P103

Full Digital Compensation of Timing Mismatches in Interleaved ADC

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Introduction

Research Objective

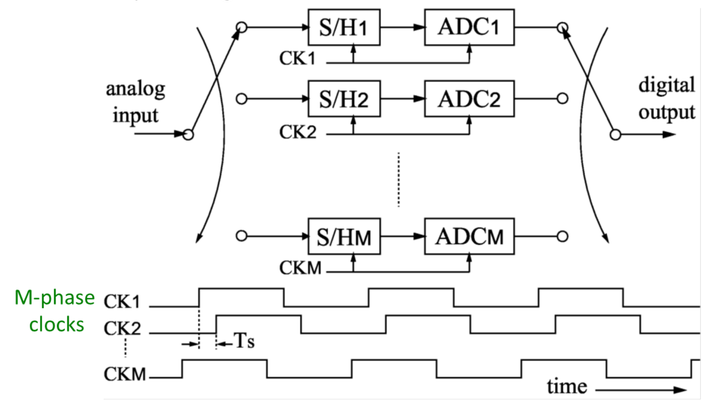
- Development of High-Speed High-Accuracy ADC for High Performance Measurement Instruments

Our Approach

- High-Speed
  Interleaved ADC
- High-Accuracy
  Fully Digital Calibration of Its Timing Skew

Interleaved ADC

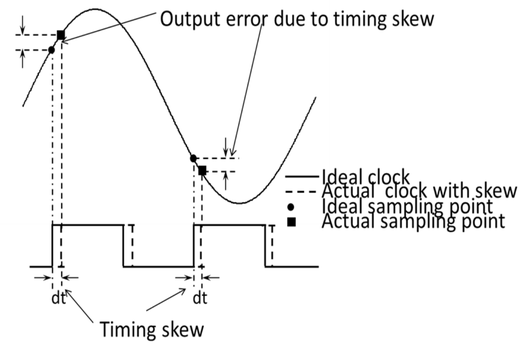
A high sampling-rate ADC with M channel ADCs operating in a interleaved manner.



M channel ADCs = M times sampling rate

Timing Skew Problem

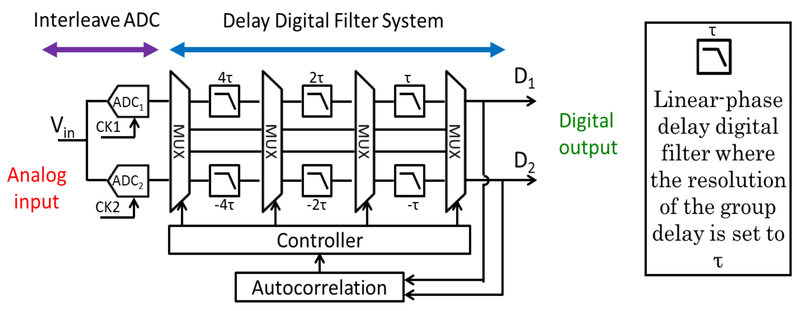
M-phase clocks
timing skew dt
cause ADC output error
difficult to correct



Proposed Timing Skew Calibration Method

Proposed Calibration System

Skew Detection: Autocorrelation among channel ADC outputs
Correction: Proposed linear-phase delay digital filter



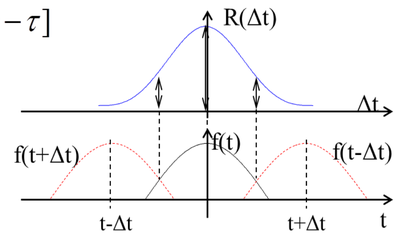
Skew Detection

Autocorrelation

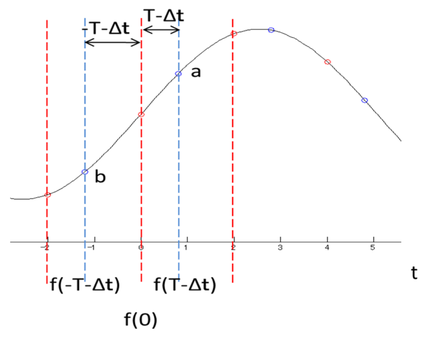
$$R_{ff}(\tau) = (f(t) * f(-t))(\tau) = \int_{-\infty}^{\infty} f(t) f(t-\tau) dt$$

