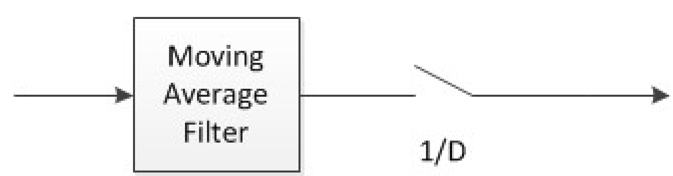
Overview

- 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

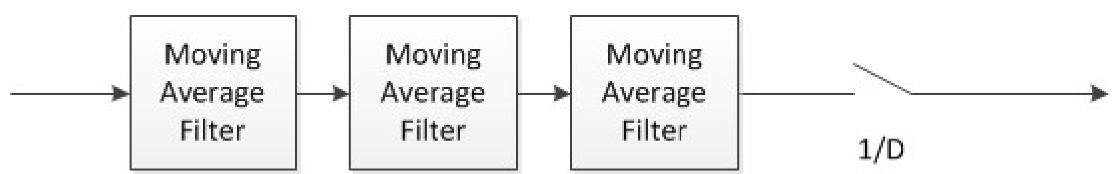
Over-Sampling and Averaging

- Increases Bit resolution
- Increasing N bits out requires 2^N samples
- Increasing Effective Number of Bits(ENOB)
  - $Fos=Fout*2^{(2n)} \Rightarrow n=\log_4(Fos/Fout)=\log_4(D)$
- For 50MHz sampling and 16kHz output
  - Fos/Fout = 3125
  - 11.6 Bits out
  - 5.8 ENOB



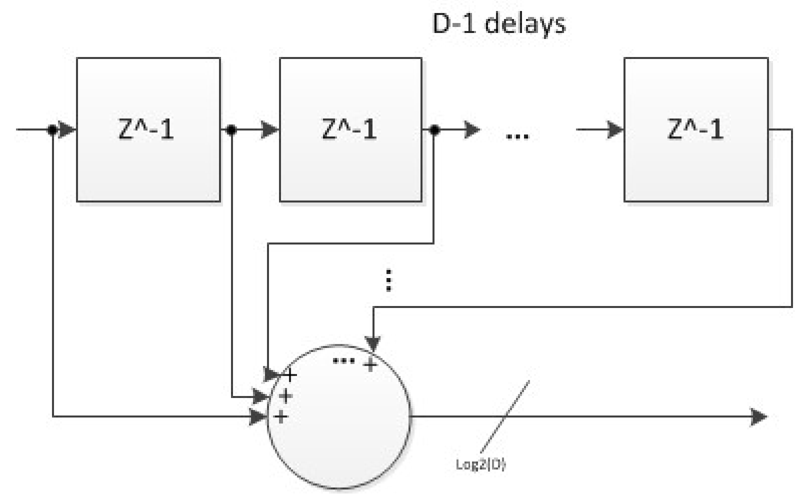
Getting 16 ENOB

- Add 2 more averaging filters
  - Bit width = 11.6*3=34.8
  - ENOB = 3*5.8=17.414 bits
- Resource usage grows exponentially



