Numerical Simulations on Microwave Assisted Magnetic Recording (MAMR)

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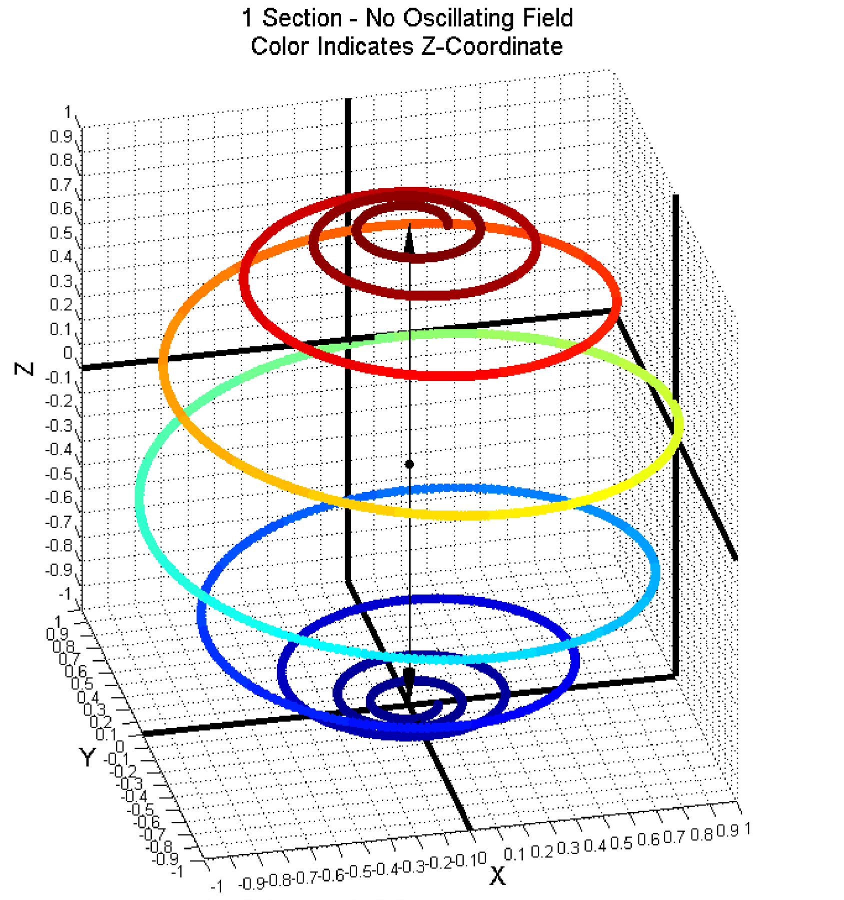
Background on Magnetic Recording

