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A Concatenate Code for Error Correcting Code in Bit Pattern Media Recoding System

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Abstract Bit Pattern Media Recording (BPMR) is the modern HDD recording technique which can overcome the constraint of conventional technique by offering tremendous areal density. However, narrow track of BPMR can cause noise generating from inter-track interference (ITI) and In. inter-symbol interference (ISI). One traditional technique used to improve BER of the system is the introducing of error control coding. In this paper, we investigate concatenate code applied to BPMR. We proposed inner code with low-density parity-check (LDPC) and Reed-Solomon (RS) codes as outer code. The obtained simulation results confirmed to us that the concatenated coding scheme yielded better performance compared with the single LDPC code deployment.

Introduction

Nowadays, usage of internet and digital communication has growth continuity. This is also one of the major drive for digital storage needs. Hard disk is the most widely used for such the kind of digital storages. A conventional HDD system is composed of recording plate which is coated with a thin film of magnetic (magnetic grain). The size of magnetic grain is in nanometer scale, and each grain is in disordered direction. In order to write data into disk, the recording head needs to control magnetic grain in either perpendicular or longitudinal direction respected to the recording media. An alternative technique to achieve tremendous areal density is to reduce the size of magnetic grain. However, reducing the magnetic grain can cause unstable data in storage and thermal fluctuation. The external heat may effect magnetic characteristic changing. The data bit might change to opposite direction. This phenomenon called super-paramagnetic limit [1].

The new technologies that challenge the conventional one; such as Perpendicular Magnetic Recording (PMR), Heat Assisted Magnetic Recording (HAMR) [2], Bit Patterned Magnetic Recording (BPMR) [3], and Two Dimensional Magnetics Recording (TDMR) [4] are now drawing high interest. Those technologies, the capacity of more than 1 Tb/in^2 can be possible. BPMR is expected to achieve areal density up to 1-4 Tb/in^2 by storing one bit per cell into a single-domain rectangular magnetic island of the nano-meter scale. Researches in recording media have been developed greatly by various techniques such as nanolithography, self-assembly, electron beam lithography and Nano-imprint lithography, etc.

Recently, the areal density at 1 Tb/in^2 has been accomplished via the use of magnetic island. It is already brought to practical applications [5]. BPMR has many advantages such as minimize noise during transition, nonlinear bit shift, ease of data recovery, and facilitate on servo system tracking, etc. Nonetheless, BPMR is still encounter with read channel problem due the reduction of size and shape of the magnetic island. The read back signal may also be influenced by pulse response and the occurrence linear superposition effect between main track and adjacent track called inter-track interference (ITI). If the distance between island even closer together it may generate inter-symbol interference (ISI) accordingly. Both effects can cause error of data and performance degradation of BPMR during read back process.

Improving BER of the HDD system with the deployment of error control code is commonly known. Reed Solomon code has been used intensively from the very beginning of HDD development to some years after 2000. Since the re-discovery of LDPC code in late 1990, such codes had been applied to HDD system and gradually replace Reed Solomon code. Either Reed Solomon code or LDPC code, only one coding scheme is used and concatenation of codes is not yet found in the published literatures.

In this paper, we propose an error correction coding scheme to correct the error of read back data. We will examine a BPMR channel with areal density of 2 Tb/in^2 and 2.5 Tb/in^2. A single reading head and partial response maximum likelihood (PMRL) is the environment used. At the receiver, 1-D target and 1-D equalizer with decoder soft-input soft-output (SISO) detector are used. Within SISO detector, the soft output viterbi algorithm (SOVA) and SISO decoder with Low Density Parity Check Code (LDPC) are deployed. An extra error correction code, Reed Solomon Code (RS), is added to the system. Basically those 2 coded are concatenated. The performance of the system is measured in term of bit error rate (BER) and sector error rate (SER) versus signal to noise ratio (SNR). The obtained results can clarify to us the benefit of using RS-LDPC concatenated code.

Channel Model

In BPMR, the change of magnetic islands characteristics which are uniformly distributed on the media, is influenced by the 2-D pulse response. Relevent parameters to model the BPMR channel are given by [6] and [7], where the 2-D Gaussian pulse response *H(x,z)* is written as

$$H(x,z) = A\exp\left\{-\frac{1}{2}\left(\frac{x^2}{w_x^2}+\frac{z^2}{w_z^2}\right)\right\}, \tag{1}$$

