A TA Suppression Method Based on Wavelet Transform for Perpendicular Recording Channels

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Abstract

A novel thermal asperity (TA) suppression method for perpendicular recording channels is proposed, which consists of two channels running in parallel, one for an $H(D)$ target, and the other for a $G(D)H(D)$ target equipped with a bandpass filter $G(D) = 1 - D^2$. The Viterbi detector (VD) in the $H(D)$ channel has a lower bit-error rate (BER) in the absence of TA, while that in the $G(D)H(D)$ channel has a lower BER in the presence of TA. The wavelet transform is applied to detect the TA, where its location is identified by a hard thresholding approach. The overall decoded bit stream is selected from these two VDs, depending on whether the TA is detected. Experimental results indicate that the proposed method provides at least 1 dB gain at BER = 10^{-4} over the existing ones, and is also robust to changes in the peak TA amplitude.

Keywords: Bandpass filter, perpendicular recording channels, thermal asperity suppression, wavelet transform

1. Introduction

To achieve very high recording densities, the magneto-resistive (MR) read heads have been used in magnetic recording systems instead of the inductive heads. Practically, the MR read head senses the change in a flux via the transitions of the magnetization pattern, resulting in an induced voltage pulse called a transition pulse. When an asperity contacts with the MR read head, the voltage transient known as *thermal asperity* (TA) [1] is generated.

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 – 3 times the peak of the readback signal [1 – 2]. In practice, the TA effect can cause a burst of errors in data detection that could easily exceed the correction capability of an error-correction code and results in a sector read failure. With an increasing of the recording density yet with the decreasing of the flying heights, the TA effect, as a consequence, is taken into account even more seriously, especially for the designs of future disk drives. Undoubtedly, an approach to suppress the TA effect is crucial, especially in perpendicular recording channels.

Many TA suppression methods have been proposed in the literature to mitigate the TA effect. Generally, 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. Thus, Klaassen and van Peppen [3] proposed the TA detection by looking at the baseline of the averaged readback signal, while the TA correction was performed by use of a high-pass filter. Dorfman and Wolf [2] proposed a method to combat with the TA effect by passing the TA-affected readback signal through a filter $(1 - D)$, where D is a delay operator. This method has been tested with an EPR4 target in longitudinal recording channels, where the number of bits corrupted by the TA effect is significantly reduced. However, this method is not suitable for a perpendicular recording channel because this channel has a d.c. component. For perpendicular recording channels, Fatih and Erozan [4] proposed a TA detection and correction method by use of different low-pass and high-pass filters, whereas Mathew and Tjhia [5] proposed a simple threshold-based approach to detect and suppress the TA effect. Eventually, Kovintavewat and Koonkarnkhai [6] proposed a TA suppression method based on a least-squares fitting technique for perpendicular recording channels.

This paper proposes a novel TA suppression method to mitigate the TA effect in perpendicular recording channels, which consists of two channels running in parallel, one for the $H(D)$ target, and the other for the $G(D)H(D)$ target equipped with a bandpass filter $G(D) = 1 - D^2$ [7]. Practically, the Viterbi detector [8] in the H(D) channel has a lower BER in the absence of a TA, whereas that in the $G(D)H(D)$ channel has a lower BER in the presence of a TA. The wavelet transform [9] is applied to detect the TA, where its location is identified by a hard thresholding approach. Finally, the overall decoded bit stream is selected from these two VDs, depending on whether a TA is detected.

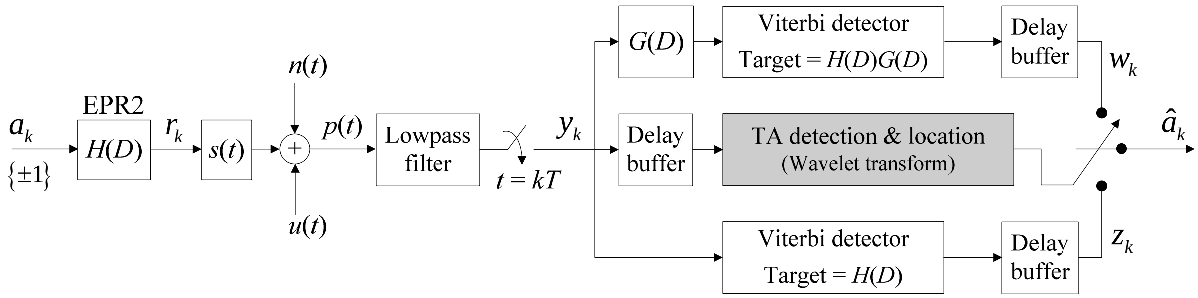

Figure 1. Channel model with the proposed TA suppression method.

The rest of this paper is organized as follows. After explaining the channel model in Section 2, Section 3 describes a widely used TA model. Section 4 presents the proposed TA suppression method. Numerical results are given in Section 5. Finally, Section 6 concludes this paper.

