DRONE SCOUT

Development Team

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Team Lead

System Design

PCB

Maga Kim

Software Development

Feature Detection

Anthony Chen

Software Development

GUI

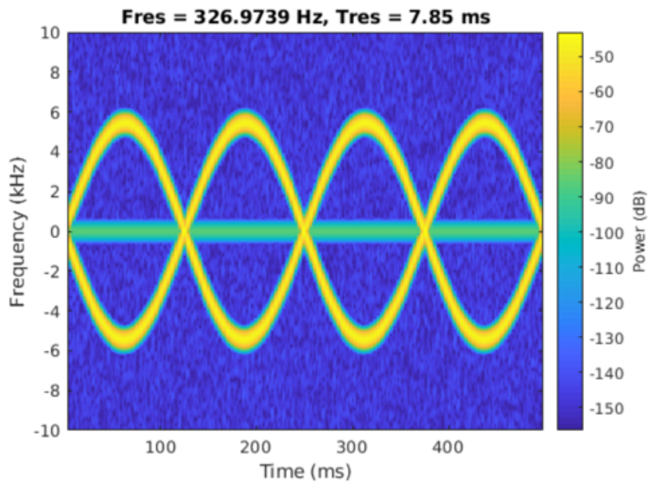
Sungin Kim

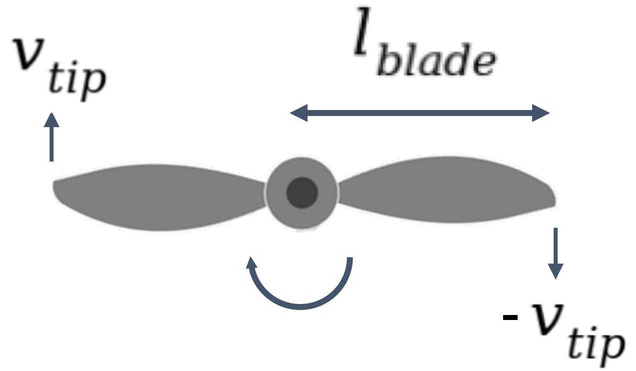
Software Development

Feature Detection

Overview

- Drone Scout is an X-band radar system capable of detecting a drone hovering in a targeted area
- By analyzing the micro-doppler signatures of a drone's propellers in the radar return signals, we can determine the presence of a drone along with some of its features
- An external HDMI display will show the following:
  - Spectrogram plot
  - Drone features

