Inter-Layer Interference (ILI) Suppression in Dual-Layer Bit-Patterned Magnetic Recording Systems

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Dual-layer bit-patterned magnetic recording (DL-BPMR) systems are promising for achieving higher areal densities. However, they face significant challenges, including inter-symbol interference (ISI), inter-track interference (ITI), and inter-layer interference (ILI). To address these issues, this work proposes integrating a sum-soft-information (SSI) technique and an ITI suppression method to enhance detection reliability. The SSI technique is initially used to improve the reliability of the log-likelihood ratio for the bottom layer signal by leveraging the mutual information derived from a staggered array reader configuration. The enhanced data sequence from the bottom layer is subsequently utilized to suppress ILI by applying a weighting before it is subtracted from the top layer readback signals. Simulation results demonstrate that the proposed method significantly improves bit error rate (BER) performance compared to conventional single-layer and dual-layer BPMR systems, particularly at a user density of 4.0 Tb/in^2, making it a promising approach for next-generation high-density magnetic recording.

Index Terms—**Dual-layer bit-patterned magnetic recording, Sum soft-information, Interlayer interference suppression**

I. Introduction

To achieve ultra-high areal density (AD) in bit-patterned magnetic recording (BPMR), reducing bit island and track spacing is necessary, but this leads to increased inter-symbol interference (ISI) and inter-track interference (ITI), which degrades detection performance. To overcome these limitations, dual-layer BPMR (DL-BPMR) has been introduced by stacking two magnetic layers on a single platter, potentially doubling the AD up to 10 Tb/in^2 [1-2]. Each layer independently stores data using arrays of magnetic islands, enabling three-dimensional data recording. However, simultaneous reading of both layers introduces a new challenge—inter-layer interference (ILI)—caused by magnetic field interactions between the layers. While advanced detection techniques like one-dimensional (1D) and two-dimensional (2D) partial response maximum likelihood (PRML) [3-4] have been used to mitigate ISI and ITI, they are insufficient to suppress ILI, especially at higher densities.

To address this issue, this study proposes a sum-soft-information (SSI) technique to enhance the reliability of the bottom layer data by aggregating log-likelihood ratios (LLRs) information from adjacent tracks through an optimized array reader configuration. This setup not only improves the effectiveness of the bottom layer detection but also reduces ITI and ILI in the upper layers by positioning the read heads closer together to increase the relationship of the mutual information, as illustrated in Fig. 1. Once the bottom layer data is refined using the SSI method, it is then fedback to subtract interference from the top layer readback signals, thereby improving the overall system performance.

Simulation results demonstrate that the proposed approach significantly outperforms both conventional single-layer BPMR (SL-BPMR) and standard DL-BPMR systems, particularly at a user density of 4.0 Tb/in^2 (2.0 Tb/in^2 per layer), confirming its effectiveness for high-density magnetic recording.

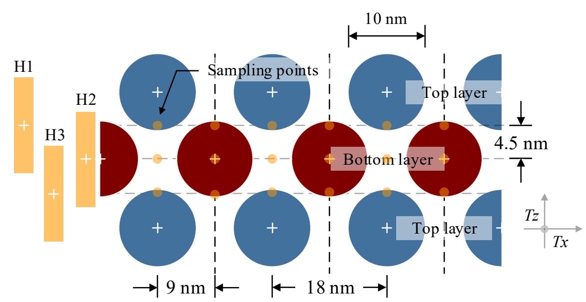

Fig. 1. Illustration of the bit-island arrangement in both top and bottom layers, sampling points, and the array reader's placement.

II. Proposed Systems

This study presents a DL-BPMR system where bit islands are arranged in a regular grid across two layers, with the top layer islands staggered relative to the bottom layer, achieving a total areal density of 4.0 Tb/in^2, as illustrated in Fig. 1. Consider the DL-BPMR channel model in Fig. 2, binary input data sequences, $a_{m,k}$ of the m-th track and the k-th bit, $m \in \{1,2,3\}$, are recorded onto media where the odd and even data sequences are recorded onto the top and bottom layers, respectively. An array of three read-heads consisting of H1, H2, and H3 are used to retrieve all three data tracks simultaneously. The middle head is positioned at the track center of the bottom layer. At the same time, the centers of the adjacent heads are placed between the bottom and top layer tracks to reduce ITI and ILI effects and enhance mutual information correlation of the bottom layer.

Three readback signals are immediately retrieved and oversampled at a sampling period $T_x/2$, as shown in Fig. 1, where T_x is the bit pitch. Path-A, the discrete-time data sequences, $r_{1,k}$, $r_{2,k}$, and $r_{3,k}$ are first sent through the 1D equalizers and 1D soft-output Viterbi algorithm (SOVA) detectors to generate soft-output LLRs of the first to the third tracks, $\lambda_{1,k}$, $\lambda_{2,k}$, and $\lambda_{3,k}$, respectively.

