Micromagnetic Calculation of the High Frequency Dynamics of Nano-Size Rectangular Ferromagnetic Stripes

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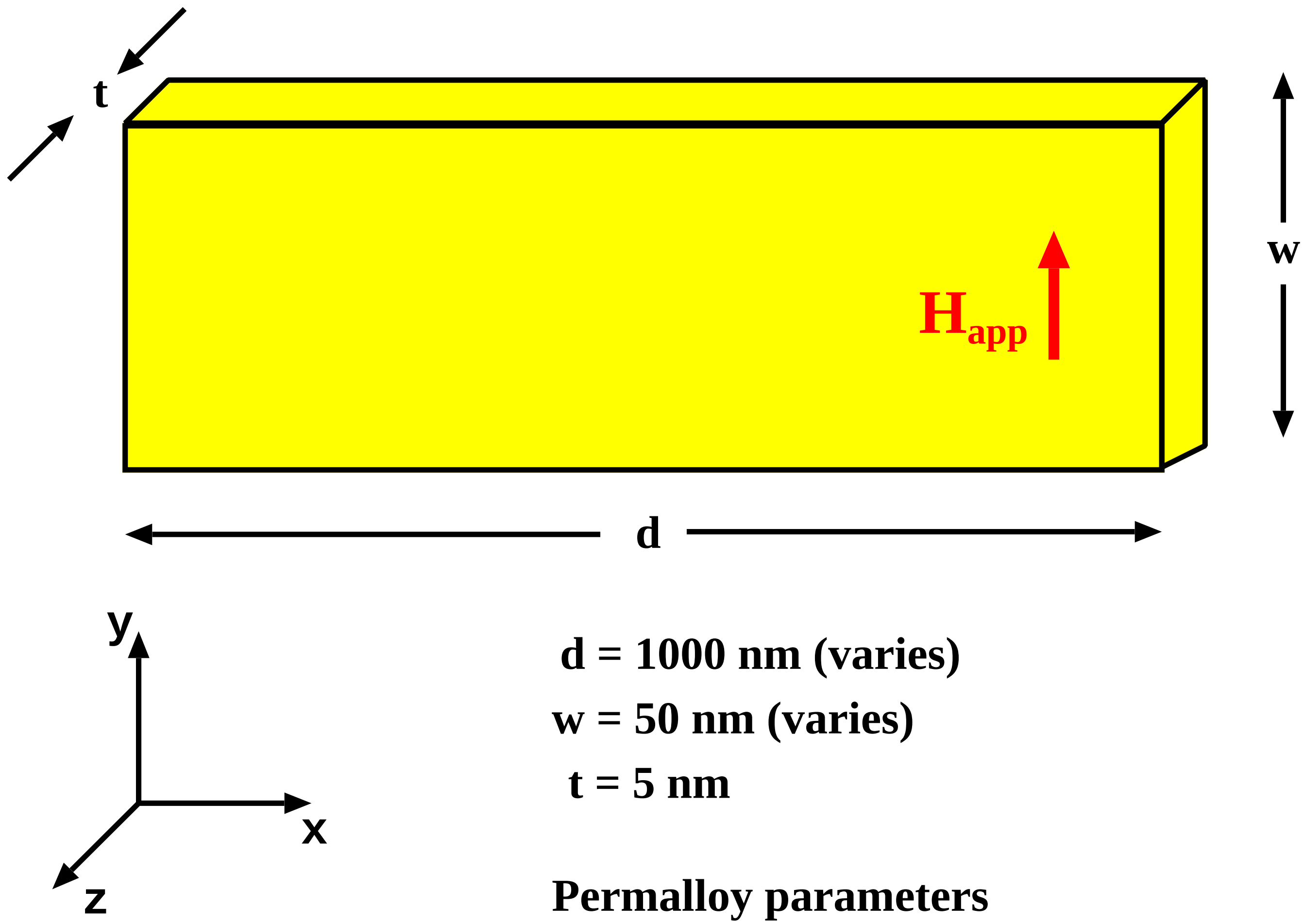
NIST CENTENNIAL 1901-2001

Simulation Schematic



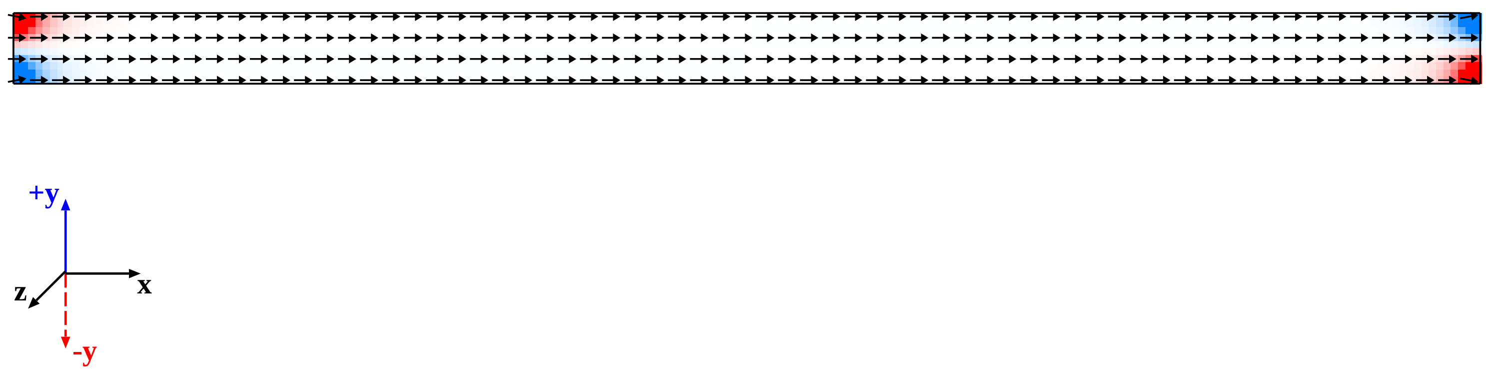
d = 1000 nm (varies)

w = 50 nm (varies)

