Noise And Discontinuities in GMR Transfer Curves

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***Abstract*— High frequency switching between discrete resistance states has been observed in giant magnetoresistive (GMR) read elements when they are exposed to specific magnetic fields. These high frequency switching events appear as popcorn like noise spikes when sampled though a high frequency channel, or as a discontinuity in a resistance vs. field, R(H), curve sampled through a low frequency channel on a quasi-static tester (QST). Both instantaneous and smooth R(H) discontinuities have been found to be caused by high frequency field dependent GMR switching, and appear different due to filtering effects.**

***Index Terms*— Magnetic Recording, Magnetic Noise, Magnetic Heads, Magnetoresistive Devices.**

I. Introduction

Artifacts known as discontinuities, or kinks, in GMR R(H) curves, as shown in figure 1, have been previously reported [1]. This paper explains how these R(H) curve discontinuities are caused by a GMR element fluctuating between discrete resistance states when specific magnetic fields are applied. Resistance vs. time waveforms, captured using a high speed oscilloscope, in the region of R(H) discontinuities will be shown, and the filtering effects associated with the channels through which they were captured will be discussed. These filtering effects explain why some R(H) discontinuities appear gradual, such a region A in figure 1, and others instantaneous, such as region B in figure 1.

It should be noted that the high frequency switching events reported here did not occur without applied magnetic field stresses nor were they writer induced. Whereas this noise may appear superficially similar to popcorn or random telegraph noise, it is different and will escape many tests designed to detect these other types of noise.

II. Experimental Setup

All R(H) transfer curves were collected using an ISI 2002-QST [2]. All digital waveforms were captured using a LeCroy digital oscilloscope attached to the QST's high frequency (~250 MHz) AC-coupled channel, or low frequency (~100 kHz) DC-coupled channel. All R(H) curves were acquired using the same low frequency channel.

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III. Results & Discussion

A representative resistance vs. field curve from a head with illustrative R(H) discontinuities is shown in Fig. 1. To further understand the genesis of these discontinuities a series of waveforms were captured using a digital oscilloscope at fields between –150 and –100 Oe, as indicated by the labels in figure one. These waveforms are shown in figures two through five on the following page.

As noted in the experimental setup, the waveform captured in figures 3 through 5 were made through the QST's high frequency (250 MHz bandwidth) AC-coupled channel, where as the R(H) curve was captured through the low frequency (100 kHz bandwidth) DC-coupled channel. It should be noted that no write stress was used to excite these heads prior to capture.

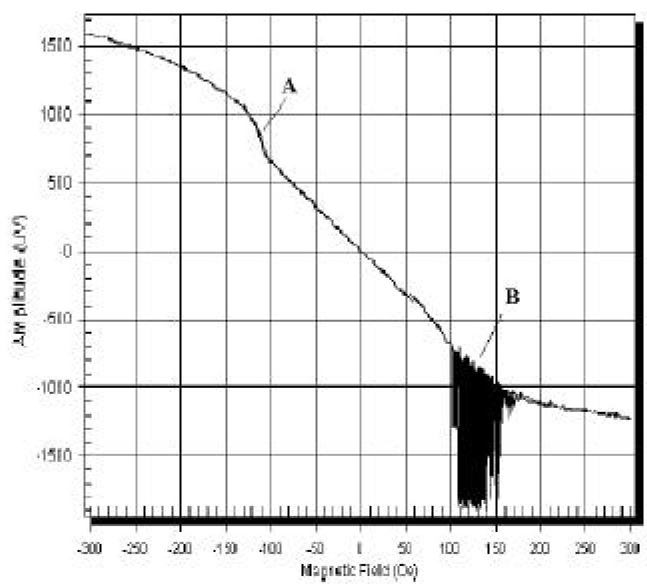

Fig. 1. Amplitude as a function of applied field, the R(H) curve, for an unstable GMR read element captured using a ISI-2002 QST. The labels 'A' and 'B' correspond to two different R(H) discontinuities centered at –120 Oe and 120 Oe, respectively.

Figure 2 was captured at a field at the left end of discontinuity A, and consists of a few negative-going noise spikes. Figure 3 was taken from the left-center of discontinuity A, and shows more frequent negative-going noise spikes. Figure 4 was captured from the right-middle, and shows a mix of positive and negative-going noise spikes. And finally, figure 5 was captured from the right end of discontinuity A, and shows a few positive-going noise spikes.

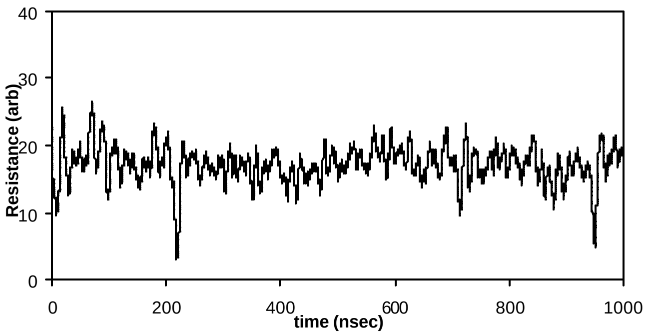

Fig. 2. Amplitude as a function of time waveform, captured through a high frequency AC coupled channel at –125 Oe, at the left end of GMR R(H) curve discontinuity ‘A’ in Fig. 1.

