Frequency-selective wireless programming of a Spintronic Neural Network to solve classification of Radio-Frequency Signals

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In-memory computing eliminates the energy cost of shuttling data between memory and processing units. A key challenge is programming individual non-volatile memory elements within dense arrays without compromising efficiency or scalability. Current platforms rely on individual access lines or selector transistors, which increases footprint, complicates 3D stacking, and flexibility. We introduce a scalable paradigm for remotely programmable neuromorphic hardware bridging device physics, circuit functionality, and system-level learning.

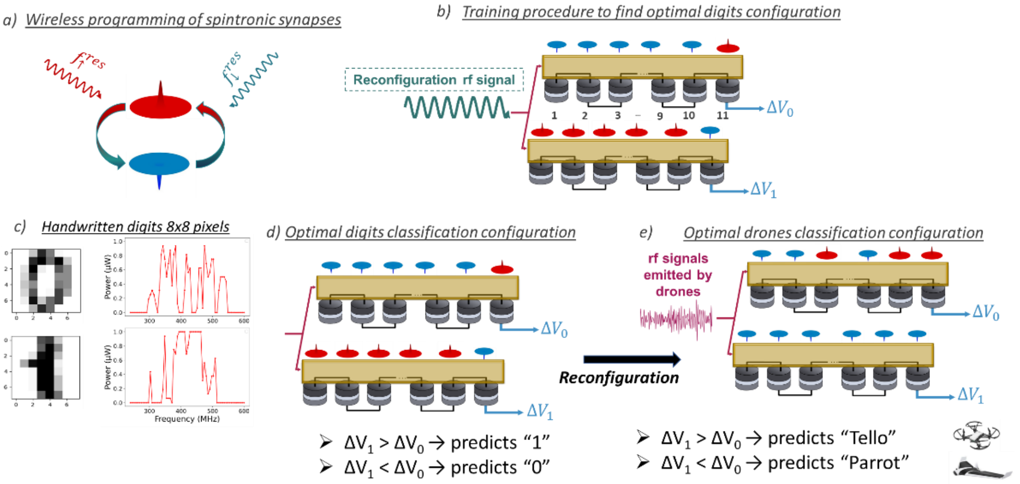

Figure 1 Wireless programming of an RF-neural network system for two different tasks. a) Programable states in an MTJ shown in: red (spin up) and blue (state down). b) Injection of a single RF signal to program the state of MTJs individually. c) Conversion of an image dataset into RF signals. d) System trained for classify an RF-digits' sub-dataset. e) System trained to classify RF signals from drones.

We exploit the intrinsic frequency selectivity of magnetic tunnel junctions (MTJs) hosting magnetic vortex states. Each MTJ features a distinct diameter and unique base resonant frequency. Synaptic weights are encoded in the vortex core polarity, deterministically switched via microwave excitation for frequency-selective control. We fabricated chains of 11 series-connected MTJs that natively perform weighted summation of input radio-frequency (RF) signals. Weights are programmed remotely using a global stripline delivering broadcast RF signals, eliminating the need for individual electrical access.

Combining 2 chains, we realize a compact neural network with 22 synapses and 2 outputs. This architecture supports independent, deterministic reconfiguration of all weights via broadcasted signals, enabling rapid, on-the-fly adaptation without modifying physical interconnects. We validated the hardware on benchmark and real-world RF classification tasks. The system achieves 94.9% accuracy distinguishing handwritten digits (0/1) and 97.3% accuracy classifying drone RF signals. By removing individual physical access and harnessing MTJ RF dynamics, this work paves the way toward ultra-compact, energy-efficient computing systems.

[1] A. Ross et al., Nat. Nanotechnol. 18, 1273–1280 (2023).