Performance Comparison of Detection Methods in Magneto-optical Disc System with (1, 7) RLL Code

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Abstract—The performance of detection methods is analyzed in the magneto-optical disc (MOD) system with (1, 7) runlength limited (RLL) code. The peak detection, threshold detection, and partial response channel with maximum likelihood (PRML) detection are considered. The MOD system uses SHG green laser and has storage capacity of 4.2 Gbyte. The channel model is based on the implemented MOD system. Bit error probabilities of each detection methods are obtained from simulation for three cases of only media noise, only electronic noise, and mixed noise of them. It is shown that PRML detection and threshold detection achieve much smaller bit error probability than peak detection and have similar bit error probability if SNR is large.

I. INTRODUCTION

Recently there has been greater interest in magneto-optical disc (MOD) system as an alternative to a read/write and high capacity storage system. Although optical storage systems have high storage capacity, its read-only features limit applications. The MOD system, on the other hand, not only reads and writes but it also has high storage capacity that is comparable or better than the optical storage system[1]. These features place MOD systems more suitable for multimedia applications. In 1992, Lynch analyzed the performance of the MOD system under Gaussian modulation transfer function (MTF) model[2]. However a detailed specification for the MOD system is yet to be determined and many other schemes are still being researched.

The MOD posses mixed characteristics of optical and magnetic materials[1], [3]. Recording density of the MOD system that was limited by the optical characteristic of laser has been significantly improved through laser wavelength reduction and improvement of optical devices. Red laser, which has been used for compact disc, possesses long wavelength for MOD application. Therefore, second harmonics generation (SHG) green laser has been studied for the high density MOD application[1], [4]. A modulation code is used as a method to increase recording density because it enables density ratio (DR) greater than one. In magnetic storage system, it was shown that (1, 7) runlength limited (RLL) code performs better as a result of its wide detection window and proper DR[3], [5]. There are three detection methods to be considered in practical applications of optical and magnetic storage system.

Gated peak detection (GPD) is widely used for magnetic storage system[3]. Threshold detection (THD) is used for optical storage system[1]. More recently, partial response channel with maximum likelihood (PRML) detection is used in some applications. PRML detection is a digital/sampling detection which has been widely studied in magnetic storage system as an alternative method to increase recording density[2], [6], [7], [8].

In this paper, the performance of peak detection, threshold detection, and PRML detection in MOD system with (1, 7) RLL code and SHG green laser is analyzed through a simulation. The simulated MOD channel model is based on practically implemented MOD system. In Section II, descriptions of implemented MOD system: GPD, THD and PRML detections: and simulated MOD channel model are given. In Section III, we discuss and analyze simulation results. In Section IV, conclusions are presented.

II. MAGNETO-OPTICAL DISC SYSTEM

Fig. 1 shows the block diagram of the implemented MOD system[1], [2], [3], [4]. Reed-Solomon code is used for error correcting code (ECC) to protect information data, and (1, 7) RLL modulation code is used to increase recording density. The optical modulator with SHG green laser transforms electrical signal to optical signal using the light intensity modulation. The photodetector converts optical signal to electrical signal. In Table I, detailed specifications of the MOD system are given. The MOD system uses a pulse width modulation (PWM) with nonreturn to zero inverse (NRZI) coding method. Scanning scheme is a constant angular velocity (CAV) scheme.

A. Channel Model

Recording density of the magneto-optical disc is dominantly determined by the intensity profile and the spot size of optical stylus. The intensity profile of optical stylus is approximately Gaussian. It is denoted by full width at half maximum size (FWHM) typically given by 0.54 λ/NA where λ is the wavelength of laser and NA is numerical aperture of the objective lens[1], [2]. In our MOD system, SHG green laser is used for source of optical beam and its wavelength is 530nm. In optical disc system, due to the diffraction effect of laser beam, the maximum frequency of read signal is limited to the cutoff frequency of channel which is given by

\[ f_{\text{cutoff}} = \frac{2\pi NA}{\lambda} \times v \quad \text{[Hz]}, \]  

(1)
where $r$ is line-velocity of scanning-optical stylus[1]. The read channel of optical recording system is characterized by modulation transfer function (MTF). For read-only optical system such as compact disc (CD), MTF is given by

$$H(f) = \frac{2}{\pi} \cos^{-1}(f - \sqrt{1 - f^2}), \quad 0 \leq f \leq 1. \quad (2)$$

where $f$ is the normalized frequency by the cutoff frequency of channel[1]. Magneto-optical disc system has a different MTF because a domain on magneto-optical disc is not like a pit found in read-only optical system but a dispersive pit. Because of the fact that the intensity profile of optical stylus is similar to a Gaussian distribution, Gaussian MTF model was used for magneto-optical system[11, 21]. In this work, to maintain the reliability of MOD channel model, we used a MTF model of magneto-optical disc obtained from samples of the implemented MOD system[4].

