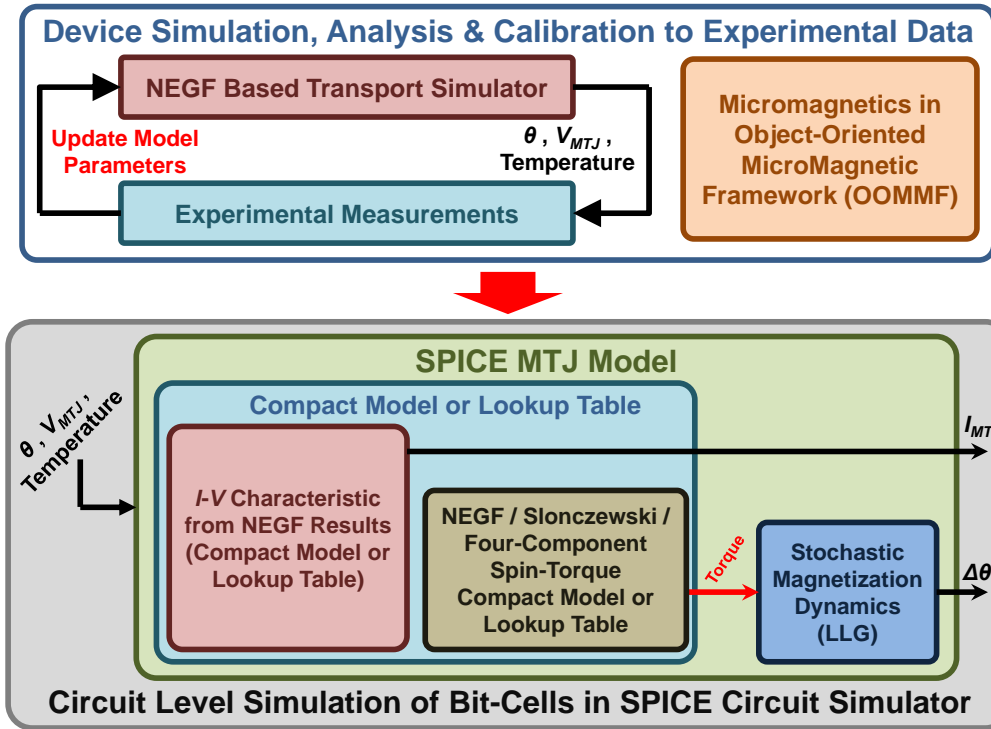


# **SPICE Model for Magnetic Tunnel Junctions**

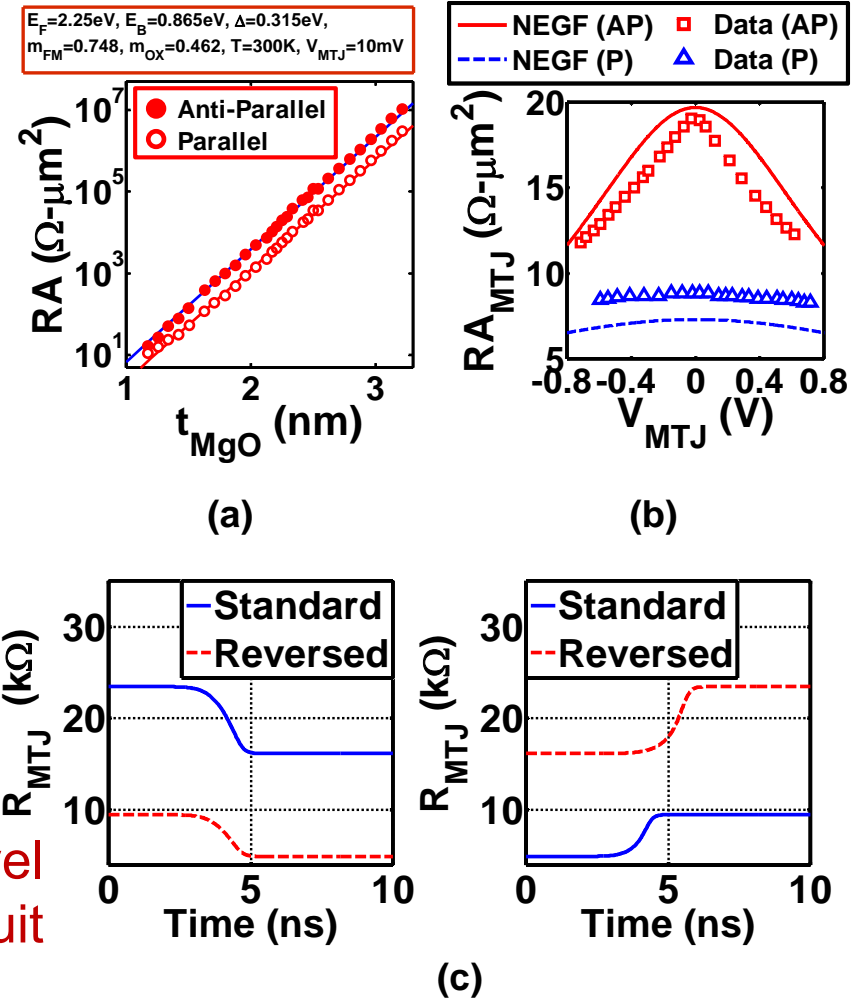
Xuanyao Fong, Sri Harsha Choday, Georgios Panagopoulos  
Charles Augustine, and Kaushik Roy

