Very long

\[ X(t) \text{ random} \]

\[ h(n) \]

\[ y(t) \]

\[ \approx H(s) \]

Estimating the spectral mag of a signal

- \text{abs} (\text{fft}(x))

- \text{psd}(x)

- \text{spectrum}(x) \rightarrow \text{pwelch}(x)
FIR Filter Hardware

\[ y(n) = h(n) + x(n) \]

\[ = \sum_{k=-\infty}^{\infty} x(k) h(n-k) \]

Assume \( h \) has length 3

\[ y(n) = x_n \cdot h_2 + x_{n+1} \cdot h_1 + x_{n+2} \cdot h_0 \]
- Can scale the magnitude of the entire filter without changing the frequency response.

  - Watch out for:
    - Overflow - if scaled larger
    - Quantization noise - if scaled smaller
If \( \text{wffe} = [9 \ 18 \ 45 \ 18 \ 9] \)

12 PPs

\[ 0.899 \times \text{wffe} = [8 \ 16 \ 40 \ 16 \ 8] \]

1 \ 1 \ 2 \ 1 \ 1

6 PPs

**Diagram:**

- **Initial**
  - FIR
  - A

- **Ideal #1**
  - 0.899
  - FIR
  - A

- **Ideal #2**
  - 0.899
  - FIR
  - A'

- **Hopefully not necessary**
  - 0.899
  - FIR
  - \( \times 0.125 \)
  - A
Worst-case inputs

For all adders, make sure output width is sufficient for all inputs.

What is the worst-case for an FLP?

Exs 4-bit inputs 

\[ x \rightarrow y \]

\[ [-8, +7] \]

\[ \text{coeffs} = [-2, 3, 7, 3, -2] \]

\[ x(n) \quad h(n) \]

\[ \text{Not:} \quad -8, -2, 3, 7, 3, -2 = -8 \times 9 = -72 \times \]

\[ \text{Not:} \quad +7, +7, +7, +7, +7, +7 = +7 \times 9 = +63 \times \]

1) 

\[ x(n) \]

\[ 1 \quad 7 \quad 7 \]

\[ -8 \]

\[ 16 + 21 + 49 + 21 + 16 = 123 \]

2) 

\[ x(n) \]

\[ 7 \quad 7 \]

\[ -8, -8, -8 \]

\[ -14 - 24 - 56 - 24 - 14 = -132 \]
- Large
  Peak-to-average ratios

1) Widen output word enough
   - Can be wasteful

x 2) Let it overflow
   - Risks bad idea

3) Saturate
   - Distortion
   + Efficient in HW

4) Compression
   + Friendly form of saturation
Saturation

\[ n \rightarrow \frac{1}{2} n \]

\[ n \rightarrow \frac{1}{2} n \]

Saturation

Remaking

127

"Chipping"

-128

\[
\begin{array}{cccc}
\times & \times & \times & \times \\
Y & Y & Y & Y \\
\end{array}
\]

Two steps:

1) Saturate input to SAT-H1 and SAT-L0

2) Delete redundant bits if saturation produced any.

Often efficient to do both steps simultaneously.
Ex: input 4-bit 2's complement $[-8, +7]$
output 3-bit $[-4, +3]$

SW: if $in > sat_{HI}$ $=$ else if $in < sat_{LO}$ $=$ else $= $

HW: