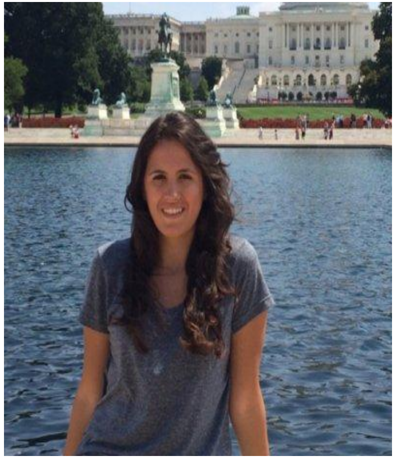
SDR in ORBIT:

Spectrum Sensing

WINLAB Summer Internship 2015

Team



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SDR in ORBIT

Three groups currently working with software-defined radio:

Indoor Localization

Spectrum Sensing

LTE-Unlicensed

Software-defined radio - radio communication system in which components that would usually be implemented using hardware are instead implemented using software

SDR in ORBIT

- The ORBIT testbed has an array of Universal Software Radio Peripherals for use in software-defined radio applications.
- USRPs can transmit or receive signals ranging from DC to 6 GHz.
- Controlled by software applications such as GNU Radio

Spectrum Sensing

Project Goals

- Using ORBIT, configure radio receiver(s) to collect IQ time samples
- Process the samples to obtain frequency-domain data
- Analyze frequency data to identify any unknown signals
- Repeat with modified receiver carrier frequency, sampling rate, etc. to scan the available frequency spectrum for signals
- Implement methods above in real-time

Spectrum Sensing

Project Divisions

- **CPU Implementation** - Mike Collins, Nicole DiLeo
    - Design of signal processing algorithms, data visualization tools
    - Implementation in MATLAB and C++
- **FPGA Implementation** - Christina Baaklini, Nick Cooper
    - Performance improvement on high-speed processor
    - Implementation in VHDL

CPU Division

Current Progress

- Basic Research in Digital Signal Processing
- Familiarization with ORBIT Framework
- Familiarization with MATLAB Signal Processing Tools
- Design of ORBIT Grid Experiments
- Development of MATLAB Spectrogram Script
- Beginning of C++ Implementation

CPU Division

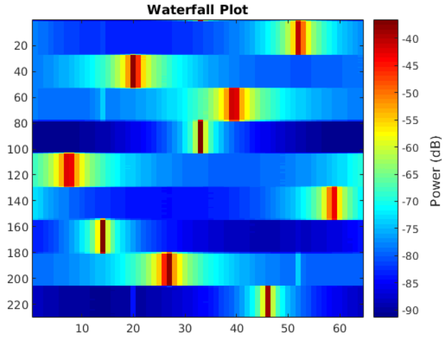
Preliminary Research and Training

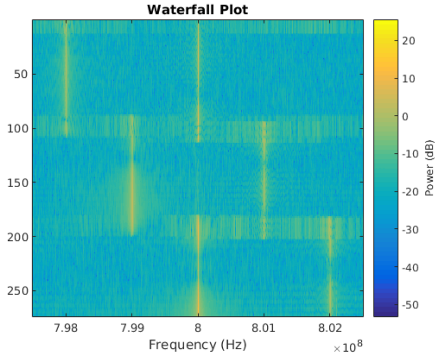
- Learned basic Digital Signal Processing concepts such as:
  - ***Sampling*** - measurement of analog signal at discrete time intervals
  - ***Quantization*** - conversion of a continuous range of values into discrete values using a certain number of bits
  - ***Nyquist Frequency*** - twice the highest frequency of the continuous-time signal
- Learned to use the ORBIT Measurement Framework and Wiserd application to run tests and take measurements on ORBIT
- Learned MATLAB signal processing tools such as:
  - **fft/ifft** - Fast Fourier Transform and Inverse
  - **fft_shift** - Adjusts zero-frequency component in FFTs

CPU Division

ORBIT Grid Experiments

- Used the ORBIT Experiment Description Language and the Wiserd application to run experiments on the ORBIT testbed
- Started with one transmitter and one receiver and collected preprocessed frequency-domain data
- Expanded experiments to multiple transmitters/receivers and extracted raw IQ time samples





CPU Division

MATLAB Spectrogram Script

- Converts time-domain signal into frequency-domain
- Applies moving average filter to reduce noise
- Calculates power magnitudes at given frequencies
- Generates a waterfall plot
- Plots individual FFTs and applies a simple peak-finding algorithm

