# A STUDY ON ENVELOPE DETECTION USING TEMPORAL MAGNETIZATION DYNAMICS OF RESONANTLY INTERACTING SPIN-TORQUE OSCILLATOR FOR THREE-DIMENSIONAL MAGNETIC RECORDING

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## I. 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. We proposed the envelope model to develop the data detection scheme for the temporal magnetization dynamics of a resonantly interacting STO flying over a bit patterned medium in our previous report [4]. The detection scheme is intended for use in a three-dimensional MAMR in which the patterned dots have multiple discrete recording layers. In this report, we show the data detection scheme by the envelope model.

## II. READ/WRITE CHANNEL USING ENVELOPE MODEL

Figure 1 shows the temporal magnetization dynamics of the STO by a magnetic dipolar field using micromagnetic simulation [2] and the envelope obtained the envelope model which constructs by by the convolution operation of attenuation functions [4] shown in Fig. 2. The recorded data pattern is "000111000111" as shown in bottom of Fig. 1, and the STO reacts to the recorded dots for “0”. In this study, 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 and solid lines show the temporal magnetization dynamics using the micromagnetic simulation and the reproducing envelope model normalized by the saturation level of the STO magnetization $A$, respectively. The horizontal axis shows the time normalized by the channel dot

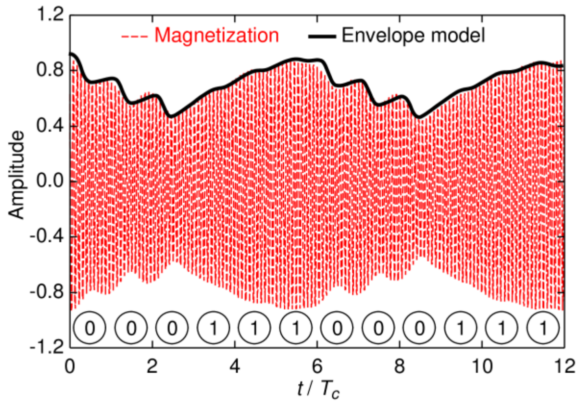


Fig. 1. Temporal magnetization dynamics of the STO and the envelope model obtained by the convolution of the attenuation function.

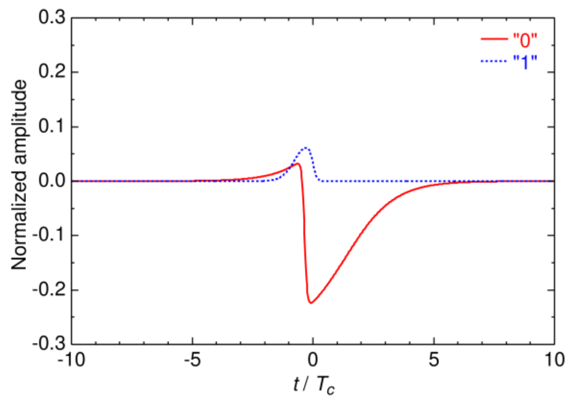


Fig. 2. Attenuation functions for the STO. The solid and dotted lines show attenuation functions for recorded data “0” and “1”.

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interval $T_c$. The solid and dotted lines in Fig. 2 show the attenuation functions for the recorded dots of "0" and "1" normalized by $A$. The envelope is obtained by the convolution operation of the attenuation functions of "0" and "1", and it looks like the envelope of STO magnetization shown in Fig. 1. The amplitude of STO oscillation waveform attenuates as the STO comes close to the recorded dot "0", on the other hand, as it leaves from the dot of "0", the amplitude increases again. However, the recorded dot of "1" has few influence on the amplitude. Therefore, we get the idea of adding another STO with the opposite behavior to improve the reading performance. We assumes that the other STO reacts to the recorded dot of "1" as the opposite reaction of the STO which reacts to the recorded dot of "0". Thus, we enployed the dual STO in this research. Furthermore, we employ the generalized partial response class-I (GPR1) [6], and evaluate the bit error rate (BER) performance. In the evaluate system, the input data sequence is recorded on the dots, and reproduced by the dual reader with two STOs reacting "0" and "1" dots scanning on the same recorded dots or the same track [7]. The respective envelopes are sampled by $T_c$ are equalized to the GPR characteristic [6] after subtraction operation, and decoded by the soft-output Viterbi algorithm (SOVA) [8].

## III. PERFORMANCE EVALUAT10N AND D1SCUSS10N

Figure 3 shows the BER performances for the system noise ($SNR_S$) [4]. The symbols of filled circle, open circle, filled triangulate, and open triangulate show the performances of GPR1 with dual STO, PR1 with dual STO, GPR1 with single STO, and PR1 with single STO, respectively. As can be seen from the figure, the BER performances of the systems with dual STO are better than those with single STO. The PR1 with dual STO achieves the BER of $10^{-4}$ at the required $SNR_S$ of 25.3 dB, while the PR1 with the single STO need the $SNR_S$ of about 28.0 dB. Furthermore, the GPR1 with dual STO improves the $SNR_S$ by about 0.9 dB compared with PR1 with dual STO.

Therefore, these signal processing using the envelope detection are important technologies for the three-dimensional magnetic recording needed to increase the recording density of future hard disk drives.


## ACNALEGEMENT

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## REFERENCES


1) H. Suto et al., *Nanotechnology*, 25(24) 245501, (2014).
2) T. Kanao et al., *J. Appl. Phys.*, 123(4) 043903, (2018).
3) J. Zhu et al., *IEEE Trans. Magn.*, 44(1) 125–131, (2008).
4) Y. Nakamura et al., *AIP Advances*, 8(5) 056512, (2018).
5) K. Kudo et al., *Jpn. J. Appl. Phys.*, 55(11) 07MA01, (2016).
6) N. Shinohara et al., *Journ. Magn. Magn. Mater.*, 320(22) 3136–3139, (2008).
7) Y. Nakamura et al., *IEEE Trans. Magn.*, 54(11), (2018). (Accepted)
8) J. Hagenauer et al., *Proc. IEEE GLOBECOM 1989*, 1680-1686, (1989).


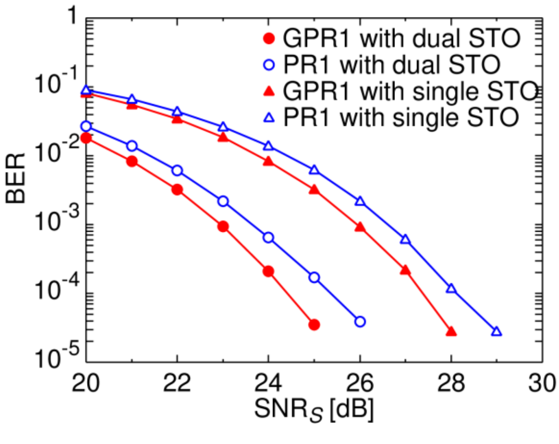


Fig. 3. BER performance for the $SNR_S$.