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Evaluation of read channel performance for perpendicular patterned media

I.T. Ntokas, P.W. Nutter*, B.K. Middleton

Department of Computer Science, University of Manchester, Oxford Road, Manchester M13 9PL, UK

Abstract

The use of patterned media is one of the proposed approaches for extending magnetic storage densities and delaying the problems imposed by the superparamagnetic limit. In this paper, we investigate the reliable recovery of data from patterned media with perpendicular anisotropy using a software tool developed to simulate the read channel. The bit error rate against signal-to-noise ratio (SNR) performance of various partial-response maximum-likelihood (PRML) channels is evaluated. It is shown that the PRML channels for perpendicular recording offer better performance than the conventional channels for longitudinal recording. In addition, simulations reveal that the use of run-length limited encoders and the existence of a soft magnetic underlayer contribute to an improved performance in terms of SNR.
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1. Introduction

Despite the fact that for the past four decades the magnetic recording industry has consistently achieved areal densities beyond expectations, still higher storage densities (in the order of Tbit/in^2) are required. An important criterion for judging the performance of a magnetic recording system is the stability of recorded data against thermal decay. In the case of magnetic media, increased storage density results in low signal-to-noise ratio (SNR) due to the reduced number of magnetic grains used to store each bit. To improve SNR requires a reduction in grain size, but this is at the expense of thermal stability, the so-called superparamagnetic limit. Among the most promising approaches proposed to increase the storage density of magnetic media, and push back the density limits imposed by the superparamagnetic effect, is the use of patterned media, whereby each bit is recorded to an isolated ‘island’ of magnetic material [1]. The use of patterned media for

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*Corresponding author. Tel.: +44 (0)161 275 5709; fax: +44 (0)161 275 4527.
E-mail address: p.nutter@man.ac.uk (P.W. Nutter).

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recording has motivated many researchers, who have focused their attention particularly towards media fabrication techniques [2]. However, little work has been published regarding the recovery of data recorded on such media. This work therefore concentrates on investigating the efficient recovery of data from patterned media, and in particular, media with perpendicular magnetic anisotropy.

2. Channel simulation

Fig. 1 illustrates a typical magnetic recording channel, where the use of partial-response maximum-likelihood (PRML) detection for the efficient recovery of recorded data has become commonplace [3].

In the following analysis, a PRML channel has been applied for use in a magnetic recording system incorporating patterned media with perpendicular anisotropy. In order to simulate the performance of the read channel in patterned media, replay and channel models have been developed.

2.1. Replay model

The replay response to an isolated magnetic island using a giant-magnetoresistive (GMR) replay head is simulated using the reciprocity integral, following the well-known Potter approximation [4], whereby the width of the GMR read head is assumed to be infinite with respect to the assumed square island. Pulse superposition is then used to generate the output waveform due to a train of random data, where each channel 'bit' is recorded to an individual physical island.

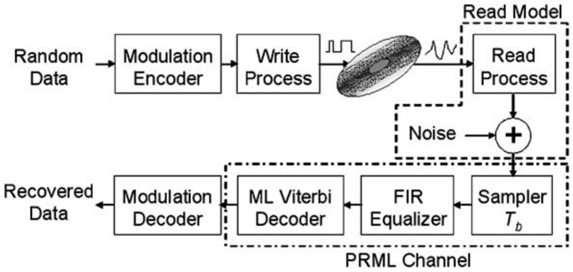

Fig. 1. PRML magnetic recording channel.

In the following analysis, a GMR head with a sensor thickness (along track) of 4 nm and a shield-to-shield separation of 90 nm has been used [5]. The model predicts the isolated pulse response due to varying media characteristics such as island length, film thickness, GMR head fly height and the presence or not of a soft magnetic underlayer (SUL) of infinite permeability. Fig. 2 illustrates isolated pulse responses (normalized with respect to the absolute peak pulse amplitude) due to an island of length 30 nm and thickness 20 nm for two cases: no SUL present and a SUL present 10 nm below the recording film.

