Interference Mitigation via Top-Layer-Assisted Signal Rescaling in Dual-Layer 3D Magnetic Recording

Ke Luo[1,3], Ziqian Liu[2,3], Yuqian Zhao[2,3], Yugen Jian[1,3], Simon Greaves[4*], Jincai Chen[1,3*], and Ping Lu[2,3]
[1]Wuhan National Laboratory for Optoelectronics, Huazhong University of Science & Technology, 430074, China
[2]School of Computer Science & Technology, Huazhong University of Science and Technology, 430074, China
[3]Key Laboratory of Information Storage System, Engineering Research Center of Data Storage Systems & Technology, Ministry of Education of China, Huazhong University of Science & Technology, 430074, China
[4] Research Institute of Electrical Communication (RIEC), Tohoku University, Sendai 980-8577, Japan
Corresponding author: Simon Greaves (simon@riec.tohoku.ac.jp), Jincai Chen (jcchen@hust.edu.cn).

ThreeDimensional magnetic recording (3DMR) technologies, such as threeDimensional heat-assisted magnetic recording (3D HAMR) and threeDimensional bit-patterned magnetic recording (3D BPMR), enhance areal density by stacking multiple recording layers and leveraging heat-assisted writing to encode multi-bit data through vertically combined magnetization states. Current 3DMR systems primarily employ dual-layer media (also termed dual-layer magnetic recording), where the readback signal from a single head comprises superimposed responses from a top layer and a bottom layer, introducing severe threeDimensional interference—including inter-symbol interference (ISI), inter-track interference (ITI), and inter-layer interference (ILI). To improve bottom-layer detection reliability in 3DMR, this paper proposes a scaling-based signal extraction method that refines the bottom-layer signal using detected top-layer data. This approach enables efficient oneDimensional detection while significantly reducing the bottom-layer bit error rate (BER). Compared to the previously proposed dual-layer PRML detection, the method maintains the same top-layer BER while achieving a 80% reduction in the bottom-layer BER under the areal density of 3.3 Tbpsi. Moreover, it demonstrates superior bottom-layer detection performance across areal densities ranging from 1 to 4.5 Tbpsi per layer (2–9 Tbpsi for dual-layer systems).

***Index Terms*—3D magnetic recording, inter-layer interference, signal extraction, bottom-layer detection**

I. Introduction

THE growing demand for storage capacity has driven magnetic recording from conventional 2D systems toward threeDimensional architectures. Notably, threeDimensional heat-assisted magnetic recording (3D HAMR) and 3D bit-patterned magnetic recording (3D BPMR) stack multiple layers and encode data using vertically combined magnetization states, enabling higher areal densities (ADs). Dual-layer magnetic recording (DLMR) is currently the most practical implementation of 3DMR. However, transitioning to 3D recording introduces challenges in signal acquisition and detection. One major issue is weak far-field sensitivity: the increased head-media spacing (HMS) causes bottom-layer signal to be overshadowed by top-layer signal. Although tunneling magnetoresistive (TMR) heads are used, signal attenuation remains significant. Another challenge is severe 3D interference, including inter-symbol (ISI), inter-track (ITI), and inter-layer interference (ILI).

To mitigate these issues, prior works have explored layer-selective sensing using spin-torque oscillators (STOs) [1], Curie-temperature-tuned dual-layer media from Seagate, and asymmetric bit geometries to improve state distinguishability [2]. Iterative detection algorithms, such as Turbo equalization for dual-layer BPMR [3], have also been proposed.

Our previous study modeled dual-layer 3DMR under inter-layer misalignment and showed that neural network-based reconstruction improves bottom-layer detection, though at a high computational cost. Since bottom-layer signals are more affected by interference, low-cost and effective detection methods are needed. Existing strategies fall into two categories:

- Mutual layer-assisted detection (exploiting inter-layer correlations),
- Layer-separated detection (processing each layer independently).

In this paper, we propose a scaling method that enhances the bottom-layer signal using detected top-layer data, enabling independent 1D detection. Compared to traditional dual-layer partial response maximum likelihood (PRML), the proposed method maintains top-layer BER while reducing bottom-layer BER across 1–4.5 Tbpsi per layer (2–9 Tbpsi total).

