Influence of Recorded Pattern on Background Interference impact in Magnetic Recording

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Abstract. This paper discusses the impact of background interference on a recorded pattern for heat-assisted magnetic recording technology (HAMR). Several patterns of the background track were examined, with the log bit error rate and signal to noise ratio measured via a spin-stand tester using HAMR head and media. It was found that the low frequency pattern gave the highest BER and SNR loss due to the strong magnetic field from the adjacent tracks. Similar to its practical use, the PRBS pattern also showed high interference. These observations may be used to support HDD areal density growth.

1. Introduction
The digital data growth rate has increased due to social media, personal computer, and smartphone device technological advancements. IDC forecasts that the global data sphere will grow from 33 Zettabytes (ZB) in 2018 to 175 ZB by 2025 [1], requiring the deployment new data storage solutions to support this demand.

For applications requiring very high storage capacity, hard disk drives (HDD) which use magnetic recording technology, provides a much lower total cost of ownership than that of solid-state drives (SSD). However, with current perpendicular magnetic recording (PMR) technology, the areal density growth rate is slowing down due to the superparamagnetic limit [2]. To maintain SNR, as the bit size shrinks the magnetic recording grains in the media also need to shrink. If the grains are made too small, they become thermally unstable. To achieve thermal stability, high-coercivity media is required. The conventional PMR magnetic writer is not sufficient to write such a high-coercivity media. To overcome this limit, researchers have proposed heat-assisted magnetic recording (HAMR) [3] as a promising alternative to achieve an ultra-high density storage. This approach employs a near-field transducer (NFT) to assist the conventional writer by raising the temperature of the HAMR media to temporarily reduce the coercivity and allowing it to be magnetized by the write head. The heat sink layer in the media enables thermal gradient (TG) improvement and the ability to quickly cool the media back to room temperature.

In 2019, Seagate demonstrated 2.27 terabits per square inch (Tbpsi) with interlaced track-layout and multiple reader architecture [4], establishing HAMR as a leading candidate for the future data storage technology. There are still many challenges to increasing areal density further. For instance, HAMR’s signal to noise ratio (SNR) is limited by several constraints: 1) HAMR’s unique switching field
distribution results in added transition jitter and saturation noise [5], 2) the integrated NFT writer creates more transition curvature and broadening effects than a PMR writer because of thermal spot effects driven by the NFT design [6], and 3) the trade-off between recording performance and reliability of the HAMR system as TG increases with heat sink thickness [7].

In this study, we consider the impact of the side reading or background interference (BGI) for conventional HAMR recording, i.e. the interference from the written adjacent track on the read-back signal [8]. Triple recorded tracks were compared among several background patterns and track pitch offsets and the log bit error rates (BER) were calculated to determine the HAMR recording head and media performance using a spin-stand test system. SNR’s were measured to understand the noise characteristics.

The rest of this paper is organized as follows. Section II briefly describes the experimental details, and Section III discusses the BGI impact on the recorded pattern with BER and SNR results. Finally, Section IV concludes this study.

2. Experimental Methods

In order to assess the BGI impact from the recorded pattern, the sample HAMR heads and media were tested via a spin-stand test system. This spin-stand test system is a high-precision instrument, which is widely used to characterize head and media performance.

The test condition was set at a radius of 0.869 inches (equivalent to a skew of 1.38°) at 10,500 RPM. The active fly height was 2 nm for writing and reading. The laser operating condition was optimized for each head by sweeping the laser bias current until -2 decades log BER was achieved at the data rate of 1,222 Mbps. The single tone BGI tracks employed 305.5 MHz (611 Mbps) and 76.4 MHz (152.7 Mbps) for the high and low frequency patterns, respectively.

2.1. Track layouts and log BER measurement

We designed track layouts for BGI investigation as shown in Fig. 1, including a reference track without background as depicted in Fig. 1 (a). For all cases, the recorded data was a pseudo-random bit sequence (PRBS) pattern on the center track. Fig. 1 (b) and 1 (c) show track layouts having a single tone pattern (low & high frequencies) and a PRBS as the background tracks, respectively. The track pitch (TP) was defined as the distance between the centers of the reference track and the background track. In the analysis, the track pitch was also varied by 50%, 100%, and 120% of the nominal TP.

![Figure 1. Schema of triple tracks with a various written adjacent track condition (a) non-background pattern (b) single tone pattern (c) pseudo-random bit sequence pattern.](image)

To characterize the magnetic recording performance, a typical system contains three main parts, 1) encoding/decoding, 2) writing, and 3) reading. Before recording a user data pattern into the media, the recorded pattern is encoded to avoid noise from several sources, i.e., media noise, electronic noise, interference and distortion. The reader provides read signals to the decoder in order to decode the user data. The log bit error rate [9] is typically used as the performance metric and calculated using the number of read bit errors divided by the total number of user bits. For example, if the decoder shows 1,000 bits in error while encoded data contains 1,000,000 bits, the log BER would be log10 (1,000/1,000,000), which is equal to -3 decades.
2.2. Signal to noise ratio measurement

