Efficient Multidimensional Signal Processing Scheme for Heated-Dot Magnetic Recording with Triple-Layered Bit Patterned Media

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This research explores a new method of multidimensional signal processing which is applicable to a heated-dot magnetic recording (HDMR) system using triple-layered bit-patterned media (BPM). For each data sequence recorded on a single track of respective layers, the proposed signal processing scheme detects each data sequence in the order of upper layer, middle layer, and lower layer. Our proposed method further expands the existing method which is applied to the signal pressing scheme using double-layered BPM. This new method is expected to be applied to a HDMR system with an effective recording density of up to 7.5 Tdpsi. The proposed HDMR system with triple-layered BPM uses two types of multiple symbol detectors and a single one-dimensional (1D) symbol detector. The effective transmission rate of the proposed HDMR system is capable of increasing three times that of the HDMR system with single-layered BPM. It is evaluated that the error rate performance of the proposed HDMR system gives a significant improvement over the conventional HDMR system with single-layered or double-layered BPM by computer simulation.

***Index Terms*—heated-dot magnetic recording, multi-layered recording, triple-layered bit-patterned media, two-dimensional generalized partial response equalization**

I. Introduction

The recently emerging combined technologies for high areal density digital magnetic recording have been introduced to attain an effective recording density of 5 Tdpsi [1]. These technologies consist of the following three elemental technologies: heated-dot magnetic recording (HDMR), double-layered magnetic recording, and multi-track recording. As a result, this combinational method using above three elemental technologies is useful for increasing the effective transmission rate of the HDMR system with double-layered bit-patterned media (BPM). However, considering the signal-to-noise ratio (SNR) of the reproducing signals generated from the recorded data in both top and bottom layers, the SNR of the reproducing signals generated from the bottom layer significantly deteriorates compared to that of the reproducing signals generated from the top layer. In other words, increasing the effective transmission rate leads to suppressing deterioration of signal quality regarding transmission using a plurality of magnetic recording media. Based on this combinational method, we propose *the two-stage signal processing scheme* as an effective signal processing technique [1], [2]. This two-stage signal processing scheme is provided with two serially connected one-dimensional (1D) multi-level log-likelihood ratio (LLR) detectors for two-track recording and detects the data sequences recorded on both top and bottom layers in turn. In this digest, we will expand the existing two-stage signal processing approach mentioned above and propose a new three-stage signal processing scheme for the HDMR system with triple-layered BPM. This HDMR system is capable of achieving an effective recording density of 7.5 Tbpsi. This proposed scheme is constituted of three-stages of 1D LLR detectors for single-track recording in cascade connection. Every recorded data sequence in each layer is detected at each stage in the order of upper layer, middle layer, and lower layer. After completing three-stage detection, the total error rate performance is evaluated.

II. Proposed HDMR System

Fig. 1 shows the block diagram of the proposed HDMR system with triple-layered BPM and the three-stage signal processing scheme. We assume the head/medium conditions and modeling with FePt granular magnetic media to achieve an areal density of 2.5 Tdpsi for each layer using micro-magnetic simulation. A raw data sequence $\{a_k\}$ is input to each encoder which generates run length limited (RLL) constraint sequences with no error correction coding $\{b^u_{i,k'}\}$, $\{b^m_{i,k'}\}$, and $\{b^\ell_{i,k'}\}$ for the down-track direction in the upper, middle, and lower layers, respectively. The notations of u, m, ℓ correspond to the upper, middle, and lower layers, respectively.. The notation of i represents the track number for the cross-track direction while k and k' represent the symbol numbers for the down-track direction. The sequences $\{b^u_{i,k'}\}$, $\{b^m_{i,k'}\}$, and $\{b^\ell_{i,k'}\}$ are transformed into the precoded sequences $\{c^u_{i,k'}\}$, $\{c^m_{i,k'}\}$, and $\{c^\ell_{i,k'}\}$, respectively.

