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Research Report

A Channel Model for a Magnetic Tape Storage System with Dropouts

Sundararajan Sankaranarayanan,[1] Jens Jelitto,[2] Evangelos Eleftheriou,[2] and Bane Vasić[1]

[1]Department of Electrical and Computer Engineering
University of Arizona
Tucson, AZ 85721
USA

E-mail: ssundar@ece.arizona.edu, vasic@ece.arizona.edu

[2]IBM Research GmbH
Zurich Research Laboratory
8803 Rüschlikon
Switzerland

E-mail: jje@zurich.ibm.com, ele@zurich.ibm.com

A Channel Model for a Magnetic Tape Storage System with Dropouts

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Abstract— **Dropout events are one of the main contributors to errors in magnetic tape storage systems, and their deteriorating effects are manifested in the read-back signal. The first step in designing signal-processing and/or coding solutions to alleviate dropout events is to model these events. In this paper, we present a channel model defined by a time-varying filter that captures the increased intersymbol interference effects and read-back signal-attenuation effects of dropout events. In addition, we present an efficient software implementation of the dropout-channel model.**

I. Introduction

In a magnetic tape storage system, a *dropout* event results in the deterioration of the read-back signal spanning over tens or hundreds of bits. The main sources of dropouts are asperities in the magnetic medium and loose (or dust) particles on the medium. For example, the magnetic head rubbing against a dust particle on the medium can increase the head-to-medium spacing, resulting in a dropout event. A dropout event can occur during the write and/or the read process. It can result in a decrease of the amplitude of the read-back signal, an increase in the intersymbol interference effects of the channel, and a spatial shift in the transition peak during the write process.

In this paper, we assume that dropouts are caused by an increase in the head-to-medium spacing during the write and/or the read process. In Section II, we present the channel model conventionally used in simulations of magnetic read-channels. In Section III, we introduce a time-varying component to the channel model in order to take into account the effects of dropouts. A statistical characterization of dropout events is presented in Section IV. Such a statistical model is necessary to simulate dropout events using the simulation model presented in Section V. We conclude this paper with a few thoughts on improving the quality of the model, especially the statistical model, by studying experimentally captured dropout events.

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S. Sankaranarayanan and B. Vasić are with the Department of Electrical and Computer Engineering, University of Arizona, Tucson, AZ 85721 USA (email: ssundar@ece.arizona.edu, vasic@ece.arizona.edu).

J. Jelitto and E. Eleftheriou are with the IBM Zurich Research Laboratory, 8803 Rüschlikon, Switzerland (email: jje@zurich.ibm.com, ele@zurich.ibm.com).

II. Magnetic Channel Model

The noiseless read-back signal of a tape channel for a positive transition is well-modeled mathematically as

$$h_{\text{step}}(x) = \left[\frac{1}{1 + \left(\frac{2x}{\text{PW}_{50}} \right)^2} \right], \tag{1}$$

where PW_{50} is the full width between half-maximum amplitude points of $h_{\text{step}}(x)$. As the tape medium is magnetized by transitions in the input levels, the BPSK-modulated input data bits are passed through a $(1 - D)$ filter in order to compute these transitions. The output of the $(1 - D)$ filter convolved with $h_{\text{step}}(x)$ models the noiseless read-back signal of the BPSK-modulated input data bits. Several models for noise characteristics of the magnetic channel are available in literature. As the aim of the paper is to present a model for the magnetic recording channel with dropouts, we have chosen to omit details on noise models.

III. A Model for the Magnetic Channel with Dropouts

The dropout model proposed in [1] captures the signal-degrading effects of a dropout event due to an increase in the head-to-medium spacing. Combining the results from [2] and [3], the authors of [1] have designed a time-varying linear filter with a frequency response $S(f, t)$ at time t to model the effects of dropout events that occur during both the read and the write process:

$$S(f, t) = e^{-2\pi\gamma\Delta d(t)|f|}, \tag{2}$$

where f represents the frequency, γ is a constant, and $\Delta d(t)$ is the liftoff at time t. The liftoff at a time t is assumed to take a value from $[0, \infty]$. The head-to-tape velocity is assumed to be a part of the constant γ. The inverse Fourier transform of $S(f, t)$ resembles a Lorentzian pulse, and can be written as

$$s(x, t) = \left[\frac{1}{\pi\gamma\Delta d(t)} \right] \left[\frac{1}{1 + \left(\frac{x}{\gamma\Delta d(t)} \right)^2} \right]. \tag{3}$$