For discrete functions at lag τ

$$R_{ff}[\tau] = \lim_{n\to\infty} \frac{1}{n} \sum_{-n}^{n} f[n] f[n-\tau]$$



Timing Skew Detection



Compare the autocorrelation R(a) (at lag a) and R(b) (at lag b) between CH1 and CH2

Calculation of R(a), R(b)

CH1 ADC output: $f[n]$

CH2 ADC output: $g[n] = f[n+T-\Delta t]$

Autocorrelation between CH1 and CH2:

$$R_{ff}[\tau] = \lim_{n\to\infty} \frac{1}{n} \sum_{-n}^{n} f[n] f[n+T-\Delta t-\tau]$$

at lag a, $\tau = 0$

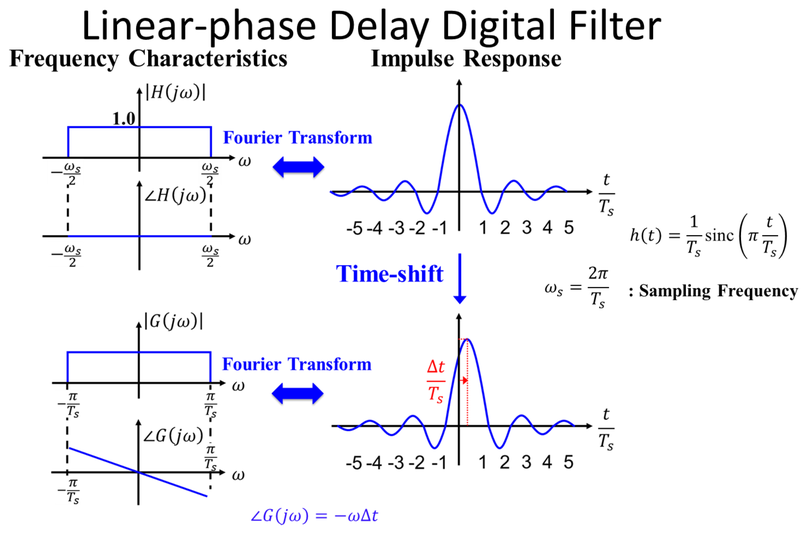
$$R(a) = R_{ff}[0] = \lim_{n\to\infty} \frac{1}{n} \sum_{-n}^{n} f[n] f[n+T-\Delta t]$$

at lag b, $\tau = -2T$

$$R(b) = R_{ff}[-2T] = \lim_{n\to\infty} \frac{1}{n} \sum_{-n}^{n} f[n] f[n-T-\Delta t]$$

