Utilizing the Transversal Encoder with Modified PRML Detection for Dual-Layer Magnetic Recording

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Dual-layer magnetic recording, which contains two discrete recording layers, can support very high data densities compared to current technologies. However, this technology has to contest with inter-layer interference (ILI), which significantly affects the accuracy of data signal detection. Therefore, this work presents a signal processing technique in which written tracks in the lower layer are wider than those in the upper layer. In addition, we developed a transversal coder to reduce the impact of ILI and increase detection efficiency. A comparative evaluation of the bit error rate (BER) and signal-to-noise ratio between the proposed systems and a conventional recording system showed that our proposed systems can provide significantly lower BER.

Index Terms— **3D magnetic recording, interlayer interference, modified Viterbi detector.**

I. Introduction

To manage massive amounts of data efficiently, high-density storage devices are essential. Technologies like two-dimensional magnetic recording [1], heat-assisted magnetic recording [2], and microwave-assisted magnetic recording [3] have been implemented to surpass the superparamagnetic limitations of conventional recording technology. Dual-layer magnetic recording (DLMR) [4] is also an ultra-high-density recording technology, in which a second recording layer is added to increase capacity, but faces the problem of inter-layer interference (ILI). Therefore, advanced signal processing is needed to mitigate ILI and improve data estimation accuracy. While partial response maximum likelihood (PRML) [5] is widely used in magnetic recording systems, conventional implementations are inadequate for handling ILI. Developing improved interference reduction/suppression techniques, specialized encoding schemes, and enhanced decoding capabilities are therefore crucial. This research presents a dual-layer magnetic recording structure with wider tracks on the lower layer, combining 1D PRML processing with transversal coding that maps bit relationships between layers to specific signal magnitudes (+2, −2, 0). Using this proposed media structure leads to efficient mitigation of ILI through modified Trellis detection, which is designed according to the encoding scheme. Bit error rate (BER) measurements across various signal-to-noise ratio (SNR) levels confirm that our system significantly outperforms conventional single-layer magnetic recording systems.

II. Media Structure

DLMR technology is developed by stacking recording layers, with each layer designed using a discrete Voronoi model [6] to achieve realism. This study examines the impacts of transition noise and three-dimensional interference. This includes inter-symbol interference (ISI) and inter-track interference (ITI) within each recording layer, as well as inter-layer interference (ILI) between the magnetic recording layers. Fig. 1 illustrates the structure of the dual-layer magnetic recording media. Fig. 1(a) shows a top view where the lower recording layer has wider tracks than the upper recording layer, while the track in the upper recording layer is offset to the center of the lower recording layer track. Both recording layers have adjacent tracks, with the read head positioned at the center of both recording layer tracks. Fig. 1(b) depicts the offset between transitions in the two recording layers, which was half the bit length (BL) in the down-track direction, with BL in both recording layers set at 22 nm. Fig. 1(c) shows that the track pitch (TP) of RL2 was 14.75 nm, while RL1 had a TP twice that of RL2 at 29.5 nm, resulting in areal densities of 1 Tb/in² and 2 Tb/in² for RL1 and RL2, respectively.

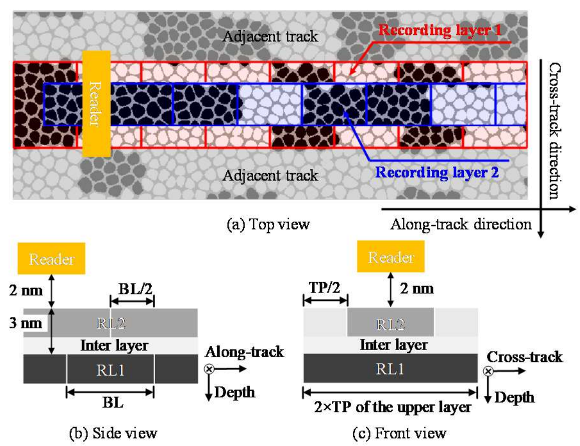

Fig. 1. Structure of dual-layer magnetic recording media in (a) top, (b) side, and (c) front views, respectively.

III. Signal Processing

A. Partial response maximum likelihood detection

Fig. 2(a) shows the channel model of the DLMR system. The process begins with recording user bits, $a_k^{(2)}$ and $a_k^{(1)}$, onto the upper and lower recording layers, respectively, under perfect writing. Subsequently, the one-dimensional partial response maximum likelihood (1-D PRML) detection system, comprising a 1-D equalizer and a 1-D detector, such as the 1-D Viterbi algorithm, is used for signal processing. The process starts by receiving the continuous-time signal, r_t, which passes through a low-pass filter before the sampling process.