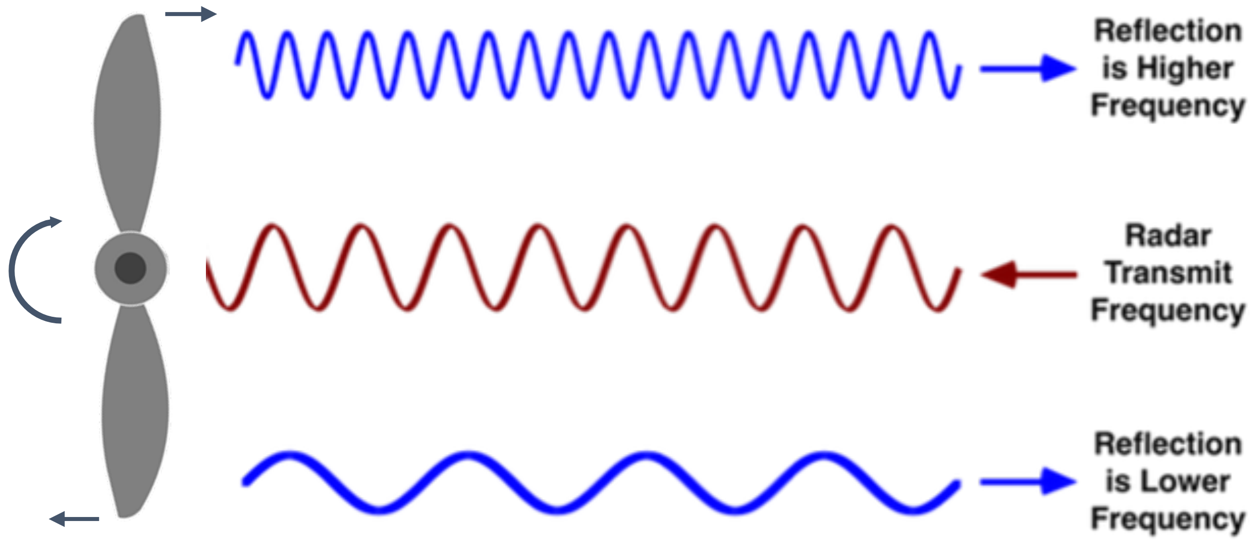




Applications

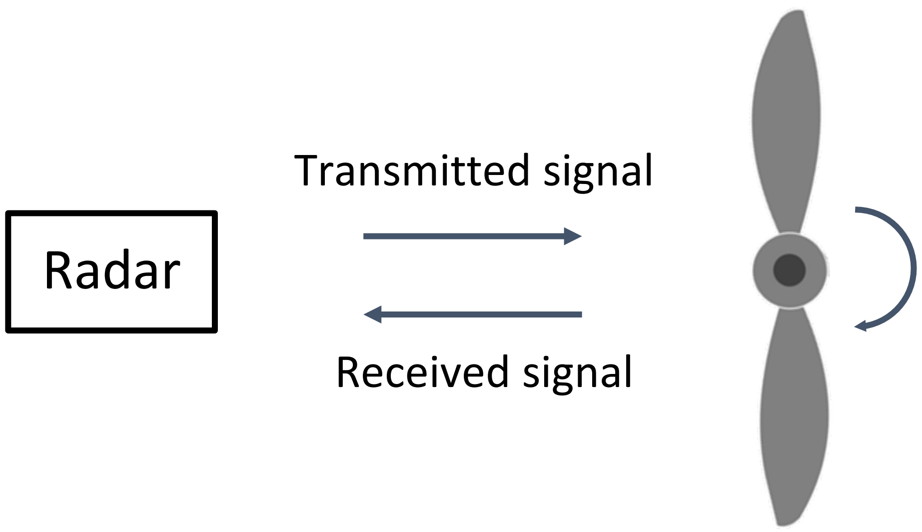
- Defend against possible military and terrorist attacks
  - Large drones carrying dangerous payloads:
    - Explosives
    - Biological weapons
- Protect government and civilian privacy
  - Smaller drones equipped with:
    - Cameras
    - Microphones
    - Other sensors

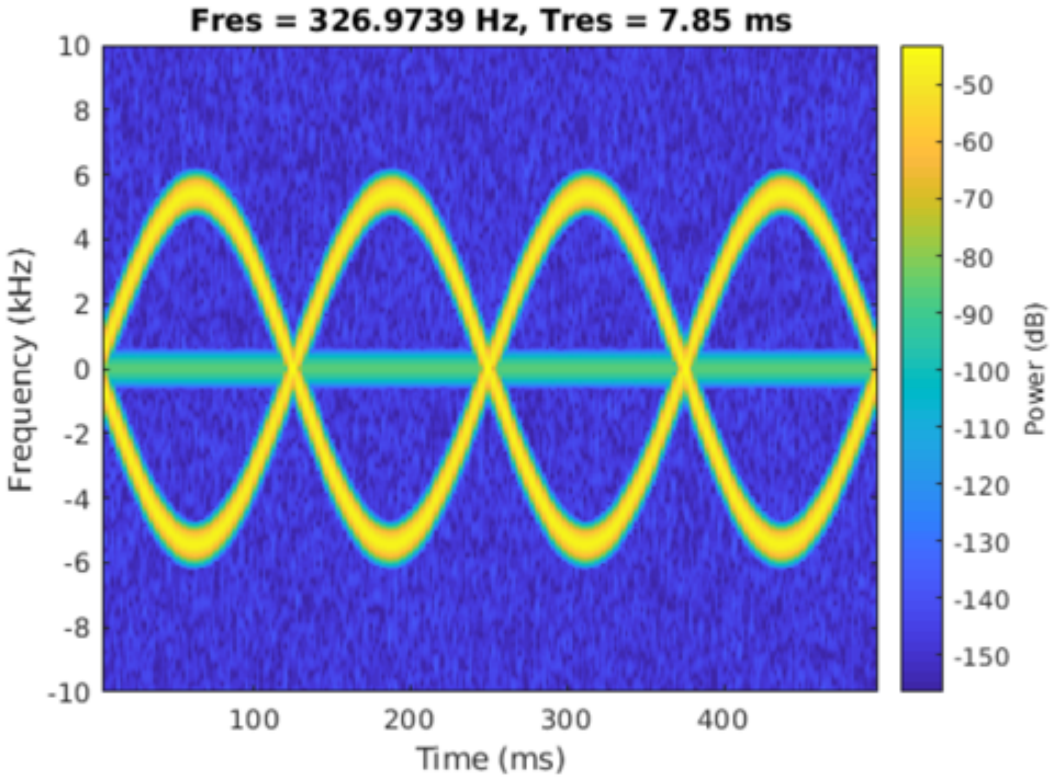
Micro-Doppler Effect in Radar



- Mechanical vibration or rotation of an object that may induce additional frequency modulations on the return signal of a radar
- The reflection from a propeller would cause an increase and decrease in frequency at any given time
- High frequency and short wavelength associated with X-band radars allow the detection of these modulations