CPU Division

C++

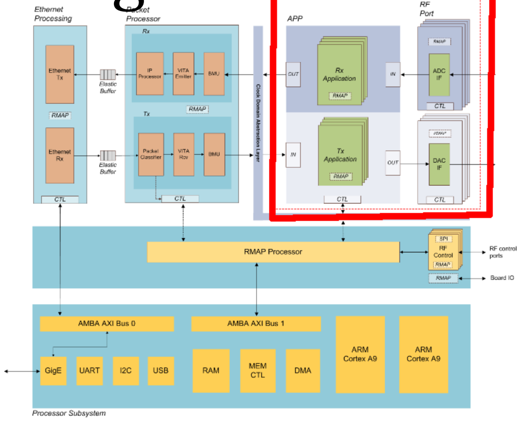
```
function [ffts,moving_avg,peaks]=spectro(m,c_fr,s_fr,k,o,w,avg)
% m = row matrix of IQ samples
% c_fr = carrier frequency
% s_fr = sampling frequency
% k = size of FFTs
% o = overlap between FFTs (between 0 and 1)
% w = row matrix of size k to be used as a window function
% avg = number of ffts to be averaged together
o = 1-o; N = numel(m);
start = @(j) k*o*j+1; % beginning of each FFT
stop = @(j) start(j)+k-1; % end of each FFT
ffts = [];

i = 0;
fprintf('Generating FFTs ... ');
while stop(i) < N
        s = m(start(i):stop(i));
        s2 = w.*s;
        s2f = fft(s2,k);
        s2f_shift = fftshift(s2f);
        ffts = [ffts;s2f_shift];
        i = i+1;
end
fprintf('Done\n');
```

```
void fft_avg::spectro() {
        overlap_ = 1-overlap_;
        unsigned int N = iq_samples_.size();
        int index = 0;

        vector<complex<float> > s;
        vector<complex<float> > s2;
        s.resize(fft_size_);
        s2.resize(fft_size_);
        empty_vector_.resize(fft_size_, 0);

        out_ = (fftwf_complex*) &(empty_vector_.front());
        plan_ = fftwf_plan_dft_1d(fft_size_, in_, out_, FFTW_FORWARD,
        FFTW_ESTIMATE);

        while (stop(index, fft_size_ , overlap_) < N) {
                for (unsigned int i = start(index, fft_size_ , overlap_);
                i <= stop(index, fft_size_, overlap_);  i++) {
                        s.push_back(iq_samples_[i]);
                        s2.push_back((window_[i])*(s[i]));
                }
                in_ = (fftwf_complex*) &(s2.front());
                fftwf_execute(plan_);
                fft_data_.push_back(empty_vector_);
                index++; }
}
```

VHDL/FPGA Division

Goals

- Implement spectrum sensing programs onto a Xilinx FPGA (ZedBoard)
- Use this to identify available frequencies using an FMC receiver.