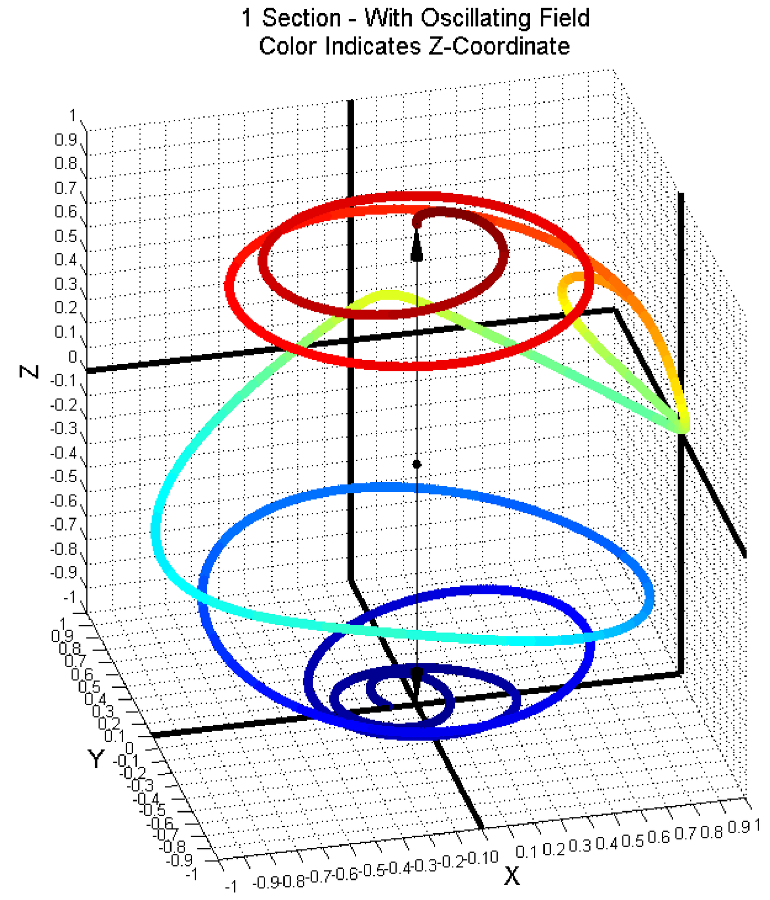
- Two key aspects of hard disk drive design are areal density and resistance to noise due to thermal fluctuations.
- Resistance to noise is proportional to both the anisotropy (k) and volume (v) of a grain.
- Anisotropy is a measure of the "hardness" or "softness" of a ferromagnet in ergs/cm^3. A hard ferromagnet has high anisotropy and requires a strong switching field to flip. A soft ferromagnet has low anisotropy and requires a weak switching field to flip.
- In order to increase the data density of hard disk drives while keeping noise resistance high, grain volume must decrease while average anisotropy increases.
- If we use harder magnetic materials, stronger switching fields are required. There is an upper limit to the strength of switching fields that can be created by today's recording head technology, so we must research other methods of building or writing these grains.
- A recent development in the construction of magnetic grains is in the area of Composite Recording Media. This technology produces magnetic grains with multiple coupled layers with varying degrees of hardness. This method maintains noise resistance while requiring smaller switching fields for a given average anisotropy across layers.
- Quantum mechanical exchange coupling (J) causes adjacent layers in a composite medium to push or pull on each others' magnetizations (see plots on far right).
- We are still seeking other methods of writing magnetic recording media to further decrease the required switching fields.

Microwave Assisted Magnetic Recording

- In 2008, researchers at Carnegie Mellon University and Qualcomm presented, in a paper, a method of writing magnetic recording media that uses a microwave frequency oscillating magnetic field to assist the switching field in writing a bit.
- This method takes advantage of the ferromagnetic resonance phenomenon.
- In the presence of an external magnetic field, a magnetization vector will precess around that field at microwave frequencies as it switches direction. A circularly polarized oscillating magnetic field of correct frequency will add energy to the system thereby requiring a smaller switching field.



Switching Field = 40,000 Oe



Switching Field = 10,000 Oe, f = 44GHz, H-Osc = 4500 Oe

These plots show the path of a magnetization vector as it starts at +z and switches to –z. These systems represent a non-composite medium with only 1 layer of k=10^7 ergs/cm^3. The oscillating field rotates in the counter-clockwise direction when looking down from +z.

Purpose

- To determine the feasibility and utility of using microwaves to assist in writing data on a magnetic recording medium such as a hard drive.
- To design composite media schemes that best harness the MAMR effect.
- To determine the frequencies and field strengths of the oscillating field in it's useful range.

Significance

- Higher density hard disk drives are very important for data centers where heat and power are key. Small drives are important in everyday laptops.

