Effect of Cutoff Frequency of Lowpass Filter on the Performance of Perpendicular Magnetic Recording Channel

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Abstract

In this paper, the effect of cutoff frequency of the front-end low-pass filter on the performance of perpendicular recording channel is investigated. With positive and negative deviation from the nominal value, the partial -response maximum-likelihood (PRML) system shows more degradation by the positive deviation than the negative one. The noise-predictive maximum-likelihood (NPML) system shows the results otherwise.

Introduction

Current magnetic recording system employs perpendicular media , thus the transition response is vastly different from the longitudinal media with existent dc component. The front-end components in the read channel chip consists of variable gain amplifier (VGA), amplitude asymmetry correction, thermal asperity (TA) detection and correction and low-pass filter. The low-pass filter has a function of suppressing the out-of-band noise. Its coefficients, cut off frequency, frequency boost factor among others can be adapted for each media and read-write system so that bit error rate (BER) can be optimized. In this paper, we aim to investigate the influence of the cutoff frequency deviation to the system performance, in particular, the PRML and NPML detector in the environment of electronics noise and jitter noise. In Section 2, we overview the readback system model, 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.

Readback System Model

The readback system block diagram for the perpendicular magnetic recording is shown in Figure 1.

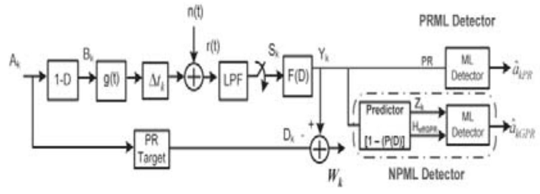

Figure 1. The readback system block diagram

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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.

The transition response for perpendicular recording can be written as(Kovintavewat et al., 2002).

$$g(t) = erf\left(\frac{2t\sqrt{ln2}}{PW50}\right) \qquad (1)$$

where *erf* (.) is an error function defined as $erf(x) = \frac{2}{\sqrt{\pi}}\int_0^x e^{-z^2} dz$, and $PW50$ determines the pulse width of the derivative of $g(t)$. The recorded normalized density is defined by $ND = PW50/T$, hence, the readback signal $r(t)$ can be expressed as

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

where $n(t)$ is additive white Gaussian noise (AWGN) with two-sided power spectral density $No/2$, and Δt_k is jitter noise modeled as a random shift in the transition position, which has a Gaussian distribution function with zero mean and variance $\sigma_j{}^2$,where σ_j isspecified as a percentage of T and $|\Delta t_k| \le T/2$.

The readback signal $r(t)$ is filtered by a Butterworth lowpass 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 target with adjusted trellis adjusted by output of the noise predictor.

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 target in the form of $F(D)=(1 + f_1 D + f_2 D^2 + \ldots + f_N D^N)$, where the $fi(i = 2,\ldots,N)$ is the coefficients of the filter. The equalized output is

$$y_k = a_k + \sum_{i=1}^{n} f_i a_{k-i} + w_k \qquad (3)$$

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 $P(D)=(1 + p_1 D + p_2 D^2 + \ldots + p_N D^N)$ 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

$$\begin{aligned} e_k &= w_k - \hat{w}_k \\ &= w_k - \sum_{i=1}^{N} w_{k-i}\, p_i \quad , \end{aligned} \qquad (4)$$

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

$$\hat{w}_k = \sum_{i=1}^{N} w_{k-i}\, p_i \qquad (5)$$

The coefficients of a noise predictor filter are determined by solving the system of well-known normal equation given by and variance $\sigma_j{}^2$, where σ_j is

$$R_{ww}(i)=\sum_{j=1}^{N} p_i R_{ww}(i-j)\,, \qquad i=1,2,\ldots,N \qquad (6)$$

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

$$\underbrace{\begin{bmatrix} R_{ww}(1) \\ R_{ww}(2) \\ \cdot \\ \cdot \\ \cdot \\ R_{ww}(N) \end{bmatrix}}_{\mathbf{r}} = \underbrace{\begin{bmatrix} R_{ww}(0) & R_{ww}(1) & \cdot\;\cdot\;\cdot & R_{ww}(N-1) \\ R_{ww}(1) & R_{ww}(0) & \cdot\;\cdot\;\cdot & R_{ww}(N-2) \\ \cdot & \cdot & \cdot\;\;\;\cdot & \cdot \\ \cdot & \cdot & \cdot\;\;\;\cdot & \cdot \\ \cdot & \cdot & \cdot\;\;\;\cdot & \cdot \\ R_{ww}(N-1) & R_{ww}(1) & \cdot\;\cdot\;\cdot & R_{ww}(0) \end{bmatrix}}_{\mathbf{R}} \underbrace{\begin{bmatrix} p_1 \\ p_2 \\ \cdot \\ \cdot \\ \cdot \\ p_N \end{bmatrix}}_{\mathbf{p}}, \qquad (7)$$