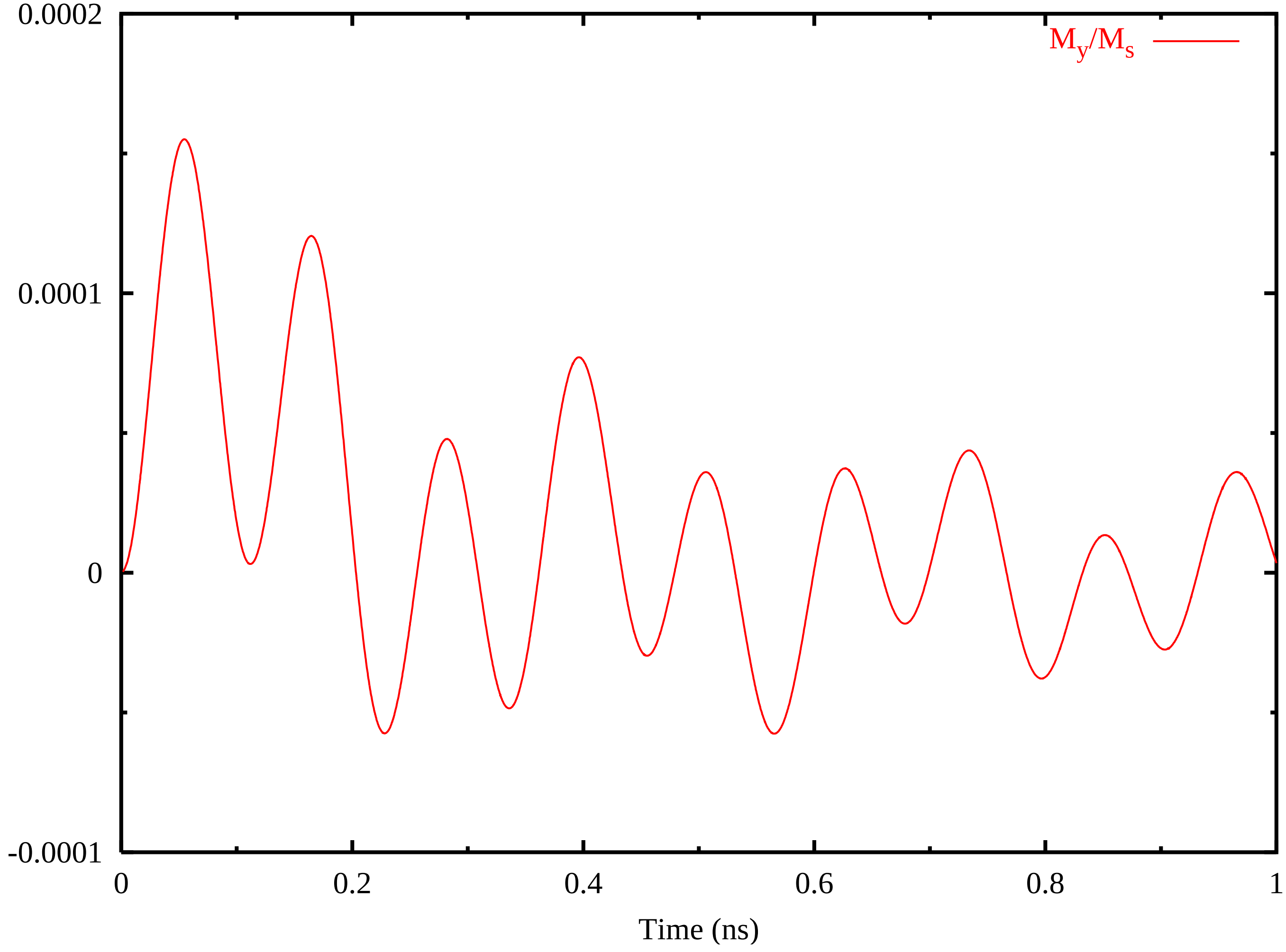
t = 5 nm

Permalloy parameters

Remanent State



Time Series Response



High Frequency Susceptibility

Define susceptibility χ by

$$< \mathbf{M}(t) > \cdot \mathbf{u} = \int_{-\infty}^{+\infty} \chi(t-t')[\mathbf{h}(t') \cdot \mathbf{u}]dt',$$

or in Fourier domain

$$M(t) = \chi(t) \star h(t) \leftrightarrow M(\omega) = \chi(\omega) \cdot h(\omega).$$