Department of Electrical and Computer Engineering,  
Purdue University, West Lafayette, IN  
<https://engineering.purdue.edu/NRL/index.html>

# Overview



Parameters for calibration of device level simulation go into SPICE model for circuit level simulations.



a) S. Yuasa *et al.*, *Nature Materials* vol. 3, no. 12, pp. 868-871, Dec. 2004, b) C. J. Lin *et al.*, *IEDM*, Dec. 2009, pp. 11.6.1-11.6.4, c) T. Kishi *et al.*, *IEDM*, Dec. 2008, pp. 12.6.1-12.6.4.

# Where To Get The Files?

[NanoHub.org](https://nanohub.org)

<https://nanohub.org/resources/19048>

The screenshot shows the NanoHub.org website interface. At the top, the logo 'nanoHUB.org' is displayed with the tagline 'an ncn project'. To the right, it says 'ONLINE SIMULATION AND MORE FOR NANOTECHNOLOGY'. A search bar and user options like 'Logout' and 'My Account' are visible. Below the header, a navigation menu includes 'Home', 'Resources', 'Members', 'Explore', 'nanoHUB-U', 'Partners', 'About', and 'Support'. A breadcrumb trail reads: 'Home > Downloads > SPICE Models for Magnetic Tunnel Junctions Based on Monodomain Approximation > About'.

The main content area features the title 'SPICE Models for Magnetic Tunnel Junctions Based on Monodomain Approximation' with an 'Edit' link. Below the title, the author information is listed: 'By Xuanyao Fong<sup>1</sup>, Sri Harsha Choday<sup>1</sup>, Panagopoulos Georgios<sup>1</sup>, Charles Augustine<sup>1</sup>, Kaushik Roy<sup>1</sup>'. A note indicates '1. Purdue University'.

On the right side of the main content, there is a 'Download (TGZ)' button. Below it, a message states 'Additional materials available (1)'. A Creative Commons license icon is shown with the text 'Licensed according to this deed.'.

On the far right, a sidebar displays a '0.0 RANKING' bar, '0 Citation(s)', '0 review(s) (Review this)', and an 'Add to your favorites!' button. Below these are social media share icons for Facebook, Twitter, and Google+.

At the bottom, there is a tabbed interface with 'About', 'Citations', 'Reviews', and 'Supporting Docs' tabs. The 'About' tab is selected. Below the tabs, the 'Category' is 'Downloads' and the 'Published on' date is '21 Aug 2013'. An 'Abstract' section is partially visible at the bottom, starting with 'Models for simulating a magnetic tunnel junction in HSPICE. The usage description is included in the "USAGE" text'.

On the right side of the bottom section, there are two boxes: 'SEE ALSO' and 'RECOMMENDATIONS', both containing the text 'No results found.' Below these boxes, it says 'Powered by ...'.