For the readback channel, the readback signal of BPM is represented by the evaluated two-dimensional (2D) pulse response obtained by the defined BPM model. The readback signal waveform $\{r_{i,k'}\}$ is given by as follows. $r_{i,k'} = r^u_{i,k'} + r^m_{i,k'} + r^\ell_{i,k'} + n_{i,k'}$, where the noise sequence $\{n_{i,k'}\}$ is added at the reading point and $n_{i,k'}$ is additive white Gaussian noise (AWGN) with zero mean and variance σ_n. The reproducing waveforms corresponding to the recording sequences readback by the reading head are input into the equalizer which consists of a 2D low-pass filter (LPF) and the 2D transversal filter (TVF). Equalization is performed so that the overall characteristic between the input of the recording head and the output of each equalizer is equal to the aimed 2D generalized partial response (GPR) targets $\boldsymbol{g}_t$. The equalizer output sequence $\{y^j_{k'}\}$ is obtained which sums equalizer output sequences from trios of upper, mididle, and lower dots. Tap-gain coefficients in the 2D TVF are evaluated by minimizing the expectation of the mean square error $E(\{e^j_{i,k'}\})$, where

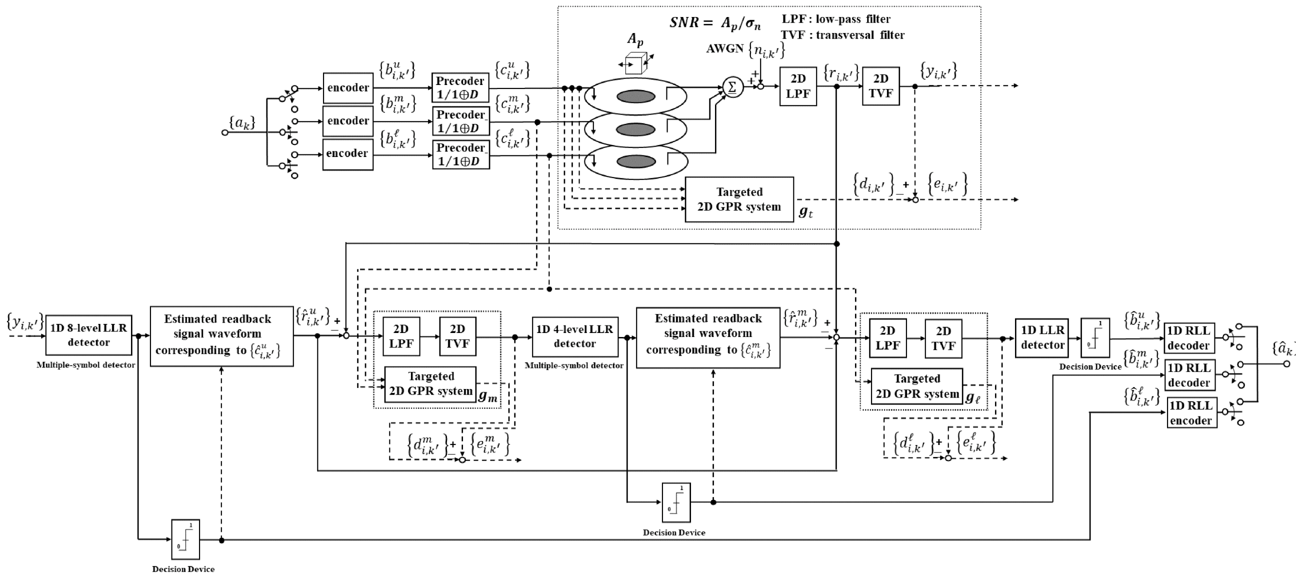

Fig. 1. The block diagram of the proposed HDMR system with triple-layered BPM.

the sequence $\{e^j_{i,k'}\}$ is the equalized error sequence between the ideal GPR target output sequence $\{d^j_{i,k'}\}$ and the sequence $\{y^j_{i,k'}\}$. The SNR at the reading point is defined as the ratio of the normalized peak amplitude A_p and the noise power of AWGN.