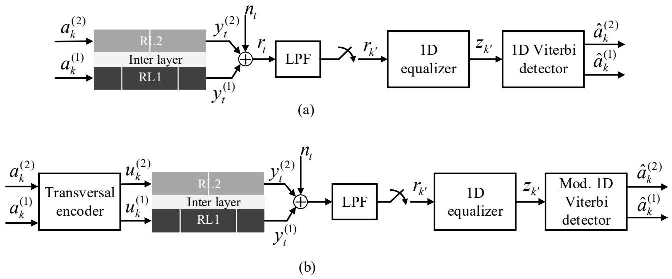

Fig. 2. Schematic of signal processing channels for dual-layer magnetic recording (a) 1D PRML and (b) transversal encoder with modified 1D PRML.

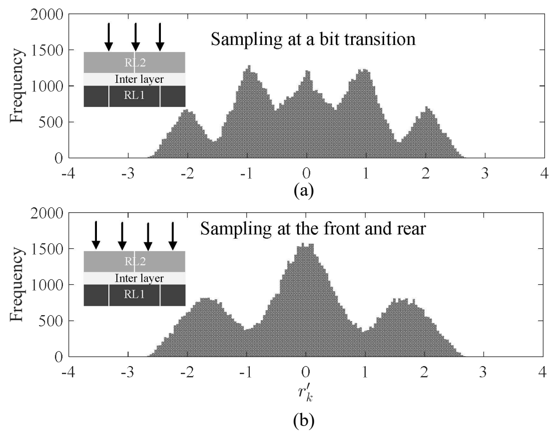

Fig. 3. Sampling position and distribution of readback signal data samples under SNR = 14 dB where (a) the sampling point begins at position BL/2 and (b) the sampling point is at position BL/4.

The discrete-time signal, r_k , is obtained using the oversampling technique at a rate of BL/2. We first consider the case of the sampling point at the bit transition, as shown in Fig. 3(a). Data from both recording layers is converted into a discrete data signal sequence, which can be classified into five groups. This signal-processing approach corresponds to partial response class 2 (PR2) with coefficients [1 2 1]. Therefore, the 1D equalizer and 1D detector can be designed to match PR2 to detect data from both the upper and lower recording layers within the same data sequence. However, this processing method cannot effectively reduce the effects of ILI.

B. Transversal encoder with modified PRML detection

As noted above, 1D PRML cannot efficiently process signals due to ILI. We, therefore, present a transversal encoder approach combined with modified PRML detection, as shown in Fig. 2(b). The user bits are sent through the traversal encoder before being recorded in the media. For user bits $a_k^{(2)}$ (upper layer) and $a_k^{(1)}$ (lower layer) at position k, the encoding follows specific rules: when $a_k^{(2)}$ is '+1' and if we need to record '+1' at position k-1 in the lower layer, the upper layer bit must be '+1', yielding a combined signal of '+2'. If position k-1 has '−1,' the upper bit must be '−1,' resulting in '−2.' However, if position k has '−1' status, the upper bit must be opposite to the previous lower layer state, yielding '0.' During reading, signals of '+2' or '−2' are decoded as '+1' bits, while '0' is decoded as '−1'. The signal is also oversampled at BL/2 rate, where the starting point is at BL/4 or the front and rear half, creating the pattern shown in Fig. 3(b). Though signals are distributed into three groups due to various interference types and noise, a 1D equalizer and detector can be designed explicitly for these encoded data. Then, using a modified trellis diagram that aligns with the data distribution can significantly improve the detection accuracy.

IV. Simulation Result and Conclusion

We compared our proposed systems with a single-layer (SL) magnetic recording system with TP and BL of 18 nm and 12 nm, yielding an areal density of 3 Tb/in^2 using 1D PRML processing. Performance evaluation involved comparing BER at various SNRs. The proposed systems include DL-1D PRML and DL-Trans-w-Mod. 1D PRML. These were compared with an SL system SL-1D PRML, as shown in Fig. 4. The results demonstrate that our proposed 1D PRML systems significantly outperformed conventional systems. Furthermore, the dual-layer system with transversal encoding and modified PRML achieved BER as low as 10^{-4}. Therefore, we can summarize that using a dual-layer approach with wider tracks in the lower recording layer combined with 1D PRML signal processing is possible. Moreover, transversal encoding and modified PRML detection can effectively mitigate the effects of ILI.

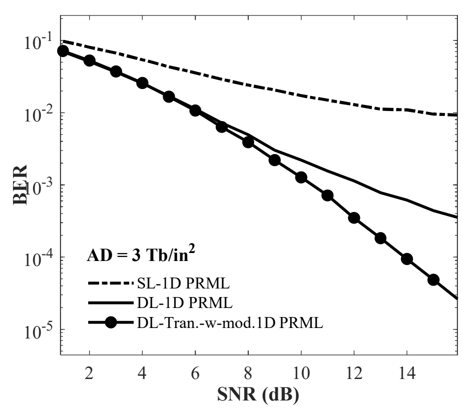

Fig. 4. BER performance comparison as a function of SNR for various recording systems.

Acknowledgments

This project is funded by School of Integrated Innovative Technology, grant number 2568-02-10-003, King Mongkut's Institute of Technology Ladkrabang, Thailand.

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