# GUI-Based Read Channel Simulation Tools in Magnetic Recording System

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Keywords: Read Channel, Magnetic Recording System, GUI tools

**Abstract:** This paper presents a simulation and visualization tool for the read channel in magnetic recording system based on MATLAB and GUI tools. The system consists of read-back signal generator, low-pass filter (LPF), FIR equalizer, Viterbi detector and Graphical user interface (GUI) structure. Simulation results show the signals of each component in read channel model and users can modify important relevant parameters in each subsystem.

## 1. Introduction

To understand signal processing in magnetic recording system, it is beneficial to learn the functions of each block and see how the signals are changed by each process. The learning tool we present is to help visualize the operation of realistic channel model in magnetic recording system. The model is close to the real system because it consists of all the important parts in the read channel. Users can modify important parameters and display the resultant signals. In addition, new algorithms can be included and replace existing functions for simulation purpose.

## 2. Magnetic Recording System

A magnetic recording system model is shown in Fig 1. In the writing process, message bits are encoded by error correction code (ECC) [1] encoder. Currently, most hard disk drives employ Reed Solomon (RS) code as ECC [2]. The encoded data are then encoded by modulation encoder to ensure the minimum and maximum run length of 0’s in the data sequence. A commonly used code is Run Length Limited (RLL) code. The output data from modulation encoder are then written on the storage media, called recorded bits.

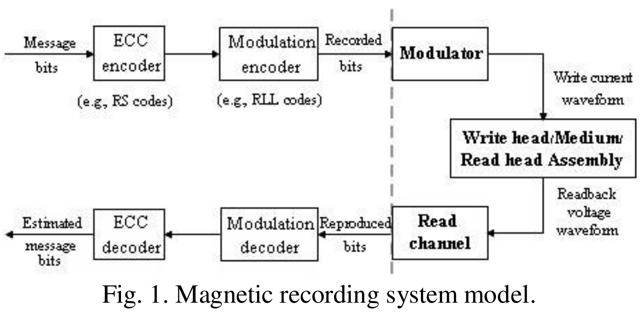


Fig. 1. Magnetic recording system model.

Consequently, recorded bits are sent to the modulator to convert data bits into write current waveform and then to the write head for writing the data on the storage media. In magnetic recording system, information is stored in the transition of magnetic polarities. In the reading process, the read head senses the magnetic transition from the storage media. When it moves to magnetic transition zone, it reads out the voltage waveform, called read-back signal. The read-back signal is then sent for processing in read channel circuits consisting of low-pass filter (LPF), analog-to-digital (A/D) converter, FIR equalizer [3] and Viterbi detector [4]. The combination of partial response (PR) target and Viterbi detector is often termed “PRML.” The output data are decoded by modulation decoder and ECC decoder, respectively, to produce estimate of message bits.

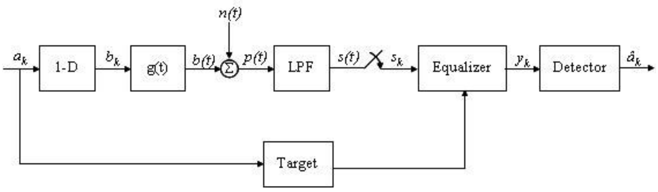


Fig 2. Read channel model.

The read channel model is shown in Fig 2. Sequential binary input data $a_k \in \{0, 1\}$ with period $T$ are sent to the ideal differentiator 1-$D$, where $D$ is a delay. This changes data to $b_k \in \{-2, 0, 2\}$, where $b_k = \pm 2$ is a positive transition or negative transition and $b_k = 0$ represents no transition change. The signal $b_k$ will be sent through the recording channel with isolated response $g(t)$. For longitudinal channel, $g(t)$ is defined as

$$g(t) = \frac{1}{1+\left(\frac{2t}{PW_{50}}\right)^2}, \tag{1}$$

where $PW_{50}$ is the pulse width of g($t$) at half of the maximum amplitude. For perpendicular channel, $g(t)$ is defined as

$$g(t) = erf\left(\frac{2t\sqrt{\ln 2}}{PW_{50}}\right), \tag{2}$$

where $PW_{50}$ is the pulse width of $g'(t)$ or differential of $g(t)$ at half of the maximum amplitude. An error function is defined as

