Vector Recording: Advancing Areal Density in HAMR with Innovative Read Head Design

R. H. Victora[1], *Life Fellow IEEE,* Kamal Hosen[1], and M. F. Erden[2]

[1]Department of Electrical and Computer Engineering, University of Minnesota Twin Cities, USA.
[2]Seagate Technology, MN, USA. **Corresponding author:** victora@umn.edu

Heat-assisted magnetic recording (HAMR) enables enhanced areal density capacity (ADC) beyond that provided by perpendicular magnetic recording. However, the existing reader architecture restricts the increase in bits per inch (BPI) and tracks per inch (TPI), becuase it requires scaling down the reader dimension to read data with a smaller bit length and narrower track width. Recently, two-dimensional magnetic recording (TDMR) has shown some ability to increase the ADC of the reading process by relaxing the reader scaling, but this improvement is not sufficient to address the data storage crisis. In this paper, we propose a novel read head design to detect the magnetic field both perpendicular and parallel to the surface of the recording layer, thus resulting in higher ADC.

***Index Terms*—Reader Design, HAMR, Vector Recording, Read-Head Dimension, Areal Density.**

I. Introduction

THE DEMAND for data storage is growing exponentially over time due to modern technologies such as artificial intelligence and advanced communications. On the other hand, the hard disk drive (HDD) industry is experiencing a data storage crisis as the existing data storage architectures approach their limits in enhancing areal density capacity (ADC) [1]. In recent times, the HDD industry has shifted from perpendicular magnetic recording (PMR) to heat-assisted magnetic recording (HAMR) to meet this immense demand for data storage. In HAMR systems, ADC improvement is possible by writing smaller bits and narrower tracks. However, smaller bit length means high KBPI that demands small grain size. Narrower tracks have less need for small grain size, however, this likely demands new readback processes to be developed. The scaling of the reader width is approaching its limit [1] and a single reader is insufficient to further improve ADC. Over the years, researchers have proposed some alternative techniques as shown in Fig. 1 (b) where two written bits in two adjacent tracks result in four possible states (+ +, - -, - +, + -). In two-dimensional magnetic recording (TDMR), the readers can distinguish only three states and cannot differentiate between + - and - +. This limitation of TDMR reduces the effective ADC to $log_2(3)/log_2(4)$ = 79% of the original written ADC for a particular KTPI [2].

In this regard, Seagate has proposed a novel recording technique named "vector recording" to achieve better ADC with higher KTPI [2]. This technique consists of two readers: a conventional reader (R_c) and a vector reader (R_v), each scanning two tracks as shown in Fig. 1 (c). R_c reads the magnetic field perpendicular to the recording layer plane (R_c = T1 + T2) and is not able to distinguish magnetization conditions 3 (- +) and 4 (+ -). Therefore, to detect conditions 3 and 4 separately we have designed a vector reader (R_v) which reads magnetic field parallel to the media plane (R_v = T1 - T2) and is not capable of reading condition 1 (+ +) and 2 (- -). Now, by combining a vector reader with a conventional reader, we can successfully read four different writing states between two adjacent tracks, ensuring a 21% higher ADC than TDMR with the same KTPI and without any reduction in reader dimension. We demonstrate the compatibility of our novel reader design with existing HAMR systems and analyze its performance using micromagnetic simulations.

