Physics Based Time Domain Simulation of Magnetic Recording Signal and Noise

Xiaobin Wang\textsuperscript{1}, Zhen Jin\textsuperscript{2}, Xuebing Feng\textsuperscript{1}, and Dimitar Dimitrov\textsuperscript{1}

\textsuperscript{1}Seagate Technology, Bloomington, USA
\textsuperscript{2}Hitachi Global Storage Technology, San Jose, USA

Abstract — Progresses of a fast time domain simulator for magnetic recording signal and noise waveforms are reported. The simulator is a combination of recording physics calculation, micro-magnetic simulation and experimental data information extraction. The simulator takes head media physics parameters as inputs and calibrates to measurements at current area density and scales to recording system at higher area density. It can generate millions of bits in short times, suitable for equalized signal to noise and channel bit error rate simulation. Key topics discussed in this paper to illustrate our techniques include: newly developed transition noise formula and its validation to micro-magnetic simulation, synthesizing time domain position-dependent transition jittering noise and colored electronic noise from measurement data, effects of non-saturation DC noise and head jittering on signal and noise waveforms.

1. INTRODUCTION

Accurately simulating signal and noise waveforms from basic recording head/media physics parameters is a challenge task. This paper reports the progress of a fast time domain simulator for magnetic recording signal and noise waveforms. In order to generate millions of bits for equalized Signal to noise ratio (SNR) and channel bit error rate simulation at short computational times, the simulator combines recording physics calculation, micro-magnetic simulations and experimental data information extraction. The simulator takes head/media physics parameters as inputs, calibrates to measurements at current area density and scales to recording system at higher area density.

After a brief introduction to the simulator procedure in Section 2, progresses in key features of the simulator are discussed. Section 3 discusses analysis and synthesis transition noise based upon newly developed physics formula and demonstrates the validation to micro-magnetic simulation. Section 4 explains our procedure of synthesizing and scaling colored electronic noise waveform in time domain from measurement noise in frequency domain. Effects of non-saturation DC noise and head jittering on signal and noise waveforms are studied in Section 5.

2. SIMULATING PROCEDURE

Random bits waveforms generated by simulator include read-back signal, noise and nonlinear distortion [1]. Key parameters for signal are pulse width and amplitude. Averaged read-back signal width (TW65) mainly depends upon written transition width on media, reader geometry and head media spacing. For high area density recording, signal amplitude quality is strongly affected by written pattern saturation level on the media. In the simulator, parameters of read-back signal are obtained from regression on micro-magnetic simulation. Micro-magnetic read-back simulation is performed to provide pulse width dependence upon given media transition width, reader geometry and head media spacing. Media saturation level in the simulator is determined by writing head field magnitude and regression equation on media magnetization vs external field (MH loop). Media saturation level determines read-back amplitude through regression on micro-magnetic read-back. Noise sources in the simulator include transition noise, electronic noise, DC saturation noise and additional head jittering noise. Detailed noise analysis, synthesizing and scaling will be discussed through Section 3 to Section 5. This paper mainly focuses on signal and noise treatment, particularly on recording noise generation. A novel lookup table technique is used to generate leading and higher orders of nonlinear distortion in the simulator. However, due to paper length constrain, the detailed discussion of nonlinear distortion is deferred to other publications.
3. TRANSITION NOISE ANALYSING AND SYNTHESIZING

Media noise is the dominant noise source for current magnetic recording system. Media noise is composed of transition jittering noise and DC saturation noise. Here we will discuss transition noise analysis and synthesis. In transition noise model [2], Media jittering is determined by transition parameter and cross track correlation length. Analytical formulas have been obtained before for transition parameter and cross track correlation length for high area density recording [3, 4]. Compared to traditional analytical approach such as William-Comstock model, the main contributions of these formulas are the capability of linking media noise parameters to detailed media microphysics parameters (such as grain size, inter-granular exchange etc). When these formulas are validated to micro-magnetic simulation for current recording system, they are further developed. It should be pointed out here that micro-magnetic simulation is still the best approach that can be used to validate media transition noise formulas. The difficulty of directly validating transition noise model to experimental measurement is largely due to reader resolution effects on media noise as described in [5]. The newly development in transition noise formula include media clustering effects, head field angular effects and generalization of cross track correlation length formula. Media clustering formula follows [6] where the cluster size is determined by media mean grain size, grain size distribution, exchange and exchange distribution. Head field angular effect on transition parameter is modeled through dependence of media coercivity on head field angle. The dependence of media coercivity on field angle is obtained from regression equation on micromagnetic simulation of media MH loop. The cross track correlation length formula in [4] is further generalized to include whole M-H loop shape, instead just the slope. An iteration procedure is used to eliminate the limitation of Taylor expansions in the original paper.

