Motivation and Contributions

- Critical ADC tasks: Sampling and quantization play vital roles in an ADC
- Inefficient conventional ADCs: Conventional ADCs waste power and bandwidth due to underutilization of signal information
- TEM for signal encoding: Time encoding machines (TEM) encode input signals into time sequences, effectively utilizing signal information
- Enhanced noise robustness: Moving the quantization process from the signal amplitude domain to the time domain improves amplitude noise resilience
- Power-efficient sub-Nyquist sampling: Our presented TEM hardware enables efficient sub-Nyquist sampling and recovery of ECG signals, benefiting heart rate monitoring applications

ECG Sampling and Reconstruction

- Variable width pulses: \( x(t) = \sum_{k=1}^{L} s_k(t) \), where \( x_k(t) = x_k^0(t) + x_k^1(t) \)
- The signal components \( x_k^0(t) \) and \( x_k^1(t) \) are the symmetric and antisymmetric parts of the pulse
- 4L+1 Fourier samples of \( x(t) \) uniquely determine the parameters \( x_0, x_1, \ldots, x_{4L} \)
- If the signal is defined on the interval \([0, T]\), the local rate of innovation is \( 4L+1 \times \frac{1}{T} \)
- Sub-Nyquist sampling scheme enables computation of the Fourier samples from low rate samples

IF-TEM

- An integrate-and-fire time-encoding machine is paramerised by:
  - \( b \): The bias
  - \( \kappa \): The integrator constant
  - \( \delta \): The threshold

ECG-TEM Sampling

- ECG signal modeling: We adopt a VPW-FRI signal model for the ECG signal within the interval \([0, T]\)
- IF-TEM input and output: The IF-TEM takes in a filtered ECG signal and produces time instants as outputs
- Selection of IF-TEM parameters: We choose IF-TEM parameters to ensure there are 8L+2 time instants within the time interval \( T \)
- Definition of IF-TEM firing rate: The firing rate of the IF-TEM is determined by the number of time instants in the interval \([0, T]\)
- Computation of Fourier coefficients and estimation: By utilizing TEM time instants, we compute the Fourier coefficients of \( x(t) \) and estimate VPW-FRI parameters from them

Hardware

- Signal generation
- Sampling kernel
- ECG Signal Generator
- Bandpass Filter - \( g(t) \)
- IF-TEM
- DSP

Results – ECG reconstruction and HRM

- The HRM is calculated from the recovered ECG signal
- Specifically, we examined the resting scenario, and compared the statistical metrics of the HR estimate with the reference output

Conclusions

- Power-efficient sub-Nyquist sampling: Our TEM hardware enables efficient sub-Nyquist sampling and recovery of ECG signals, benefiting heart rate monitoring
- Enhanced noise robustness: The ECG signal is filtered to remove its zeroth frequency to improve noise resilience
- The processed filtered signal, \( y(t) \), is sampled using an IF-TEM sampler, resulting in a firing rate of 42-80Hz, equivalent to approximately 120-1/40 of the Nyquist rate

User Interface

- Heart Rate Monitoring for ECG signals with Time Encoding Machine
- Sampling rates: Nyquist 2KHz, IF-TEM firing rate: 42-80Hz

Method

- Success rate [25%, 2 bps]
- FDR [25-50]
- MAE [0-10]
- RMSE [0-20]

Results

- ECG-TEM
  - Success rate: 95.78%
  - FDR: 0.9598
  - MAE: 0.1510
  - RMSE: 0.6429