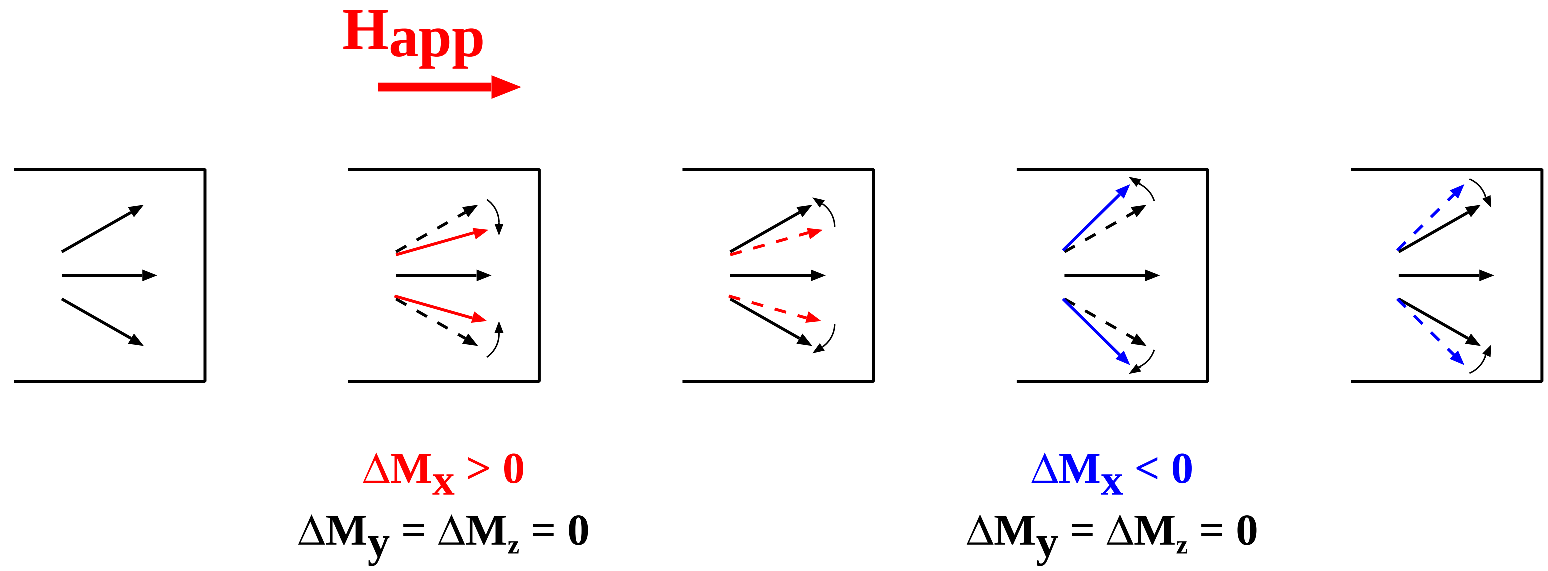
In the following we use

$$h(t) = 1_{[0,\infty]} \, Ce^{-7.675t} \leftrightarrow h(\omega) = \frac{C}{7.675 + 2\pi i\omega}$$

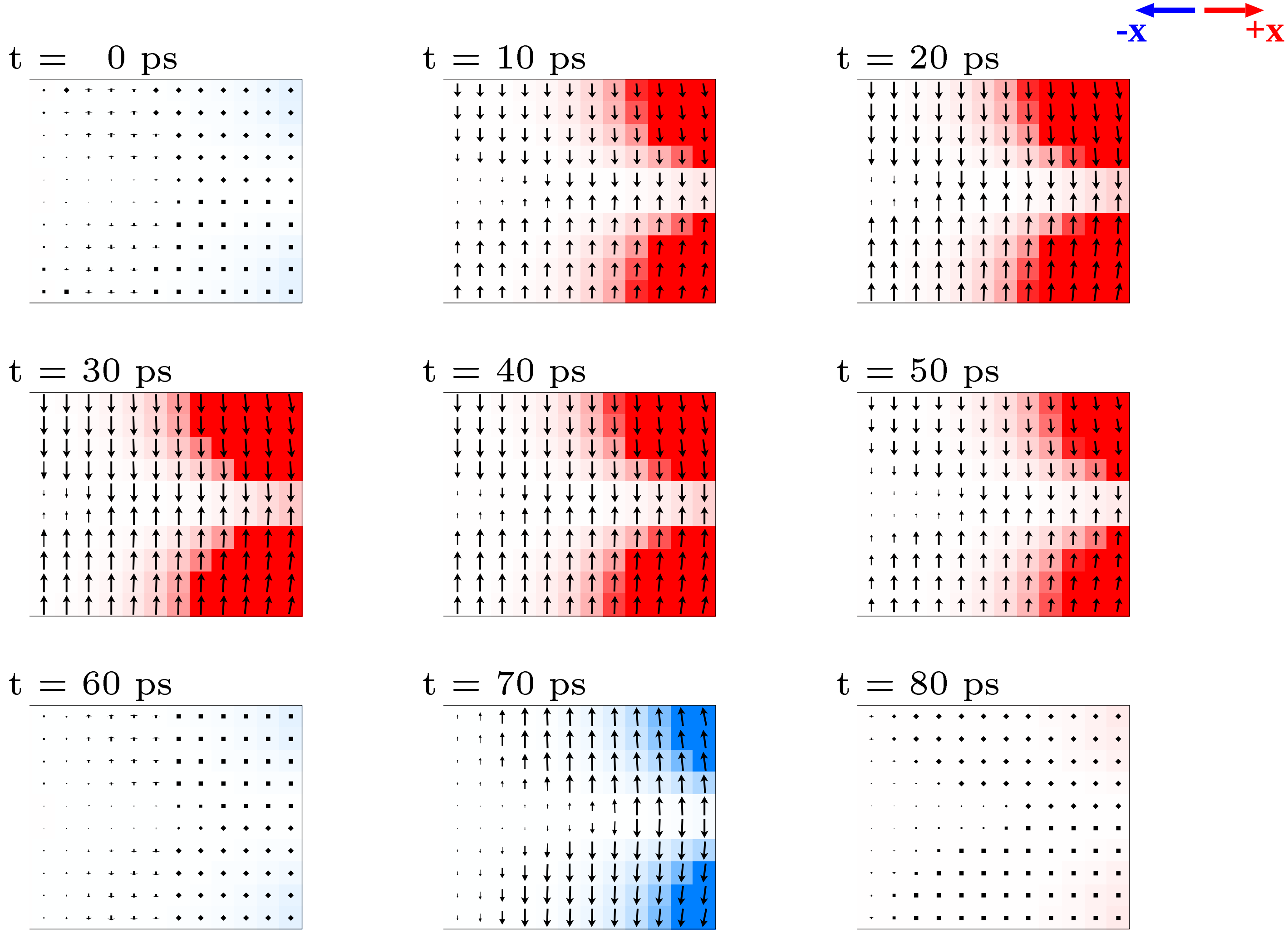
where

$$\begin{aligned} C \quad &= \quad 7.96 \text{ A/m } (= 0.1 \text{ Oe}), \\ t \quad &\text{in} \quad \text{ns}, \\ \omega \quad &\text{in} \quad \text{GHz}. \end{aligned}$$

