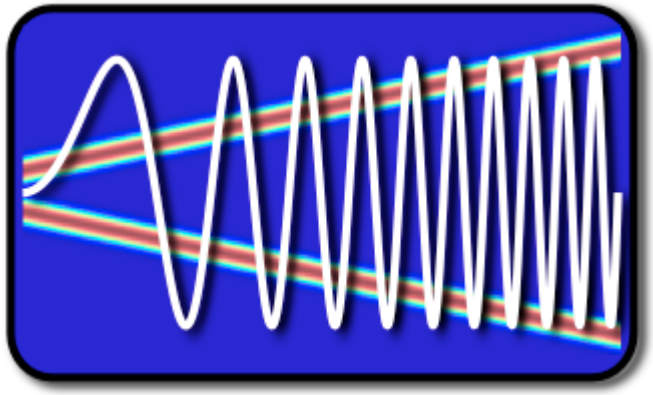
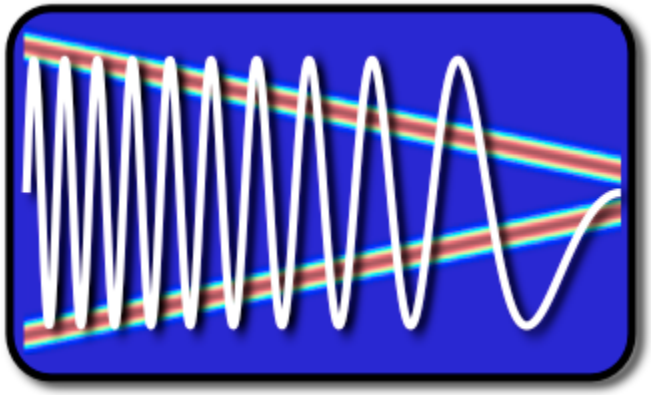


EE123 Digital Signal Processing



Lecture 13
Lab II
Finish Wavelets

M. Lustig, EECS UC Berkeley

Announcements

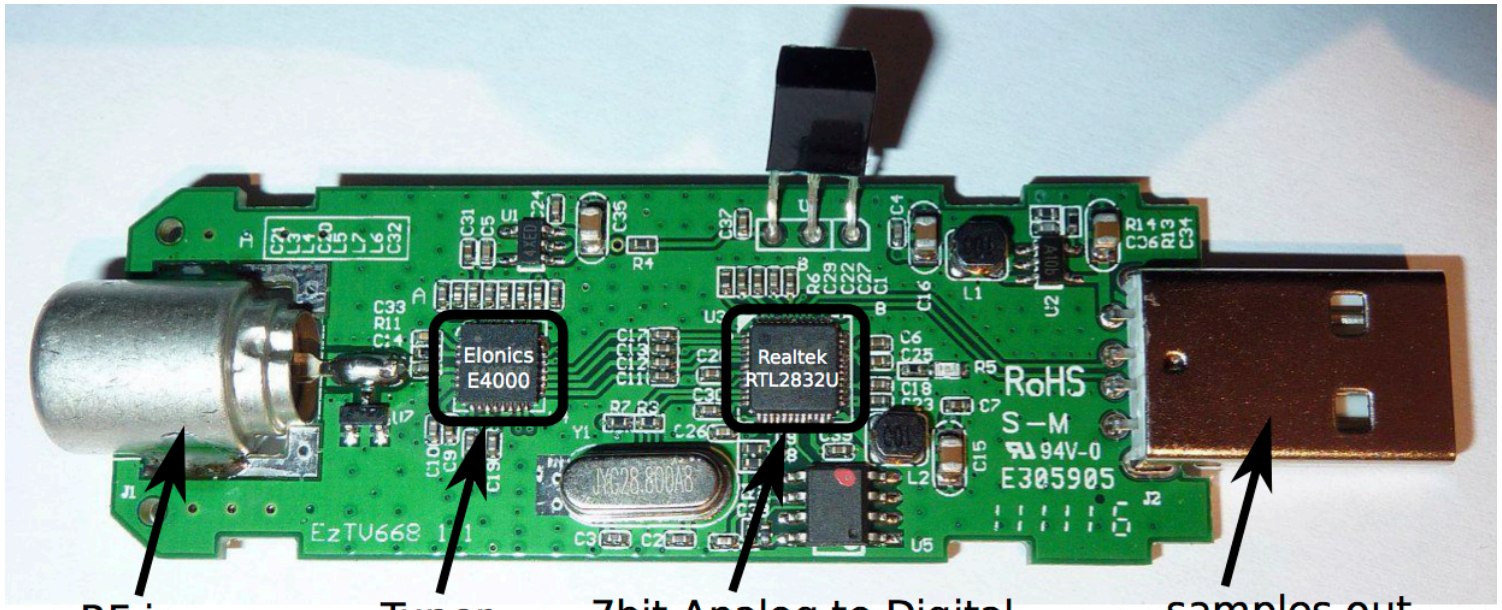
- Pre-Lab any issues?
- Midterm I Monday
- Midterm II April 4th

Interesting stuff

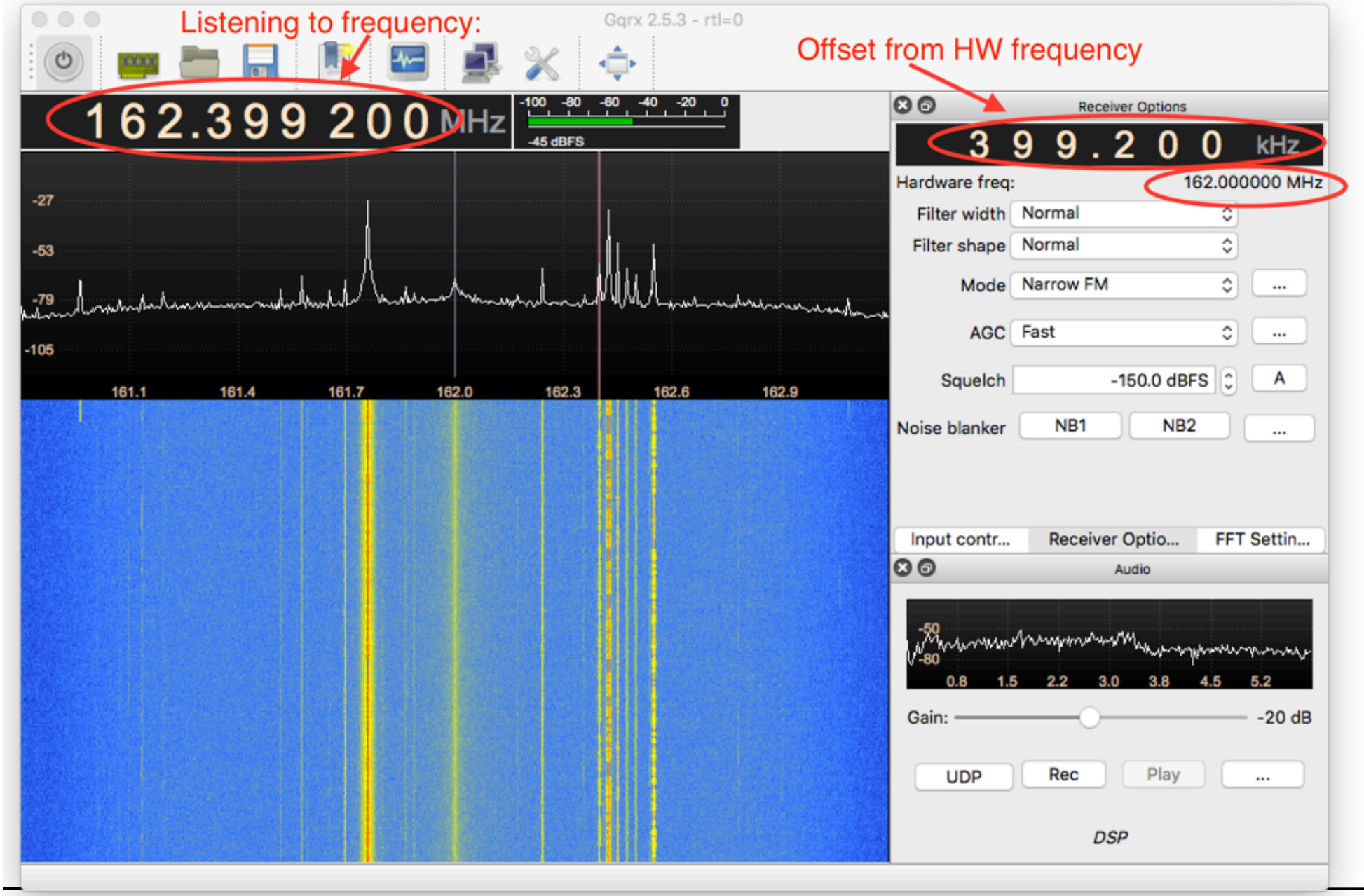
- Gravity Waves:
  - https://losc.ligo.org/s/events/GW150914/GW150914_tutorial.html

SDR Stuff

- Samples you measure from the SDR are COMPLEX! WHY?
- Aren't physical signals real??????

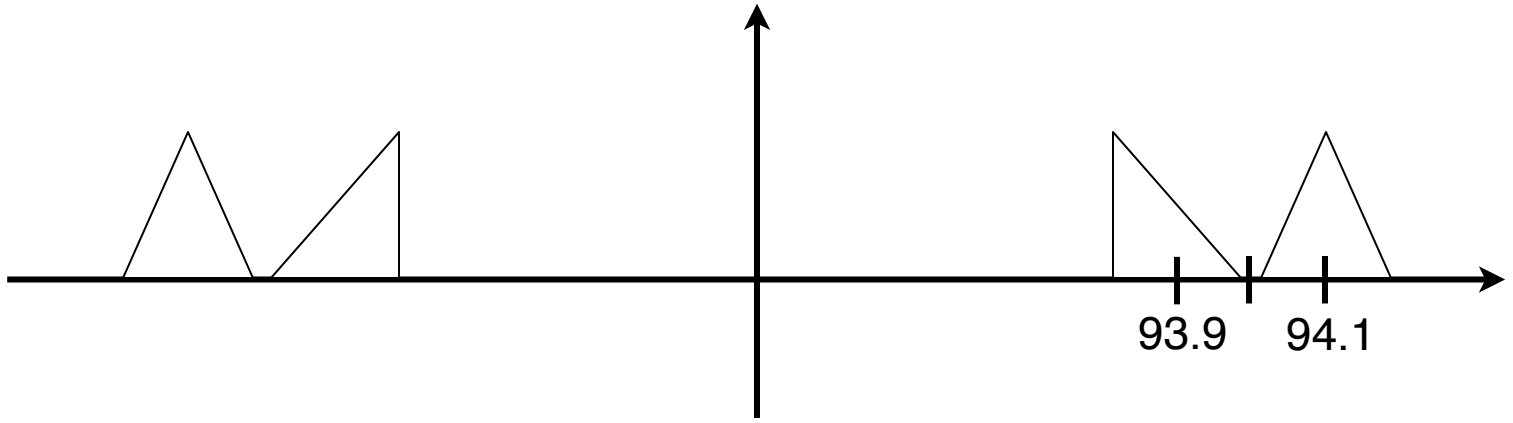


Gqrx


Listening to frequency:
Gqrx 2.5.3 - rtl=0
Offset from HW frequency
162.399 200 MHz
-45 dBFS
Receiver Options
399.200 kHz
Hardware freq:
162.000000 MHz
Filter width
Normal
Filter shape
Normal
Mode
Narrow FM
AGC
Fast
Squelch
-150.0 dBFS
Noise blanker
NB1
NB2
Input contr...
Receiver Optio...
FFT Settin...
Audio
Gain:
-20 dB
UDP
Rec
Play
DSP

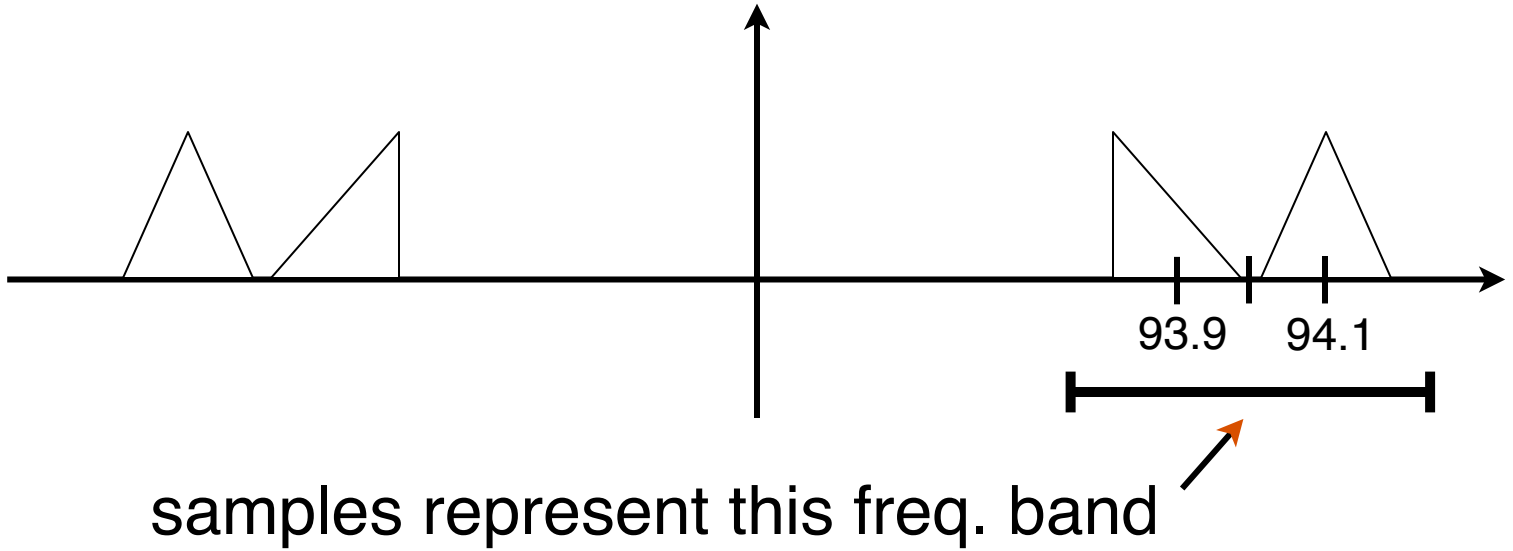
SDR Stuff

- Samples you measure from the SDR are COMPLEX! WHY?
- Aren't physical signals real??????

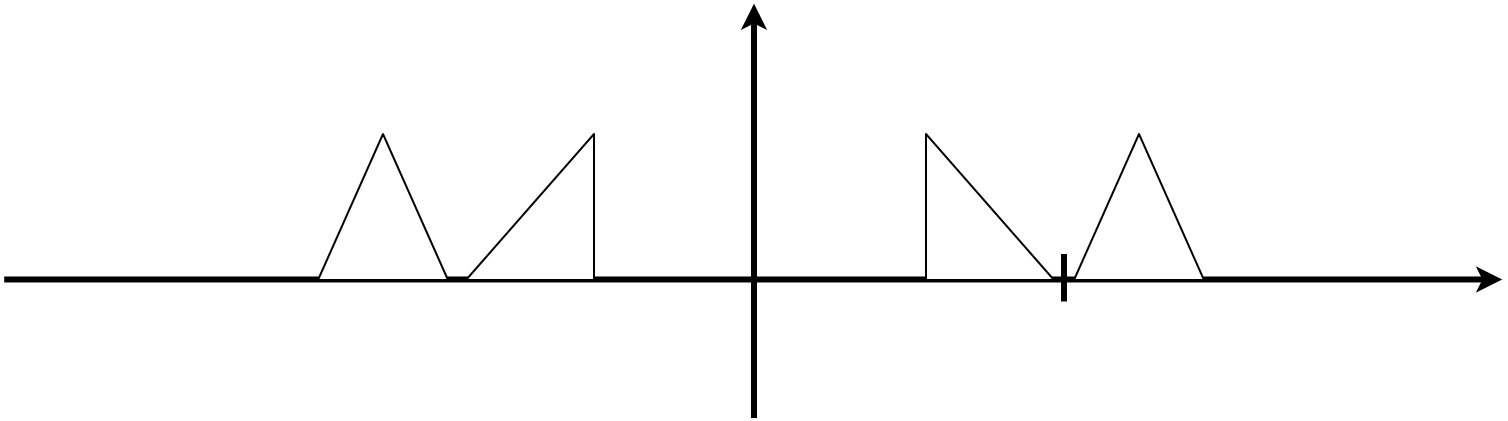


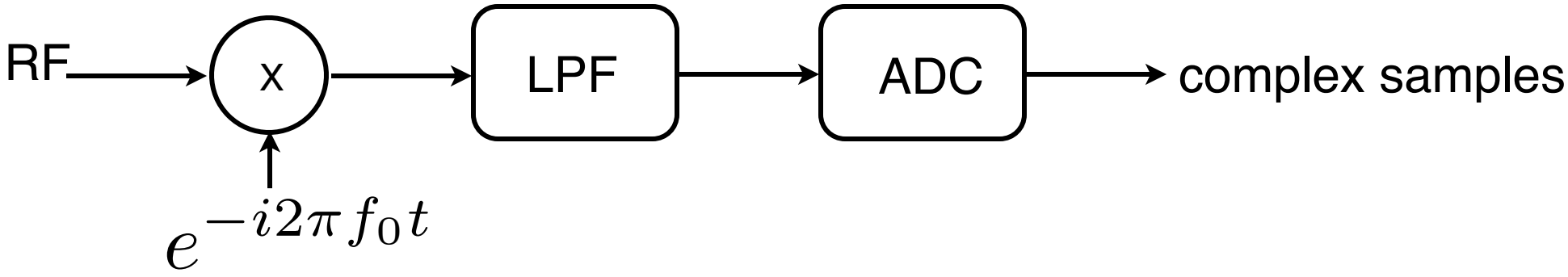
SDR Stuff

- With the SDR we look at part of the spectrum
- Example:
  >> rtl_sdr -f 94e6 -s 5e5

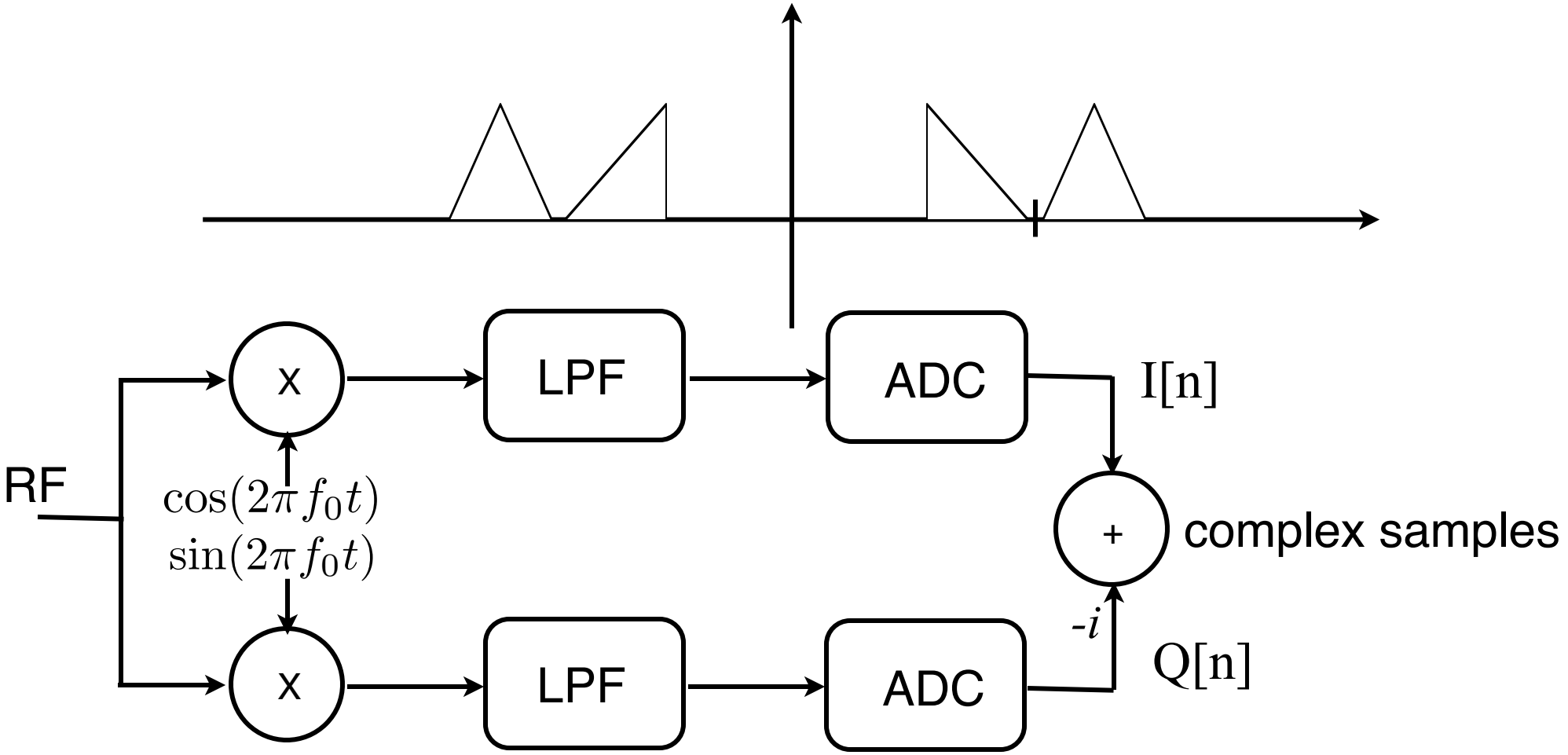


- How is it implemented?



