A Study of the Effects of Thermally Degraded Pulses on PRML Error Events

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Abstract

The superparamagnetic limit imposes a constraint on the bit cell size that can be used in conventional longitudinal magnetic recording technology. Until a new recording technology such as thermo-magnetic (hybrid) recording supersedes current methods, engineers will continue to design drives that are increasingly less thermally stable. Since the thermal decay of magnetization is accelerated in large fields and since there are large fields in and around recorded transitions, most of the thermal decay a drive experiences will be primarily located in the region of the transition. Thus, pulses written at the beginning of a product's life could experience a significant amount of degradation during the product's lifetime. The shape (size and width) of written pulses, and, hence, the error events that occur in a drive will all be adversely affected.

Abstract (cont'd)

To study the effect of thermal decay on PRML error events we model anisotropic longitudinal recording media using a full 3D micromagnetic model with a hexagonal grain structure. An NRZI pulse (00100) is written on the recording disk using a three-dimensional inductive write head. For the first part of this study a single pulse is thermally decayed using a Monte Carlo technique in combination with integration of the Landau-Lifschitz equation. The pulse is read back using reciprocity with a spin valve read head. Voltage wave forms are sampled at uniform logarithmic time intervals and stored to disk. Finally, using the thermally decayed pulse, data wave forms are constructed and passed through a PRML channel model. As the wave forms decay with time, the emergence of error events are characterized.

Abstract (cont'd)

In the second part of this study NRZI Monopulses (00100), dipulses (001100), and tripulses (0011100) are written on the recording disk. Dipulses and tripulses not only show the effect of partial erasure and transition shift, but also an enhanced thermal decay due to superposed demagnetization fields of neighboring transitions. Using these three primary pulses, data waveforms are again constructed and passed through a PRML channel model. As the transitions decay with time, error events emerge. These are compared with the error events that arise from linear superposition of decaying isolated transitions. The results show the importance of accounting for the accelerated decay of high-density transitions when predicting system level performance.

Micromagnetic Simulation Parameters

Micromagnetic Model- used commercially available micromagnetic modeling program, Advanced Recording Model (ARM) which has a hexagonal grain geometry and which includes all pertinent micro-magnetic interactions:

- Magnetostatic fields
- Magnetocrystalline anisotropy (uniaxial)
- Intergranular exchange
- Applied fields
- Thermally assisted magnetization

Media Parameters

	Isotropic	Anisotropic
H_c (Oe)	3026	3588
M_r (emu/cc)	282.4	378.5
S	0.71	0.95
S^*	0.97	0.98
SFD	0.128	.030
Orientation Ratio	1.0	2.28
$M_r t$ (memu/cm$_2$)	0.311	0.416
M_s (emu/cc)	400.0 (80)	400.0 (80)
Exchange Const.	0	0
H_k (Oe)	6500 (45)	6200 (45)
Angle Dispersion	90 degrees	40 degrees
D, Width (A)	120	120
Thickness (A)	110	110
Temperature (K)	300	300
Damping Factor	0.5	0.5
Prec. (Hz/Oe)	2.8 e 6	2.8 e 6

