Applications of General-Purpose Reconfigurable LLRF Processing Architectures

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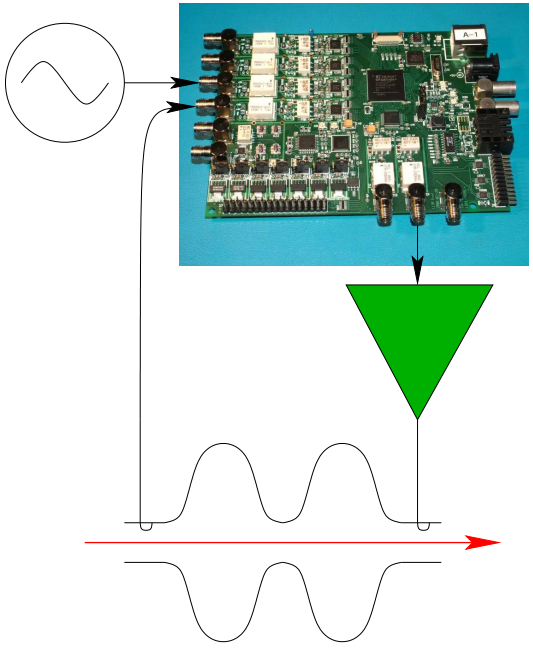
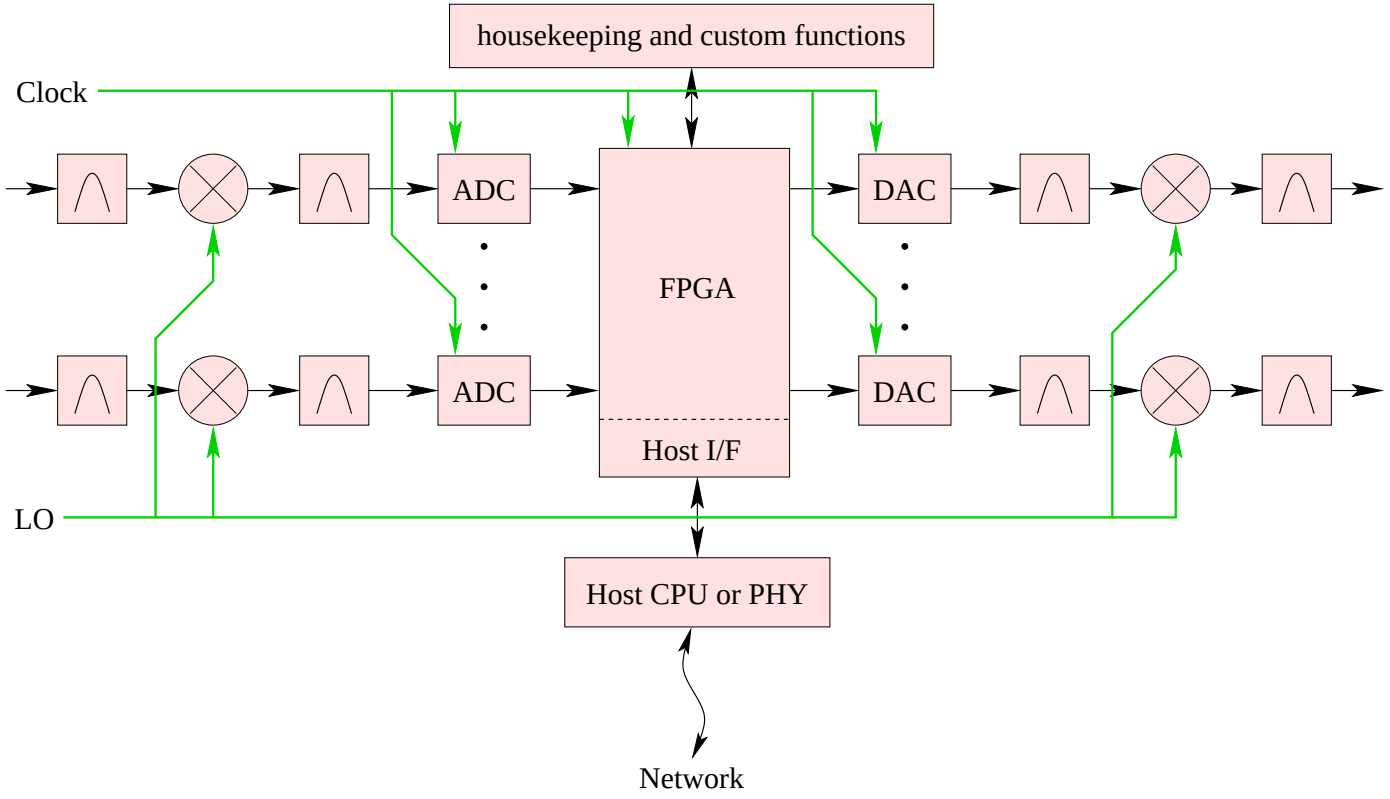
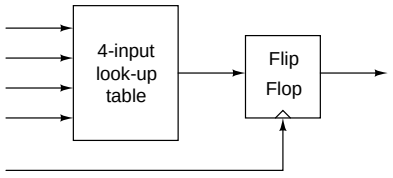
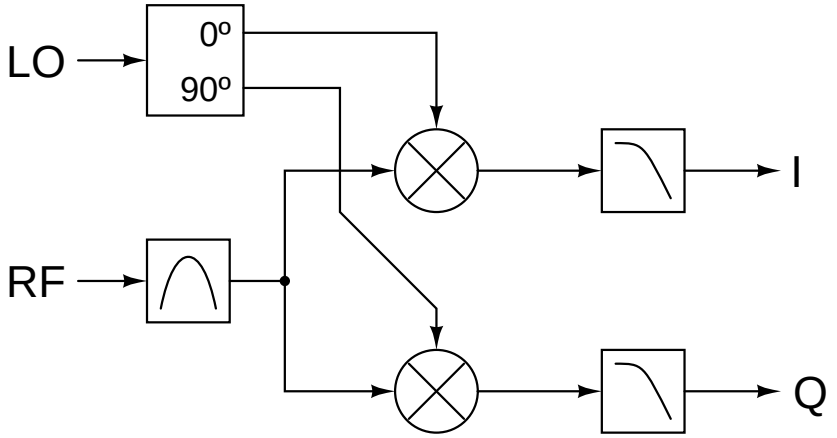