$$erf(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt . \quad (3)$$

The noise corrupted read-back signal $p(t)$ can be written as

$$p(t) = \sum_{k=-\infty}^{\infty} b_k \cdot g(t - kT) + n_k , \quad (4)$$

where $n_k$ is sampled additive white Gaussian noise (AWGN). The read back signal $p(t)$ is then filtered with a low-pass filter to remove out-of-band noise. Consequently, the resulting signal is sampled by the A/D converter. Sampling data are then sent to FIR equalizer which shapes the original ISI into partial response (PR) target, and sent to a Viterbi detector, respectively, to search for possible sequential input data, an approximate value of $a_k$ or $\hat{a}_k$. The commonly used detector in magnetic recording systems is a Viterbi detector, however, in future generation, to exploit iterative processing, it is most likely replaced by soft-out Viterbi detector (SOVA).

## 3. Evaluation Tool

We use MATLAB program to build this simulation tool of the magnetic recording system. For building this simulation tool, we implement two tasks. The first task includes writing MATLAB function of each component and the other is Graphical user interface (GUI) construction. The functions of read-back signal generator, LPF, FIR equalizer and Viterbi detector are constructed. For each component, important input parameters are displayed for modification by users. On each GUI page, users can modify parameters on the left side, and the results are displayed on the right side. When the "Simulate" button is pressed, the program gets all parameters into the input variables, and calls the function to simulate the process of read channel. And then it keeps the output of signal into the output variables. After that, when the "Display" or "Plot" button is pressed, the program takes output variables, plot the graph and display.

## 4. Results

Initially, we show the simulation of isolated pulse and dibit pulse response of longitudinal and perpendicular channel that compare the results in different ND, where ND is a normalized recording density and it is defined as

$$ND = \frac{PW_{50}}{T} , \quad (5)$$

where $T$ is a period of each bit. "Isolated pulse" is a one bit transition response that is $g(t)$ and "Dibit pulse" is two bits transition response that is defined as

$$m(t) = g(t) - g(t - T) . \quad (6)$$

Let $T$ is a constant value. If normalized density increases, amplitude of transition pulse response will decrease and the signal will spread into many periods. Adjacent transition pulse response will overlap.

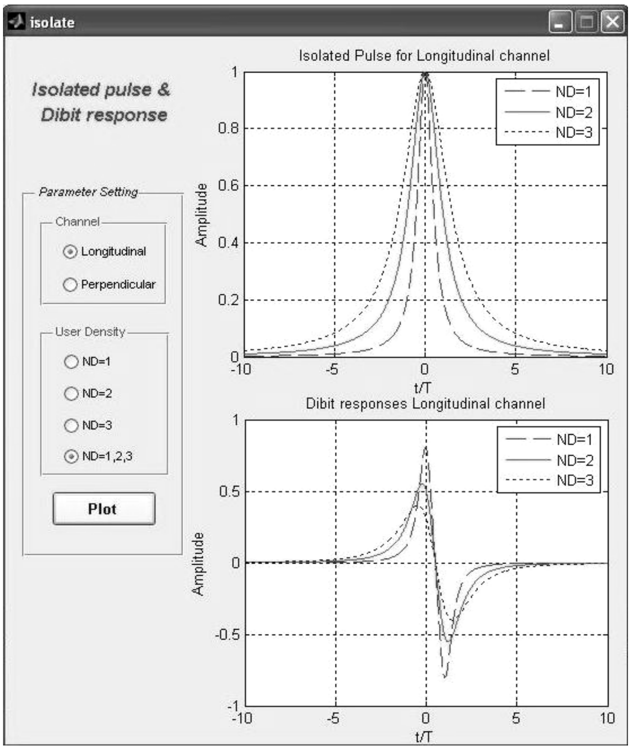


Fig. 3. Isolated pulse & Dibit response of Longitudinal channel.

