A new tracking error detection method using amplitude difference detection for signal waveform modulation multi-level discs*

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The sub-land/sub-pit affects the characteristic of the tracking error signal which is generated by the conventional differential phase detection (DPD) method in the signal waveform modulation multi-level (SWML) read-only disc. To solve this problem, this paper proposes a new tracking error detection method using amplitude difference. Based on the diffraction theory, the amplitude difference is proportional to the tracking error and is feasible to be used for obtaining the off-track information. The experimental system of the amplitude difference detection method is developed. The experimental results show that the tracking error signal derived from the new method has better performance in uniformity and signal-to-noise ratio than that derived from the conventional DPD method in the SWML read-only disc.

Keywords: signal waveform modulation, multi-level technology, tracking error, amplitude difference

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1. Introduction

Multi-level (ML) technology can increase the storage density of the optical disc without changing the optical and mechanical units.[1−5] Recently, the preliminary study of the signal waveform (SW) ML (SWML) read-only disc which is based on the optical and mechanical units of the commercial digital versatile disc (DVD) is presented.[6,7] The SWML read-only disc employs sub-lands/sub-pits, which are inserted on the conventional pits/lands, to achieve multi levels. By changing the length or the insertion position of sub-lands/sub-pits, readout signals with different waveforms can be generated, indicating different levels.

Tracking servo which maintains the focused laser beam on the centre of the desired information track is indispensable to the optical disc system. In the high-density read-only disc, the differential phase detection (DPD) method especially DPD2 method is adopted as the standard tracking error detection method.[8] The DPD method employs the phase (or time) difference between the high frequency components of readout signals from a four-quadrant photo detector to derive a tracking error (TE) signal. However, the application of ML technology always affects the characteristic of the TE signal.[9] In the SWML read-only disc, readout signals of short run-length such as $3T$ and $4T$ (T is channel clock length) are more sensitive to the crosstalk of sub-lands/sub-pits, and these phase information which makes major contribution to the conventional DPD signal becomes inaccurate. Thus, the conventional DPD signal of the SWML read-only disc deteriorates in the uniformity and contains more noise.

In this paper, a new tracking error detection method for SWML read-only discs, called amplitude difference detection (ADD) method, is proposed to improve the uniformity and signal-to-noise ratio (SNR) of the TE signal. Based on the diffraction theory, the principle and feasibility of the ADD method is analysed. Then the implementation of the ADD method is presented. Finally, the experiment is carried out and confirms the effectiveness of the ADD method.

2. Principle of the ADD method

The readout model of optical discs can be described by the diffraction theory.[10,11] Figure 1 shows

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a two-dimensional far-field pattern generated by an optical disc where x-axis presents the tangential direction of the spiral track and y-axis presents the radial direction in which off-track occurs. The inner part of the zeroth order is the four-quadrant detector denoted by A∼D. The high frequency signal from each quadrant is the result of interference between these diffracted orders. For the reason of simplicity, the high frequency signals $S_{\rm A} \sim S_{\rm D}$ from the four-quadrant detector can be expressed as[11]

$$\begin{aligned} & S_{\rm A}(t,\varphi_r) \\ &= \cos(2\pi\omega t+\psi)+\alpha\cos(2\pi\omega t+\varphi_r+\psi), \quad (1) \\ & S_{\rm B}(t,\varphi_r) \\ &= \cos(2\pi\omega t-\psi)+\alpha\cos(2\pi\omega t-\varphi_r-\psi), \quad (2) \\ & S_{\rm C}(t,\varphi_r) \\ &= \cos(2\pi\omega t-\psi)+\alpha\cos(2\pi\omega t+\varphi_r-\psi), \quad (3) \\ & S_{\rm D}(t,\varphi_r) \\ &= \cos(2\pi\omega t+\psi)+\alpha\cos(2\pi\omega t-\varphi_r+\psi), \quad (4) \end{aligned}$$

where ω is the time frequency dependent on the scanning velocity of the spiral track, α is a small factor approximated to 0.1, ψ is the simplified phase between zeroth and first diffracted orders and φ_r is the phase derived from the tracking error. Here φ_r is proportional to the tracking error r and can be expressed as

$$\varphi_r = 2\pi r/q, \quad (5)$$

where q is the track pitch.