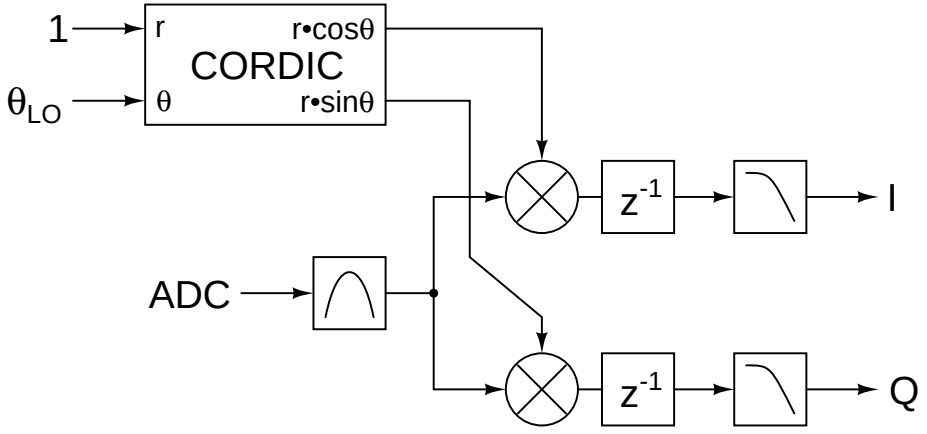

housekeeping and custom functions
Clock
ADC
ADC
FPGA
Host I/F
DAC
DAC
LO
Host CPU or PHY
Network