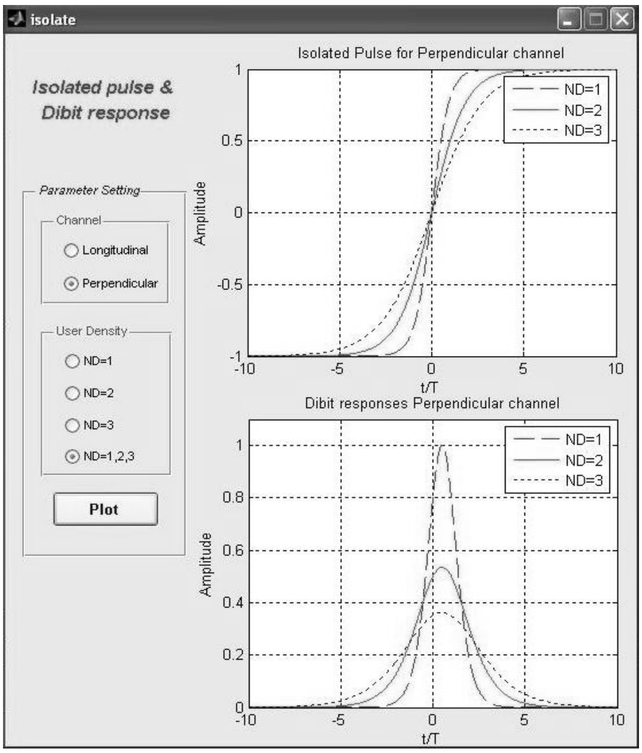


Fig. 4. Isolated pulse & Dibit response of Perpendicular channel.

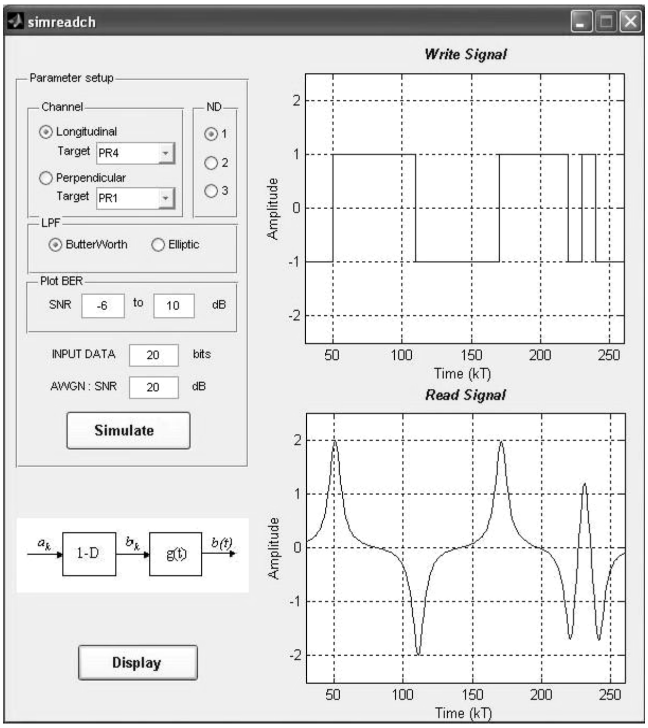


Fig. 5. The write signal and read-back signal without noise.

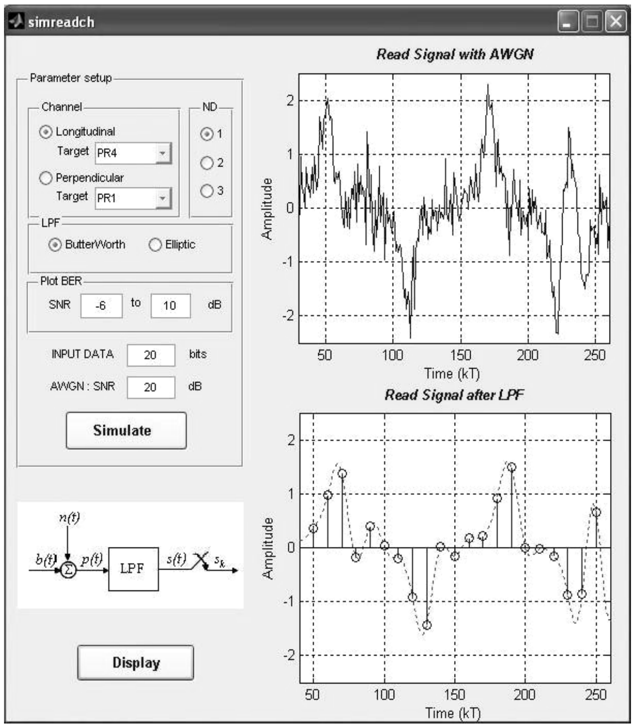


Fig. 6. The read-back signal with AWGN (20dB) and the signal after LPF with sampling signal.