# Where To Get The Files?

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## SPICE Models for Magnetic Tunnel Junctions Based on Monodomain Approximation [Edit](#)

By [Xuanyao Fong](#)<sup>1</sup>, [Sri Harsha Choday](#)<sup>1</sup>, [Panagopoulos Georgios](#)<sup>1</sup>, [Charles Augustine](#)<sup>1</sup>, [Kaushik Roy](#)<sup>1</sup>

*1. Purdue University*

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(TGZ, 31.27 [Kb](#))  
[NRL\\_SPICE\\_MTJ\\_LIB\\_stable100413.tgz](#)

(TGZ, 130.76 [Kb](#))  
[NRL\\_SPICE\\_MTJ\\_LIB\\_Example.tgz](#)

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### SEE ALSO

No results found.

### RECOMMENDATIONS







No results found.

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# Archive Contents




NRL\_SPICE\_MTJ\_LIB\_stable100413.tgz

Contains a directory “mtj\_libs\_encoded”

 LLG.lib	9/25/2013 3:42 PM	LIB File	13 KB
 LLGThermRandNum.va	9/19/2013 11:54 AM	VA File	1 KB
 MTJ.lib	9/25/2013 3:42 PM	LIB File	16 KB
 MTJ_res.va	7/28/2013 4:45 PM	VA File	2 KB
 NRL_MTJ_SPICE_ENC_LIB.inc	10/28/2013 10:03 ...	INC File	1 KB
 USAGE	10/4/2013 11:02 AM	File	3 KB

NRL\_SPICE\_MTJ\_LIB\_Example.tgz

Contains a directory “stt”

 MTJ_calib.sp	10/28/2013 10:45 ...	SP File	4 KB
 nrl_mtj_calib_ap2p.printtr0	10/28/2013 10:44 ...	PRINTTTR0 File	206 KB
 nrl_mtj_calib_p2ap.printtr0	10/28/2013 10:45 ...	PRINTTTR0 File	206 KB

# Archive Contents

## NRL\_SPICE\_MTJ\_LIB\_stable100413.tgz

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NRL_MTJ_SPICE_ENC_LIB.inc	10/28/2013 10:03 ...	INC File	1 KB
USAGE	10/4/2013 11:02 AM	File	3 KB

Main library files

Include file for convenience

Readme file: your best resource  
Also contains default values, description  
of model parameters, etc.

## NRL\_SPICE\_MTJ\_LIB\_Example.tgz

Contains a directory “stt”

MTJ_calib.sp	10/28/2013 10:45 ...	SP File	4 KB
nrl_mjt_calib_ap2p.printtr0		RINTTRO File	206 KB
nrl_mjt_calib_p2ap.printtr0		RINTTRO File	206 KB

Calibration Results

Example SPICE Netlist

## Example Netlist - Header

```

*****
**
**
**          MTJ_calib.sp
**
*****
** Author: Xuanyao Fong
** Email: xfong@ecn.purdue.edu
**
** This SPICE file demonstrates the operation of an MTJ device.
**
*****
***          Libraries          ***
*****
.inc './mtj_libs_encoded/NRL MTJ SPICE ENC LIB.inc'

```

SPICE include file in archive for convenience

SPICE options given in the file were used to correct for accuracies due to different numerical integration method used in SPICE and in OOMMF.

## Always ensure simulation results converge!!!



# Example Netlist - Instantiation

\*\*\*\* Available MTJ models:

- 1) PMAMTJ
- 2) IMAMTJ

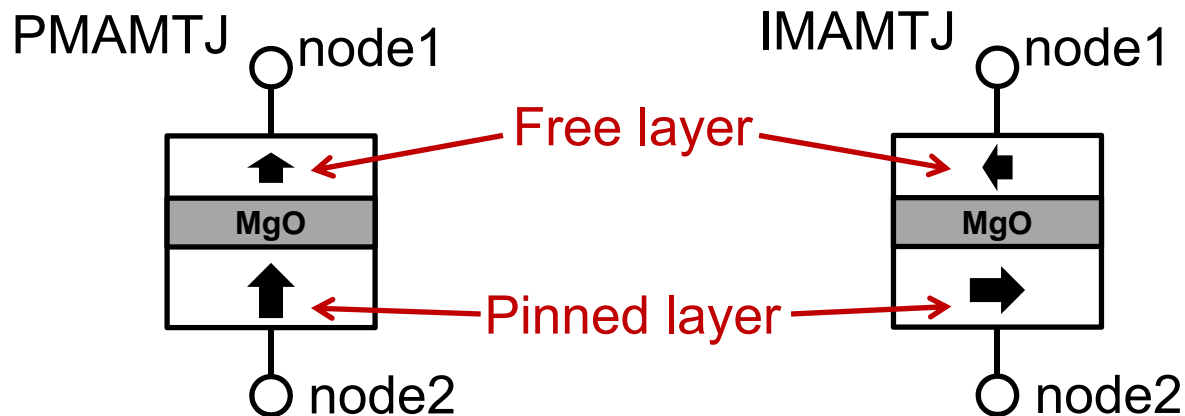
\*\*\*\* Example line to instantiate the model in your netlist:

```
X* node1 node2 node3 node4 node5 *MTJ
+ W='width' L='length' Tm='t_FL' TMgO='TMgO'
+ alpha='damping' Ms='Msat' Ku2='Ku2'
+ th_hard='th_hard' phi_hard='phi_hard'
+ LLG_Temp='Temperature' mu_r_therm='mu_r_therm'
+ thermScale='therm_scale'
```

- node1 is the node name for the free layer of the MTJ

- node2 is the node name for the hard layer of the MTJ

- Voltages of node3, node4, and node5 represent the x, y, and z-components of the applied magnetic field on the free layer (in CGS units), respectively.





# Example Netlist - Instantiation

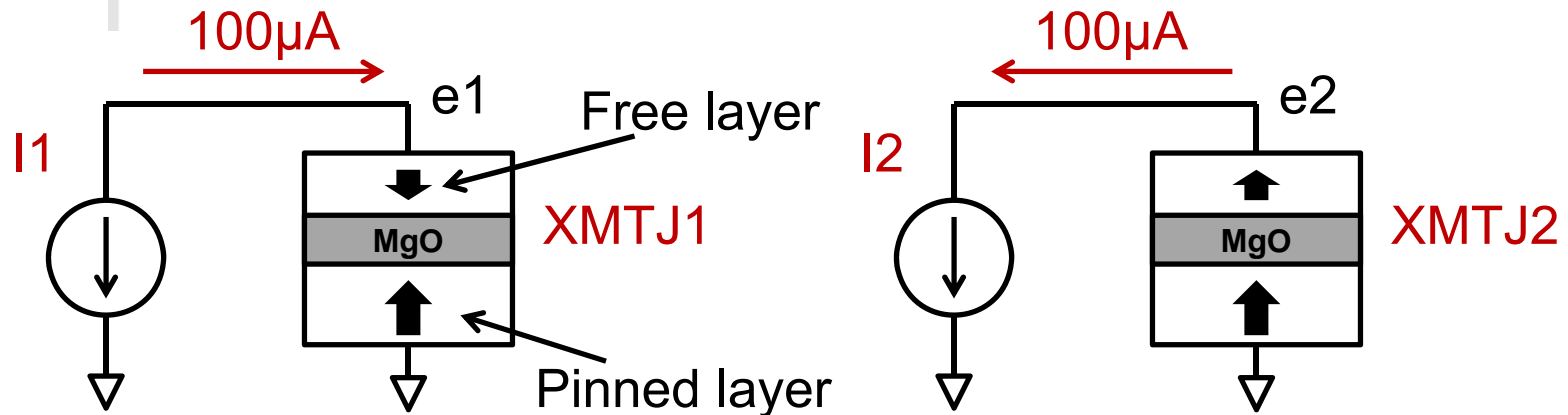
```
V_HAX hax 0 '0.0'
V_HAY hay 0 '0.0'
V_HAZ haz 0 '0.0'
```

```
I1 0 e1 '-100e-6'
```

```
XMTJ1 e1 0 hax hay haz PMAMTJ Ku2='K' W='W' P_L='P_L' P_R='P_R'
+ L='L' Tm='Tm' Ms='Ms' Lambda=0 alpha='alpha' Lambda_L='Lambda_L'
+ Lambda_R='Lambda_R'
```

```
I2 0 e2 '100e-6'
```

```
XMTJ2 e2 0 hax hay haz PMAMTJ Ku2='K' W='W' P_L='P_L' P_R='P_R'
+ L='L' Tm='Tm' Ms='Ms' Lambda=0 alpha='alpha' Lambda_L='Lambda_L'
+ Lambda_R='Lambda_R'
```