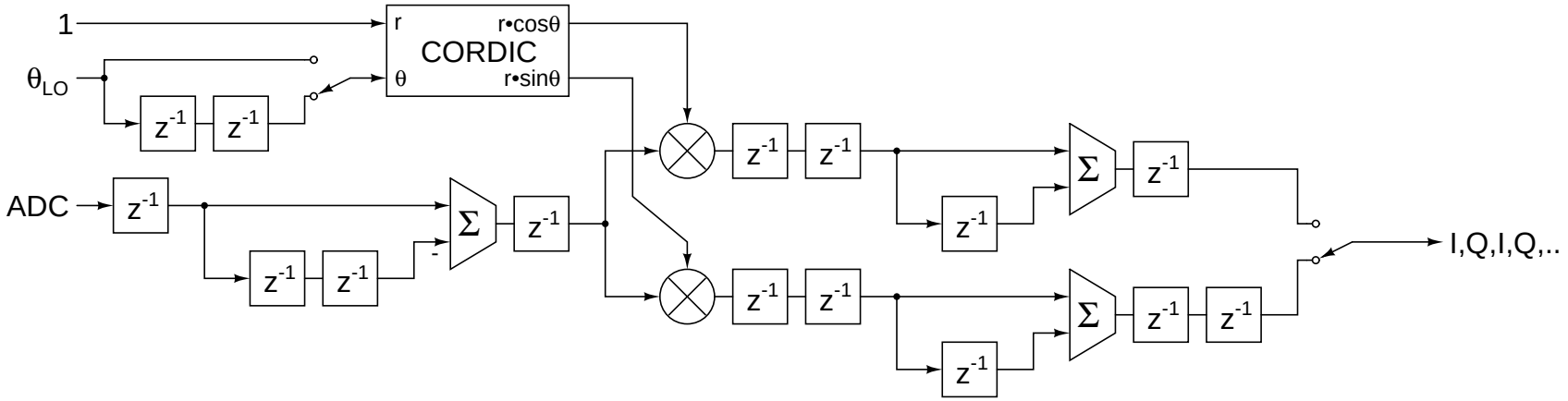
	Computer	FPGA
Programmable digital logic device	Yes	Yes
Major suppliers	uncountable	2
Glue-less hookup to most DAQ hardware	-	Yes
Guaranteed low-latency processing	-	Yes
Good programming languages	Yes	-
Good programming requires thought and experience	Yes	Yes



1536 (US$10) to 178176 (US$6000) cells,
plus routing, carry chains, multipliers, RAM, input, and output


LO
0º
90º
RF
I
Q


1
r
r•cosθ
CORDIC
θLO
θ
r•sinθ
ADC
z-1
z-1
I
Q



Successive ADC samples in terms of I and Q:

$$\begin{pmatrix} y_n \\ y_{n+1} \end{pmatrix} = \begin{pmatrix} \cos n\theta & \sin n\theta \\ \cos(n+1)\theta & \sin(n+1)\theta \end{pmatrix} \begin{pmatrix} I \\ Q \end{pmatrix}$$

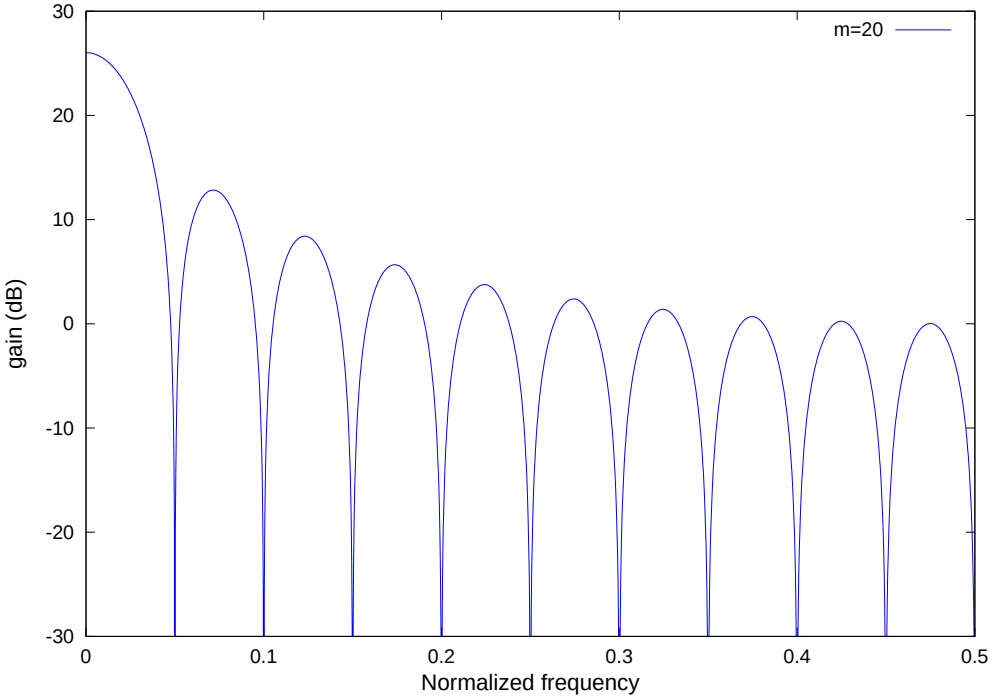
I and Q reconstructed from those samples:

$$\begin{pmatrix} I \\ Q \end{pmatrix} = \frac{1}{D} \begin{pmatrix} \sin(n+1)\theta & -\sin n\theta \\ -\cos(n+1)\theta & \cos n\theta \end{pmatrix} \begin{pmatrix} y_n \\ y_{n+1} \end{pmatrix}$$

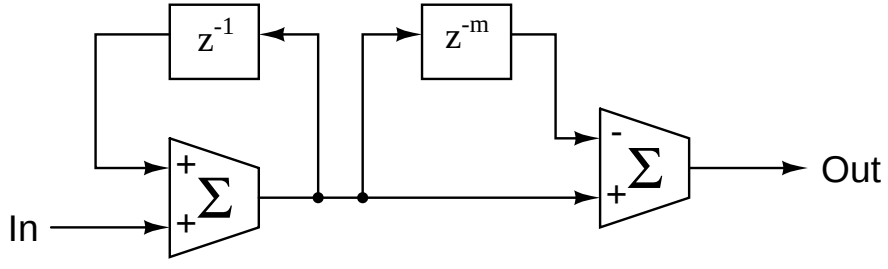
where $D = \sin\theta$

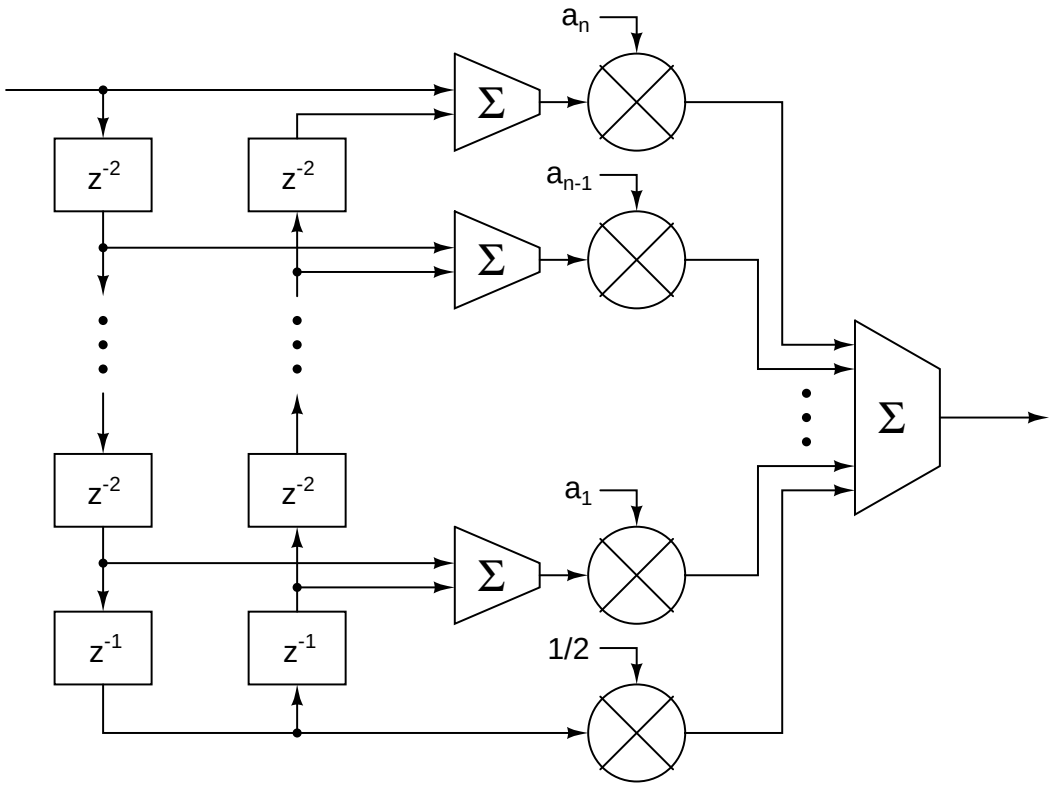
Four views of a first-order CIC (Cascaded Integrator Comb) filter

