University of Central Florida

IEEE ISEC 2020

Adaptive Behavioral Simulation Framework for 2-Terminal MTJ-based Analog to Digital Converter

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Saturday, August 1, 2020 via Zoom meeting

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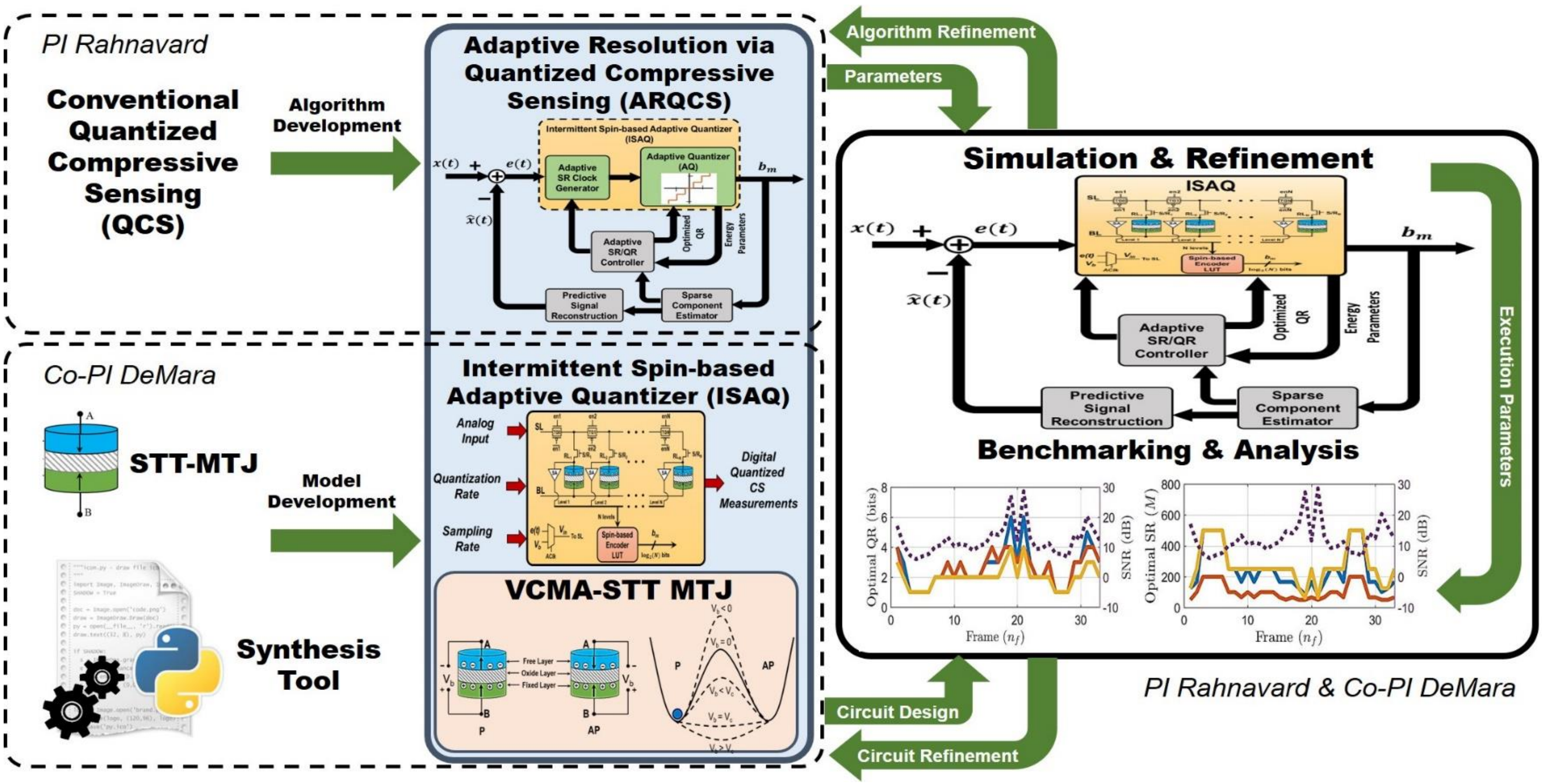
Spintronic-Enabled Signal Processing