Micro-Doppler Signatures of Drones





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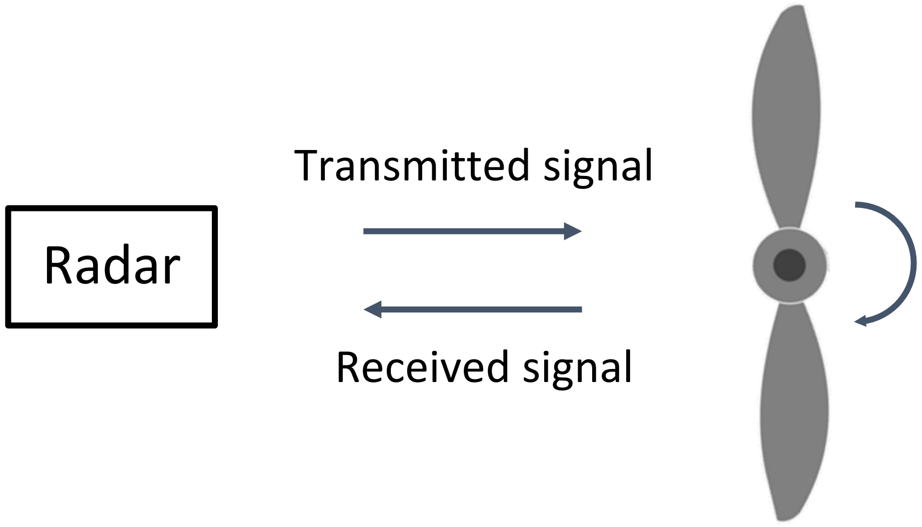
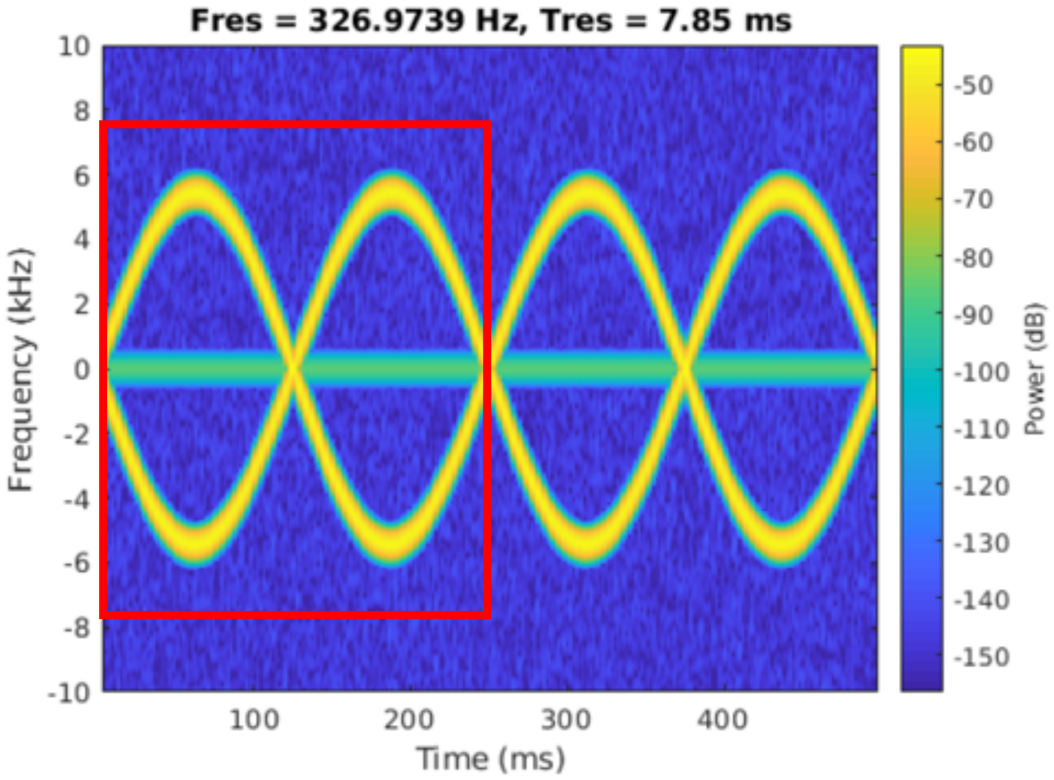
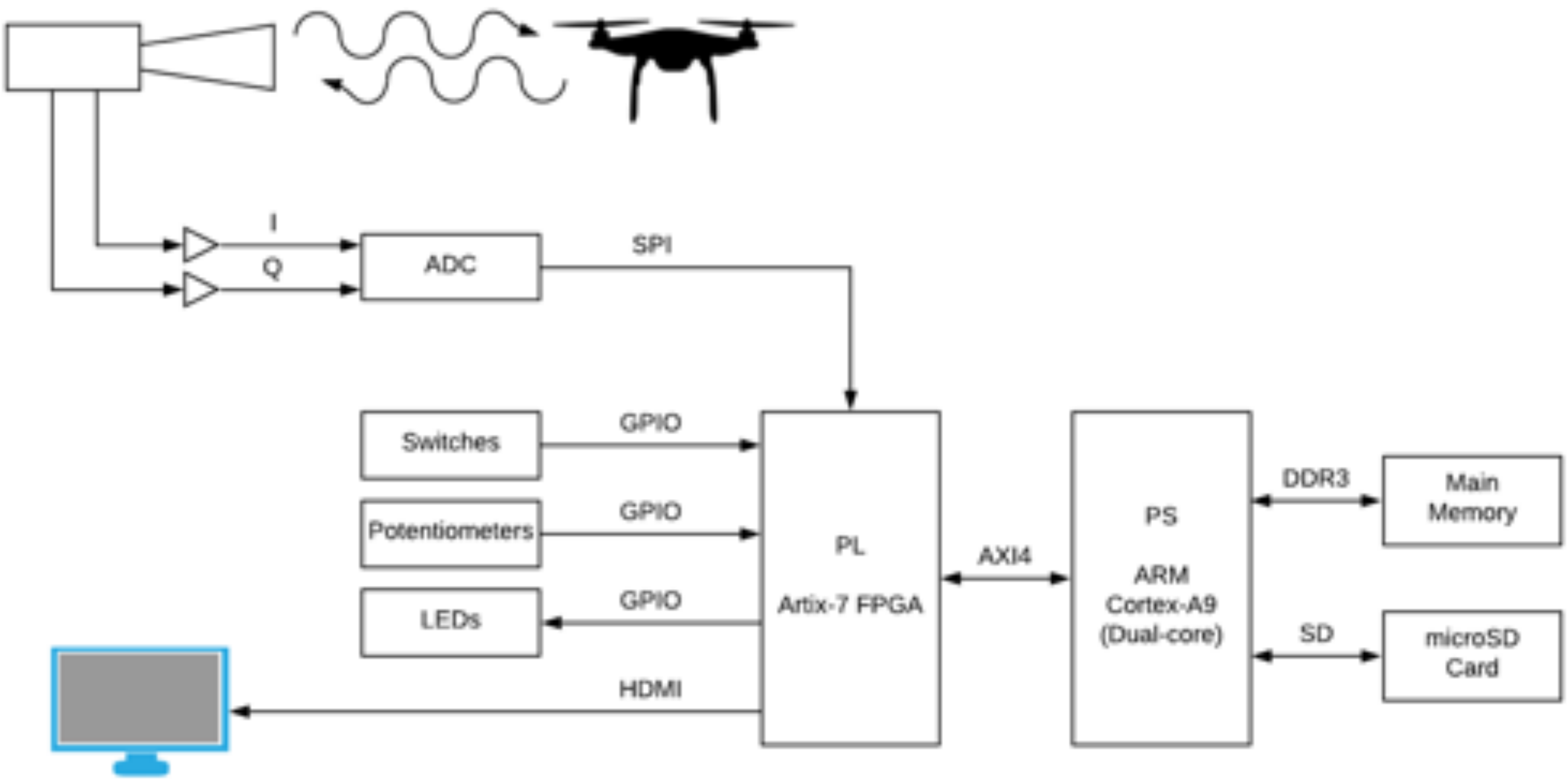