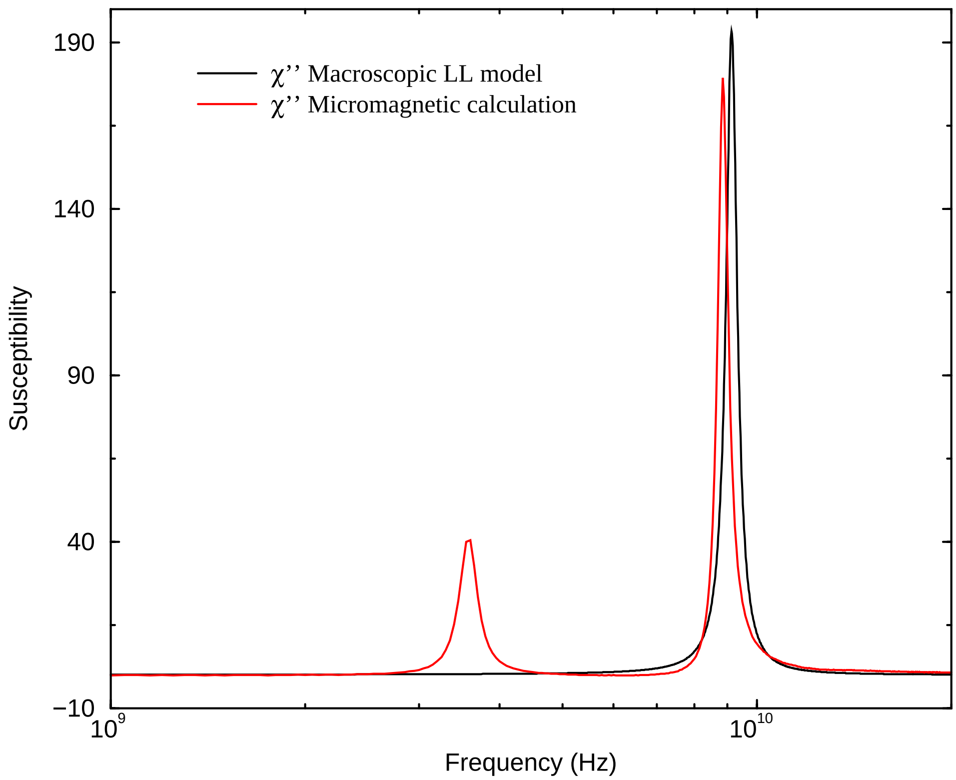
"Breathing" mode, x-excitation



$\mathbf{M}[t] - \mathbf{M}_{\text{remanence}}$, x-excitation



Rotational modes, y-excitation

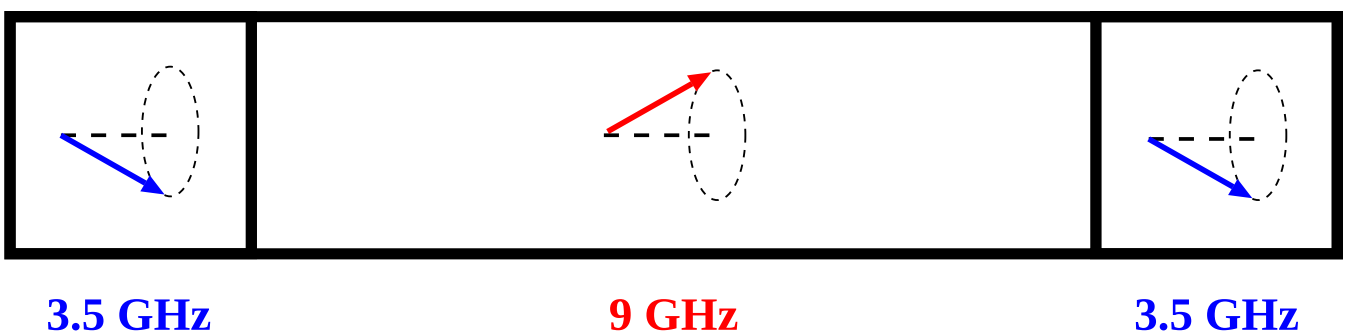


Permalloy stripe, 1 μm $\times$ 50 nm $\times$ 5 nm.

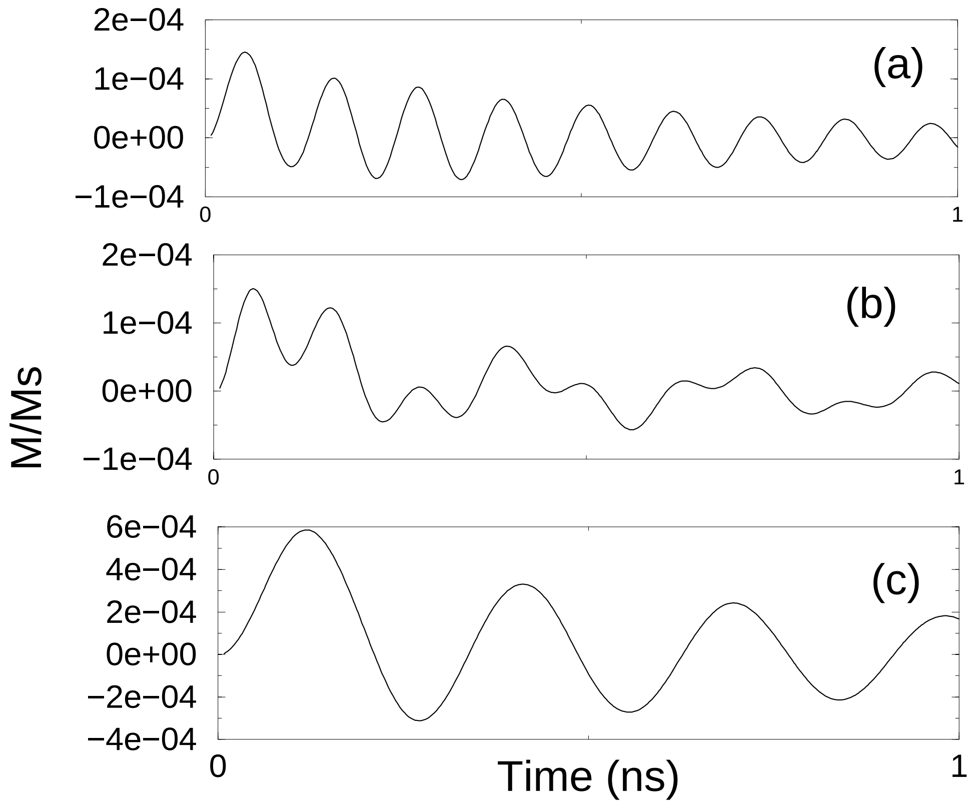
Black: uniform magnetization model.