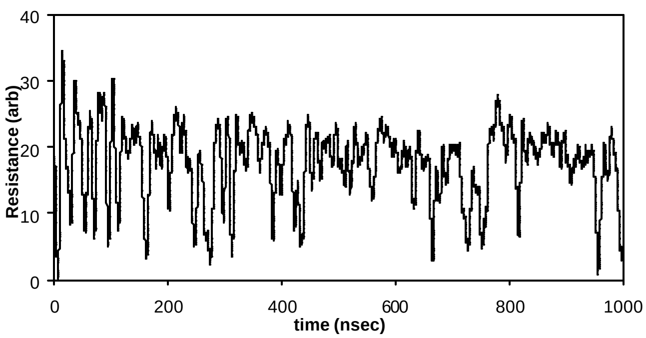

Fig. 3. Amplitude as a function of time waveform, captured through a high frequency AC coupled channel at –120 Oe, at the left middle of GMR R(H) curve discontinuity ‘A’ in Fig. 1.

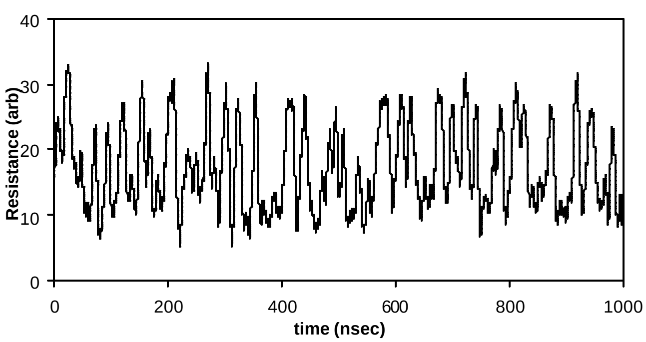

Fig. 4. Amplitude as a function of time waveform, captured through a high frequency AC coupled channel at –115 Oe, at the left middle of GMR R(H) curve discontinuity ‘A’ in Fig. 1.

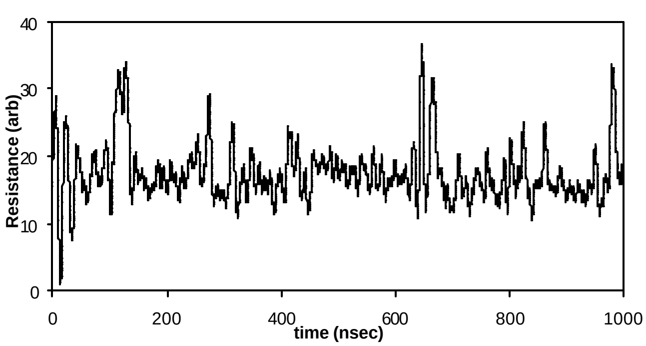

Fig. 5. Amplitude as a function of time waveform, captured through a high frequency AC coupled channel at –110 Oe, at the left end of GMR R(H) curve discontinuity ‘A’ in Fig. 1.

These high bandwidth waveforms demonstrate that there are two discrete resistance states which the GMR element fluctuates between. The discontinuity appears smooth in the R(H) curve because the low frequency channel used to capture the R(H) curve averages away the spikes.

Noise spikes in the smudged region ‘B’ are less frequent and look different than spikes in the in region ‘A”. Spikes in region ‘B’ appear in pairs of alternating polarity impulses (sharp rising edges followed by exponential decays), as shown in figure 6. These impulses often superimpose on top of one another, as shown in figures 7 & 8, and in the extreme case create noise spikes which resemble those in the gradual kink.

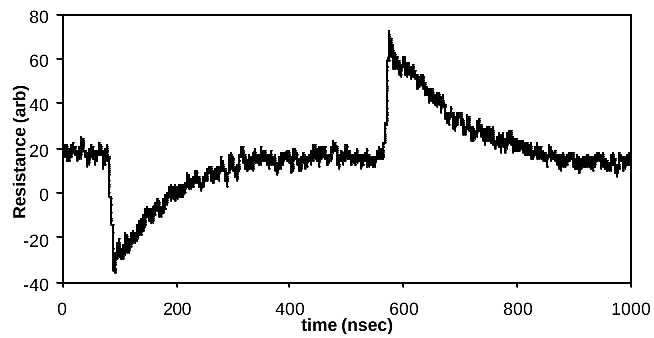

Fig. 6. Amplitude as a function of time waveform, captured through a high frequency AC coupled channel at +110 Oe, in the middle of GMR R(H) curve discontinuity ‘B’ in Fig. 1.

