SPECTROMETER
AVN TRAINING 2019

National Research Foundation

SARAO
South African Radio Astronomy Observatory

Mr. Heystek Grobler – SARAO/HartRAO/UJ

Content

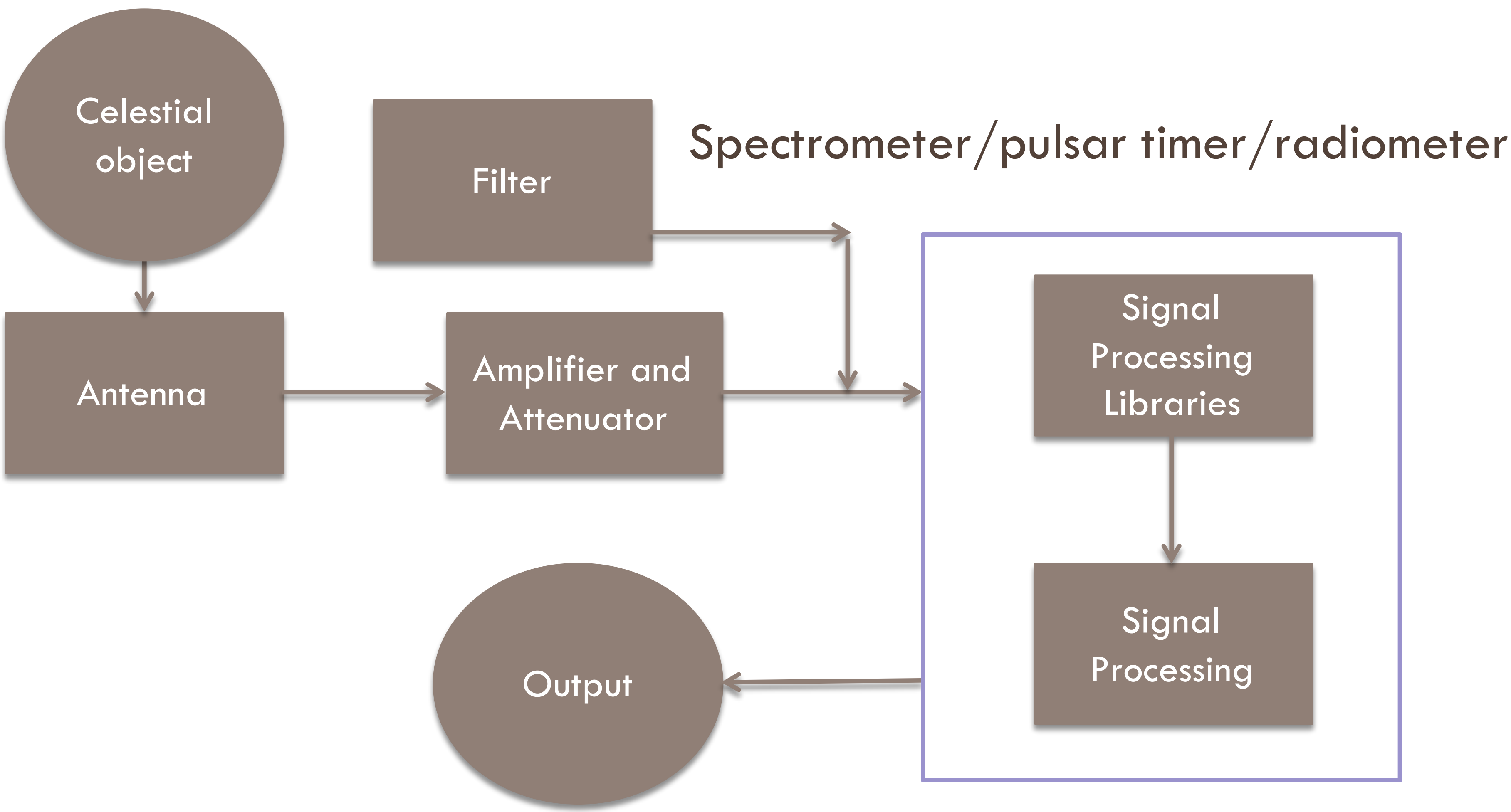
- Introduction
- Background/History
- Integrated Circuit Chips (ICs)
- Central Processing Units (CPUs)
- Graphical Processing Units (GPUs)
- Field Programmable Gate Arrays (FPGAs)
- Berkley Emulation Engine (BEE2)
- Internet Breakout Board (IBOB)
- Reconfigurable Open Architecture Computing Hardware (ROACH)
- Analogue to Digital Converter (ADC)
- Signal Processing on ROACH
- ROACH Software Demonstration
- Questions

Introduction

Spectrometer:

In radio astronomy, a spectrometer is an instrument for studying the spectrum of cosmic radio emissions received by a radio telescope.