Red: micromagnetic simulation.

Simple Three Domain Model



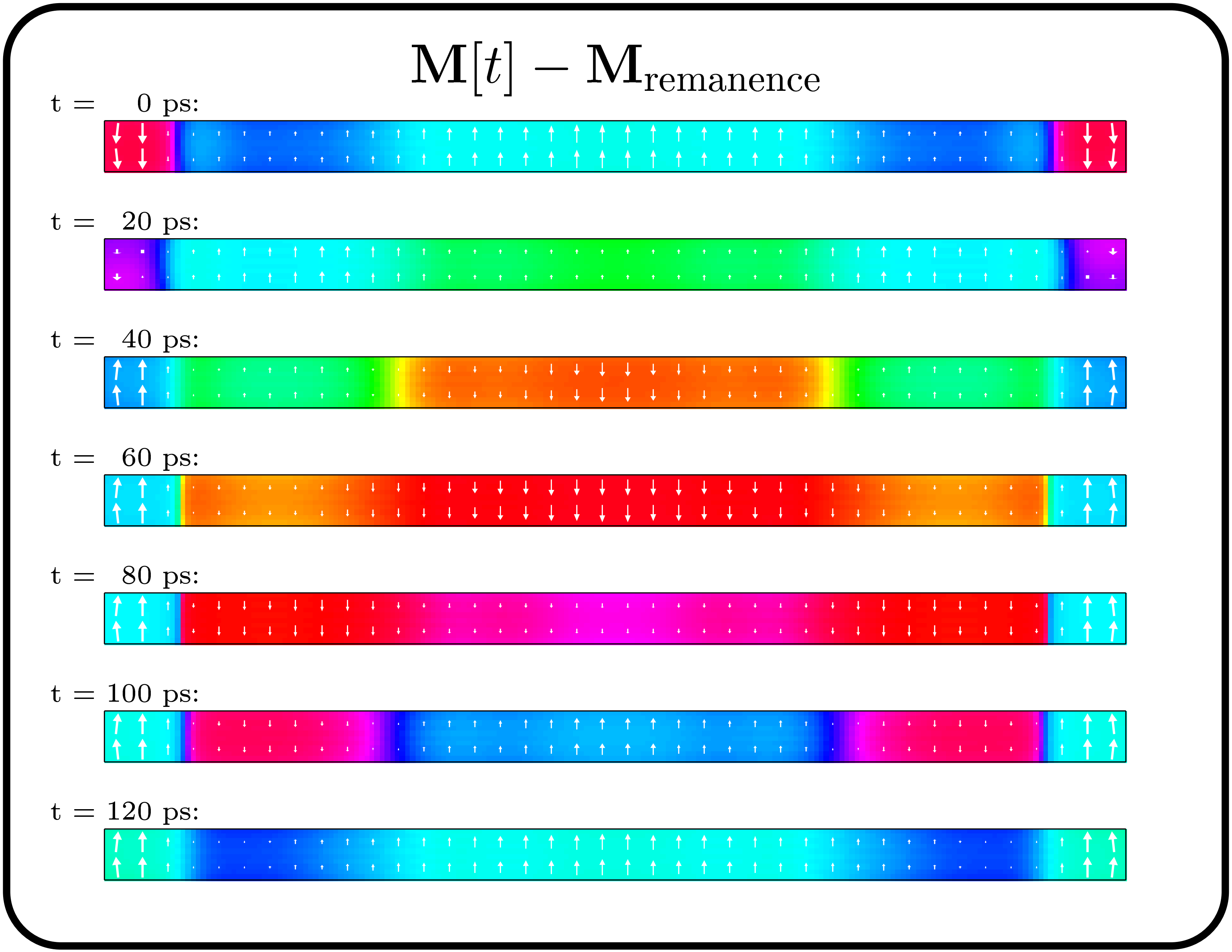
Single Spin Dynamics



(a) Center spin

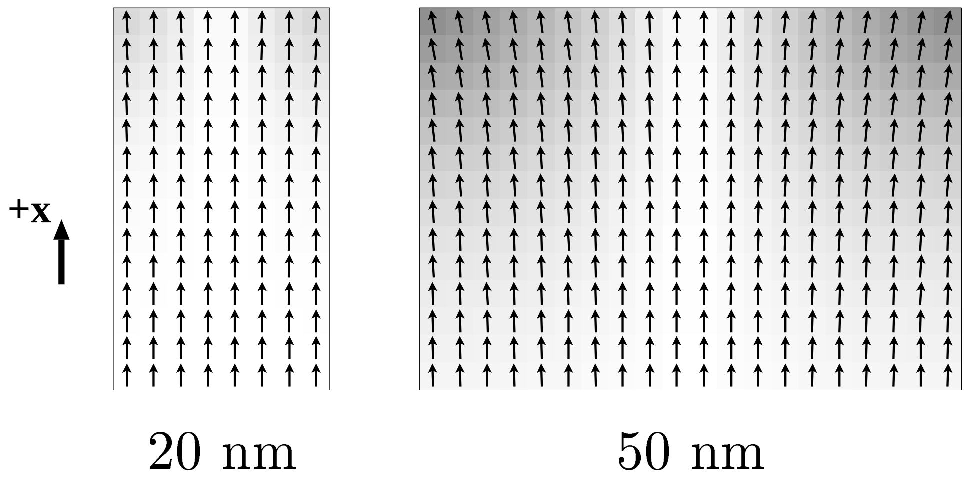
(b) Intermediate spin