It can be seen that the pulse responses differ considerably depending on the presence or not of a SUL. In the case when no SUL is present, the pulse response is characterized by the existence of overshoots on either side of the main pulse, whereas in the case where the SUL is present, these overshoots are removed.

In the case of a thick recording medium, a similar result is observed, with a broadening of the pulse in both cases and a reduced amount of overshoot for the no-SUL case.

2.2. Channel simulation

In order to predict the reliability of channel designs, a simulator has been developed that

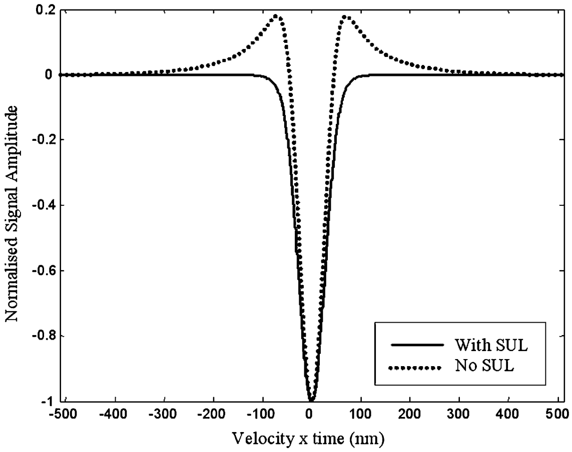

Fig. 2. Isolated pulse responses due to an island of length 30 nm.

predicts the bit-error-rate (BER) performance of the read channel as a function of the replay SNR.

In a patterned magnetic medium, the noise is largely media dependent and is introduced as jitter due to a variation in island shape, size and distribution introduced by inefficiencies in the patterning process [6]. However, for this analysis we have assumed that the patterned medium is ideal, i.e. no jitter, and any noise present is assumed to be additive white Gaussian.

The read channel model comprises a sampler, of sample rate equal to the island period (T_b), a 7-tap finite-impulse-response (FIR) equalizer, which equalizes the replay signal to a desired partial response (PR) target (optimized using the least-mean-square algorithm), an ML Viterbi detector and run-length-limited (RLL) encoder/decoder (if present). The model permits the investigation of different PR equalization schemes, different encoding and decoding strategies, and the effect the media has on the channel performance, i.e. island size, thickness, presence of a SUL, etc.

For the following analysis, the system parameters listed in Table 1 were used. The patterned island has a length of 30 nm (along the track) and a period (T_b) of 50 nm; this offers a potential storage density of approximately 258 Gbits/in^2 for an assumed square island of equal length and period in both the along and across track directions.

Table 1
Simulation parameters

Parameters	Values
Media	
Island length	30 nm
Island period	50 nm
Island orientation	Perpendicular
Thickness	20 nm, 100 nm
Interlayer thickness	10 nm
Gbit/in^2 (square island)	258
Replay head	
GMR element thickness	4 nm
Shield-to-shield distance	90 nm
Fly height	20 nm
Width	Assumed infinite
Channel	
RLL encoder	None, 2/3(1,7)
FIR taps	7

3. PRML channels for perpendicular recording

The PR targets that have been investigated are PRML channels for perpendicular magnetic recording proposed by Ide [7] with PR polynomial

$$y = (1 + D)^P (D^Q - 1)(1 - D). \quad (1)$$

These channels take several forms, depending on the integer values of the two parameters P and Q. In particular, the combinations of P and Q values listed in Table 2 were investigated; also illustrated are the impulse response sample levels for each PR filter.

4. Results

Plots of BER vs. SNR for the PR channels listed in Table 2 are shown in Fig. 3. Also illustrated, for comparison reasons, is the performance of the well-known E^{2}PR4 channel [8].

We conclude that for the PR channels investigated, PR(−1,0,1,1,0,−1) offers the best performance (in terms of lower SNR for a specific BER) for the head specification and media characteristics investigated. The gain in SNR over the E^{2}PR4 channel is approximately 2 dB for an acceptable BER of 10^{-5}. Additional studies varying the island length and island period (not shown here) have demonstrated similar results, with the PR(−1,0,1,1,0,−1) channel still offering best data recovery performance.