$$A = \frac{1 - z^{-m}}{1 - z^{-1}} = \sum_{k=0}^{m-1} z^{-k}$$

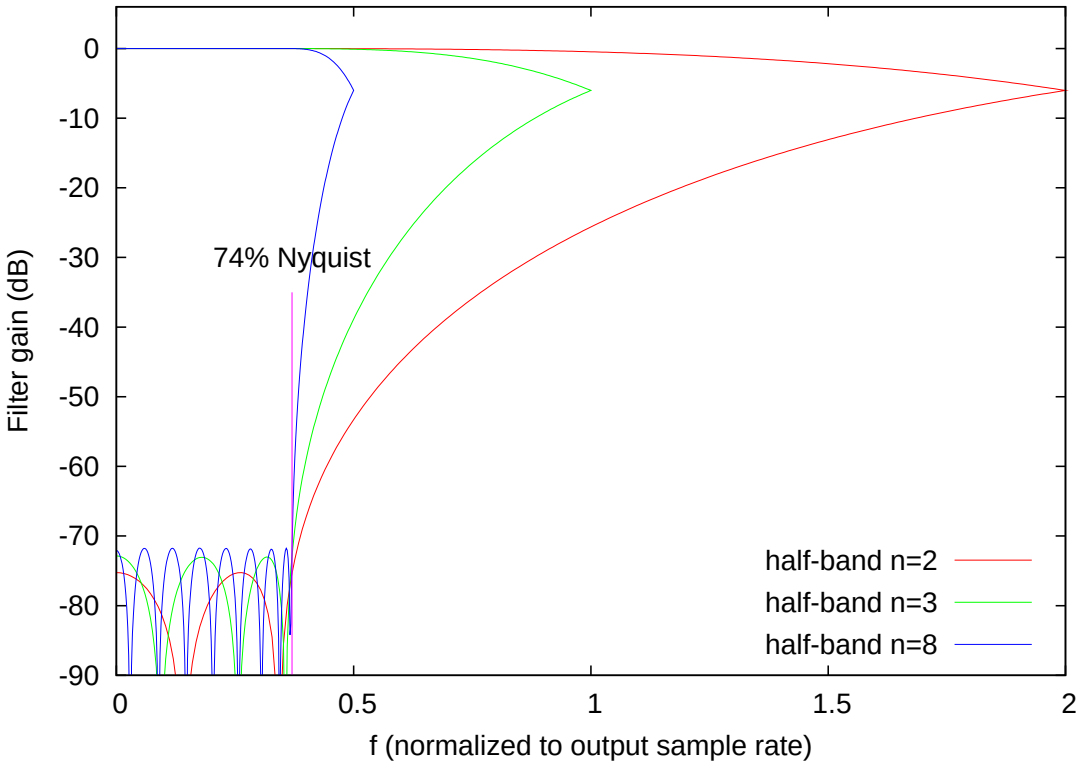



```
always @(posedge clk) begin
        a <= a + xin;
        if (sync) begin
                p <= a;
                d <= a-p;
        end
end
assign xout = d;
```