Hardware

System Block Diagram



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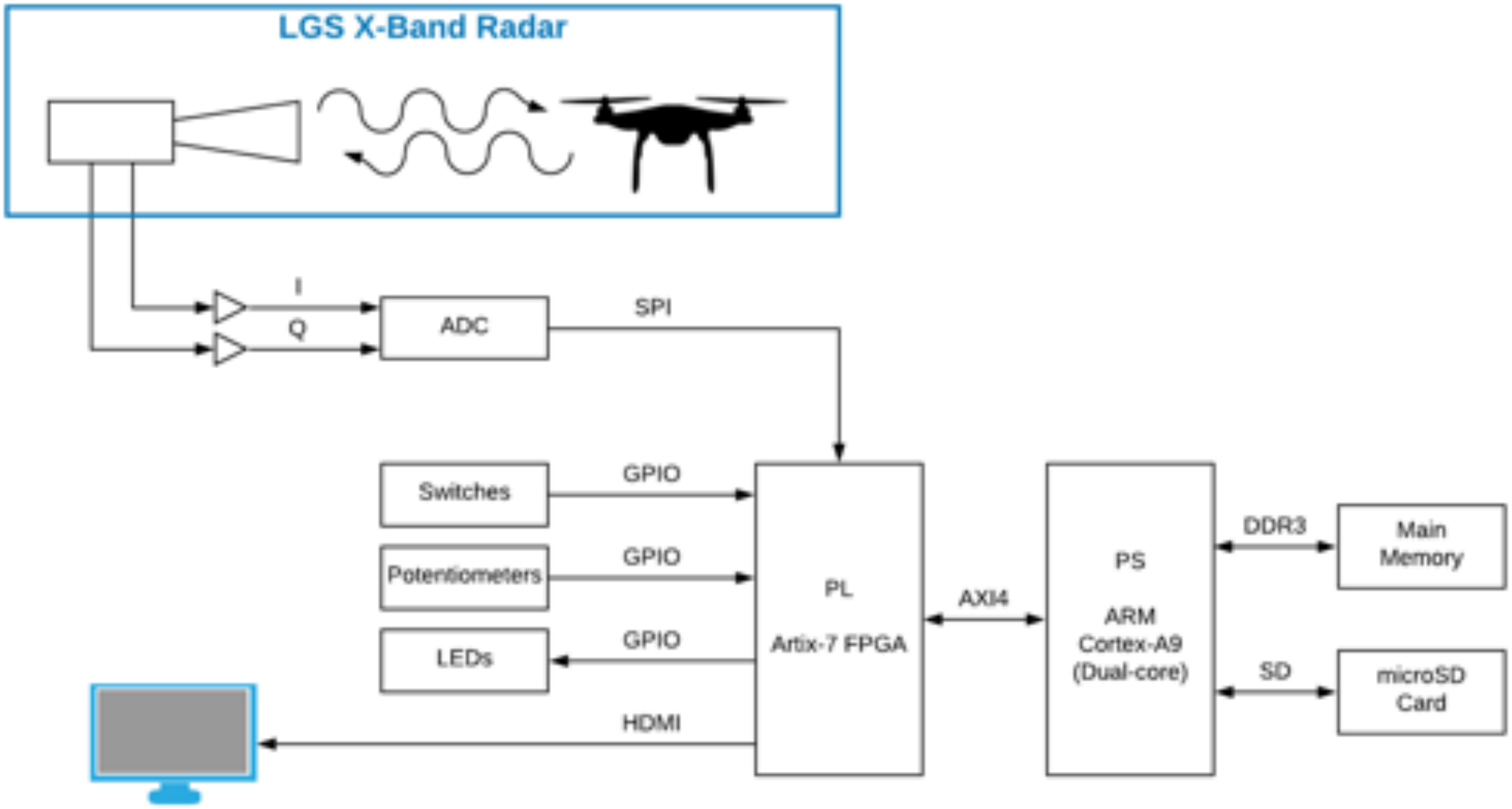