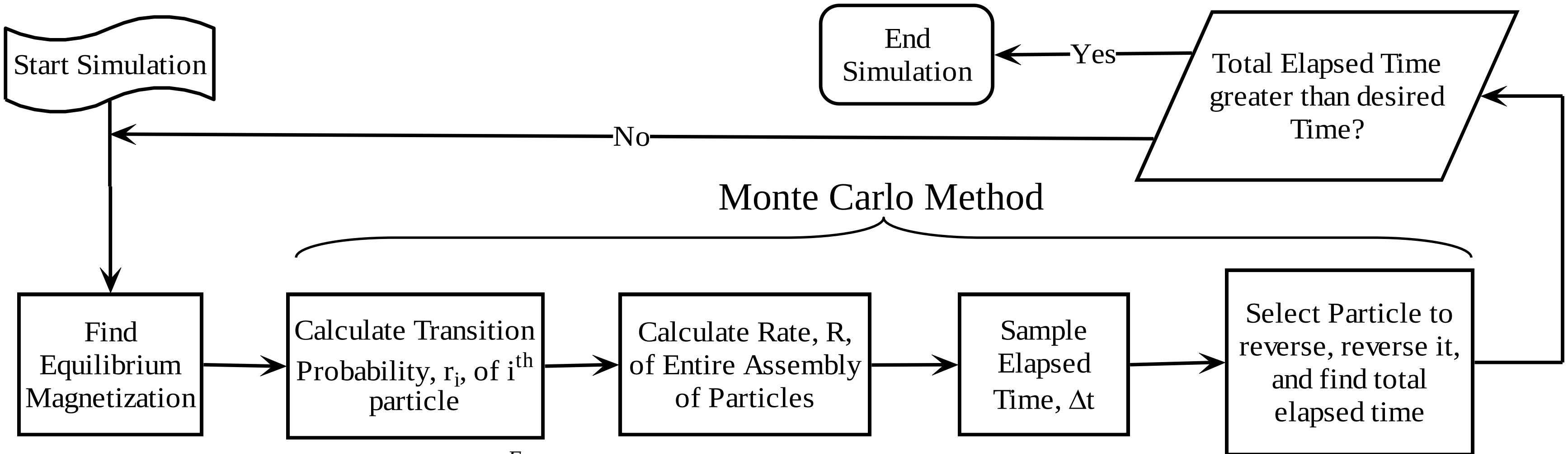
Write Head

- Karlquist, Long.
- H_g: 8000 Oe
- Gap: 0.2 µm
- spacing: 200 A
- velocity: 17 m/s

Write Head

- Spin Valve, Linear
- dR/R: 3.2 %
- Height: 1 µm
- Width: 1.5 µm
- Shield-to-Shield spacing: .23 µm
- Read Current: 6 mA

Thermal Decay Model*

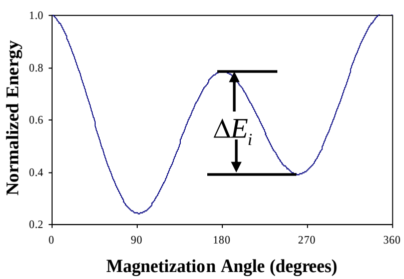


$$r_i = \frac{1}{\tau_i} = f_o\, e^{-\frac{E_i}{kT}}$$

$$R = \sum_{i=1}^{N} r_i$$

$$\Delta t = -\frac{1}{R}\ln(\xi)$$

ξ is a random number between 0 and 1



f_o = 1.0 x 10^9 "attempt frequency"
E_i is the energy barrier to reversal
k is Boltzmann's constant
T is the temperature
K_u is the anisotropy constant
V is the volume of magnetic particle