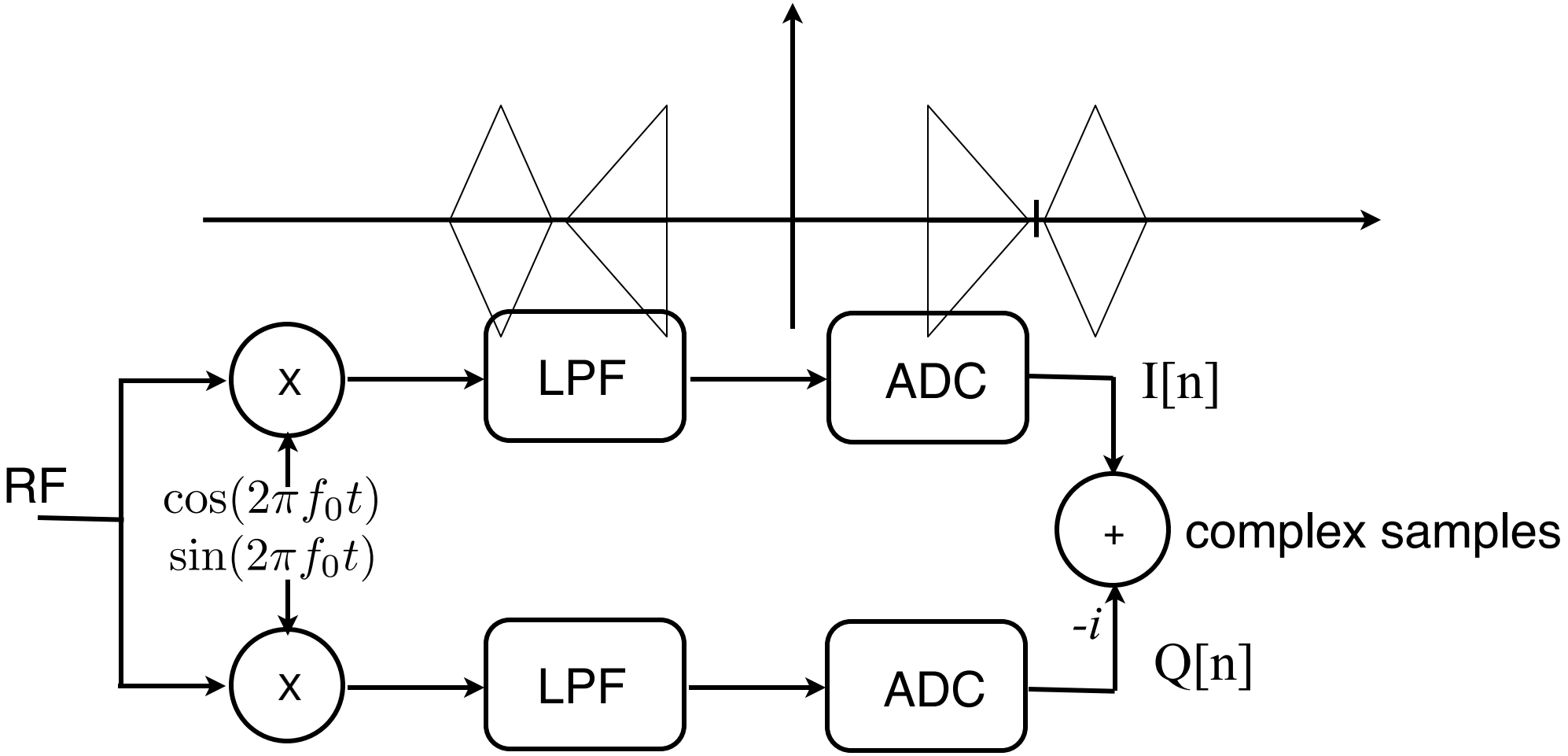


- How is it physically implemented?



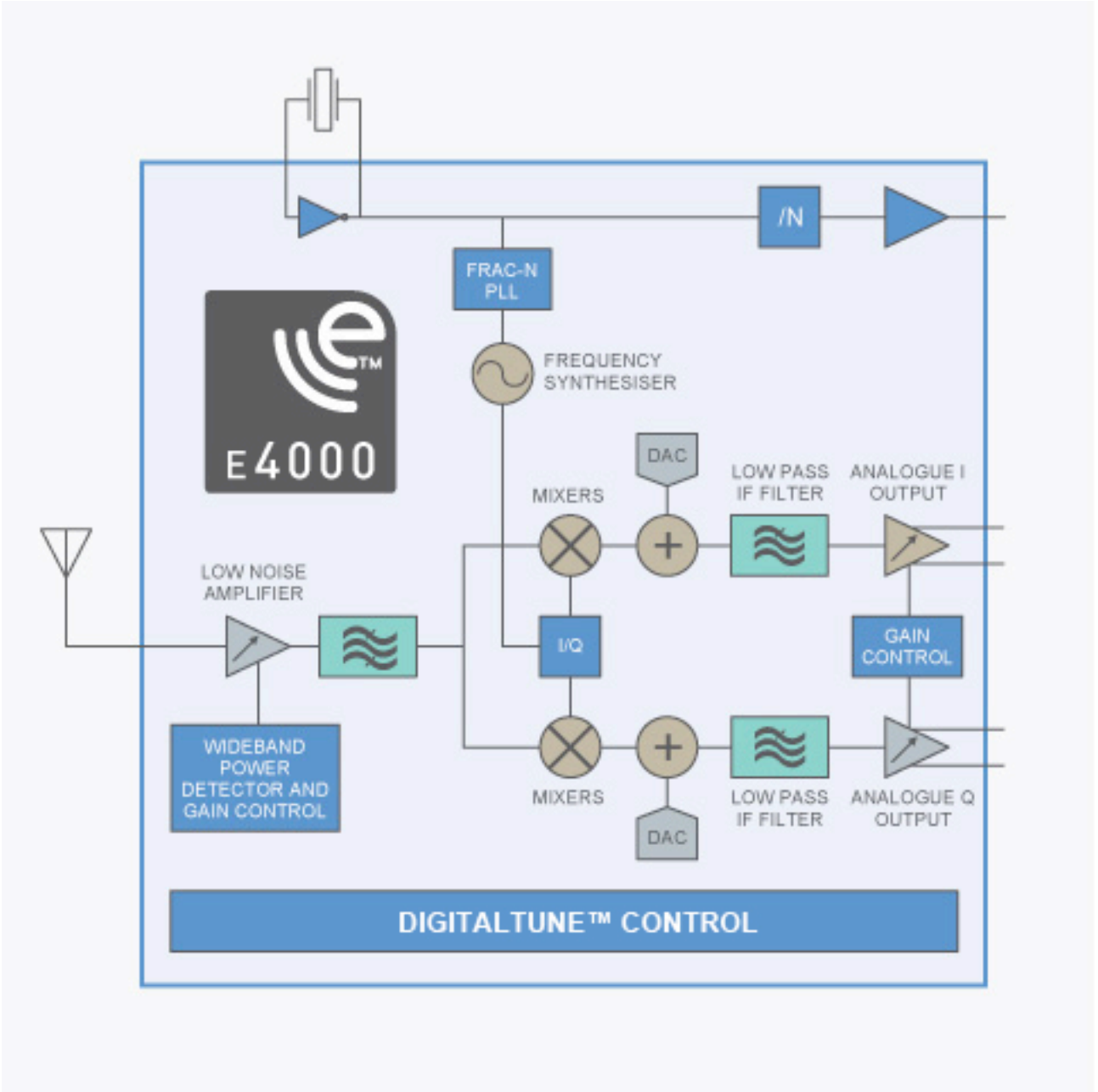
$$e^{-i2\pi f_0 t} = \cos(2\pi f_0 t) - i\sin(2\pi f_0 t)$$

- How is it physically implemented?



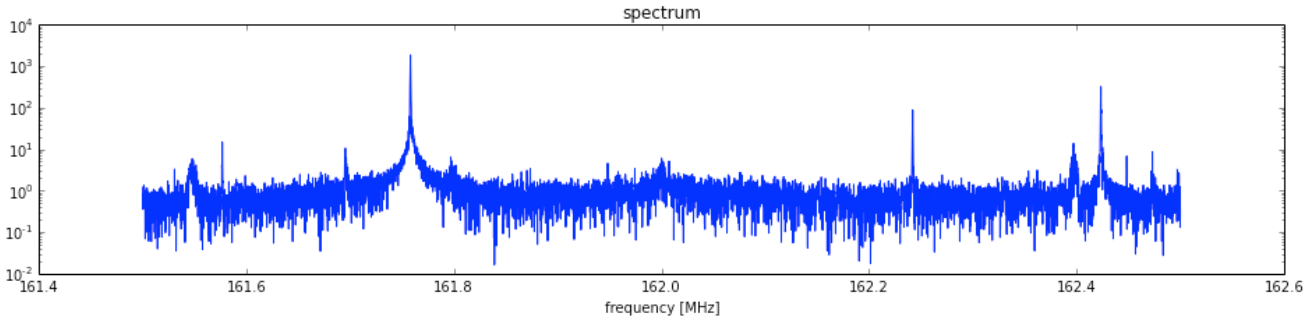
$$e^{-i2\pi f_0 t} = \cos(2\pi f_0 t) - i\sin(2\pi f_0 t)$$

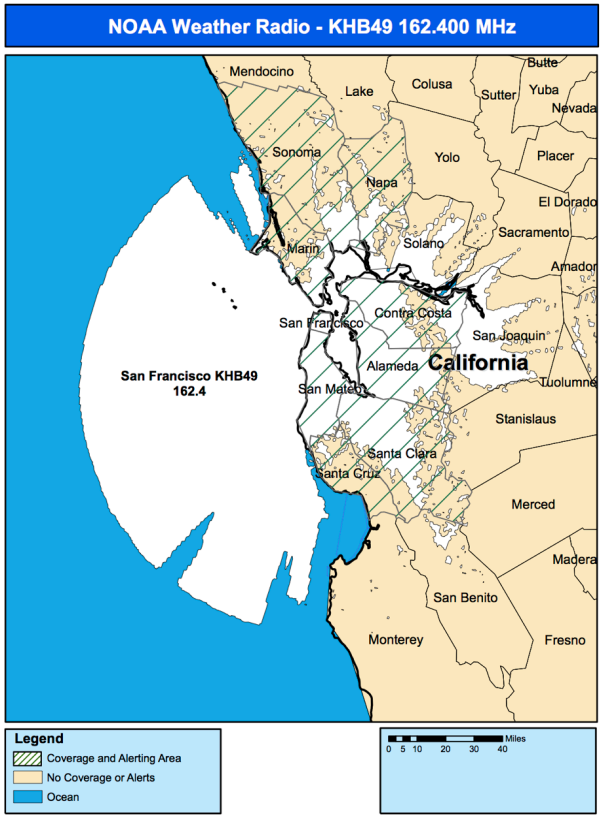
SDR Stuff


/N
FRAC-N PLL
FREQUENCY SYNTHESISER
E4000
DAC
MIXERS
LOW PASS IF FILTER
ANALOGUE I OUTPUT
LOW NOISE AMPLIFIER
I/Q
GAIN CONTROL
WIDEBAND POWER DETECTOR AND GAIN CONTROL
MIXERS
LOW PASS IF FILTER
ANALOGUE Q OUTPUT
DAC
DIGITALTUNE™ CONTROL

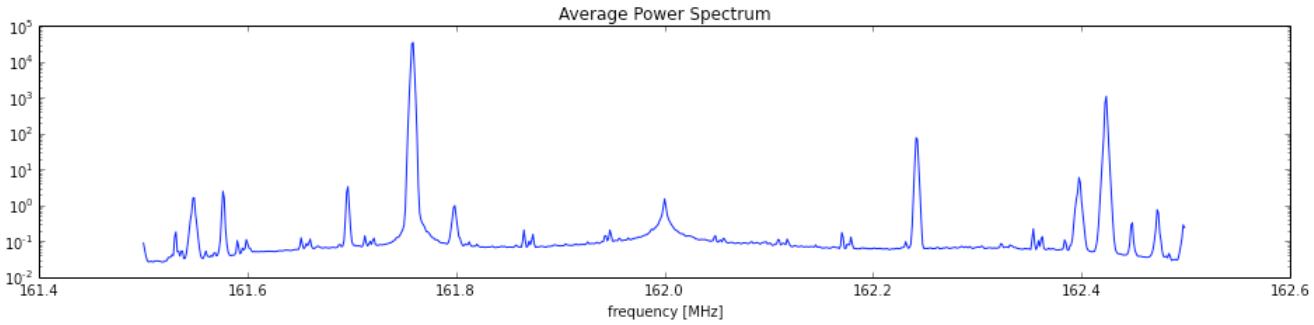
Lab I part III - SDR

- Get samples around 162Mhz
  - –Compute DFT 8000



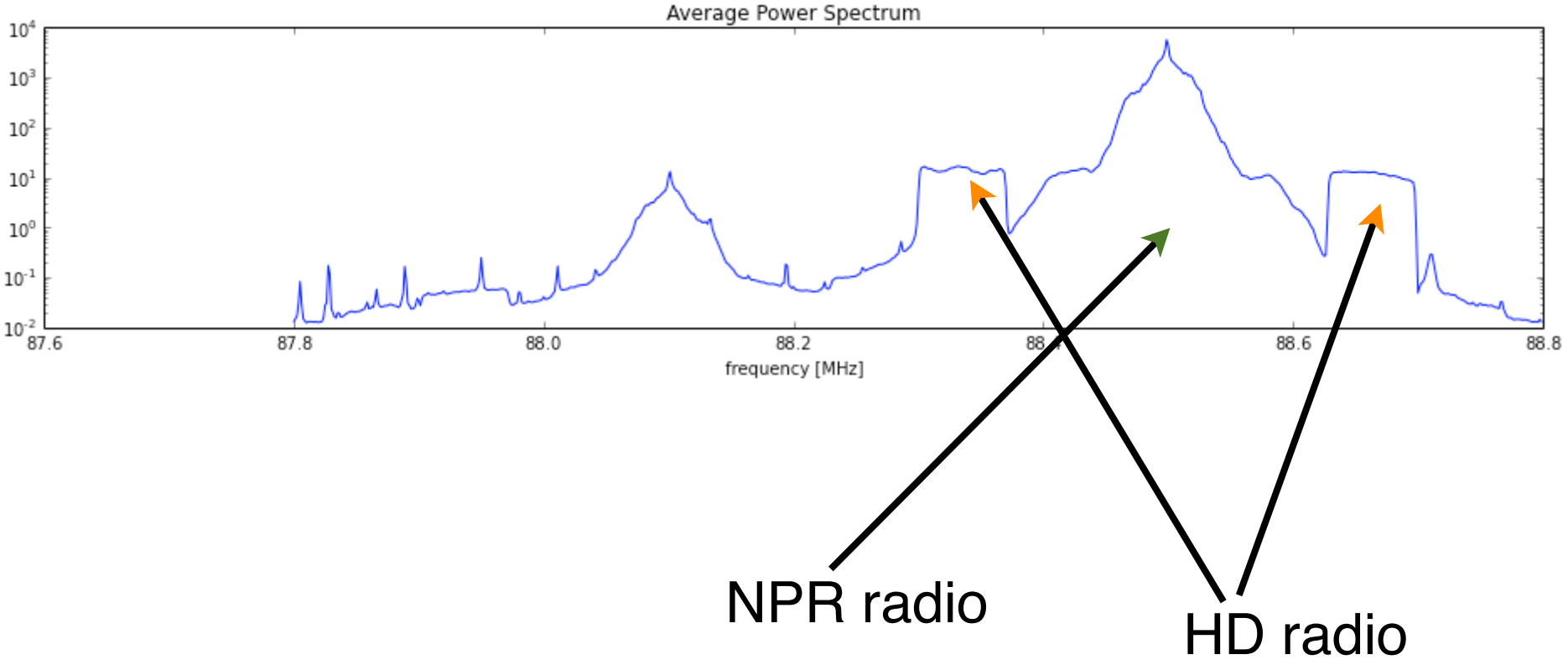


  - –Compute average DFT of many windows size 800

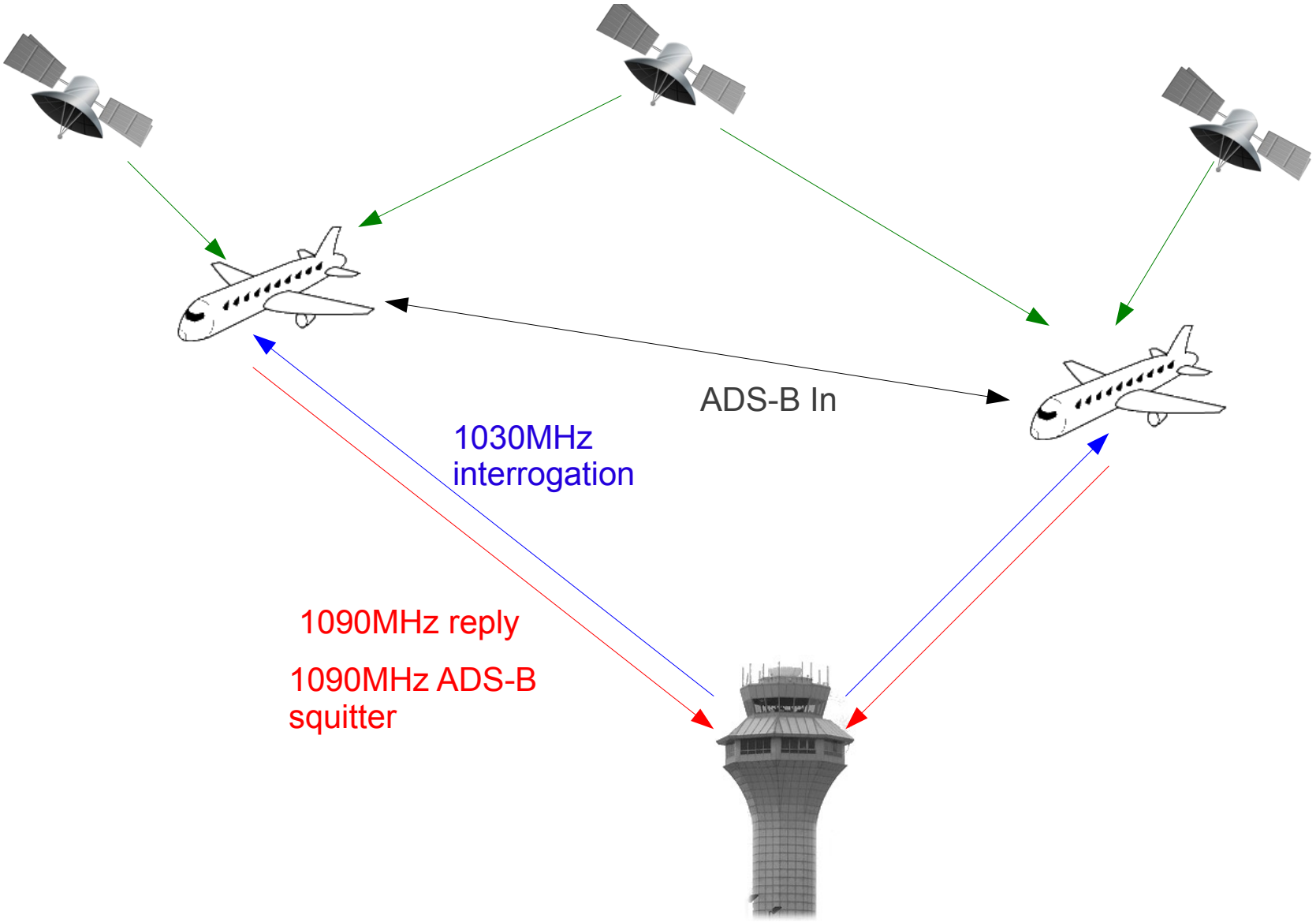


Lab I part III - SDR

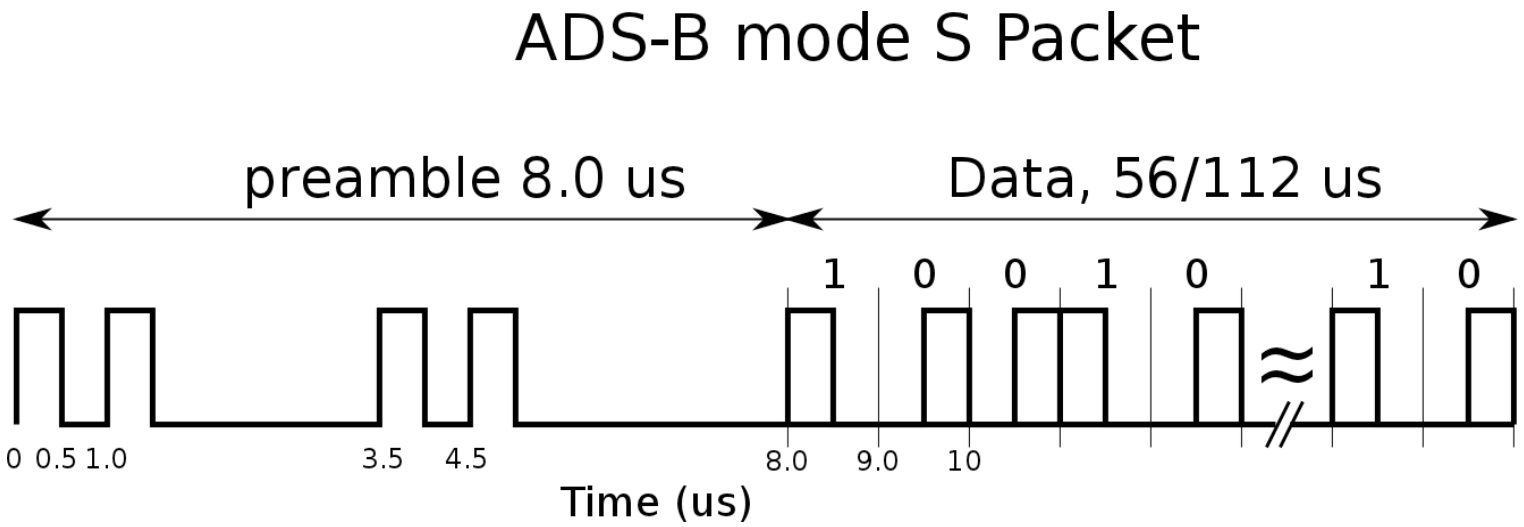
- Compute spectrum of FM radio around 88.3MHz