The coefficients of a channel, *H(D),* can be obtained by sampling (1) at bit period (T_x) and the track pitch (T_z). Given here: A = 1 is amplitude of a 2-D pulse response, $w_x = W_x/2.5348$, $w_z = W_z/2.5348$, where W_x is an along-track PW50, and Wz is an cross-track PW50 repectively. As described by [6], the areal density of BPMR is limited by T_x and T_z according to the given below equation;

$$\text{Area density} = T_z/T_x \quad \text{bit/sq.inch} \tag{2}$$

BPMR channel with RS-LDPC concatenated code is illustrated in Fig. 1. A binary input sequence $a_{k,m} \in \{0,1\}$ is grouped to match the symbol size and encoded with a RS encoder. The output sequence $b_{k,m} \in \{0,1\}$ is subsequently encoded by a LDPC encoder. An RS encoder can be bypassed in the case that only LDPC code is required. Then the signal $u_{k,m} \in \{\pm 1\}$ is to be recorded into the media where $H_m(D)$ denotes the channel of the m-th track. The read back signal be written as

$$y_k = \sum_i \sum_m h_{i,m} u_{k-i,m} + n_k \tag{3}$$

Here hi_m's are the coefficient of 2-D channel response. D is an unit delay operator, and n_k is AWGN with zero mean and variance. In this system, we assume that the system has synchronized perfectly and the media characteristic is uniform without TMR effect. Target *G(D)* and Equalizer *F(D)* shown in Fig. 1 are generalized partial response targets (GPR) as described in [8].

Thebequalized sequence x_k is then fed to a turbo equalizer, which iteratively exchanges soft information between the SOVA equalizer and the LPDC decoder implemented based on a message passing algorithm with 3 internal iterations. A RS decoder is of neccessary just in the case of code concatenated scheme.

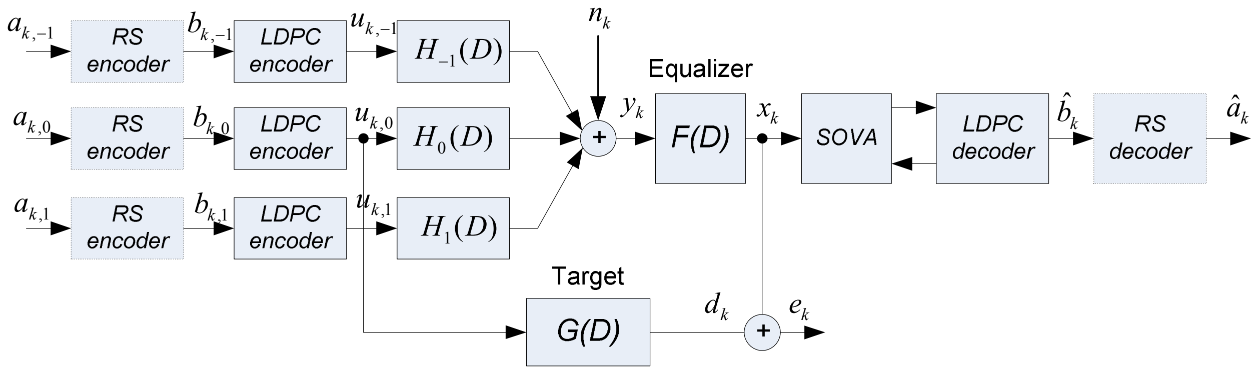

Fig. 1 A BPMR channel model with 1-D equalizer and 1-D target design

Error Correcting Code

Low Density Parity Check Code

LDPC codes are linear block codes which are define by a sparse parity check matrix, where the weights of the columns and the rows are far smaller than the size of its located columns and rows. The parity check matrix H of a QC-LDPC code can be constructed as given by (4) below.

$$H = \begin{bmatrix} I & I & I & \dots & I & \dots & I \\ 0 & I & \alpha^{1} & \dots & \alpha^{j-2} & \dots & \alpha^{k-2} \\ 0 & 0 & I & \dots & \alpha^{2(j-2)} & \dots & \alpha^{2(k-2)} \\ \vdots & \vdots & \vdots & & \vdots & & \vdots \\ 0 & 0 & 0 & \dots & I & \dots & \alpha^{(j-1)(k-1)} \end{bmatrix}_{pj \times pk} \tag{4}$$

Where $2 \le j \le k \le p$ and I is an identity matrix $(p \times p)$ and α is a position permuted matrix ($p \times p$). An example of matrices I and α is given herewith in (5).

$$I = \begin{bmatrix} 1 & 0 & 0 & \dots & 0 \\ 0 & 1 & 0 & \dots & 0 \\ 0 & 0 & 1 & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & \dots & 1 \end{bmatrix}_{p \times p} \quad \alpha = \begin{bmatrix} 0 & 1 & 0 & \dots & 0 \\ 0 & 0 & 1 & \dots & 0 \\ 0 & 0 & 0 & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & 0 & 0 & \dots & 0 \end{bmatrix}_{p \times p} \tag{5}$$

For parity check matrix design, for the sake of simplicity, we employed the technique described in [9].

