Magnetic Recording Channel Model with Intertrack Interference *

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Abstract—**We propose a magnetic recording channel model incorporating both old information (OI) present in the guard band and data from adjacent tracks. We model the side reading properties of the head using the reciprocity integral to compute the flux transition response. Using a result of Lindholm[1] to represent the field of an inductive head, we compute specific channel models for various values of misregistration.**

This channel model is useful for the design and evaluation of future detection algorithms. It can be easily extended to include the effects of media noise and pulse distortion. The inclusion of intertrack interference and OI in the model facilitates study of system performance vs. track density.

1. INTRODUCTION

At high track densities, interference from adjacent tracks has a significant effect on magnetic disk system performance. Model–based detection schemes such as sequence detection and Decision Feedback Equalization (DFE) have recently been proposed as alternatives to peak detection [2, 3]. Both sequence detection and DFE rely on an accurate model of the channel to equalize it to a fixed response. An accurate channel model including intertrack interference will improve the performance of these techniques.

We propose a multichannel model for saturation recording which includes interference from adjacent tracks. In saturation recording, the signal is recorded as a series of flux reversals on the medium. Each track is a pulse amplitude modulated (PAM) signal, where the pulse shape is the system response to a flux reversal. The old information (OI) in each guard band is also modeled as a single PAM signal. The incorporation of OI in the model also allows the simulation of the 747 curve[4] for a given system and detector, and facilitates realistic studies of the tradeoff between track and linear density. We determine the pulse shape as a function of the head–to–track registration for each adjacent track and OI track. The pulse shapes are computed using the reciprocity integral.

2. MULTICHANNEL MODEL

For generality, we model the magnetic recording process as L adjacent channels detected by K sensors. This model will thus be capable of simulating future multihead systems, which offer the prospect of effective cancellation of intertrack interference. In most applications the number of sensors will be the same as the number of detected tracks. It may, however, be advantageous to have $K > L$ for the purpose of fine servoing of the head position, as in the case of three heads side by side detecting a single track. Another example which has been proposed[5] involves three heads detecting two tracks.

Each of the L channels in the model is a track recorded on the medium whose information is modeled as a PAM signal. Each of the K sensors is a read head element. The sensor responds to the track beneath it as well as two adjacent channels on each side of the sensor. One channel on each side is an adjacent track and the second channel represents old information (OI) recorded in the guard band between tracks.

The channel is modeled in discrete time by combining the read head response with the filtering, sampling and equalizing functions in the receiver. The l^{th} channel signal $e_l(n)$ is given by:

$$e_l(n) = \sum_{j=-M}^{N-1} \theta_{lj} p_{ll}(n-j) + \sum_{k=l-2,k\neq l}^{l+2} \sum_{j=-M}^{N-1} \theta_{kj} p_{kl}(n-j) + \eta(n), \tag{1}$$

where $\{\theta_{lj}\}$ represent the data stream along the track being detected and the double sum represents the response to data $\{\theta_{kj}\}$ in the adjacent two tracks and two guard bands. The noise $\eta(n)$ is Gaussian.

The discrete time response for a single track $p_{kl}(n)$ is formed by sampling the convolution of the read head with the impulse response of the front end filter, and then convolving that discrete time function with the equalizer response:

$$p_{kl}(n) = \sum_{m=1}^{K} [p_{km}(t-\tau_{km}) * h(t)]_{(t=nT+\tau_l)} * f_{ml}(n). \tag{2}$$

This equation is illustrated schematically in Fig. 1. Note that there are $(2L+3)$ input channels consisting of: the L tracks which are to be detected; one interfering track on each side of those L tracks; and $L+1$ channels of OI, one for each guard band between the $L+2$ tracks.

The head response $p_{km}(t)$ is a function of head–to–track registration and the width of the track as well as

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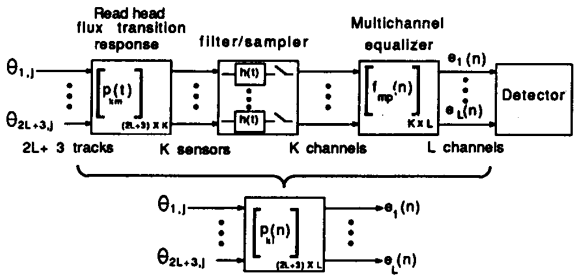

Figure 1: Derivation of discrete time channel model

various read process parameters such as flying height, head geometry, media thickness, etc. A phase τ_l is included for each track in case the tracks are not phase-synchronous. Each pulse has its own phase τ_{km}, which can be made random to simulate phase jitter or data-dependent to simulate peak shift.