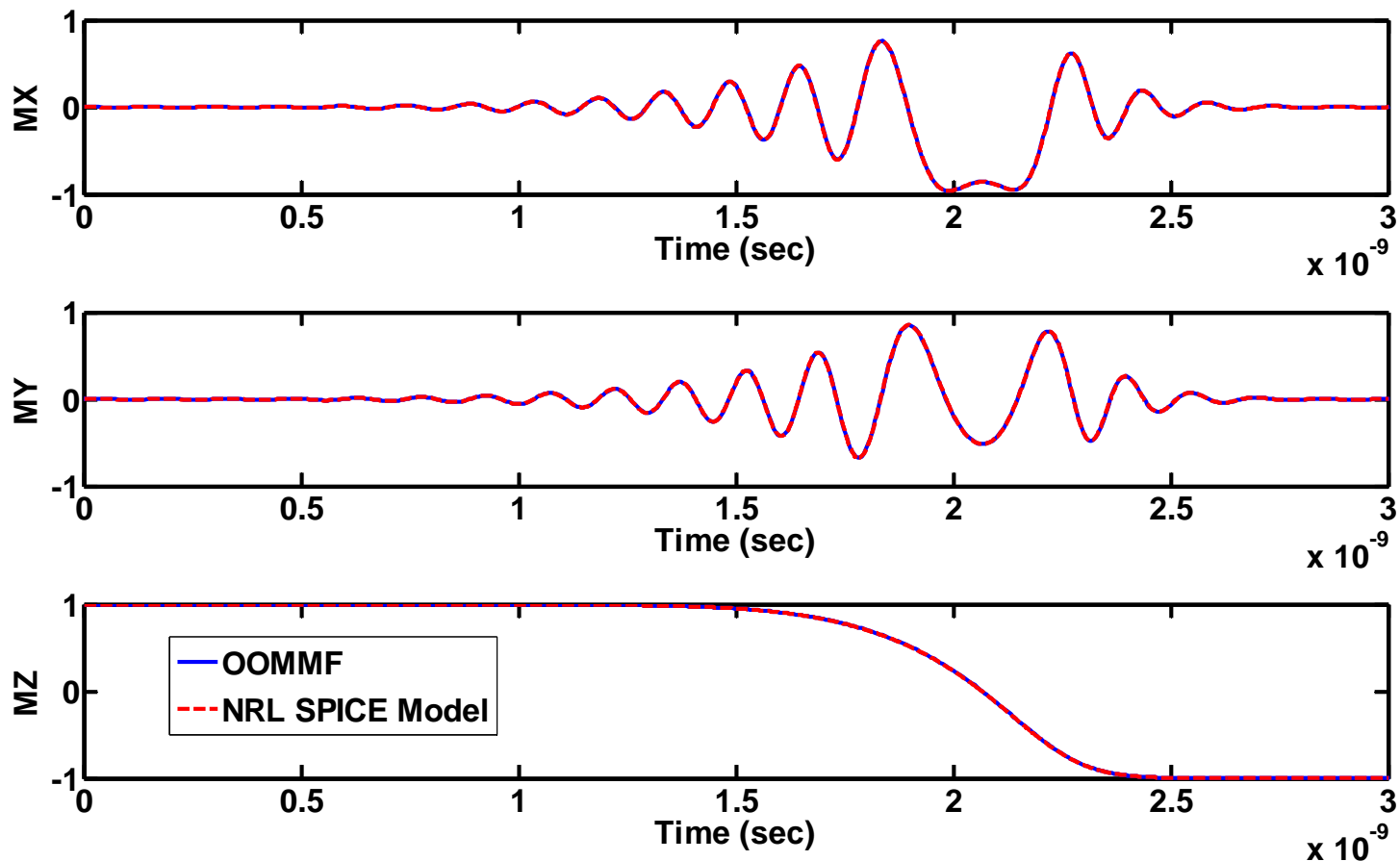
```
*****
***                               Initial Conditions                               ***
*****

.ic V(XMTJ1.XLLG_Eq.thInt) '0.1*pi/180'
.ic V(XMTJ1.XLLG_Eq.phiInt) '0.0*pi/180'
.ic V(XMTJ2.XLLG_Eq.thInt) '179.9*pi/180'
.ic V(XMTJ2.XLLG_Eq.phiInt) '0.0*pi/180'
```