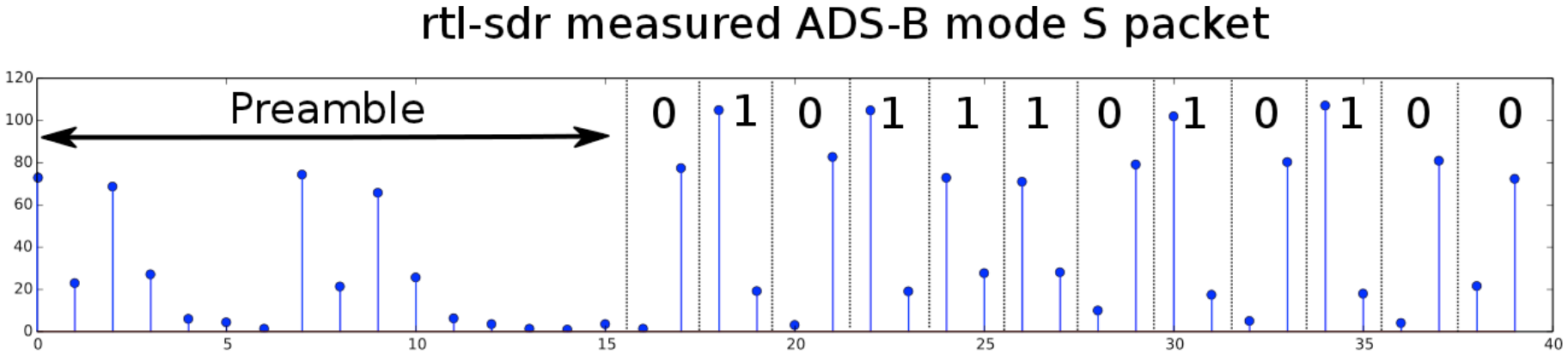


ADS-B


ADS-B In
1030MHz
interrogation
1090MHz reply
1090MHz ADS-B
squitter

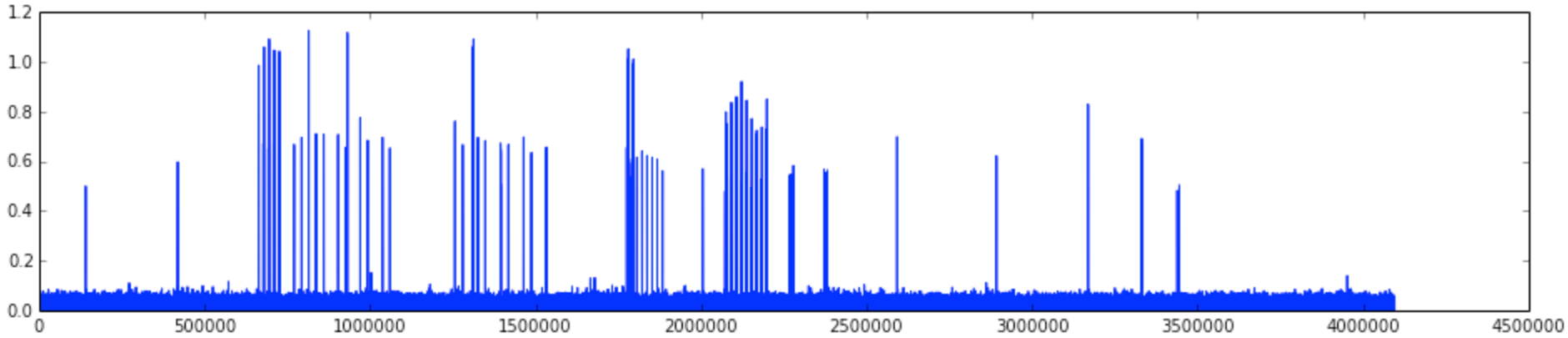
ADS-B


ADS-B mode S Packet
preamble 8.0 us
Data, 56/112 us
1 0 0 1 0 1 0
0 0.5 1.0
3.5 4.5
8.0 9.0 10
Time (us)

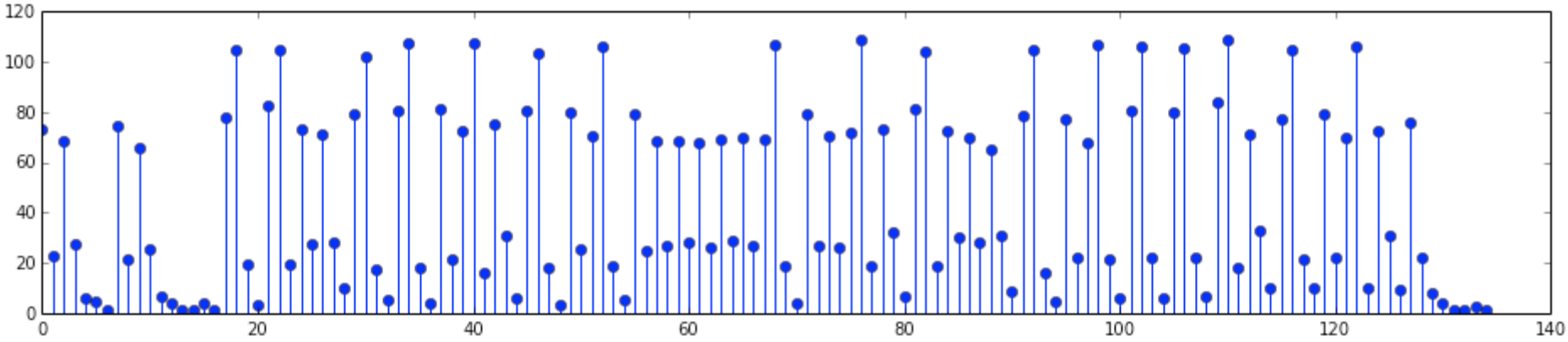

rtl-sdr measured ADS-B mode S packet
Preamble
0 1 0 1 1 1 0 1 0 1 0 0
120
100
80
60
40
20
0
0 5 10 15 20 25 30 35 40

ADS-B

- Acquire 1 seconds

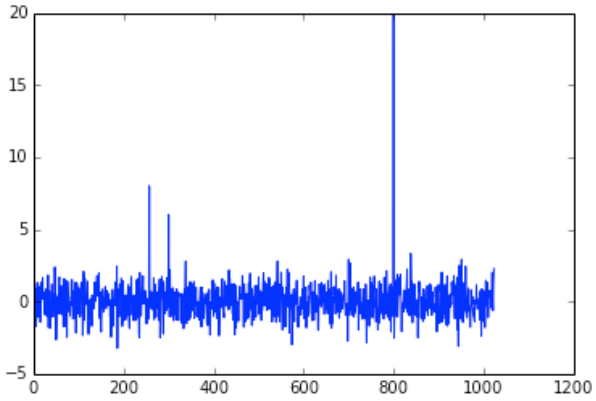


- Extract 1 packet

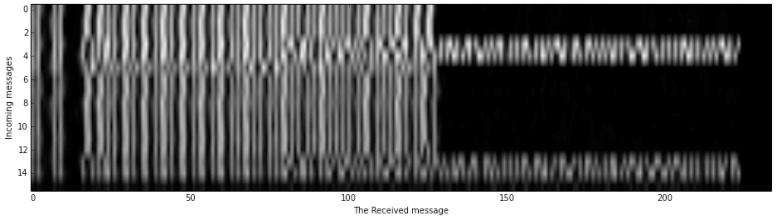


Detect Preamble

- Energy:
  - –Median and MAD to estimate noise
  - – Set threshold based on noise



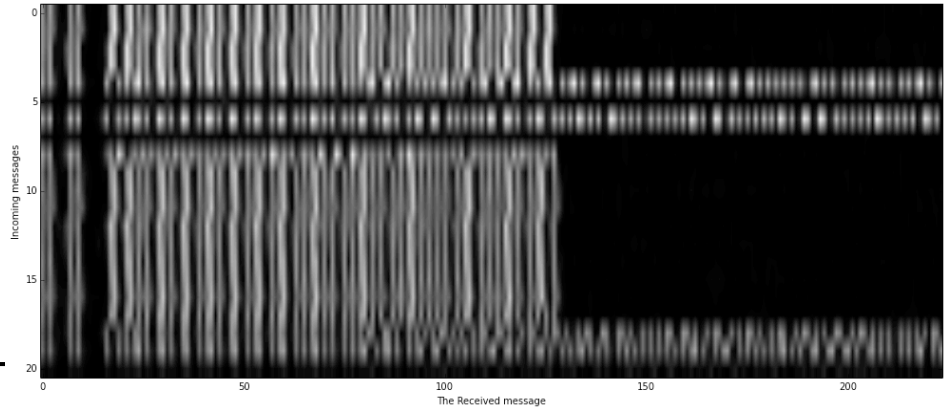
- Using cross correlation



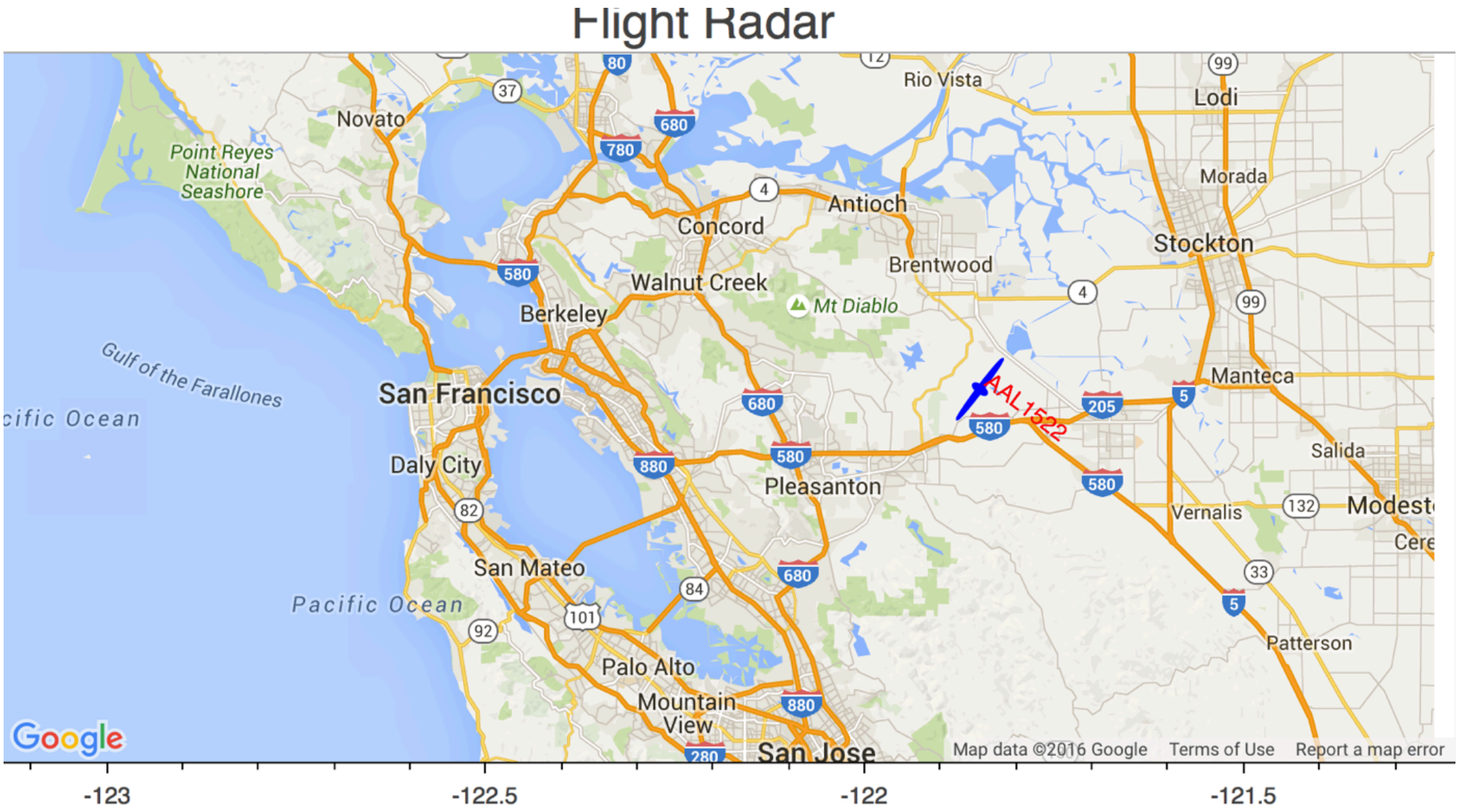
$$\hat{R}_{xy}[n] = \frac{\sum_{k=0}^{15}(x[n+k]-\hat{x}_n)(y[k]-\hat{y})}{\|x[n]-\hat{x}_n\| \cdot \|y-\hat{y}\|}$$