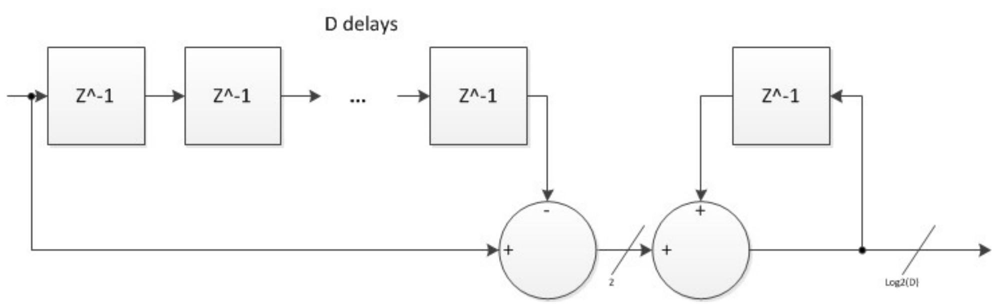
Basic Moving Average w/ Gain

- 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



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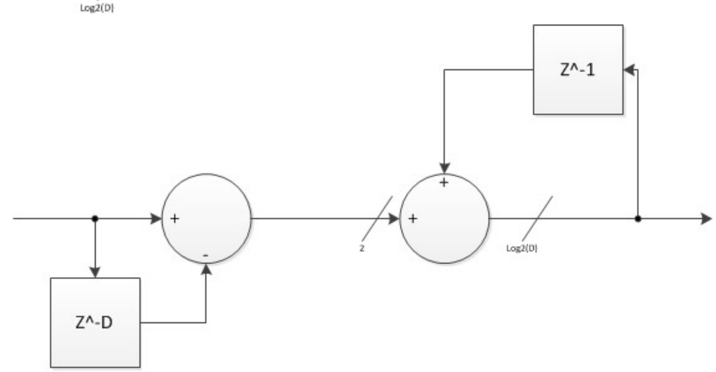
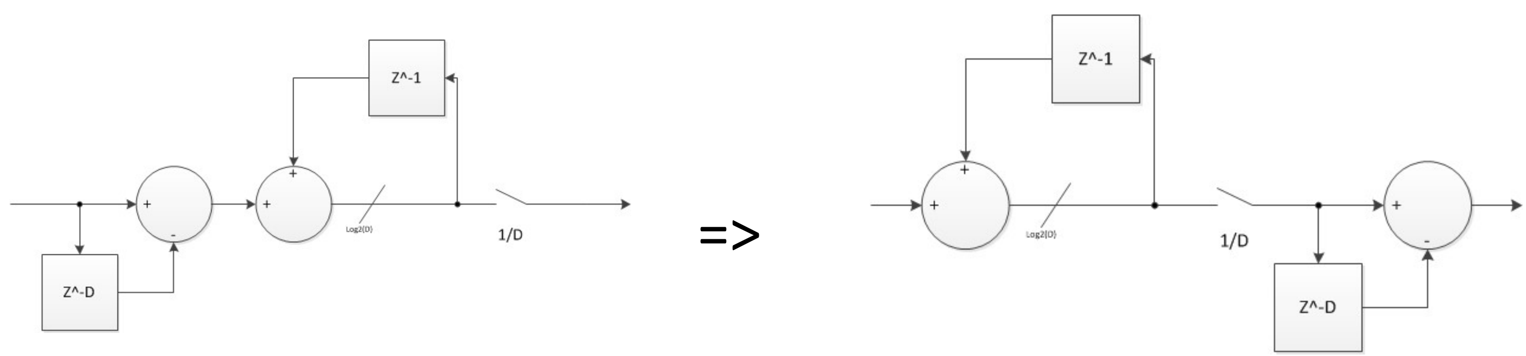


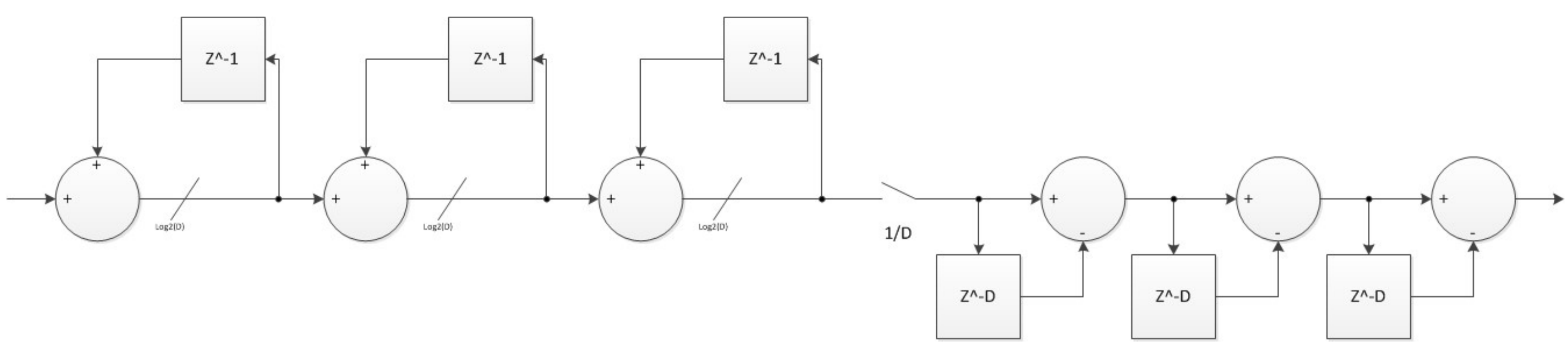
Re-arrange LTI systems

- 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



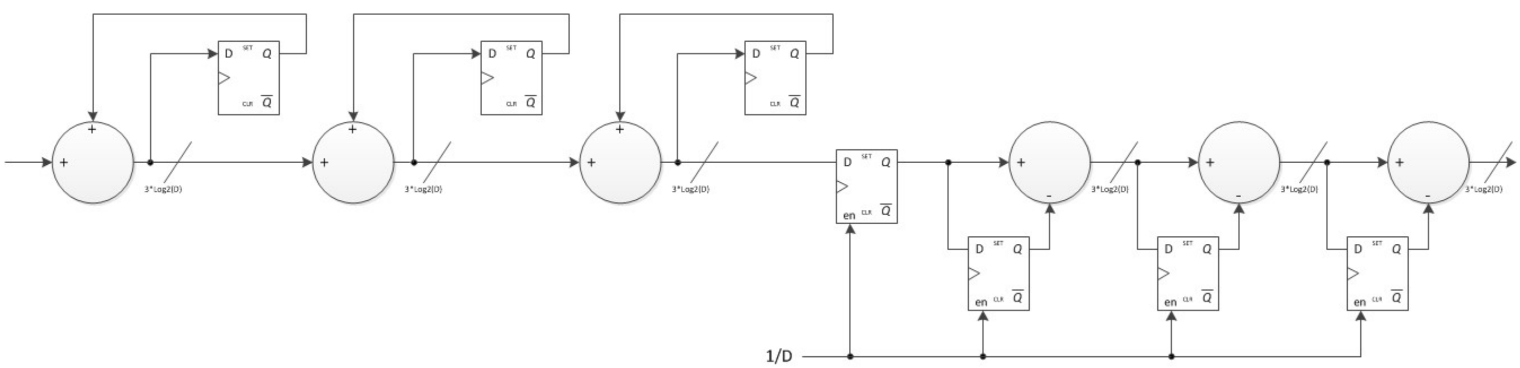
Nth order Cascade Integrated Comb Filter

- 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 $N*\log_2(D)$



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*N+1)*N*$\log_2$(D) bits of storage