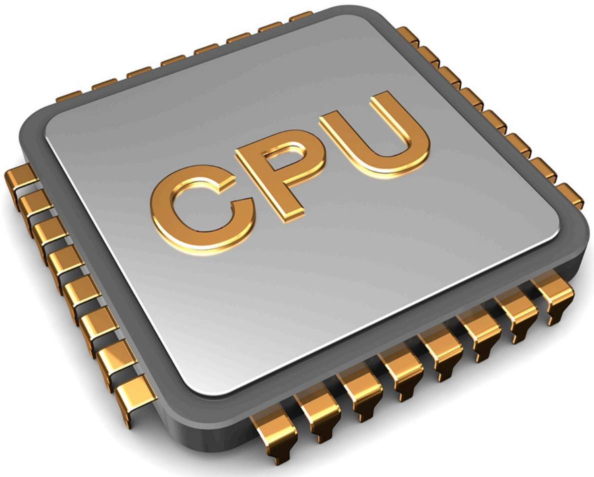
Background/History

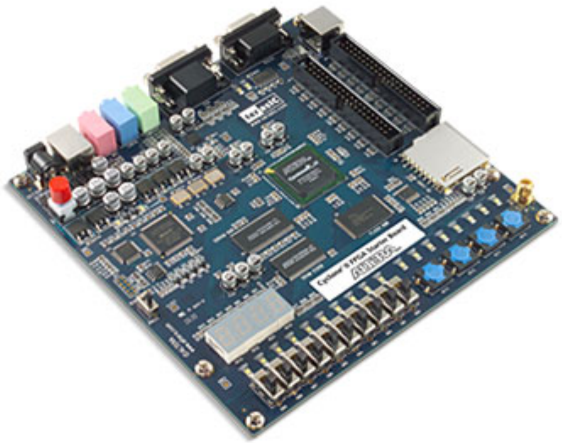


Background/History

There are currently four available solutions:

1. Signal Processing Chips
2. CPUs
3. GPUs
4. FPGAs





Integrated Circuit Chips (ICs)

Digital Signal Processing (DSP) Chips consist of a microprocessor that can be programmed in a range of programming languages (such as C and C++) for radio astronomy applications.

Texas Instruments TMS320C6455

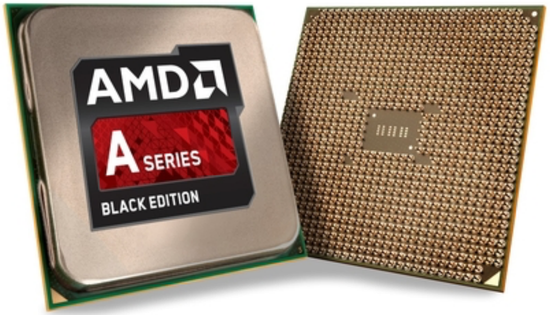
- 1GHz
- 64 Bits of data

Central Processing Units (CPUs)

NRF National Research Foundation | SARAO South African Radio Astronomy Observatory

Digital signal processing applications for radio astronomy can also be implemented is through the use of Central Processing Units such as:

- Intel generation processors (I3, I5, I7, I9, Xeon)
- AMD processors



Graphical Processing Units (GPUs)

Another way to implement digital signal processing applications for radio astronomy is through the use of General Purpose Computing on Graphical Processing units (GPGPU). GPGPU is the method of using a GPU to perform applications and computations that are traditionally handled by a Central Processing Unit (CPU).

Beneficent over CPUs due to:

- Larger amount of memory bandwidth
- Increased amount of computational power

Field Programmable Gate Arrays (FPGAs)

Field Programmable gate Arrays architecture provides high computational density and configurability. FPGA's cost thousands of dollars and can be five times more expensive than Intel and AMD processors. FPGAs are a lot more powerfull than CPUs, GPUs or DSP Chips

The Xilinx Virtex 2 Pro 70 FPGA can do up to 48 billion MAC (16 bit) operations per second. That is 50 times more than Intel's Pentium 4 processor.