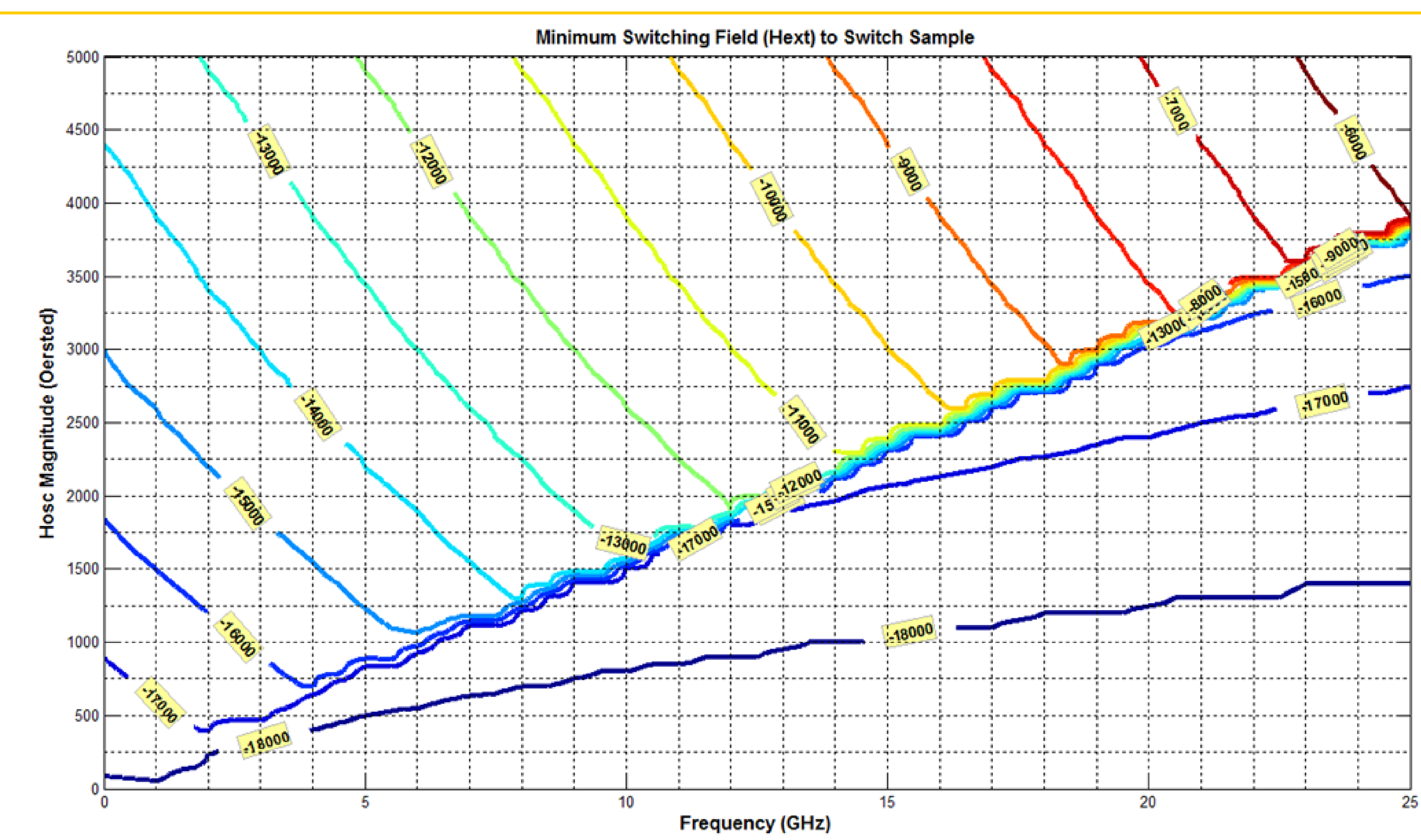
Experimental Method

- To achieve these tasks, a simulation was written in C. It is based on numerical integration of the Landau-Lifshitz-Gilbert equation which describes the motion of a magnetization vector in an external magnetic field. It is from this equation that the precessional motion described earlier arises. This equation was rewritten as two separate equations describing its motion in the spherical coordinates φ and θ.