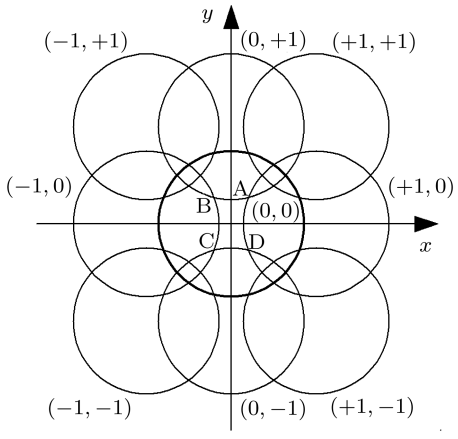


Fig. 1. Diffraction pattern of the optical disc.

The conventional DPD method measures the time difference between the diagonally summed signals $S_{\rm A+C}$ and $S_{\rm B+D}$ to generate the TE signal. From Eqs. (1)–(4), $S_{\rm A+C}$ and $S_{\rm B+D}$ are given by

$$\begin{aligned} & S_{\rm A+C}(t,\varphi_r) \\ &= 2[\cos(2\pi\omega t)+\alpha\cos(2\pi\omega t+\varphi_r)]\cos\psi, \quad (6) \\ & S_{\rm B+D}(t,\varphi_r) \\ &= 2[\cos(2\pi\omega t)+\alpha\cos(2\pi\omega t-\varphi_r)]\cos\psi. \quad (7) \end{aligned}$$

As shown in Fig. 2, the time difference Δt_i can be described as follows:

$$\begin{aligned} & \Delta t_i(\varphi_r) \\ &= t_2 - t_1 \\ &\doteq \frac{S_{\rm B+D}(t_i,\varphi_r)}{S'_{\rm B+D}(t_i,\varphi_r)} - \frac{S_{\rm A+C}(t_i,\varphi_r)}{S'_{\rm A+C}(t_i,\varphi_r)} \\ &\propto -\frac{\alpha\sin\varphi_r}{\pi\omega(1+\alpha\cos\varphi_r)}. \end{aligned} \quad (8)$$

According to Eq. (8), Δt_i is a bipolar function of the tracking error r, so it can present the off-track information.

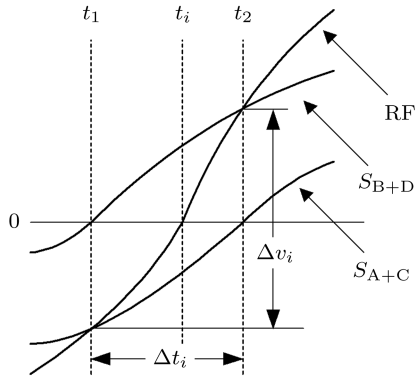


Fig. 2. Schematic diagram of time and amplitude difference between readout signals.

Instead, the ADD method measures the amplitude difference of the radio frequency (RF) signal between time t_1 and t_2 in Fig. 2. The RF signal is the summation signal of the four-quadrant detector and can be expressed as

$$S_{\rm RF}(t,\varphi_r) = 4(1+\alpha\cos\varphi_r)\cos\psi\cos(2\pi\omega t). \quad (9)$$

So the amplitude difference Δv_i of the RF signal between time t_1 and t_2 can be written as

$$\begin{aligned} & \Delta v_i(\varphi_r) \\ &= S_{\rm RF}(t_2,\varphi_r) - S_{\rm RF}(t_1,\varphi_r) \\ &\doteq S'_{\rm RF}(t_1,\varphi_r)\Delta t_i(\varphi_r) \propto \alpha\cos\psi\sin\varphi_r. \end{aligned} \quad (10)$$

From Eq. (10), we find that Δv_i is also a bipolar function of tracking error r. This means that the ADD method which measures amplitude difference Δv_i of the RF signal can also obtain the off-track information.

