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A New Method of Amplitude Asymmetry Detection for Magnetic Recording Channels

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Abstract—**The amplitude asymmetry (AA) present in the readback signal is primarily due to the quality of the magneto-resistive (MR) read head, causing the overall system performance degradation. Thus, the method to detect and correct the AA effect is of much importance. Conventional method to detect the AA is performed by first writing a series of isolated pulses into the media, and then measuring the percentage of the AA effect from the corresponding readback signal. We propose a new method to detect the AA effect by directly using the data samples from the readback signal, thus reducing the test time for checking the AA effect in the manufacturing process. Results show that the proposed method can detect the AA as well as the conventional method. In addition, the proposed method can also use fewer data sectors to detect the AA than the conventional method, which implies low complexity.**

Keywords - Amplitude Asymmetry; Magneto-resistive head; Magnetic recording.

I. INTRODUCTION

To achieve a high recording density, the read head technology has been changed from the inductive read head to the magneto-resistive (MR) read head. Practical MR read head senses the flux directly from the transition of magnetization pattern, resulting an induced voltage pulse called a transition pulse. Then, the read channel transforms this induced voltage pulse into the output response known as the *readback signal*. When the performance of the MR read head degrades, it causes the *positive* readback amplitude to be larger than the *negative* readback amplitude, or vice versa. This phenomenon is called the *amplitude asymmetry* (AA) effect in the readback signal.

Generally, the conventional method to detect the AA effect in the readback signal is to write a series of isolated pulses [1] or to write a low-frequency (LF) square-wave $6T$ pattern, where T is a system clock [2], and then measure the AA. In practice, the AA is defined as the percentage of the difference between the positive and the negative readback amplitudes with respect to the average of those two readback amplitudes [1], [3]. It is clear that the AA effect can cause data loss during data detection process. Specifically, the higher the percentage of AA, the lower the system performance in terms of bit-error rate (BER) [1], [2], [4], [5], as will be shown later in Fig. 2.

Many methods have been proposed in the literature [1],[2], [4]. For example, Takeo *et al.* [1] studied and investigated the read/write characteristics and the BER performance under the influence of giant magneto-resistive (GMR) nonlinearity. The GMR nonlinear distortion was divided into two types, namely, GMR saturation and GMR asymmetry. The GMR asymmetry was computed using a parameter called track amplitude average (TAA); however, this method required more differential amplitude peak shift so as to obtain a good estimate of the asymmetry. Luo *et al.* [2] proposed a technique to measure the AA by creating new recording patterns so as to measure a baseline shift induced by the measurement through a.c. couple electronics. These new recording patterns, which separate large bit space regions by an even number of high frequency transition, were proposed to overcome the baseline shift caused by reading through a.c. couple electronics. The result of using the new recording patterns has shown good and accurate result for characterizing the AA. Finally, Tyner and Proakis [4] proposed the channel model that includes the AA effect (0% – 30%), where the asymmetric pulse response was only applied to the negative readback amplitude, and used this model to evaluate the performance of linear and decision-feedback equalizers for longitudinal recording.

To simplify the discussion, this paper proposes a new method to measure the percentage of AA in longitudinal recording systems, which has lower complexity than the conventional method used in today's hard drives. It will be demonstrated that the proposed method yields a similar result to the conventional method.

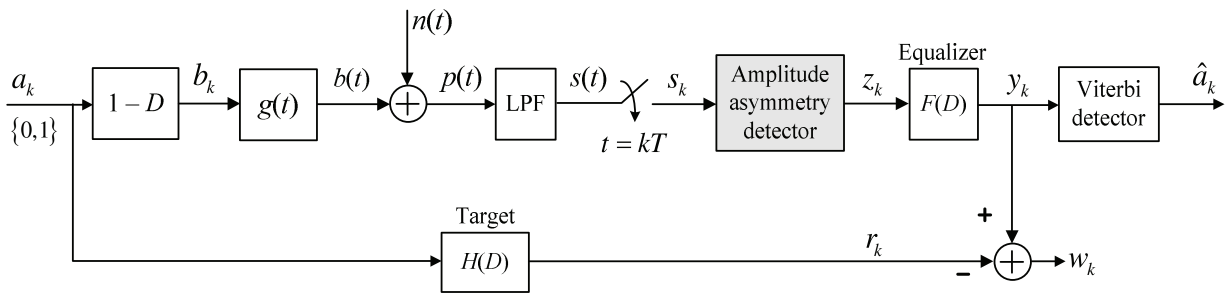

Fig. 1. A channel model with target design.