In general, the signal to noise ratio measurement is used to analyze a recording head and media characteristic via a spin-stand tester. It is useful for understanding the effects of the head, media, and recording conditions. The signal to noise ratios can be calculated using an ensemble waveform analysis [10]. This method extracts electronic, transition and remanence noises. The detailed test procedures are explained as follows:

- The pseudo-random bit sequence (PRBS) generator polynomial for \( m^8 + m^4 + m^3 + m^2 + 1 \) is selected for the data pattern, with 255 bits of PRBS with 64 consecutive periods recorded on the mentioned track layouts. A reader then captured the recorded PRBS signal for 50 rounds to remove electronic or reader noise.
- A reader then captures the recorded PRBS signal for 50 rounds to remove electronic or reader noise.
- The averaging waveform of the 64 consecutive periods provides a spatially noisy waveform.
- The overall signal power can be divided into noise-free signal, spatial noise and electronic/reader noise. An appropriate weighting function can separate the spatial noise into the media transition and remanence noise. Finally, the SNR is the ratio of the overall signal power to the respective noise power.

3. Results and Discussion

Four recorded patterns and three-track pitch conditions were investigated. The background interference impact on HAMR performance was assessed by BER and SNR measurements as described above.

3.1. Bit Error Rate vs. Recorded Pattern

In Fig. 2, the effects of different background tracks on the recorded pattern were determined using log BER. This enabled the comparison of the center track log BER with the cases with and without background patterns. In addition, the track pitch impact was also investigated. The best recorded performance was achieved when the user data was recorded over the non-background condition. However, we observed that the worst condition occurred under a low frequency BGI, i.e. BER degraded by 0.37 decades relative to the non-background (Fig.3). The PRBS BGI pattern was also found to show performance degradation, but slightly better than the low frequency condition since a PRBS contained low frequency components from a long bit period. Note that the PRBS BGI case demonstrates the practical case where old data is directly overwritten by new data. We also observed that the BGI impact could be reduced using a high frequency pattern (higher data rate). The 100% TP condition had the greatest BGI impact while the shingled recording style (50% TP) and adjusted erase bands (120% TP) also looked promising.

![Figure 2. BER vs. recording pattern at various track pitch.](image)

![Figure 3. BER degradation vs. recorded pattern at 100% of the nominal track pitch.](image)
3.2. Signal to noise ratio vs. Recorded Pattern

To study the background interference impact of the recorded pattern, we investigated the interference source via ensemble waveform analysis technique as mentioned above. Here, the total, electronic, transition, and remanence SNR’s were extracted from the read-back signals. We compared the SNR among 1) non-background pattern, 2) low frequency pattern, 3) high frequency pattern, and 4) pseudo-random bit sequence pattern conditions.

Fig. 4 shows the total SNR versus the recorded pattern. In this experiment, the maximum SNR was approximately 13.5 dB for the non-background and high frequency conditions, indicating a lower BGI impact in agreement with the BER results. However, the PRBS and low frequency recorded patterns showed large SNR loss due to a strong background signal, with the PRBS SNR losing 2.5 dB relative to the non-background condition.

Similar to the BER results, 100% TP offset demonstrated the highest SNR loss. In reducing the track pitch to 50% of the nominal, some background tracks were effectively trimmed by the center track resulting in a reduced level of background interference. The extracted electronic SNR is shown in Fig. 5, which confirms that the reader noise is independent of the BGI tracks.

Fig. 6 depicts the transition noise from the read-back signal for each BGI pattern, and shows that the maximum BGI impact occurs in the low frequency and PRBS conditions, particularly when the track pitch is at 100%. The transition SNR loss is about 2.1 dB relative to the non-background condition. Furthermore, the remanence SNR, which describes the center bit signal, shows 4.6 dB degradation under the PRBS condition. This impact is higher than that of the transition noise, suggesting that the BGI mainly affects the center bit signal. When comparing between the various BGI cases, the transition and remanence noise behaviors are comparable to that of a total SNR (Fig. 4). This indicates that the majority of the noise is contributed by the remanence noise and followed by the transition noise.

Finally, these results show that SNR degradation is mostly impacted by the transition noise and remanence noise, with a PRBS pattern as the background track. In the experiment, the same transducer was used to write and read tracks. Therefore, the stray field from the background track is the root cause of degradation. In other words, the main problem was the side reading that interferes the reader during the read-back process either at the center or transition bits. Hence, these results signify that the read error performance is dependent of the background patterns.
4. Conclusions
In this study, the impacts of background interference and track pitch on HAMR recorded pattern were investigated. The spin-stand test results showed significant performance loss from the low frequency and PRBS background interference, particularly at 100% track pitch offset. The SNR measurements confirmed that both the transition and remanence SNRs were degraded due to the strong remanence magnetic field of the adjacent background tracks. Finally, interference noise reduction was achieved by increasing the data rate (decreasing the bit length). Consequently, these observations are expected to support HDD areal density improvement in order to commercially drive the use of HAMR.

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