Practical Modulo Sampling: Bridging the Gap Between Theory and Hardware

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Paper

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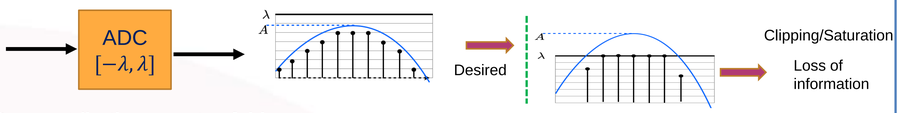
1. Motivation and Contributions

- ADCs play a crucial role in digital signal processing, demanding a dynamic range (DR) greater than the input signal to avoid information loss.
- While sampling is fundamental to ADC performance, higher rates lead to increased costs and complexity.
- Leveraging the modulo operator enables the development of ADCs with extended DR while operating at lower sampling rates, effectively addressing the DR challenge.



Our contributions are twofold:

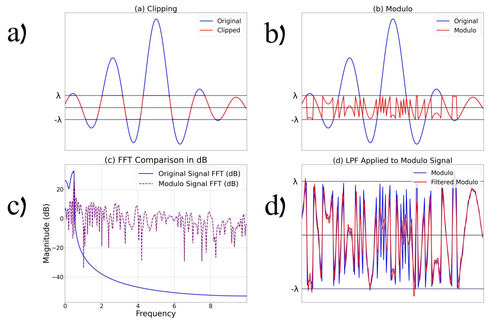
- We have developed hardware capable of performing modulo operations on signals up to 10 kHz, utilizing an ADC with a bandwidth equal to the sampling rate of 50 kHz.
- Through simulations and hardware tests, our approach has demonstrated superior noise resilience and efficiency compared to existing methods, making it a viable sampler for real-world applications.

The design efficiently handles high-frequency components from the modulo operation, ensuring **practicality for real-world use**.

It reduces **quantization error** with the same bit budget, outperforming conventional samplers in accuracy and efficiency.

2. Problem Statement

Modulo Sampling:



$$M_\lambda(a) = (a+\lambda)\ mod\ 2\lambda - \lambda$$

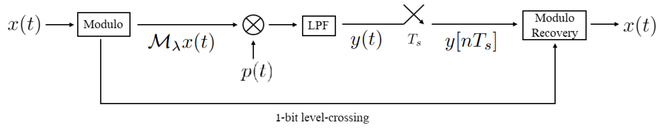
$$f_\lambda[n] = f[n] + z[n],\ z[n] \in 2\lambda\mathbb{Z}$$

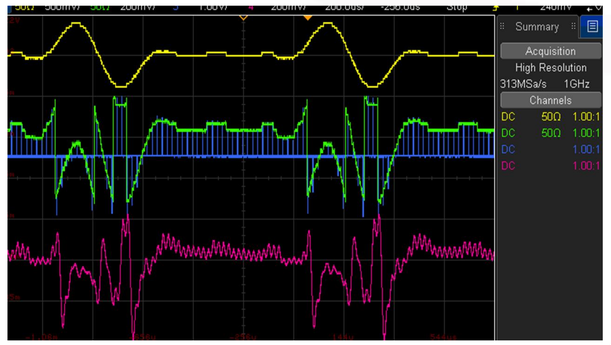
- Modulo operations introduce high-frequency components, complicating recovery.
- Low-pass filters (LPF) remove critical frequencies, causing information loss.
- Existing methods cannot effectively handle challenges from modulo operations and LPF effects.
- Higher bandwidths require more powerful ADCs, increasing cost and complexity.

3. Practical Sampling System

Use of mixer and LPF

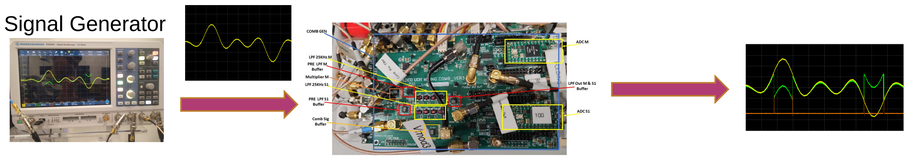
Extra-bit information



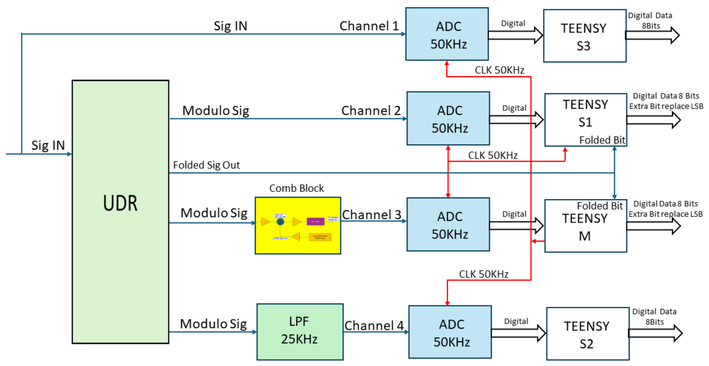


4. Hardware

Signal Generator

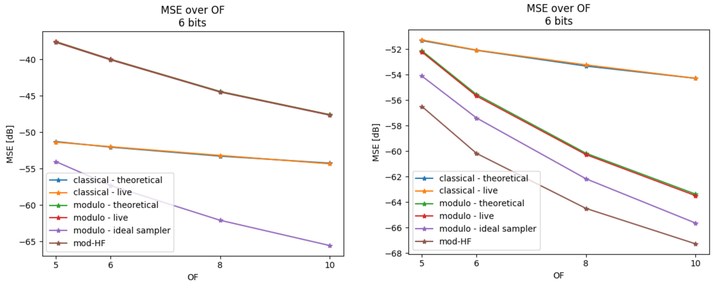


- Comparators generate a trigger signal whenever the input signal exceeds the ADC's DR.
- The trigger activates a voltage generator, which adjusts the input signal to keep it within the DR.

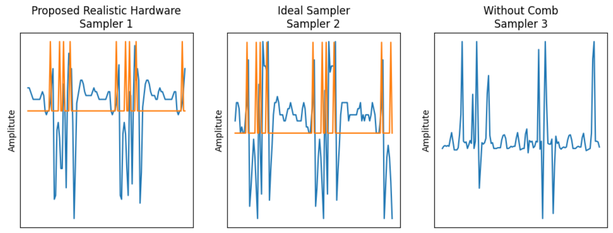


5. Results

Simulation

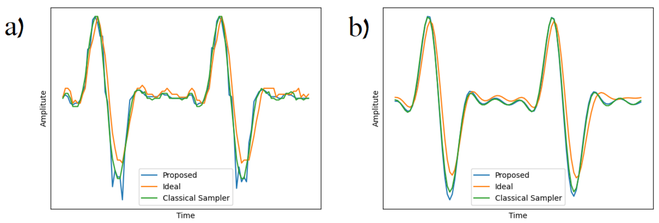


Hardware



Recovered Signals Comparison

Ideal (ADC Band 20 MHz), Proposed (ADC Band 50 KHz)



Conclusion

- Modulo sampling generates high-frequency components.
- Current methods depend on high-rate ADCs to capture the frequencies.
- Our approach offers a practical hardware solution to addre these challenges efficiently.