II. CHANNEL MODEL

We consider a longitudinal recording channel given in Fig. 1. A binary input sequence $a_k \in \{0, 1\}$ with bit period T is filtered by an ideal differentiator (1 – D), where D is a unit delay operator, to obtain a transition sequence $b_k \in \{\pm 1, 0\}$, where $b_k = \pm 1$ corresponds to a positive or a negative transition, and $b_k = 0$ corresponds to the absence of a transition. The transition sequence b_k passes through the magnetic recording channel represented by $g(t)$. The transition response $g(t)$ for longitudinal recording is given by

$$g(t) = \frac{1}{1+\left(\frac{2t}{\mathrm{PW}_{50}}\right)^2}, \tag{1}$$

where PW_{50} determines the width of the transition pulse $g(t)$ at half its maximum. In the context of magnetic recording, a normalized recording density is defined as ND = PW_{50}/T, which determines how many data bits can be packed within PW_{50}. Without the AA effect, the readback signal, $p(t)$, can be written as

$$p(t) = \sum_k b_k g(t-kT) + n(t), \tag{2}$$

where $n(t)$ is an additive white Gaussian noise (AWGN) with two-sided power spectral density of $N_0/2$.

On the other hand, when the readback signal experiences the AA effect, a positive transition ($b_k = +1$) will lead to the output response of $+g(t)$, while a negative transition ($b_k = -1$) will lead to the output response of $-\alpha g(t)$, for $0.5 < \alpha < 1$, which implies an asymmetry of $(1 - \alpha)$, or $100(1 - \alpha)\%$ amplitude asymmetry [4]. Therefore, to express the readback signal that has the AA effect, we define a new three-level sequence I_k as

$$I_k = \begin{cases} 1, & \text{when } a_k = 1 \text{ and } a_{k-1} = 0 \\ 0, & \text{when } a_k = a_{k-1} \\ -\alpha, & \text{when } a_k = 0 \text{ and } a_{k-1} = 1 \end{cases}, \tag{3}$$

where $b_k = a_k - a_{k-1}$. Thus, the AA-affected readback signal can be expressed as

$$p(t) = \sum_k I_k g(t-kT) + n(t), \tag{4}$$

where the asymmetry is present in the sequence $\{I_k\}$.

At the receiver, the signal $p(t)$ is filtered by a seventh-order Butterworth low-pass filter (LPF), whose cutoff frequency is at $1/T$, and is then sampled at time $t = kT$ assuming perfect synchronization. In practice, the sampler output s_k will be fed to the AA detection, resulting in the AA-unaffected readback samples z_k. The sequence z_k is equalized by an equalizer $F(D)$, where D is a unit delay operator, such that an equalizer output y_k closely resembles a desired sample r_k. Note that the design of a target $H(D)$ and its corresponding equalizer can be found in [6]. Finally, the sequence y_k is fed to the Viterbi detector to determine the most likely input sequence, $\hat{a}_k$.

Note that in this paper, we focus only on developing a new AA detection method whose performance is similar to the conventional method, but with low complexity.

II. AMPLITUDE ASYMMETRY DETECTION

The conventional AA detection method begins with cleaning the remaining signal on magnetic media by writing a DC erase pattern of one revolution at desired location. Next, we write a series of isolated pulses (or a low frequency square-wave of $6T$ pattern) into magnetic media. Then, we measure the average positive and negative amplitudes of the AA-affected readback signal, and compute the percentage of AA according to [1, 3]

$$\text{Asymmetry (\%)} = \frac{|A_p| - |A_N|}{|A_p| + |A_N|} \times 100, \tag{5}$$

where A_p and A_N are the average positive and negative amplitudes of the AA-affected readback signal, respectively, and $|x|$ takes the absolute value of x.

