The Performance Comparison Between DC-Full and DC-Attenuation Partial-Response Targets in Perpendicular Magnetic Recording Channel

Yupin Suppakhun\textsuperscript{1}, Pornchai Supnithi\textsuperscript{2}
\textsuperscript{1,2} Faculty of Engineering and Research Center for Communications and Information Technology (ReCCIT)
King Mongkut’s Institute of Technology Ladkrabang
3 Moo 2 Chalongkrung Rd., Ladkrabang, Bangkok, Thailand, 10520.
E-mail: \textsuperscript{1}9060001@kmitl.ac.th, \textsuperscript{2}ksuporn.c@kmitl.ac.th

Abstract: In this paper, we investigate the performance of perpendicular recording channel for dc-full and dc-attenuation partial-response targets under the environment of electronics noise and jitter noise. We compare the performance of partial-response maximum-likelihood (PRML) and noise-predictive maximum-likelihood (NPML) detector for both types of targets. The NPML system is more suited for dc-attenuation targets, whereas the dc-full targets are suited to PRML system at low jitter noise.

1. Introduction

In order to achieve high-density recording, the development of the signal processing schemes matching the perpendicular magnetic recording (PMR) channel is desired. Partial-response maximum-likelihood (PRML) and noise-predictive maximum-likelihood (NPML) detector which are signal processing technique for to day hard disk drive.

In this paper, we investigate the performance of partial-response maximum-likelihood (PRML) and noise-predictive maximum-likelihood (NPML) detector for high density perpendicular magnetic recording (PMR) channel with the environment of electronics noise and media noise. The performance of perpendicular recording channel is consider with dc-full and dc-attenuation targets types. In previous work, perpendicular magnetic recording with PRML detector for dc-full targets give higher performance than the dc-attenuation targets\textsuperscript{[1]}. We report the BER performance of NPML system with dc-attenuation targets can be improved more than to PRML system while the dc-full targets suited to PRML system because can to received nearly gain as the complexity of the viterbi detector is not increased at low jitter noise. The next section of this paper, we overview the read-back system model, targets types of PMR, the NPML system and related parameters. The simulation results and discussions are then illustrated in Section 3. The conclusion is described in Section 4 and the references are in Section 5.

2. Read-back System Model

The read-back system block diagram for the perpendicular magnetic recording is shown in Fig. 1.

The binary random sequences $a_k \in \{ \pm 1 \}$ are input of the channel, where $k$ represents the discrete time index, $k = 1 \ldots K$ ($K$ is total number of transmitted bits). A data input sequence with bit period $T$ is filtered by ideal differentiator (1-D) to form a transition sequence $b_k \in \{-2, 0, 2\}$, where $b_k = \{ \pm 2 \}$ corresponds to a positive and negative transition, and $b_k = \{ 0 \}$ corresponds to the absence of transition. The sequence $b_k$ passing through the channel is convolved with the transition response.

![Figure 1. The read-back system block diagram](image)

The transition response for perpendicular recording can be written as\textsuperscript{[2]},

$$g(t) = \text{erf} \left( 2\sqrt{\ln 2} \right) \frac{2}{\sqrt{\pi}} \int_{0}^{\Delta t_0} e^{-z^2} dz,$$

where $\text{erf}(\cdot)$ is an error function defined as $\text{erf}(x) = \frac{2}{\sqrt{\pi}} \int_{0}^{x} e^{-z^2} dz$, and $PW50$ determines the pulse width of the derivative of $g(t)$. The recorded normalized density is defined by $ND = PW50 / T$. The noise in PMR can be model as a mixture of additive white Gaussian noise (AWGN) with two-sided power spectral density $N_0/2$ and media noise, assume to be transition jitter dominated. We apply a jitter noise modeled as a random shift in the transition position, which has a Gaussian distribution function with zero mean specified as a percentage of $T$ and $\Delta t_k \leq T / 2$. Hence the read-back signal $r(t)$ can be expressed as

$$r(t) = \sum_{k=-\infty}^{\infty} b_k g(t - kT + \Delta t_k) + n(t)\quad (2)$$

where $n(t)$ is additive white Gaussian noise (AWGN), and $\Delta t_k$ is transition jitter noise.