- Using Logic

1's bigger than 0's

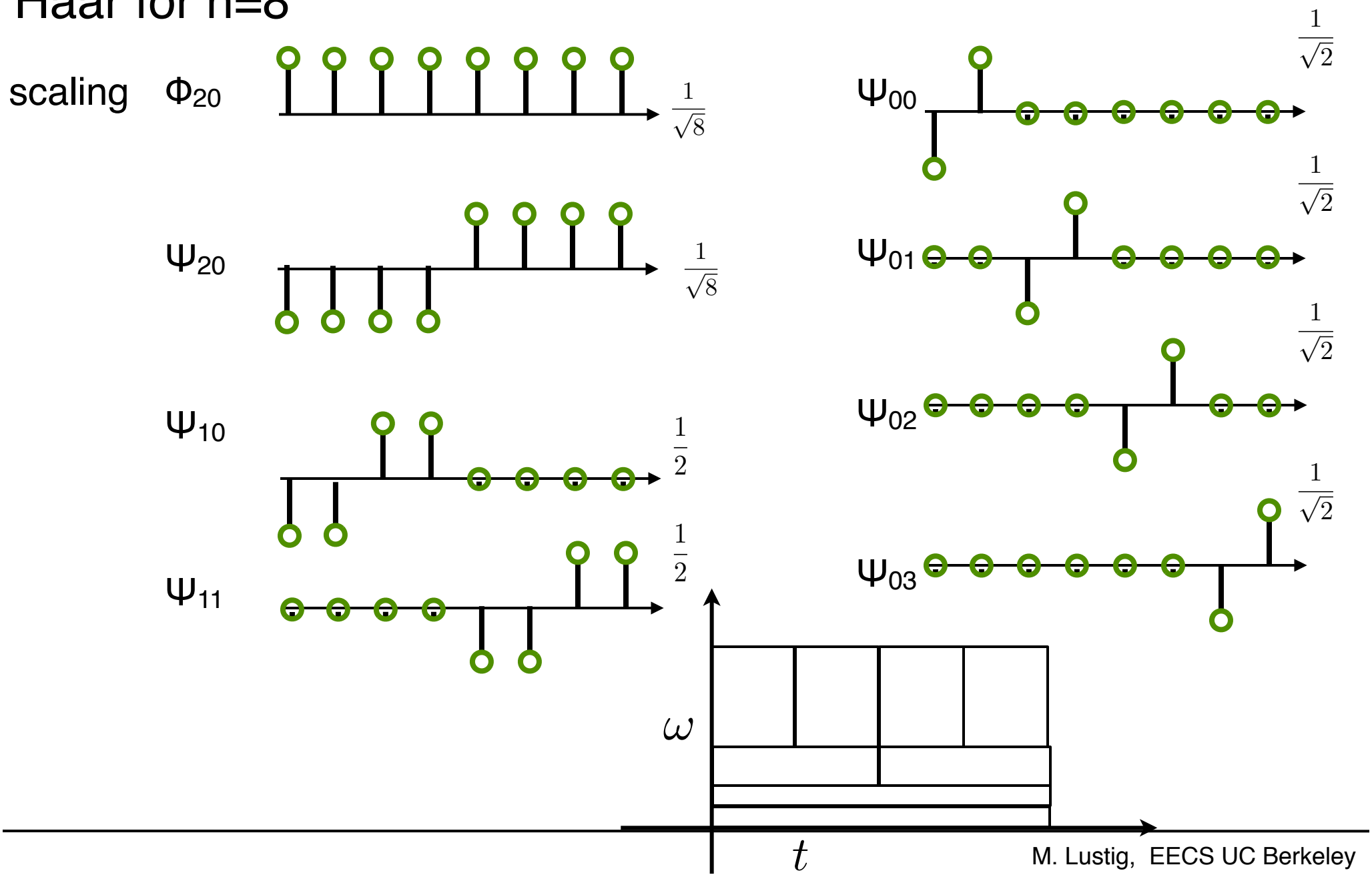


See airplane position

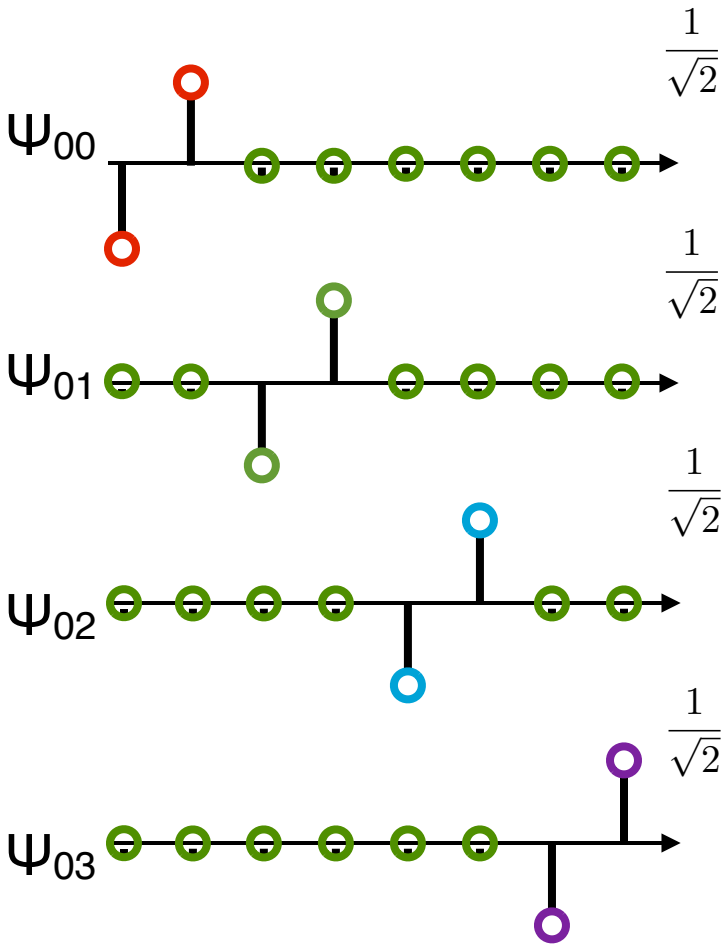


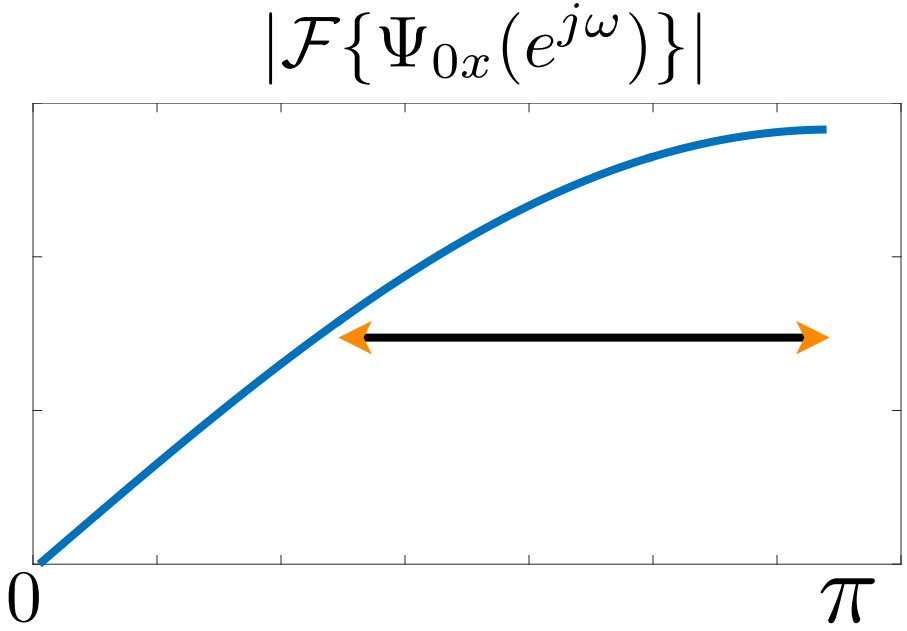
Discrete Orthogonal Haar Wavelet

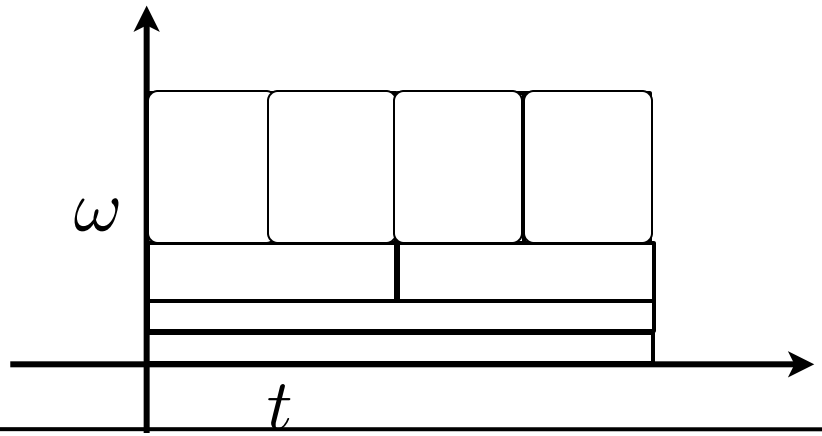
Haar for n=8



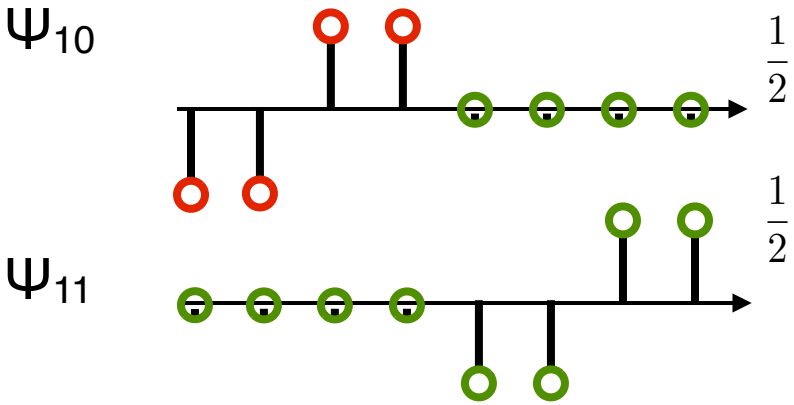
Discrete Orthogonal Haar Wavelet

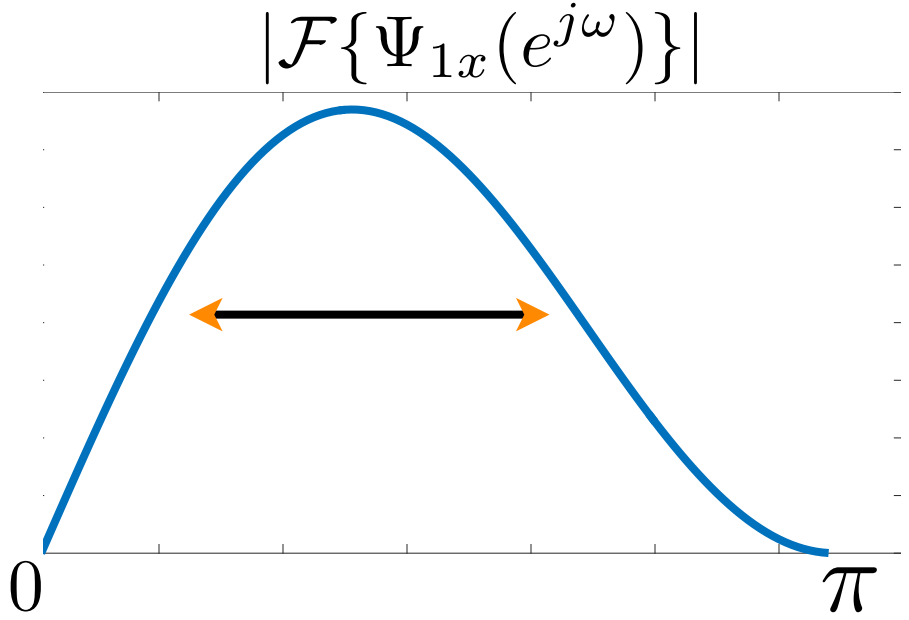


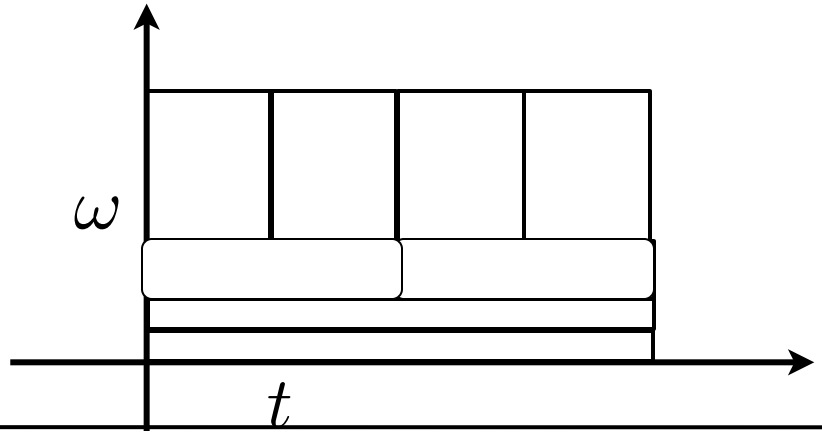




Discrete Orthogonal Haar Wavelet

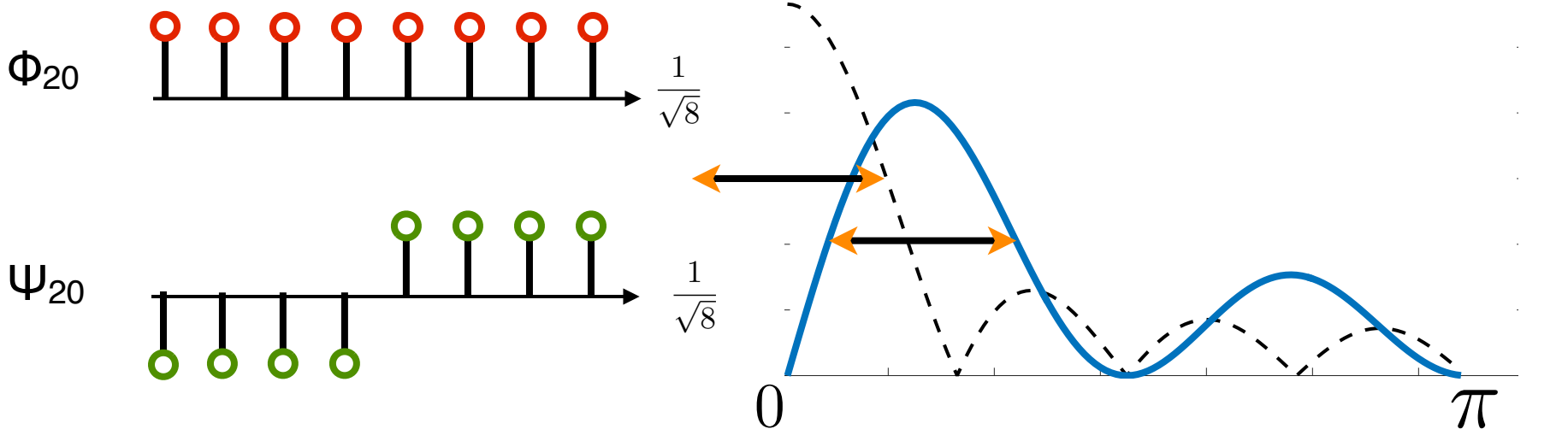


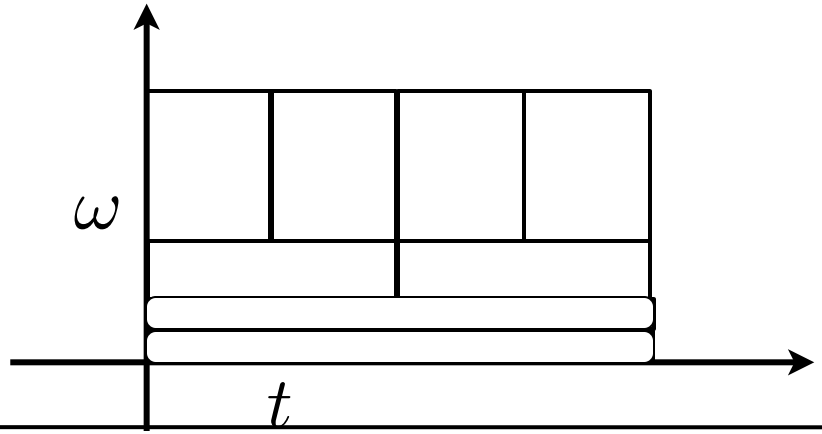




Discrete Orthogonal Haar Wavelet

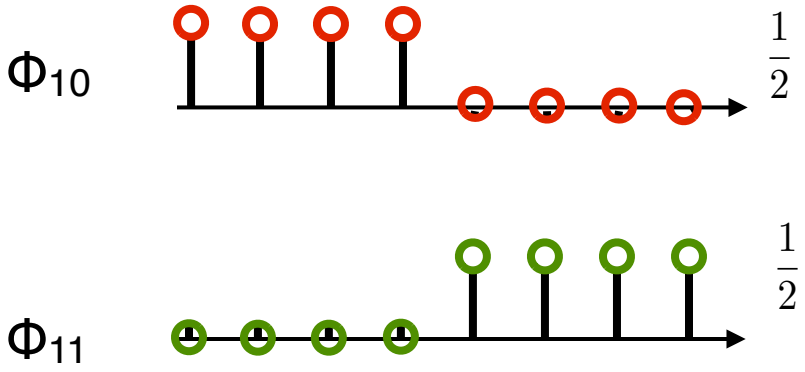
scaling

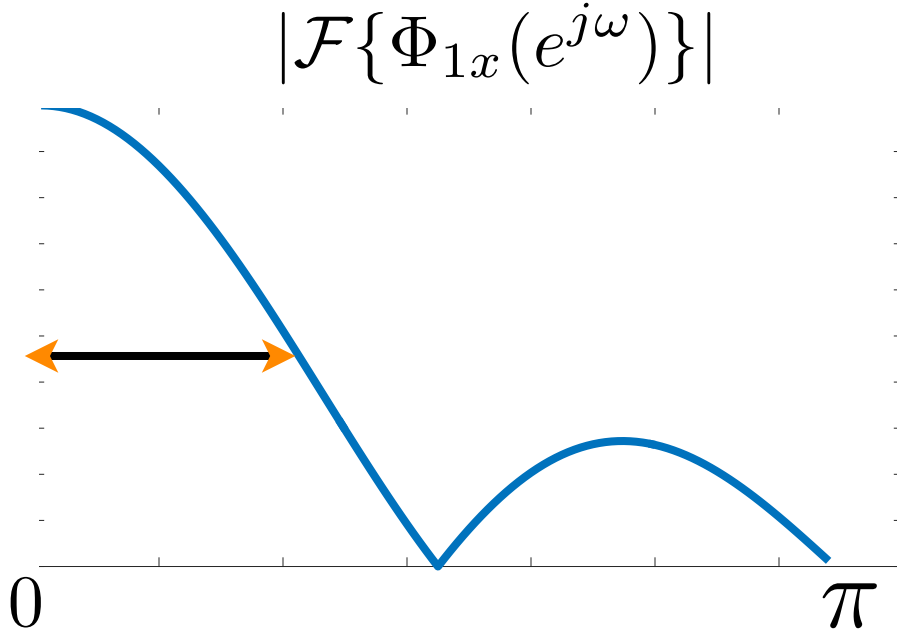


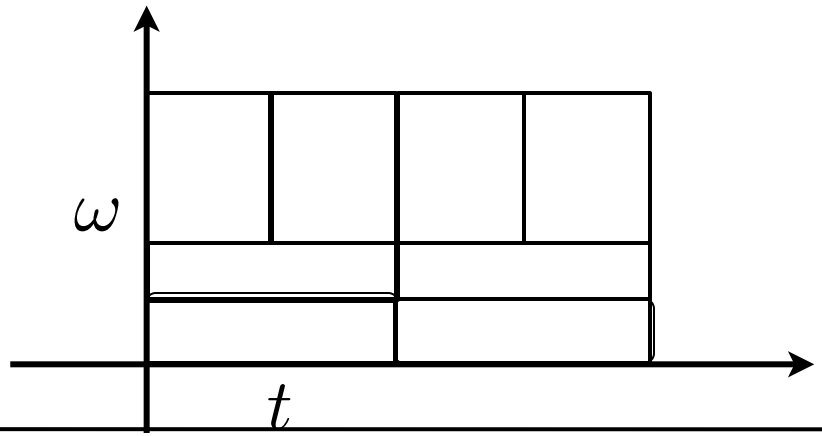


Optional: stop decomposition at Level 1

scaling



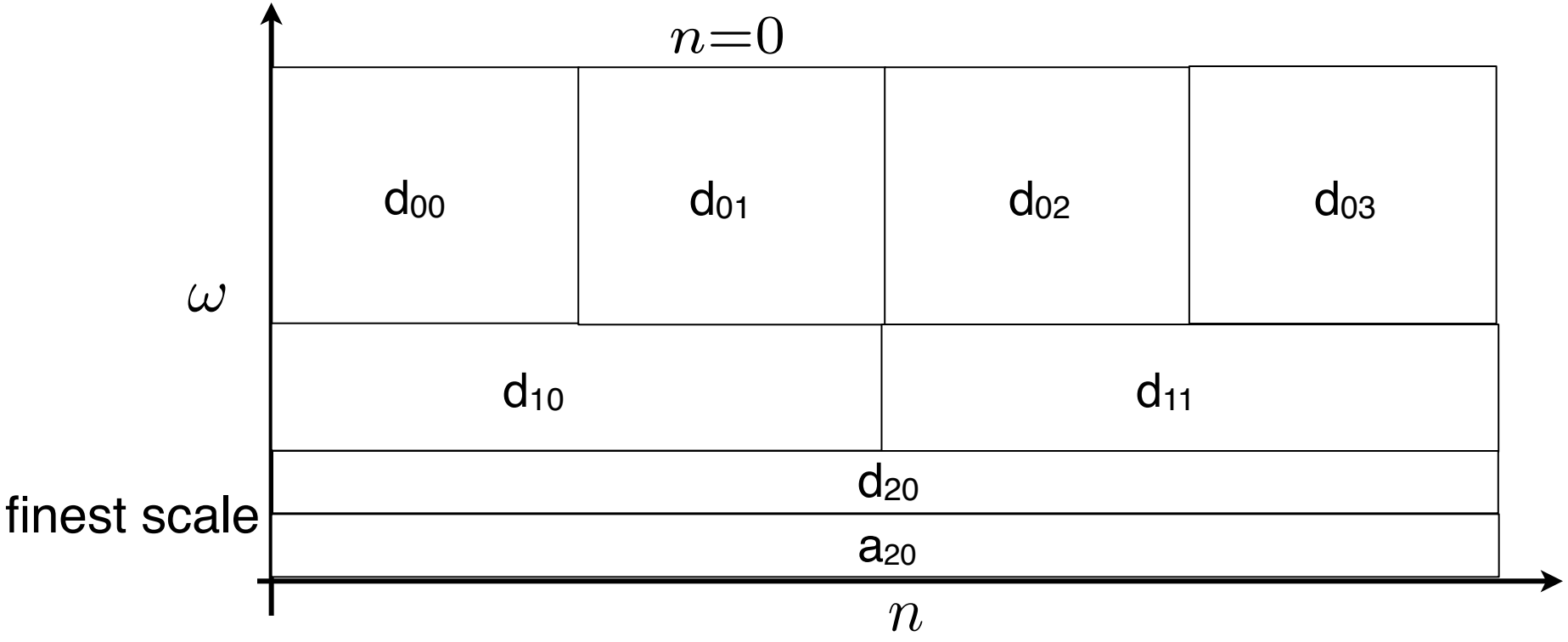




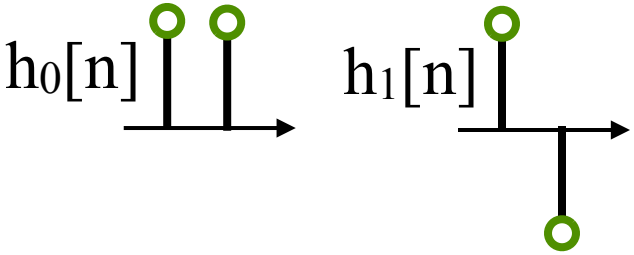
Discrete Wavelet Transform

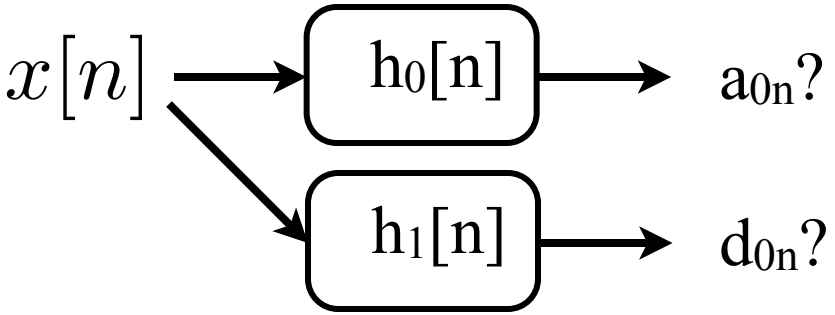
$$d_{\mathrm{s,u}} = \sum_{n=0}^{N-1} x[n]\Psi_{\mathrm{s,u}}[n]$$

$$a_{\mathrm{s,u}} = \sum_{n=0}^{N-1} x[n]\Phi_{\mathrm{s,u}}[n]$$

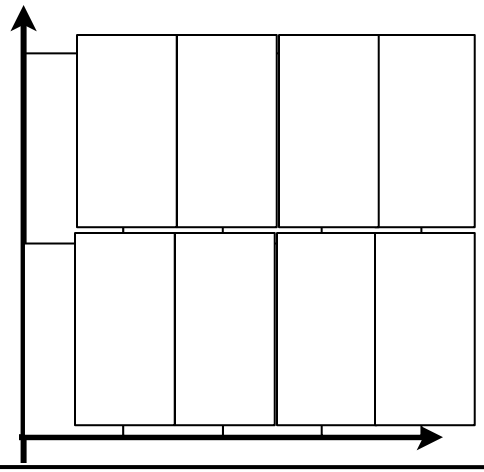


Fast DWT with Filter Banks (more Later!)

