Mar. 8

\[ V = A + Bw_b + Cw_c + Dw_a \]

\[ W = A - jBw_b - Cw_c + jDw_a \]

\[ X = A - Bw_b + Cw_c - Dw_a \]

\[ Y = A + jBw_b - Cw_c - jDw_a \]

Normally:

DIT: bit-reversal before butterfly

DIF: "after" butterfly
Higher Radixes than 2,4

- 2, 4 most popular
- Radix 4 is ≈ 20% more efficient than radix 2

I. Common-Factor FFTs

- "Can log-Tilney" FFTs
- Factors of N used in decomposition have common factors

A) Radix-r

- \( N = r^k \), \( k \) positive integer
- \( r \) is base
- \( \frac{N}{r} \) butterflies per stage
- \( k = \log_r N \) stages

\( k = 0, 1, 2, \ldots \) stages
B) Mixed-radix

\[ N \neq r^k \]

Ex.: \[ N = 32 = 4 \times 4 \times 2 = 2^5 \]

\[ \text{radix 4} \}
\[ \text{radix 4} \}
\[ \text{radix 2} \]

II. Prime-Factor FFTs

\[ N = \text{product of relatively prime numbers} \]

Ex.: \[ 7 \times 11 \times 13 = 1001 = N \]

III. Other FFTs

- Split-radix

- FFTW

\[ \equiv \]
Calculating the IFFT

0) Design a separate IFFT processor

- Re-use a forward FFT engine to calc. IFFT()

1) \( a = \text{FFT}(\text{imag}(\text{in}) + j \cdot \text{real}(\text{in})) \)
   \( \text{out} = \text{imag}(a) + j \cdot \text{real}(a) \)

2) \( a = \text{FFT}(\text{conj}(\text{in})) \)
   \( \text{out} = \text{conj}(a) \)

3) \( a = \text{FFT}(\text{in}) \)
   \( \text{out} = [a(0), a(N-1), a(N-2), \ldots, a(2), a(1)] \)

Multi-rate signal processing

- Upsample

- Down-sampling
Upsampling

- To upsample by $I$, add $I-1$ zeros between samples

\[
\begin{align*}
\uparrow & \quad I \\
\uparrow & \quad I \\
\uparrow & \quad I \\
\uparrow & \quad I \\
\end{align*}
\]
After upsampling, filter out $\frac{\pi}{2}$ to $\frac{3\pi}{2}$

"anti-image filter"

**Downsampling**

- To downsample by $D$, keep one of every $D$ samples

**Ex:** 1 MSample/sec signal, 0-100 KHz interested

downsampling as much as possible
\( \sqrt{1} \) \( \frac{1}{4} \) 3 

[Graph with frequency labels: 167 kHz, 333 kHz, \( 2\pi /f \), \( f \)]

\( \sqrt{\text{maybe}} \) \( \frac{1}{4} \) 4

[Graph with frequency labels: 125 Hz, 250 Hz, \( f \)]

\( \sqrt{x} \) \( \frac{1}{5} \) 5

[Graph with frequency labels: 100 Hz, 200 Hz, \( f \)]

Viterbi's coding

[Diagram with data, coding, conventional code, Viterbi decoder, and ACS (Add, Compare, Select)]

1) Calculating the Trellis

- ACS - Add, Compare, Select
2) Find Most Likely Path
3) Trace back
4) Recover data bit

![Diagram]

branch metric A

state metric 0

state metric 1

branch metric B

compare

select

decision bit

ew state metric