$$Stability\ \ Factor = \frac{K_u V}{kT}$$

Stability factor = 40
yields a time constant equal to 10 years*

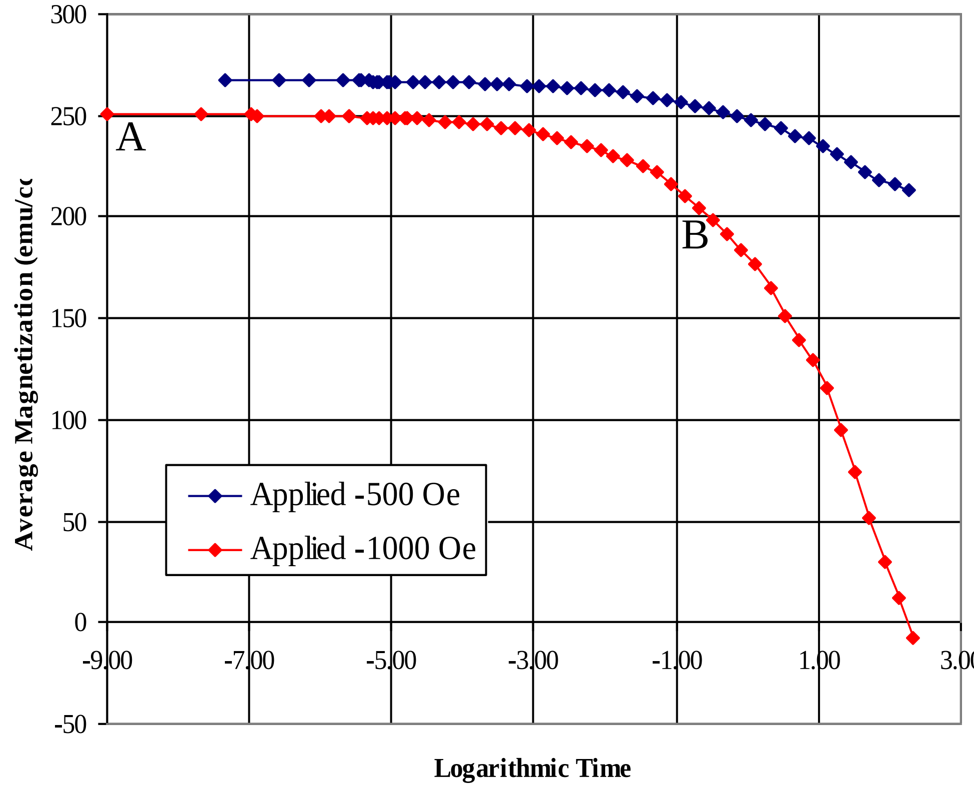
*after Y. Kanai and S. H. Charap, "Simulation of Magnetic Aftereffect in Particulate Recording Media," IEEE Trans. Magn., Vol. 27, p. 4972, 1991.

Thermal Modeling Results

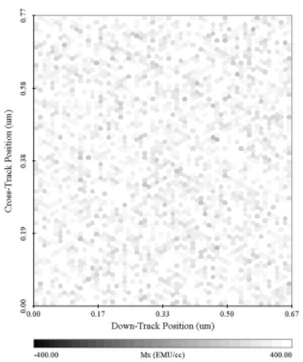
- Magnetization decays with time
  - Decreases signal amplitude
  - Increases noise

- In an applied field M_r is reduced

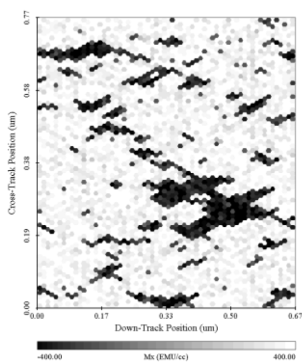
Magnetization decays faster in large fields