Reed Solomon Code

Reed-Solomon codes are non-binary cyclic codes with symbols made up of m-bit sequences, where m is any positive integer having a value greater than 2. R-S (n, k) codes on m-bit symbols exist for all n and k. Where k is the number of data symbols being encoded, and n is the total number of code symbols in the encoded block. By adding $2t$ check symbols to the data, then an RS codes can detect any combination of error bits up to $2t$ erroneous symbols, or correct up to t symbols. The maximum codeword length (n) is $n = 2^m - 1$, where m is a symbol size.

Experiment Setup

From BPMR channel shown in Fig.1, we define areal density as 2Tb/in^2 and 2.5Tb/in^2 in equation (1) then the coefficients of a channel *H(D)* can be computed as [6], [7]

$$H(D)_{2.5Tb/in^2} = \begin{bmatrix} 2.11\times10^{-4} & 0.0503 & 0.3124 & 0.0503 & 2.11\times10^{-4} \\ 1.08\times10^{-4} & 0.1612 & 1 & 0.1612 & 1.08\times10^{-4} \\ 2.11\times10^{-4} & 0.0503 & 0.3124 & 0.0503 & 2.11\times10^{-4} \end{bmatrix} \quad (6)$$

$$H(D)_{2Tb/in^2} = \begin{bmatrix} 2.54\times10^{-5} & 0.0238 & 0.2336 & 0.0238 & 2.54\times10^{-5} \\ 1.08\times10^{-4} & 0.1021 & 1 & 0.1021 & 1.08\times10^{-4} \\ 2.54\times10^{-5} & 0.0238 & 0.2336 & 0.0238 & 2.54\times10^{-5} \end{bmatrix} \quad (7)$$

The data in a sector is set to 4,075 bits. The target and equalize are defined similar in [7]. A block size of 3,586 bits is encoded with a LDPC encoder of an irregular (4, 25) with a code rate of 0.88. Similarly, a block size of 3423 bits is encoded with irregular (3, 25) LDPC encoder at a code rate of 0.84. For the concatenate coding scheme, we use an irregular (4, 25) LDPC code with a code rate of 0.88. It is combined with shortened RS code in $GF(2^9)$ with code rate of 0.95 and minimum distance is 10. As a result, the actual code rate is 0.84.

Simulation Results

Fig. 2 and Fig. 3 show the bit error rate and sector error rate performance of various codes; i.e. LDPC code with the rate of 0.88, rate of 0.84 and the concatenated code with the rate of 0.84. Obviously seen in BER:- LDPC with code rate of 0.84 is better than a concatenated code. Surprisingly when we look into SER, it is founded that the concatenated code is better. The LDPC code with rate of 0.88 is the most poorest compared to others

We all know that RS code cannot do anything if the number of errors excesses its capability (10 symbols, in this case). In such a situation, the presence of RS code has no meaning. However, the situation is improved if the number of errors is less than 10 symbols per block. This is why the SER can be made better.

