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An Improved TA Suppression Method for Coded PR Channels

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Abstract. Thermal asperity (TA) resulting from the collision between the slider and the asperity on a magnetic medium during read process can deteriorate the performance of hard disk drives (HDDs). Without TA detection and correction algorithms, the system performance can be unacceptable, depending on how severe the TA is. This paper presents an improved TA suppression method for coded partial response (PR) channels, which consists of two channels running in parallel. Specifically, one channel is matched to the target $H(D)$, while the other is matched to the target $H(D)G(D)$, where $G(D) = 1 - D^2$ is a bandpass filter and D is a delay operator. The soft-output Viterbi algorithm (SOVA) detector in the $H(D)$ channel yields the high-quality soft information in absence of the TA, while that in the $G(D)H(D)$ channel produces the high-quality soft information in presence of the TA. Then, the overall soft information chosen from these two detectors, depending on if a TA is detected or not, is sent to the decoder according to turbo equalization principle. Experimental results show that the proposed method performs better than the conventional and the previously proposed ones, when operating at high signal-to-noise ratio (SNR) region where a practical HDD works.

Introduction

In practice, a magneto-resistive (MR) read head is used in current HDDs to sense a magnetic flux directly from the transitions of the magnetization pattern, resulting in an induced voltage pulse called a transition pulse. While reading the data bits on a magnetic medium, if the slider contacts with an asperity (or a surface roughness), both the slider surface and the asperity tip are heated. This causes an additive voltage transient known as *thermal asperity* (TA) [1] in the readback signal. Typically, a TA signal has a short rise time (50 – 160 ns) with a long decay time (1 – 5 μs), and its peak TA amplitude is 2 to 3 times the peak of the readback signal [2], [3]. In general, the TA can cause severe transient noise burst, loss of timing synchronization, or off-track perturbation, which leads to an error burst. This error burst could easily exceed the correction capability of the error-correction code, thus leading to a sector read failure. As the recording density keeps increasing and the flying height keeps decreasing, the TA effect becomes even more severe in HDDs. Hence, an efficient method to combat the TA effect is crucial.

Many works have been proposed to alleviate the TA effect. Because the TA causes a shift in the baseline of the readback signal, the average value of the normal readback signal is zero, whereas that of the TA-affected readback signal is not. Therefore, Klaassen and van Peppen [2] introduced the TA detection by looking at the baseline of the averaged readback signal, while the TA correction was performed by a high-pass filter. Dorfman and Wolf [3] presented a TA suppression method by feeding the TA-affected readback signal through a filter $(1 - D)$, where D is a delay operator, which performed well in longitudinal magnetic recording channel.

However, for a perpendicular magnetic recording (PMR) channel, which has a d.c. component, Erden and Kurtas [4] proposed a TA detection and correction method by use of different low-pass and high-pass filters, whereas Mathew and Tjhia [5] presented a simple threshold-based approach to detect and mitigate the TA effect.

Additionally, Kovintavewat and Koonkarnkhai [6] proposed a TA suppression method based on a least-squares fitting technique, and they also presented a joint TA suppression and turbo equalization method [7] on the partial-response (PR) channels with ECCs. Although the method in [7] performs

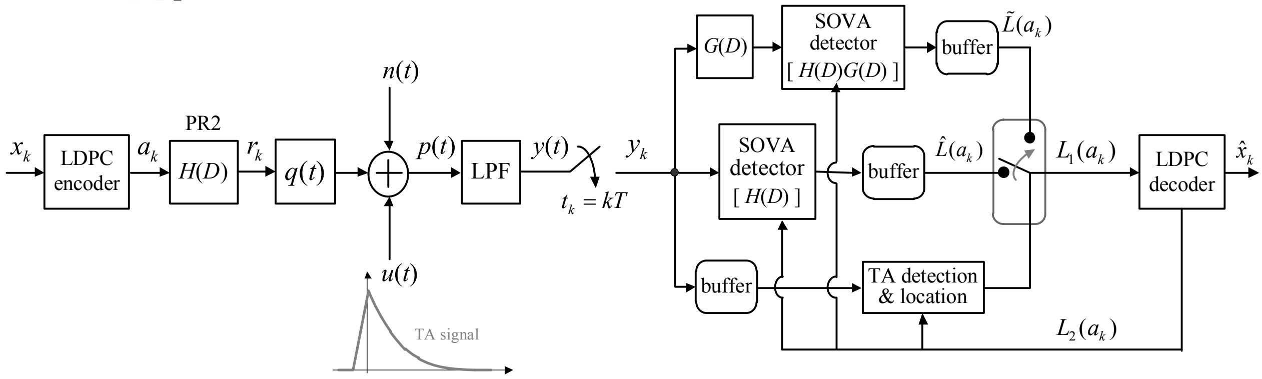

Fig. 1. A channel model with the proposed TA suppression method.

well, it has a high error floor, which is undesirable for a practical HDD. To improve its performance, this paper introduces an improved TA suppression method for coded PR channels, which can provide a low error floor and yield a large performance gain at high SNR scenario.