Point A



Point B



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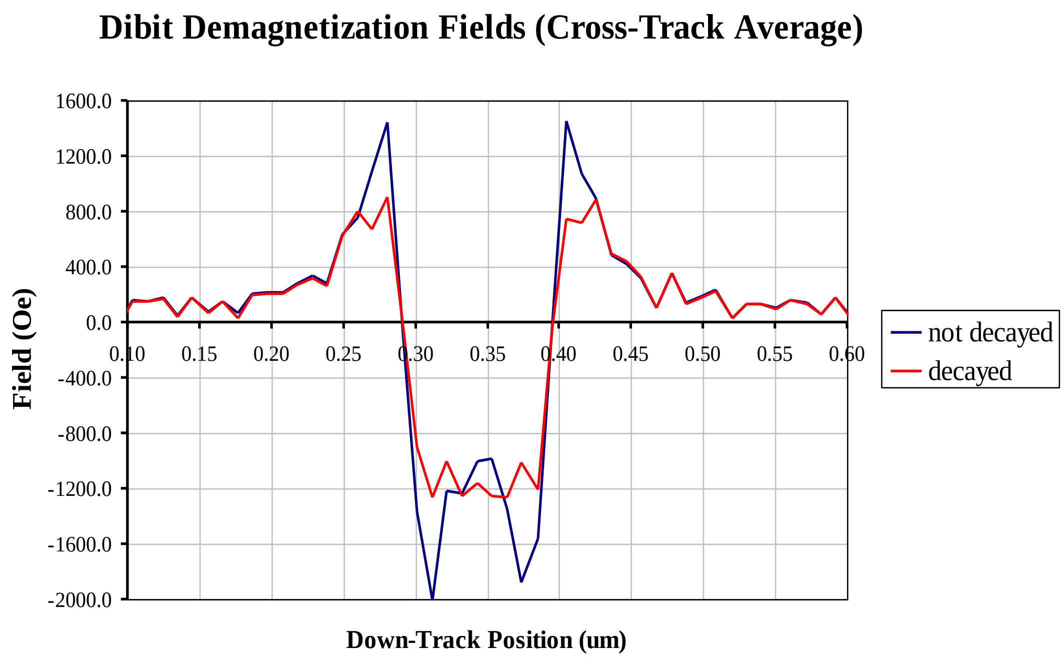
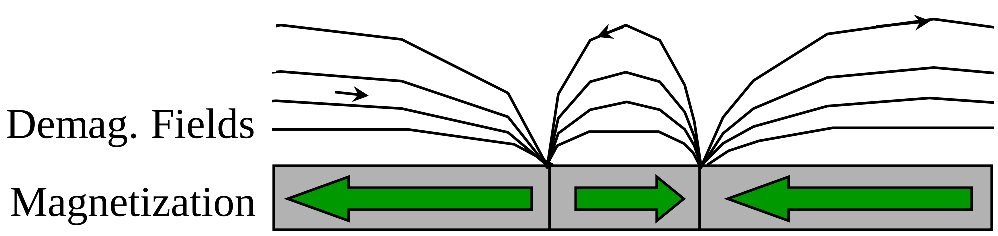
Thermal Decay of Transitions

- The rate of thermal decay is increased in areas with large fields
- Large fields exist in the area around transitions, therefore, thermal decay is greatest near transitions