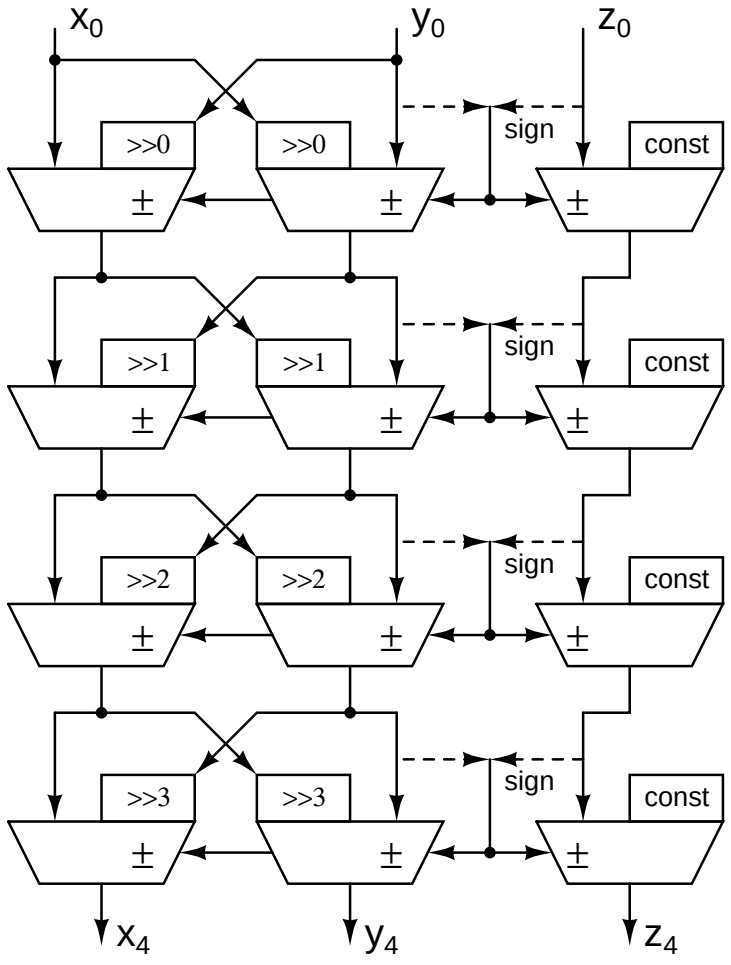


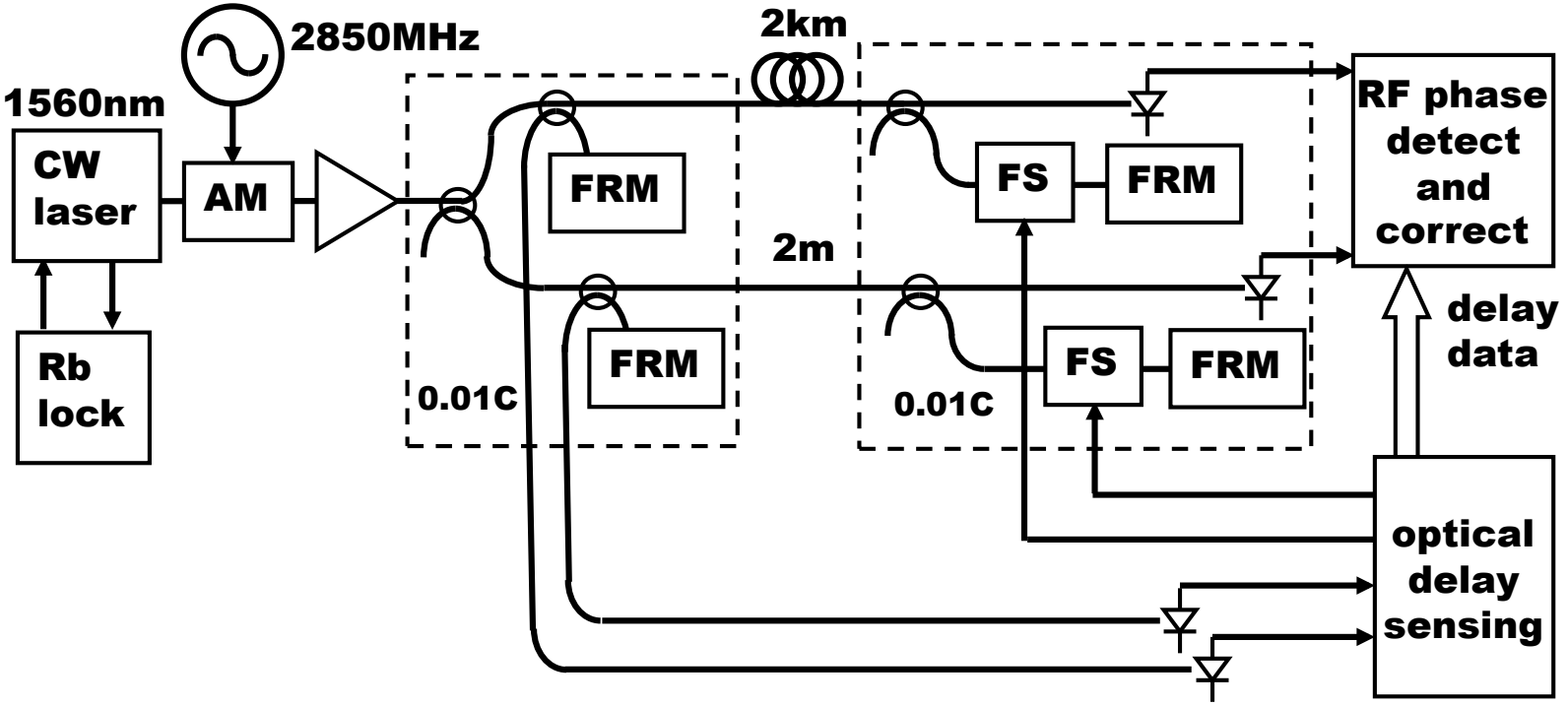
Block diagram of half-band filter