This paper proposes a new AA detection method, which can directly use the data samples extracted from the AA-affected readback signal. Therefore, only the data samples that have the

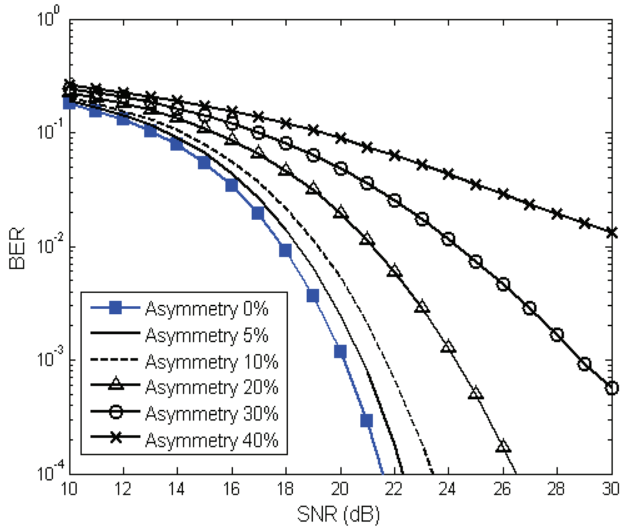

Fig. 2. BER performance of the system with different percentages of AA.

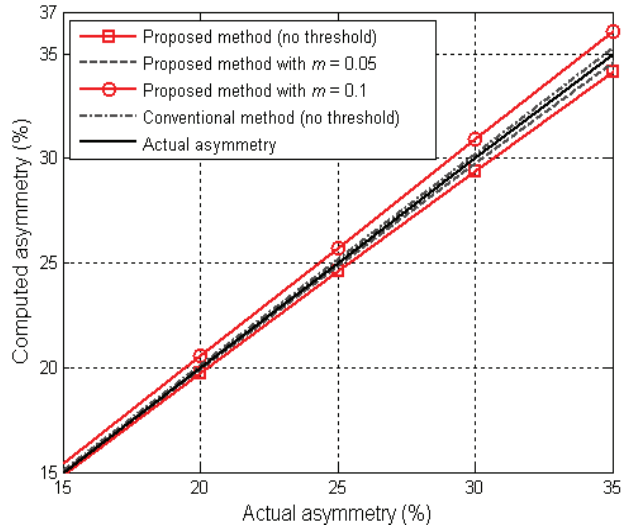

Fig. 3. Performance comparison of the AA detection methods with different thresholds.

absolute value greater than or equal to the threshold value, m, will be used to measure the percentage of AA according to (5).

Obviously, the proposed method can reduce the test time in the manufacturing process because there is no need to spend time writing a DC erase pattern, and then write a series of isolated before measuring the measure the percentage of AA as done in the conventional method.

III. Simulation Results

We consider a longitudinal recording channel at ND = 1.0 The signal-to-noise ratio (SNR) is defined as SNR = $10\log_{10}(E_i/N_0)$ in decibel (dB), where E_i is the energy of the channel impulse response. The target and its corresponding 7-tap equalizer was designed at the SNR required to achieve BER = 10^{-4} in the absence of AA.

Fig. 2 shows the BER performance of the system with different amounts of AA levels, where the equalizer $F(D)$ shapes the overall channel response to the PR4 target $H(D) = 1 - D^2$, and each BER point is computed using as many 4096-bit data sectors as needed to collect at least 1000 error bits. It is clear that the AA effect in the readback signal will degrade the system performance. The higher the percentage of AA, the worse the BER performance becomes.

In the followings, we will explore the performance of the proposed AA detection method in terms of the accuracy and robustness to estimate the amount of AA. To do so, we first compare the performance of the proposed method with the conventional method as a function of the amount of AA levels as depicted in Fig. 3, based on 30 data sectors. That is, all 30 data sectors were used to compute the percentage of AA. It is apparent that the proposed method with $m = 0.05$ can measure the percentage of AA as precisely as the conventional method does within 0% – 35% amplitude asymmetry levels, which are the practical region present in actual hard drives. Furthermore,

