A Generalized HSPICE* Macro-Model for Pseudo-Spin-Valve GMR Memory Bits

by

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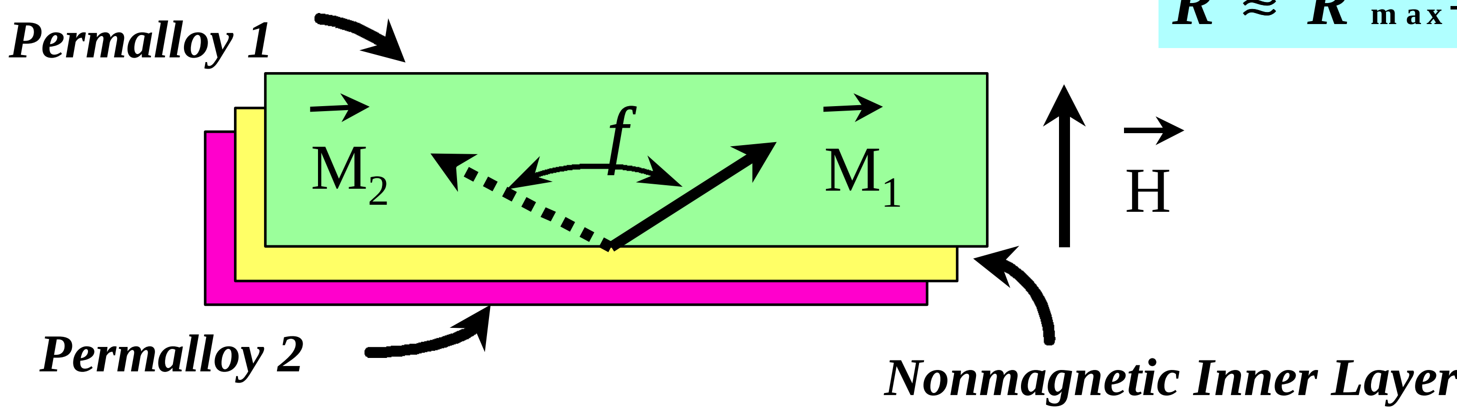
Outline

- Introduction to Giant Magneto Resistance (GMR) Devices
- GMR Characteristics and Applications
- Pseudo-Spin-Valve Characteristics
  - Typical
  - Generalized
- HSPICE Macro-Model
  - Schematic
  - Attributes
  - Simulation
- Current and Future Work
- Summary and Conclusion

Introduction to GMR Devices

- **Two ferromagnetic layers separated by non-magnetic *spacer* layer**
- ***Spin-Valve* : one layer *pinned* by anti-ferromagnetic layer**
- ***Pseudo-Spin-Valve* : both the layers are free to rotate (not pinned)**

$$R \approx R_{max} - k.\cos f$$



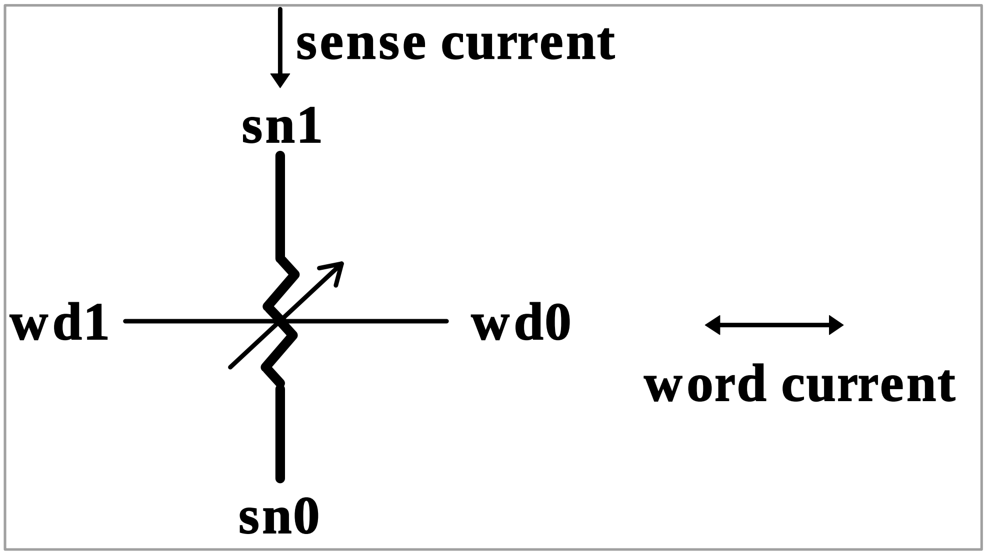
- **Resistance is function of *difference* between magnetizations**
- **Variations of 6%+ have been demonstrated for practical bits**