The read-back signal $r(t)$ is filtered by a Butterworth low-pass filter with cutoff frequency at $1/2T$, which is sampled at a symbol rate. Its function is to eliminate out-off-band noise.

The detection process is composed of two components. The first component is a noise predictive filter that reduces distortion (noise) from equalized signal. The second component is the viterbi detector based on trellis of the PR targets with adjusted trellis to the output of the noise predictor.
2.1 Noise-Predictive Maximum-Likelihood (NPML) Detector

Let $y_k$ be output data sequence of the PR equalizer at instant $k$. The finite impulse response (FIR) filter has the polynomial of the PR targets in the form of

$$F(D) = (1 + f_1 D + f_2 D^2 + \ldots + f_N D^N)$$

where the $f_i$ ($i = 1, 2, \ldots, N$) is the coefficients of the filter. The equalized output is

$$y_k = a_k - \sum_{i=1}^N f_i a_{k-i} + w_k$$

where $w_k$ is the colored noise sequences at the output of equalizer. The power of the colored noise component can be reduced by noise prediction. The NPML system uses a predictor with $N$-coefficients. Given the transfer polynomial of the FIR noise predictor filter is $P(D) = (p_1 D + p_2 D^2 + \ldots + p_N D^N)$ or, equivalently, $E(D) = [1 - P(D)]$ denotes the transfer polynomial of the predictor error filter, then the whitened noise component $e_k$ from the predictor can be computed by

$$e_k = w_k - \hat{w}_k$$

$$= w_k - \sum_{i=1}^N w_{k-i} p_i$$

where the noise predicted sample $\hat{w}_k$ can be defined as

$$\hat{w}_k = \sum_{i=1}^N w_{k-i} p_i$$

The length $N$ coefficients of a noise predictor filter are determined by solving the system of well-known normal equation given by [3]

$$R_{ww}(i) = \sum_{j=1}^N p_j R_{ww}(i-j), \quad i = 1, 2, \ldots, N$$

where $R_{ww}$ is the autocorrelation function, which can be written in the matrix form as

$$\begin{bmatrix}
R_{ww}(1) \\
R_{ww}(2) \\
\vdots \\
R_{ww}(N)
\end{bmatrix} =
\begin{bmatrix}
R_{ww}(0) & R_{ww}(1) & \cdots & R_{ww}(N-1) \\
R_{ww}(1) & R_{ww}(0) & \cdots & R_{ww}(N-2) \\
\vdots & \vdots & \ddots & \vdots \\
R_{ww}(N) & R_{ww}(N-1) & \cdots & R_{ww}(0)
\end{bmatrix}
\begin{bmatrix}
p_1 \\
p_2 \\
\vdots \\
p_N
\end{bmatrix}$$

where $\mathbf{R}$ represents the square matrix, $p_i$ is determined by

$$\mathbf{p} = \mathbf{R}^{-1} \mathbf{r}$$

where $\mathbf{p} = [p_1 \ p_2 \ \ldots \ p_N]$ and

$$\mathbf{r} = [R_{ww}(1) \ R_{ww}(2) \ \ldots \ R_{ww}(N)]^T.$$

The NPML detection results from the embedding of the noise prediction/whitening process into the branch metric computation of the viterbi detector. The output of noise predictor error filter $Z_k$ to viterbi detector can be computed by

$$z_k = y_k + \sum_{i=1}^n p_i y_{k-i}$$

or in D domain is

$$z_k = (y_k)[1-P(D)]$$

and

$$H_{eff}(D) = H(D)[1-P(D)]$$

where $H_{eff}(D) = (1-g_1 D - g_2 D^2 - \ldots - g_N D^N + v)$ represents the transfer polynomial of effective targets which corresponds to noise predictor error filter, where the $g_i$ ($i = 1, 2, \ldots, N$) is the $N$-tap coefficients of the effective targets, $v$ is the memory of PR targets and $H(D)$ is partial response targets, then the viterbi detector uses a state trellis with the number of state $2^{N+1}$.