2. Channel model

Consider the perfectly equalized EPR2 channel model in Fig.1, where $H(D) = \sum_k h_k D^k = 1 + 3D + 3D^2 + D^3$. The TA-affected readback signal can then be written as

$$p(t) = \sum_k r_k s(t - kT) + n(t) + u(t), \qquad (1)$$

where $r_k = h_k * a_k$ is the noiseless channel output, $a_k \in \{\pm 1\}$ is an input data sequence with bit period T, * is a convolution operator, $s(t) = \sin(\pi t/T)/(\pi t/T)$ is an ideal zero-excess-bandwidth Nyquist pulse, $n(t)$ is additive white Gaussian noise (AWGN) with two-sided power spectral density $N_0/2$, and $u(t)$ is a TA signal.

At the receiver, the signal $p(t)$ is filtered by an ideal lowpass filter, and is sampled at time $t = kT$ at the sampling rate of 500 Mbps, assuming perfect synchronization, to obtain a sequence y_k. Then, the sequence y_k is fed to different TA suppression methods, followed by the VD to determine the most likely input sequence.

3. Thermal Asperity Model

We considers a widely used TA model described by Stupp *et al*. [1], as illustrated in Fig. 2, because it fits captured spin stand data and drive data very well. Typically, the TA signal associated with the MR sensor head will have a short rise time with a long decay time, and its effect is assumed to decay exponentially, which can be modeled as [6]

$$u(t) = \begin{cases} A_0 t / T_r, & 0 \le t \le T_r \\ A_0 \exp\left(-\left(t - T_r\right) / T_d\right), & T_r < t \le T_f \end{cases} \qquad (2)$$

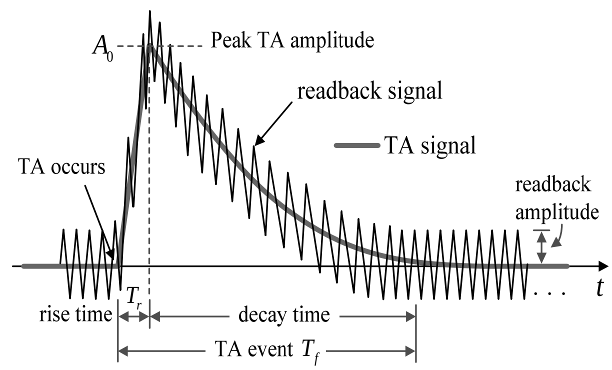

Figure 2. The TA signal associated with the MR sensor head.

where $A_0 = \beta \sum_k |h_k|$ is the peak TA amplitude, $\beta \ge 0$ is a peak-factor, T_r is a rise time, and T_d is a decay constant. In this paper, the TA duration is assumed to be $T_r + 4T_d$ [6], where a decay time of $4T_d$ is sufficient because it will reduce the amplitude of the TA signal to approximately 1.8% of its peak amplitude.

4. Proposed Method

The proposed method is furthered developed from [2], where the two VDs running in parallel are employed, i.e., one for the $H(D)$ target, and the other for the $G(D)H(D)$ target, equipped with the $G(D)$ filter. In addition, because the perpendicular recording channels appear to have a significant low-frequency content, we apply a bandpass filter $G(D) = 1 - D^2$ [7] to eliminate TA, while retaining most energy of the readback signal.

It can be shown that the VD in the $H(D)$ channel has a better BER when TA is absent, whereas that in the $(1 - D^2)H(D)$ channel has a better BER when TA is present [2]. Therefore, the overall decoded bit stream is chosen from the outputs of these two VDs. If a TA is detected, a decoded bit w_k is selected; otherwise, a decoded bit z_k is selected.

4.1 TA Detection Using Wavelet Transform

To detect a TA, the readback signal $\{y_k\}$ is normalized and then is transformed using the wavelet transform. The Haar wavelet [9] is chosen as a mother wavelet because it gives better results based on trial and error experiments. A hard thersholding is applied to all of the wavelet coefficients. The wavelet coefficients whose absolute values are larger than the selected threshold are referred to as the significant wavelet coefficients and are retained while the others are set to zero according to

$$d_m(x) = \begin{cases} x & \text{if } |x| > T \\ 0 & \text{if } |x| \le T \end{cases}, \qquad (3)$$

where x is any wavelet coefficient.

The inverse wavelet transform is applied to those significant wavelet coefficients to generate the estimated TA. The estimated TA is normalized (referred to as the "EN TA") and then is passed to a peak detector to determine the starting point of the TA, where the starting point of the TA is estimated by using the first point of the EN TA, whose value is larger than another selected threshold. To determine the ending point of the TA, the EN TA is passed to a lowpass filter, whose transfer function is given by

$$F(z) = \frac{1}{m^2 + 2m(1-m)z^{-1} + (1-m)^2 z^{-2}} \qquad (4)$$

where m is the cutoff frequency. Then, the resulting signal from the lowpass filter is normalized and passed to the peak detector to determine the ending point of the TA. The estimated ending point of the TA is the first point, where its value is less than the other selected threshold.