Spintronic Educational Simulation

"Cross-layer Adaptive Rate/Resolution Design for Energy-Aware Acquisition of Spectrally Sparse Signals Leveraging Spin-based Devices"

- Develop **energy-efficient adaptive framework** to acquire **spectrally-sparse signals**
- Integrate **adaptive quantized Compressive Sensing** w/ beyond-CMOS devices



Three Pathways to Educational Impacts

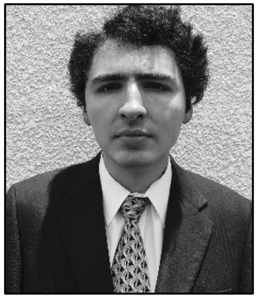
Research Expertise ↔ REU Experiences ↔ High School Outreach

Spintronic Educational Simulation

Doctoral Graduates / Students

1) Foster Scholarly Research Expertise

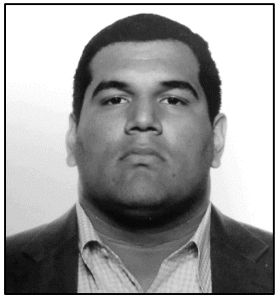
Soheil Salehi, Ph.D.
Completed Ph.D.; now a Post-Doctoral Researcher at UC-Davis



Adrian Tatulian, M.S.
Doctoral Student

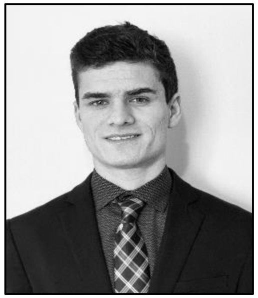
REU Graduates / Students

2) Mentor Impactful REU Experiences



Gustavo Camero
Completed REU; now a Doctoral Student at Carnegie Mellon Univ.

Adedoyin Adepegba
REU currently interning at Intel



Paul Wood
REU currently interning at Intel

Daniel C. Mulvaney
REU currently interning at L3-Harris

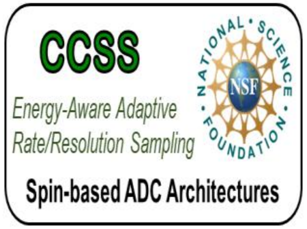
Three Pathways to Educational Impacts

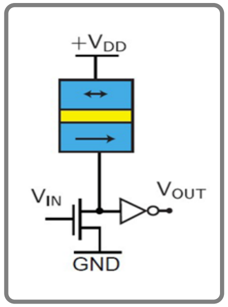
Research Expertise ⇔ REU Experiences ⇔ High School Outreach

3) Creating Educational Outreach for High Schoolers

Outreach Goals & Approach

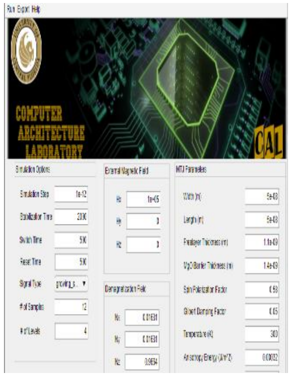
- **Mentor** U/G's via NSF REU supplement
- **Paid REUs** conducted lit surveys of signal encoding/conversion, performed SPICE simulations w/ MTJ circuits designed by GRAs
- **REUs learned** SPICE circuit modeling tools via structured examples, and practived proofreading of articles composed by team members, post-CMOS technical knowledge and authoring skills