A time-varying linear channel filter $h_{\text{step}}(x, t)$ is designed by convolving $s(x, t)$ and the isolated transition response $h_{\text{step}}(x)$. Note that $h_{\text{step}}(x, t)$ is a function of time t whereas the isolated

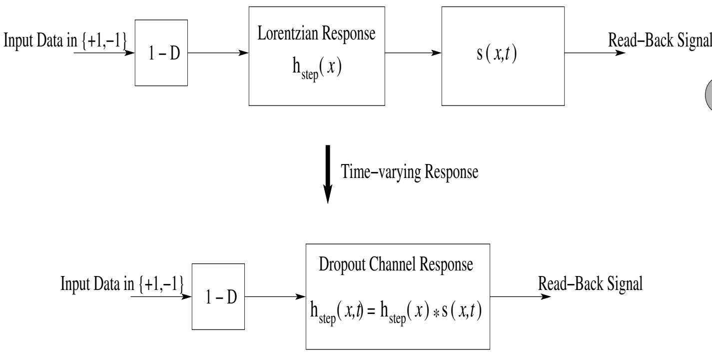

Fig. 1. Model for magnetic channel with dropouts

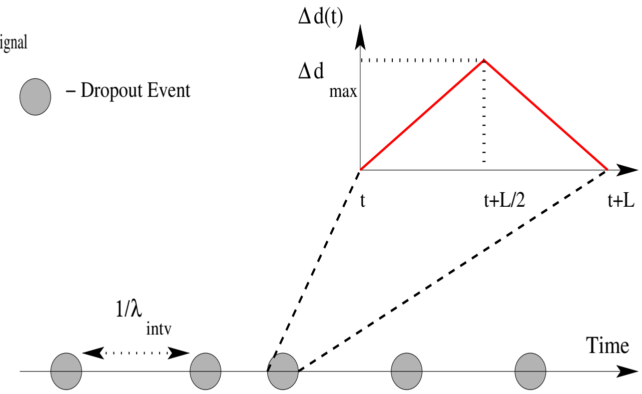

Fig. 2. Statisitcal model of dropouts

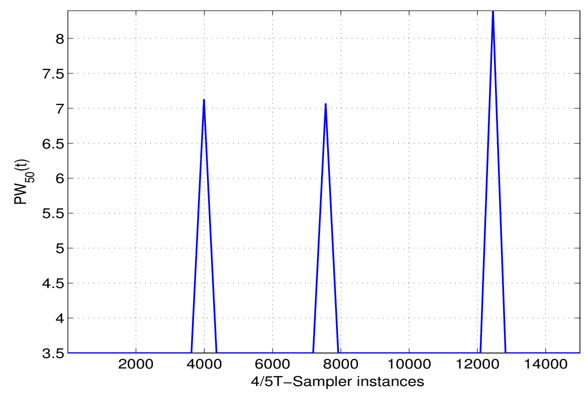

Fig. 3. Snapshot of the $\mathrm{PW}_{50}(t)$ profile

transition response is time-invariant:

$$\begin{aligned} h_{\text{step}}(x,t) &= h_{\text{step}}(x) * s(x,t) \\ &= \left[\frac{\mathrm{PW}_{50}}{2\gamma\Delta d(t)+\mathrm{PW}_{50}}\right]\left[\frac{1}{1+\left(\frac{2x}{2\gamma\Delta d(t)+\mathrm{PW}_{50}}\right)^2}\right] \\ &= \frac{\mathrm{PW}_{50}}{\mathrm{PW}_{50}(t)}\left[\frac{1}{1+\left(\frac{2x}{\mathrm{PW}_{50}(t)}\right)^2}\right], \end{aligned} \tag{4}$$

where $\mathrm{PW}_{50}(t) := \mathrm{PW}_{50} + 2\gamma\Delta d(t)$. At any time t, the channel filter is an attenuated Lorentzian pulse with the width parameter of $\mathrm{PW}_{50}(t)$ and an attenuation factor of $\frac{\mathrm{PW}_{50}}{\mathrm{PW}_{50}(t)}$. In [1], the authors discuss other attenuation factors for periodic read-back waveforms. Here, we have used (4) to define the time-varying channel filter. In Fig. 1, the time-invariant channel filter has been replaced by the time-varying channel filter $h_{\text{step}}(x,t)$.