$$\frac{d\bar{M}}{dt} = \gamma(\bar{M} \times \bar{H}) - \frac{\alpha\gamma}{1+\alpha^2}\left(\hat{M} \times (\bar{M} \times \bar{H})\right)$$

The Landau-Lifshitz-Gilbert Equation

- The integration is based on the Runge-Kutta 4th Order Method (RK4).
- The two plots shown in the bottom left corner are examples of the magnetization path with and without the assistance of an oscillating microwave field and are the direct results of this integration.
- Furthermore, the simulation scans across values of frequency and magnitude for the oscillating field and determines the minimum required magnitude of the static switching field that successfully switches the sample. This produces contour plots as shown below. From these plots it can be determined which combinations of frequency, oscillator magnitude, and switching field magnitude work well and which do not.
- The simulation also accepts different grain system configurations. A grain with 1 or more layers with different anisotropies and different couplings between them can be simulated. I focused on grains with 1, 4, and 8 layers.



Results: Composite Media and MAMR

- One main area of research was to determine an arrangement of varying anisotropy layers that best harnesses the MAMR effect. Below are examples of three 4-layer systems. For each system studied, the average anisotropy across all layers is kept constant at k=10^7 ergs/cm^3.

Distributions: Square Root

N=3	K=$\sqrt{3}$ x const.
N=2	K=$\sqrt{2}$ x const.
N=1	K=$\sqrt{1}$ x const.
N=0	K=0 x const.

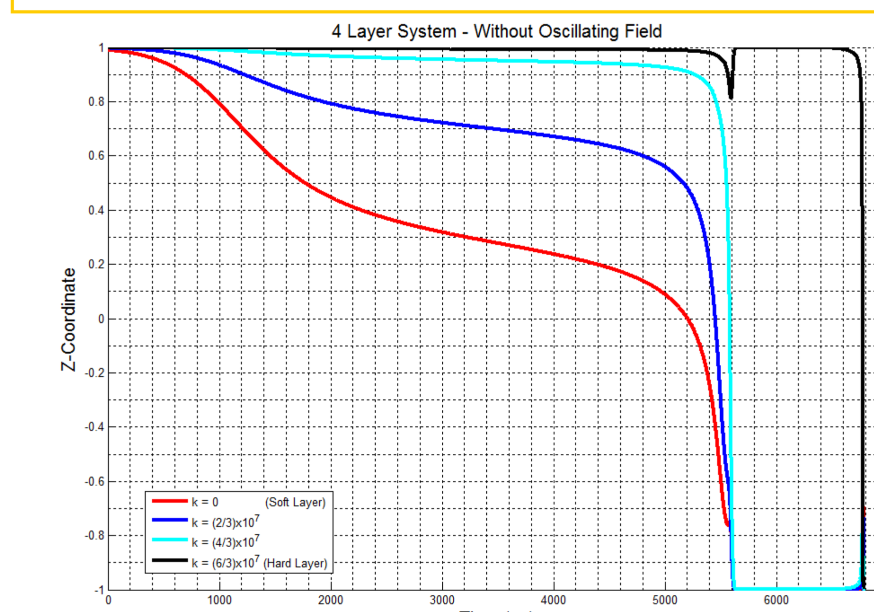
Linear

N=3	K=3 x const.
N=2	K=2 x const.
N=1	K=1 x const.
N=0	K=0 x const.

