Redundant analog-to-spike encoding with an InP resonant tunneling diode

I. Luntadila Lufungula, D. Harmsen, K.A. Williams, V. Dolores-Calzadilla

Photonic Integration Group, Department of Electrical Engineering, Eindhoven University of Technology

Spiking neural networks promise to be energy-efficient and noise-resilient alternatives to artificial neural networks, however their performance still lags behind. A key factor influencing both performance and efficiency is signal conversion and encoding. Here, we demonstrate via simulations a redundant analog-to-spike encoding scheme based on the dynamics of an experimentally characterized resonant tunneling diode (RTD) on InP[1]. The input amplitude is encoded simultaneously in the time-to-first-spike (TTFS) and spike count, yielding a redundant representation potentially robust to noise.

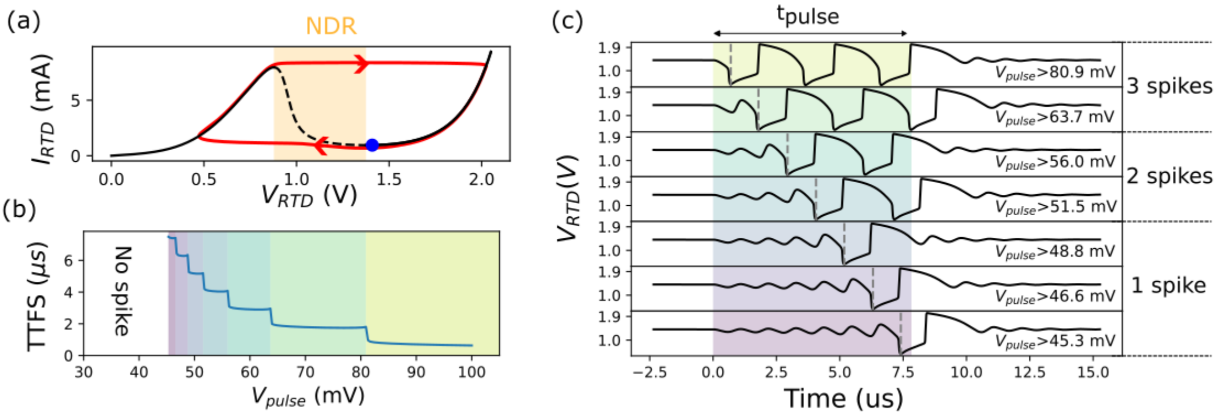

Figure 1: **(a)** RTD IV-curve (fit to experimental data) and spiking trajectory (red) **(b)** TTFS for different pulse amplitudes. **(c)** Spiking output for input amplitudes in each logarithmic interval (colors match (b))

The InP-based RTDs consist of a quantum well (5.7 nm InGaAs) between two thin barriers (1.7 nm AlAs) which allow for a negative differential resistance (NDR) region (see Fig. 1(a)), leading to oscillatory and excitable dynamics [1]. We simulate the system numerically with a circuit model implementing the RTD as a voltage controlled current source in parallel with a capacitor (C= 300 pF) [1] driven by a bias voltage through a cable with inductance L=100 µH. We bias our RTD past the NDR and modulate the bias voltage with negative voltage pulses of 8 µs at different amplitudes, moving the RTD voltage into the NDR and exciting spikes. Fig. 1(c) shows that the input amplitude affects both the TTFS and the spike count. The TTFS decreases with larger inputs while the spike count increases resulting in a redundant encoding with logarithmically sized quantization intervals (Fig 1(b)). Similar logarithmic intervals have been observed in biological senses such as human loudness perception and provide higher sensitivity at low amplitudes and improved robustness to noise [2]. Prior RTD-based TTFS approaches suffer from small continuous timing differences [1]; our method has larger and discrete jumps in timing resulting from the varying amount of pre-spike oscillations at different input amplitudes (see Fig. 1(c)). These oscillations arise from the underdamped regime the RTD is biased in [3]. They have nearly constant frequency but a growing amplitude where the input amplitude V_{pulse} determines the rate of growth which in term determines how many oscillations are needed to induce a spike. The 8 µs input pulse combined with a rest time of 7 µs to let the post-oscillations subside leads to a maximal sample frequency of ~66 kHz which is e.g. fast enough to process sound data. The frequency could however be increased by using smaller inductance and capacitances in the circuit as THz RTD oscillators have already been demonstrated. In conclusion we have shown hardware-specific simulations demonstrating redundant TTFS-spike count encoding using RTDs. Future work will focus on experimental validation of this mechanism.

[1] Donati, Giovanni, et al. *Phys. Rev. Appl* 24.2 (2025): 024041.

[2] Portugal, R. Doyle, and Benar Fux Svaiter. *Minds Mach* 21.1 (2011): 73-81.

[3] Adair, A., et al.. European Quantum Electronics Conference (p. jsi_p_16) 2025

The work was funded by the SpikeSense TU/e package and EU SpikePro project (No. 101129904).