There are two additive Gaussian noise sources in the channel: electronic noise and media noise. At the input to the filter $h(t)$ the electronic noise is assumed to be white and the media noise is colored with the same spectrum as the on-track head response. The discrete time noise for each channel is further colored by filtering, sampling, and equalization:

$$\eta_l(n) = \sum_{m=1}^{L} [\eta_m(t) * h(t)]_{(t=nT+\tau_l)} * f_{ml}(n). \quad (3)$$

The channel model presented here is linear, but nonlinearities can be easily incorporated into it. Peak shift can be incorporated into the channel by making the phase of each pulse $p_{kl}(n)$ dependent on preceding and succeeding data. Pulse distortion can be incorporated by varying the pulse shape.

3. GENERATION OF THE MODEL

The read process is essentially linear, so in saturation recording the total read head response is the superposition of its responses to individual flux reversals in the medium. Thus, the read head output is a PAM signal with the pulse shape equal to the head response to an individual flux reversal[1]. The channel model is constructed by computing the pulse shape of the head response to a flux reversal as a function of head-to-track registration y_0 and the width of the flux reversal w. For each pulse $p_{lk}(t; w, y_0)$, w and y_0 are simple functions of the read process parameters, defined in Table 1. For the on-track pulse shape $p_{ll}(t)$:

$$\begin{aligned} w &= w_t; \\ y_0 &= m_{wr}. \end{aligned} \quad (4)$$

Parameter	Symbol
Flying height	d
Head gap	g
Head velocity	V .
Media thickness	δ
Nominal track width	w_t
Track pitch	y_{tp}
Erasure band width	w_e
Head width	w_h
Width of flux reversal	a_x
Write-to-write misregistration	m_{ww}
Write-to-read misregistration	m_{wr}

Table 1: System parameters

For an adjacent track pulse:

$$\begin{aligned} w &= w_t; \\ y_0 &= y_{tp} + m_{ww} + m_{wr}. \end{aligned} \quad (5)$$

For OI in an adjacent guard band:

$$\begin{aligned} w &= y_{tp} - w_t - m_{ww} - 2w_e; \\ y_0 &= y_{tp}/2 + m_{wr} - m_{ww}. \end{aligned} \quad (6)$$

Fig. 2 illustrates the head-to-track geometry as well as the definition of w_t, y_{tp}, m_{wr}, and m_{ww}.

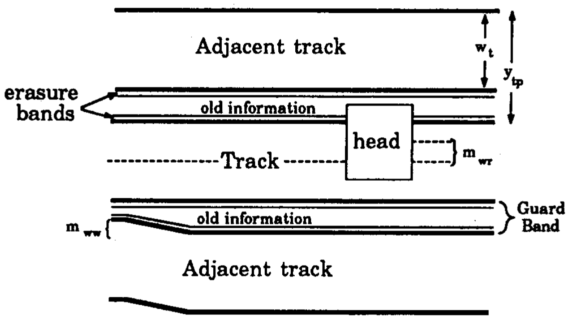

Figure 2: Read process geometry

The reciprocity equation (7) computes the convolution of the H field of the head with the magnetization M of the medium along the direction of the head motion (x), averaged over the volume of the flux reversal, to yield the pulse $p(\overline{x})$, where $\overline{x} = Vt$[6]. The flux transition is assumed to reside in a rectangular volume of thickness δ, width w, and length l:

$$p(\overline{x}; w, y_0) = -\mu V \cdot \int_{d}^{d+\delta} dz \int_{y_0-w/2}^{y_0+w/2} dy \int_{-l/2}^{l/2} \frac{\partial M_x(x-\overline{x}, y, z)}{\partial \overline{x}} \cdot \frac{H_x(x, y, z)}{i} dx. \quad (7)$$

The media is assumed to be longitudinal, so only the x components of M and H figure in the dot product.