The spatial shift in the positions of transitions during the write process is referred to as the *peak-shift* effect. An increase in the head-to-medium spacing can result in peak shift effects. In [1], the amount of peak-shift was reported to be linearly proportional to $\Delta d(t)$. In our simulation model, we choose to capture the peak-shift effect by increasing the intensity of the position jitter parameter σ_j^2.

IV. Statistical Model of Dropouts

The length L of a dropout event is defined as the number of bits such an event spans. In other words, a dropout event of length L lasts for a duration of LT, and in that duration $\Delta d(t)$ take non zero values. Although short dropouts are more likely than long ones, the probability that a long dropout occurs is not negligible. The length of a dropout event is modelled to follow an exponential distribution with a mean of $\frac{1}{\lambda_{\text{L}}}$.

The occurrence of dropout events is modelled as a Poisson process, and consequently the inter-dropout time follows an exponential distribution with a mean of $\frac{1}{\lambda_{\text{intv}}}$. The *inter-dropout* time is defined as the time duration between the end of a dropout event and the start of the next dropout event. This definition of the inter-dropout time is necessary to guarantee its exponential distribution in simulations.

The intensity of a dropout event is defined by the maximum liftoff $\Delta d_{\max}$ achieved in that event; $\Delta d_{\max}$ is assumed to follow an exponential distribution with a mean of $\frac{1}{\lambda_{\text{drop}}}$ [4]. In a dropout event, the liftoff is assumed to follow a triangular profile, reaching $\Delta d_{\max}$ at the center of the event. A different liftoff profile, such as a Lorentzian function [1], can also be chosen.

An illustration of this statistical model of dropouts is shown in Fig. 2.

V. Implementation of the Dropout-Channel Model

In the simulation model, the time-varying channel filter $h_{\text{step}}(x,t)$ replaces the time-invariant channel filter $h_{\text{step}}(x)$. A discrete-time implementation of $h_{\text{step}}(x,t)$ in the simulation model, programmed in C, is operated in an oversampled domain. The dropout realization over a user-specified time duration is generated, based on the user-specified statistical parameters, prior to the write and the read process. Figure 3 illustrates the $\mathrm{PW}_{50}(t)$ profile in a window of approximately 11200 input bits. The last dropout event captured in the illustration is more severe than the two preceding events.

If a dropout occurs, the coefficients of the discrete-time equivalent of the $h_{\text{step}}(x,t)$ filter have to be generated for every value of discrete-time. In Figure 4, we illustrate the time-varying responses of the channel filter for a dropout. The x-axis of the plot is the $\frac{T}{16}$-sampled time and the y-axis is the amplitude of the filter responses. The PW_{50} of the filter responses vary from a minimum of 3.5 to a maximum of 6.75.