Benefits of the FPGA:

- Open Source
- Not specialized
- Parallel Processing
- Powerful

Field Programmable Gate Arrays (FPGAs)

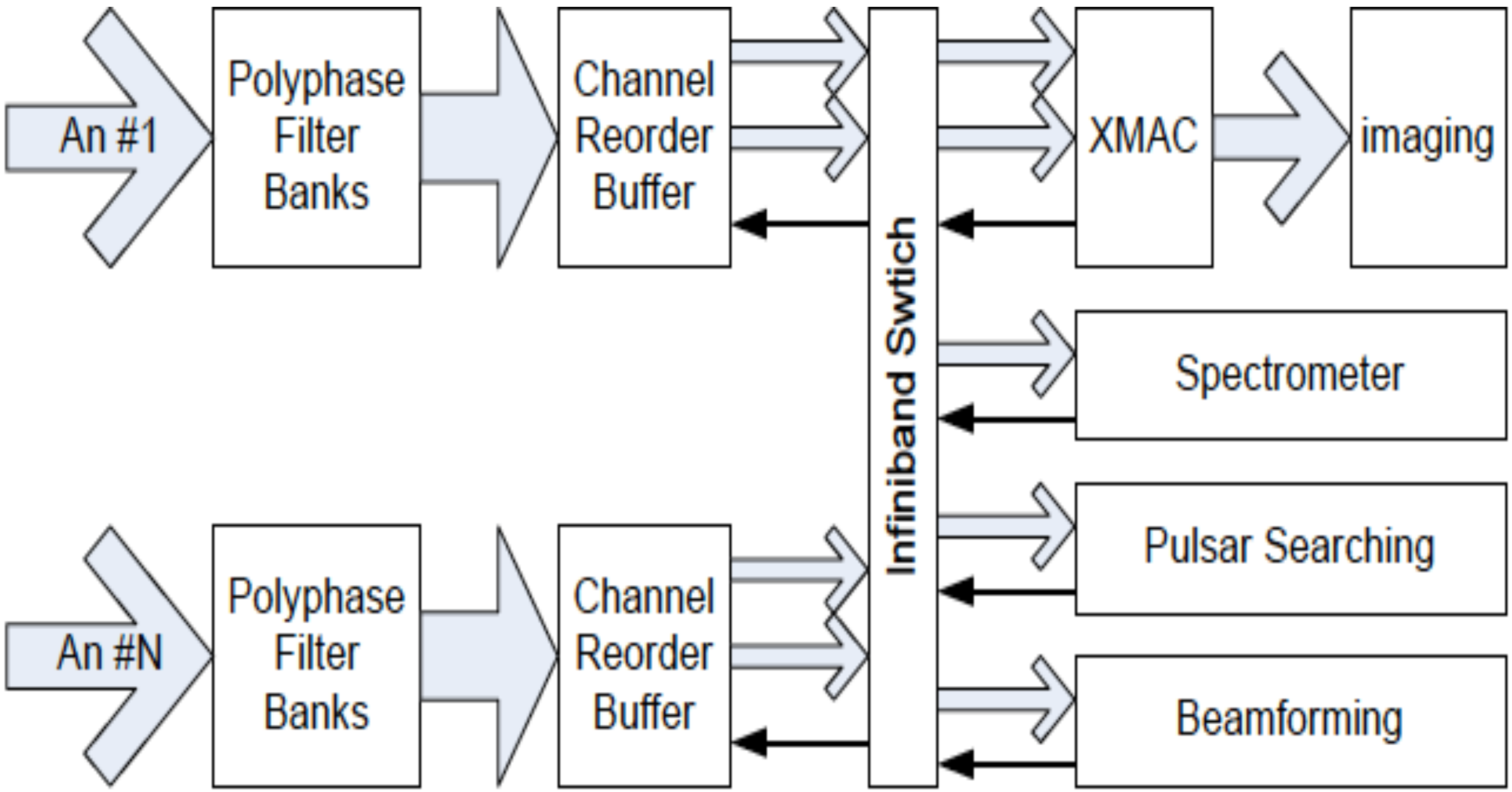
The current FPGA choice is the XILINX FPGAs that work with The Center for Astronomy Signal Processing and Electronics Research (CASPER) Libraries and tool chain:

https://casper.berkeley.edu/wiki/Main_Page

The current CASPER products and technologies are:

- Bee (Second Generation XILINX Vertex FPGA)
- BEE2 (Third Generation XILINX Vertex FPGA)
- IBOB (Fourth Generation XILINX Vertex FPGA)
- ROACH (Fifth Generation XILINX Vertex FPGA)
- ROACH 2 (Sixth Generation XILINX Vertex FPGA)
- SKARAB (Seventh Generation XILINX Vertex FPGA)

Berkley Emulation Engine (BEE2)



BEE2 Implementation

Internet Breakout Board (IBOB)

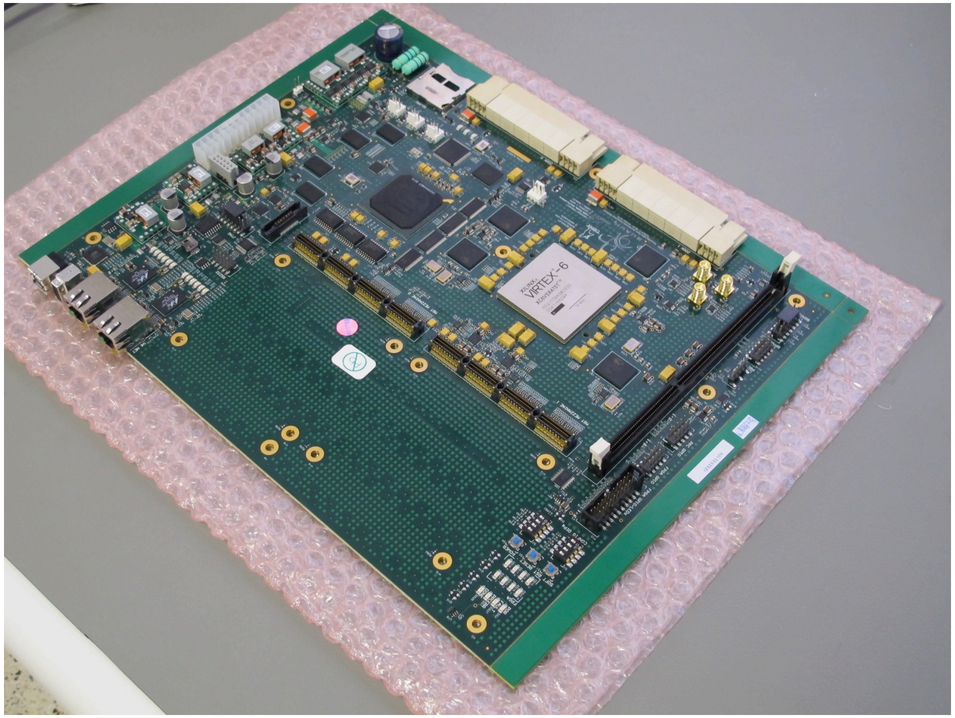
The IBOB was mainly intended to be a breakout board but turned out to be an effective pre-processing board as well as a powerful standalone platform. The IBOB platform has been used in many applications such as to interface ADC boards in digitizing data for processing.

The successful implementation of the IBOB platform and its widespread applications led to the development and design of a next-generation board called the ROACH that is based on the Virtex-5 FPGA.

Reconfigurable Open Architecture Computing Hardware (ROACH)