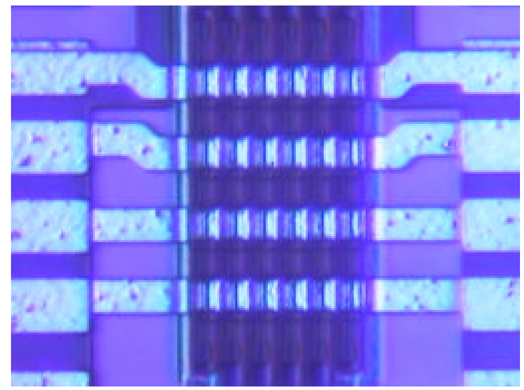
Typical Characteristics and Applications of GMR

- **Characteristics:**
  - **Stable magnetic states (*non-volatile*)**
  - **Resistant to ionizing radiation**
  - **Significant signal improvement relative to older single-layered Anisotropic Magneto Resistance (AMR) material**

- **Applications:**
  - **Non-volatile memory (MRAM)**
  - **Magnetic sensors**
  - **Disk read-heads**
  - **Isolation devices**

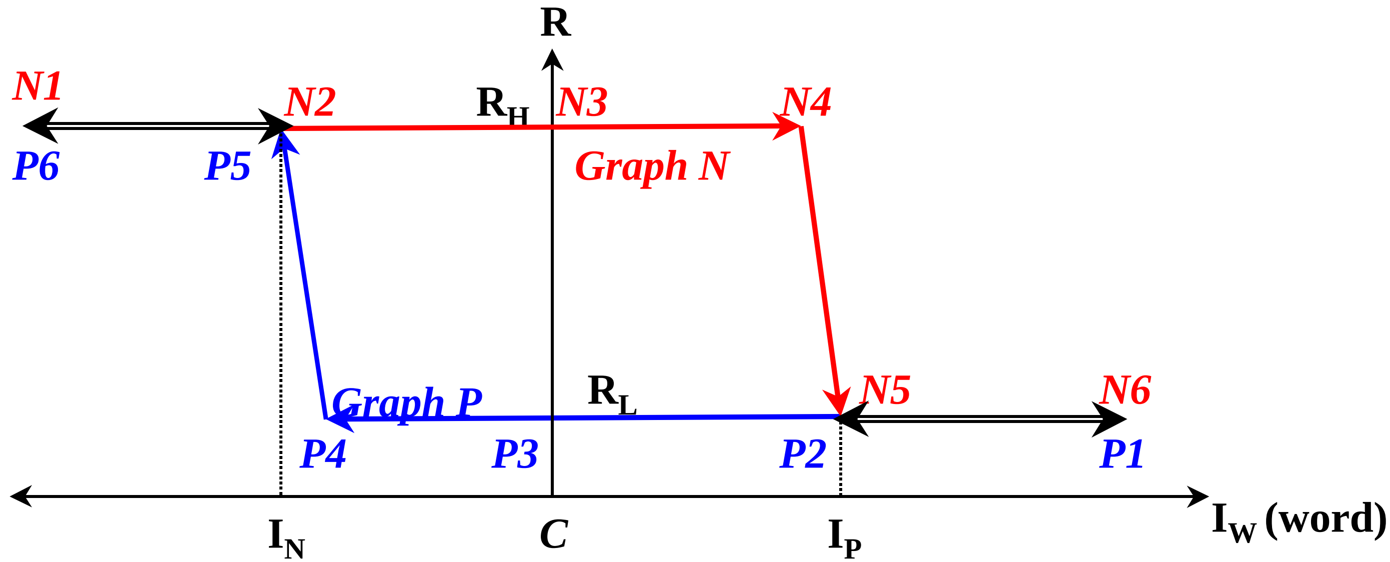
Basic GMR Bit Configuration





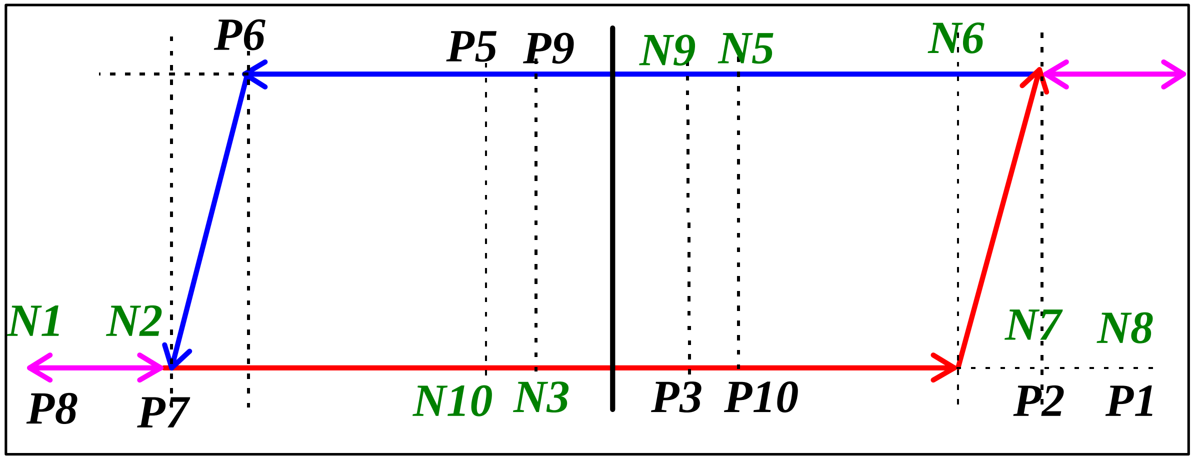
- Read with sense current (may stack bits)
- Write design options:
  - word current alone (small memories)
  - coincident sense and word current (large memories)