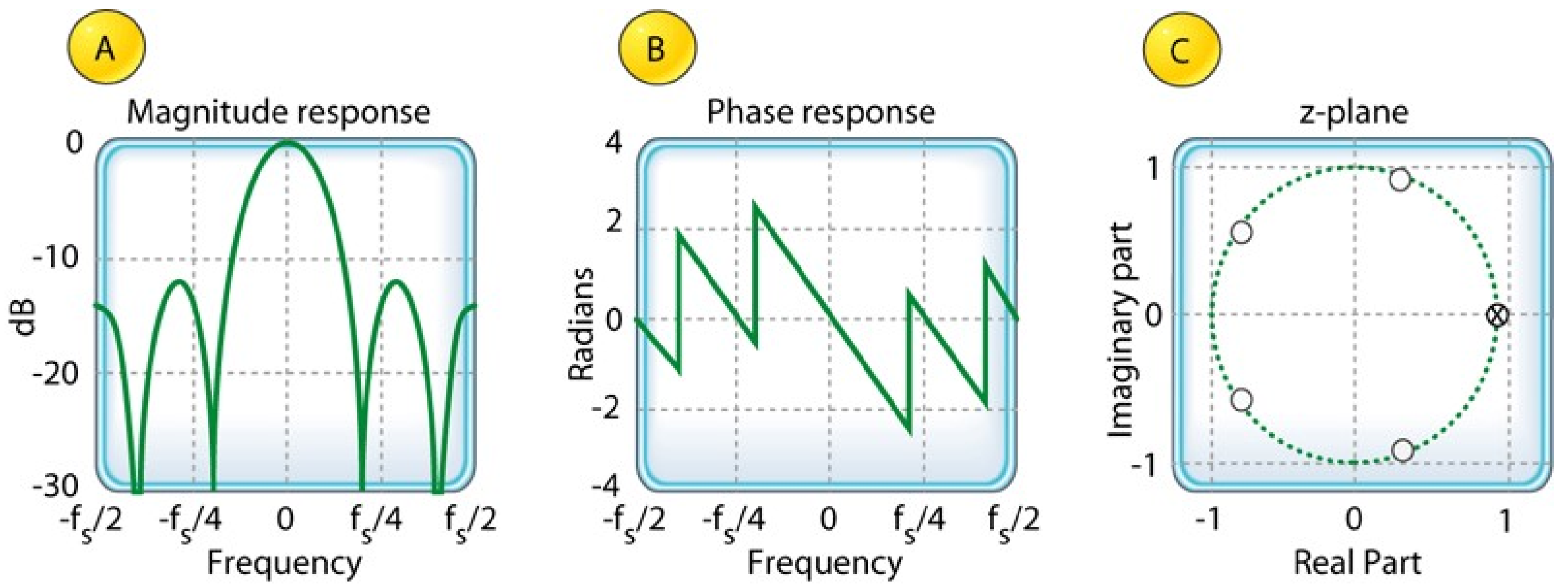


Frequency Response

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

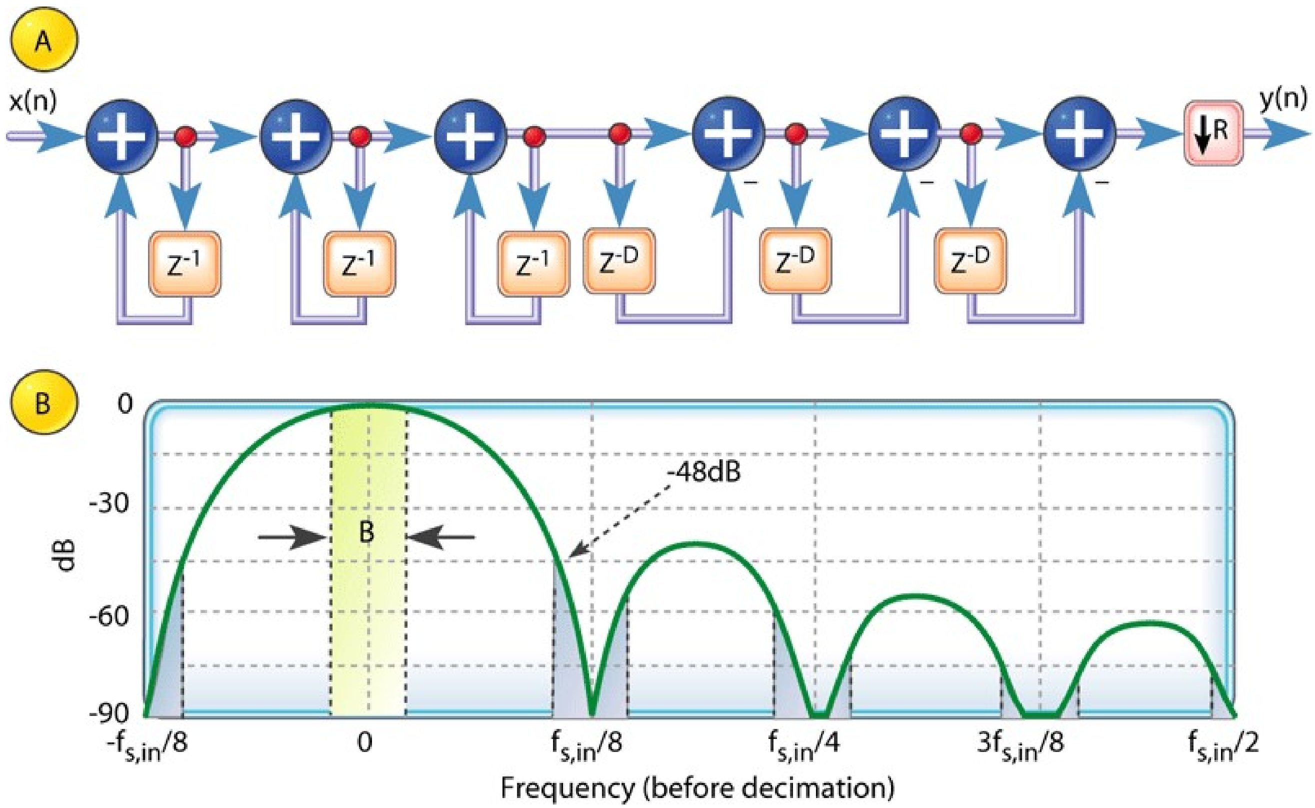
Frequency Response

- 1^{st} order CIC filter response
  - D=8



Frequency Response

- 3rd order CIC filter frequency response
  - D=R=8



Frequency Response