II. Experimental Setup

In this study, we adopt the same experimental parameters and reader structure as described in [4]. The bit length (BL) and track pitch (TP) are identically configured for both layers, with values ranging from 12 nm to 25 nm. This configuration ensures consistent linear and track densities across experiments. We focus on the detection performance of the bottom layer, assuming perfect interlayer alignment.

III. Double-Layer Data Detection

We employ the previously proposed dual-layer PRML detection as our benchmark, which jointly detects data from both recording layers in a 3D magnetic recording system. It utilizes a 2D finite impulse response (FIR) equalizer to mitigate ISI and ITI, followed by a Viterbi detector that operates on a combined target response. To account for the varying signal sensitivities between layers, weighted contributions from the top and bottom layers are incorporated during maximum likelihood sequence detection.

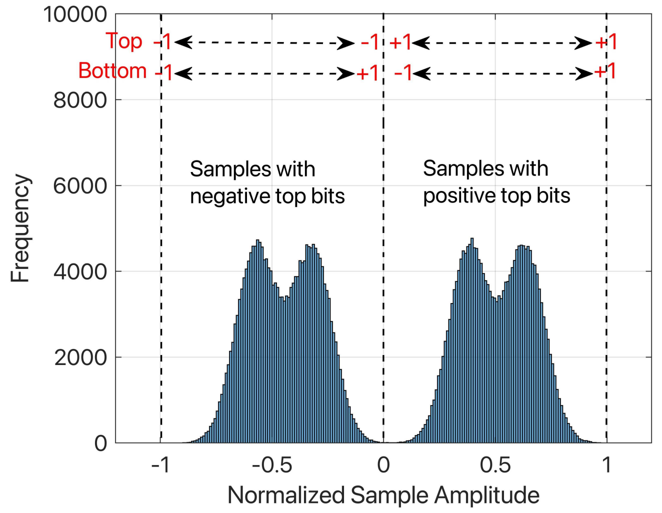

Fig. 1. Amplitude distribution of readback samples (BL=18 nm and SNR=16 dB).

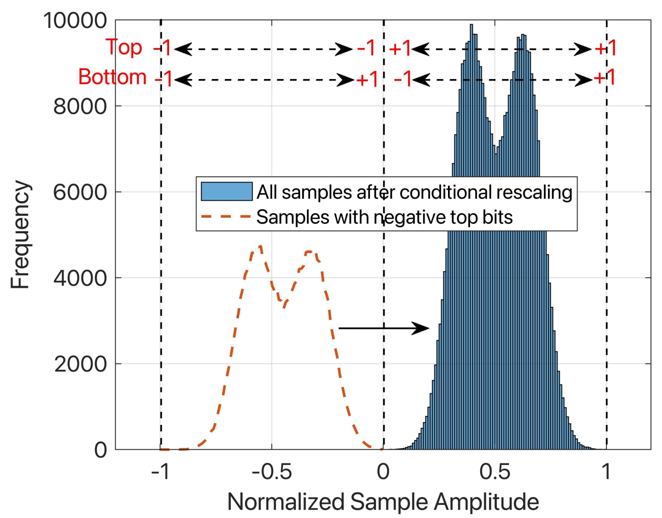

Fig. 2. The amplitude distribution of readback samples (BL=18 nm and SNR=16 dB): rescaled samples with negative top bits and original samples with positive top bits.