where R represents the square matrix, p_i is determined by

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 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 in D domain term is

$$Z_k\ = (y_k)[1\text{-}P(D), \qquad (9)$$

and

$$H_{eff}(D)\ =\ (H(D))[1\text{-}P(D)], \qquad (10)$$

where $H_{eff}(D)\ =\ (1 - g_1D\text{-}g_2D^2\text{-}\ldots\text{-}g_N+_vD^{N+v}$ represents the transfer polynomial of effective target which corresponds to noise predictor error filter, where the gi ($i = 1, 2,\ldots,N$) is the N-tap coefficients of the effective target, v is the memory of PR target and $H(D)$ is partial response target, then the viterbi detector uses a state trellis with the number of state $2^{\,N+v}$.

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

$$\lambda_k(p,q)\ \ =\ \ \left|Z_k-\hat{O}_k(p,q)\right|^2 \qquad (11)$$

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 target ($H_{eff}(D)$) defined as

$$\hat{O}_k\ \ =\ \ a_k * H_{eff} \qquad (12)$$

Where * denotes the convolution operator.

Simulation Results and Discussions

In this section, we present BER simulation results for various percentage of cutoff frequency (%Wn) on infinite impulse response(IIR) low pass filter, and investigate the BER performance in PRML detector and NPML detector at DC-Attenuation target (5 6 0 -1). 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 target 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) = 10%. and noise predictive filter (NP_Tap) = 4 tap. The average BER from the results are plotted versus the SNR(dB). The percentages of cutoff frequency that deviates from the nominal value 1/2T may be positive or negative. For example, with +/-10% deviation, Wn = 110 and Wn = 90, respectively , with +20%

deviation, Wn = 120, and with -30% deviation, Wn = 70. In Figure 2, the NPML detector at different percentages cutoff frequency versus the system performance is shown. We can see that the performance degrades as %Wn changes, for example at BER = 2×10^{-4} with Wn = 70, there is an error loss of 1.2 dB compared with the case when the cutoff frequency is at 1/2T (Wn = 100).

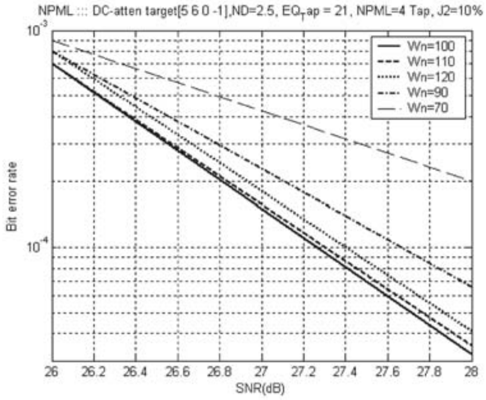

Figure 2. NPML performance of percentages cutoff frequency various base on DC-attenuation target(5 6 0 -1)

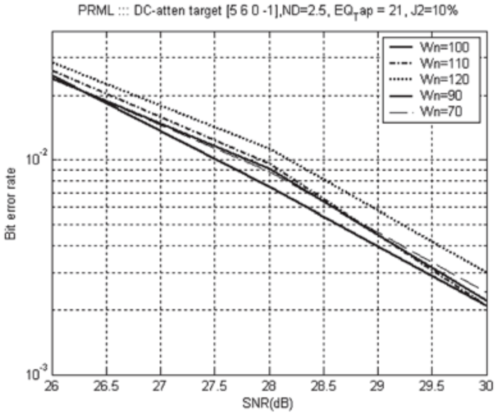

Figure 3. PRML performance of percentages cutoff frequency various base on DC-attenuation target(5 6 0 -1)

In Figure 3 the BER performance of PRML detector system affected by %Wn is shown. The performance degrades more with positive deviation from nominal cut frequency compared with the negative one. For example, at BER = 3×10^{-3} with Wn = 120, there is an error loss of 0.6 dB compared with the nominal cutoff frequency.

Conclusions

We have investigated the effect of cutoff frequency percentage various of LPF in perpendicular magnetic recording channel model in terms of the BER performance of PRML and NPML detector for DC-attenuation PR target. From the simulation results, the NPML performance is affected by the negative deviation of cutoff frequency more than the positive one. On the contrary, the PRML performance is affected by the positive deviation of cutoff frequency more than the negative one.

References

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