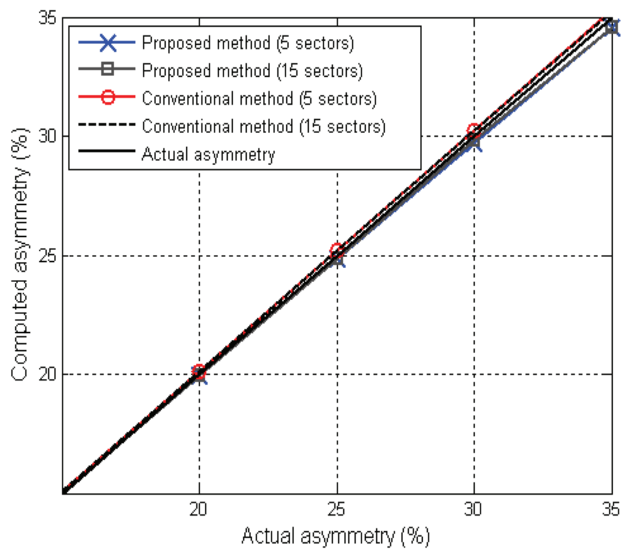

Fig. 4. Performance comparison of the AA detection methods with different numbers of sectors used to compute the percentage of AA.

we observed that the proposed method yields the same results as the conventional method does at low AAs (e.g., 0% – 15%).

We also compare the performance of AA detection methods that employs different number of data sectors to compute the percentage of AA, as illustrated in Fig. 4. It is clear that the proposed method yields similar results regardless of how many data sectors were used to compute the percentage of AA. However, we found that the conventional method will give a good result if the number of data sector used to calculate percentage of AA is large. Therefore, it can be implied that the proposed method is robust to the number of data sectors used to compute the amount of AA in the readback signal. Note that

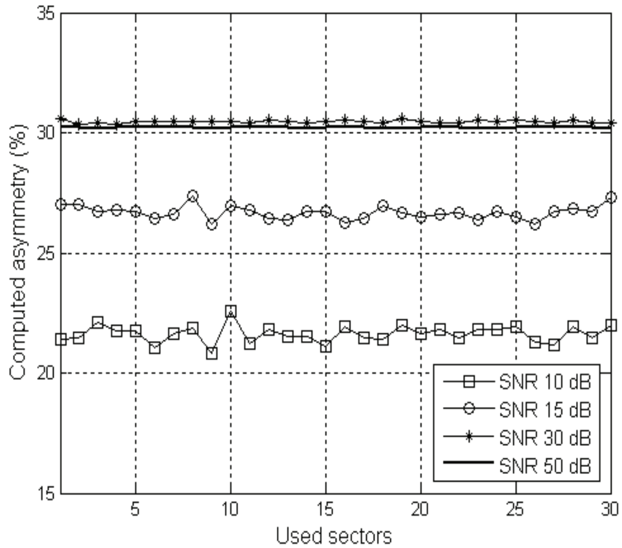

Fig. 5. Performance of the proposed AA detection method at different SNRs when the actual AA is set to 30%.

the conventional method practically utilizes 30 data sectors to measure the percentage of AA in the manufacturing process. As a result, the proposed method can reduce the test time even further.

Finally, Fig. 5 compares the performance of the proposed AA detection method as a function of SNRs when the system experiences 30% amplitude asymmetry. Clearly, computing the percentage of AA at high SNRs will give better result than that at low SNRs. This means that the noise present in the AA-affected readback signal can degrade the performance of the proposed method. Thus, the higher the operating SNR, the better the performance of the proposed method becomes.

IV. Conclusion

The amplitude asymmetry (AA) effect can distort the readback signal to the extent of causing an error burst in data detection process. The method to detect the AA effect is crucial in magnetic recording channels. This paper focuses on the AA detection method only.

The conventional AA detection method starts with writing a DC erase pattern into magnetic media, followed by writing a series of isolated pulses into magnetic media. Then, we measure the average positive and negative amplitudes of the AA-affected readback signal so as to compute the percentage of AA according to (5).

This paper proposes the new AA detection method, which can directly use the data samples from the readback signal to compute the percentage of AA, thus reducing the test time in manufacturing process. Furthermore, we found that the proposed method is also robust to changes in the number of data sectors used to compute the AA level. Therefore, it is worth employing the proposed method to measure the AA level in the readback signal so as to reduce the test time in manufacturing process.

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