Therefore, inter-symbol-interference (ISI) in the read-back signal increases when normalized density increases. Results of the isolated pulse and dibit pulse response of longitudinal channel are shown in Fig. 3 and the isolated pulse and dibit pulse response of perpendicular channel are shown in Fig. 4.

To run the read channel simulation tool, set the input data "20 bits," channel "longitudinal," target "PR4," AWGN "20 dB," type of LPF " Butterworth," SNR for plot Bit error rate (BER) " -6 to 10" dB, and "ND = 1." For longitudinal channel, in the case of negative-to-positive transition, the read-back signal shows positive peak, but for positive-to-negative transition, the negative peak appears. Multiple adjacent transitions cause lower amplitude of the read-back signal as shown in Fig. 5. The obtained read-back signal is then added with AWGN noise to produce realistic signal. The intensity of noise depends on the target signal-to-noise ratio (SNR). After the read-back signal is filtered with LPF to remove out-of-band noise, the smoothened output signal is shown in Fig. 6. In the "Signal after LPF" figure, the sampled discrete sequence is shown; the dotted line represents corresponding analog signal. Then the signal is adjusted by equalizer for "target response" that is result of input data convolution with target, and sent to the Viterbi detector to find possible data and calculate BER of the system. Signal after the equalizer and BER graph are shown in Fig. 7.

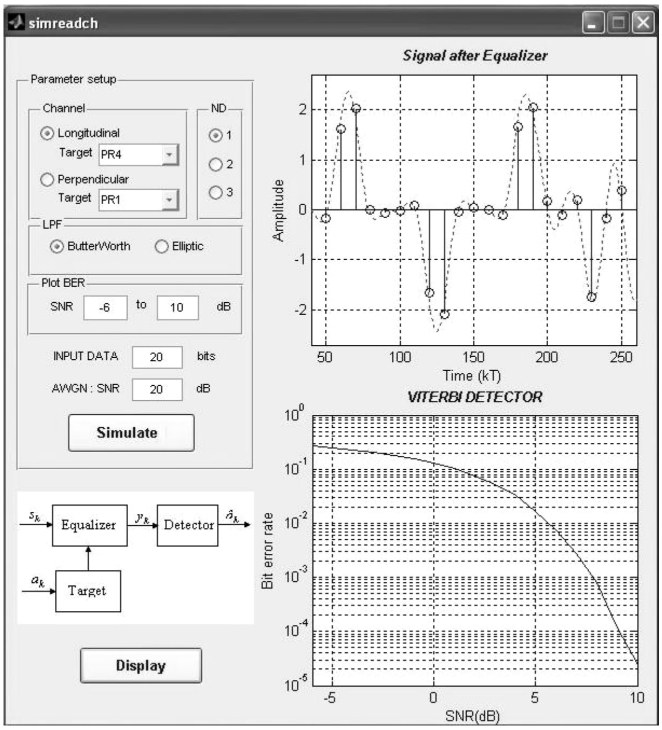


Fig. 7. Signal after the equalizer and BER graph.

## 5. Conclusions

Read channel simulation tools help visualize the write signal, read-back signal without noise, read-back signal with AWGN, the signal after LPF with sampling signal, the signal after equalizer and BER graph respectively. They clearly show the signals in each part and variation of the signals when users modify parameters. This simulation is a good learning tool for studying the read channel in magnetic recording system with the theory of the read channel model.


## Acknowledgement

This work was supported by National Electronics and Computer Technology centre (NECTEC), Data Storage Technology and Applications Research Center (D*STAR) under grant HDDA50-010M.


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