- The demag. fields from each transition in a dibit combine to enhance thermal decay of the area between transitions
- Thermal Decay reduces demag. Fields near the transition





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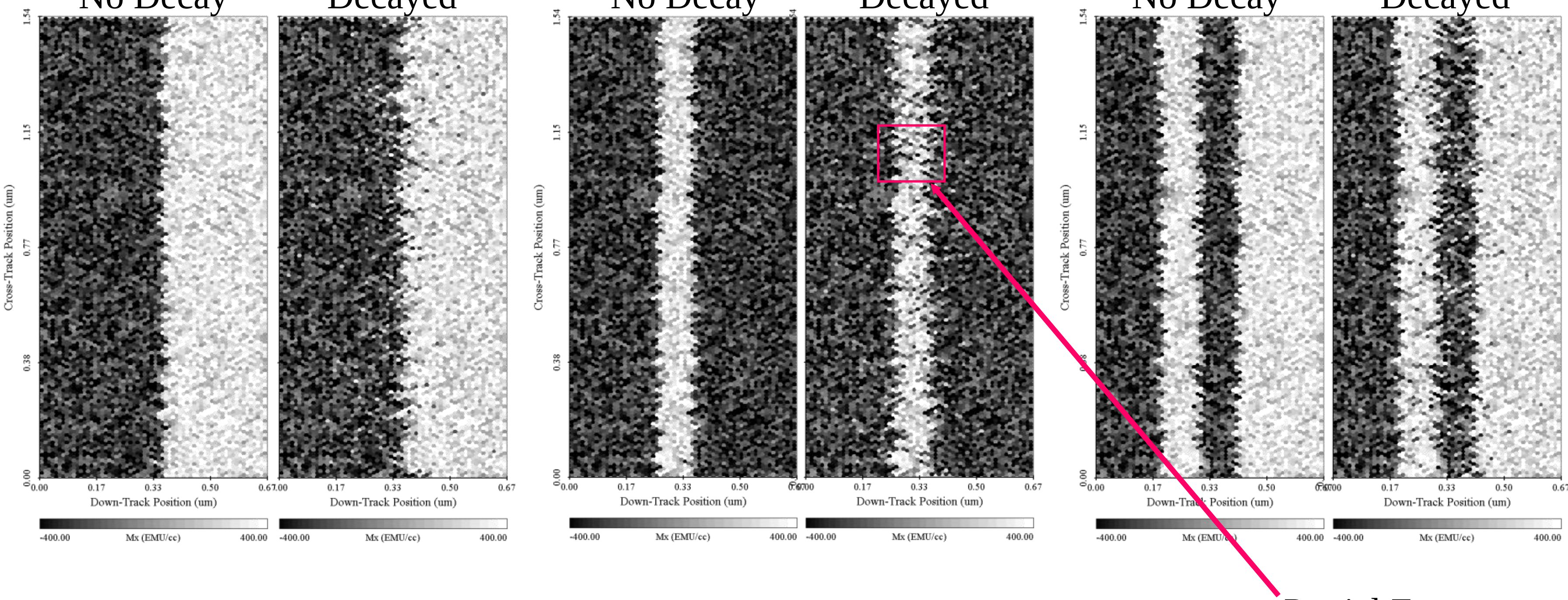
Isotropic Medium