Fig. 2 shows a simple channel model of the MOD system[1], [3], [8], [10]. The MOD channel is modeled as a discrete-time, discrete-valued (binary) input, and a continuous-time, continuous-valued output. The channel is assumed to use saturated noiseless output of the MOD channel to be denoted by $h_{\text{med}}(\cdot)$. The read signal $r(t)$ is given by

$$r(t) = (\sum c_k A P_T(t - k T_e) + n_m(t) \ast h_{\text{med}}(t) + n_\epsilon(t). \quad (3)$$

where $c_k$ is the NRZI input data modulated by (1, 7) RLL code and $T_c$ is the period of channel bit, and $P_T(t)$ is a write pulse which is given by

$$P_T(t) = \begin{cases} 1, & 0 \leq t \leq T_c, \\ 0, & \text{elsewhere}. \end{cases} \quad (4)$$

Let $y(t)$ denote the noiseless output of the MOD channel. Then equation (3) becomes

$$r(t) = y(t) + n_m(t) \ast h_{\text{med}}(t) + n_\epsilon(t)$$

$$= y(t) + n(t) \quad (5)$$

where $n(t) = n_m(t) \ast h_{\text{med}}(t) + n_\epsilon(t)$ is total noise of electronic noise and media noise. The media noise whose spectrum is shaped by $I_{\text{med}}(w)$ is found with the Fourier transform of $h_{\text{med}}(t)$. Consequently, the total noise $n(t)$ is zero mean, stationary Gaussian random process with power spectral density of [1], [3], [10]

$$S_n(w) = |H_{\text{med}}(w)|^2 \frac{N_m}{2} + \frac{N_\epsilon}{2}. \quad (6)$$

In this work, we use the signal-to-noise ratio (SNR) as follows[10]. Let $BW_c$ denote the bandwidth of receiving filter, then

$$\text{SNR} = 10 \log_{10} \frac{\int_{-\infty}^{\infty} y^2 dt}{\int_{-\infty}^{\infty} n^2 dt} \quad (7)$$

To analyze the effect of media noise and electronic noise, we use the fraction $\gamma$ of noise power spectral density due to the media noise which is given by

$$\gamma = \frac{\sigma_m^2}{\sigma_m^2 + \sigma_\epsilon^2} \quad (8)$$

where $\sigma_m^2$ and $\sigma_\epsilon^2$ are the variances of media noise and electronics noise, respectively. If $\gamma = 1$, it denotes the case where power of electronic noise is zero. If $\gamma = 0$, it denotes the case where power of media noise is zero. In the practical system, its value is determined by measurement.

B. Detection Methods

Fig. 3 shows the MOD system model with the peak detector, the PRML detector, and the threshold detector for simulation. The coded sequence by modulation code is converted to the NRZI sequence. It is converted to the modulated signal by a pulse signal generator. The channel impulse response is measured from the implemented MOD system[10], [11]. The channel output signal passes through a lowpass filter and an equalizer and then it is detected.

The peak detection with RLL code has been widely used in magnetic storage systems with medium recording density[3], [9]. In simulation, we use the gated peak detector. The gated peak detector differentiates the read signal twice and looks for zero crossings. These zero crossings must occur at the points of maximum slope in the read signal corresponding to the points of transition of domain in the disc. The defect of peak detection is the noise enhancement produced by double differentiation.

The threshold detection has been used in optical storage system such as CD[1]. In simulation, we use a simple threshold detector. It detects whether the read signal crosses a threshold value. In general, the performance of threshold detection is superior to peak detection, however threshold detection has a problem of extracting correct threshold level in the presence of a wandering baseline[1], [2]. In simulation, we do not consider a wandering baseline.

The partial response (PR) channel is regarded as the linear digital filter in which the present channel output is a linear combination of present channel input and previous channel inputs. It is well known that the PR channel for a MOD channel is well modeled by

$$H(D) = (1 + D)^n \quad (9)$$

where $D$ is a delay operator and $n$ is a positive integer. This is called as “PR-n channel”. We use PR-2 channel model with ML detection in simulation. In PRML detection, an equalizer shapes the channel transfer function of MOD channel to that of PR channel.

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The ML detector extracts the transmitted sequence with Viterbi algorithm[2], [6], [7]. PRML detection achieves better performance of three detection methods if the difference between the MOD channel and the PR channel is not so large to require boosted noise power for equalization. However, PRML detection has disadvantages that it is not easy to be adopted for analog storage system immediately and it requires high hardware complexity[2], [7]. In Fig. 4, the ideal PR-2 channel model with ML detector is given to be compared with PRML detector on the MOD system.