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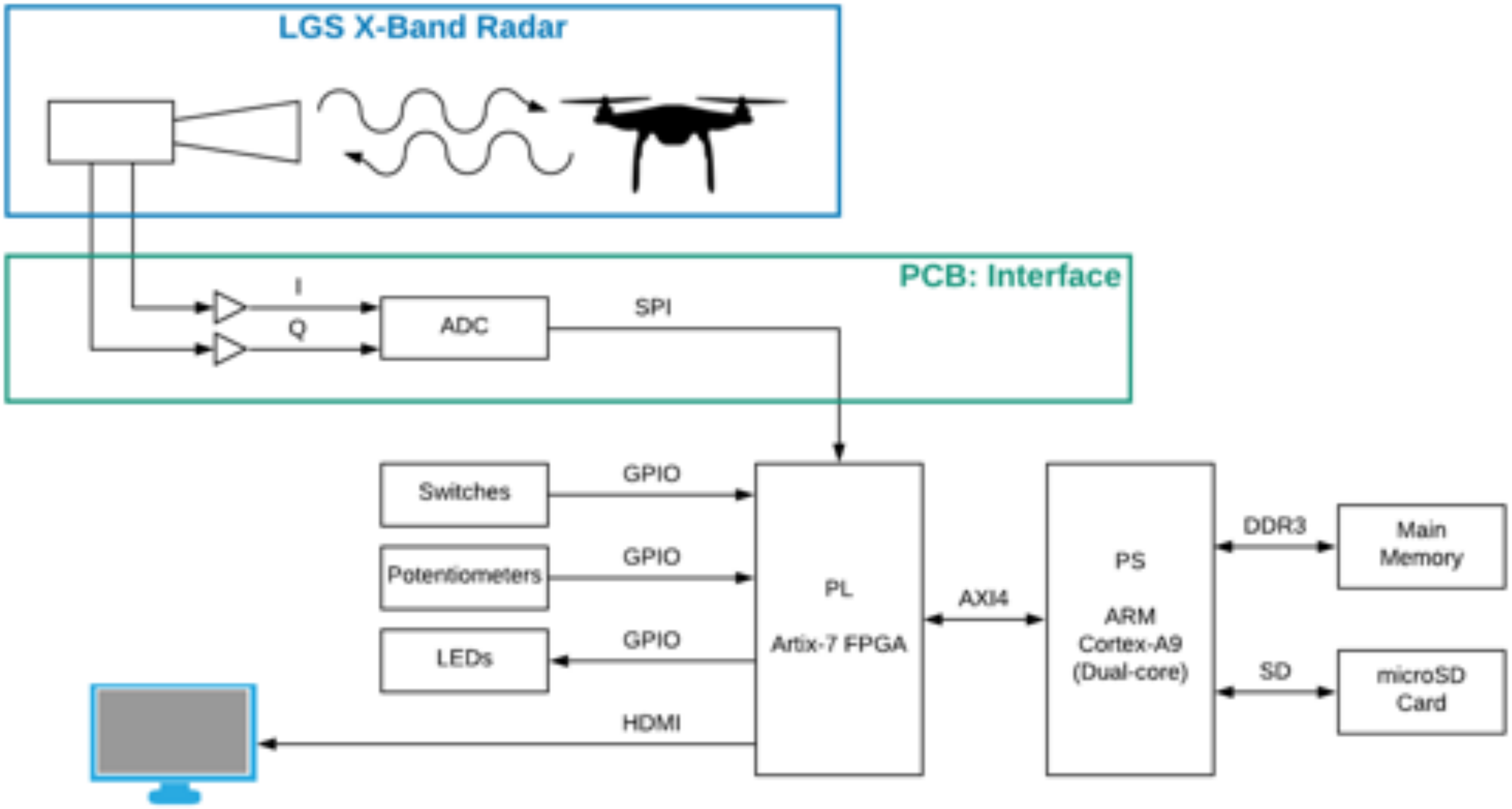