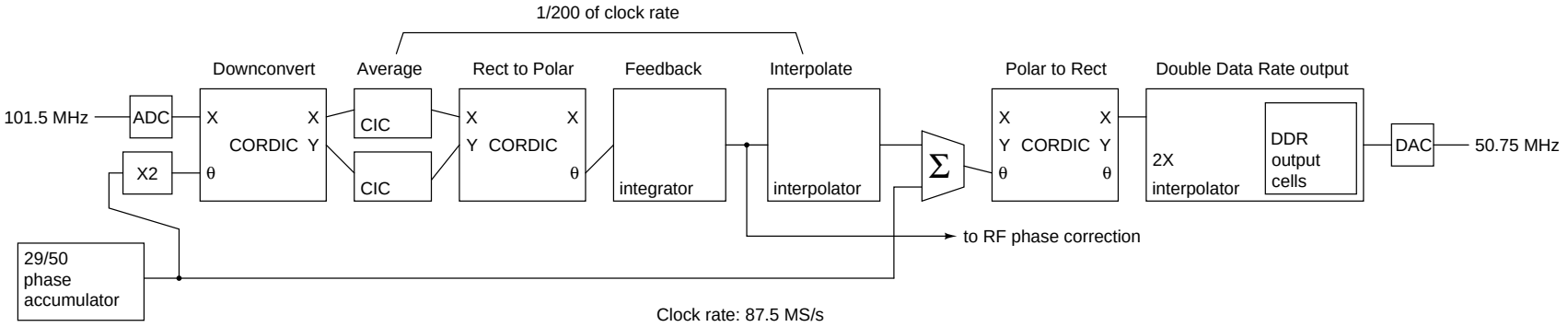
Three stages of half-band filter response
(overall decimation by 8)