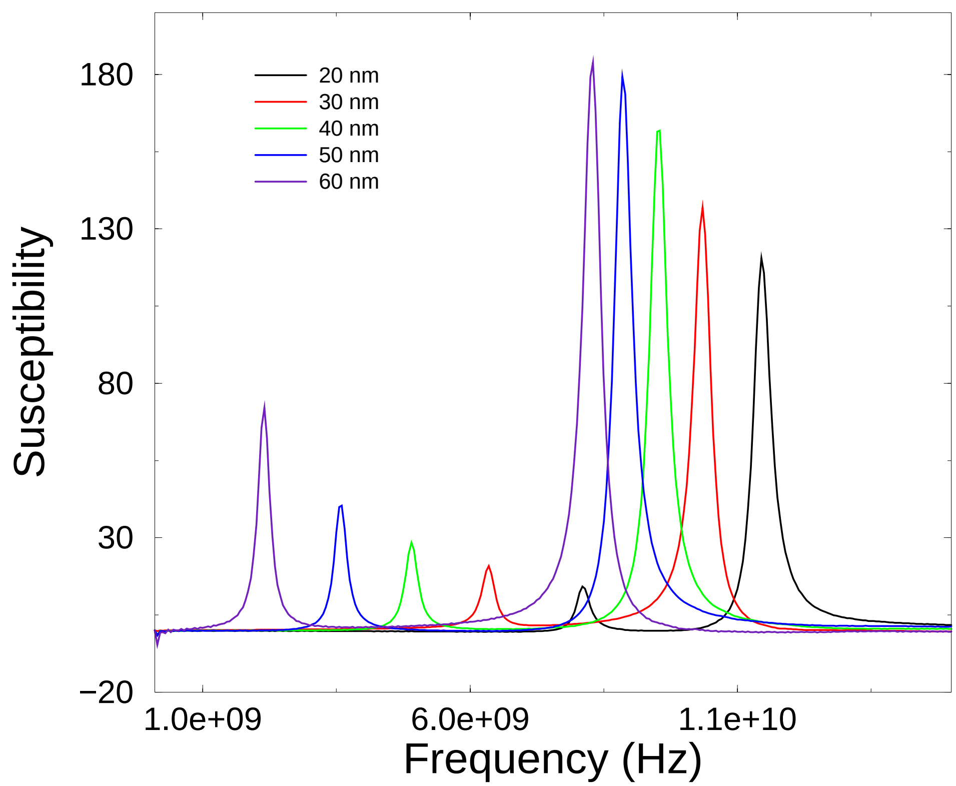
(c) End spin



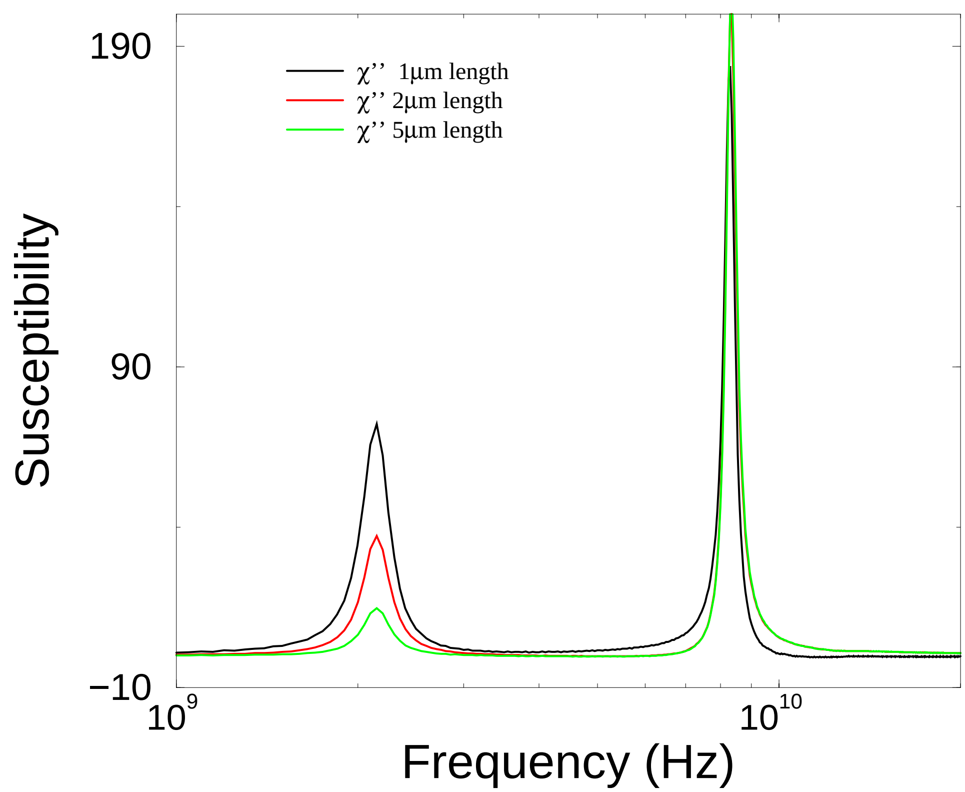
M[t] − M_remanence
t = 0 ps:
t = 20 ps:
t = 40 ps:
t = 60 ps:
t = 80 ps:
t = 100 ps:
t = 120 ps:

Stripe Width Effects

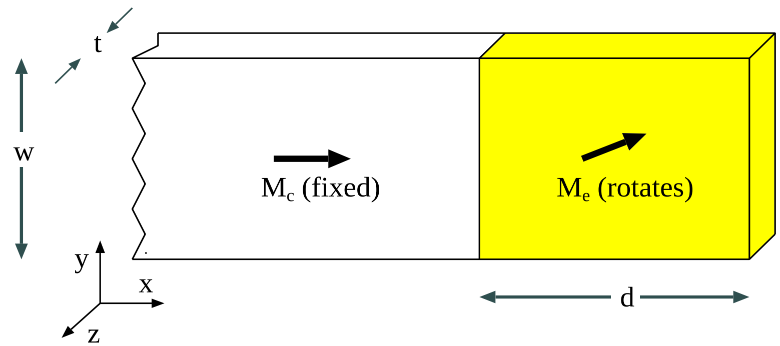




Stripe Length Effects



Simple Edge Spin Model



$$H_{\text{exch}} = \left(2A/(\mu_0 M_s d^2), 0, 0\right)$$

$$H_{\text{demag}} = (-N_x M_x/2, -N_y M_y, -N_z M_z)$$

Then

$$\text{Freq} = \frac{\gamma M_s}{2\pi}\sqrt{\left(\frac{2A}{\mu_0 M_s^2 d^2} - \frac{N_x}{2} + N_y\right)\left(\frac{2A}{\mu_0 M_s^2 d^2} - \frac{N_x}{2} + N_z\right)}$$

where

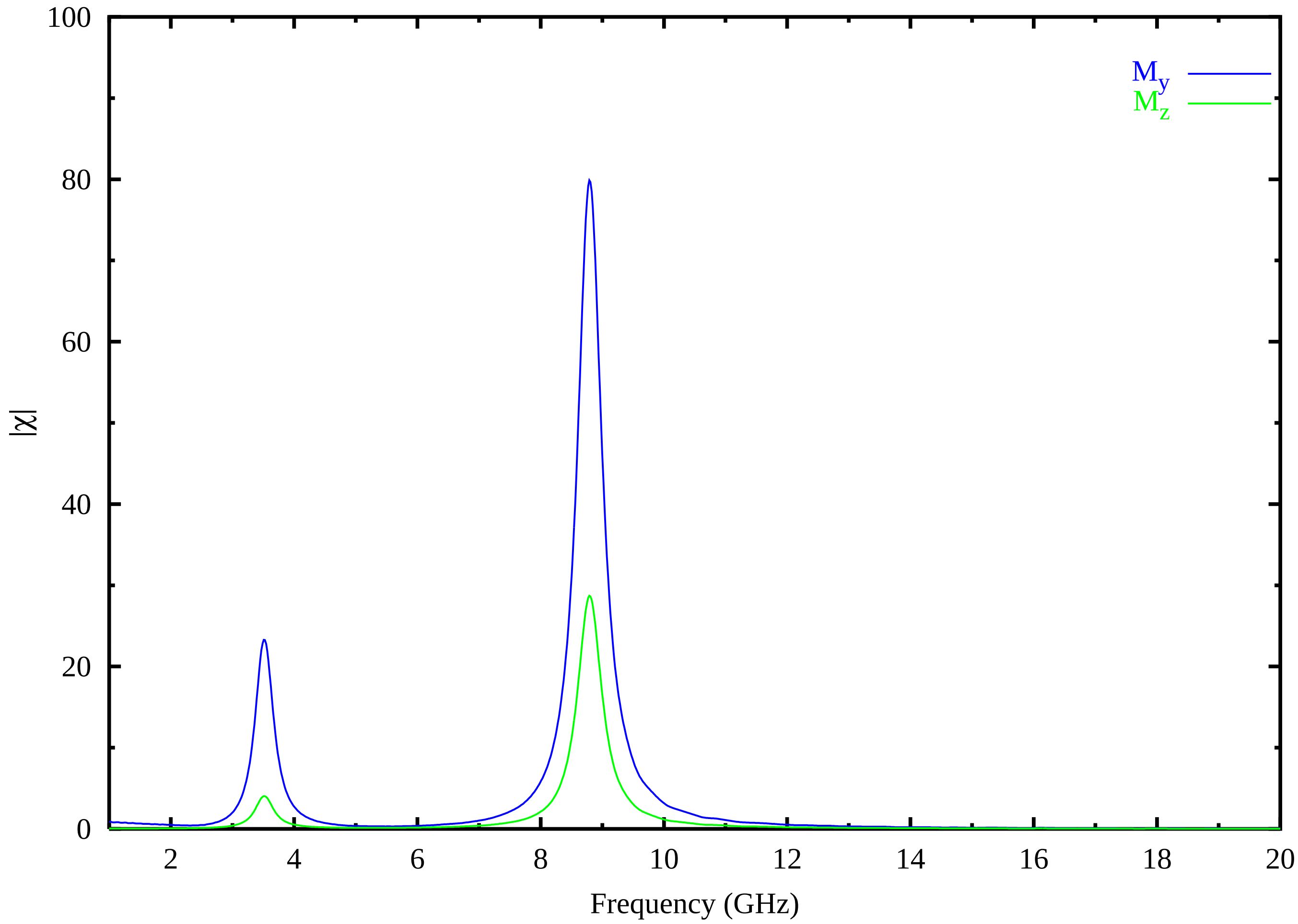
$$d \approx 4\, l_{\text{ex}} = 4\sqrt{2A/\mu_0 M_s^2}$$