3. Implementation of the ADD method

Figure 3 shows the block diagram of the ADD method for the SWML read-only disc. First, the high frequency signals from four quadrant detectors A∼D are readout by the optical pickup unit. The digitized pulse signals AC and BD are produced respectively by slicers using zero-crossing detection according to the diagonally summed signals (A+C) and (B+D). The RF signal is generated by the sum of signals from the four-quadrant detector. Then these three signals AC, BD and RF are sent to the amplitude detector. The amplitude detector uses the rising and falling edge of signals AC and BD as trigger signals to sample and hold the amplitude of the RF signal, and then calculate the amplitude difference to output as signal E. Finally, the TE signal is produced by smoothing the signal E with a low-pass filter (LPF).

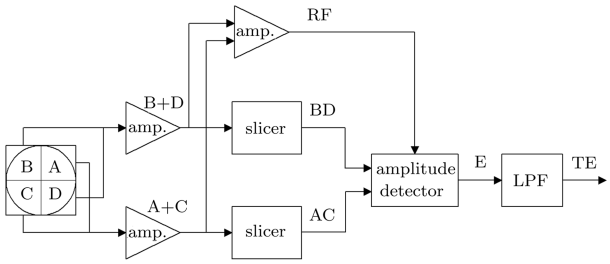


Fig. 3. Block diagram of the ADD method.

Figure 4 illustrates the signal processing of the amplitude detector. Take the rising edge for example, u_1 is the amplitude value of the RF signal when signal AC is rising; u_2 is the amplitude value of the RF signal when signal BD is rising. The amplitude detector outputs the amplitude difference (u_2-u_1) from time t_2 to t_5 which is the length of the current run-length. It can be noted that the time difference (t_3-t_1) is replaced by the amplitude difference (u_2-u_1) in the ADD method. The output signal E with positive value means signal AC leads signal BD while that with negative value means signal AC lags signal BD. Because value u_2 is obtained after time t_2, the amplitude detector should output signal E with a certain time delay ΔT. As the longest recording mark in the SWML read-only disc is $14T$ (refer to the DVD-system,[8] $1T$ represents 133 nm in length and 38 ns in time), the time delay ΔT can be selected as 500 ns which is sufficient and will not affect real-time of the final TE signal. After signal E is generated by the amplitude detector, the TE signal can be produced by the low-pass filter.

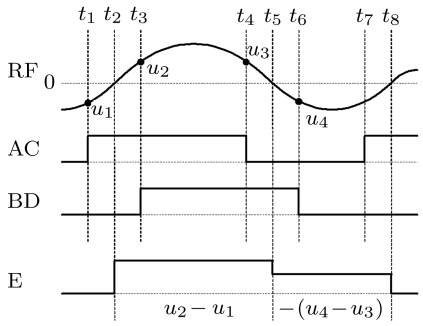


Fig. 4. Signal processing of the amplitude detector.

In the SWML read-only disc, the inter-symbol interference (ISI) is more serious than the conventional optical disc, and the phase information from the long run-length is more accurate than that from short run-length. In the ADD method, the output of the amplitude difference is multiplied with the length of the run-length of the RF signal. In this way, the long run-length will contribute more phase information to the final TE signal. So the ADD method is expected to have an advantage for the SWML read-only disc and to improve on the uniformity and SNR of the TE signal.

4. Experiment and results

To confirm the effectiveness of the ADD method, the experimental system based on a standard DVD driver is carried out. The signals, including A∼D and RF, are readout by the standard DVD driver on the condition of focusing servo enabled and tracking servo disabled. Then the above signals are sampled by the analogue-to-digital converters and sent to a field programmable gate array where the ADD method is implemented. The low-pass filter is a first order filter and has the same cut-off frequency of (−3 dB) 30 kHz as that used in the conventional DPD method. For

comparison, the conventional DPD signal, one of the output signals of the standard DVD driver, is also sampled.