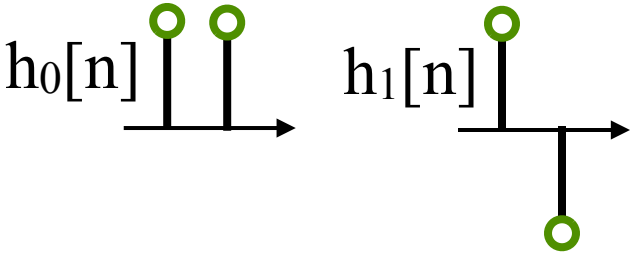


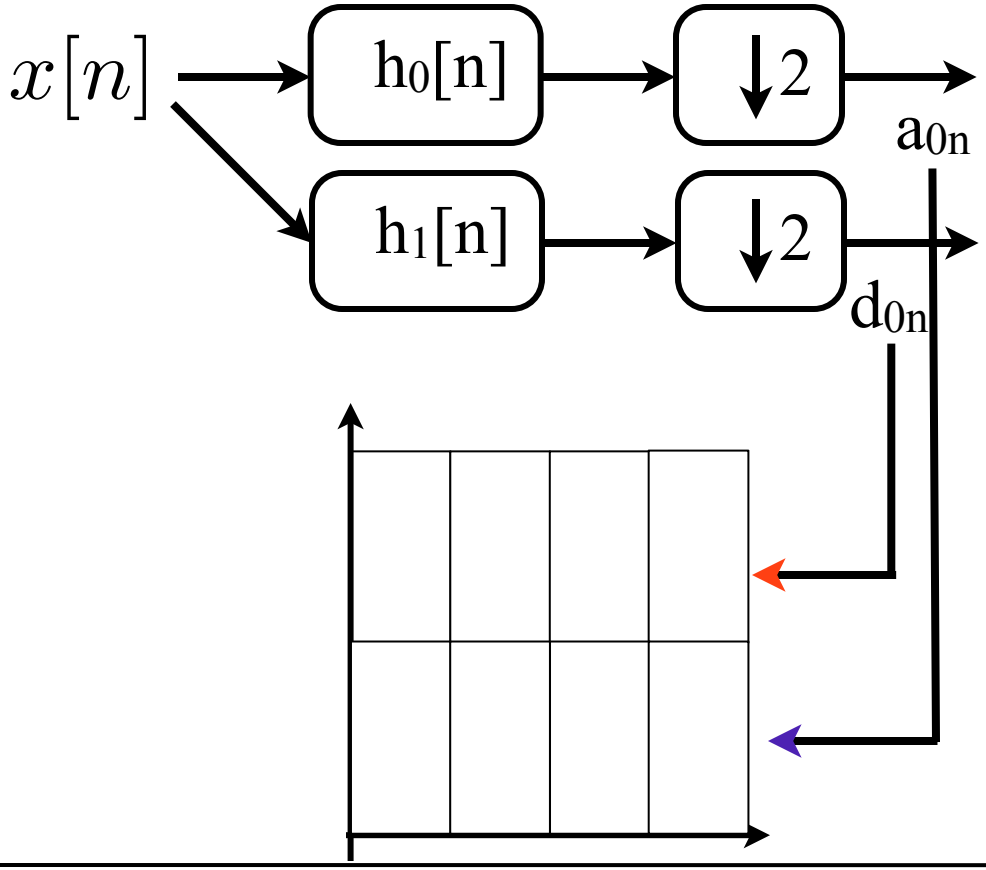


not quite...
too many
coefficients

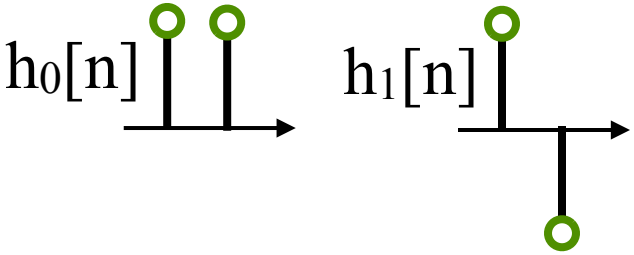


Fast DWT with Filter Banks





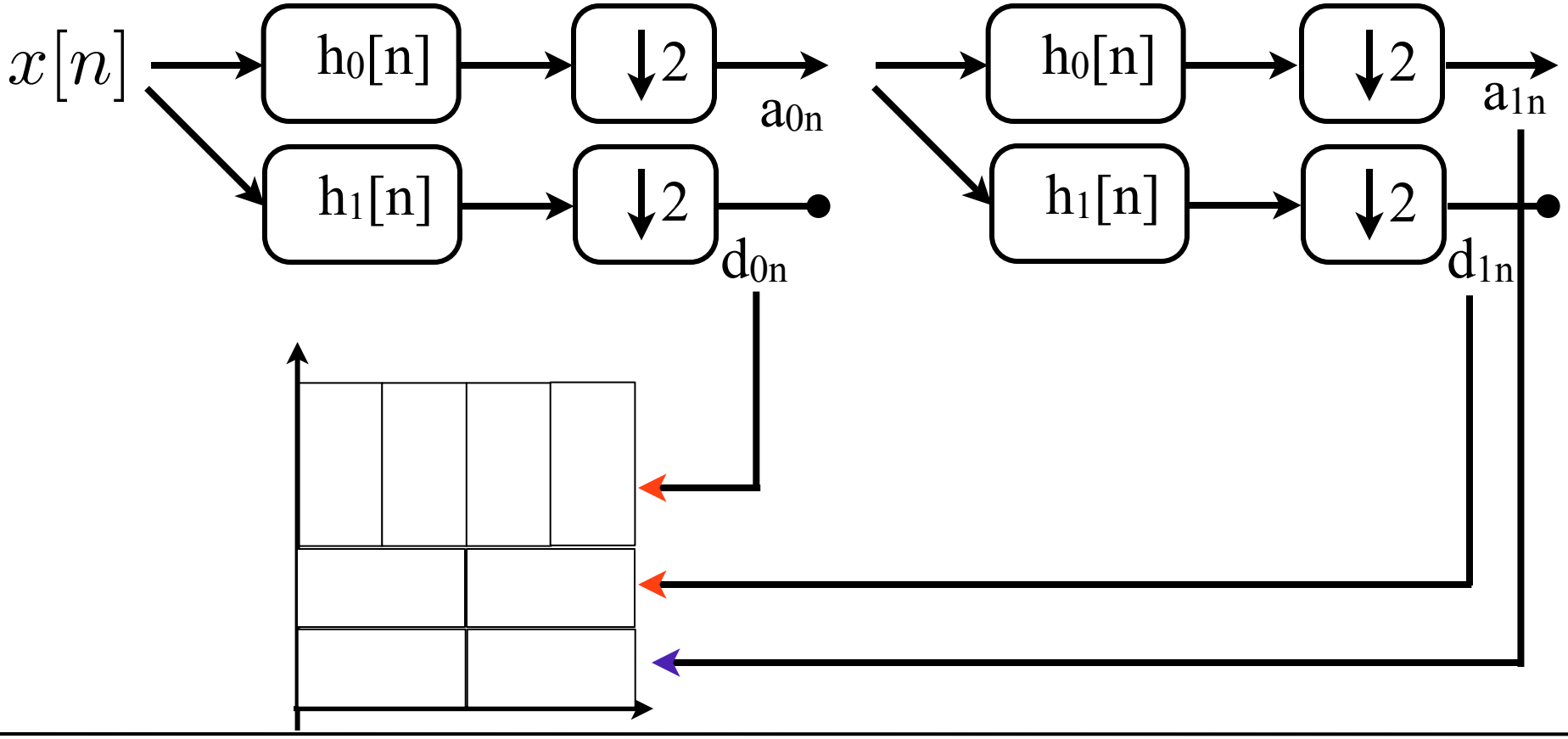
Fast DWT with Filter Banks



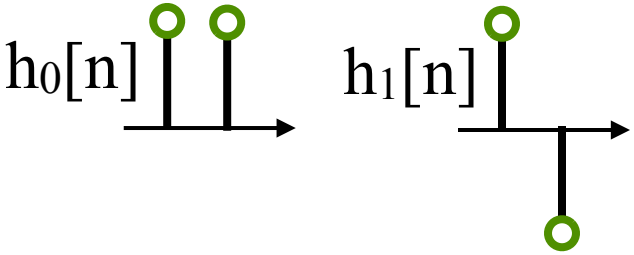
complexity:

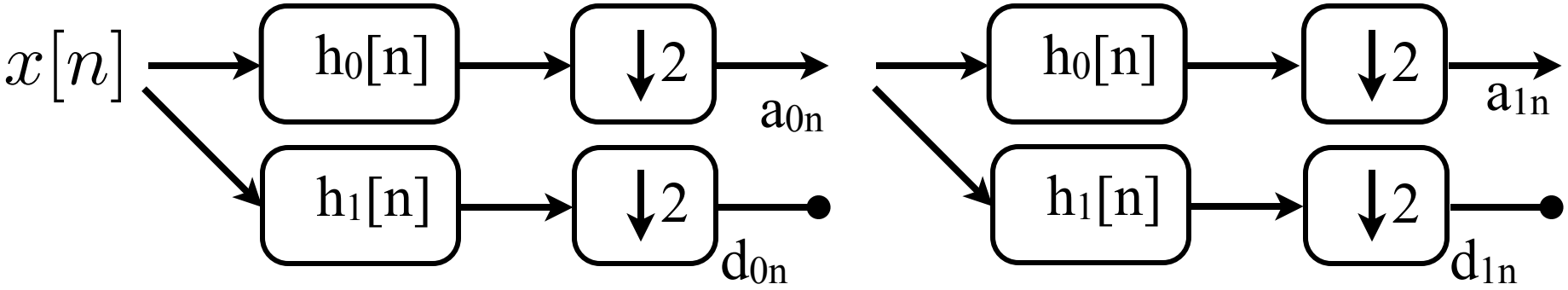
N + N/2 + N/4 + N/8 +...+ = 2N

=O(N)