Channel Model

Consider a coded PR channel in Fig. 1, where $H(D) = \sum_k h_k D^k = 1 + 2D + D^2$ is a PR2 channel. An *i.i.d.* message sequence $x_k \in \{0, 1\}$ is encoded by a low-density parity-check (LDPC) encoder and is mapped to a binary sequence $a_k \in \{\pm 1\}$ with bit period T. The readback signal is then given by

$$p(t) = \sum_k r_k q(t - kT) + n(t) + u(t),$$

(1)

where $r_k = a_k * h_k \in \{0, \pm 2, \pm 4\}$ is the noiseless channel output, $*$ is the convolution operator, $q(t) = \sin(\pi t/T)/(\pi t/T)$ is an ideal zero-excess-bandwidth Nyquist pulse, $n(t)$ is an additive white Gaussian noise with a two-sided power spectral density $N_0/2$, and $u(t)$ is a TA signal. Here, we consider a widely used TA model described by Stupp *et al.* [1] because it fits the captured spin stand data and the drive data very well, which is given by

$$u(t) = \begin{cases} \beta(t/T_r)\sum_k |h_k|, & 0 \le t \le T_r \\ \beta \exp\left(-(t - T_r)/T_d\right)\sum_k |h_k|, & T_r < t \le T_f \end{cases},$$

(2)

where $\beta \geq 0$ is a peak factor, T_r is a rise time, and T_d is a decay constant. Moreover, we assume that the TA duration is $T_f = T_r + 4T_d$ [5–7]. In a conventional receiver, the signal $p(t)$ is filtered by the 7th-order Butterworth lowpass filter (LPF) and is sampled at a symbol rate of 500 Mbps [5], assuming perfect synchronization. Then, the sampler output, y_k, is fed to the TA detection and correction block based on a least-squares technique [6] followed by the turbo equalizer [7], which iteratively exchanges soft information between the SOVA detector [8] and the LDPC decoder, to obtain an estimate of x_k.

Proposed TA Suppression Method

The proposed TA suppression method has a similar structure presented in [3], which consists of two SOVA detectors working concurrently, one for the target $H(D)$, and the other for the target $G(D)\mathrm{H}(D)$ equipped with a bandpass filter $G(D) = 1 - D^2$ [9]. This bandpass filter is selected to eliminate the TA effect while capturing most energy of the readback signal, because the PMR channel has significant low-frequency content. In general, the SOVA detector in the $H(D)$ channel outputs the high-quality soft information in absence of the TA, while that in the $G(D)H(D)$ channel produces the high-quality soft information in presence of the TA. Consequently, the overall soft information is chosen from these two detectors, depending on if a TA is detected or not. Specifically, if a TA is

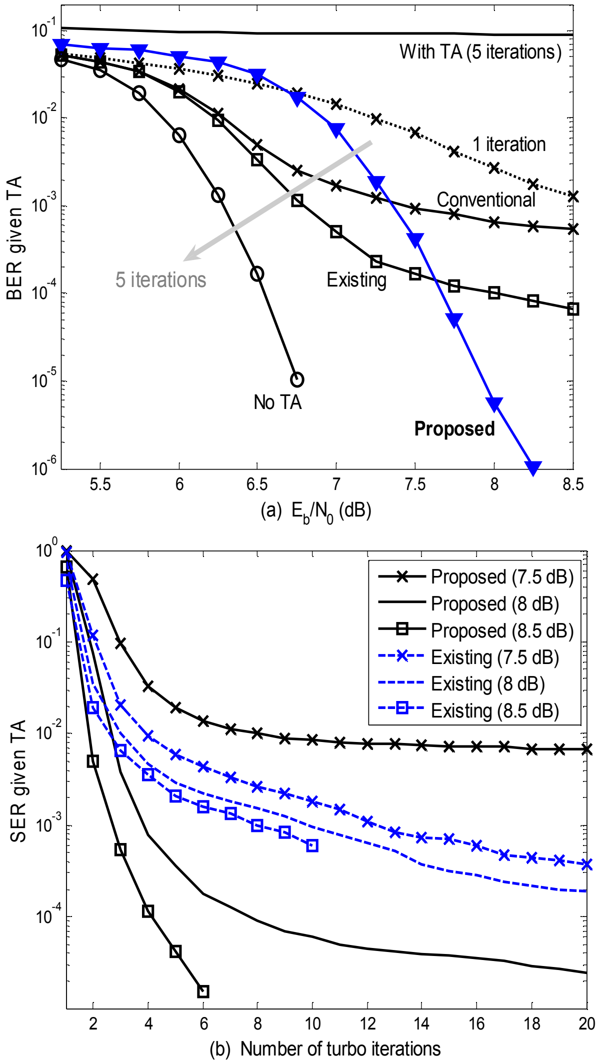

Fig. 2. (a) BER performance of different schemes, and (b) SER versus the number of iterations.

detected, we obtain $L_1(a_k) = \tilde{L}(a_k)$; otherwise, $L_1(a_k) = \hat{L}(a_k)$. Thus, the soft information $L_1(a_k)$ is fed to the LDPC [10] decoder. Finally, the LDPC decoder outputs the log-likelihood ratio (LLR) for the bit a_k, which will be sent back to these two SOVA detectors for the next turbo iteration.

