CHAIN: Week of June 17

June 17

- Goals:
  - Identify factors (and their solutions) which can reduce quality of a signal
  - Research how power can be optimized by utilizing signal processing techniques
  - Read on wavelets
  - Predicting plot of signal in frequency domain given plot in time domain
- What I learned:

Purpose

- An adaptive FIR filter which uses the Parks McClellan algorithm to calculate coefficients
- Parks McClellan algorithm provides an optimal set of initial filter coefficients
  - Filter starts with near-ideal response, reducing the time and iterations needed for adaptation
  - Algorithm tries to achieve the best possible approximation to a desired frequency response in terms of minimizing the maximum error (the Chebyshev criterion)
  - Having a near-ideal response can be computationally intensive
  - Passband/stopband characteristics

- Adaptive filters are used to identify and cancel out noise from signals
  - LMS

Scope

- Digitizedcomplex.py can handle complex signals
  - Complex coefficients, input signals, and output signals
  - Decomposing signals into real and imaginary can reveal:
    - Phase information
    - Signal symmetry and asymmetry
    - Frequency content
    - Noise characteristics
- Digitized takes binary coefficients
- Parks McClellan algorithm
- Adaptive filtering
- DumbFilter.py uses basic arithmetic, digitizes coefficients
  - Threshold calculated dynamically by minimizing intra-class variance

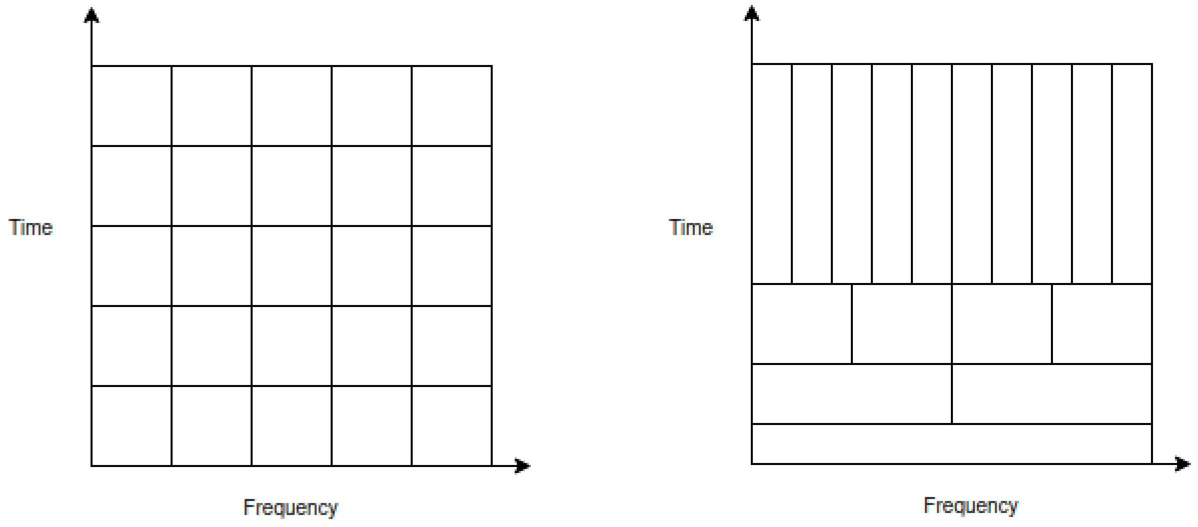
Spectral Analysis

- Purpose: represent a function by a sum of weighted sinusoidal functions called spectral components
- A spectrum can often be a revealing description of the function
- Spectral leakage
  - Causes: discontinuities in the original, non-integer number of periods
  - Soln.: Window function
    - Reduces the amplitude of the discontinuities at the boundaries of each finite sequence acquired by the digitizer
- Signal extraction problem
  - Soln.: spectral filtering

Wavelet Transform

- Fourier transform only works for stationary signals
  - Non-stationary signal: signal where there is change in the properties of signal
    - Q: In context of data collected by CHAIN, which of the properties are susceptible to change?
      - To me, "signal" is still very abstract term, like what makes up the signals we collect, what are we trying to look for in these signals?
  - Can tell the frequency but not at which time it occurred
  - Solution? Short-time Fourier transform (STFT)
    - Divide the signal into windows and perform Fourier transform on these windows
      - A narrow window size will have good time resolution but result in bad frequency resolution
      - A wider window size will have good frequency resolution but result in bad time resolution
  - Wavelets often given better signal representation using multiresolution analysis
  - Issues with frequency time resolution
- Wavelet transform allows us to analyze signals in different frequencies with different resolutions
  - Wavelets have time-widths adapted to their frequencies
- Wavelets can represent variety of signals, require few coefficients

Time and frequency resolutions of STFT and wavelet transform are illustrated in the figure below:



STFT Wavelet transform

How Can Wavelet Transform be Utilized to Reduce Power Consumption in an FPGA?

- Efficient signal representation
- Multi-resolution analysis
- Data compression
- Efficient hardware implementation
- Dynamic power management
- Targeted processing
- Reduced precision arithmetic

Drawbacks of Wavelet Transform

- Sacrifice frequency resolution in exchange for time localization
- Non-orthogonal basis
  - Work with frames
    - Generalization of Parseval's identity
      - Relaxes orthogonality requirement

$$A||f||^2 \leq \sum_{i=1}^{\infty} |\langle f, g_n \rangle|^2 \leq B||f||^2$$

  - May encode redundant information
    - Gram-Schmidt process can reduce redundancy
- Susceptible to boundary effects

June 18

- Goals:
  - Research wavelet theory
  - Power optimization implementations of FIR filters in Verilog
- What I learned:

June 19

- Goals:
  - Applications of wavelet transforms to CHAIN data
  - Learn what features of a signal we are trying to down-convert
  - What is our current digital down conversion architecture?
  - Discrete wavelet transform architectures
  - What information are we trying to extract from the signal data?
  - Performance requirements
  - DSP repository? What are we currently using?
  - Must down-sampling be statistical? Is it necessary?
    - What processes are involved in down-sampling?
- What I learned:
  - Tomographic inversion
  - "Local" information, theory behind locality

What Kind of Data Does MODIS collect?

- Primarily non-stationary data
  - Temporal variability
  - Spatial variability
  - Dynamic processes
  - Tomographic inversions

June 20

- Goals:
  - Cocotb
  - Cross verification
  - Implementing DumbFilter.py in Verilog
  - Design flow in Verilog
- What I learned:
  - Design steps in Verilog

Design Flow in Verilog

1. think about a design you want to implement, e.g. an adder
2. implement the design in VHDL/Verilog
3. implement a testbench in VHDL/Verilog
4. use the testbench for simulating your design (from step 2)
5. if this works and the simulation is successful, try to synthesize the design
6. do all the other stuff, like map, place and route
7. build a .bit file
8. use your JTAG to program your FPGA

June 21

- Goals:
  - Cocotb implementation
  - Look more into Elyas' summer 2023 project
- What I learned:

Resources

- https://dsp.stackexchange.com/questions/79586/advantage-of-stft-over-wavelet-transform
- https://onlinelibrary.wiley.com/doi/10.1002/cta.3822
- https://link.springer.com/article/10.1007/s10470-023-02227-y
- https://www.slideshare.net/slideshow/introduction-to-wavelet-transform-with-applications-to-dsp/37136588
- https://kth.diva-portal.org/smash/get/diva2:212488/FULLTEXT01.pdf