# Example Results (P to AP)

```
*****
***                               Analysis                               ***
*****

.tran 1p 3.0n START=1e-14 uic
.print tran v(XMTJ1.XLLG_Eq.MX) v(XMTJ1.XLLG_Eq.MY) v(XMTJ1.XLLG_Eq.MZ)
*.print tran v(XMTJ2.XLLG_Eq.MX) v(XMTJ2.XLLG_Eq.MY) v(XMTJ2.XLLG_Eq.MZ)
```

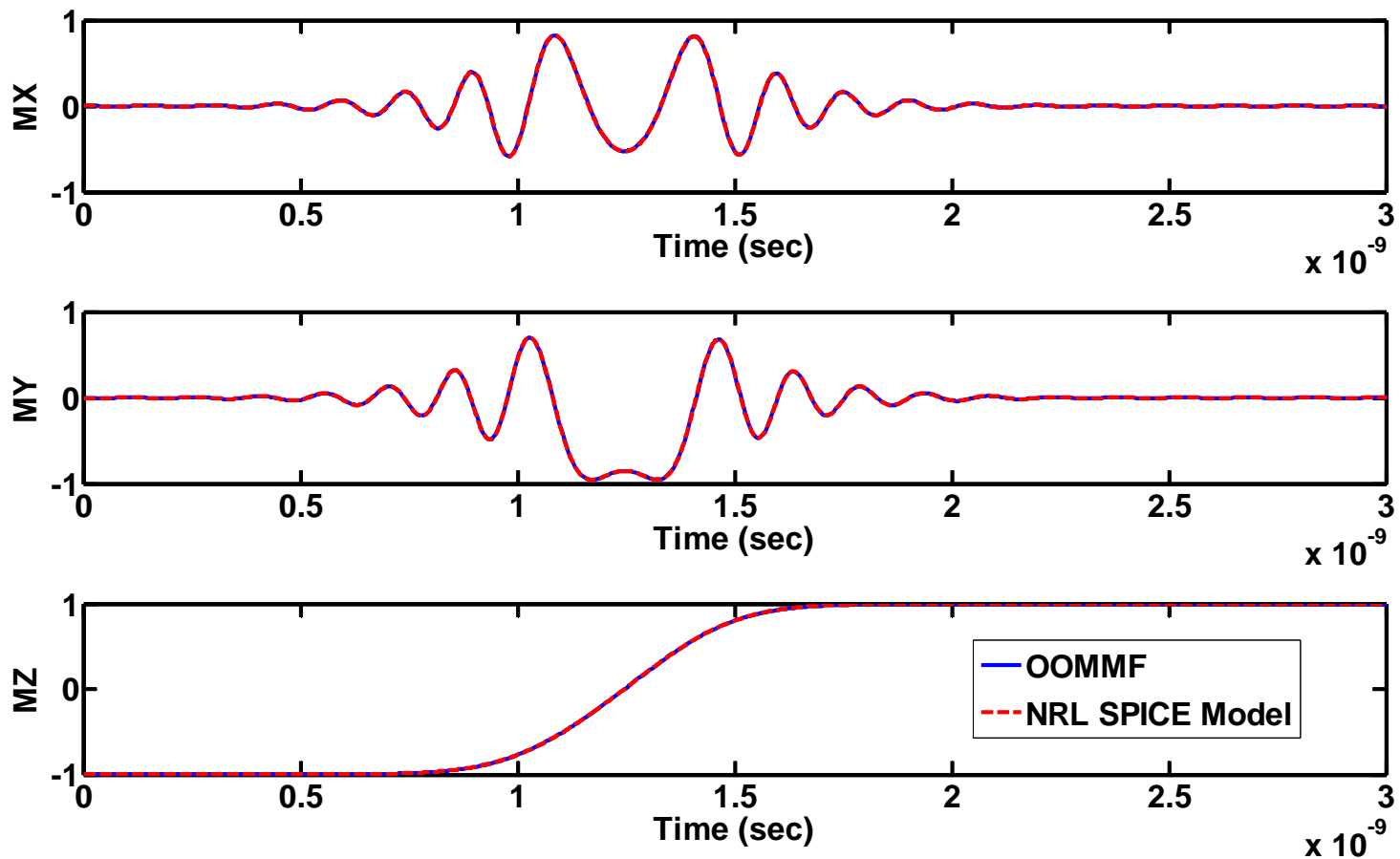


Tested in HSPICE-G-2012.06

# Example Results (AP to P)

```
*****
***                               Analysis                               ***
*****

.tran lp 3.0n START=1e-14 uic
.print tran v(XMTJ1.XLLG_Eq.MX) v(XMTJ1.XLLG_Eq.MY) v(XMTJ1.XLLG_Eq.MZ)
*.print tran v(XMTJ2.XLLG_Eq.MX) v(XMTJ2.XLLG_Eq.MY) v(XMTJ2.XLLG_Eq.MZ)
```



Tested in HSPICE-G-2012.06

# How to Change MTJ Resistance Model?

Contains MTJ resistance or I-V characteristic

LLG.lib	9/25/2013 3:42 PM	LIB File	13 KB
LLGThermRandNum.va	9/19/2013 11:54 AM	VA File	1 KB
MTJ.lib	9/25/2013 3:42 PM	LIB File	16 KB
MTJ_res.va	7/28/2013 4:45 PM	VA File	2 KB
NRL_MTJ_SPICE_ENC_LIB.inc	10/28/2013 10:03 ...	INC File	1 KB
USAGE	10/4/2013 11:02 AM	File	3 KB

```
// Creator: Harsha Choday
// Email: schoday@purdue.edu
// Contributors: Xuanyao Fong
// This file is a copy of MTJ_QCOM5_res.va with added comment lines
// Resistance model of MTJ with physical params:
// Eb=0.8, delta=0.75, m_fm=0.735, m_ox=0.74, Ms=800, Ku2=30000
// This file and the coefficients for fitting equation generated by MATLAB
```

```
`include "disciplines.vams"
`include "constants.vams"
```

All terminals must exist!!!

```
module MTJ_res(t1,t2,MTJ_curr,th,phi,th_hard,phi_hard);
inout t1,t2;
input th,phi,th_hard,phi_hard;
output MTJ_curr;
electrical t1,t2,MTJ_curr,th,phi,th_hard,phi_hard; //External Terminals of the resistor