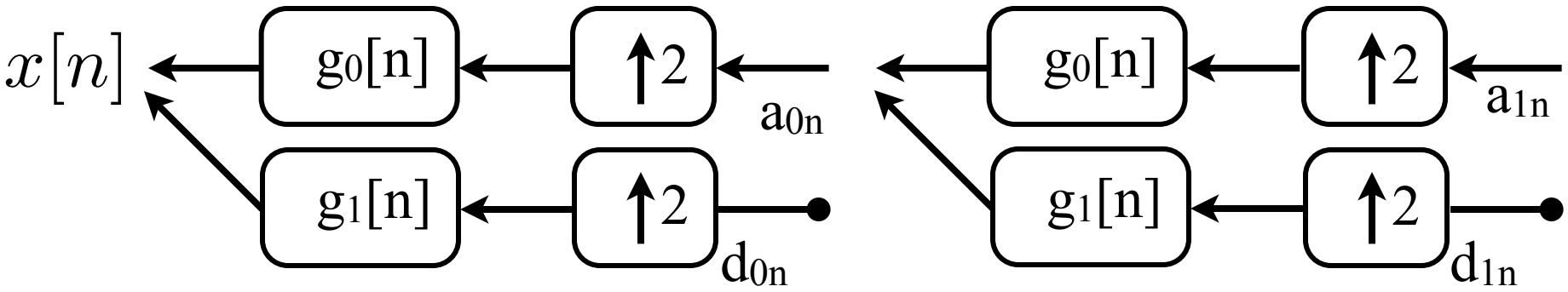


Decomposition



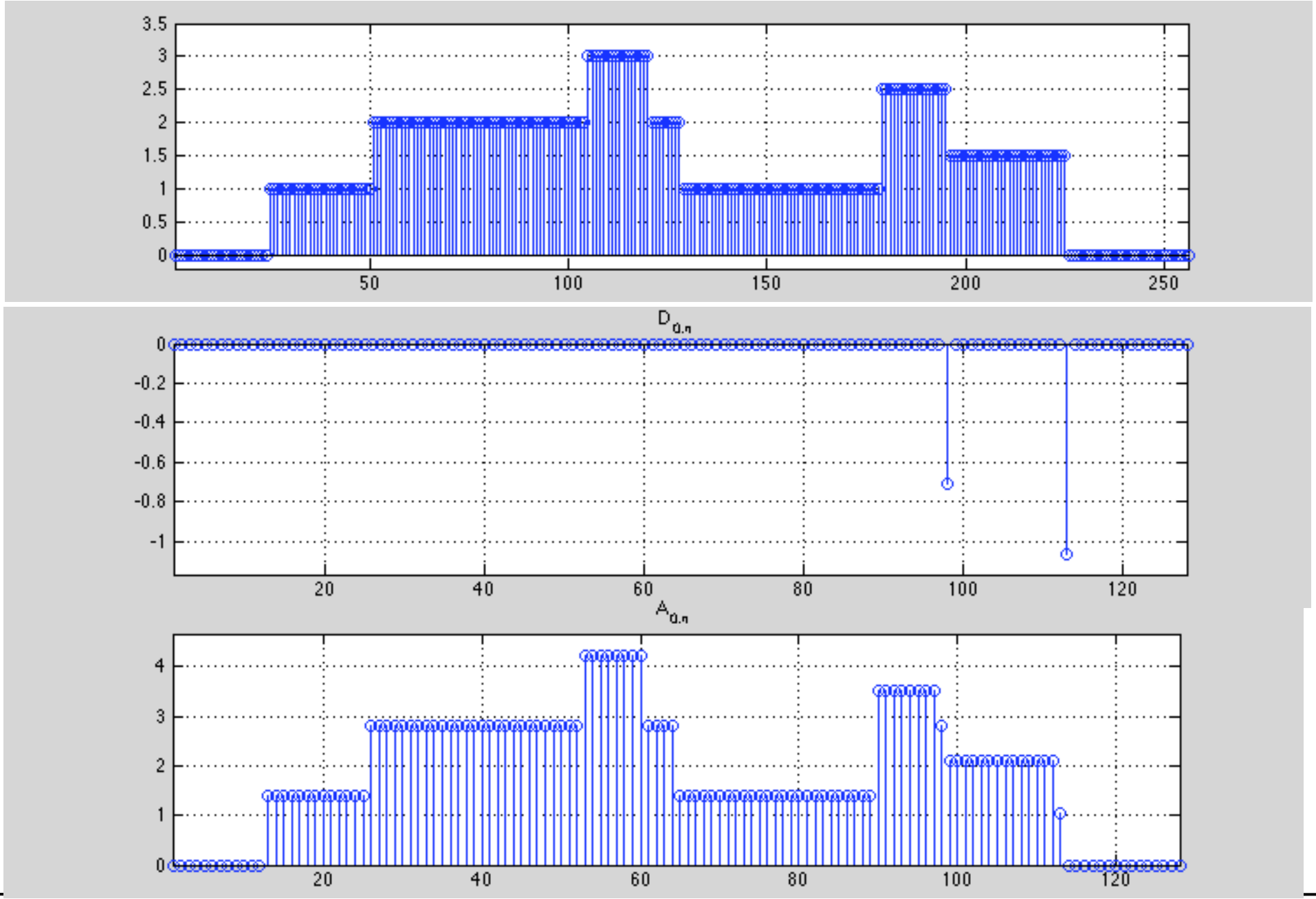


Reconstruction

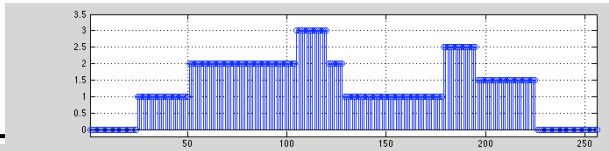


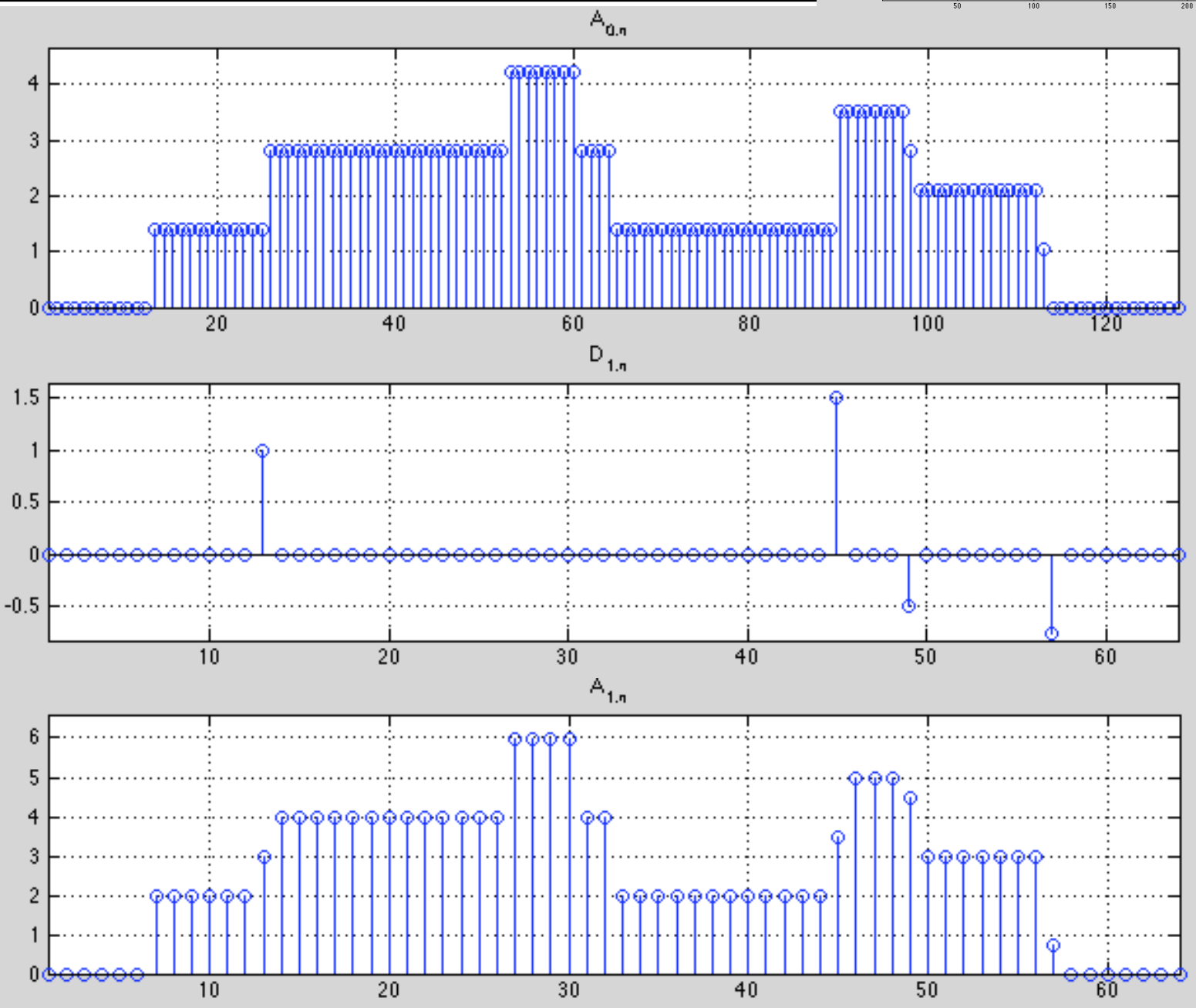
Just flip arrows,
replace h with g

Example, Haar DWT - Level 0

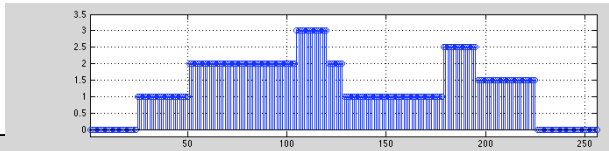


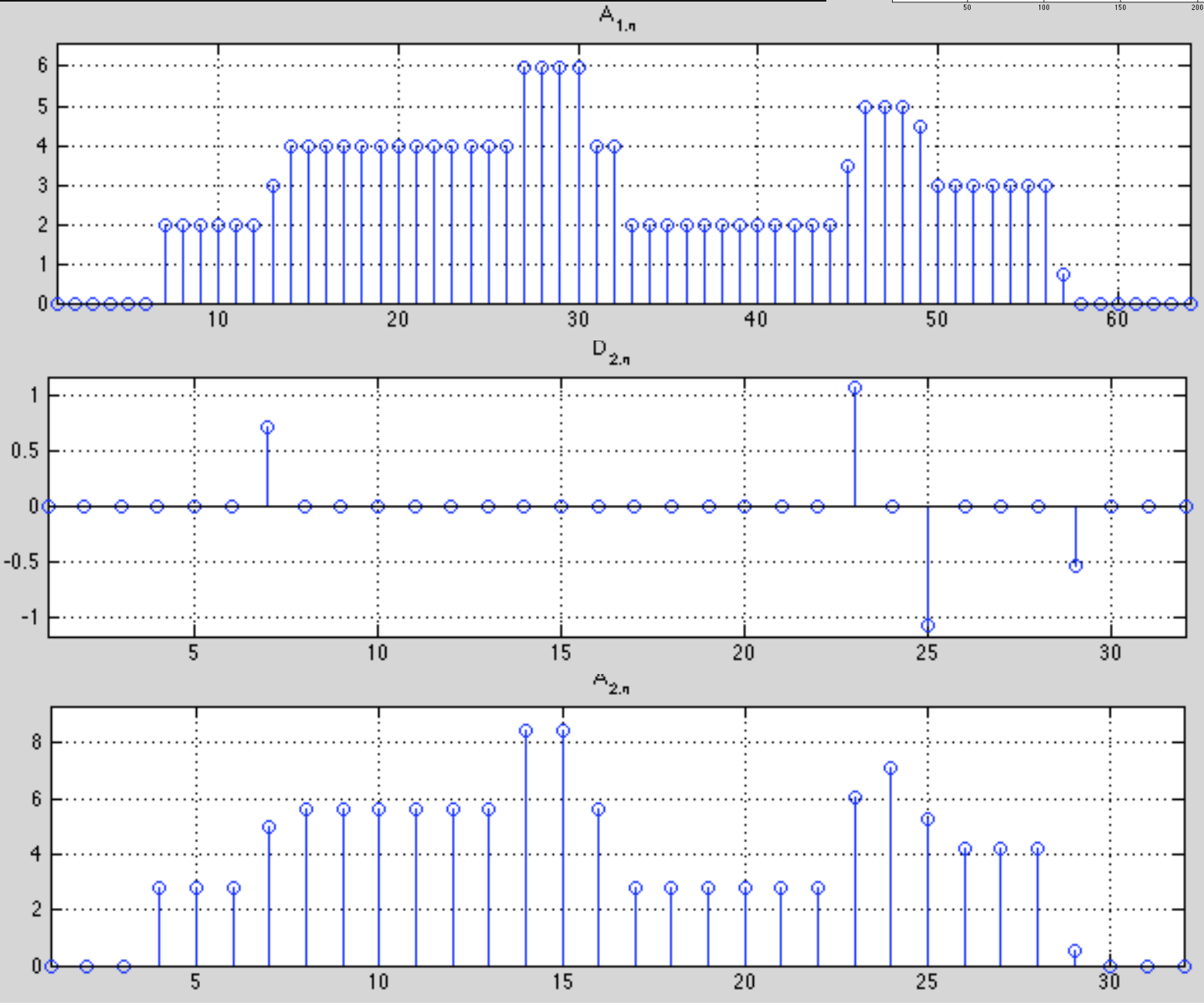
Example, Haar DWT - Level 1



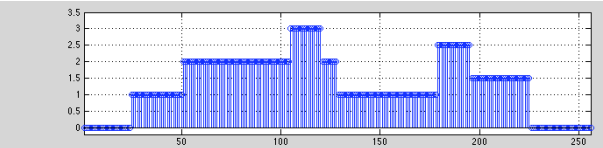


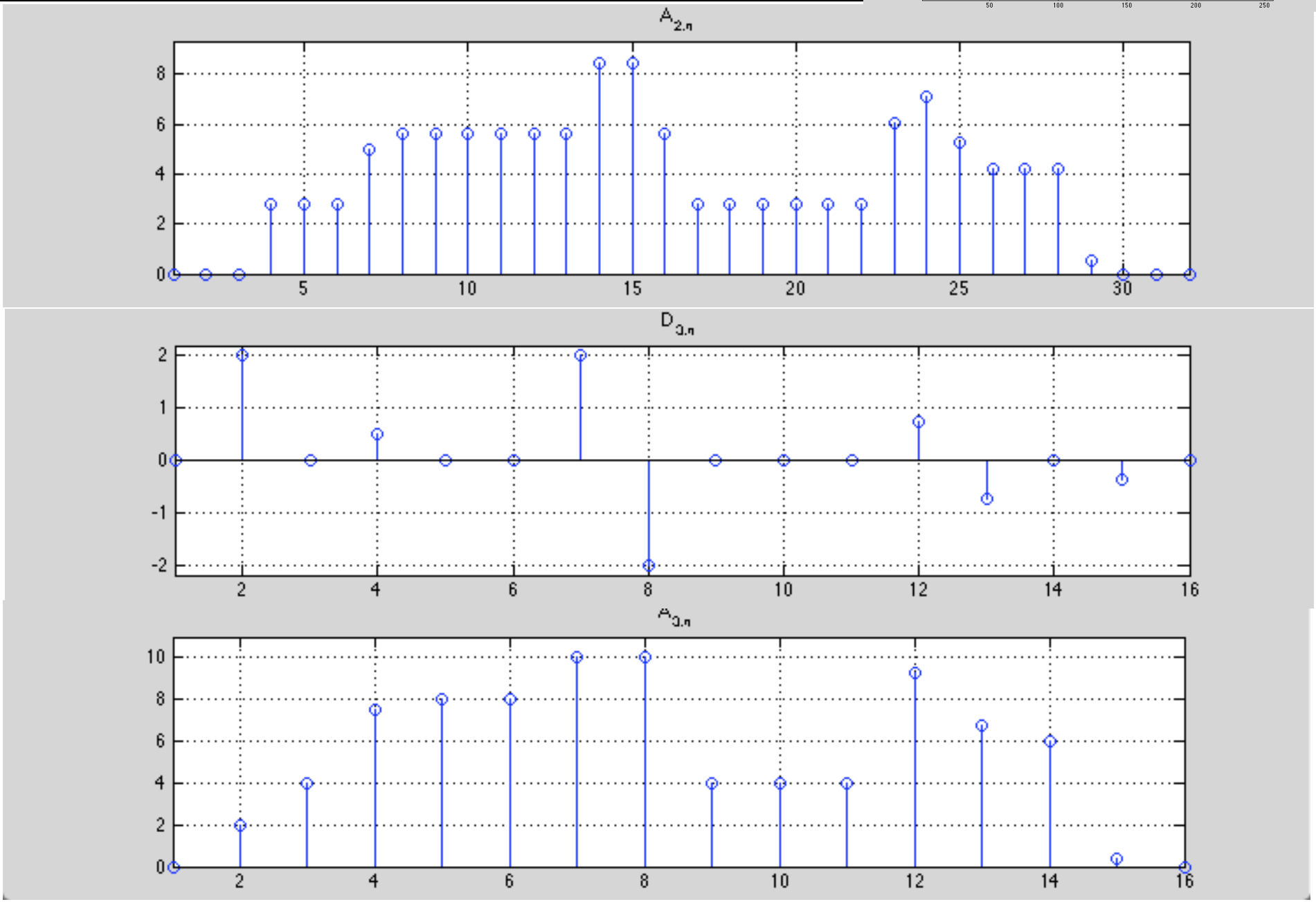
Example, Haar DWT - Level 2



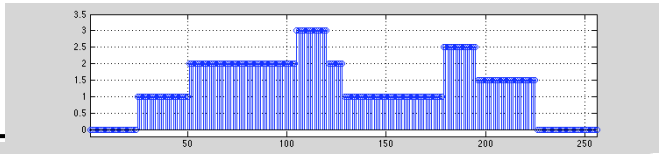


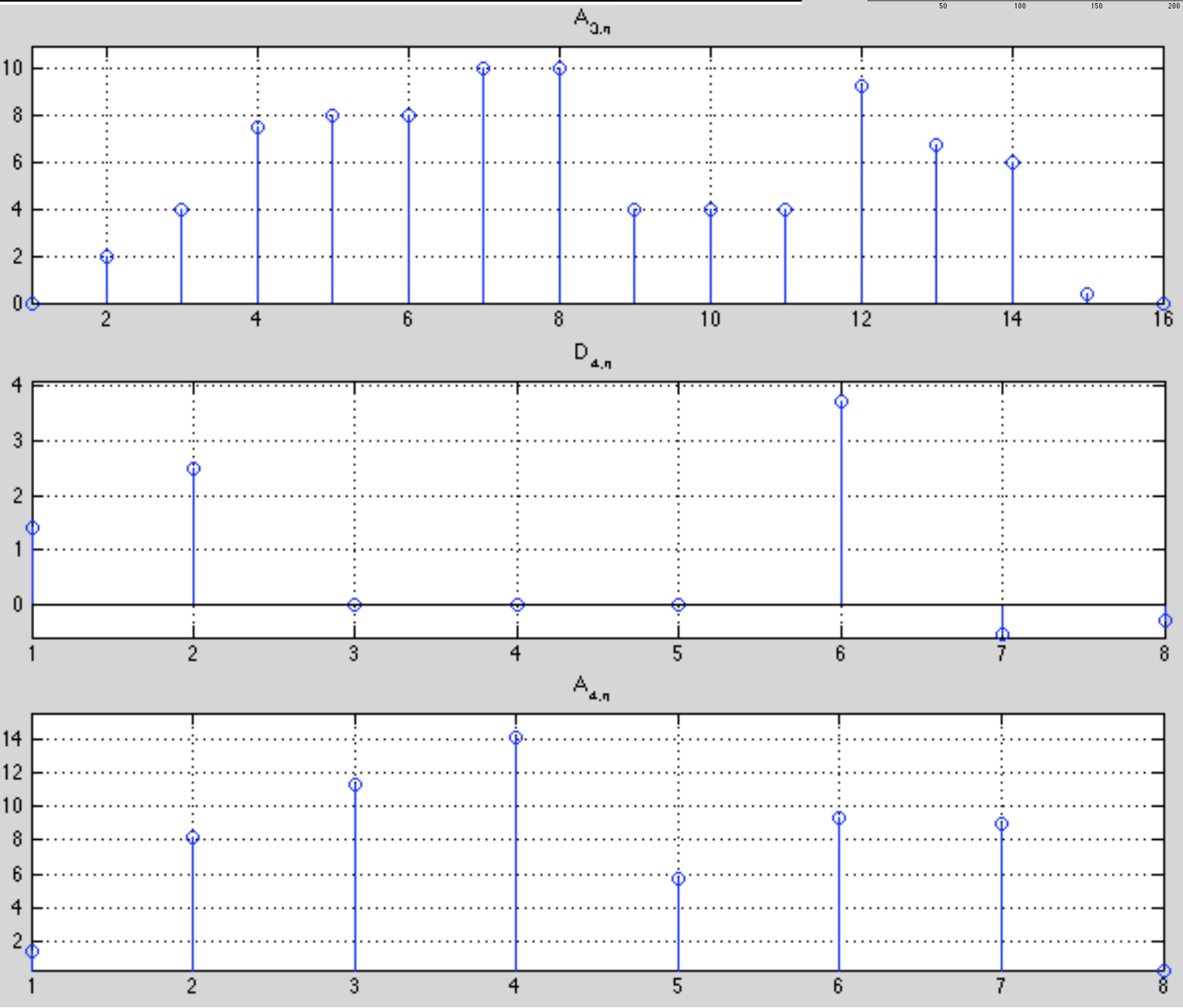
Example, Haar DWT - Level 3



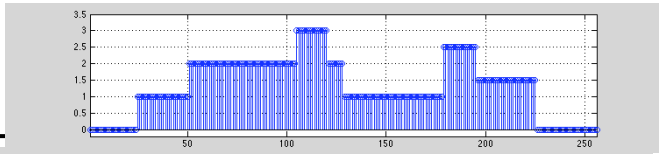


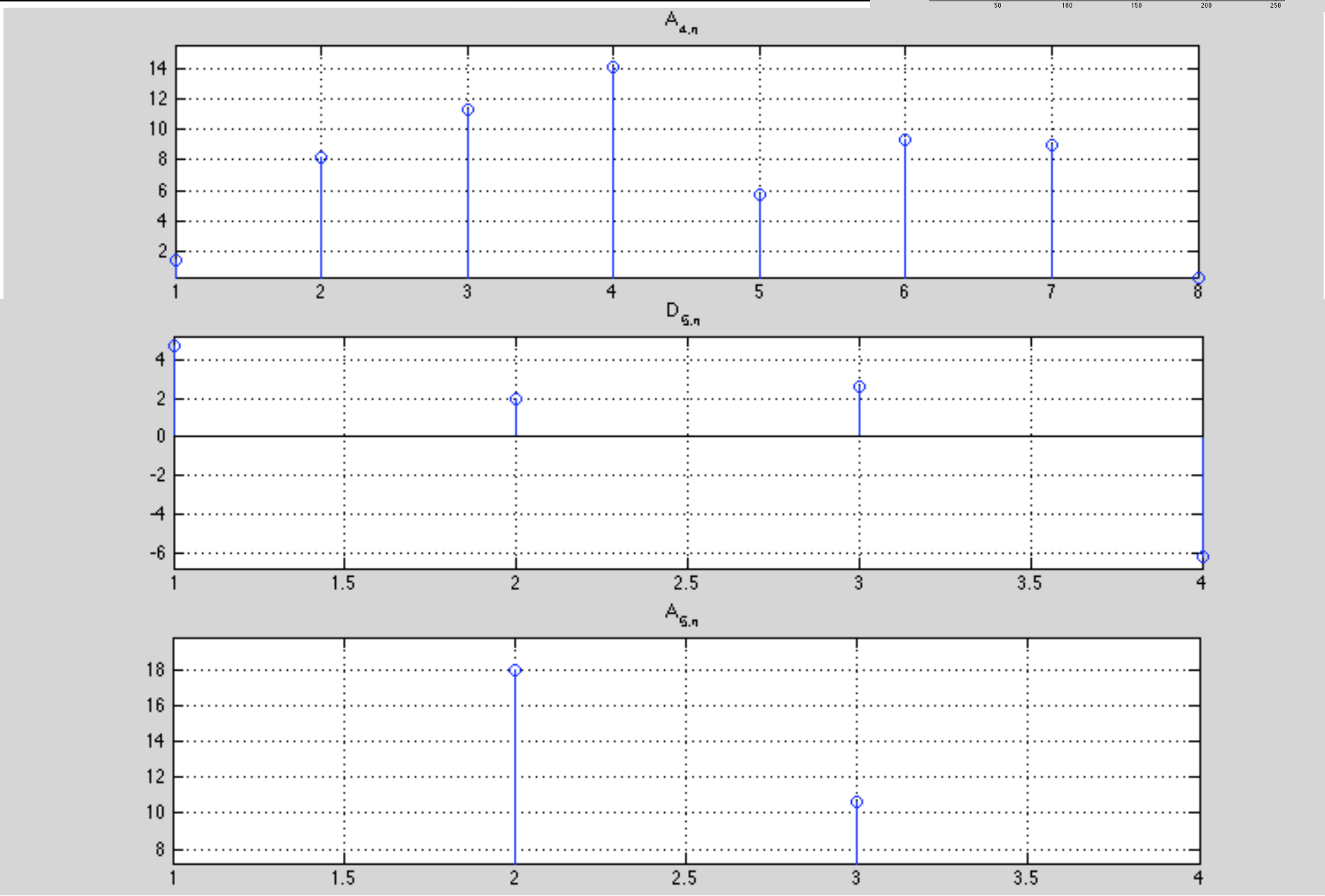
Example, Haar DWT - Level 4



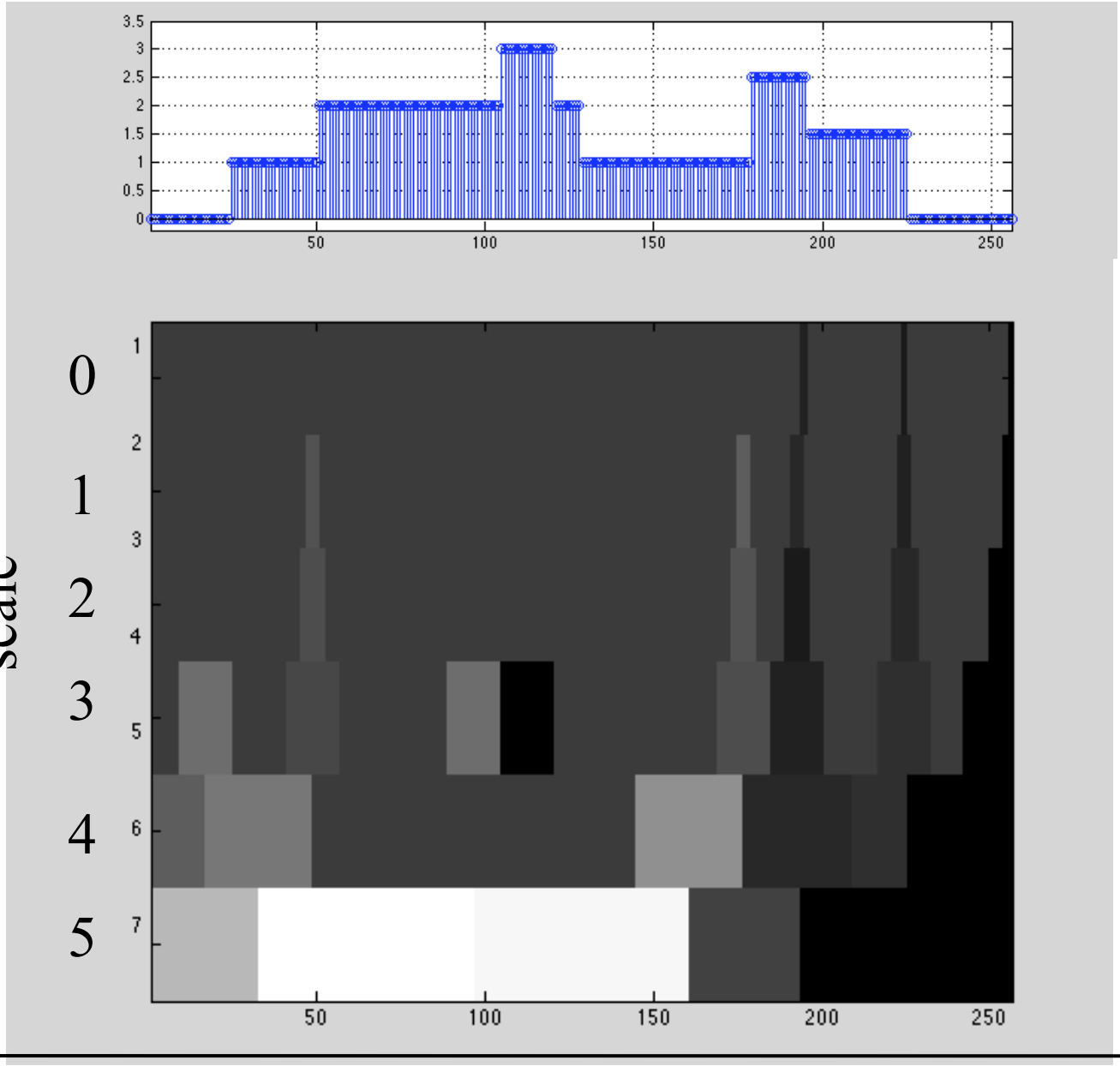


Example, Haar DWT - Level 5