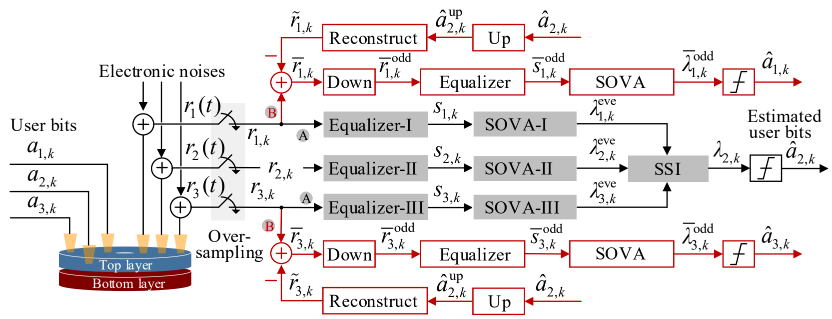

Fig. 2. The proposed dual-layer BPMR channel model incorporates the SSI technique and the reproduced readback signal.

However, only the LLRs in the even position of all three SOVAs, i.e., $\lambda_{1,k}^{\text{eve}}$, $\lambda_{2,k}^{\text{eve}}$, and $\lambda_{3,k}^{\text{eve}}$, which are the mutual information of the bottom layer, are sent to SSI to estimate the highest LLR reliability of the bottom layer using the following equation:

$$\lambda_{2,k} = \lambda_{1,k}^{\text{eve}} + \lambda_{2,k}^{\text{eve}} + \lambda_{3,k}^{\text{eve}}. \quad (1)$$

This LLR is then passed to the threshold detector to produce the estimated user bits of the bottom layer, $\hat{a}_{2,k}$. Note that even if all three SOVAs can generate all possible LLRs in odd and even positions, information from the odd positions will be disregarded. After obtaining the estimated user bits of the bottom layer, consider Path-B; the estimated user sequence will be inserted with zeroes at the odd position to have the upsample sequence, $\hat{a}_{2,k}^{\text{up}}$. The reconstructed data sequences of the first and the third tracks can be generated from the following equations:

$$\tilde{r}_{1,k} = \mathbf{h}_1 * \hat{a}_{2,k}^{\text{up}} \text{ and } \tilde{r}_{3,k} = \mathbf{h}_3 * \hat{a}_{2,k}^{\text{up}}, \quad (2)$$

respectively, where $\mathbf{h}_1$ and $\mathbf{h}_3$ are the channel coefficients related to the positions of the first and the third read heads. These two reconstructed data sequences are then subtracted from the mixed data sequence through the following equations:

$$\overline{r}_{1,k} = r_{1,k} - \alpha\tilde{r}_{2,k} \text{ and } \overline{r}_{3,k} = r_{3,k} - \alpha\tilde{r}_{2,k}, \quad (3)$$

where α is a weighting factor. These sequences are then downsampled again by deleting the data samples at the even positions. This gives us the estimated raw data sequences of the top layer, i.e., $\overline{r}_{1,k}^{\text{odd}}$ and $\overline{r}_{3,k}^{\text{odd}}$. Finally, the predesigned 1D PRML detectors can be applied to process the top layer's estimated raw data sequences for better BER performance.

III. Simulation Results

Fig. 3 illustrates the BER performance of the various recording systems as a function of SNR at a total areal density of 4.0 Tb/in^2. Here, SL-1D PRML represents the single layer media operated under conventional 1D PRML. DL-top/bot-H1-3 represents the dual media layer where the top and bottom layers are read using H1 to H3, respectively. This system operates similarly to our proposed system but has no SSI or ILI suppression techniques. DL-bot-H2-SSI is the system that uses only the SSI technique to improve the performance of the bottom layer. DL-top-H1-3-ILI-sup represents our proposed system in adopting SSI and ILI suppression techniques. As shown in Fig. 3, the single layer system did not perform well due to the severity of ITI and ISI at high areal density. The conventional DL-BPMR can provide better BER than a single-layer system. Both top layer tracks also yield better BER than the middle track, which is the bottom layer. This is not surprising: since the bottom layer is farther from the read head we obtained a poor readback signal. However, we can improve the BER by utilizing the SSI technique, which can reduce the BER by an order of magnitude at higher SNR. Moreover, at BER=10^{-4}, the BER performance of the top layer can be improved by more than 1.5 dB over the system without the proposed ILI suppression technique. These results reveal that our proposed system is well-suited for high-density magnetic recording.

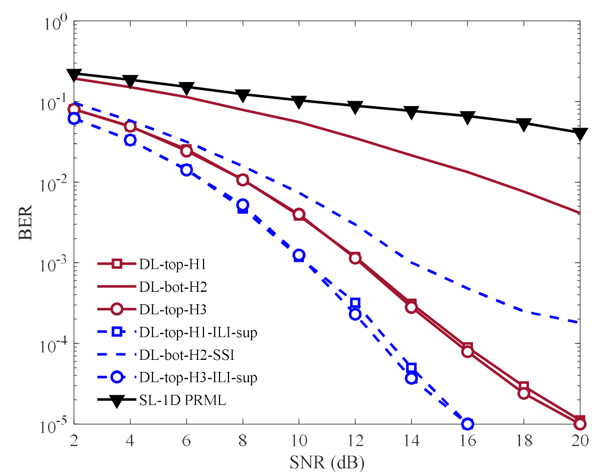

Fig. 3. Comparison of BER performance of SL- and DL-BPMR systems.

Acknowledgments

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