In the decoding process, the sequence $\{y^j_{i,k'}\}$ is detected by respective 1D LLR detectors during the decoding process of each stage. The estimated sequence $\{\hat{c}^u_{i,k'}\}$ is given as the first detector outputs. From the sequence $\{\hat{c}^u_{i,k'}\}$, we generate the replicated readback signal waveform $\{\hat{r}^u_{i,k'}\}$ corresponding to the sequence $\{\hat{c}^u_{i,k'}\}$. Using this first replicated waveform $\{\hat{r}^u_{i,k'}\}$, we can obtain the second replicated waveform $\{\hat{r}^m_{i,k'}\}$ as the difference waveform between the waveforms $\{r_{i,k'}\}$ and $\{\hat{r}^u_{i,k'}\}$. The replicated waveform $\{\hat{r}^m_{i,k'}\}$ is input into 2D TVF and equalized to generate the aimed 2D GPR re-equalized sequence and the second 1D LLR detector gives the estimated sequence $\{\hat{b}^m_{i,k'}\}$ from this re-equalized sequence. Moreover, using the second replicated waveform $\{\hat{r}^m_{i,k'}\}$, we can obtain the third replicated waveform $\{\hat{r}^\ell_{i,k'}\}$ as the difference waveform between the waveform $\{r_{i,k'}\}$ and the synthetic waveform created by combining two replicated waveforms $\{\hat{r}^u_{i,k'}\}$, $\{\hat{r}^m_{i,k'}\}$. The sequences $\{\hat{b}^u_{i,k'}\}$, $\{\hat{b}^m_{i,k'}\}$, and $\{\hat{b}^\ell_{i,k'}\}$ are decoded by respective RLL decoders. After demodulation, we get the estimated input sequence $\{\hat{a}_k\}$. The bit error rate (BER) performance is evaluated by computer simulation between the sequences $\{a_k\}$ and $\{\hat{a}_k\}$.

III. Error Rate Performance Evaluations

Fig. 2 shows the BER performances for several three-stage schemes for HDMR systems. These signal processing schemes use the same 64/65 (0,8) RLL coding scheme. In Fig. 2, the symbol of ◯ shows the BER performance of the proposed three-stage signal processing scheme with the triple-layered BPM. This three-stage signal processing scheme has three different 1D LLR detectors to detect recording sequences recorded in the upper, middle, and lower layers.

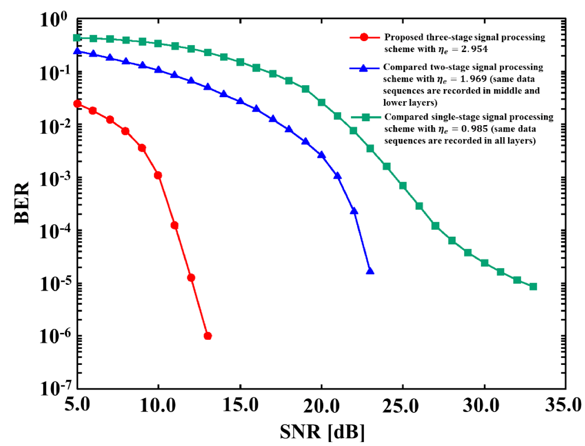

Fig. 2. BER performances of several three-stage signal processing schemes.

The proposed three-stage signal processing scheme has *the effective transmission rate* η_e = 2.954. The symbols of △ and □ show the BER performances of the compared two-stage and single-stage signal processing scheme with triple-layered BPM, respectively. These two compared schemes have the rate η_e = 1.969 and 0.985. Compared to these schemes, it is found that increasing the rate η_e leads to remarkably improve the error rate performance of the HDMR system.

IV. Conclusion

In this research, we propose a three-stage signal processing scheme for a HDMR system with triple-layered BPM. The simulation result shows that our proposed signal processing scheme is useful for improving the error rate performance of the HDMR system with triple-layered BPM.

References

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[2] H. Saito and F. Akagi, *IEEE Trans. Magn.*, vol. 61, no. 4, 3100210, Apr. 2025.