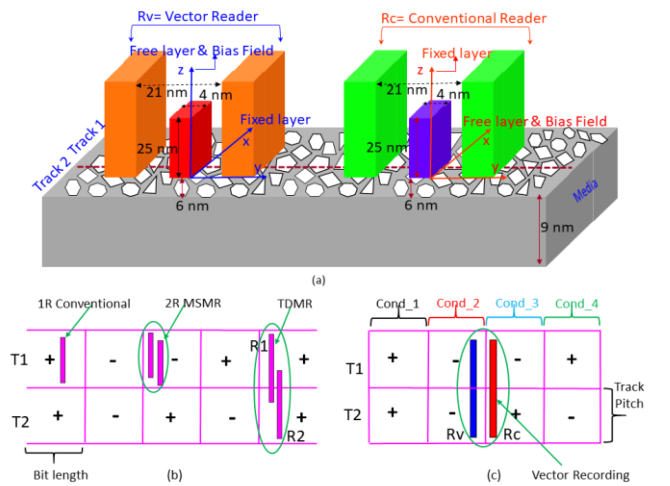

Fig. 1. (a) 3D schematic diagram of two readers with respective filed orientation. (b) Different types of read head architectures [2]. (c) Reading strategy of vector recording.

Figure 1 (a) shows the 3D schematic diagram of two readers along with their respective field orientation that we have considered in our reader simulations. For the conventional reader, we kept the fixed layer along the direction perpendicular to the media surface (along z axis) and the free layer was biased along the crosstrack direction (along x axis). For the vector reader we fixed our pinned layer along the x axis and biased the free layer along the z axis. Here the assembly moves from –y to +y direction (along down track direction) and reads perpendicular and parallel magnetic fields from the media by conventional and vector reader respectively. For the readback process we have calculated the magnetic head potential for both readers using the reciprocity theorem [3].

II. Signal-to-Noise Ratio (SNR) Analysis

We examined two distinct writing patterns in order to compare the performance of the new vector reader (R_v) with the conventional reader (R_c): same single tone (ST) on both

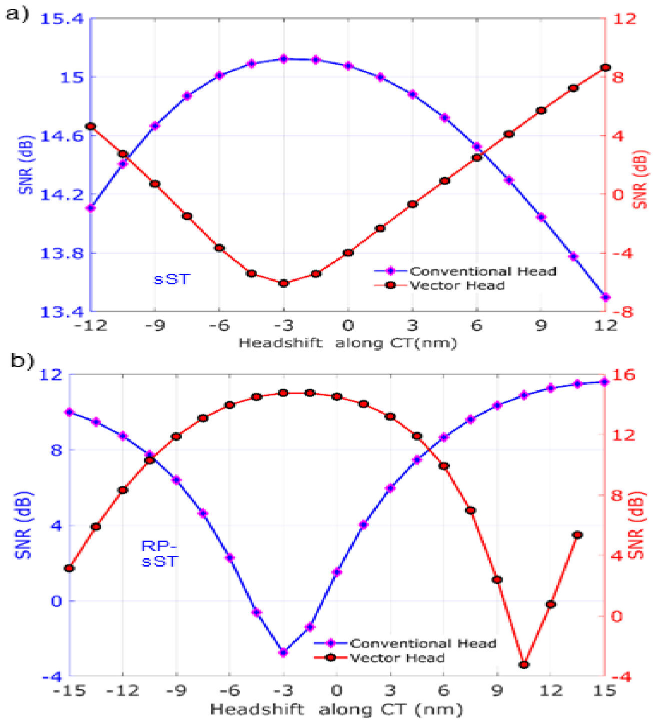

Fig. 2. SNR characteristics of conventional and vector reader at different head-shift position along cross track direction: a) sST, b) RP-sST.