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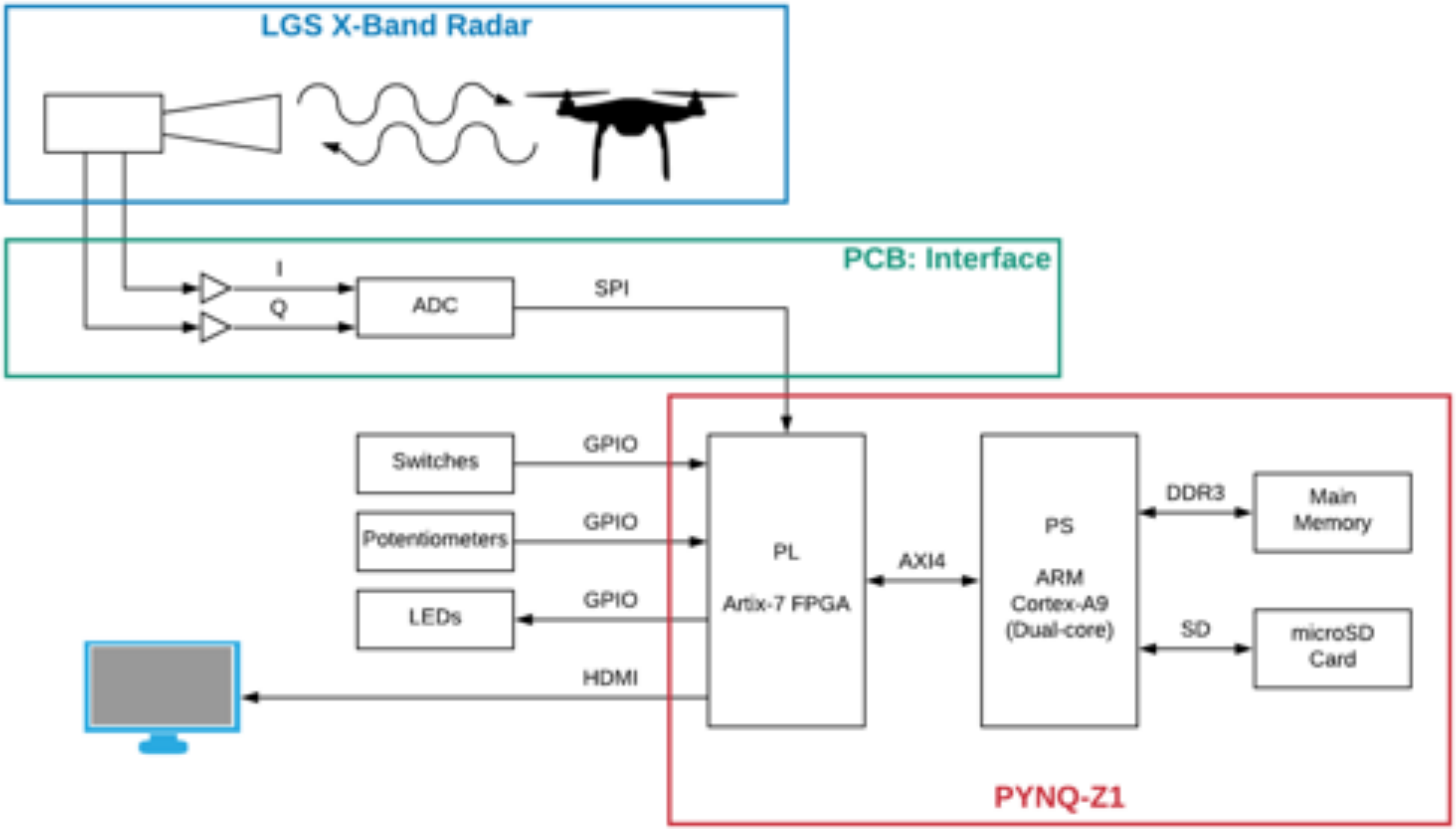