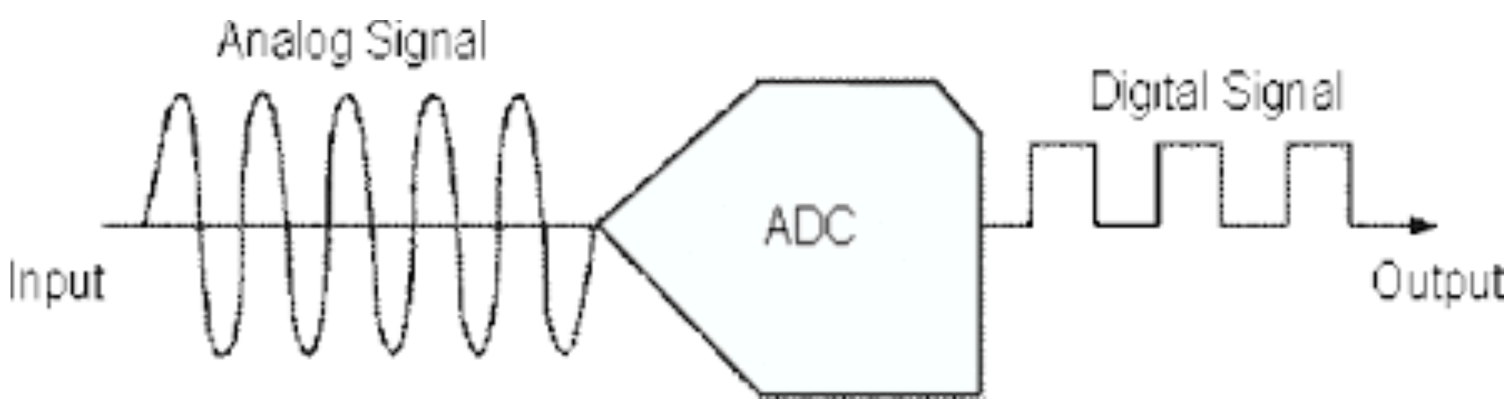
ROACH stands for Reconfigurable Architecture Computing Hardware and is a standalone processing board. The ROACH platform is also designed and developed by CASPER. It makes use of a XILINX 5 Vertex FPGA

This is also the main platform for the new spectrometer here at HartRAO



Analogue to Digital Converter (ADC)

Digitization or digital sampling is the method of converting an analogue signal to a digital signal. This is done through sampling devices known as analogue to digital converters (ADCs). An ADC is characterised by the number of bits per sample and its sampling rate.



Signal Processing Theory:

Bandwidth: The width of your frequency spectrum, in Hz. This depends on the sampling rate.

$$BW = sampling\ rate = \frac{1}{sampling\ period}.$$

For **Nyquist** sampled data the rate is half this

$$BW = \frac{sampling\ rate}{2} = \frac{1}{2 \times sampling\ period},$$

Signal Processing on ROACH

Frequency resolution: The frequency resolution of a spectrometer, Δf, is given by

$$\Delta f = \frac{BW}{no.\ channels},$$

Time resolution: Time resolution is simply the spectral dump rate of your instrument.

Signal Processing on ROACH

Nyquist Theorem

One of the most fundamental theorems for sampling is the Nyquist Theorem. The theorem states that a band-limited signal can be fully recovered when the sampling rate is double the bandwidth.

The Nyquist sampling rate is also known as the critical sampling rate

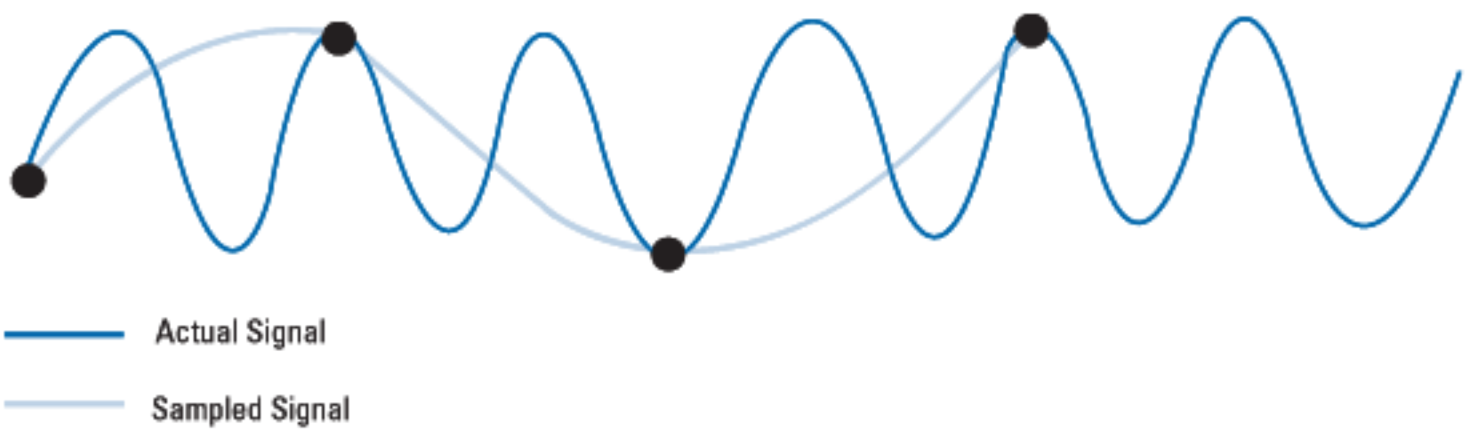
Signal Processing on ROACH

Aliasing: Occurs when the input signal is changing much faster than the sample rate. For example, a 2 kHz sine wave being sampled at 1.5 kHz would be reconstructed as a 500 Hz (the aliased signal) sine wave.

