Magnetic Tunnel Junctions & Spin Torque Nano-Oscillators

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MTJ’s come in a variety of sizes and typologies suited for different applications.
MTJ’s are mostly compatible with traditional foundries.
MTJs consist of several ferromagnetic and insulator layers.
MTJs can operate in two states, switching between effective resistances.
MTJ resistance states can be changed by an applied current.
This property allows MTJ’s to be used in memory applications, like STT-RAM.
Spin Torque Nano Oscillators
MTJs output various AC currents at different frequencies based on DC biasing.
This oscillation stems from the intrinsic property of MTJ switching, called “precession.”
There is an inherent problem with STNOs... they take time to stabilize their oscillations.
The model we used for the MTJ and STNO was developed by Mehdi Kabir and Mircea Stan at the University of Virginia and is based off the Landau-Lifshitz-Gilbert Equation.

\[
\frac{dM}{dt} = -\gamma \left( M \times H_{\text{eff}} - \eta M \times \frac{dM}{dt} \right)
\]
Applications

STT-RAM

Hybrid MTJ-CMOS Circuits

Microwave Signal Sources

RF Filters
STT-RAM

Free Layer
Tunnel Barrier
Fixed Layer

Electrons

Writing Current (> Critical Current $J_C$)

BL=1
WL=1
SL=0

“0”
Low R ($R_P$)

BL=0
WL=1
SL=1

“1”
High R ($R_{AP}$)

Writing Current (> Critical Current $J_{C+}$)
Hybrid MTJ-CMOS Circuits

Magnetic Tunnel Junction (MTJ) device

MTJ layer

CMOS layer
Hybrid MTJ-CMOS Circuits

- Register replacements (shadow memory)
- 2D memory arrays (LUTs)
- PLA
Microwave Signal Sources
Simulations for Microwave Signal Sources

<table>
<thead>
<tr>
<th>Applied Voltage (mV)</th>
<th>Oscillation Frequency (GHz)</th>
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</thead>
<tbody>
<tr>
<td>500</td>
<td>0.650</td>
</tr>
<tr>
<td>550</td>
<td>0.918</td>
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<tr>
<td>600</td>
<td>1.190</td>
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<tr>
<td>700</td>
<td>1.480</td>
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<tr>
<td>750</td>
<td>1.500</td>
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Phase Locked Loop (PLL)

Current research utilizes oscillations of 100nA, amplified through a transimpedance amplifier to generate highly stable phase-locked oscillators.

STNO’s offer tunability.
Lincoln Labs is working on a phased array with an input of 1.3GHz. Tuning circuitry adds phase noise and destability.
STNO RF Filters (Narrow Notch)
STNO RF Filters (Current Mirror)
Other Applications

- **Base Station**
  - Filter out spurs

- **RF Test Equipment**
  - Need wideband LO for spectrum analyzer

- **Stealth Detection**
What conclusions can be drawn?

Many applications exist where MTJs and STNOs can potentially outperform traditional oscillators

- On-chip integration
- Wide (and simpler) tunability
- Low power and high Q
We would like to thank Professor Stan and Mehdi Kabir for all their help with this project.