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A Hardware Prototype of Sub-Nyquist Time-Based Sampling of FRI Signals

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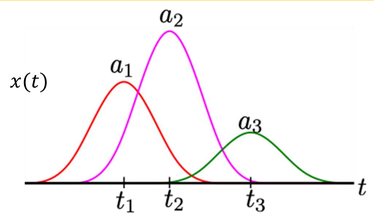
Motivation and Contributions

- Sampling and quantization are critical tasks of an ADC
- Conventional ADCs fail to utilize the signal information resulting in unnecessary power and bandwidth consumption
- Time encoding machines (TEM) utilize signal information and encode the input signal into a time sequence
- Increase amplitude noise robustness by moving the quantization process from the signal amplitude domain to the time domain
- We present a TEM hardware for power efficient sub-Nyquist sampling and recovery of finite-rate-of-innovation signals

FRI Sampling and Reconstruction

- Stream of known pulses: $x(t) = \sum_{\ell=1}^{L} a_\ell h(t-\tau_\ell)$ (Known)
- Signal $x(t)$ is parametrized by amplitudes and time-delays
- $2L$ Fourier samples of $x(t)$ uniquely determine the parameters
- If the signal is defined on the interval $[0,T]$ the local the rate of innovation is $\frac{2L}{T}$
- Sub-Nyquist sampling scheme enables computation of the Fourier samples from low rate samples



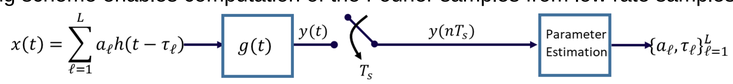
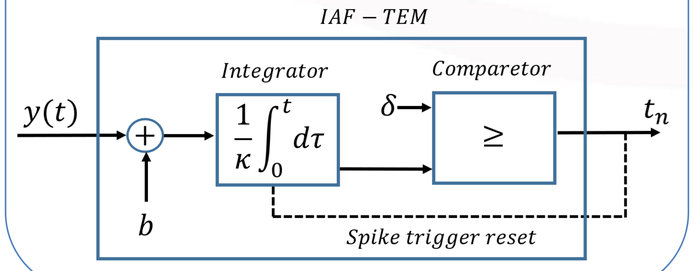


Fig: Sampling and reconstruction of FRI signal by using a sampling kernel $g(t)$

IAF-TEM

- An integrate-and-fire time-encoding machine is paramerised by:

b: The bias
δ: The threshold
κ: The integrator constant

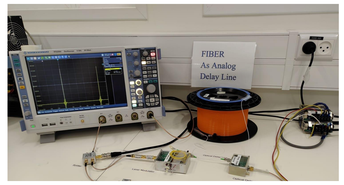


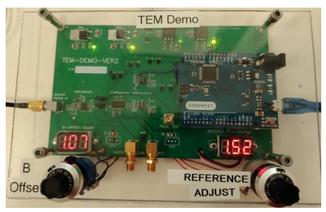
FRI-TEM Sampling

$$x(t) = \sum_{\ell=1}^{L} a_\ell h(t-\tau_\ell) \rightarrow \boxed{g(t)} \xrightarrow{y(t)} \boxed{TEM} \rightarrow \{t_n\} \rightarrow \boxed{R} \rightarrow \{a_\ell, \tau_\ell\}_{\ell=1}^{L}$$

- We consider an FRI signal in the interval $[0,T]$
- The IAF-TEM input is a filtered FRI signal and the outputs are the time instants
- The IAF-TEM parameters are selected such that there are $2L+2$ time instants within in a time interval T
- The IAF-TEM firing rate is defined as the number of time instants in the interval $[0,T]$
- Using TEM time instants $2L$ Fourier coefficients of $x(t)$ are computed from which FRI parameters are estimated

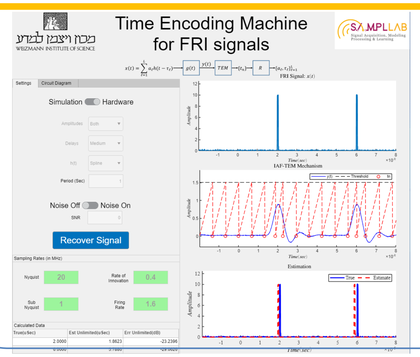
Hardware



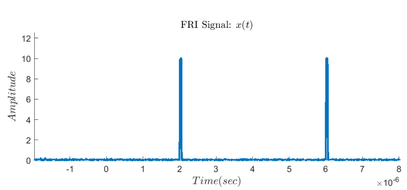


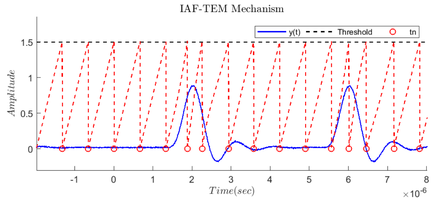
FRI Signal Generator → $x(t)$, $20\ MHz$ → Lowpass Filter - $g(t)$ → $y(t)$, $1MHz$ → IAF-TEM → $\{t_1, t_2, \cdots\}$ → DSP → Time-delays

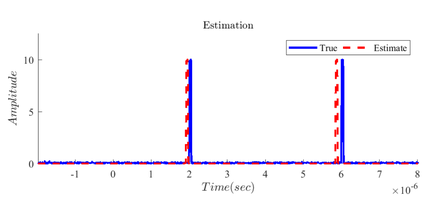
User Interface



Results







Sampling rates: Nyquist 20MHz, Rate of innovation or sub-Nyquist: 0.4MHz, TEM firing rate: 1.6MHz

- We consider an FRI signal $x(t)$ consisting of 2 pulses of bandwidth 20MHz and delay between them is 4μs
- The rate of innovation is 0.4MHz
- The signal is lowpass filtered with a cutoff frequency 0.5MHz
- The filtered signal y(t) is passed through an IAF-TEM sampler resulting in firing a rate of 1.6MHz, $\sim\frac{1}{12}$ the Nyquist rate
- The FRI parameters are estimated up to -25dB SNR while operating at 12.5 times less than the Nyquist rate