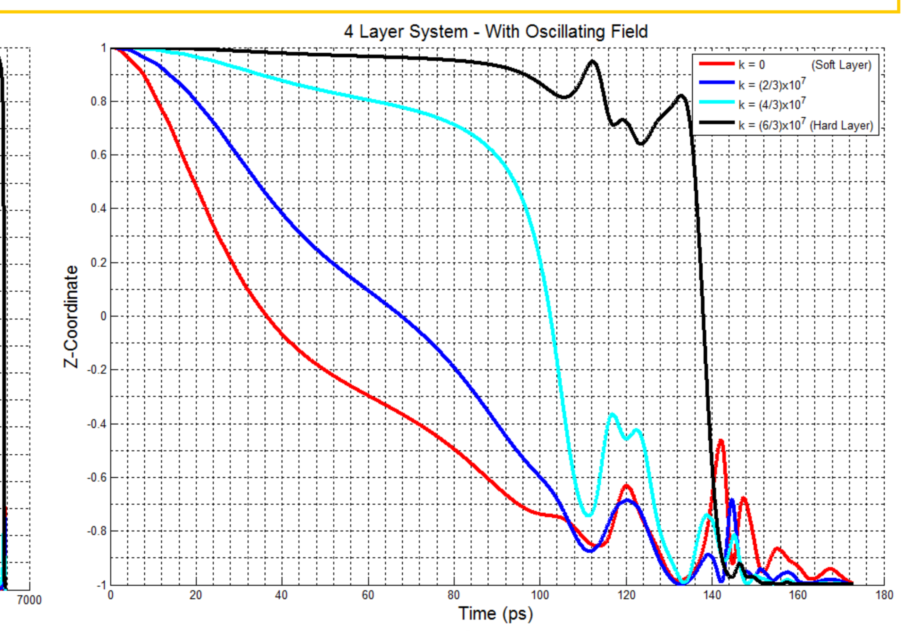
Squared

N=3	K=(3)^2 x const.
N=2	K=(2)^2 x const.
N=1	K=(1)^2 x const.
N=0	K=0 x const.

- A linear distribution of anisotropy allows MAMR to provide the greatest benefit.
- The quantum mechanical exchange coupling between layers (J) was optimized such that a minimum switching field value without an oscillating field was achieved. This method tends to produce the best results as opposed to having different J values between different layers.



Switching Field = 18,350 Oe



Switching Field = 10,000 Oe, f = 16.25GHz, H-Osc = 4500 Oe

These plots show the paths of magnetization vectors for a 4 layer system as they start at +z and switch to –z. These systems represent a composite medium with an average anisotropy of k=10^7 ergs/cm^3 arranged in a linear distribution as described above. The oscillating field helps the system switch much more rapidly.

Results: Oscillator Frequency and Magnitude

- The simulation was used to determine which frequencies and oscillator magnitudes would successfully switch a sample at an ideal switching field magnitude of 10,000 Oe. This is determined by the -10,000 contour line on the plot to the left.
- Optimal values for 1, 4, and 8 layer systems are show below. Around 15 GHz and 1,000 Oe are close to the highest oscillator values that can realistically be created in a recording head. So, 8 layers or more would be needed to use MAMR if the full anisotropy of k = 10^7 ergs/cm^3 is required.
- The greatest improvement provided by MAMR in the systems simulated is in the 8 layer case shown below. With realistic frequency and oscillator magnitudes, an improvement is seen in minimum required switching field from 14,300 Oe to 10,000, or about 30%. Although an improvement is promising, an improvement of 100%-200% would probably be needed to make MAMR commercially feasible. Other methods such as Heat Assisted Magnetic Recording provide equal or greater improvements.

	Freq. (GHz)	Osc. Mag (Oe)	Static Switching Field (Oe)	Min. switching field without oscillating field (Oe)
1 Layer	44	4,500	10,000	40,300
4 Layers	16.25	2,600	10,000	18,350
8 Layers	7	1,000	10,000	14,300

References

Griffiths, J. H. E. "Anomalous High-frequency Resistance of Ferromagnetic Metals." Nature 158 (1946): 670-71.
Kittel, Charles. Introduction to Solid State Physics. 3rd ed. New York, NY: John Wiley & Sons, Inc., 1968. 523.
Zhu, Jian-Gang, Xiaochun Zhu, and Yuhui Tang. "Microwave Assisted Magnetic Recording." IEEE Transactions on Magnetics 44 (2008): 125-31.