5. Numerical Results

In the simulation, every 4096-bit data sector $\{a_k\}$ is corrupted by one TA signal, which is occurred at the 1000-th bit with β = 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. We compute the BER of the system based on a minimum number of 500 4096-bit data sectors and 500 error bits, and call that number as "BER given TA."

In this paper, the proposed TA suppression method is compared with the method proposed in [2], which is referred to as "Method 1," and the method proposed in [5], which is referred to as "Method 2." The per-bit signal-to-noise ratio (SNR) is defined as

$$\frac{E_b}{N_0} = 10\log_{10}\left(\frac{\sum_k |h_k|^2}{2\sigma^2}\right) \qquad (5)$$

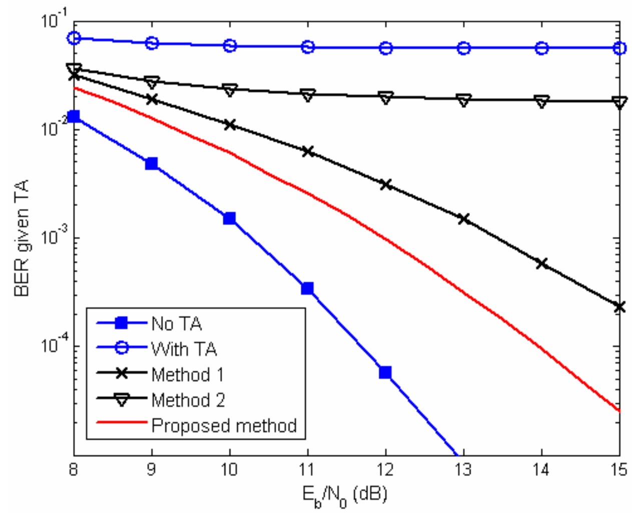

Figure 3. Performance comparison of different TA suppression methods.

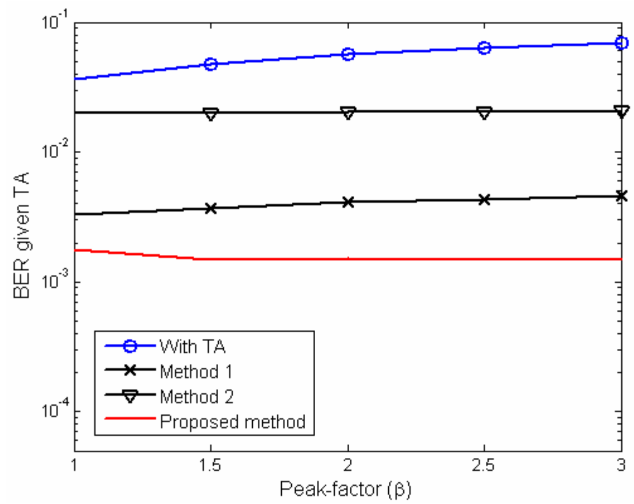

Figure 4. BER performance with different peak-factors.

in decibel (dB), where $\sum_k |h_k|^2$ is the energy of a channel and $\sigma^2 = N_0/(2T)$ is AWGN power.

Figure 3 compares the performance of different TA suppression methods as a function of of E_b/N_0's, where the system performance in the absence of TAs is referred to as "No TA." It is apparent that without the TA suppression method, the system performance is unacceptable (denoted as "With TA"). As illustrated in Fig. 3, the proposed TA suppression method performs better than Method 1 and Method 2. Specifically, the proposed method provides at least 1 dB gain at BER = 10^{-4} over Method 1.

We also compare the BER performance of different TA suppression methods as a function of peak-factors in Fig. 4

at E_b/N_0 = 11.6 dB, where the system without a TA event yields BER $\approx 10^{-4}$. Clearly, the proposed method still performs better than other methods for all peak TA amplitudes, and is robust to large peak TA amplitudes.

6. Conclusion

The TA effect can distort the readback signal to the extent of causing a sector read failure. This paper proposes a novel TA suppression method for perpendicular recording channels, using a bandpass filter to suppress the TA effect and the wavelet transform to find the TA location. Based on simulations, it is clear that the proposed TA suppression method performs better than the existing ones for all peak TA amplitudes, and is also robust to large peak TA amplitudes.

It should be noted that the proposed TA suppression method might not suitable for the disk drives that employ the tunneling MR heads because the TA response no longer looks like the one shown in Fig. 2 [10]. Therefore, other techniques to cope with this TA response should be considered for such a hard drive [11].

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