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Reducing the Thermal Asperity Effect in Perpendicular Magnetic Recording System

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Abstract. In this paper, we propose a new method to estimate and reduce effectively thermal asperity (TA) in the perpendicular recording channels with state trellis. The proposed method comprises of recursively applying a previous noise estimate to a calculation of a current noise estimate to eliminate the effects of TA from the equalized signal. With partial response a maximum-likelihood detector base on partial-response (PR) target with DC-full component can improve the system performance by more than 50% when TA occurs. Unlike previous studies of TA cancellation or suppression, this method is different because we don't use PR targets with non-dc components and high pass filter.

Introduction

For perpendicular magnetic recording (PMR), an important source of distortion is thermal asperity (TA) [1]. This phenomenon occurs when the magneto resistive (MR) head on the slider comes into contact, or very close to the media, resulting to the resistance of the MR element to frictional heat source. This heat is produce causing a sharp increase and decay in signal amplitude. If it is not detected and corrected appropriately, the system performance will undoubtedly be degraded.

In previous works, perpendicular magnetic recording with a dc-full component was considered the best choice for a PMR system with the absence of disturbances other than an additive white Gaussian noise AWGN [2]. A common method to reduce the effects of TA is to implement a high-pass filter (HPF) in the system and adjust its cutoff frequency according to [3]. Dorfman and Wolf propose a method for TA suppression with the technique of using the extended partial-response class-4 (EPR4) target [4]. However, this improvement in TA operations reduces the overall performance of the system. Hioaki Ueno proposed a method to reduce error deterioration when the TA occurs by changing the characteristics of a partial response target from the PR target having a dc component to the PR target not having a dc component [5]. In [6], Mathew and Tjhia proposed a simple TA estimation method from window average, in which the TA cancellation in the read-back signal can be done by a straightforward subtraction.

In this paper, we propose a new method to estimate and reduce TA effects through the state trellis on PR target with DC-full component. The Partial Response Maximum Likelihood (PRML) detector performance can be improved more than 50% in the perpendicular magnetic recording system with TA.

Thermal Asperity Estimation and Cancellation

Perpendicular magnetic recording channel using a double-layer medium is basically a full response channel with a DC response [7]. The common PR target with DC component includes partial-response class-1 (PR1) and partial-response class-2 (PR2) targets. Here, we propose a TA estimation and cancellation method through the trellis of the PR targets. The idea is to estimate the TA signal from the PR equalized signal and then subtract the TA before feeding it to the Viterbi detector. The schematic diagram illustrating the TA estimation and cancellation in the PMR channels is shown in Fig. 1.

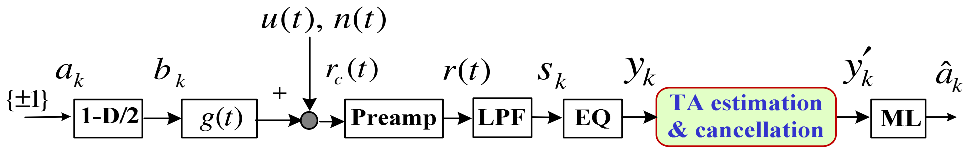

Figure 1. The magnetic recording channel model used in the simulation.

The TA modeled by S. Stupp et al. is used and can be expressed as [8]

$$u(t) = \begin{cases} A_0\left(\dfrac{t}{T_r}\right), & 0 \le t \le T_r \\ A_0 \exp\left(-\dfrac{t-T_r}{T_d}\right), & T_r \prec t \le T_f \end{cases}, \tag{1}$$

where $u(t)$ is the TA signal, A_0 is the peak TA amplitude, T_r is the rise time, T_d is the decay constant and T_f is the TA duration. A decay time equals to four times the decay constant is enough since it will reduce the magnitude of the TA signal to only 1.8% of its peak amplitude. Thus we choose the TA duration as $T_f = T_r + 4T_d$ and can see in Fig. 2.