Spintronic Simulation Website

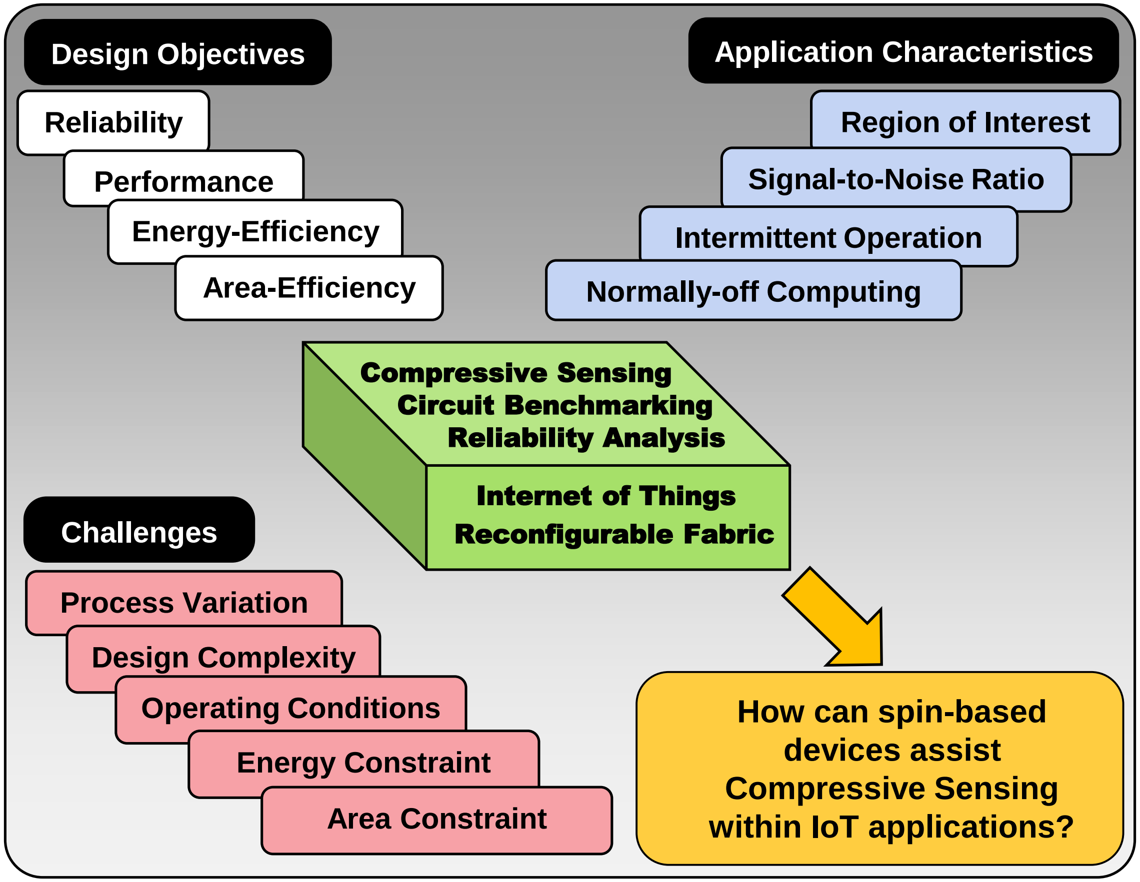
- **Simulation Framework** is an educational resource site companion to distribute the interactive tool to provide insights of the modeled Spin-based ADC
- **Broad dissemination** through web-based framework to maximize the impact of outreach