VHDL/FPGA Division

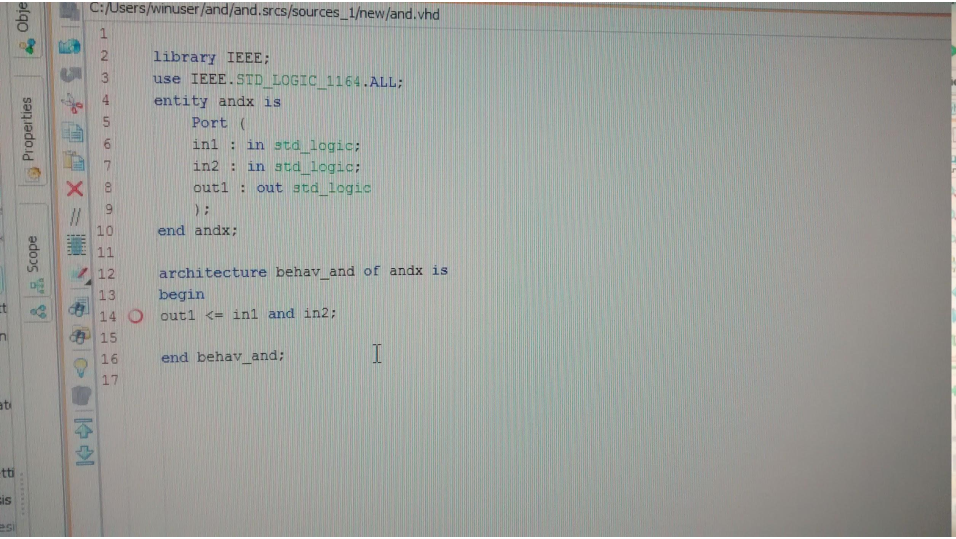
Progress

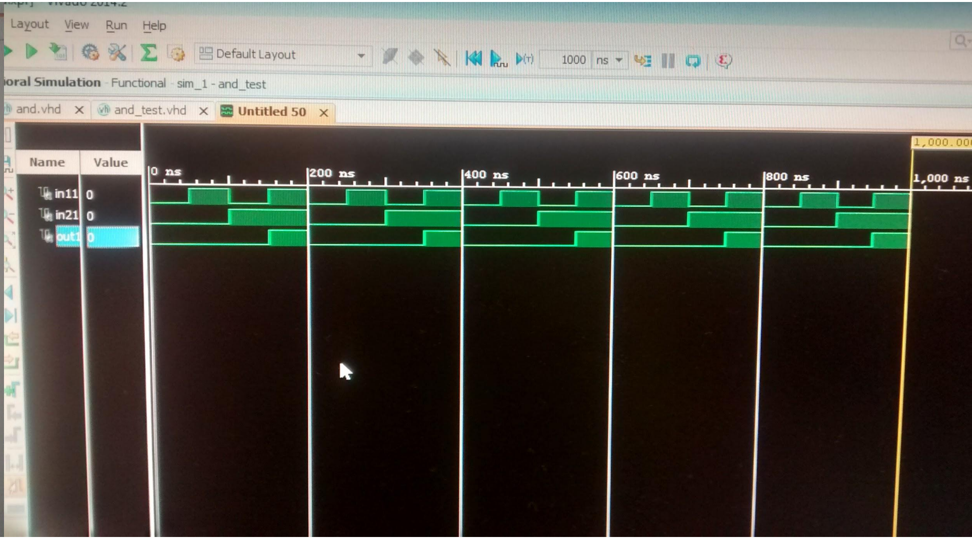
- Over the course of the last two weeks we have been learning the basics of vhdl coding and implementation onto an FPGA
- Programs created and sent to ZedBoard:
  - Simple Combinatorial Logic
  - Binary Counter (Sequential Logic)
  - Basic 4-1 multiplexer

VHDL/FPGA Division

Examples (Code and Sim Waveforms)

Simple Combinatorial Logic (and gate)