The branch metric of the NPML detector for effective targets samples corresponding to a transition from state $p$ to state $q$ takes the form

$$\lambda_k(p, q) = \left| Z_k - \hat{O}_k(p, q) \right|^2$$

where $\lambda_k(p, q)$ represents the branch metric cost from state $p$ to state $q$, and $\hat{O}_k$ is noiseless channel output from effective targets ($H_{eff}(D)$) defined as

$$\hat{O}_k = a_k * H_{eff}$$

where * denotes the convolution operator.

3. Simulation Results and Discussions

In this section, we present BER simulation results for two targets types for PMR system, and investigate the BER performance in PRML detector and NPML detector. In the simulations, the received sequence $S_k$ is equalized by 21-tap finite impulse response (FIR) filter calculated to minimize the mean-square error (MMSE) of the equalizer output and targets response such that $y_k$ resembles $d_k$. We process each sector consisting of 4096 information bits and let the parameter of normalized recording density (ND) = 2.5, media jitter noise(J2) various 10% 30% and 50%. The noise predictive filter (NP_Tap) is 4 tap. The average BER from the results are plotted versus the SNR(dB). The dc-attenuation targets polynomials are (2 3 0 -1) and (5 6 0 -1), while the dc-full targets are (1 6 7 2) and (4 6 4 2). We compare the performance of PRML and NPML detector at different target types.

In Fig. 2, the BER performance of PRML detector at different targets types between dc-attenuation targets(5 6 0 -1), (2 3 0 -1) and dc-full targets (1 6 7 2), (4 6 4 2) with 10% jitter noise is shown. We can see that the dc-full targets achieve than dc-attenuation targets.
Figure 2. PRML performance between dc-attenuation targets (5 6 0 -1), (2 3 0 -1) and dc-full targets (1 6 7 2), (4 6 4 2)

Figure 3. NPML performance between dc-attenuation targets (5 6 0 -1), (2 3 0 -1) and dc-full targets (1 6 7 2), (4 6 4 2)

In Fig. 3, the BER performance of NPML detector at different targets types between dc-attenuation targets (5 6 0 -1), (2 3 0 -1) and dc-full targets (1 6 7 2), (4 6 4 2) versus the system performance is shown. We can see at higher SNR, the dc-attenuation targets achieves better performance than dc-attenuation targets. For the example, at BER ≈ 1 × 10^{-4}, the dc-attenuation targets (5 6 0 -1) have gain more than dc-full targets (4 6 4 2) about 1.8 dB at the jitter noise is 10% and noise predictor is 4 tap.

In Fig. 4, the BER performance of PRML and NPML detector base on dc-full targets (1 6 7 2) with transition jitter noise of 10% 30% and 50%. We found that the NPML detector achieves better performance than PRML detector.

Figure 4. PRML and NPML performance of percentages jitter noise various base on dc-full targets (1 6 7 2)

Figure 5. PRML and NPML performance of percentages jitter noise various base on dc-attenuation targets (5 6 0 -1)

In Fig. 5, the BER performance of PRML and NPML detector base on dc-attenuation targets (5 6 0 -1) with media-noise-dominant model, the NPML detector achieves higher improvement gain over PRML detector at high SNR.

4. Conclusions

We investigate using PRML and NPML detector partial response targets types appropriate for high density perpendicular magnetic recording (PMR) channel with the environment of electronics noise and jitter noise. From the simulation results, The bit error rate (BER) performance of NPML system with dc-attenuation targets is better than that of PRML system, while the dc-full targets is more suited to PRML system at low jitter noise. However, with media-noise-dominant model, the NPML detector achieves higher improvement gain over PRML detector at high SNR.
5. References