Research Motivation

Need for CS solutions considering device-level constraints for IoT

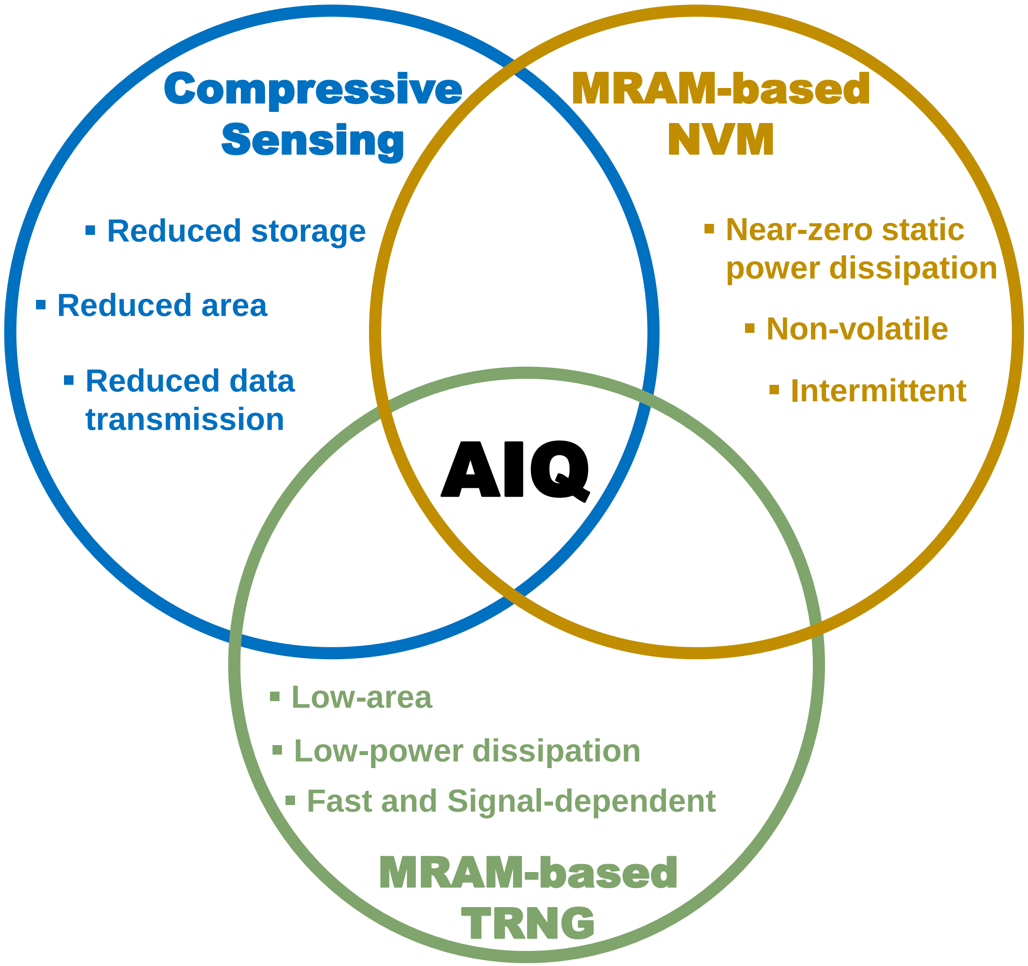
- There is a need for low-complexity, ultra-low-power circuit for signal conversion for IoT applications
- There is a demand for Compressive Sensing solutions that consider hardware constraints and signal constraints for IoT intelligent sampling and edge processing



Research Motivation

Need for CS solutions considering device-level constraints for IoT[1]

- Maximize signal sensing and reconstruction performance while **reducing energy consumption for IoT applications**
- **Compressive Sensing** reduces number of samples per frame to **decrease energy, storage, and data transmission overheads**
- Non-uniform CS in hardware requires Random Number Generator (RNG)
  - True RNGs vs. Pseudo RNGs

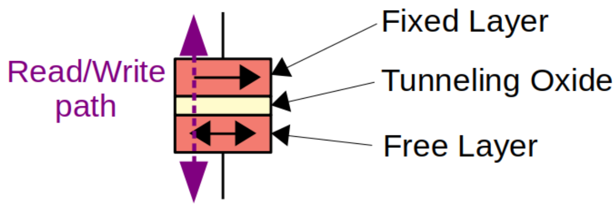


1. This work is funded by NSF-ECCS #1810256 and NSF-CCF#1739635

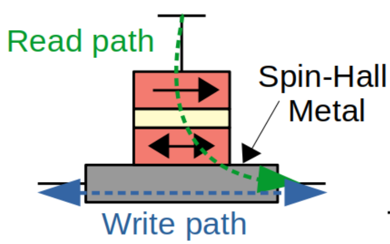
Spin Devices in Reconfigurable Fabrics

Time & Space Co-design of Digital, Analog, Storage

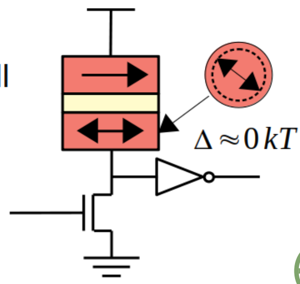
Magnetic Tunnel Junction



SHE-MTJ



Embedded p-bit



- **Magnetic tunnel junctions (MTJs)** consist of a tunneling oxide layer sandwiched between two ferromagnetic layers.
- Magnetization of free layer can be modified using a current or voltage.
- **Low-barrier MTJ** can be used to build Magnetic Random Access Memory (MRAM)-based **p-bit with stochastic switching capability**

