# Signal processing for STO reading in three dimensional magnetic recording

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## 1. Introduction

Three-dimensional magnetic recording with antiferromagnetically coupled (AFC) medium[1)] has been proposed as a candidate of the prospective recording technologies, and it uses a spin-torque oscillator (STO)[2)] as a reading sensor as well as a write-assisting device for the microwave assisted magnetic recording (MAMR)[3)]. The reproducing waveform in the reading process using the STO is given as temporal dynamics of magnetization calculated by the micromagnetic simulation[2)]. However, the amount of data obtained by the simulation is too short to evaluate signal processing schemes. We proposed the envelope model to develop the data detection scheme for the temporal magnetization dynamics of a resonantly interacting STO flying over bit patterned media.

## 2. Reading based on interaction between magnetic medium and STO

The reproducing waveform in the reading process using the STO is given as temporal dynamics of magnetization calculated by the micromagnetic simulation[2)] shown in Fig. 1. We assumed that the relative velocity between the medium and the STO, the dot diameter and pitch are 20 m/s, 20 nm and 25 nm[2)], respectively. The dashed line and cross symbols show the temporal magnetization dynamics normalized by the saturation level of the STO magnetization, $A$ and the sampled envelope with each dot interval, respectively. The horizontal axis shows the time normalized by the channel dot interval $T_c$. The recorded data pattern is "000111000111" as shown in bottom of Fig. 1, and the STO reacts to the recorded dots for “0”. As can be seen from the figure, the normalized amplitude of STO oscillation waveform decreases as the STO comes close to the recorded dots for “0”. On the other hand, as it leaves from the recorded dot of “0”, the amplitude increases again. Here, we focus the change of the amplitude between the detection target and the previous dot. If "0" is recorded, the difference of amplitude is negative. On the other hand, if “1” is recorded, the difference is positive. Therefore, the recording pattern can be detected by the differential amplitude of the envelope.

## 3. Read/Write channel model for signal processing

The amount of data obtained by the micromagnetic simulation is too short to evaluate signal processing systems. We proposed the envelope model to develop the data detection schemes[4)]. The envelope model is obtained by the convolution operation of the attenuation functions for the dots of “0” and “1” shown in Fig.2 according to the data pattern. Under observation of the envelope, we noticed that the partial response channel was applicable to improve the performance. We evaluate the performances of the differential detection for the envelope and a soft-output Viterbi algorithm (SOVA)[5)] detection for partial response class-I (PR1)[6)] channel. In addition, we apply the idea of adding another STO with the opposite behavior to the PR channel in order to improve the reading performance. We add another STO which reacts to the recorded dot of “1”. Thus, we employ the dual STO with the reaction to “0” and “1”.

## 4. Performance evaluation

Figure 3 shows the bit error rate (BER) performance for the system noise ($SNR_S$) [4)]. The symbols of square, triangulate, and circle show the performances of the differential detection, the SOVA detection with single STO, and the SOVA detection with dual STO, respectively. The vertical and horizontal axes show the BER performance and $SNR_S$. As can be seen from the figure, the differential detection cannot achieve the BER of $10^{-2}$ at $SNR_S$ = 30 dB. However the SOVA detections show better BER performance than the differential detection. Moreover, the SOVA detection with dual STO achieves the BER of $10^{-4}$ at the required $SNR_S$ of 25.2 dB, while the SOVA detection with the single STO needs the $SNR_S$ of about 28.0 dB. Therefore, the SOVA detection with dual STO improves the $SNR_S$ by about 2.8 dB compared with the SOVA detection with single STO.

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Reference

1) H. Suto, T. Nagasawa, K. Kudo, K. Mizushima, and Rie Sato, *Nanotechnology*, **25**, 245501 (2014).
2) T. Kanao, H. Suto, K. Kudo, T. Nagasawa, K. Mizushima, and R. Sato., *J. Appl. Phys.*, **123**, 043903 (2018).
3) J. Zhu, X. Zhu, and Y. Tang, *IEEE Trans. Magn.*, **44**, 125 (2008).
4) Y. Nakamura, M. Nishikawa, H. Osawa, Y. Okamoto, T. Kanao, and R. Sato, *AIP Advances*, **8**, 056512 (2018).
5) J. Hagenauer and P. Hoeher, P*roceedings of IEEE GLOBECOM*, 1680 (1989).
6) E. R. Kretzmer, IEEE Trans. Commun. Technol. **COM-14**, 67 (1966).

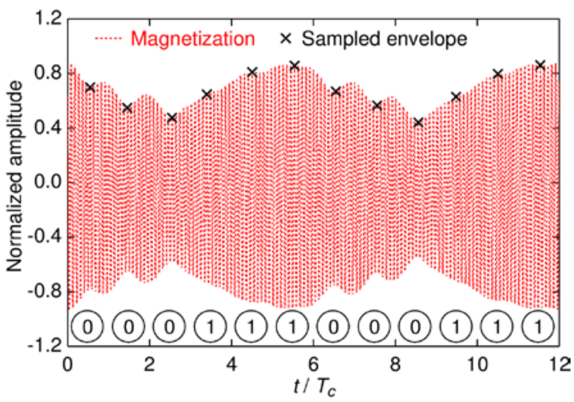


Fig. 1 Magnetization of STO and sampled envelopes.

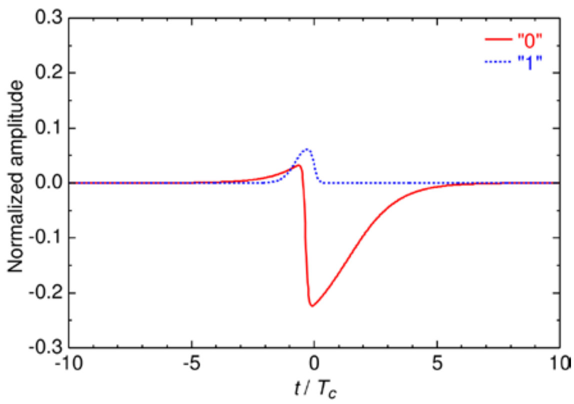


Fig. 2 Attenuuation function for STO.

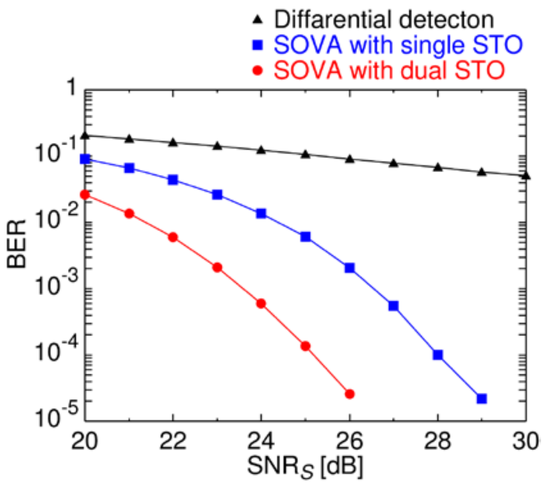


Fig. 3 BER performance.