Transistor-Level Evaluation of Event-Driven Spike Encoders for EEG Signals

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This work presents the transistor-level design and comparison of two fully asynchronous, event-driven spike encoders for electroencephalographic (EEG) signals: an Asynchronous Delta Modulator (ADM) and an Asynchronous Sigma-Delta Modulator (ASDM). Both circuits are implemented in Cadence Virtuoso using a 45 nm educational CMOS technology and are intended to operate after an analog conditioning stage providing preamplification and 0.5–40 Hz band-pass filtering of the EEG input. Their function is to convert the conditioned EEG into bipolar spike streams. Both circuits are derived from existing asynchronous implementations [1, 2]. The ADM performs continuous error evaluation between the input and an internal reference, followed by threshold comparison and reference/thresholds updating through signed spikes. The ASDM adopts a sigma-delta-inspired event-driven approach, in which the input error is integrated and output spikes are generated when the internal state crosses positive or negative thresholds. In both architectures, spike generation is achieved without a global clock, preserving fully asynchronous operation. Figure 1a shows the simplified block diagrams of the spike encoders implemented.

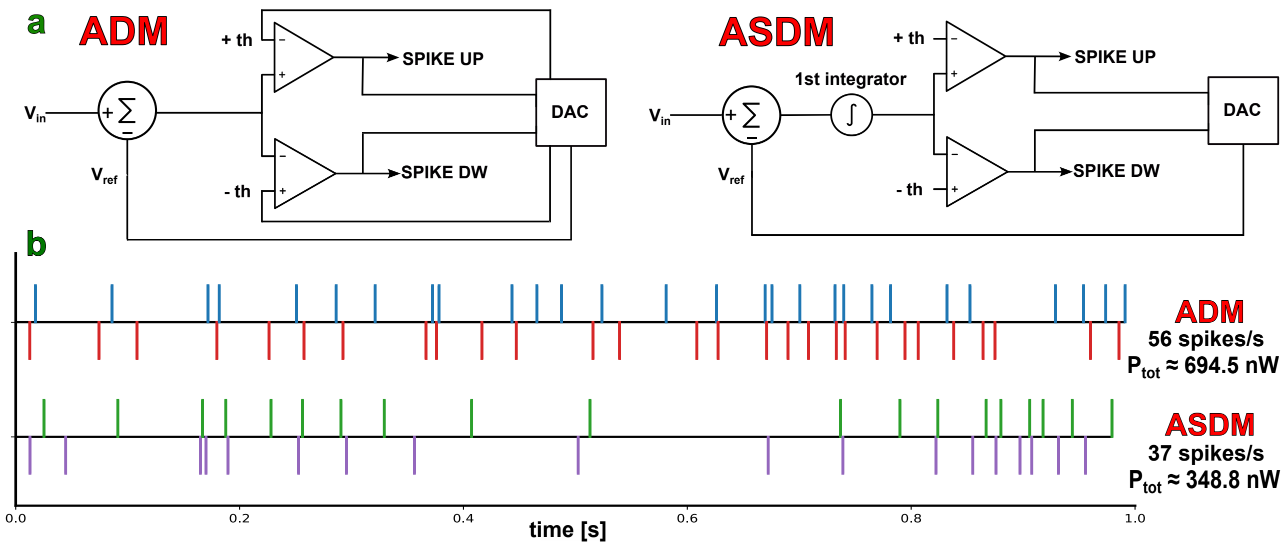

Figure 1: **a)** Block diagrams of the proposed event-driven spike encoders and **b)** bipolar spike trains generated by each encoder during 1-second simulation with single-channel EEG signal as input.

The aim of this work is to evaluate the feasibility of both architectures at transistor level, verify correct EEG-band operation, and compare spike encoding behavior and power-related trade-offs. Preliminary simulations with EEG inputs indicate a lower total power and energy per event trend for the ASDM with $V_{DD} = 1$ V (see Figure 1b). The study targets ultra-low power event-driven encoders for multi-channel EEG front ends and future edge AI or near-sensor AI biosignal processing systems [3, 4].

[1] F. Corradi and G. Indiveri, IEEE Trans. Biomed. Circuits Syst., vol. 9, no. 5, pp. 699–709, 2015.

[2] K. Ozols et al., Proc. Baltic Electron. Conf. (BEC), pp. 183–186, 2012.

[3] S. Narayanan et al., Proc. IEEE BioCAS, pp. 1–5, 2023.

[4] G. Leone et al., IEEE Trans. Circuits Syst. I, vol. 72, no. 2, pp. 790–801, 2025.