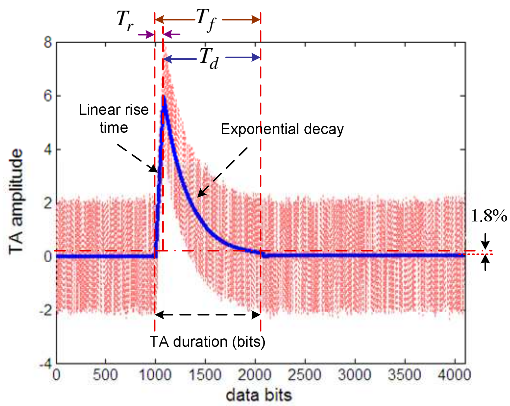

Figure 2. The simplified model and read-back signal with TA from TA model.

The schematic diagram illustrating a model of the new method to estimate and effectively reduce thermal asperity in the PMR channels with a state trellis is shown in Fig. 3.

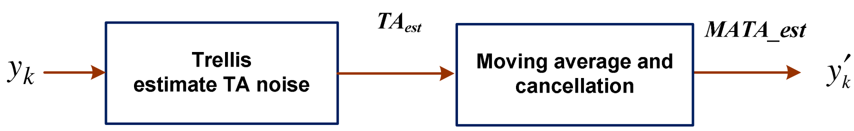

Figure 3. Proposed methods for thermal asperity estimation and cancellation.

Fig. 3, shows the block diagram of the new method to estimate and effectively reduce thermal asperity in the PMR channels. This consists of two blocks. In the first block, the trellis is used to obtain the estimate of TA noise, TA_{est}, and the other is the moving average to smooth the TA noise estimate. Then, we subtract the results from the equalized signal. The block will be explained in details in the following subsections.

1. Trellis estimate TA noise. We can divide the tasks into two parts.

(a) TA detection

The TA detection here is used to determine the start and stop positions in the PR equalized signal sequence. The TA is found from comparing the amplitude of the PR equalized signal with the threshold. Here, the threshold Γ (Gamma) is set as $\Gamma = \lambda_{\max} + \delta$, where $\lambda_{\max}$ is the maximum value of the noiseless channel output from PR targets and δ is an incremental value obtained from the simulation to ensure the accurate start-stop position of the TA.

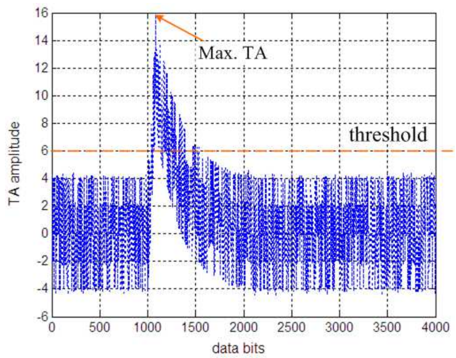

Figure 4. The Equalized signal with TA and threshold mark for TA detection of PR2 target at ND = 1.5, SNR = 25 dB, $A_0 = 3$, T_d = 250 bits and T_f = 1080 bits.

(b) TA Estimation

Once the TA start and stop positions are known, the TA estimator will provide the noise and TA estimates. The estimation is processed through the trellis of the PR target for all samples. For the TA affected samples, the TA part is estimated by compute the minimum distance to select the best path from

$$\hat{\lambda}_k = \min_{j \in \{-1,1\}} |\tilde{y}_k - \lambda_k| , \quad (2)$$

where $\tilde{y}_k$ is computed from

$$\tilde{y}_k = y_k - |TA_{est,k-1}| \quad (3)$$

Otherwise, only the noise part is estimate through the state trellis of the PR target. For the samples without TA, once the best path is selected, the corresponding noiseless PR channel output $\hat{\lambda}_k$ on the branch is used to estimate the TA (or noise) level at time k by subtracting from the equalized signal, i.e.,

$$TA_{est,k} = y_k - \hat{\lambda}_k \quad (4)$$

2. Moving average and cancellation block

After the TA (noise) estimations are completed, we obtain the moving average of the TA (noise) estimates and then subtract the result from the equalized signal y_k and the adjusted PR equalized signal y' is

$$y'_k = y_k - \left|MATA_{est,k}\right|, \tag{5}$$

where $\phi = \frac{(n-1)}{2}$ and n (an odd integer) is the window length. This signal is then used as input to the Viterbi detector.

