Introduction to DSP
or
What is Digital Signal Processing?

Outline

1. Basic DSP Architecture

2. Applications

3. Basic Algorithms
   a. FFT.
   b. Perfect mixer … divider.
   c. Digital filters (FIR and IIR filters).
Basic DSP Architecture

Digital IN → Digital Circuitry (microprocessor or FPGA) → Digital OUT

Analog IN → ADCs → Digital Circuitry (microprocessor or FPGA) → DACs → Analog OUT

Clock(s)
**DSP Advantages:**

- DSP is frequently **cheaper (in money and time)** than an equivalent analog circuit (especially circuit development).
- Analog electronics is hard … but programming is **easier**.
- **Sometimes DSP is the only option:** DSP circuits can do certain operations that are not possible with analog circuitry.

**A few DSP applications:**

- **Long distance communication:** digital communication has lower noise and can be compressed.
- **Voice and image recognition:** Use complex recognition algorithms.
- **“Software” Radio:** DSP can efficiently demodulate a signal from its RF carrier.
DSP in Physics

DSP is relatively young and has not yet made broad in roads into physics instrumentation. There are a few outstanding examples:

- **Complex coincidence triggering** in particle physics and quantum optics.
- **Custom feedback loops:** When PID feedback just isn’t good enough, a DSP-taylored feedback loop gain give you some extra feedback bandwidth.
- **DSP lock-in amplifiers:** Very stable and accurate, high dynamic range, and stable long-term integration.
- **Synthesized signal generator:** these devices generate their output signals using DSP.
  
  - arbitrary waveforms possible.
  - Very quick frequency changes.
  - Phase continuous frequency changes!
  - Extremely stable.
When should you use DSP?

You should use DSP when …

… you know that you could solve your circuit design by processing your signals with a computer, i.e. Maple, MatLab, Mathematica, C/C++, etc …

→ DSP just replaces the computer with a dedicated microprocessor or an FPGA.

→ DSP is faster, cheaper, and more stable than a desktop computer.
Basic DSP algorithms

- Fast Fourier Transform
- Multiplication … division
- Digital filters
FFT: Fast Fourier Transform

- Originally discovered by Gauss (~1805).
- Re-discovered by Cooley and Tukey (1965).
- Operates on a discrete set of \( N \) sampled values.
- Most FFT libraries require \( N = 2^n \).
- Discrete fourier transform computation time \( \sim N^2 \).
- FFT computation time \( \sim N \log_2(N) \).
  - FFT is cheaper and faster.

→ An FFT allows you to do DSP in frequency space.
→ The FFT is a standard programming library item for Microprocessors and FPGAs.
Data Windowing (I)

![Graph showing data points for time and volts]
Data Windowing (I)
Discontinuities produce extra Fourier components
Smooth the data to ZERO at the edges.

- Reduces spurious Frequency structures.
Digital Mixing (I)

Fourier Transform
Digital Mixing (II)

RED x GREEN = BLUE

Fourier Transform

Digital mixing does not produce any extra harmonics, unlike analog mixers.