Advantages

- ✓ Near-zero standby power
- ✓ Area efficient
- ✓ Fast read operation
- ✓ True randomness

https://www.theregister.co.uk/2019/03/08/samsung_mram/

- Intel now delivering embedded MRAM (eMRAM) in a 1T1MTJ architecture in conjunction with their 22-nm FinFET technology libraries[1]
- Everspin & IBM MTJ-based SSD and DRAM replacement products available
- Toshiba is fabricating SHE-MTJ[2]

https://www.everspin.com/spin-transfer-torque-mram-products

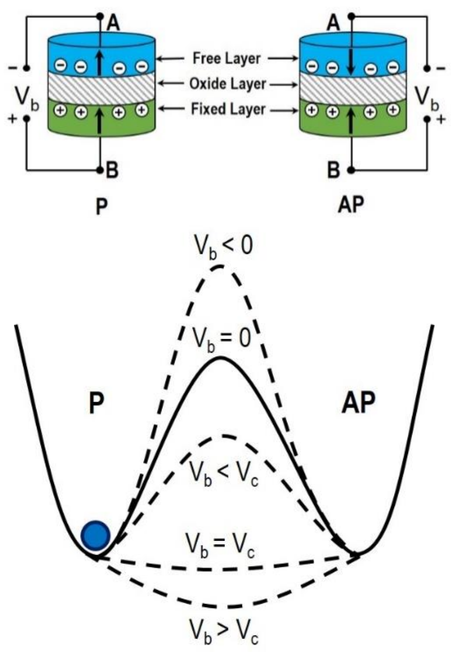
1. Wei, Liqiong, Juan G. Alzate, Umut Arslan, et al. "13.3 A 7Mb STT-MRAM in 22FFL FinFET Technology with 4ns Read Sensing Time at 0.9 V Using Write-Verify-Write Scheme and Offset-Cancellation Sensing Technique." In *2019 IEEE International Solid-State Circuits Conference-(ISSCC)*, pp. 214-216, 2019.
2. H. Yoda et al., "High-Speed Voltage-Control Spintronics Memory (High-Speed VoCSM)," 2017 IEEE International Memory Workshop (IMW), Monterey, CA, 2017, pp. 1-4.