The performance of the channel depends on numerous factors, in particular, the replay head configuration and the media characteristics. In the following analysis, the effect of RLL encoding, film thickness, presence of a SUL and different

Table 2
PRML channels for perpendicular mode

P	Q	D^0	D^1	D^2	D^3	D^4	D^5	D^6
1	2	−1	0	2	0	−1	—	—
1	3	−1	0	1	1	0	−1	—
2	2	−1	−1	2	2	−1	−1	—
2	3	−1	−1	1	2	1	−1	−1
3	2	−1	−2	1	4	1	−2	−1

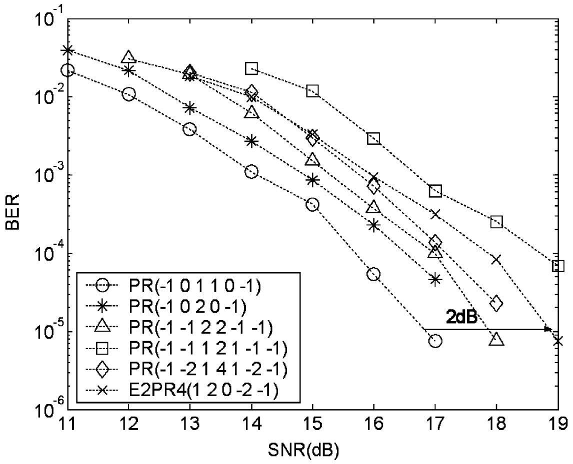

Fig. 3. Channel performance for different perpendicular PR schemes for an island length of 30 nm and period 50 nm.

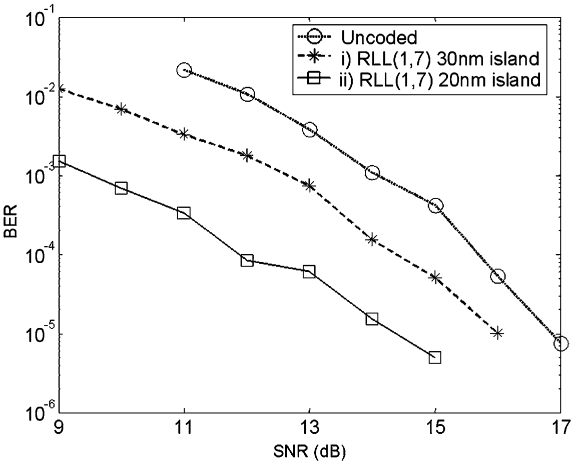

Fig. 4. Channel performance for the PR($-1,0,1,1,0,-1$) channel using RLL encoding.

island periods have been investigated using the PR($-1,0,1,1,0,-1$) channel.

Fig. 4 illustrates the channel performance in terms of plots of BER vs. SNR when the data are encoded using the well-known 2/3 RLL(1,7) coding scheme [8]. Two conditions are illustrated: (i) where the channel density remains constant with respect to the uncoded data, and (ii) where the user density remains constant with respect to the uncoded data; here the channel density has been modified by the code rate, i.e. 20 nm island length, $T_b = 33$ nm.

It can be seen that for RLL encoded data the performance of the read channel has improved, with a potential gain of up to 2 dB (in terms of SNR) for a BER of 10^{-5} over the uncoded system (depending upon the island length and period).

The BER performance in the presence of a SUL was investigated as illustrated in Fig. 5.

The presence of the SUL offers some minor improvement in the BER performance of the channel (for the same PR scheme). Since the pulse widths are similar in both cases, then the slight improvement in performance for the SUL case must arise due to the removal of the overshoot in the pulse response. Further analysis has shown that for the SUL case the E^{2}PR4 channel offers better performance.

