watanabe, K.Hibino, M.Yamada, "Hi-Vision Optical Video Disc", IEEE Trans. on Consumer Electronics, Vol.34, No.1, Feb.1988.

Biographies

Hitoshi Terasaki received his B.S. degree in 1982 from Kyushu Univ., Fukuoka, Japan. In 1982, he joined Sanyo Electric Co., Ltd. He has been engaged in the development of the optical disc system at the Information & Communication Systems Research Center. He is presently a chief researcher.



Yoichi Tsuchiya received his B.E. degree in 1981 from Gifu Univ., Gifu, Japan. In 1981, he joined Sanyo Electric Co., Ltd. He has been engaged in the development of the optical disc system at the Information & Communication Systems Research Center. He is presently a chief researcher.

Osamu Ota received his B.E. degree in 1970 from Osaka Univ., Osaka, Japan. In 1970, he joined Sanyo Electric Co., Ltd. He has been engaged in the development of the optical disc system at the Information & Communication Systems Research Center. He is presently a Manager.