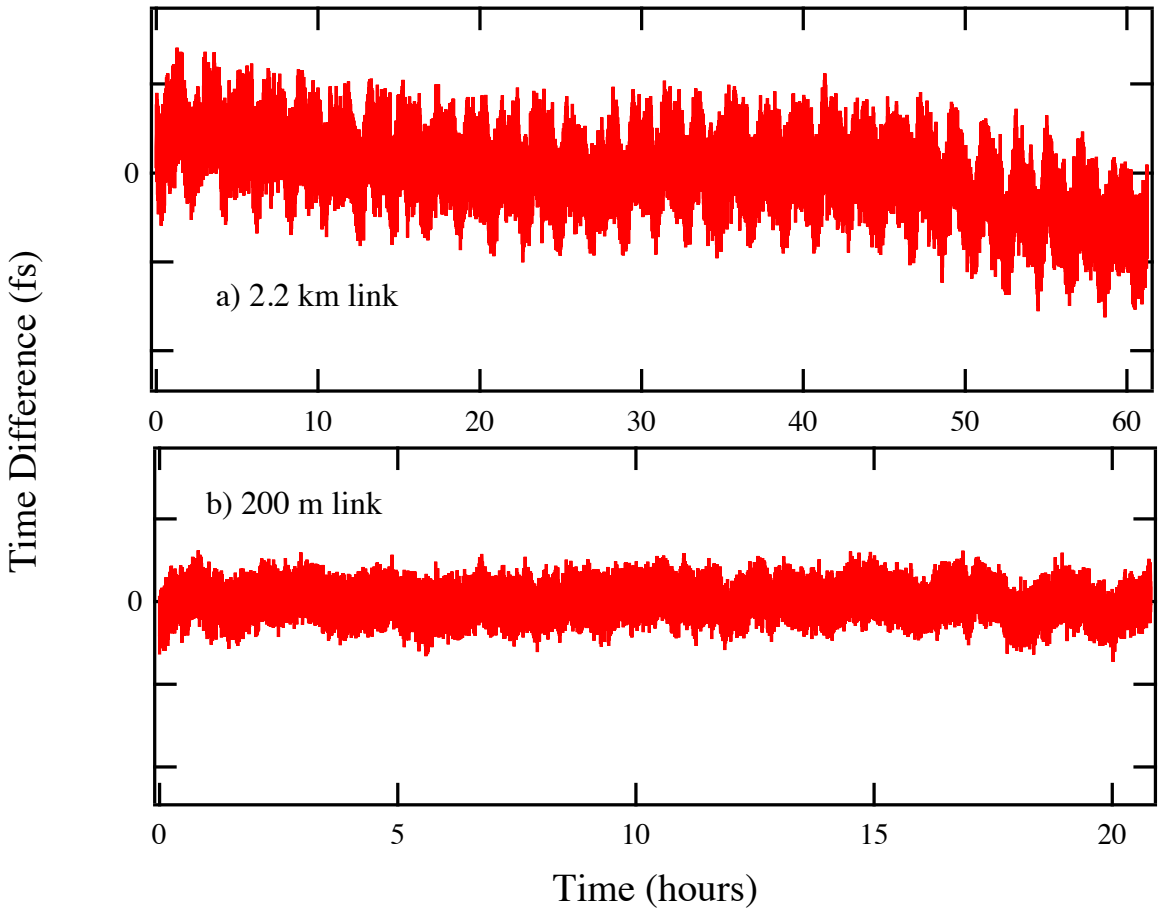
Unrolled CORDIC (Coordinate Rotation Digital Computer, invented in 1957)




2850MHz
2km
1560nm
CW laser
AM
Rb lock
FRM
FRM
2m
FS
FRM
FS
FRM
0.01C
0.01C
RF phase detect and correct
delay data
optical delay sensing

Optical Interferometer Phase Feedback to Acousto-Optic Modulator





The two plots use the same (redacted) vertical scales.
Noise and drift, even for the 2.2 km link, is substantially below our LCLS spec of 50 fs rms.

Conclusion

It is not just possible, but advantageous to use the same hardware for different LLRF applications: pulsed, CW, phase reference, etc. The only difference is programming and some bandpass filters!

Thank you for your attention, eh!

Acknowledgements

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