Spin-Valve Characteristics

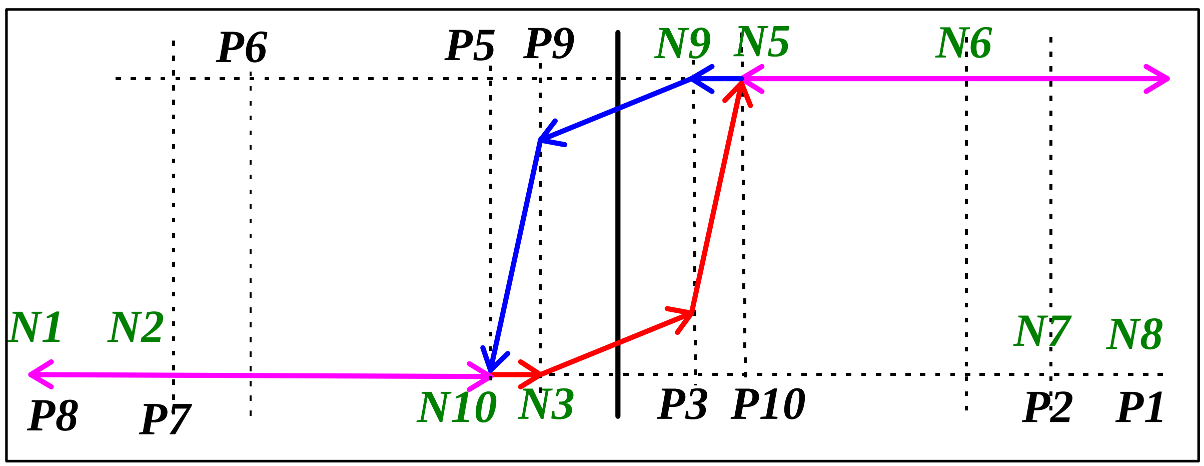


- **Hysteretic in nature**
- **Combination of graphs P and N. $I_W > I_P$: Graph P; $I_W < I_N$: Graph N**
- **Two distinct states : Graph P : St. 1 ; Graph N : St. 0 (or vice versa)**
- **$I_W > I_P$: *write* to St. 1 ; $I_W < I_N$: *write* to St. 0 ; $I_N < I_W < I_P$: *read***
- **I_N and I_P are weak functions of sense current**