Nyquist Rule: Use a sampling frequency at least twice as high as the maximum frequency in the signal to avoid aliasing.

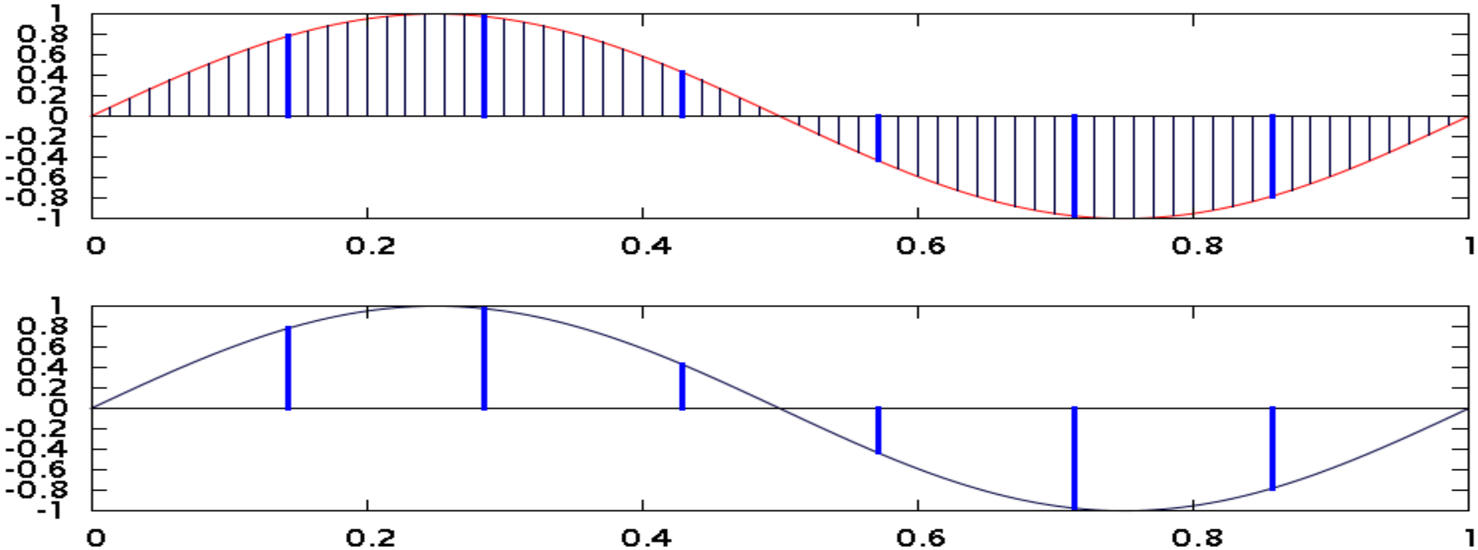
Signal Processing on ROACH

In signal processing, **under sampling** or bandpass sampling is a technique where one samples a bandpass-filtered signal at a sample rate below its Nyquist rate



Signal Processing on ROACH

In signal processing, **over sampling,** is the process of sampling a signal with a sampling frequency higher than the Nyquist rate. Theoretically, a bandwidth-limited signal can be perfectly reconstructed if the sampled signal is sampled at the Nyquist frequency or above it.



