The Design and Implementation of the Polyphase Filterbank on the Xilinx Field Programmable Gate Array

Team: Mariya Taylor, Mohammad Samad, Victoria Pettway, Alex Rogers, Asher Stemmons **Mentor: Tracee Jamison-Hooks**

BACKGROUND

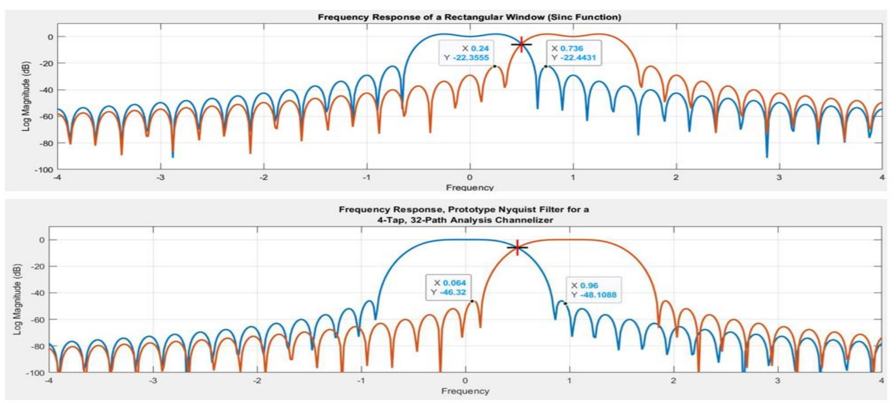
The Habitable Worlds Observatory (HWO) represents the next generation of space based astronomical exploration. Its goal is to identify biosignatures on distant exoplanets using high sensitivity detection systems by using Microwave Kinetic Inductance Detectors (MKIDs). FPGA Hardware is utilized because it is well-tested and proven. However, the transition to space qualified systems presents new challenges, such as limited resources. The role of the detector readout system is to process high amounts of data via advanced digital signal processing algorithms. When functioning properly, this system will detect faint space signals that could indicate life on other worlds.