As an example of the model, we have computed the pulse shapes for a representative set of system parameters. Our aim is to incorporate enough detail to illustrate

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[1] The response $p_{ll}(n)$ is known as the *step response* in this case, where the data is ternary. If the data is binary, the response is known as the *pulse response*. The ternary data is the same as the binary data passed through a $(1 - D)$ operator, and the pulse response is the same as the step response passed through a $(1 - D)$ operator.

salient properties of the signals and interferences, but to refrain from modeling a particular system. We represent the magnetization of a flux reversal with an arctangent function:

$$M(x-\overline{x}) = tan^{-1}\left(\frac{x-\overline{x}}{a_x}\right). \qquad (8)$$

We chose a result by Lindholm [1] to represent the head field. Lindholm derived his expression for a finite width inductive head by superimposing the head fields of opposing semi–infinite width heads and subtracting the Karlquist head field expression.

We assumed the following system parameter values for the computation: $w_h/g = 10$, $w_h/d = 20$, $d/\delta = 4$, $w_h/w_t = 1$, $g/a_x = 2$, $w_t/y_{tp} = 0.80$, $w_e/y_{tp} = 0.05$. We also assumed m_{ww} was zero. The reciprocity integral was computed to generate the pulse shapes for the track under the head, the OI in the two adjacent guard bands, and the two adjacent tracks. The results for zero m_{wr} are shown in Fig. 3. The pulses are symmetrical due to the symmetry of the expressions for the head field and flux reversal magnetization, thus only half of each pulse is plotted. The results for $m_{wr} = w_t/10$ are shown in Fig. 4. Notice that the adjacent track pulses and OI pulses are much wider, as well as much lower in amplitude, than the on–track pulse. This effect can be explained by looking at the reciprocity equation. The width of the pulse will increase monotonically with the widths of the H and the M fields in the x dimension because the reciprocity equation performs a convolution in x. The head field is more focussed directly underneath the head and is more diffuse away from head in the case of side reading. The pulse is therefore wider when the head is reading from an adjacent track than a track directly beneath the head.

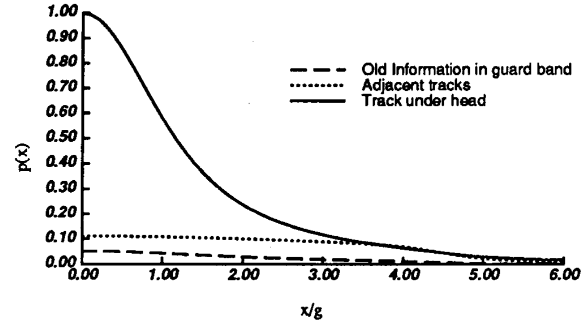

Figure 3: Pulse Shapes with Zero Misregistration

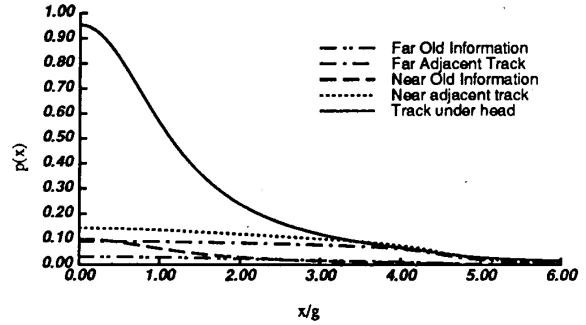

Figure 4: Pulse Shapes with 10% Misregistration

We have constructed a general channel model for the case of an inductive head, but the same method can be used to describe a particular system by replacing the result of the reciprocity integral with direct measurement of the pulse shape as a function of head–to–track registration. Also, different expressions for the head field and magnetization can be used. In place of the Lindholm head field, the field for a pole tip head or a magnetoresistive head can be substituted. Micromagnetic simulation can be used to approximate the flux transition magnetization more closely. In addition, the model itself may be modified to include nonlinearities due to pulse crowding.

4. SUMMARY

We propose a multichannel model for the magnetic recording channel. The model is useful both for simulation to rapidly evaluate detection schemes, as well as to direct the design of new detectors. It incorporates interference both from adjacent tracks and OI in the guard band, with the response modeled individually for each track. This will aid in realistic tradeoff studies of linear vs. track density in magnetic disk system design.

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