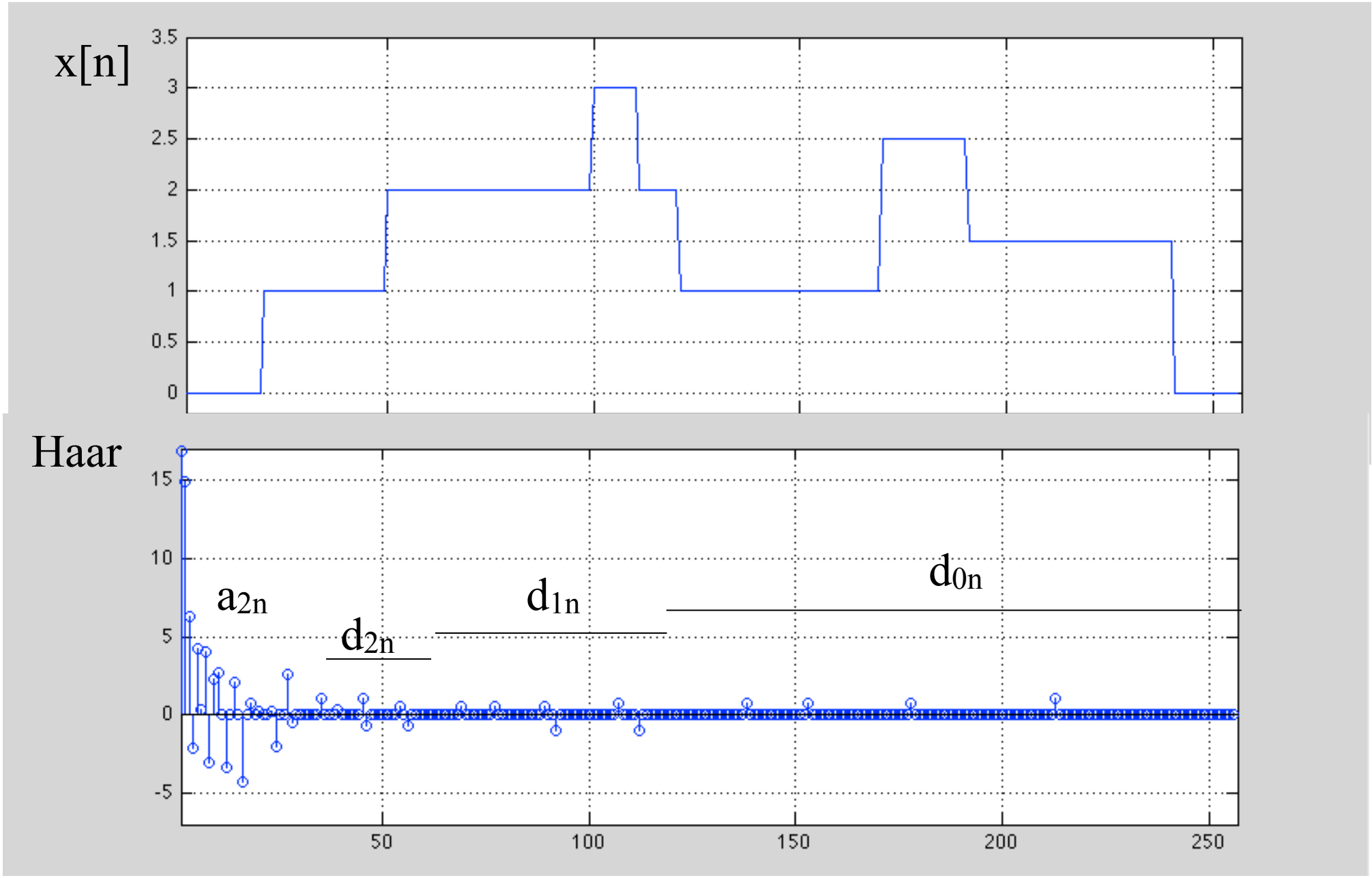




DWT Another view

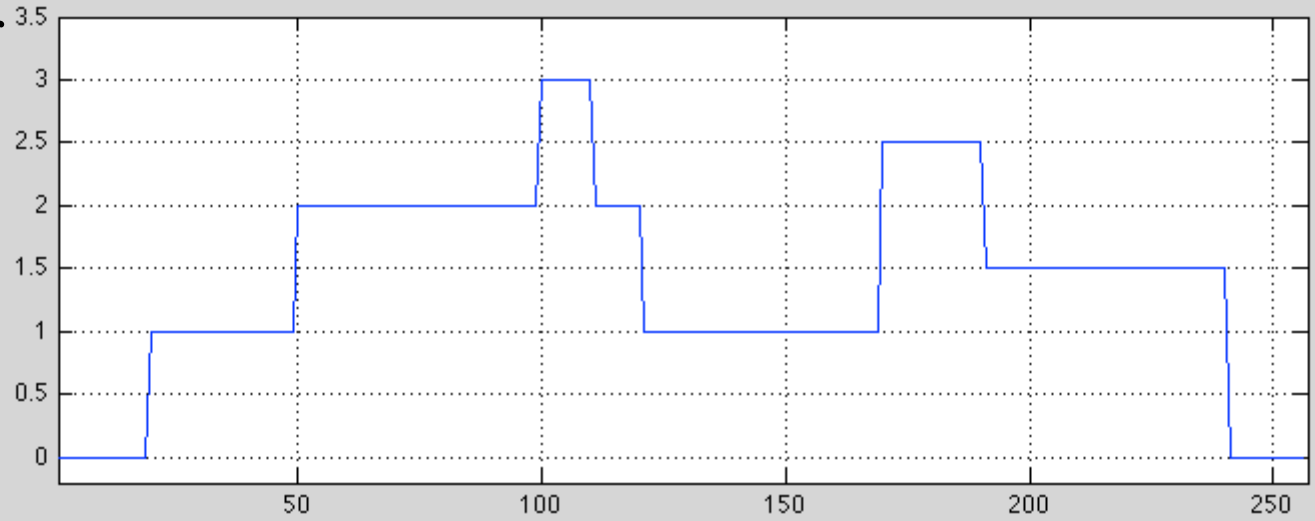


Haar DWT Example

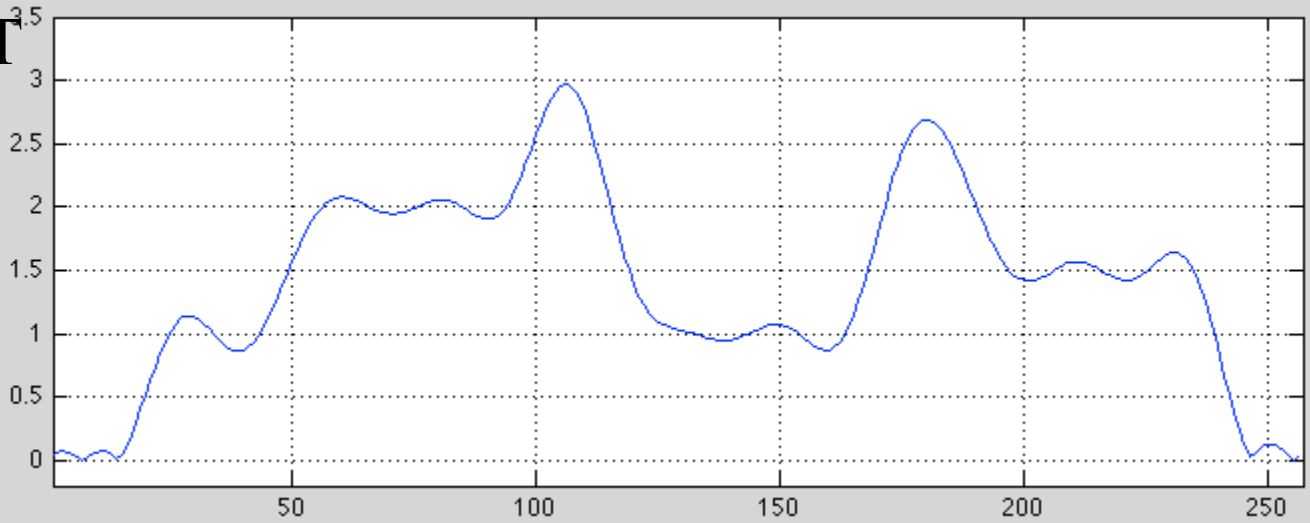


Approximation from 25/256 coefficients

Haar

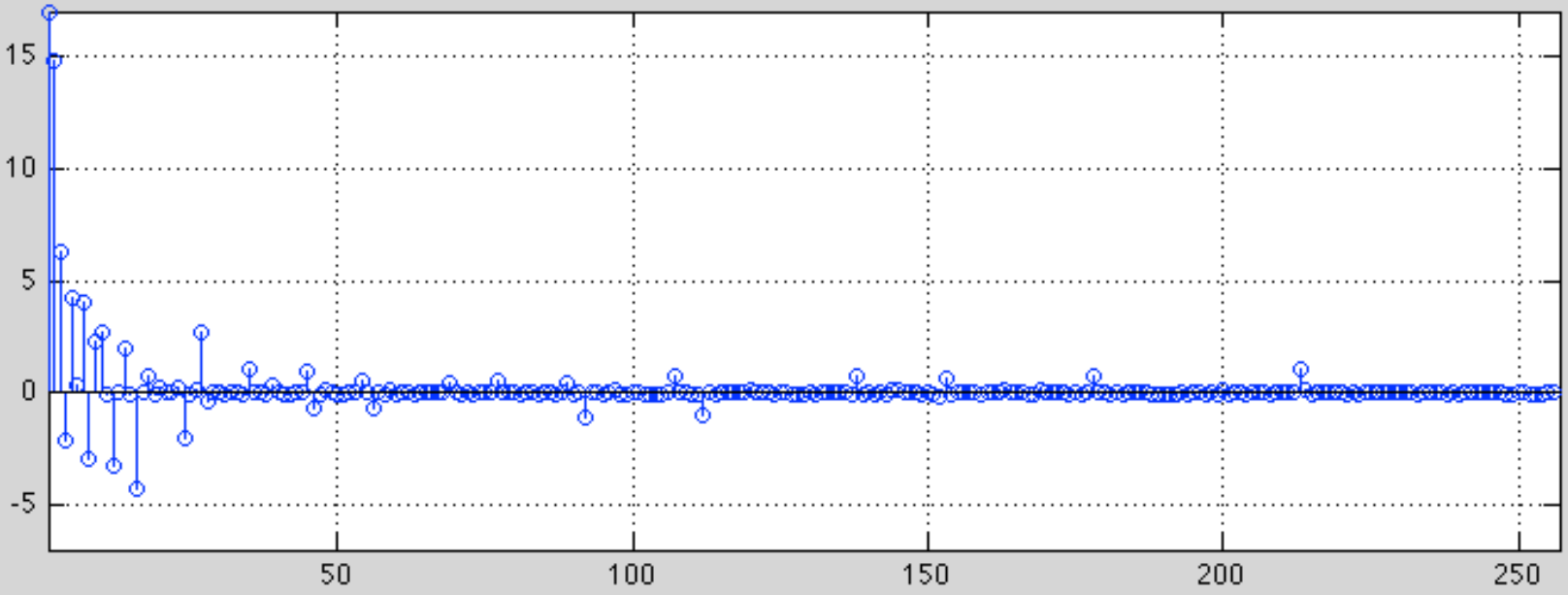


DFT



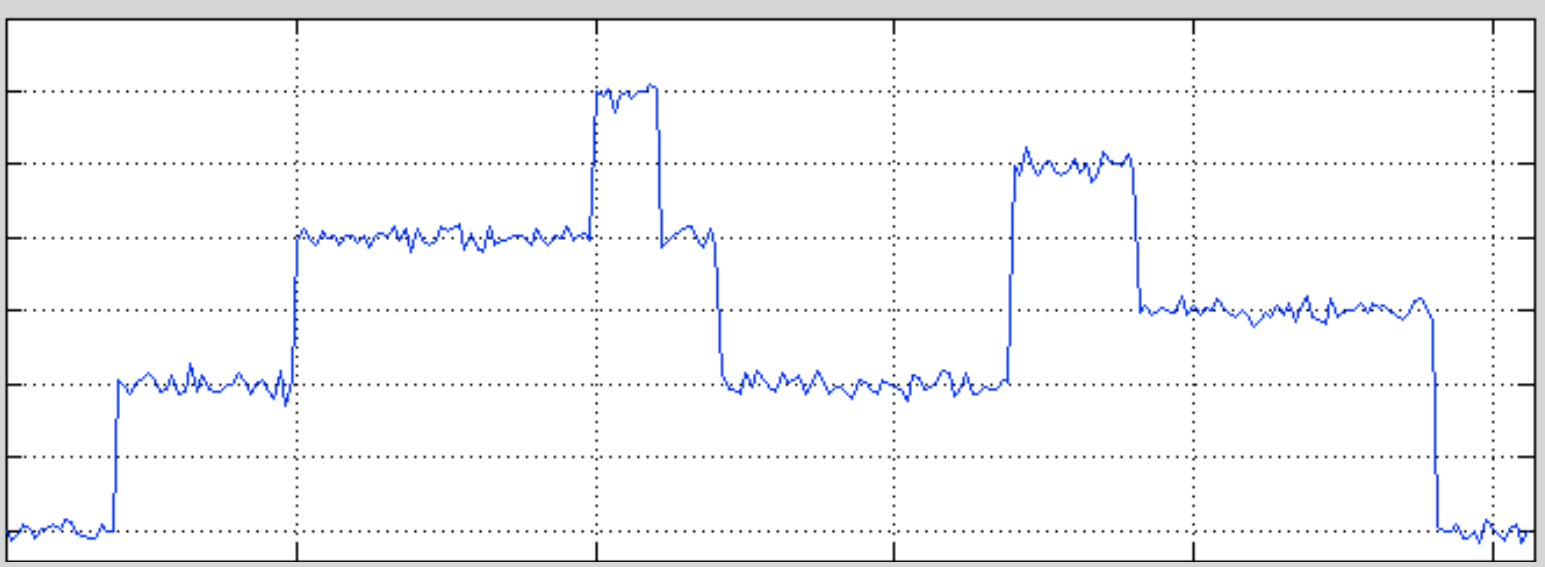
Example: Denoising Noisy Signals

Haar

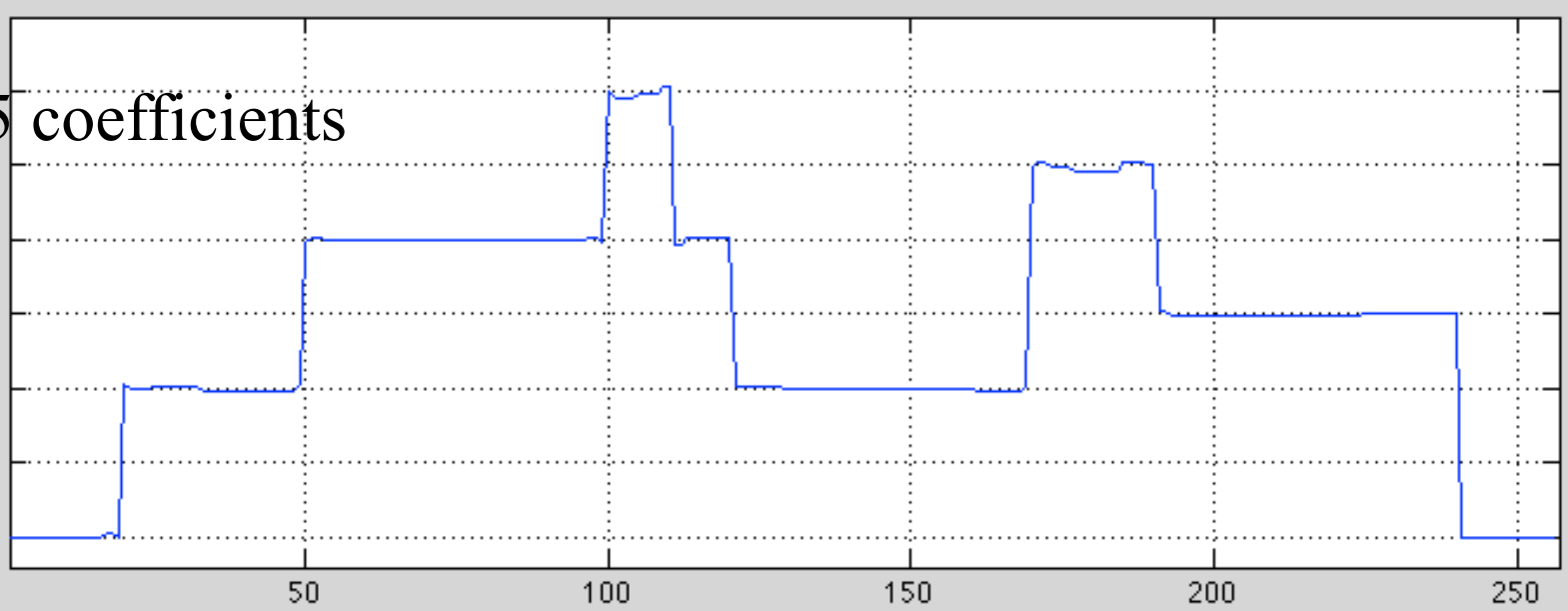


Example: Denoising by Thresholding

noisy



denoised
largest 25 coefficients



Compression - JPEG2000 vs JPEG

Jpeg2000 - Wavelet

Jpeg - DCT

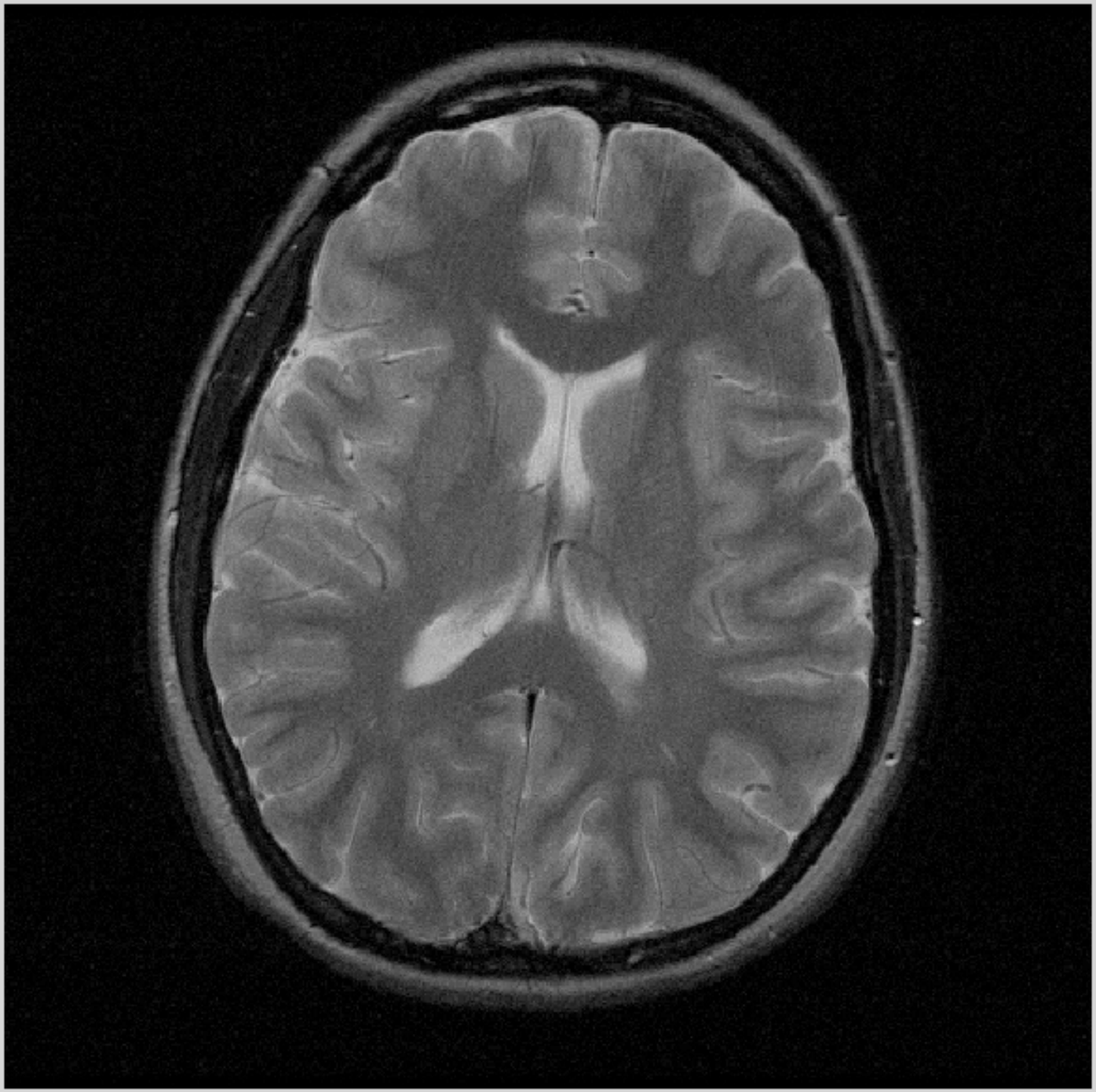
@ 66 fold compression ratio

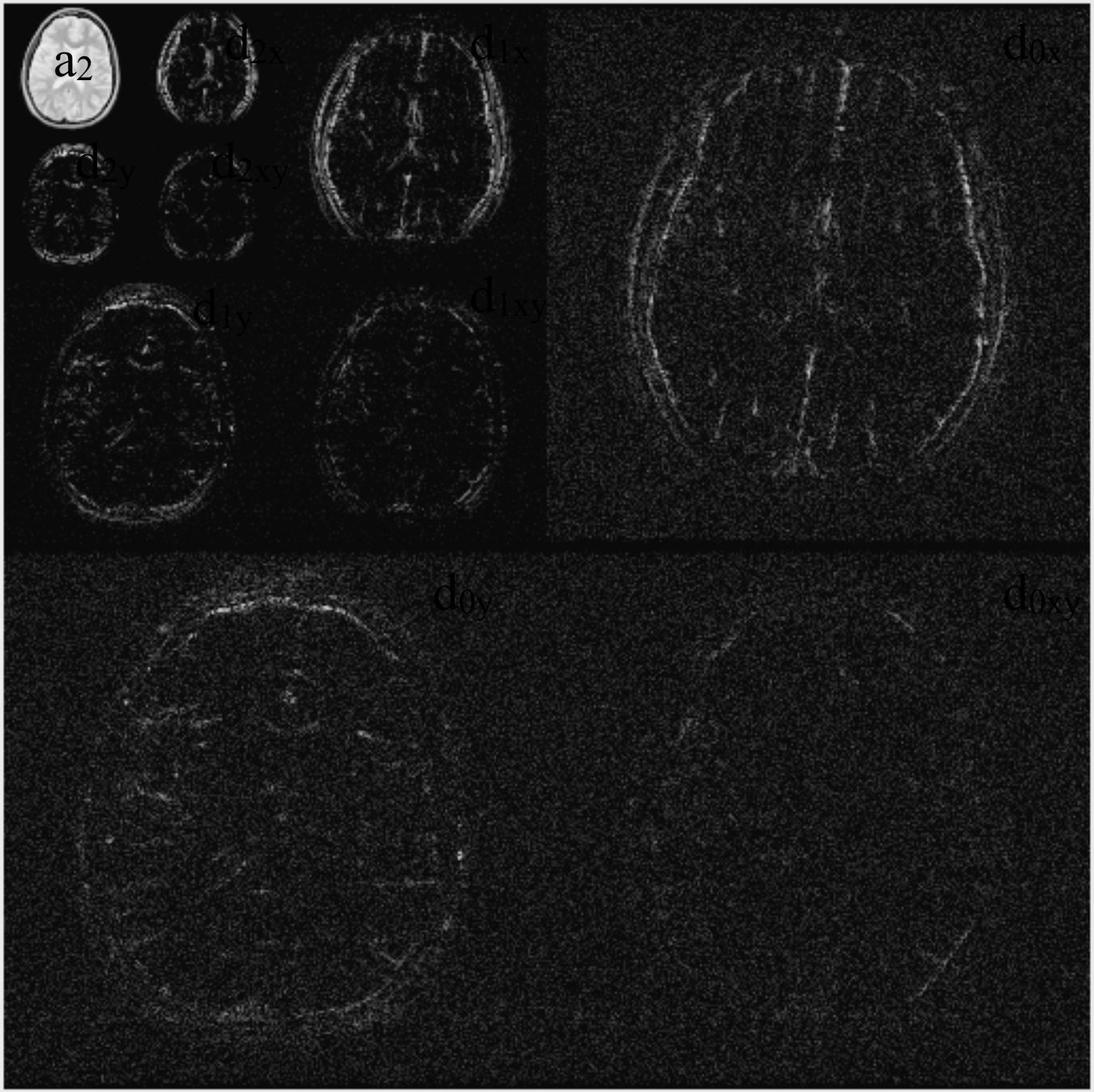
Compression - JPEG2000 vs JPEG

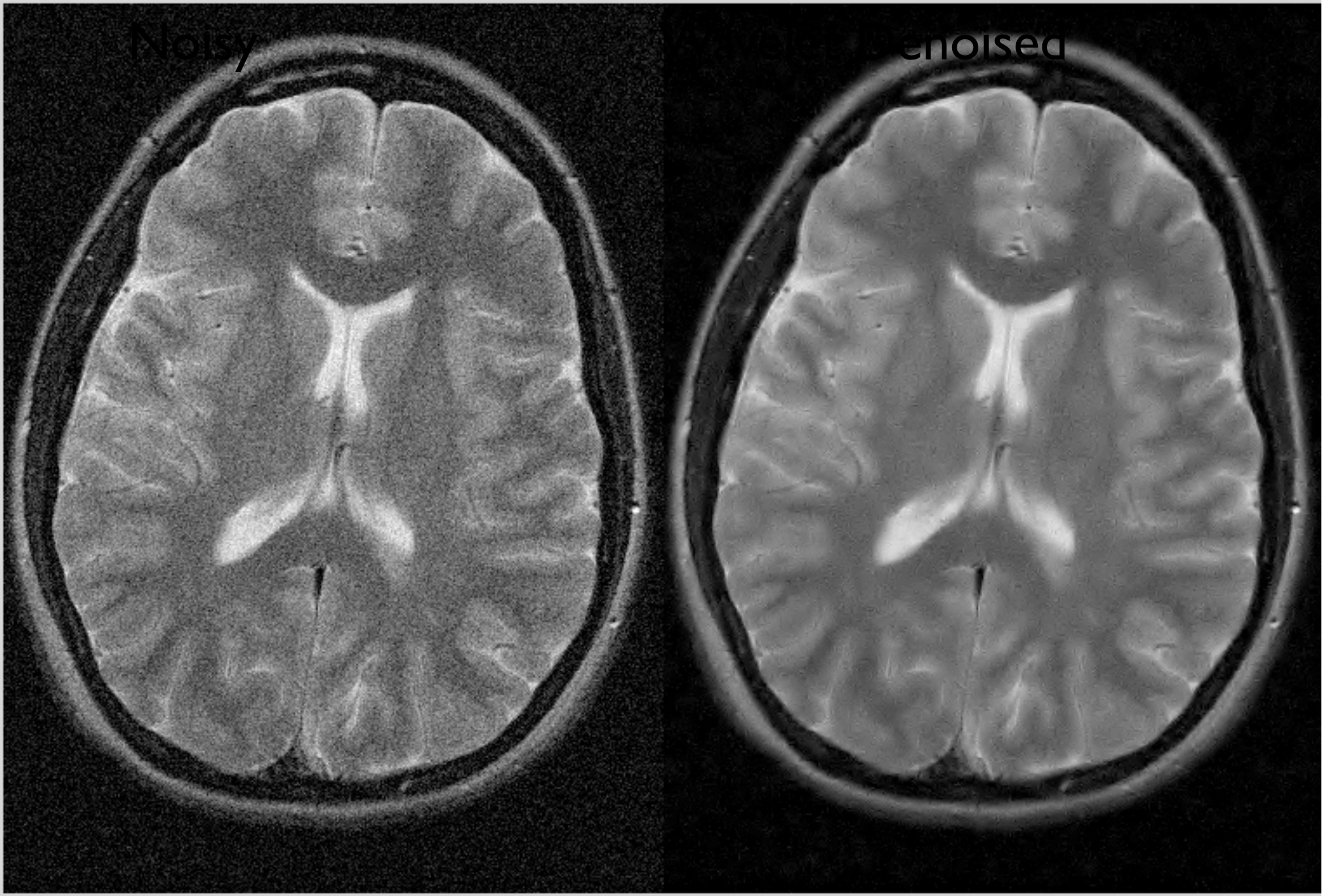
Jpeg2000 - Wavelet

Jpeg - DCT

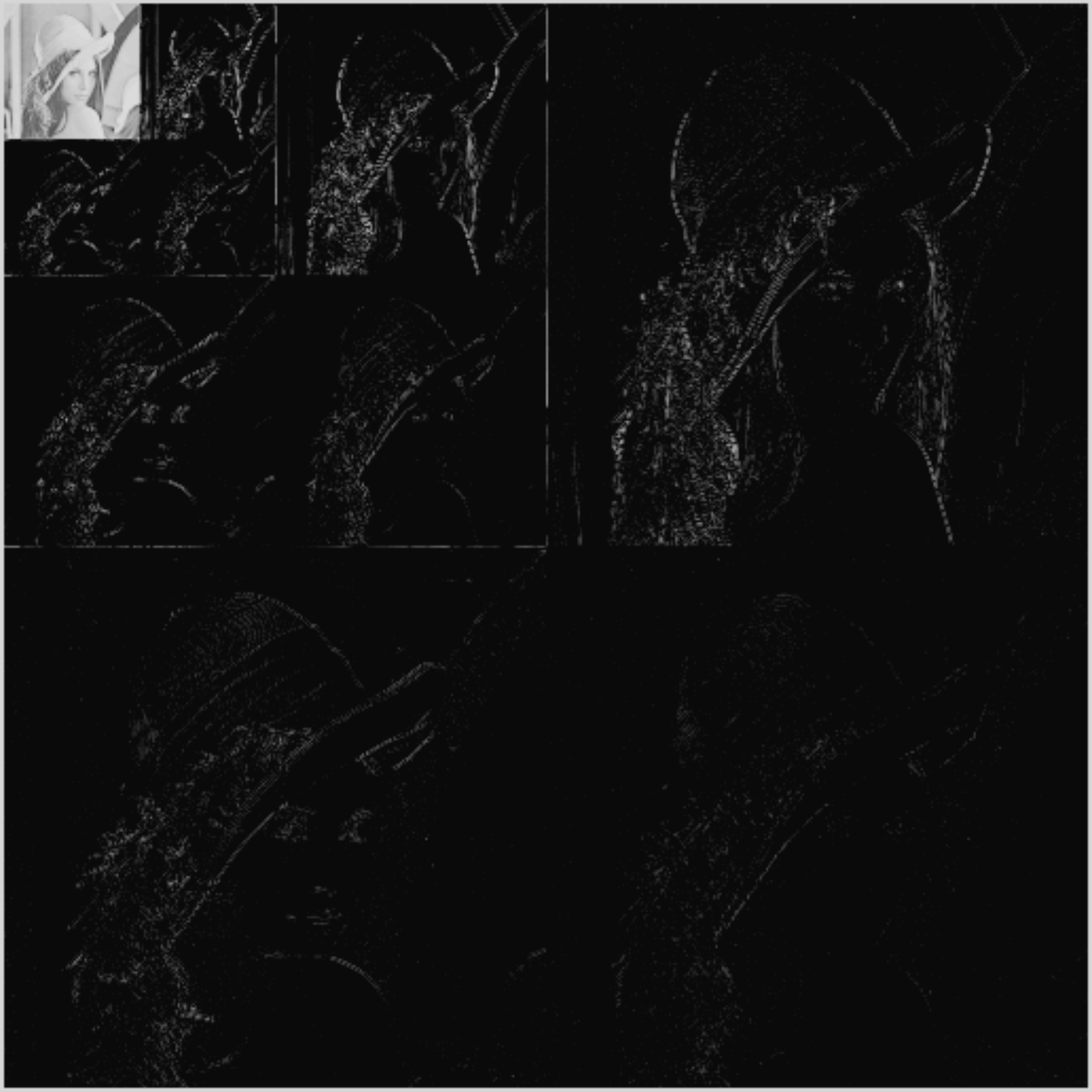