THEORY

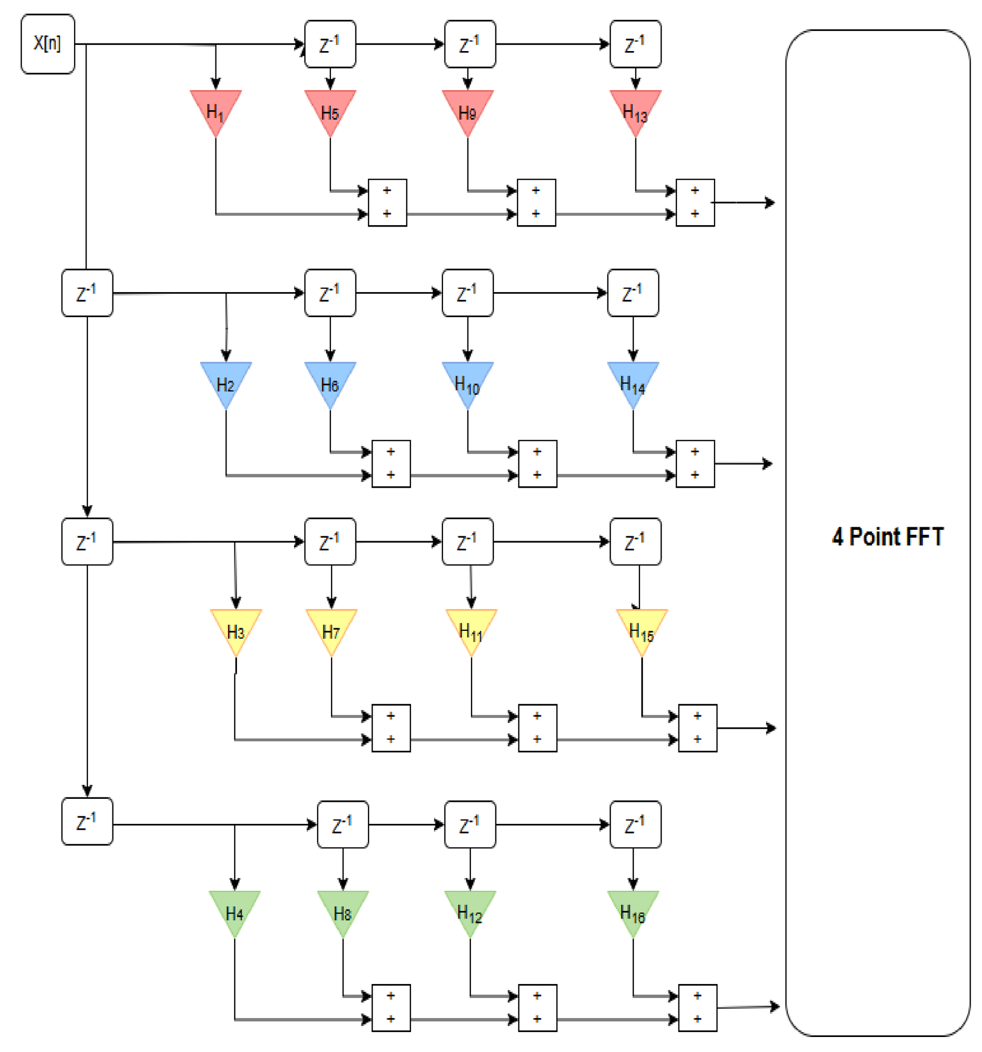
The Polyphase Filter Bank (PFB) is an efficient architecture for decomposing time-domain signals into frequency components. While frequency transformation is traditionally accomplished using the Discrete Fourier Transform (DFT), FPGA implementations utilize the computationally efficient Fast Fourier Transform (FFT). However, standard FFT implementations suffer from spectral leakage between frequency bins. The PFB addresses this by incorporating polyphase FIR filtering before the FFT stage effectively suppressing unwanted frequencies and science information spilling into adjacent bins.

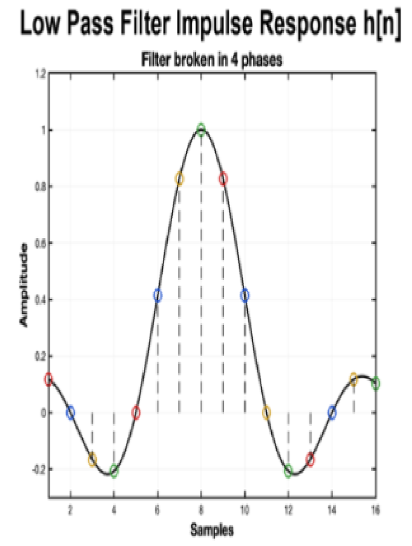
Frequency Response of FFT vs. PFB

- **FFT (Top Image)**
  - High Side-lobes (-22dB)
  - Faint Signals (below -22dB) may never be detected despite averaging.
  - Vulnerable to spectral leakage
- **PFB (Bottom Image)**
  - Frequency response of filter can be tailored to science requirements
  - Spectral leakage can be contained.