Signal Processing on ROACH

The Fast Fourier Transform (FFT)

In signal processing, the Fast Fourier Transform (FFT) is a method for doing a finite Fourier Transform on a series of N data points in approximately $N\log_2$ operations

$$\hat{f}(\xi) = \int_{-\infty}^{\infty} f(x)\, e^{-2\pi i x \xi}\, dx,$$

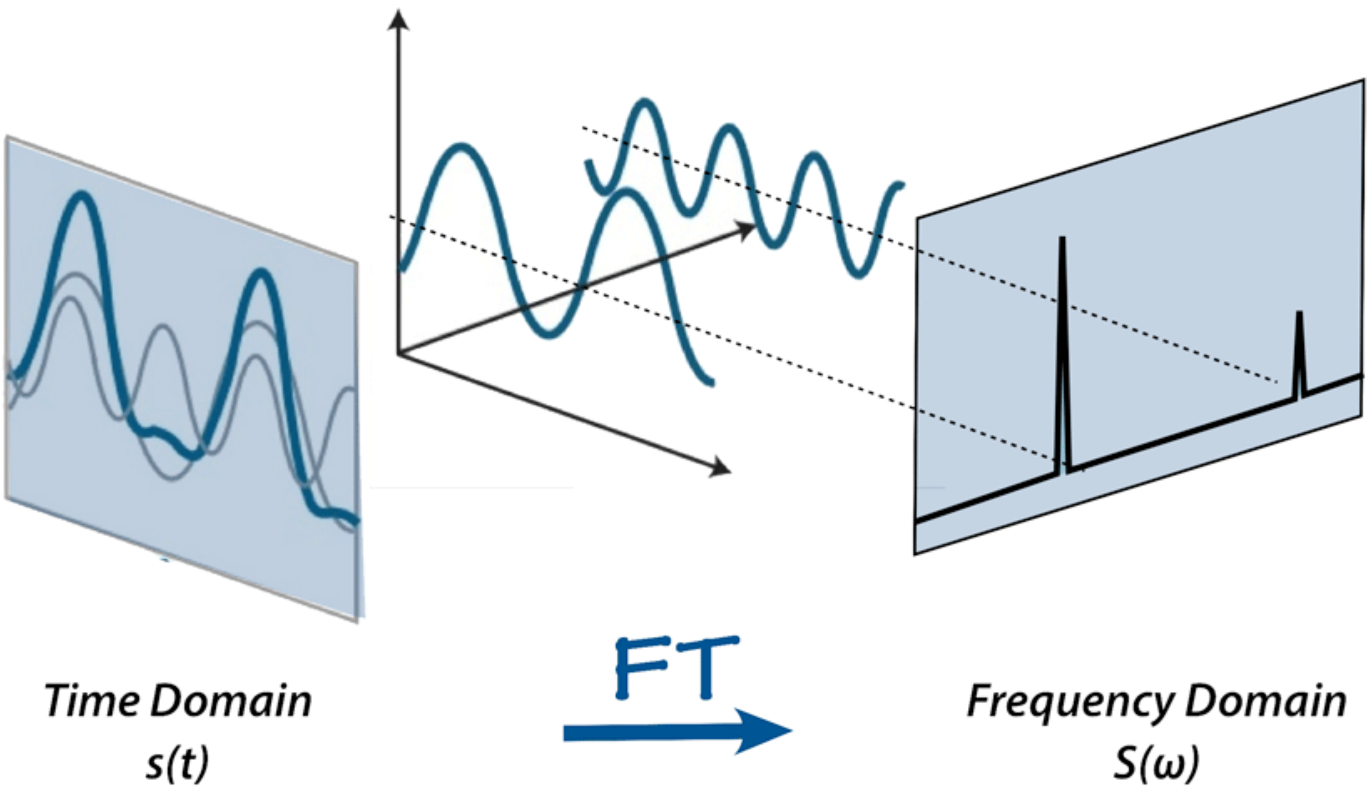
Formula for the Discrete Fourier Transform

$$f(x) = \int_{-\infty}^{\infty} \hat{f}(\xi)\, e^{2\pi i x \xi}\, d\xi,$$

Formula for the Inverse Discrete Fourier Transform

Signal Processing on ROACH

The Fast Fourier Transform (FFT)



Signal Processing on ROACH

Polyphase Filter bank

A Polyphase filter bank can be thought of as a Fast Fourier Transform with an enhanced filter response.

The PFB suppresses out of band channels and produces a flat response across all channels. When PFBs is used on FPGAs, it consumes 1.5 times more resources compared to that of a direct FFT

Correllators and Spectrometers usually make use of the PFBs

ROACH Software Demonstration

NRF
National Research Foundation

SARAO
South African Radio Astronomy Observatory

ROACH

Reconfigurable Open Architecture
Computing Hardware

Questions