@ 66 fold compression ratio




a_2
d_{2x}
d_{1x}
d_{0x}
d_{2y}
d_{2xy}
d_{1y}
d_{1xy}
d_{0y}
d_{0xy}


Noisy
Denoised

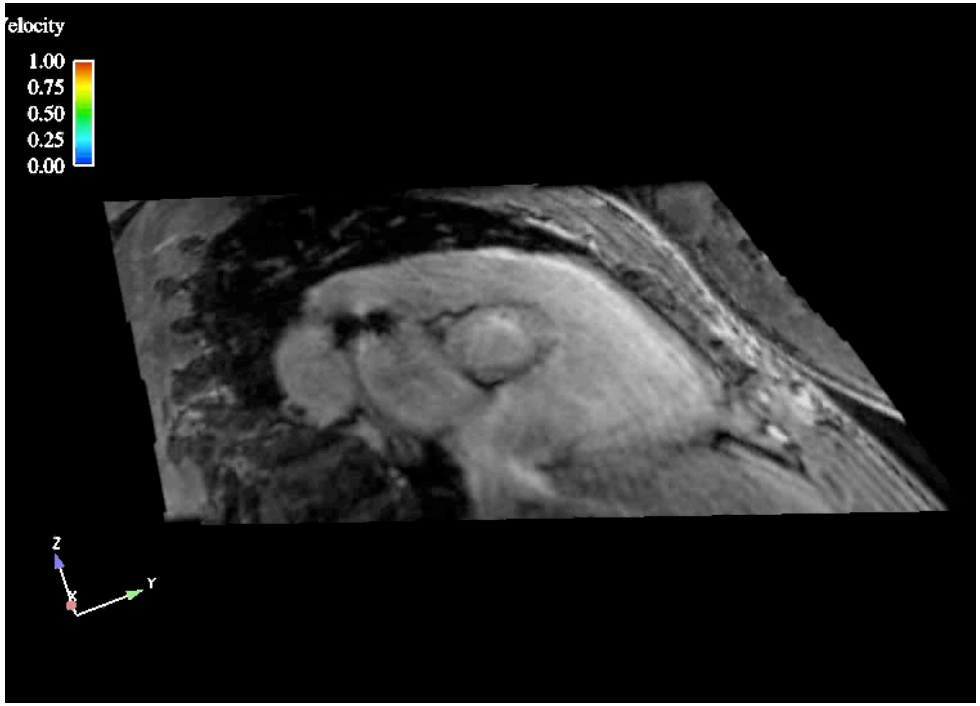
Approximation/Compression

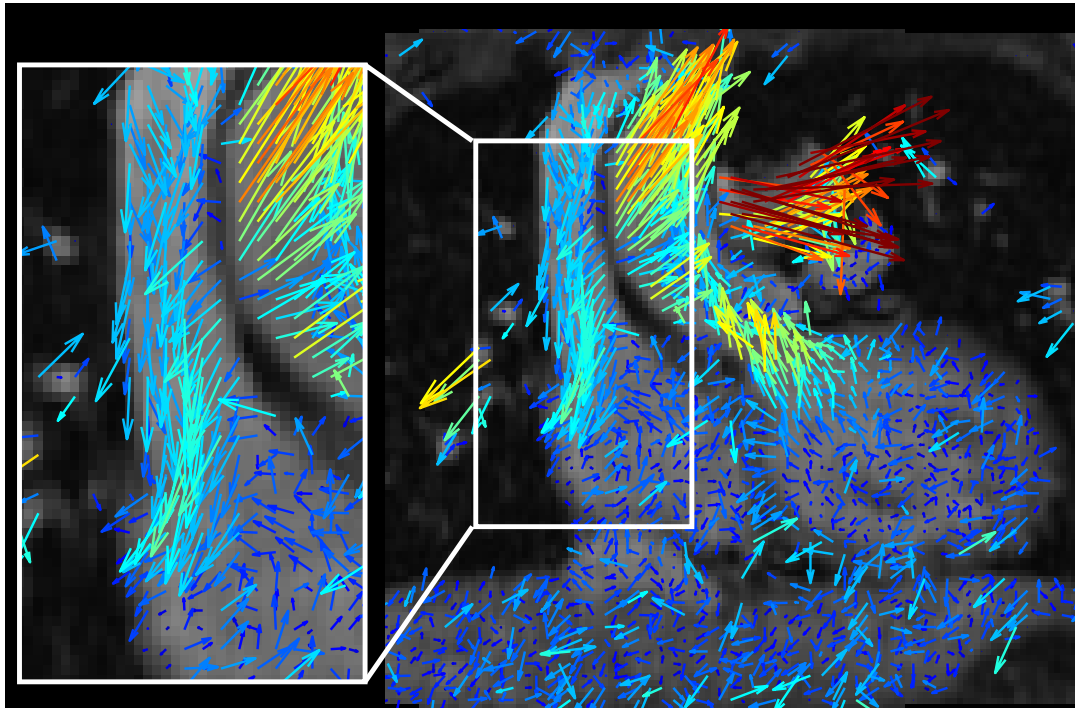


Example in Research

Robust 4D Flow Denoising using Divergence-free Wavelet Transform

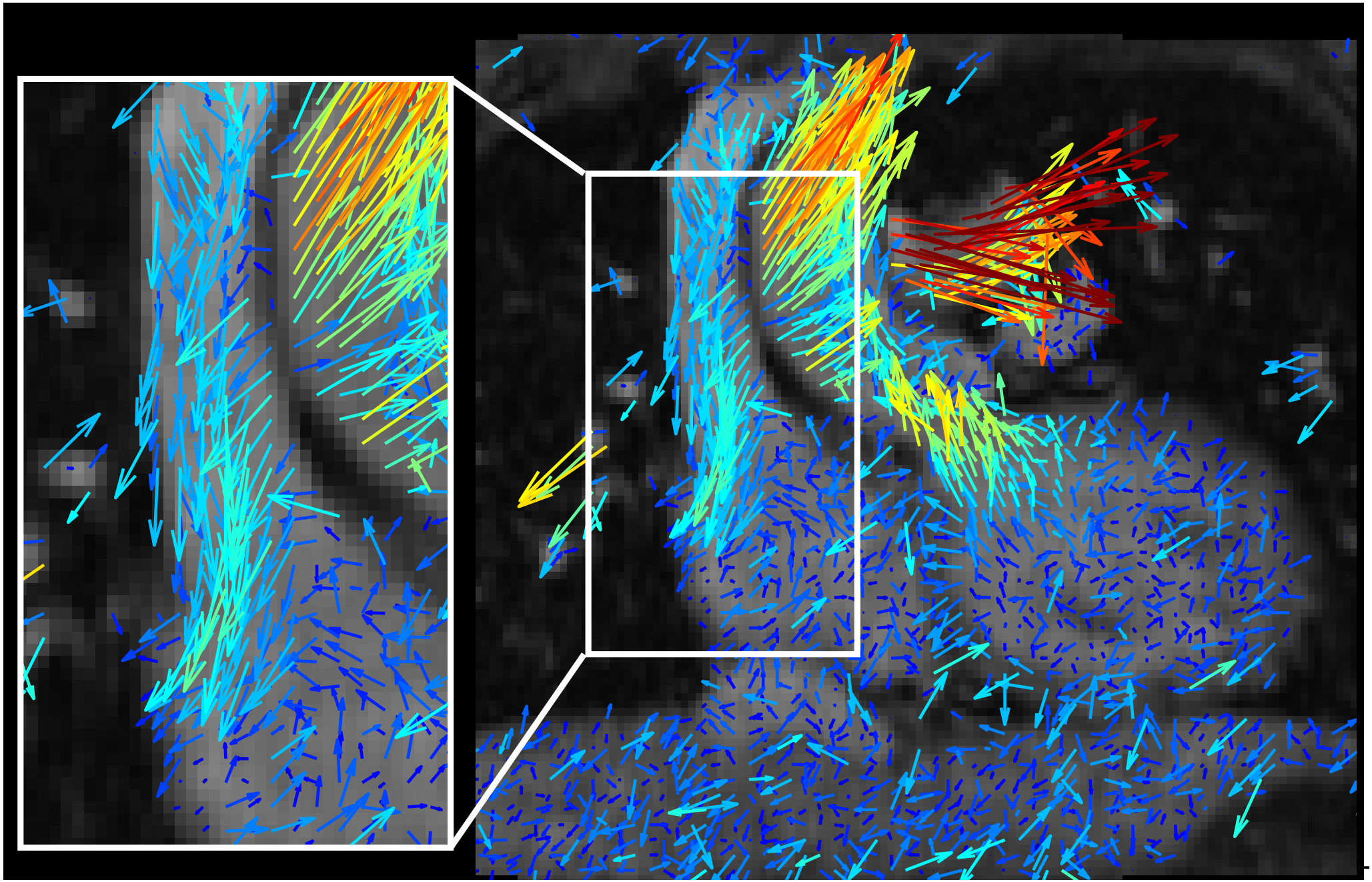
Frank Ong[1], Martin Uecker[1], Umar Tariq[2], Albert Hsiao[2], Marcus T Alley[2],
Shreyas S Vasanawala[2], Michael Lustig[1]



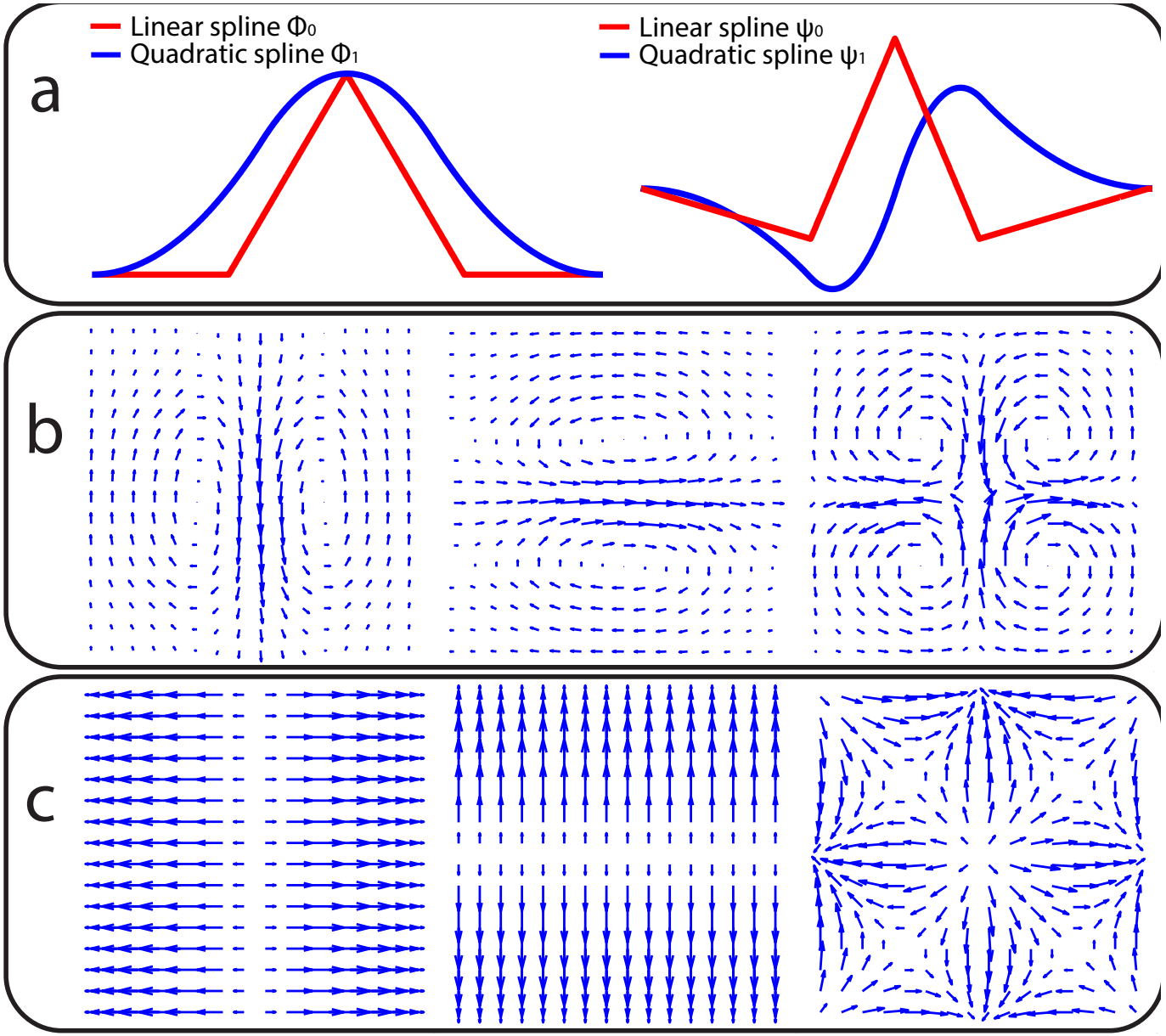


courtesy, Frank Ong and Marcus Alley

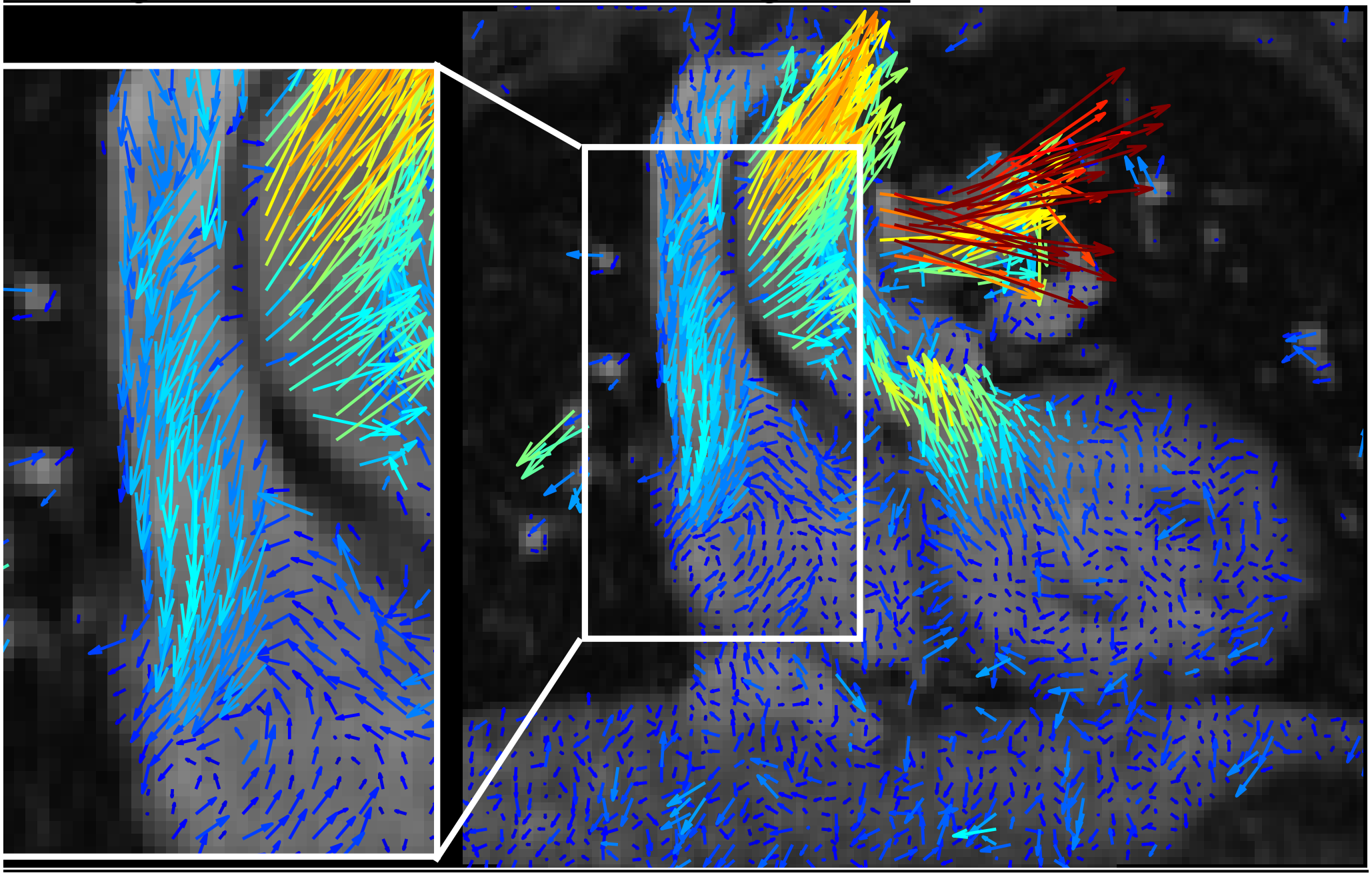
Noisy Flow Data

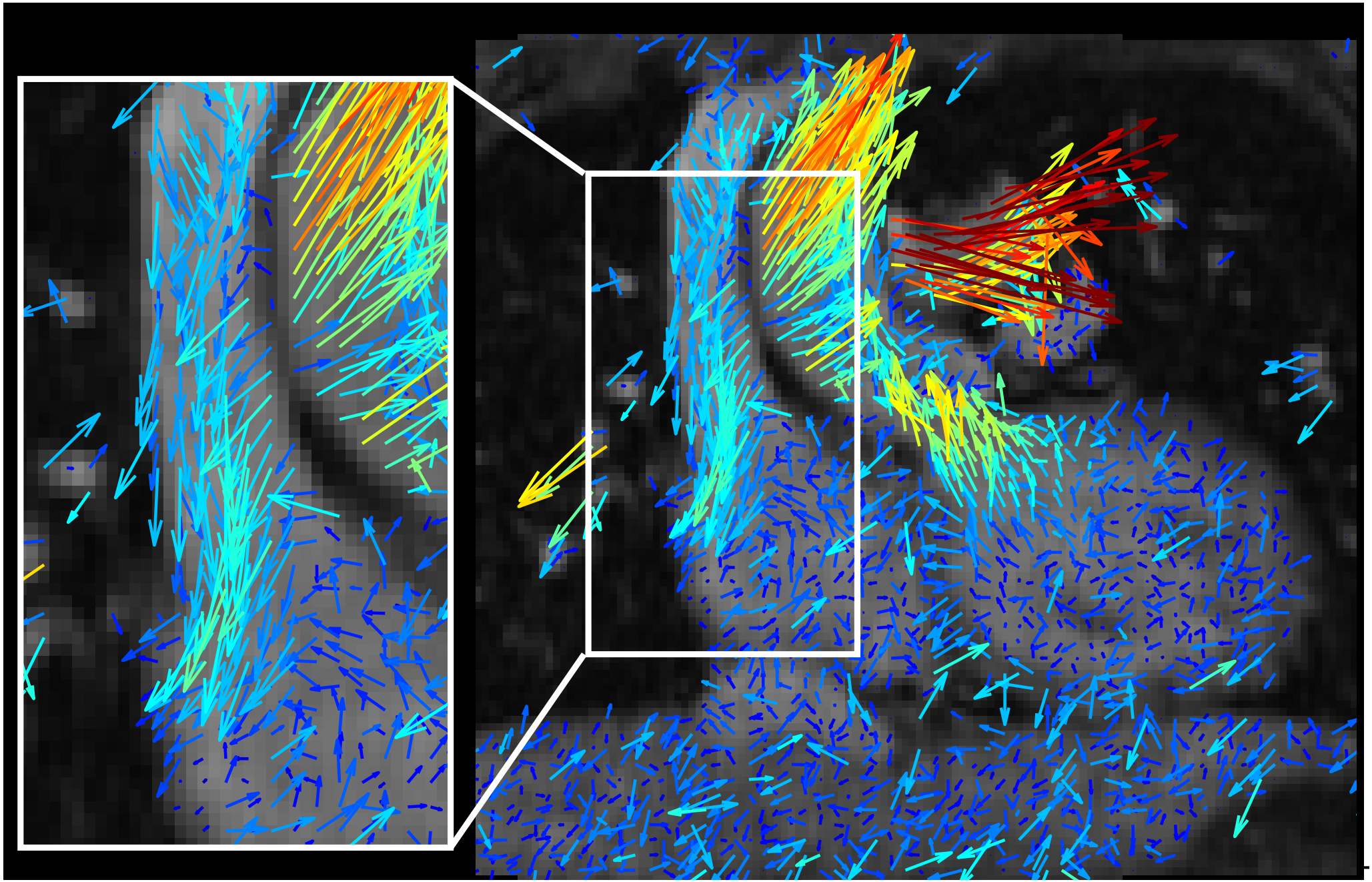


Divergence Free Wavelets



Divergence-Free Wavelet Denoising



M. Lustig, EECS UC Berkeley

Noisy Flow Data