Typical Pseudo-Spin-Valve

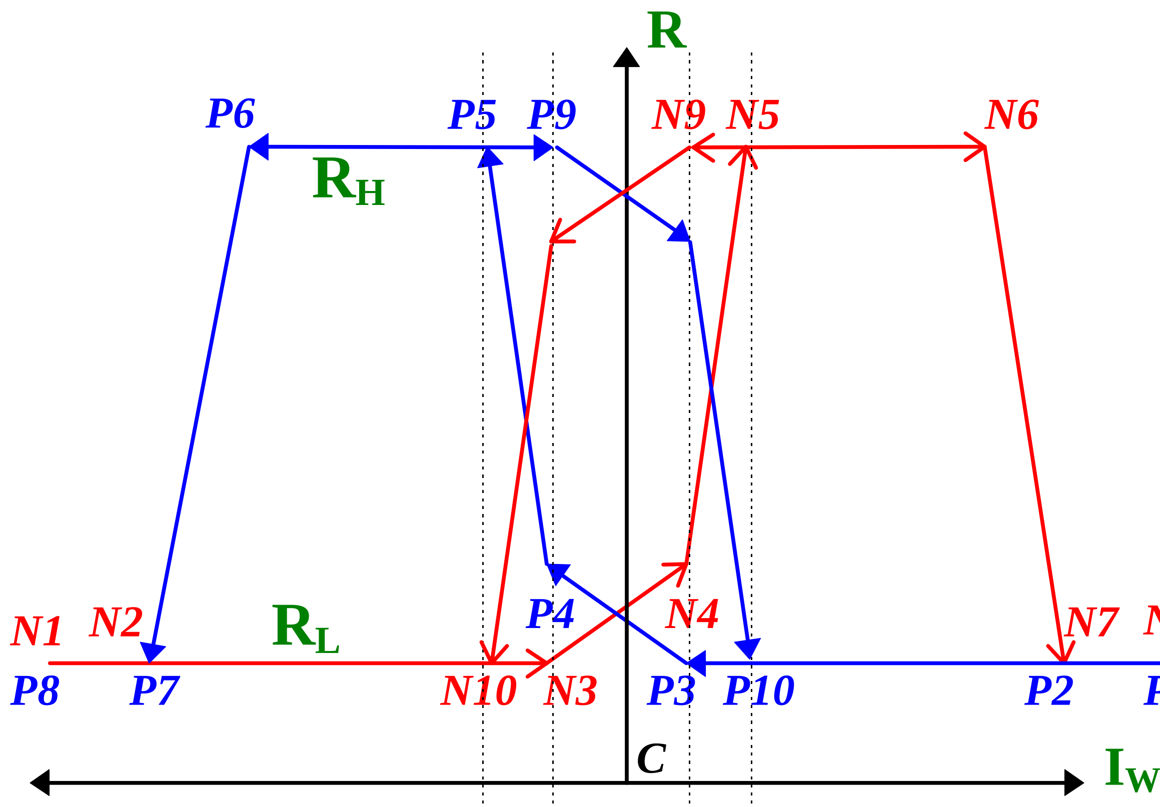


Bottom (*harder*) layer magnetization curve: higher coercive force



Top (*softer*) layer magnetization curve: lower coercive force

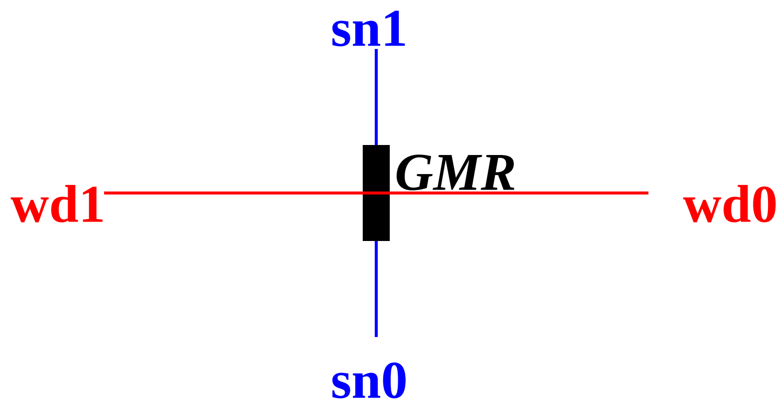
Typical Pseudo-Spin-Valve (contd.)



- **Combination of two curves : one for actual top layer and the other for bottom layer**
- **The graph is the absolute difference of the two**
- **Symmetric *Major* and *Minor* loops**

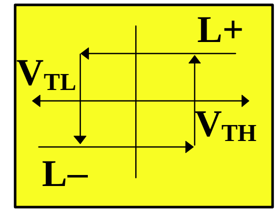
Macro-model

- Four terminal sub-circuit :
  - Two word line terminals, two sense line terminals



- Four simple parts :
  - Input (word) circuit
  - Bistable multivibrator or Schmitt Trigger
  - Decision circuit
  - Output (sense) circuit

Macro-model (contd.)