To enhance the reliability of bottom-layer detection, we propose independent layer processing. As illustrated in Fig. 1, the dual-layer readback signal exhibits an approximately symmetric amplitude distribution. The well-separated distributions on both sides indicate minimal interference on the top layer. In this figure, samples with negative-polarity top-layer bits "-1" predominantly occupy the left region, while samples with positive-polarity top-layer bits "$+1$" are located on the right. However, the bimodal distribution on each side overlaps between the two peaks, resulting in significant interference on the bottom layer. We apply 2D FIR equalization and 1D detection, followed by conditional amplitude rescaling. In this process, we transform samples with negative top bits into the normalized range of $[0, 1]$, while preserving the original amplitudes of samples with positive top bits. The resulting composite distribution, illustrated in Fig. 2, combines the rescaled negative-top samples with the unprocessed positive-top ones. Another 2D FIR equalizer and detector are then

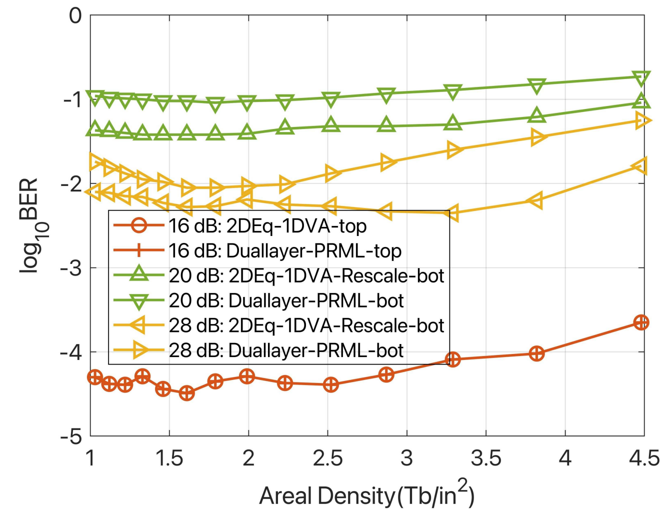

Fig. 3. BER performance comparison: proposed conditional rescaling, 1D PRML vs. dual-layer PRML across 1–4.5 Tbpsi/layer areal densities.

applied to the composite samples. The coefficients of the 2D equalizers and the partial response targets $[\alpha, 1, \beta]$ are obtained using the minimum mean square error algorithm. We utilize these targets to construct a trellis for double-layer detection. The orange dashed curve represents the distribution of samples with negative top bits. After conditional rescaling, the distribution of all samples becomes sharper. The rescaling process can be viewed as a cancellation of the top-layer component.

We evaluate the BER performance as a function of ADs ranging from 1–4.5 Tbpsi/layer that corresponds to bit lengths between 12 nm and 25 nm, as shown in Fig. 3. For top-layer detection, a 1D Viterbi detector achieves the same BER performance as dual-layer PRML detection at a SNR of 16 dB. The BER performance on the top layer, despite the low SNR of 16 dB, is superior to that on the bottom layer under higher SNRs across all ADs. Although the BER increases with higher ADs, the bottom-layer BER, after rescaling the samples with negative bits, demonstrates improved performance compared to dual-layer PRML detection. Specifically, the bottom-layer BER after conditional rescaling at an AD of 3.3 Tbpsi/layer is reduced by 80 % compared with the performance of dual-layer PRML detection.

References

[1] H. Suto, T. Nagasawa, K. Kudo, K. Mizushima, and R. Sato, "Nanoscale layer-selective readout of magnetization direction from a magnetic multilayer using a spin-torque oscillator," *Nanotechnology*, vol. 25, no. 24, p. 245501, May 2014.

[2] P. Tozman, S. Isogami, I. Suzuki, A. Bolyachkin, H. Sepehri-Amin, S. Greaves, H. Suto, Y. Sasaki, T. Chang, Y. Kubota, P. Steiner, P. Huang, K. Hono, and Y. Takahashi, "Dual-layer fept-c granular media for multi-level heat-assisted magnetic recording," *Acta Materialia*, vol. 271, p. 119869, Jun. 2024.

[3] A. Khametong, S. J. Greaves, and C. Warisarn, "Mutual soft-information improvement techniques for lower layer performance improvement in double-layered magnetic recording systems," *IEEE Transactions on Magnetics*, pp. 1–1, 2025.

[4] K. Luo, Y. Liao, K. Zhang, Y. Jian, S. Wang, J. Chen, and P. Lu, "On the impact of interlayer misalignment for dual-layer data detection in three dimensional magnetic recording," *Journal of Magnetism and Magnetic Materials*, vol. 610, p. 172522, Nov. 2024.