DESIGN

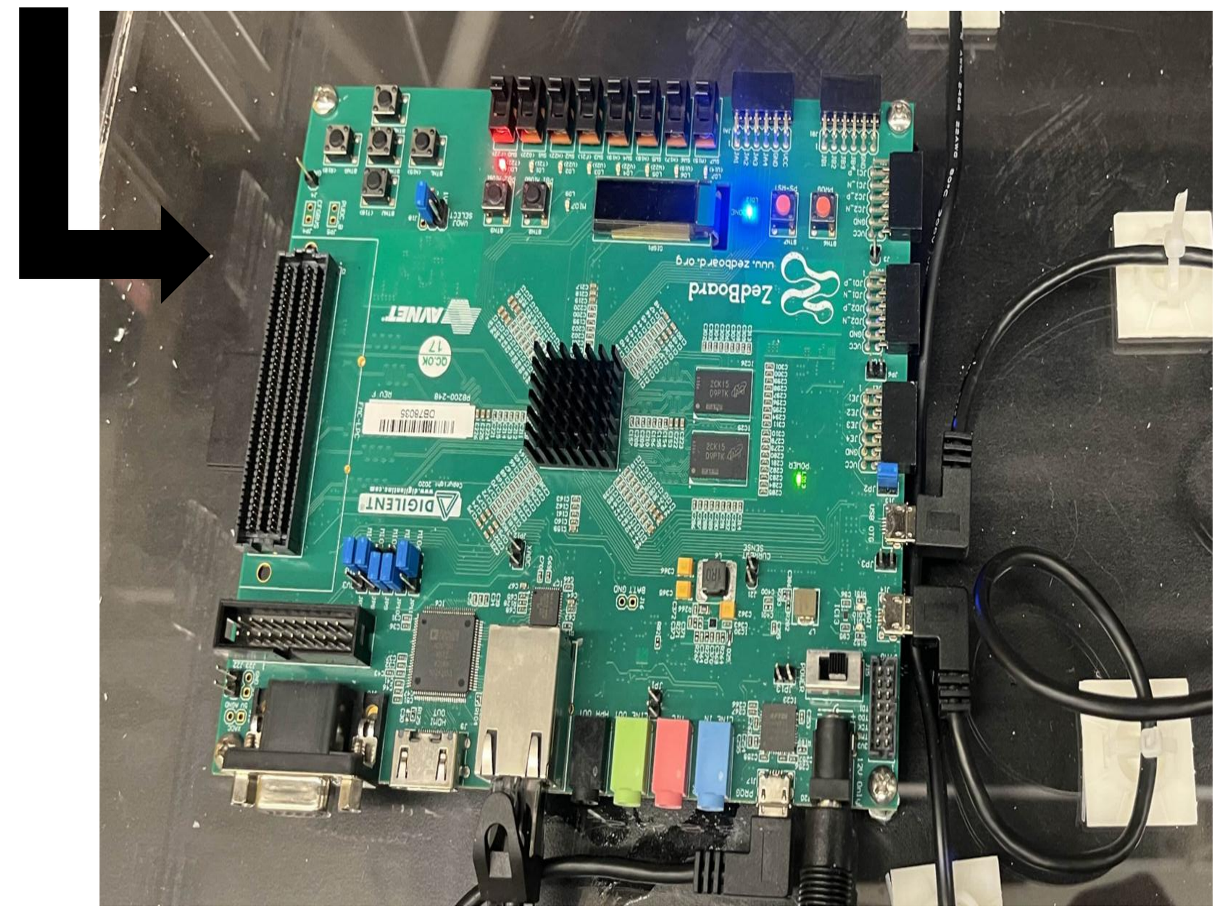




1	5	9	13
2	6	10	14
3	7	11	15
4	8	12	16

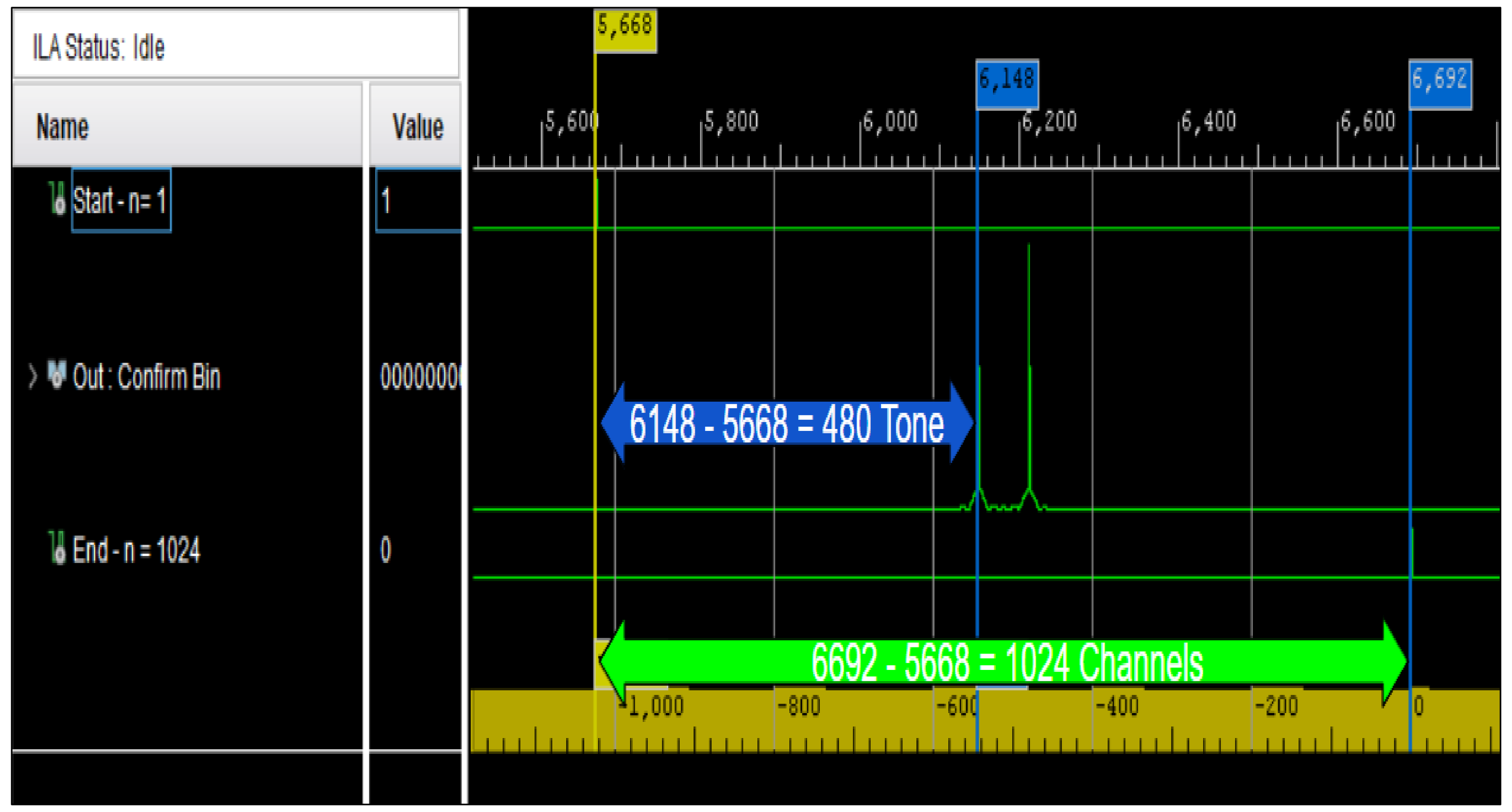
Each row is a phase of the filters impulse response h[n]

HARDWARE



Our design workflow involves creating the PFB architecture in MATLAB Simulink, converting it to hardware description language (HDL), and then synthesizing and implementing the design onto the FPGA. Once deployed on the hardware, we utilize Vivado/Vitis monitoring software to capture and analyze the output signals, verifying the PFB performance and spectral averaging accuracy.

RESULTS



Hardware Implementation of PFB

Sampling Frequency (Fs): 128 MHz
Signal Frequency (F): 60 MHz
PFB Length : 1024
n = (60 MHz / 128 MHz) × 1024
Calculated Bin Number (n): **480**

CONCLUSION

This project focuses on the detector readout system for a space-qualified FPGA as part of the Habitable Worlds Organization. The FPGA will process extremely faint signals collected in space, enabling onboard identification of frequency patterns that may indicate the presence of life.

Starting from a 4-PT PFB all the way to a 1024-PT PFB, the development of the PFB was a highly rewarding project. Combining advanced signal processing techniques with FPGA implementation introduced the team to a unique area of electrical engineering that many professionals never encounter in their academic or career paths.