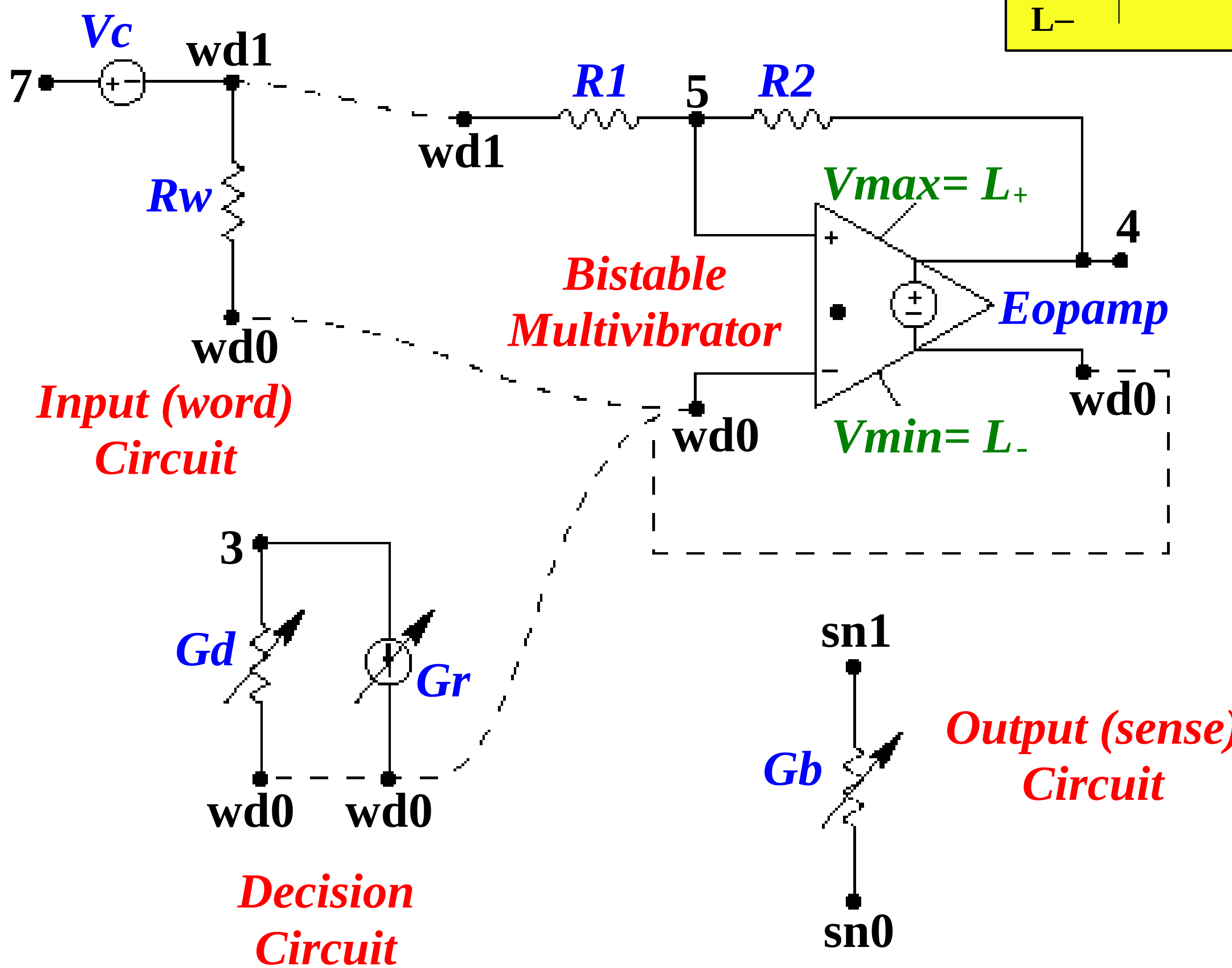
V_{TH} = -L_-(R1/R2)
V_{TL} = -L_+(R1/R2)

Eopamp : VCVS

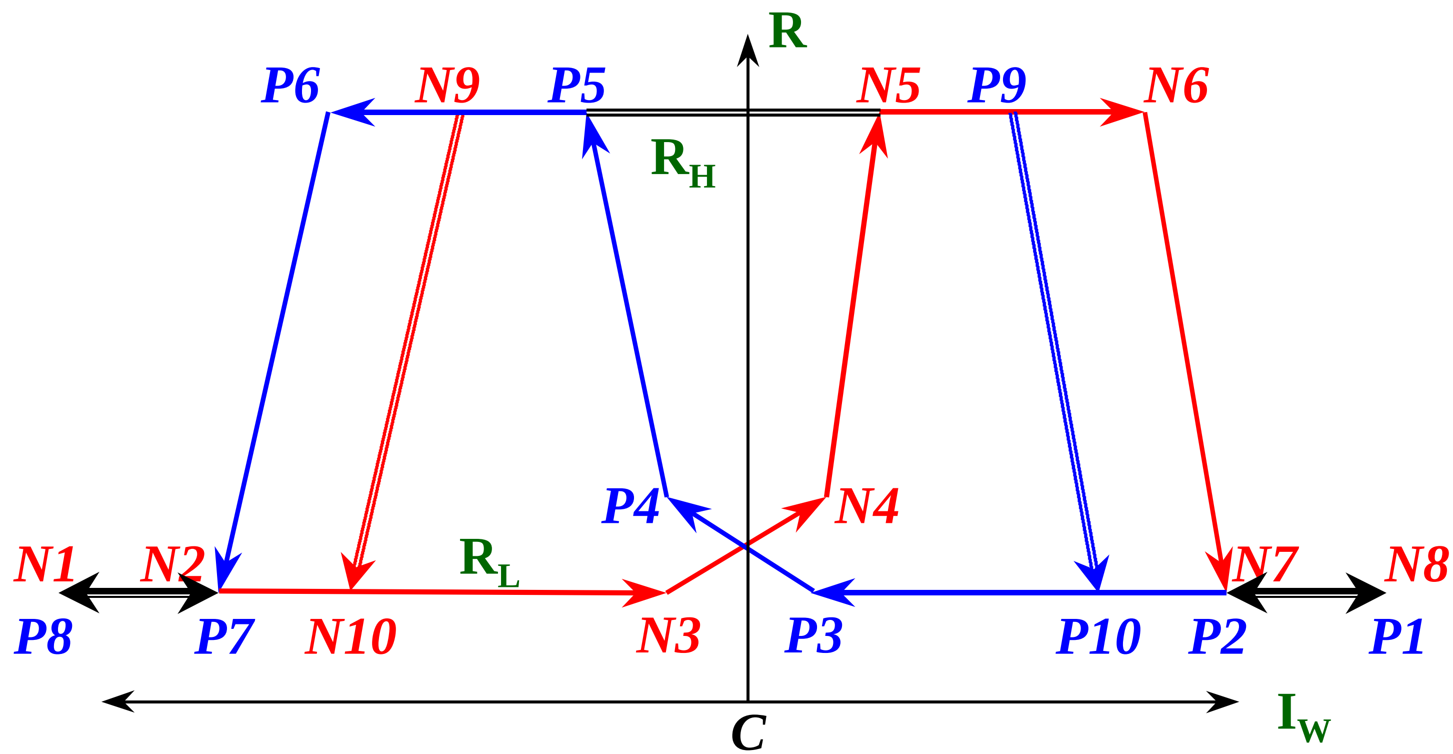
Gd : VCR [1:1]
cntl by V(7,wd0)