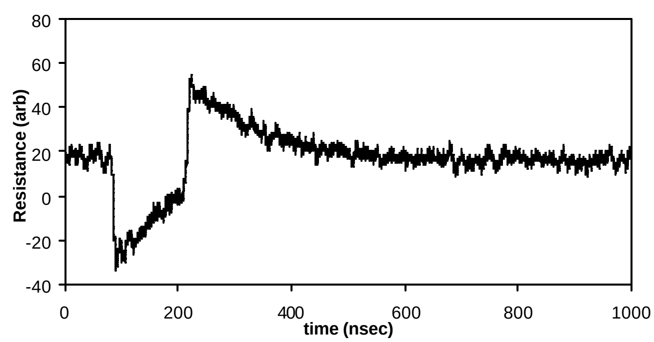

Fig. 7. Amplitude as a function of time waveform, captured through a high frequency AC coupled channel at +110 Oe, in the middle of GMR R(H) curve discontinuity ‘B’ in Fig. 1.

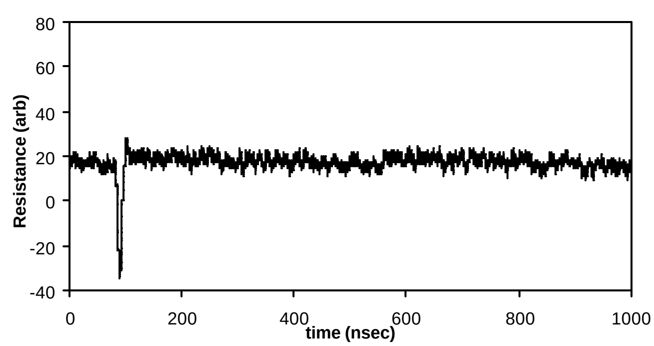

Fig. 8. Amplitude as a function of time waveform, captured through a high frequency AC coupled channel at +110 Oe, in the middle of GMR R(H) curve discontinuity ‘B’ in Fig. 1.

These impulses can be interpreted as rare (low frequency) high frequency voltage steps. This combination of high and low frequency appears as a sharp rising edge, at the high frequency limit of the channel, followed by a decay to zero at the low frequency limit of the channel. Note that these waveforms do not reveal the dynamics of the switching events themselves, as the AC-coupled channel though which the waveforms were captured limits the time resolution. The pulses come in pairs because each edge is the GMR switching from a high to low state, or vice versa.

This interpretation also relates instantaneous and gradual R(H) curve discontinuities, such those in regions 'A' and 'B', as the result of GMR switching events. The appearance of the R(H) discontinuity R(H) is dependent on it's probability, where rare fluctuations appear as instantaneous R(H) discontinuities and high probability fluctuations appear as smooth R(H) discontinuities. Note discontinuities are discussed in terms of their probability rather then frequency to avoid the assumption that they are periodic. Discontinuities have different rates of occurrence, but they are not periodic in time and therefore appear as broad band noise.

The previous conjectures on the relationship between noise spikes and R(H) discontinuities is further supported by waveforms captured simultaneously through the high frequency AC-coupled channel and the low frequency DC-coupled channel. An example of which is shown below in figure 9.

Again notice that the waveform captured throughout the high frequency AC-coupled channel, at the top of figure 9, looses the DC content between rising edges. Similarly the waveform captured through the low frequency DC-coupled channel, middle of figure 9, looses the sharp rising and falling edges. The bottom waveform is a fabricated representation of what a waveform captured through an ideal high frequency DC-coupled channel would look like.

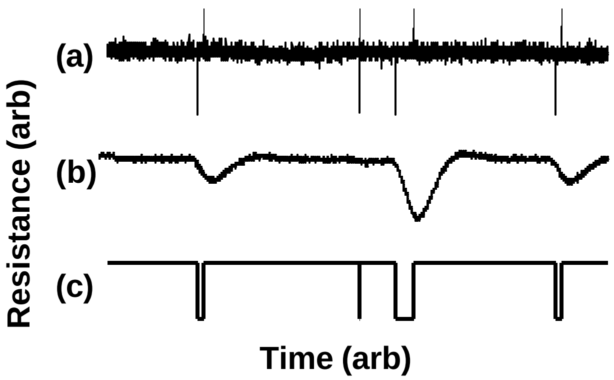

Fig. 9. Amplitude as a function of time waveforms, captured through a high frequency AC-coupled channel (a), a low frequency DC-coupled channel (b), and an idealized high frequency DC-coupled channel (c). Note the high frequency rising edges are lost in the low frequency capture and the low frequency troughs are lost in the high frequency capture.

IV. Conclusions

R(H) transfer curve discontinuities are the result of a GMR element switching between discrete resistance states when specific magnetic fields are applied. These events were not the result of writer excitation.

These GMR switching events have different probabilities. With low probability switching events resulting in instantaneous R(H) slope changes, and high probability events resulting in gradual R(H) slope changes. These differences in R(H) appearance are due to filtering effects due to QST bandwidth limitations.

GMR switching events appear as high frequency noise spikes when sampled with an high frequency AC-coupled channel.

Acknowledgment

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References

[1] A.Wallash, “A study of Voltage Fluctuation, Noise and Magnetic Instability in Spin Valve GMR Recording Heads”, IEEE Transactions on Magnetics v34(4) p.p. 1450, July 1998.

[2] Integral Solutions Int’l, “QST-2001 HGA/HSA/HDA Quasi-Static Tester User’s Manual Rev.1.9.3.1”, www.isiguys.com, 1999.