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PAPER

# An ITI-Mitigating 5/6 Modulation Code for Bit-Patterned Media Recording

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**SUMMARY** In bit-patterned media recording (BPMR), the readback signal is severely corrupted by the inter-symbol interference (ISI) and inter-track interference (ITI), especially at high recording densities, due to small bit and track pitches. One way to alleviate the ITI effect is to encode an input data sequence before recording, so as to avoid some data patterns that easily cause an error at the data detection process. This paper proposes an ITI-mitigating 5/6 modulation code for a multi-track multi-head BPMR system to eliminate the data patterns that lead to severe ITI. Specifically, each of the 5 user bits is converted into a 6-bit codeword in the form of a 3-by-2 data array, based on a look-up table. Experimental results indicate that the system with the proposed coding scheme outperforms that without coding, especially when an areal density is high and/or the position jitter is large.

***key words:*** *Bit-patterned media recording (BPMR), Euclidean distance, Inter-track interference (ITI), Modulation code*

## 1. Introduction

To support a huge demand for storing digital data, a magnetic recording density for future storage devices must be continuously increased. Currently, a hard disk drive (HDD) employs a perpendicular magnetic recording (PMR) technology, but the super-paramagnetic limit prevents it from reaching an areal density (AD) beyond 1 terabits per square inch ($Tb/in^2$) [1]. Thus, an advanced recording technology is needed to achieve the AD beyond the current limit imposed by HDD design. Among the newly proposed recording technologies, bit-patterned media recording (BPMR) is the promising technology that can achieve the AD up to 4 $Tb/in^2$ [2].

Although BPMR can provide high ADs, there are still many challenges to be resolved. In general, as the AD increases, the spacing between data bit islands in both the along- and across-track directions becomes narrower, thus leading to the increase of two-dimensional (2D) interference. This 2D interference consists of inter-symbol interference (ISI) and inter-track interference (ITI), which can significantly deteriorate the overall system performance if precautions are not taken.

To tackle the 2D interference, several 2D coding schemes have recently been proposed [3]-[8]. For example, Kurihara et al. [4] introduced a constructive ITI-coded partial-response (PR) maximum-likelihood system based on a two-track model for PMR. Specifically, the constructive ITI code was designed, based on the equalized level such that the opposite polar level can never occur simultaneously after class-I PR equalization. Also, Groenland and Abelmann [5] presented a rate-7/9 2D coding scheme for probe recording to avoid the destructive interference case by placing the redundant bits in fixed positions at every 3-by-3 data array; however, its drawback is the redundant bits have no error correction capability. Then, Shao et al. [6] proposed a rate-5/6 2D coding scheme for the BPMR readback signal with overshoot to mitigate the ISI effect, which had lower redundancy and yielded better performance than the rate-7/9 one [5]. In addition, a rate-4/6 modulation code [7] was presented to remove the fatal 2D ISI patterns in holographic data storage. Recently, Arrayangkool et al. [8],[9] introduced a recorded-bit patterning (RBP) scheme to combat the 2D interference but it had high complexity and required large buffer memory.

Practically, the ITI effect experienced in the detected bit can be either destructive or constructive, relying on the readback waveform of the detected bit and its surrounding bits [8],[9]. Note that this paper considers the BPMR readback signal without overshoot [9], which can be generated from the channel model shown in Figure 1 (will be explained later). Specifically, given the signal amplitude of an isolated bit, the destructive/constructive ITI will decrease/amplify its signal amplitude. As a consequence, when the readback signal of the detected bit encounters the destructive ITI (DITI), it could easily cause an error at the data recovery process. To combat the DITI, we propose the ITI-mitigating 5/6 modulation coding scheme, which converts an input data sequence into a 3-track recorded sequence based on a look-up table before recording onto a magnetic medium. This coding scheme guarantees that the BPMR readback signal will not be corrupted by the severe ITI, thus easing the data detection pro-

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