Gr : VCCS (+/-1)
= V(4,wd0)/L
[L = L_+ = -L_-]

Gb : PWL VCR
cntl by V(3,wd0)



Generalized PSV Characteristics



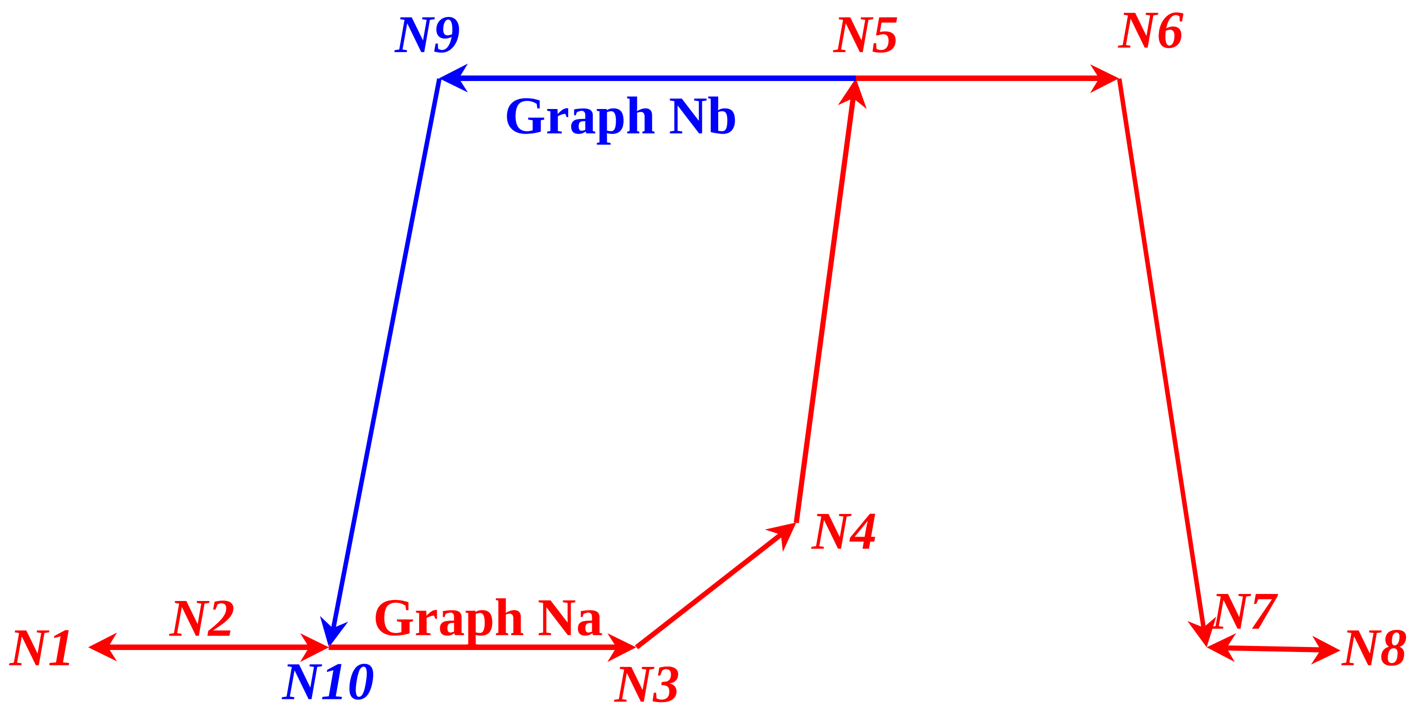
- **Hysteretic in nature: combination of *systems* P and N**