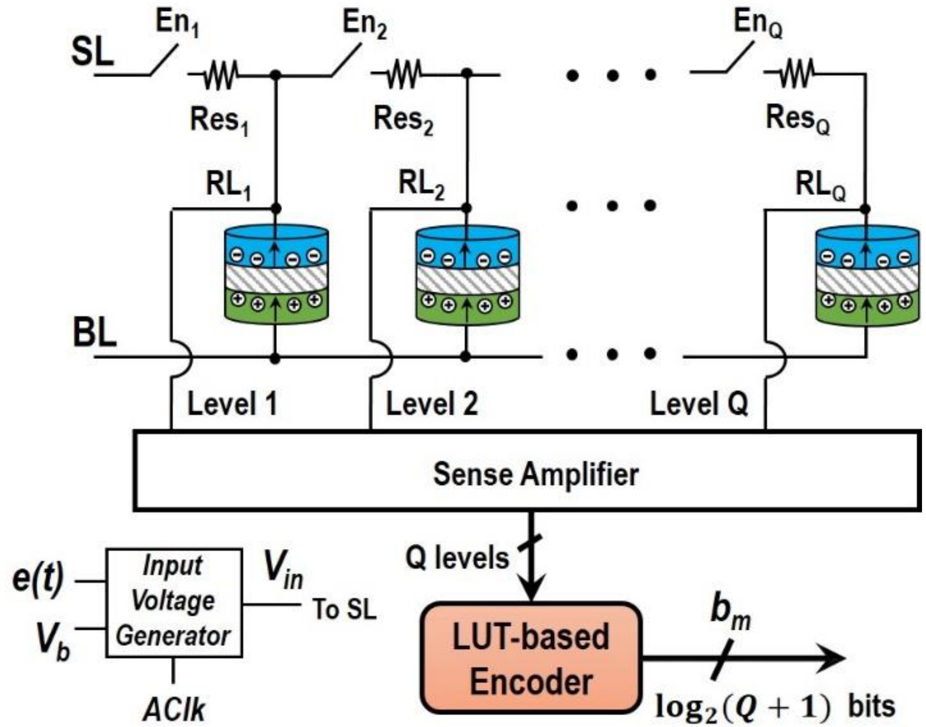
My Proposed Approach

Adaptive Intermittent Quantizer (AIQ) Circuit Design[1,2]

Voltage-Controlled Magnetic Anisotropy Magnetic Tunnel Junction (VCMA-MTJ) AIQ

1) **During Reset step:** all active VCMA-MTJs are reset to Parallel state
2) **During Sampling step:** based on determined SR and QR, first bias voltage, V_b, is applied across the active VCMA-MTJs to modify energy barrier followed by analog input, e(t), to write into the active VCMA-MTJs
3) **During Read step:** use a sense amplifier to read data stored in each VCMA-MTJ





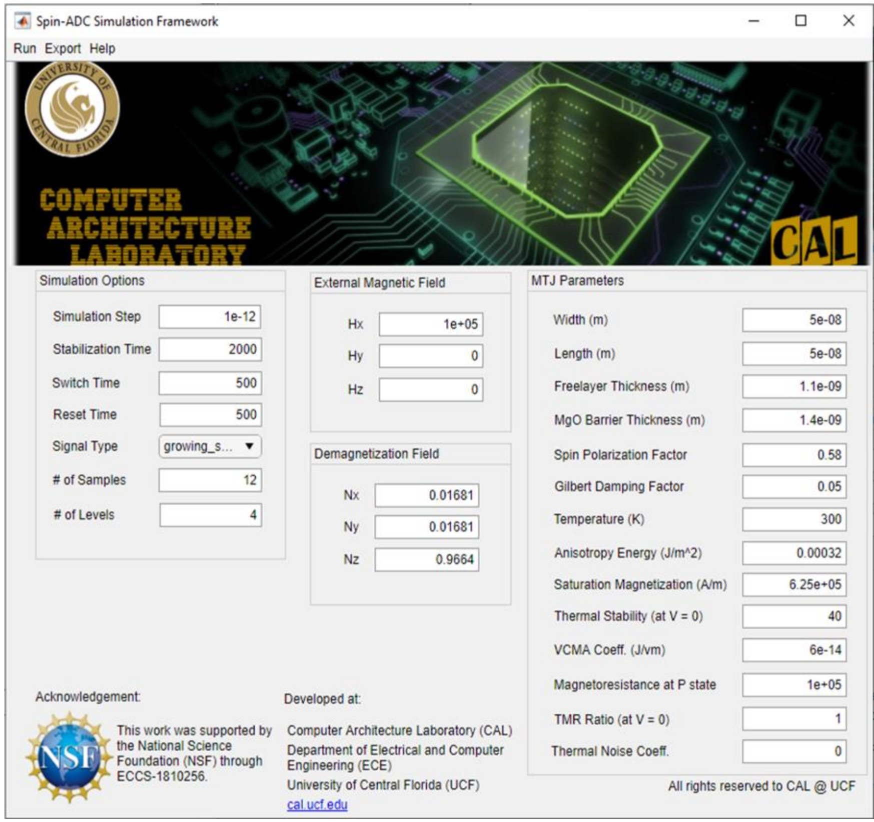
1. S. Salehi, M. Mashhadi, A. Zaeemzadeh, N. Rahnavard, and R. F. DeMara, IEEE JETCAS-2018

2. This work is funded by NSF-ECCS #1810256

My Proposed Approach
AIQ Simulation Framework[1,2,3]

Functionalities of proposed Simulation Framework:

- Proposed Interactive Simulator provides a Graphical User Interface (GUI) that allows for the modification and insertion of values for Spin-ADC simulations
- Default parameter values reflect simulation cases used in [S. Salehi, et al., 2018][2]
- Vary device parameters for running different simulations with different scenarios
- Run option that compiles all parameters and simulation options to display simulation results
- Simulation results are displayed in a different GUI window displaying different characteristics
- Help option that redirects to various educational resources site for more information



1. G. Camero, S. Salehi, and R. F. DeMara, IEEE ReConfig-2019.
2. S. Salehi, M. Mashhadi, A. Zaeemzadeh, N. Rahnavard, and R. F. DeMara, IEEE JETCAS-2018
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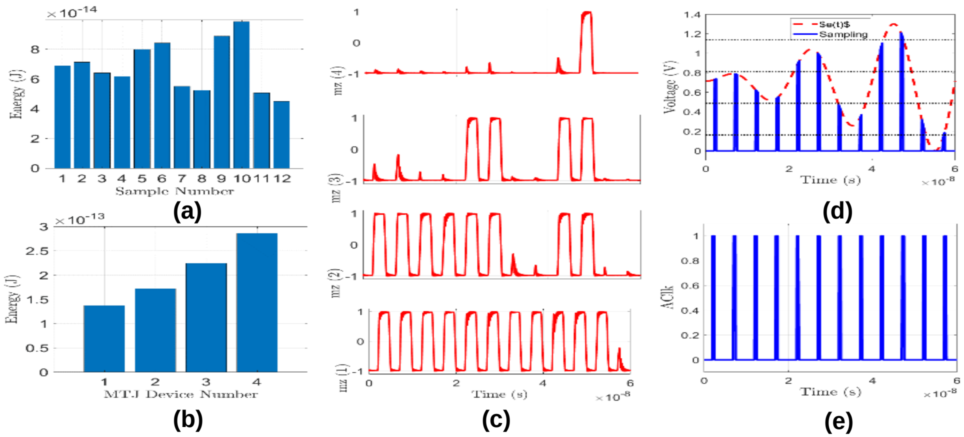
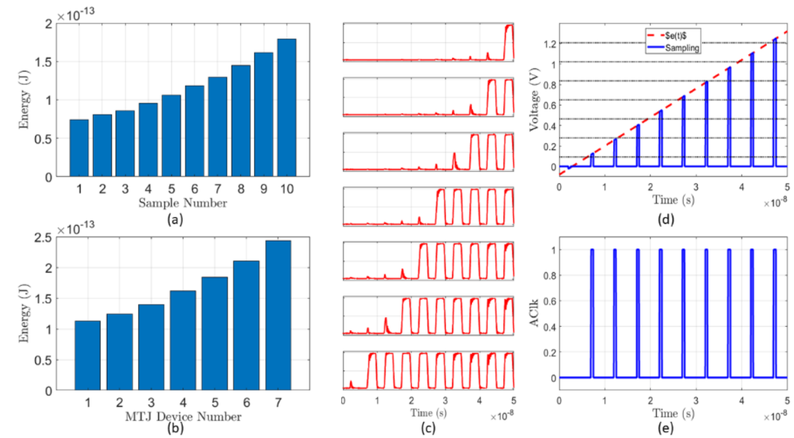
Adaptive & Interactive Framework

AIQ Simulation Framework[1,2,3]