Figure 1 shows the validation of transition noise formula to micro-magnetic simulation. There are two ways to extract transition parameter and cross track correlation length from micro-magnetic simulation. In first approach, the transition parameter is obtained by fitting to the mean magnetization transition shape. The cross track correlation length is determined by integration of cross track correlation function of media magnetization. In second approach, transition parameter and cross track correlation length are obtained from normal modes analysis of micro-magnetic simulated media noise waveform. A good reference for media noise normal modes analysis is in [7]. Compared to first approach, second approach is more time consuming because it requires micro-magnetic ensemble simulation to obtain media noise statistics. In our validation, both approaches are used to extract consistent noise parameters from micro-magnetic simulation.

Figure 1: Validation transition parameter and cross track correlation length formulas to micro-magnetic simulation.
Once intrinsic media transition noise parameter and cross track correlation length are obtained, the transition noise waveform can be synthesized based upon normal modes expansion as in [5, 7].

4. ELECTRONIC NOISE SYNTHESIZING AND SCALING

Electronic noise is the noise measured as reader away from media. For high area density recording system, it is of great importance to obtain the electronic signal to noise ratio as head, media and head media spacing scales down. Electronic signal to noise here is simulated as a combination of micro-magnetic simulation for read-back signal and electronic noise formula analysis. The signal is obtained from regression on micro-magnetic simulation as described in Section 1. The electronic noise analysis includes thermal magnetization noise [8, 9], $1/f$ noise and Johnson/shot noise. In our study, these noise formulas are used to fit measured reader electronic noise spectral at current density and head media dimension. An example fitting is shown in Figure 2. The key physics parameters are determined through fitting to measurement and knowledge of current head media dimensions. Then these physics parameters are scaled down to future area density as head dimension, media dimensions and head media spacing shrink. Through this approach, electronic SNR at future area density with decreased head media dimensions and head media spacing can be simulated, as an example in Figure 3. The electronic noise formulas fitted to current noise measurements are in frequency domain. Inverse FFT is used with the assumption of Gaussian or Poisson statistics to generate time domain waveforms. Figure 4 shows an example of generated signal and noise waveform for 128 pseudo-random sequences (both signal, media noise and electronic noise).

Figure 2: Fitting experimental measured reader noise spectral by thermal noise, $1/f$ noise and shot/Johnson noise.

Figure 3: Calibrate electronic SNR calculation to measurement at current linear density and scale to higher linear density through system modeling.

Figure 4: An example of generated signal and noise waveform for 128 pseudo-random sequences: red: signal and media noise, black: colored electronic noise.
5. DC SATURATION AND HEAD JITTERING NOISE

For high area density perpendicular recording, insufficient head writability could cause nonsaturation in media DC region. This will affect both read-back signal and noise. Figure 5 shows the effect of non-saturation on media and read-back signal. Signal could be degraded through amplitude loss and pulse broadening, if writer field is not strong enough to fully saturate media. In our simulator, this effect on signal degradation is modeled through head field magnitude and regression equation on micromagnetic simulation of media magnetization vs external field (MH loop). The media noise in DC region is called DC noise and is modeled by approach in [8]. Besides the major noise sources as discussed above, there are additional noise sources in recording system such as head jittering. The head jittering effects on media noise largely depends upon media damping parameter. This noise source, and other possible neglected noise sources could be injected to noise waveform for simulator data calibration.

![Figure 5: DC nonsaturation effects on signal quality.](image)

Cross track averaged magnetization at different writer head media spacing.

Different magnetization saturation level.

6. CONCLUSIONS

Procedure and examples of signal and various noise waveforms simulation in magnetic recording system are shown. The simulator combines newly developed recording physics formulas; micromagnetic simulations and experimental data information extraction to generate random bits waveforms in short time, and thus provides valuable information for data calibration and future system scaling.

REFERENCES