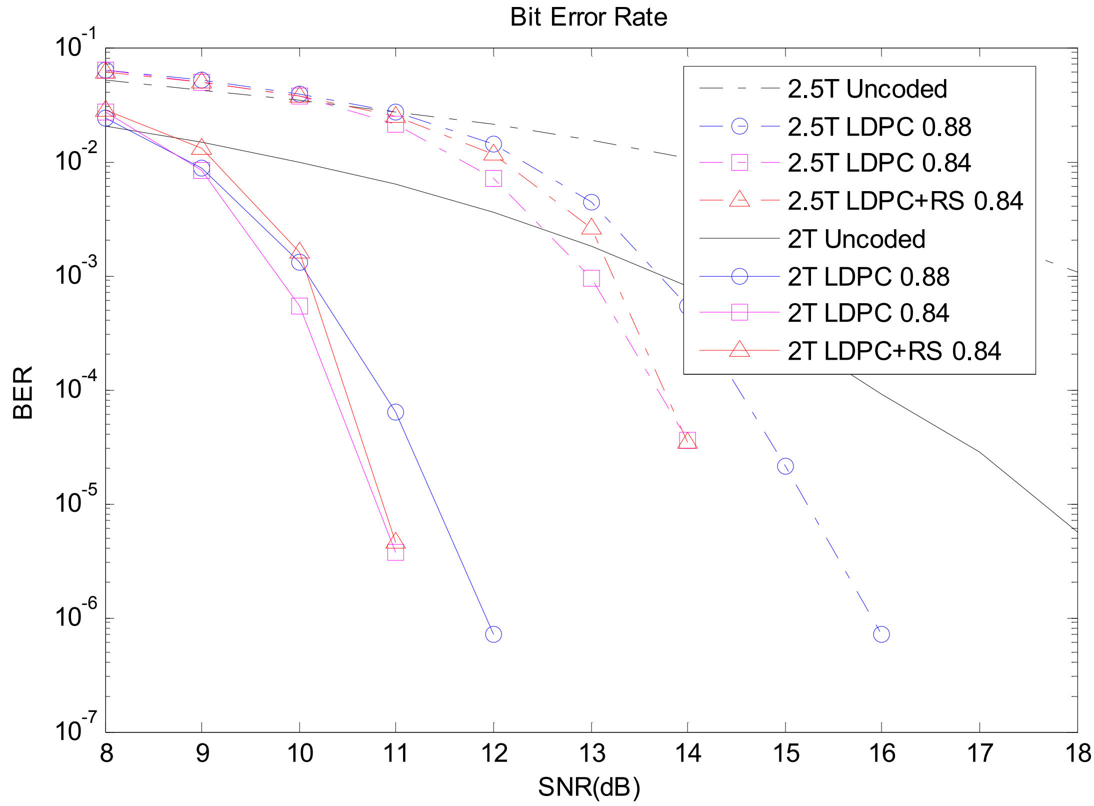

Fig. 2 Bit error rate performances

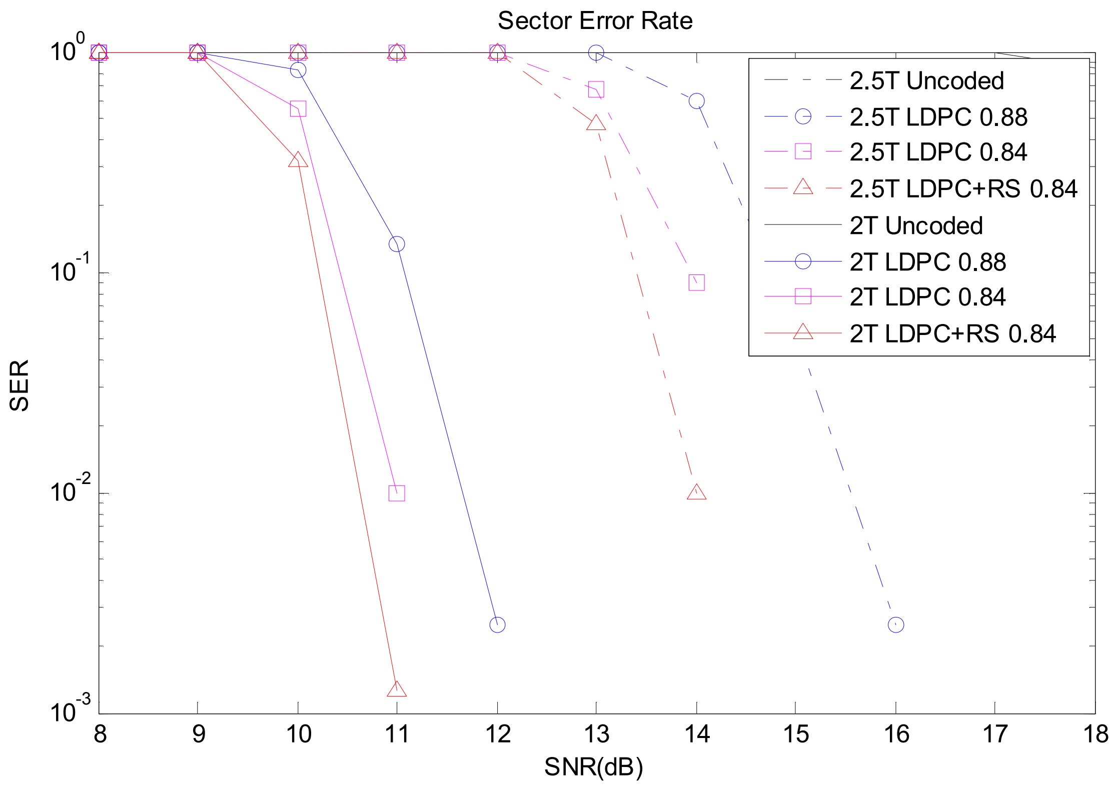

Fig. 3 Sector error rate performances

Conclusion

In this paper we have reported the performance evaluation of BPMR channel with and without concatenate code. By using the RS-LDPC concatenated code the sector error rate (SER) can be improved with a slight deteriorated in bit error rate (BER). SER can be the most desirable result since we can verify entire sector instead of number of error bits. Even though only single bit went wrong in same sector, the whole sector will be discarded. Therefore, the use of concatenated code in the ECC system with BPMR channel is superior compared to a conventional method that only RS code or LDPC code is used. Another bright side of the presence of RS code in the RS-LDPC concatenated code is that the burst error correcting can be made ideal. On the dim side, a concatenated code may require an additional processing step that can be a drawback for some implementation. This trade off should be considered case by case according to the actual requirement.

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