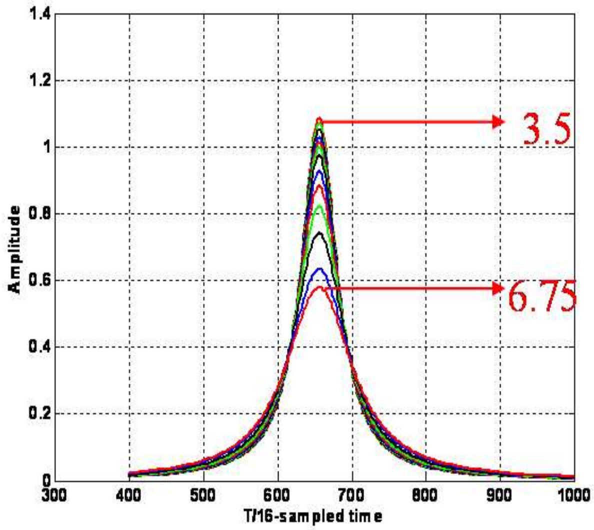

Fig. 4. Time-varying channel responses during a dropout event

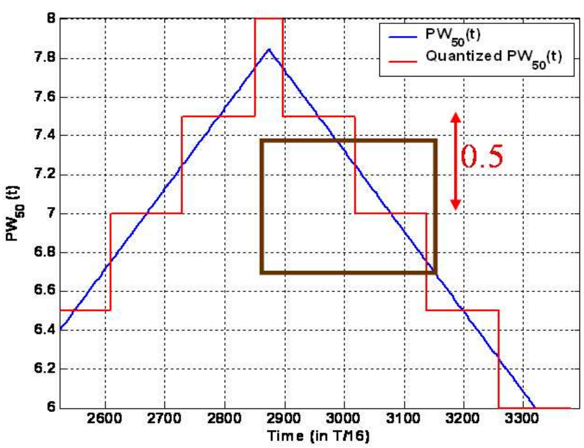

Fig. 5. Uniform quantization of $\text{PW}_{50}(t)$ profile

Such an implementation has been observed to increase the simulation time dramatically. Therefore, we have chosen to quantize $\Delta d(t)$. As the dropout realizations are generated prior to the write and the read process, we generate and store the coefficients of channel filters corresponding to various quantized values of $\Delta d(t)$ at the beginning of the simulation. In Figure 5, we have defined two quantization levels within every unit interval of PW_{50}.

Thus, in the event of a dropout, it is a matter of picking a channel filter from the filter bank based on the quantized $\Delta d(t)$ at time t. This helps to improve the speed of the simulation at the price of a loss of accuracy in the read-back signal waveform. In the region of a dropout, the amplitude of the read-back signal obtained from the $\Delta d(t)$-quantized implementation is at most $\pm 4\%$ away from that obtained from the unquantized implementation. In Figure 6, we show that the error between read-back signals obtained from quantized and those from unquantized implementations depends on the

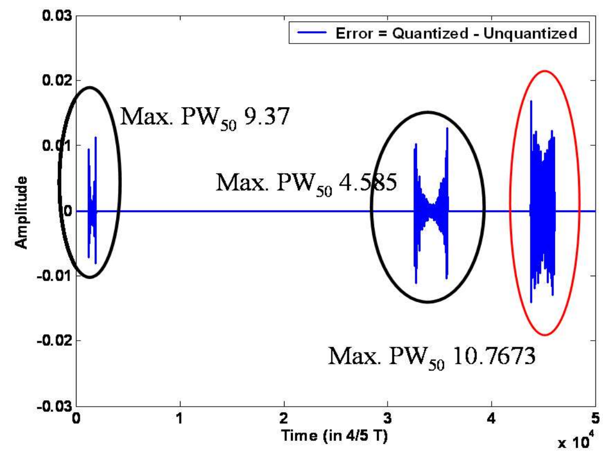

Fig. 6. Error between read-back signals from quantized and unquantized implementations

intensity of the dropout and on the fineness of quantization. A nonuniform quantization with finer quantization in a small PW_{50} region and coarse quantization in a large PW_{50} region is suggested to improve the accuracy of the read-back signal.

VI. Conclusion

The dropout-channel model presented in this paper can be improved by analyzing experimentally captured dropout events. The statistical model of dropout events has to be adjusted to suit dropout statistics computed by running experiments. Also, experiments are under way to find reasonable parametric values of the dropout-channel model.

References

[1] Fatih Sarigoz, Hongwei Song, B. V. K. Vijaya Kumar, and James A. Bain, “Dropout tolerant read channels,” *IEEE Jour. Sel. Are. Comm.*, vol. 19, no. 4, pp. 744-755, April 2004.

[2] R. L. Wallace, Jr., “The reproduction of magnetically recorded signals,” *Bell Syst. Tech. J.*, vol. 30, pp. 1145-1173, 1951.

[3] H. N. Bertram, and R. Niedermayer, “The effect of spacing on demagnetization in magnetic recording,” *IEEE Trans. Magn.*, vol. MAG-18, pp. 1206-1208, Nov. 1982.

[4] B. Steingrimsson, J. Moon, “Dropout Compensation in Magnetic Tape Channels by Adaptive Equalization and Coding,” *IEEE Trans. Magn.*, vol. 37, no. 6, pp. 3981-3993, Nov 2001.