  $I_W > I_{P2}$: System P ; $I_W < I_{N2}$: System N

- **Each *system* can be divided into two graphs**
- **Four distinct states can be utilized: two bit memory**

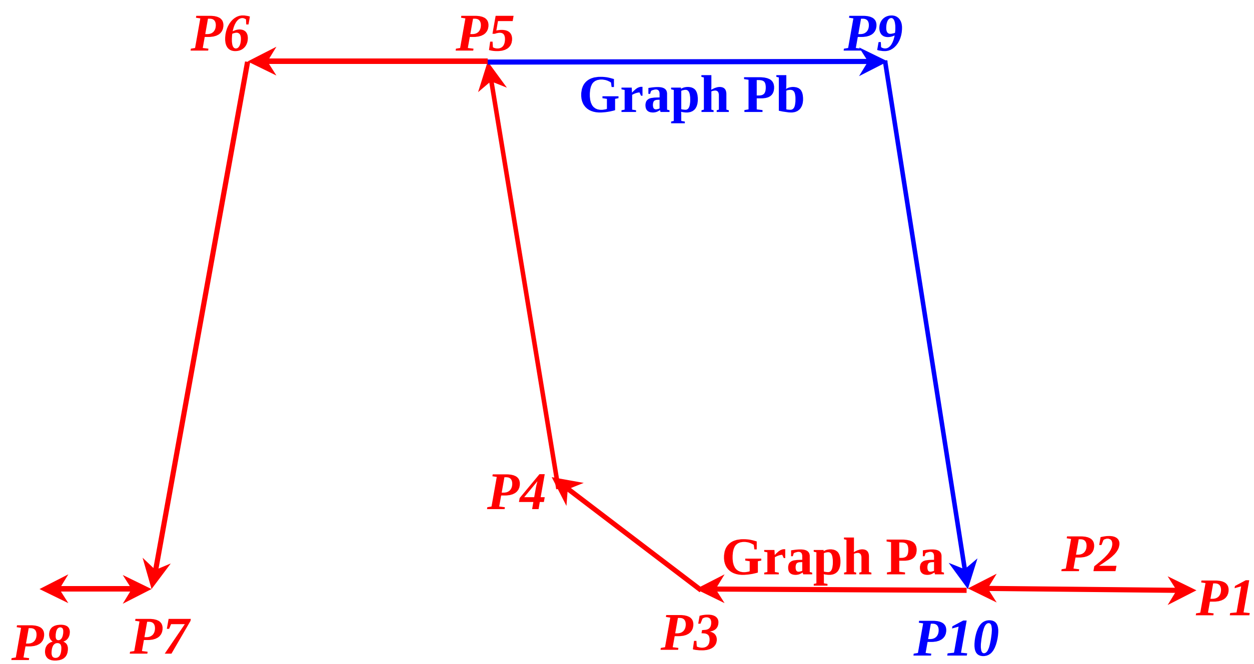
Generalized PSV Charac. (contd.)

- **As two-state memory : $I_W > I_{P2}$, $I_W < I_{N2}$: *write* ; $I_{N2} < I_W < I_{P2}$: *read***
- **I_{N2} and I_{P2} (*write thresholds*) are weak functions of sense current**



- **System N can be divided into two graphs : Na and Nb**

Generalized PSV Charac. (contd.)



- System P can be divided into two graphs : Pa and Pb

- Non-symmetric Major and Minor loops
  - *Major loop* : Na and Pa
  - *Minor loop* : Nb and Pb

Attributes of the Model

- ***Versatility***
  - **Usable with any kind of PSV GMR elements**
  - **Generalized and simple : can be modified easily to represent other kinds of hysteretic characteristics**
- ***Flexibility***
  - **All variables parameterized : .PARAM statements**
  - **No component needing power supply : non-volatile**
- ***Portability***
  - **subcircuit (.inc) can be included in any HSPICE netlist: great help for GMR memory testing**
  - **No semiconductor device : no variation with different device models**