x-component of the magnetization

$$Stability\ \ Factor = \frac{K_u V}{kT} = 43.1$$

Isolated Pulse		Dipulse		Tripulse	
No Decay	Decayed	No Decay	Decayed	No Decay	Decayed



Partial Erasure

In isotropic media amplitude reduction in a dibit or tribit occurs through the reversal of magnetization in a local region between two bits (partial erasure).

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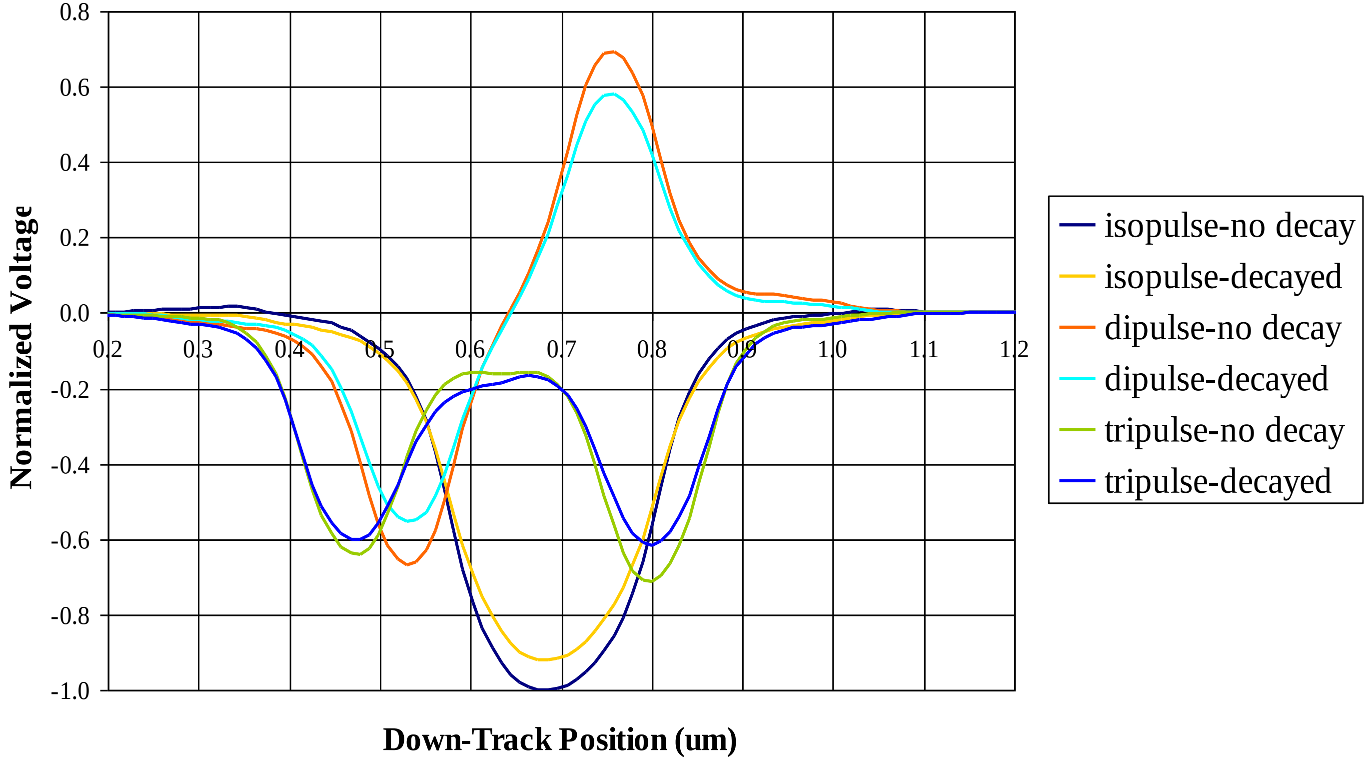
Pulses-Isotropic Medium