III. SIMULATION RESULTS

The performance of three detection methods are investigated by MonteCarlo simulation. In Table II, parameters for simulation are given. The fraction $\gamma$ of noise power due to media noise has three values of 0, 0.909, 1.0. All parameters are determined from the measured data in the practically implemented MOD system. The channel impulse response is obtained by a channel identification method using PN sequence as an input in the implemented MOD system[10], [11]. Fig. 5 compares the channel impulse responses of implemented MOD system and PR-2 channel.

We see that the measured channel impulse response is similar to that of PR-2 channel, and it is feasible to equalize output signal of the MOD system for PR-2 equalization.

Fig. 6 (a), (b), and (c) show the bit error probabilities of peak detector and PRML detector and threshold detector, respectively. In each detector, the bit error probability is analyzed in three cases: 1) $\gamma=1$: the media noise only, 2) $\gamma=0$: the electronic noise only and 3) $\gamma=0.909$: the combined media and electronic noise. In Case 3), power of media noise is ten times larger than that of electronic noise. In Fig. 6 (a), it is shown that the bit error probability of peak detector is seriously degraded by the electronic noise than the media noise. To achieve the same bit error probability of $10^{-4}$, SNR is approximately 6 dB greater for $\gamma=0$ than for $\gamma=1.0$. This reason is that the signal for $\gamma=1.0$ is less disturbed than for $\gamma=0$ since high frequency components in the media noise are removed by characteristic of the MOD channel. Also, amplitude of output signal is attenuated as frequency increases. Therefore the performance is degraded as power of electronic noise becomes larger than media noise in the peak detector and the threshold detector.

Fig. 6 (b) shows the bit error probability of the PRML detector. The bit error probability is degraded by the media noise more than the electronic noise if SNR is lower than 25.5 dB. However the difference of bit error probabilities for $\gamma=1$ and $\gamma=0$ becomes small if SNR is larger than 25.5 dB. The reason is that, for $\gamma=1.0$, the distortion of the read signal is small and the shift of the read signal occurs. Thus sampling errors occur in burst due to shift of waveform for $\gamma=1.0$ where sampling error is defined as the events where sampled value of the MOD channel is closer to the incorrect value of PR-2 channel. However, for $\gamma=0$, sampling errors occur in random. Therefore the performance of ML detector using Viterbi algorithm is degraded for $\gamma=1.0$ more than for $\gamma=0$ since Viterbi detector is weak to burst error[10].

The bit error probability of PR-2 channel is close to that of the MOD system with $\gamma=0.909$.

In Fig. 6 (c), the bit error probability of threshold detector is given. It is also shown that the bit error probability is seriously degraded by the electronic noise than the media noise. To achieve the same bit error probability of $10^{-4}$, SNR is approximately 5.7 dB greater for $\gamma=0$ than for $\gamma=1.0$. Fig. 7 compares bit error probabilities of the peak detection and the PRML detection and the threshold detection for $\gamma=0.909$. For the bit error probability of $10^{-4}$, the PRML detector and the threshold detector show 5.2 dB and 4.3 dB gain of SNR compared to the peak detector, respectively. The PRML detection has SNR gain of 0.9 dB for the threshold detection in the same bit error probability.

IV. CONCLUSIONS

In this paper, the performances of peak detection, PRML detection, and threshold detection were compared in the high density magneto-optical disc (MOD) system with (1, 7) RLL code and second harmonics generation (SHG) green laser. Channel model of the MOD system was presented which is based on the practically implemented MOD system. The PRML detection and the threshold detection showed SNR gain of 5 dB and 4.5 dB larger than peak detection at the bit error probability of $10^{-4}$, respectively. The PRML detection has SNR gain of 0.9 dB for the threshold detection. It was also shown that the bit error probability of peak detection and threshold detection are more sensitive to the media noise than electronic noise, and the PRML detection is more sensitive to the media noise than the electronic noise for low SNR.

REFERENCES

### TABLE 1. PARAMETERS OF THE MOD SYSTEM

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specifications</th>
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<tr>
<td>Diameter of disc (mm)</td>
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<td>Rotation velocity of disc (rpm)</td>
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<td>Wavelength of laser (nm)</td>
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<td>(1, 7) RLL</td>
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<td>Recording method</td>
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<td>Type of laser</td>
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<td>Focused beam diameter (mm)</td>
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<td>Storage capacity (GByte)</td>
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### TABLE 2. PARAMETERS FOR SIMULATION

<table>
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Fig. 6. Bit error probabilities of detection methods in the MOD system. (a) Peak detection. (b) PRML detection. (c) Threshold detection.

Fig. 7. Bit error probability comparison of peak detection, PRML detection, and threshold detection in the MOD system.