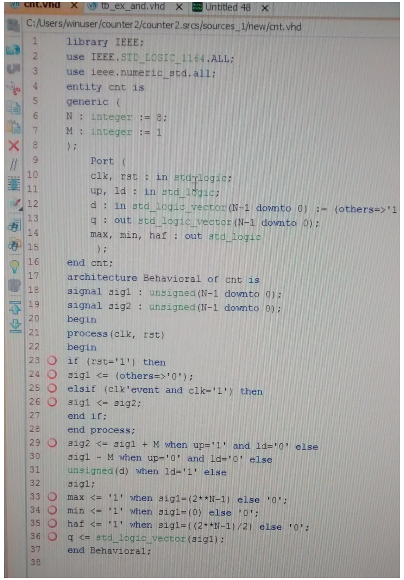


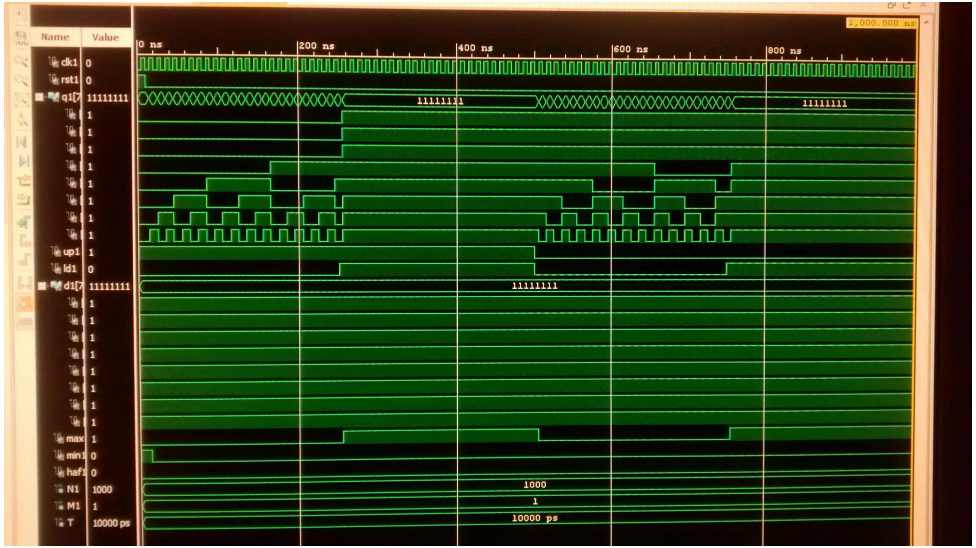


VHDL/FPGA Division

Examples (Cont.)

Sequential Circuit(Binary Counter)

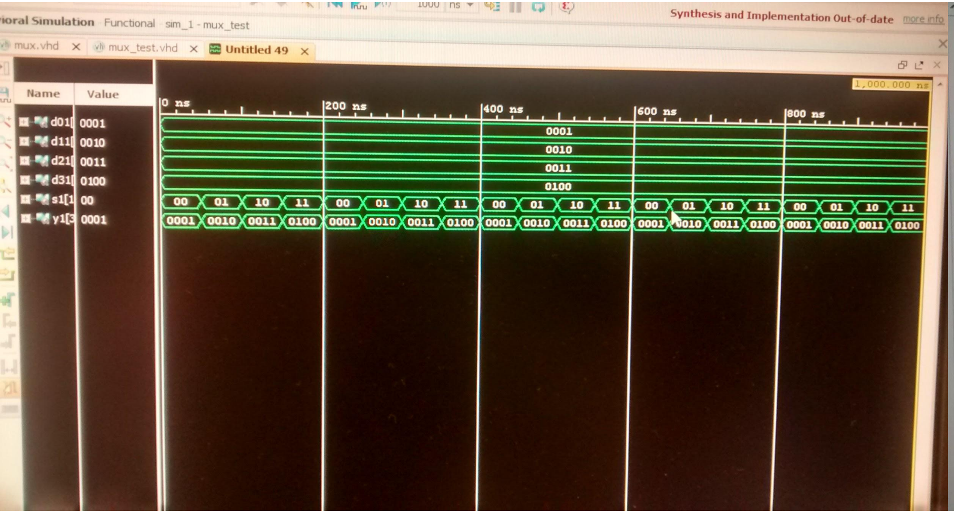


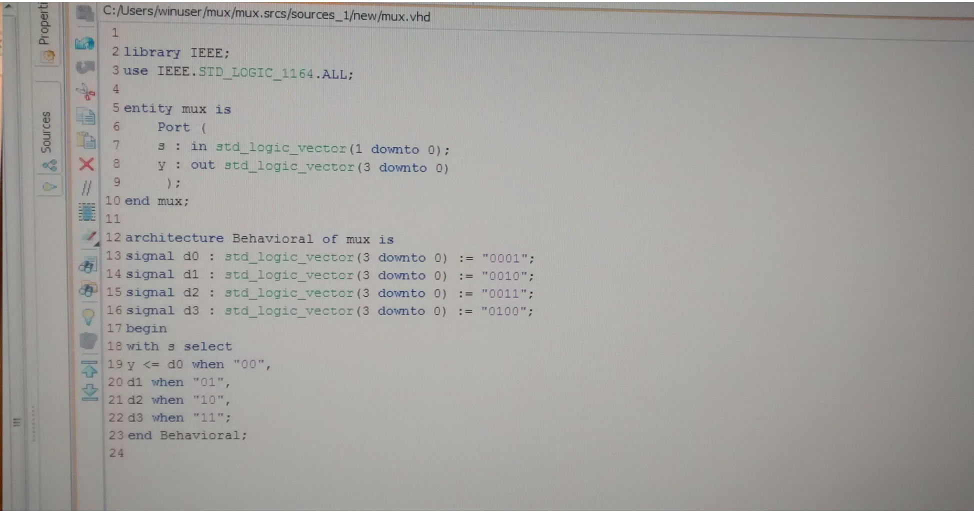


VHDL/FPGA Division

Examples (Cont.)

4-1 Multiplexer





Moving Forward

CPU Division

- Continue C++ implementation
- Start running tests with real-time analysis
- Create a user interface for scanning the frequency spectrum

VHDL/FPGA Division

- Apply VHDL to enhance SDR features on ZedBoard
- Eventually run tests with receiver attached to board