Simple Model Results

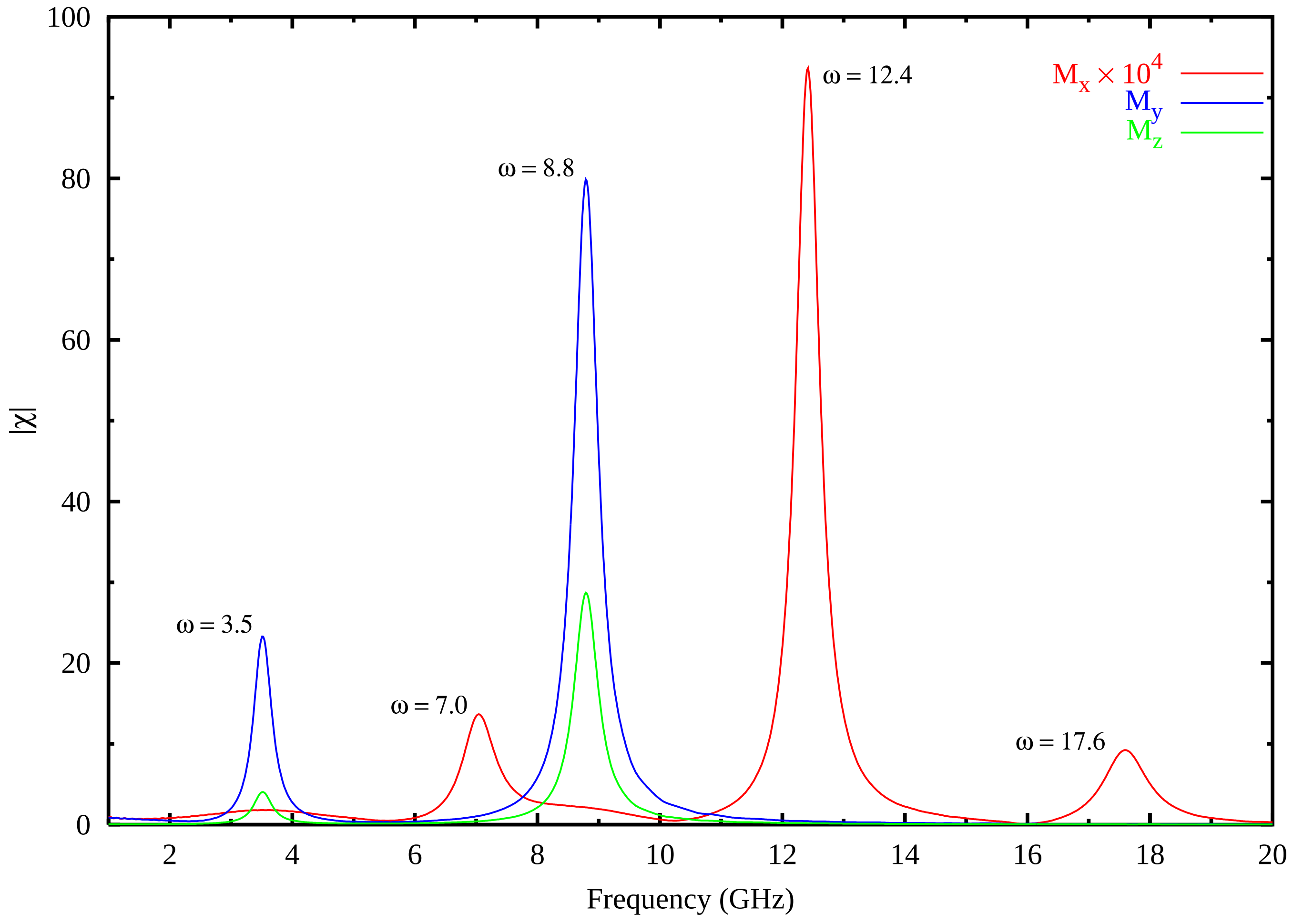
Part width (nm)	Frequency (GHz)	N_x	N_y	N_z
20	9.6	0.00422	0.229	0.767
30	7.8	0.00481	0.173	0.822
40	6.5	0.00524	0.141	0.854
50	5.4	0.00558	0.120	0.875
60	4.5	0.00585	0.104	0.890

$$\text{Freq} = \frac{\gamma M_s}{2\pi}\sqrt{\left(\frac{2A}{\mu_0 M_s^2 d^2} - \frac{N_x}{2} + N_y\right)\left(\frac{2A}{\mu_0 M_s^2 d^2} - \frac{N_x}{2} + N_z\right)}$$

Susceptibility: Other Components



Susceptibility: Other Components



Single Spin Rotation

Let

$$m_y(t) = a \cos \omega t \qquad m_z(t) = b \sin \omega t$$

with $0 < b < a \ll 1$.

Then

$$\begin{aligned} m_x(t) &= \sqrt{1 - m_y^2(t) - m_z^2(t)} \\ &= \sqrt{1 - \frac{a^2 + b^2}{2} - \frac{a^2 - b^2}{2} \cos 2\omega t} \\ &\approx 1 - \frac{a^2 - b^2}{4} \cos 2\omega t \end{aligned}$$

Conclusions:

- Identified 3 modes:
  1. "Breathing" mode from x-axis excitation.
  2. Central core rotation from tranverse excitation.
  3. End domain rotation from transverse excitation.
- Resonance frequencies sensitive to part geometry.

Thursday 4:00 pm

HF-11 Switching Dynamics and Ring Down Response of Standard Problem #4

J. Eicke, M. Donahue, R. McMichael, D. Porter

References

Micromagnetics of the Dynamic Susceptibility for Coupled Permalloy Stripes, O. Gérardin, J. Ben Youssef, H. Le Gall, N. Vukadinovic, P. M. Jacquart and M. J. Donahue, *Journal of Applied Physics,* **88**, pp 5899–5903 (2000).

Behavior of muMAG Standard Problem No. 2 in the Small Particle Limit, M. J. Donahue, D. G. Porter, R. D. McMichael and J. Eicke, *Journal of Applied Physics,* **87**, pp 5520–5522 (2000).

Exchange Energy Representations in Computational Micromagnetics, M. J. Donahue and R. D. McMichael, *Physica B,* **233**, pp 272–278 (1997).

Web Pages

- Home Page:

  http://math.nist.gov/~MDonahue/

- OOMMF:

  http://math.nist.gov/oommf/

- μMAG:

  http://www.ctcms.nist.gov/~rdm/mumag.org.html