Figure 5 shows the TE signals of the SWML read-only disc generated by the conventional DPD method and the ADD method. It can be found that the uniformity of the TE signal in the ADD method (called ADD signal for short) is much better than that of the conventional DPD signal. We statistically analyse the two signals with about 500 crossing tracks. The distribution of the peak-to-peak (PP) values of signals is shown in Fig. 6 where the solid curve is the normal distribution curve with certain standard deviation by statistics. The normalized standard deviation of the PP value of the ADD signal is about 0.058 while that of the DPD signal is 0.116. The uniformity of the TE signal is improved by the ADD method in the SWML read-only disc.

Moreover, SNR of the ADD signal and DPD signal is also estimated. Because TE signals filtered by low-pass filters with cut-off frequency of 30 kHz and below 10 kHz are useful for tracking servo, signals within the frequency band from 10 kHz to 30 kHz are considered as noise. The power of the ADD signal in this band is −18.5 dB with respect to that of the signal blow 10 kHz; while the power of the DPD signal in this band is −13.3 dB. The SNR of the ADD signal is increased about 5 dB than that of the DPD signal. This result shows that the ADD method can generate a less noisy TE signal than that of the conventional DPD method.

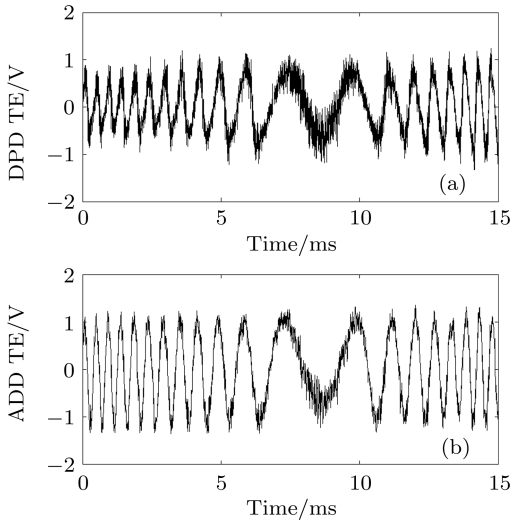


Fig. 5. The TE signals generated by conventional DPD method (a) and ADD method (b).

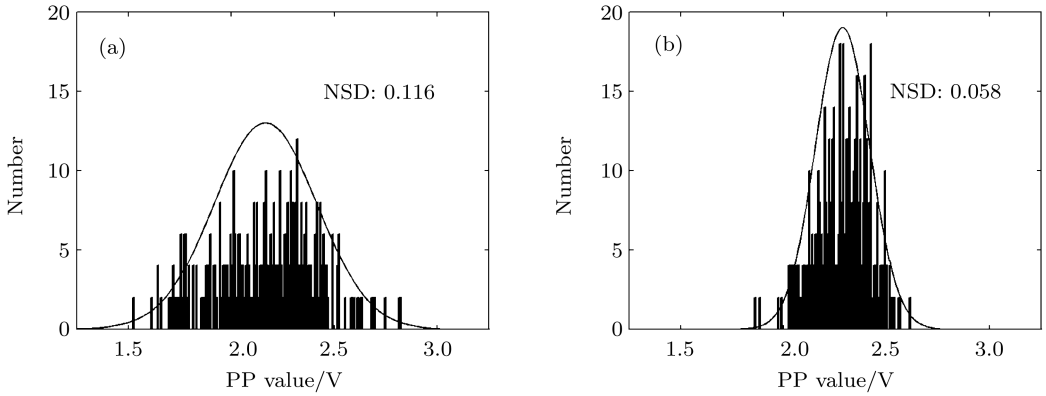


Fig. 6. The PP value distribution of (a) conventional DPD signal and (b) ADD signal.

5. Conclusion

Based on the amplitude difference, a new TE detection method for the SWML read-only disc is proposed. Compared with the conventional DPD method, the ADD method raises the contribution of long run-length to the TE signal. The experimental results show that the ADD method improves the uniformity of the TE signal. In addition, SNR of the ADD signal is increased about 5 dB than that of the conventional DPD signal. The ADD method is more effective than the conventional DPD method in the SWML read-only disc.

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