```

- Module name must be preserved (MTJ\_res)
- t1 – free layer
- t2 – pinned layer
- MTJ\_curr – current flow from t1 to t2
  - Directionality must be preserved for LLG

# How to Change MTJ Resistance Model?

```
**** Wrapper file for including the NRL MTJ SPICE Libraries
** The .hdl needs to point to the file that defines the MTJ resistance model
** (which is defined as MTJ_res)
.hdl "./MTJ_res.va" ← Point to the file containing your MTJ_res module description
** The .lib needs to point to the MTJ_enc.lib file containing the encrypted
** file for defining NRL MTJ SPICE Library components
.lib "./MTJ.lib" NRL_MTJS
```

This file needs to be able to locate LLG.lib and LLGThermRandNum.va. It must also know the definition of MTJ\_res with the terminals hard coded into the example

```
// Creator: Harsha Choday
// Email: schoday@purdue.edu
// Contributors: Xuanyao Fong
// This file is a copy of MTJ_QCOM5_res.va with added comment lines
// Resistance model of MTJ with physical params:
// Eb=0.8, delta=0.75, m_fm=0.735, m_ox=0.74, Ms=800, Ku2=30000
// This file and the coefficients for fitting equation generated by MATLAB

`include "disciplines.vams"
`include "constants.vams"

module MTJ_res(t1,t2,MTJ_curr,th,phi,th_hard,phi_hard);
inout t1,t2;
input th,phi,th_hard,phi_hard;
output MTJ_curr;
electrical t1,t2,MTJ_curr,th,phi,th_hard,phi_hard; //External Terminals of the resistor
```

All terminals must exist!!!

- Module name must be preserved (MTJ\_res)
- t1 – free layer
- t2 – pinned layer
- MTJ\_curr – current flow from t1 to t2
  - Directionality must be preserved for LLG

**Questions?**

**C-SPIN**



**STARnet**