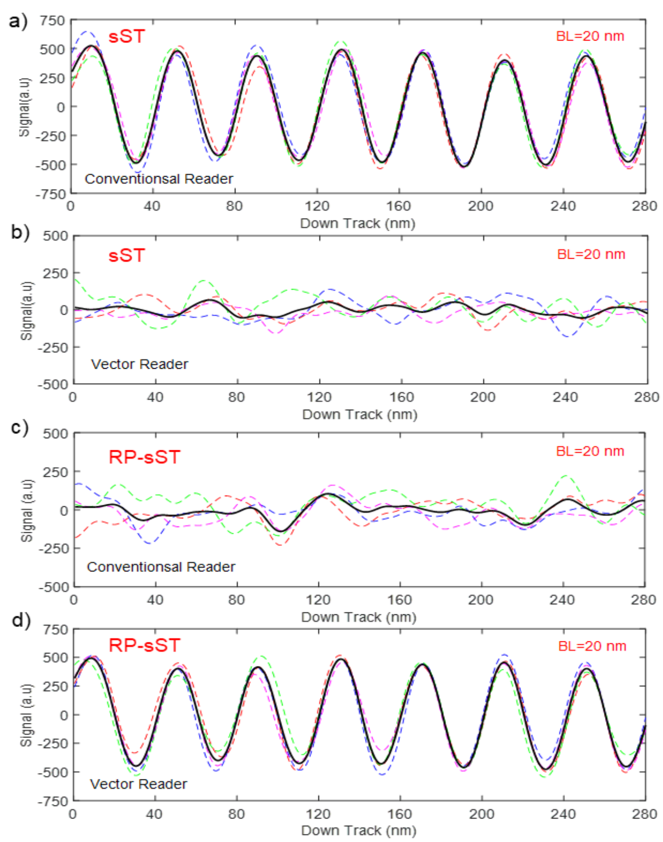

Fig. 3. Readback signals of conventional and vector reader for different single tone writing patterns at the track edge ; a) R_c with sST, b) R_v with sST, c) R_c with RP-sST, d) R_v with RP-sST.

tracks (sST) and same ST but with reverse polarity from one track to the other (RP-sST). For the sST writing pattern we first read signals using the (Rc), followed by the (R_v), and then calculated the SNR for both readers at different headshift positions along the cross track (CT) direction, as shown in Fig. 2 (a). From Fig. 2 (a) it is clear that the (R_c) SNR (blue line) exhibits a strong dependence on head position and provides maximum SNR around 15.2 dB at a headshift = -3 nm. As expected, only the (Rc) provides a strong signal because the presence of + + and - - magnetization states only produces a strong magnetic field along the perpendicular direction of the media surface. However, our newly designed (R_v) exhibits negative SNR (red line) at the track edge region as a result of the absence of + - and - + magnetization states, which would otherwise create a strong magnetic field along the parallel direction of the media surface. For the RP-sST writing pattern, we have performed the same reading technique and calculated the SNR characteristics of both (R_c) and (R_v), as shown in Fig. 2 (b). In contrast to the sST case, only the (R_v) reads a strong signal and provides the highest SNR of nearly 15 dB at headshift = -3 nm. This is because only the presence of + - and - + magnetization states creates a strong magnetic field parallel to the media plane. However, Fig. 2 (b) also shows that the SNR of R_c begins to peak up before and after the track edge region. This is because when we move R_c far from the track edge in the CT direction, it begins to read the signal from a single track, which improves the SNR.

III. Crosstalk Between Readers

The signal interference (crosstalk) between readers is a critical aspect of HAMR, given the narrower tracks and increased recording density; hence, it is essential to address this issue. We have performed readback signal analysis for both R_c and R_v with different writing patterns. The R_c and the R_v are anticipated to achieve their maximum and minimum signal power, respectively, for sST writing pattern. The readback signals of R_c and R_v along the downtrack position for sST writing pattern are shown in Fig. 3 (a)–(b). Here, the R_c provides strong readback signal as expected since only + + and - - magnetic states are available as shown in Fig. 3 (a). Conversely, the R_v is not intended to read any signals; rather, it detects weak, noisy signals as a result of the stray magnetic field that is generated by the minor lack of synchronization between two tracks as depicted in Fig. 3 (b). In the RP-sST writing pattern, Rv detects signals with optimal intensity since it only identifies the +- and -+ magnetic states, as shown in Fig. 3 (d). However, as seen in Fig. 3 (c), the R_c picks up noisy signals from the stray magnetic field produced by the small mismatch between the two tracks. In our simulation we used synchronized writing between tracks; this minor mismatch occurs mostly due to the curved transitions at the track edge region.

References

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