CIC filters

By

Sylas Ashton
Overview

• Over-Sampling and Averaging
• Effective Number of Bits (ENOB)
• Moving Average Filter
• Comb-Integrator Moving Average Filter
• Re-arranging to CIC filter
• Nth Order CIC filter
• Implementation
• Frequency Response of the CIC filter
Over-Sampling and Averaging

• Increases Bit resolution
• Increasing N bits out requires $2^N$ samples
• Increasing Effective Number of Bits (ENOB)
  – $F_{os}/F_{out} = 3125$ → 11.6 Bits out
  – 5.8 ENOB
Getting 16 ENOB

- Add 2 more averaging filters
  - Bit width = 11.6*3=34.8
  - ENOB = 3*5.8=17.414 bits
- Resource usage grows exponentially
Basic Moving Average w/ Gain

• Directly sums last D bits
  – D*Bit\_width of bits of storage
  – D adders
  – Log2(D)bits output latch for decimator
  – 3 averaging filters in series requires D+D*\log_2(D)+D*\log_2(D)*2 bits of storage and 3*D adders
Comb-Integrator Moving Average Filter

- Still needs same amount of storage
- Needs one adder/subtractor and one integrator
Re-arrange LTI systems

- Integrate, then Decimate, then Comb
- If the Comb delay is the same as the decimation time, the delay D is the last sample from the decimator, reducing storage by a factor of D
Nth order Cascade Integrated Comb Filter

• Take N moving average filters in sequence with decimation at the end
  — Rearrange all integrators first, and comb filters last, with the decimator in the middle

• Integrator overflows are removed by combs if unsigned math is used and the bit width is at least $N \cdot \log_2(D)$
Implementation

• All logic runs on main clock
• All Integrators are always enabled
• Registers for the decimator and comb filters are enabled every Dth cycle (D=3125)
• Uses \((2\times N+1)\times N \times \log_2(D)\) bits of storage
Frequency Response

- Gain = \( \text{abs}(\sin(\pi f D) / \sin(\pi f))^N \)
- Phase is linear
- For 3\(^{rd}\) order filter with 50MHz sample rate and 16kHz output rate
  - 3dB at 4250Hz
  - 11dB drop at 8kHz,
  - min 40dB suppression above 16kHz
Frequency Response

• 1ˢᵗ order CIC filter response
  – D=8
Frequency Response

- 3\textsuperscript{rd} order CIC filter frequency response
  - D=R=8
Frequency Response

3rd Order CIC Gain 50MHz Sampling Rate D=3125

- Gain
- 16-bit resolution
References