To detect the TA location, at the 1st iteration, the readback signal y_k is fed to an LPF, whose transfer function is $F(D) = 1/(f_c + (1-f_c)D)$, where f_c is a cutoff frequency, followed by the threshold detector. Thus, a TA is detected if the LPF output is greater than or equal to a threshold value m. For the 2nd or higher iteration, we propose to use the LLR sequence $L_2(a_k)$ from the LDPC decoder to find the TA location. To do so, the $L_2(a_k)$ is mapped to the hard decision and is then convolved with the target $H(D)$ to obtain an estimated channel output $\tilde{r}_k$. Hence, the sequence $c_k = y_k - \tilde{r}_k$ will be used to find the TA location, instead of the sequence y_k used in the 1st iteration.

Simulation Results

Consider a channel model in Fig. 1, where the SNR is defined as E_b/N_0 = $10\log_{10}\left(\sum_k |h_k|^2 / N_0 R\right)$ in decibel (dB), where E_b is an energy per bit and R = 8/9 is a code rate. In simulation, every data sector is corrupted by one TA signal, which is occurred randomly at the location between the 100^{th} and 3000^{th} bit with $\beta = 2$, T_r = 60 ns, and T_d = 0.5 μs (i.e., a TA event $T_f = 1030T$). This TA event can be considered as a worst case. For TA detection, we use f_c = 100, and m = 1.2 and 0.45 for the 1^{st} and higher iteration, respectively. We compute the BER based on a minimum number of 10000 data sectors and 500 error bits, and call it as "BER given TA."

Fig. 2(a) shows the BER of different schemes at 5^{th} iteration, where the performance of the system without TA effect is referred to as "No TA." Without TA detection and correction, the system performance is unacceptable, denoted as "With TA." In addition, the performance of [6] is denoted as "Conventional", whereas that of [7] is referred to as "Existing." Unlike the proposed scheme, the "Existing" seems to have an error floor at BER ≈ 10^{-4}. Furthermore, the proposed method performs better than other methods when E_b/N_0 is greater than 7.65 dB. It should be pointed out that a practical HDD normally operates at high SNR (i.e., E_b/N_0 > 7.65 dB) to guarantee reliability. Fig. 2(b) compares the performance of different schemes in terms of sector-error rate (SER) versus the number of turbo iteration at 7.5, 8 and 8.5 dB. Apparently, the proposed scheme performs better and better, as the number of iteration goes. Again, the proposed scheme yields better performance than the "Existing" scheme when E_b/N_0 > 7.5 dB.

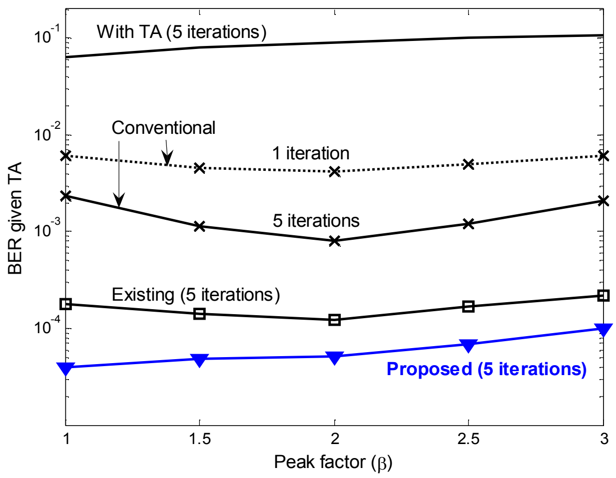

Fig. 3. BER performance with different peak factors.

We also compare the performance of different schemes as a function of peak TA amplitudes at E_b/N_0 = 7.75 dB in Fig. 3. It is evident that the proposed scheme performs better than the others for all peak TA amplitudes, and is also robust to large peak TA amplitudes.

Summary

The TA effect experienced in PMR channels can distort the readback signal to the extent of causing a sector read failure. This paper proposes an improved TA detection and correction method for coded PMR channels. The proposed consists of two SOVA detectors running in parallel, one for the target $H(D)$, and the other for the target $H(D)G(D)$ equipped with a bandpass filter

$G(D) = 1 - D^2$. In simulations that proposed method performs better than the other methods in [6] and [7] for all peak TA amplitudes, and is also robust to large peak TA amplitudes. Again, the performance of the proposed method increases when the number of iteration is large.

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