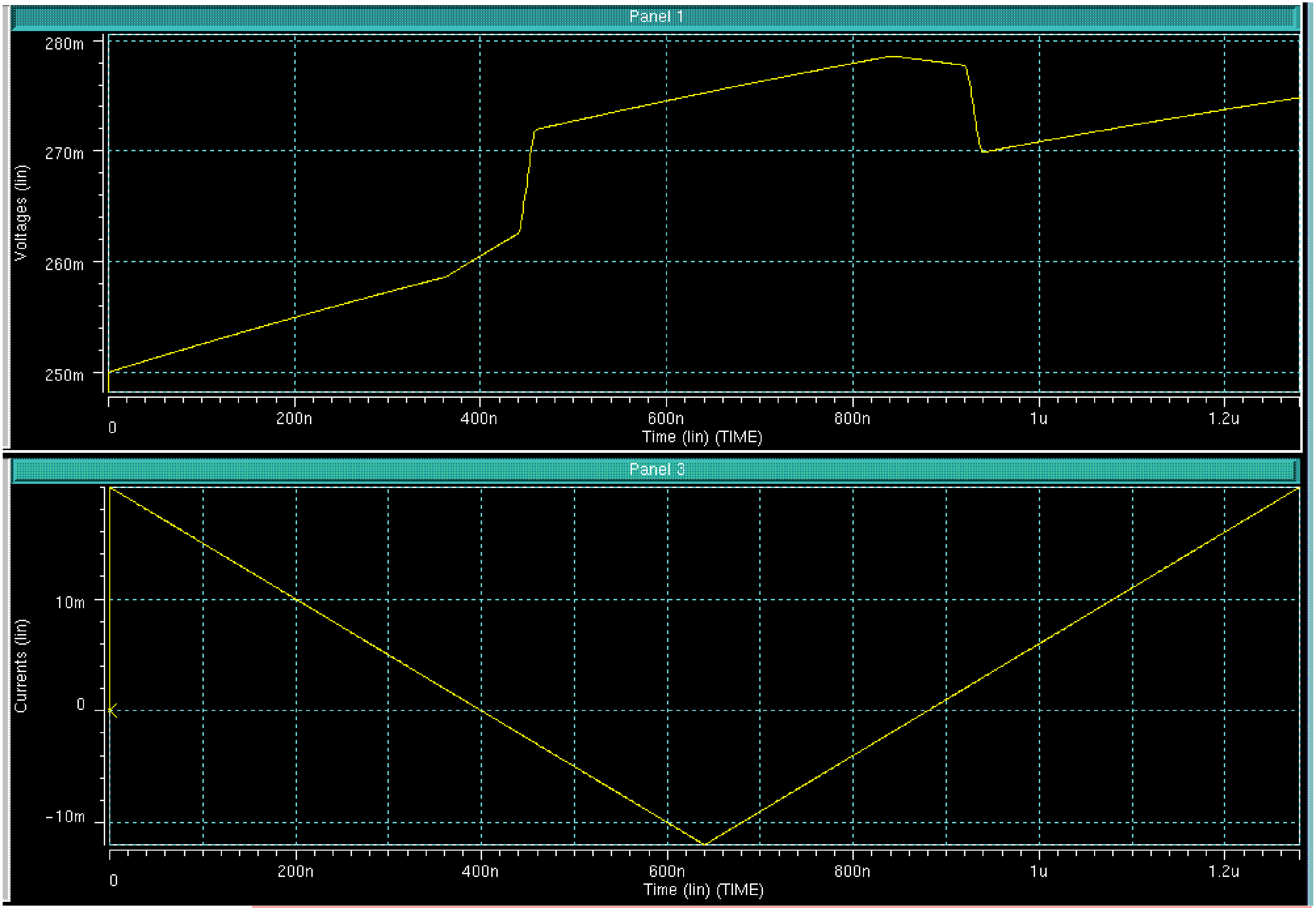
Simulation Results

- **Sub-circuit simulated with HSPICE :** ***did converge!***
- **Simulations give proper results**
- **ΔR for the GMR bit : 5%   with R_L=100Ω, R_H=105Ω**
- **DC analysis done for a wide range of word currents**
- **Transient analysis shows proper major and minor loop characteristics**
- **Simulation of non-volatile latch structures with this GMR model**
- **Simulation of novel Pseudo-Spin-Valve GMR memory structures with this model (the structure can detect all four states but destructive read)**

Current and Future Work

- **Already done:**
  - **Thermal behavior (transient and dc) incorporated**
  - ***Asteroid curve* incorporated: write thresholds depend on sense current value**

- **In the pipeline:**
  - **Noise analysis (*transient ?*), esp. near the write thresholds**
  - **A universal GMR model usable for both memory and magnetic sensors (including read heads)**


Panel 1
Voltages (lin)
280m
270m
260m
250m
0
200n
400n
600n
800n
1u
1.2u
Time (lin) (TIME)
Panel 3
Currents (lin)
10m
0
-10m
0
200n
400n
600n
800n
1u
1.2u
Time (lin) (TIME)

Summary and Conclusion

- ***First HSPICE circuit model for Pseudo-Spin-Valve GMR element***

- **Successfully modeled the resistance vs. word current characteristic of a Pseudo-Spin-Valve GMR bit**
- **The model is simple, flexible and versatile**
- **Simulations show proper results**
- **The model is very general in nature, can be applied to other hysteretic characteristics**
- **Extended to include thermal effects and sense-current-dependency of write thresholds**

Questions ?