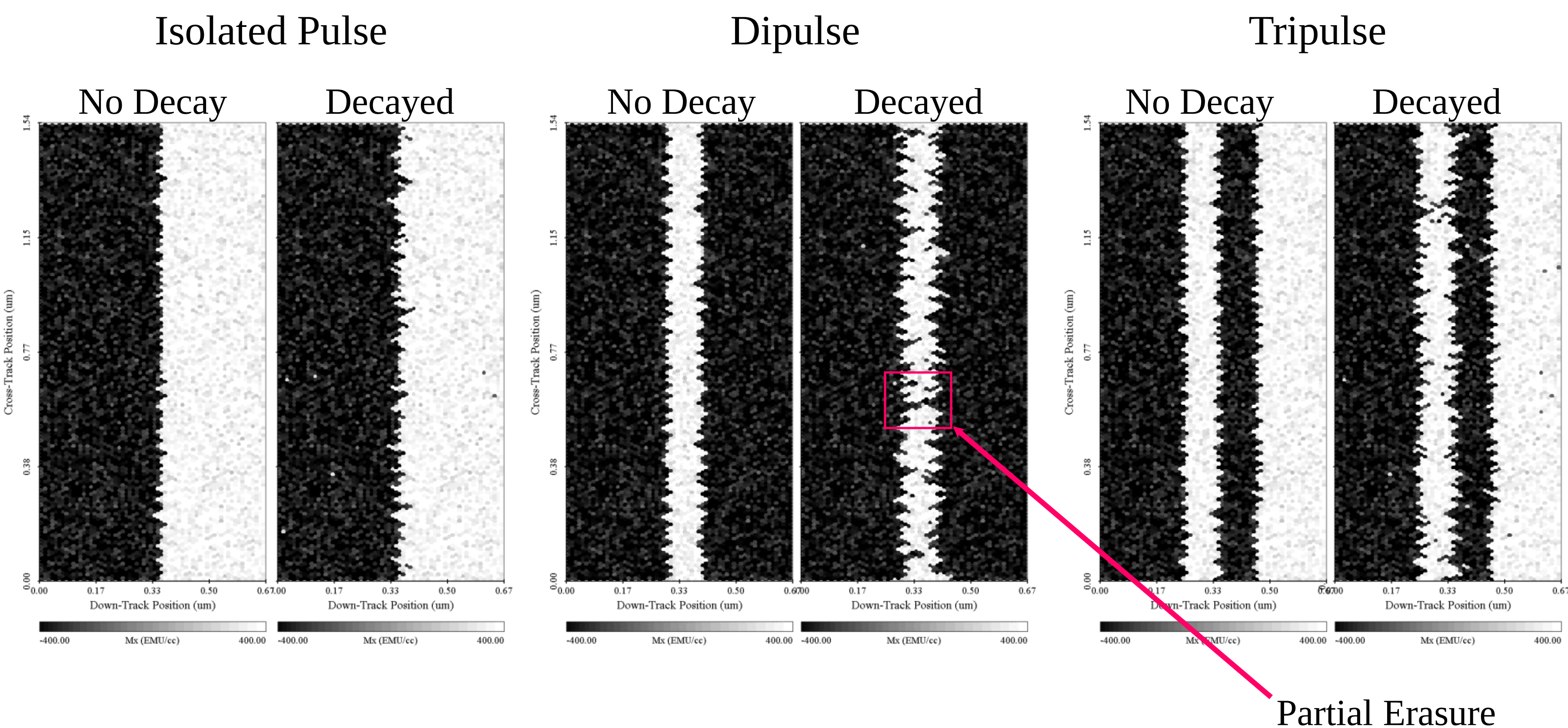


- Thermal decay causes a reduction in amplitude for all types of pulses
- Isopulse noticeably broadens
- Partial erasure accounts for most of amplitude reduction in dipulse and tripulse