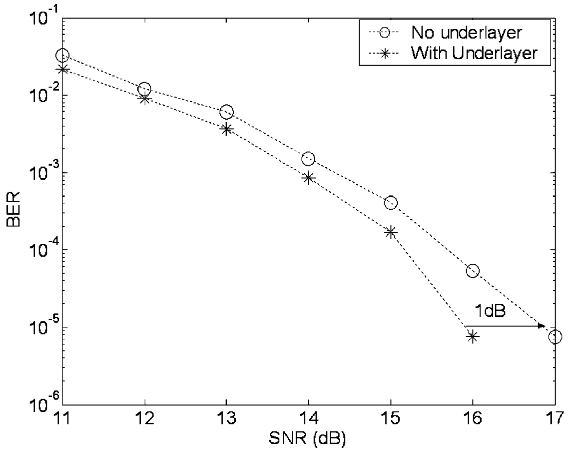

Fig. 5. Channel performance in the presence of a SUL.

Fig. 6 illustrates BER vs. SNR plots for different film thicknesses of 20 nm (thin) and 100 nm (thick).

Optimum performance is observed when a thin film is used (20 nm). This improvement is reasonable considering the fact that the isolated pulse width is wider for the case of the thick medium (100 nm). However, it must be remembered that in the case of a thick medium the pulse amplitude is much greater, which will offer improved noise tolerance.

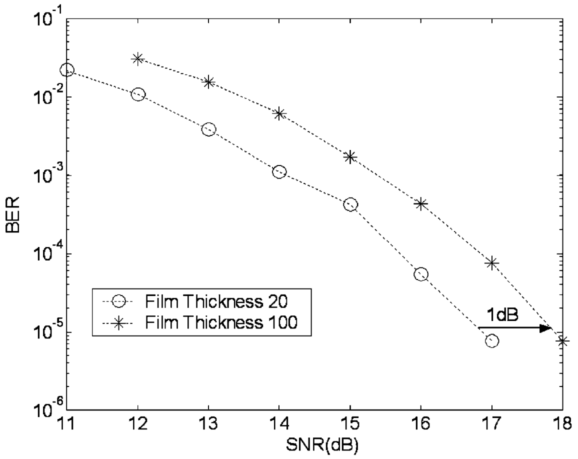

Fig. 6. Channel performance for different film thicknesses (nm).

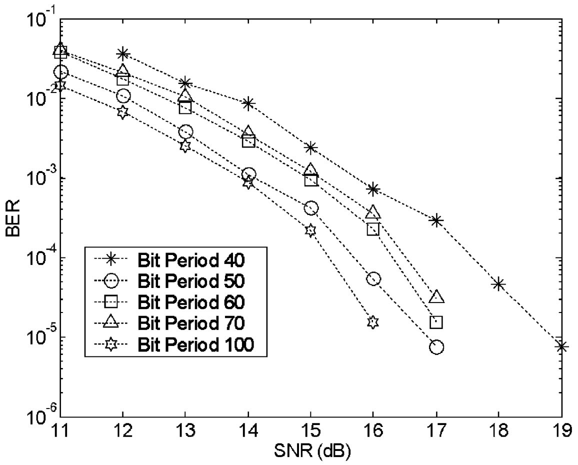

Fig. 7. Channel performance for different island periods (nm).

Another factor that affects the performance of the read channel is the island period. Fig. 7 shows BER vs. SNR curves for different island periods when the island length remains at 30 nm.

It is shown that whilst large island periods offer better performance, this is due to the reduced inter-symbol interference (ISI) and is at the expense of storage density. In the case of shorter island periods, 50 nm offers best performance (which offers comparable performance to that of a 100 nm island period), with the performance degrading as the period is reduced.

5. Conclusions

A flexible channel simulation has been implemented to predict the BER performance of the read channel in a patterned magnetic media storage system. The channel model is able to investigate the effects of the media characteristics, such as the film thickness and presence of a SUL, on the performance of the read channel using read channel strategies suitable for use in perpendicular patterned media storage systems. In addition, the model is capable of analysing the performance of read channels at much higher storage densities (greater than 1 Tbit/in^2).

We have evaluated the performance of read channels for perpendicular patterned media and we have shown that for the particular island length (30 nm) and island period (50 nm) investigated, the PR($-1,0,1,1,0,-1$) channel offers the best performance. Improved performance can be achieved by implementing RLL encoding. In addition, studies have shown that improved performance is observed for a thin recording medium (20 nm) and when a SUL is present.

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