Skew Correction

Linear-phase Delay Digital Filter

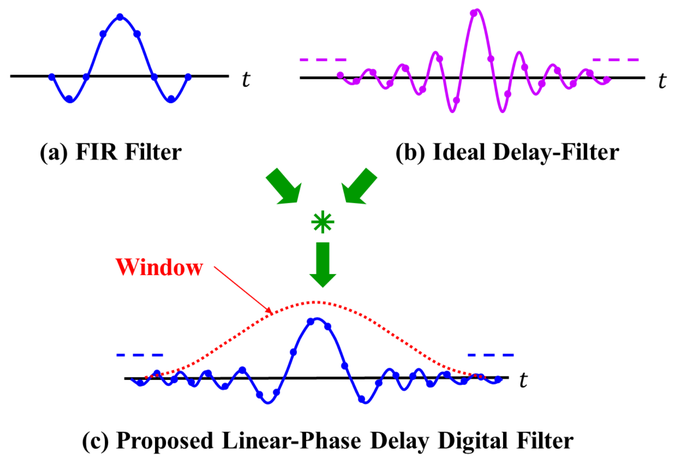


$$h(t) = \frac{1}{T_s} \mathrm{sinc}\left(\pi \frac{t}{T_s}\right)$$

$\omega_s = \frac{2\pi}{T_s}$: Sampling Frequency

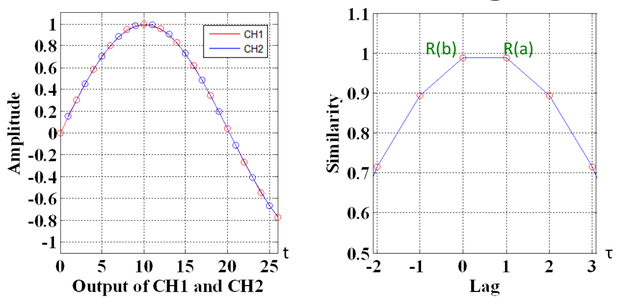
$\angle G(j\omega) = -\omega \Delta t$

Design of Linear-Phase Delay Digital Filter



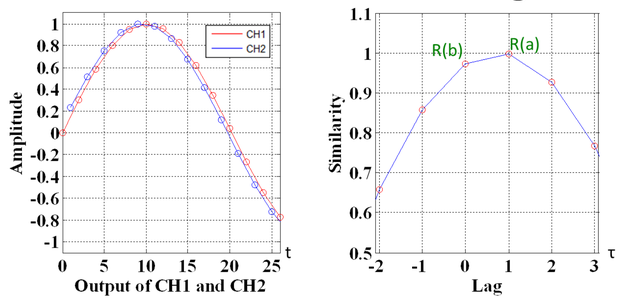
Simulation Results

Autocorrelation Without Timing Skew Case



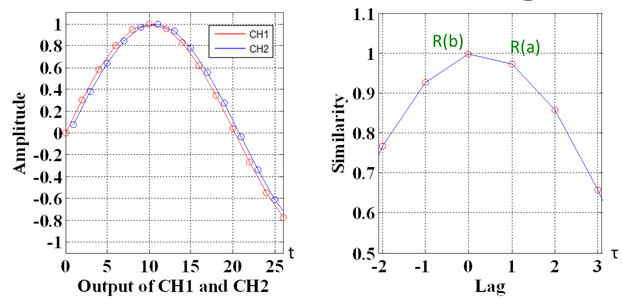
Δt=0 ⇒ R(b)=R(a)

Autocorrelation With 0.5Ts Timing Skew Case



Δt=0.5Ts ⇒ R(b)<R(a)

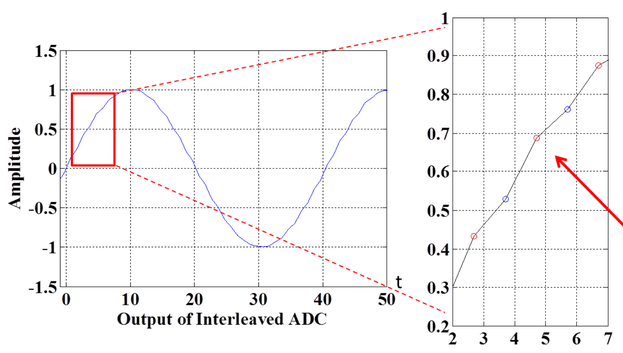
Autocorrelation With -0.5Ts Timing Skew Case



Δt=-0.5Ts ⇒ R(b)>R(a)

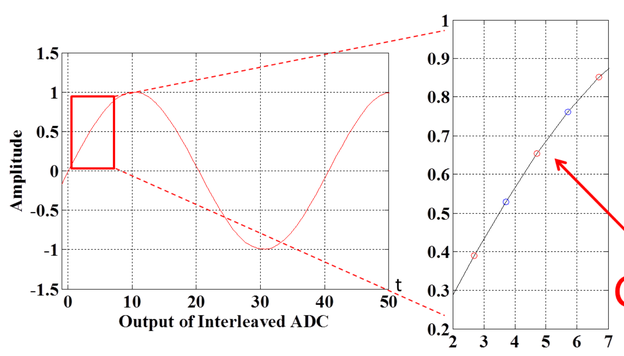
Ts: sampling rate

Output of Interleaved ADC Without Linear-Phase Delay Digital Filter



Δt=0.5Ts

Output of Interleaved ADC With Linear-Phase Delay Digital Filter



Δt=0.5Ts

Conclusion

Timing Skew Calibration Method Proposed

Skew Detection: Autocorrelation among channel ADC outputs
Correction: Proposed linear-phase delay digital filter

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Fully Digital

Stable, reliable, easy to design

Application

Automatic Test Equipment
High-speed Measuring Instruments
Digital Oscilloscope


LSI Tester


Digital Oscilloscope