Anisotropic Medium

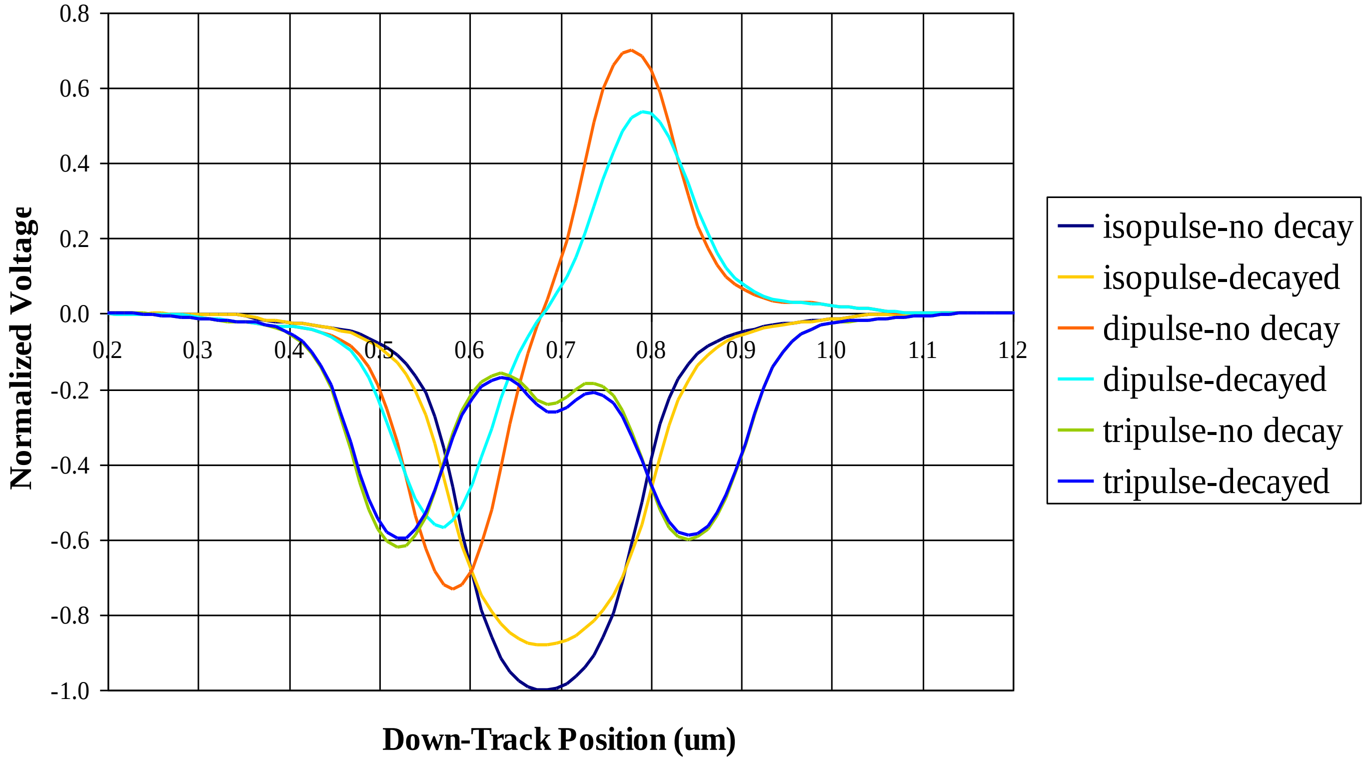
x-component of the magnetization

$$Stability\ \ Factor = \frac{K_u V}{kT} = 41.1$$



In anisotropic media amplitude reduction in a dibit or tribit occurs as a "percolation" of one direction of magnetization through another direction of magnetization (partial erasure). The size of the percolation grows with time.

Pulses-Anisotropic Medium



- Thermal decay causes a large reduction in amplitude for isopulse and dipulse
- Isopulse and dipulse noticeably broadened
- Partial erasure accounts for most of amplitude reduction in dipulse

Error Event Summary

Media	Transition Condition	Waveform Model	Number of Bit "Errors"
Anisotropic	No Decay vs. Decay	Linear	0
Anisotropic	No Decay vs. Decay	Non-linear	2
Anisotropic	No Decay	Linear vs. Non-linear	0
Anisotropic	Decay	Linear vs. Non-linear	2
Isotropic	No Decay vs. Decay	Linear	0
Isotropic	No Decay vs. Decay	Non-linear	6
Isotropic	No Decay	Linear vs. Non-linear	0
Isotropic	Decay	Linear vs. Non-linear	6
Anisotropic vs. Isotropic	No Decay	Linear	0*
Anisotropic vs. Isotropic	Decay	Linear	0*
Anisotropic vs. Isotropic	No Decay	Non-linear	0*
Anisotropic vs. Isotropic	Decay	Non-linear	8*

*NOTE: Anisotropic PW50/T = 1.9
Isotropic PW50/T = 2.2

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Error Event Conclusions

- Anisotropic: Non-linear model shows (di-bits to quad-bits)
  →→←→→←→→←←← decays to
  →→←→←→←→←←← as detected by VA
- Anisotropic: Linear model shows NO differences due to decay
- Isotropic: Non-linear model shows (di-bits to no transitions)
  ←←→→←→→←← ... ←←→→←→→←→→←←← decays to
  ←←→→→→→←← ... ←←→→→→→→→→←←←
  as detected by VA
- Isotropic: Linear model shows NO differences due to decay
- Non-linear model of decay shows Anisotropic pattern is
  ←←→→←→→←← ... ←←→→←→←→←→←←← vs.
  ←←→→→→→←← ... ←←→→→→→→→→←←←
  for the Isotropic pattern, as detected by the VA

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Modeling Conclusions

- Linear model shows NO differences between decayed Anisotropic and Isotropic media patterns
- Transitions interact with each other in highly non-linear ways, but modeling the complex non-linear interactions of transitions in long waveforms can take weeks of computer time
- Creating long waveforms by the traditional linear superposition of isolated pulses does not reveal the detrimental effects of non-linear transition interaction
- Creating long waveforms from linearly combining non-linear models of mono-, di- and tri-pulses provides a quick and more accurate picture of how transition interactions affect drive error rate
- Studying only isolated transitions yields an overly optimistic prediction of the effects of thermal decay