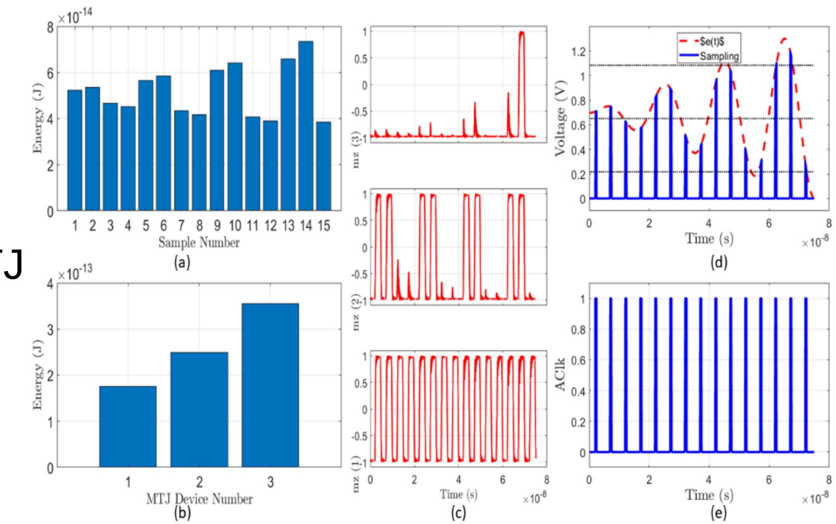
Spintronic Educational Simulation





Sample Output Waveforms:

- (a) Depicts energy consumed for each sample
- (b) Illustrates energy consumed by each MTJ
- (c) Shows Magnetization Orientation of each MTJ
- (d) Demonstrates analog input waveform
- (e) Visualizes Sampling Rate



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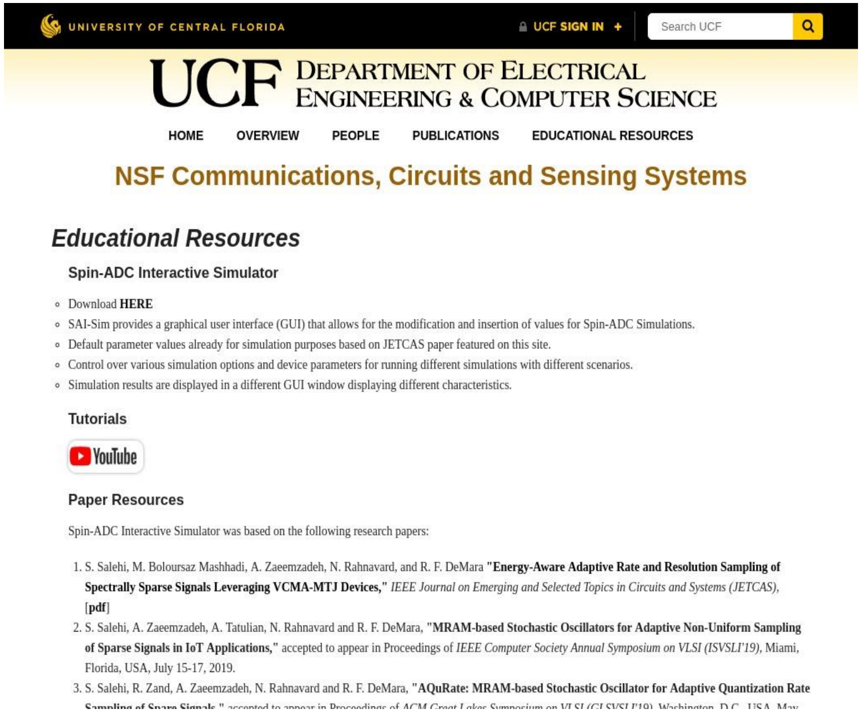
Educational Outreach Goals

CCSS Website[1]

Spintronic Educational Simulation

Outreach Objectives:

- Utilize research findings in undergraduate & graduate coursework.
- Develop an interactive tool based on research findings.
- Utilize the proposed tool to engage and attract high school students into STEM-related fields.
- Use educational resources website for explanation and distribution of the proposed interactive tool.



Current Work:

- Youtube Tutorial Video: Simulation Runs with 2-Terminal MTJs
- Youtube Tutorial Video: MTJ Parameters Walkthrough
- Finalize the export option to save the acquired data from simulations in a spreadsheet document

1. G. Camero, S. Salehi, and R. F. DeMara, IEEE ReConfig-2019.
2. S. Salehi, M. Mashhadi, A. Zaeemzadeh, N. Rahnavard, and R. F. DeMara, IEEE JETCAS-2018
3. This work is funded by NSF-ECCS #1810256

Spintronic Simulation Framework

For more information regarding the presented simulation tool, please contact us at: **https://cal.ucf.edu/ccss**

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