Simulation Results and Discussion

In this section, we present the simulation results for the proposed method in the PMR channels with the thermal asperity and investigate the BER performance of the PRML system. In the simulation, we consider the dc-full targets at ND = 1.5 to compare the performance improvement based on each sector with 4096 information bits.

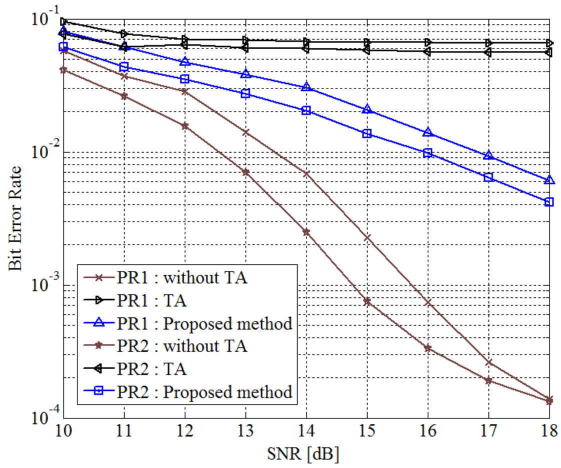

Figure 5. The BER performance between PR1ML and PR2ML detector in the perpendicular magnetic recording system with TA and without TA.

In Fig. 5, shows the BER given TA versus SNR curves to compare between PR1ML and PR2ML detector for the case signal with TA effect and without TA. We can see that the propose method for both target have gain more than 50% with TA effect in the system. And the PR2ML detector achieves than PR1ML about 1.2 dB at BER ≈ 3×10^{-3}. In addition, we present the simulation results to compare between the proposed method and the method proposed by Mathew [6].

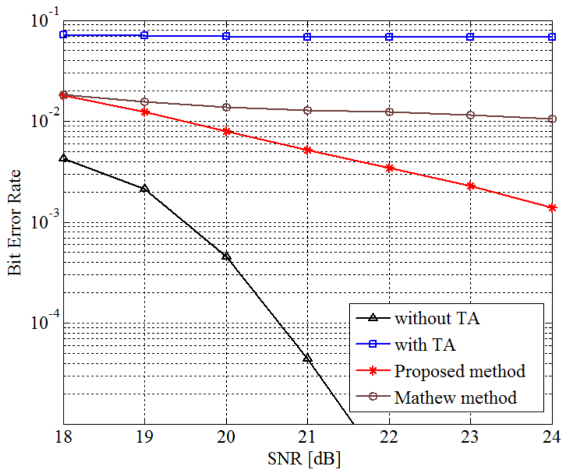

Figure 6. BER performance of the PR2ML systems with TA effects at ND = 1.5, A_0 = 3 and T_f = 1080 bits.

In Fig. 6, we compare the system performance improvement between the proposed method and the method proposed by Mathew [6] for the PR2ML system with ND = 1.5, A_0 = 3 and T_f = 1080 bits. At SNR = 24 dB, we can observe that the proposed method provides more than an order of magnitude improvement in BER compared with the Mathew method. Nonetheless, it is still inferior to the case of the equalized signal without TA.

Summary

To summarize, the method proposed is a new solution to estimate the TA signal from an equalized signal by the trellis and eliminate to improving the performance in the perpendicular magnetic recording system in the environment of thermal asperity. We compare the BER performance of the PRML system. From the simulation results, the bit error rate performance of the proposed method achieves improved performance more than 50% when thermal asperity occurs. In additional, the proposed method provides more than an order of magnitude improvement in BER compared with the Mathew method. The approach outline in this method proposed should be replicated in other recordings.

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