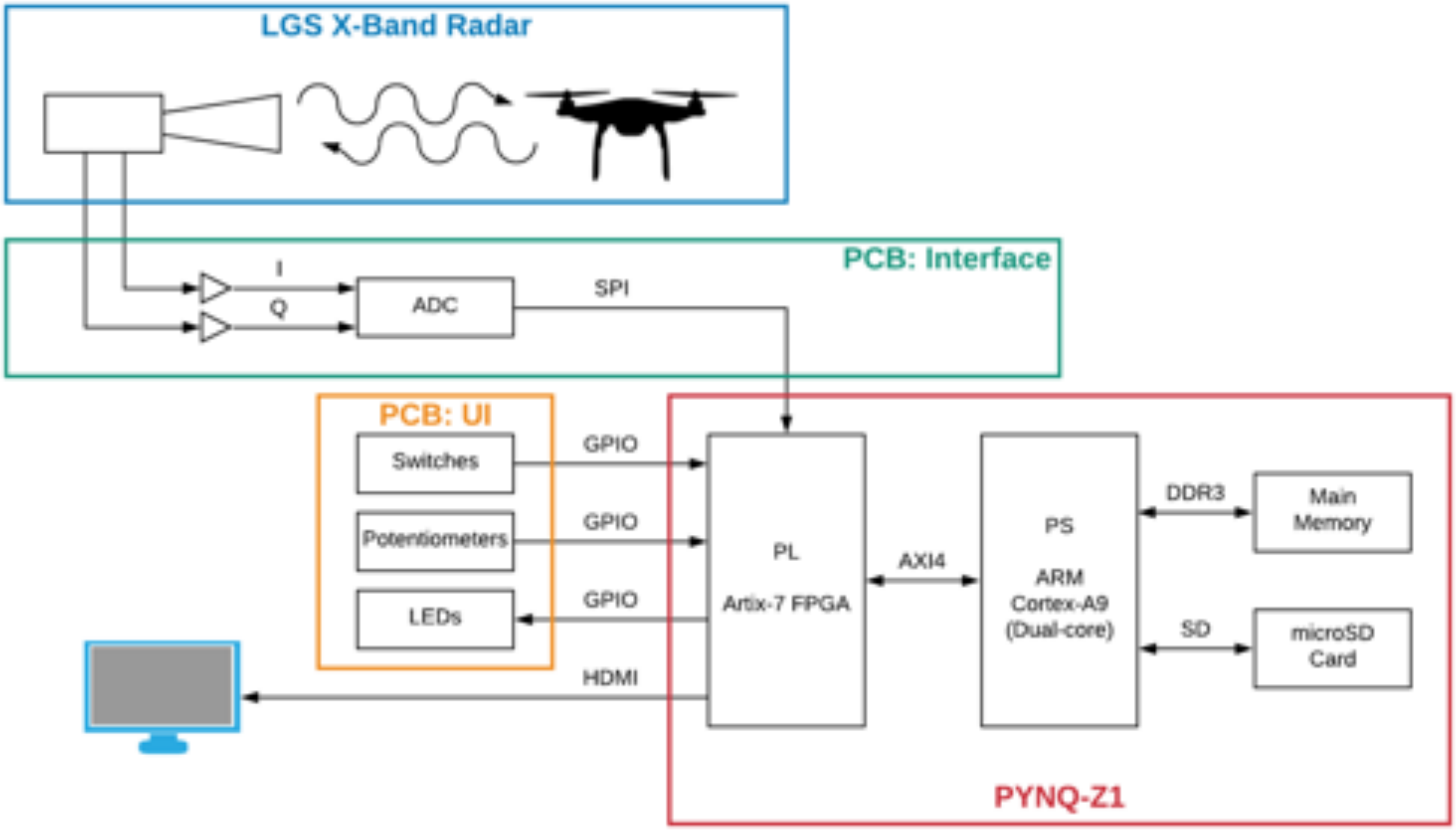
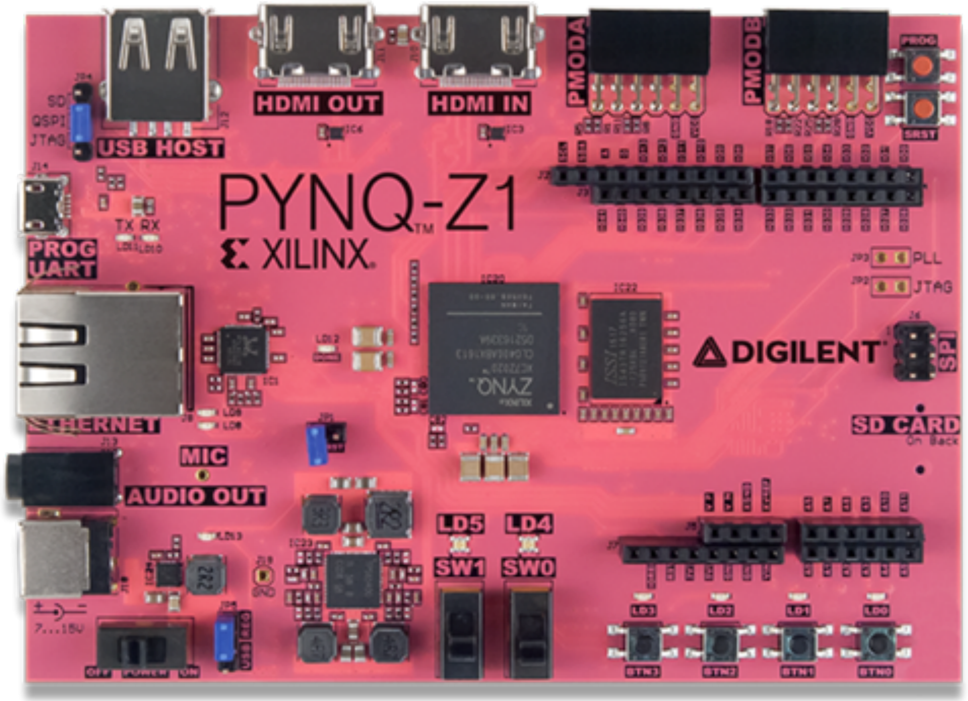


System Block Diagram



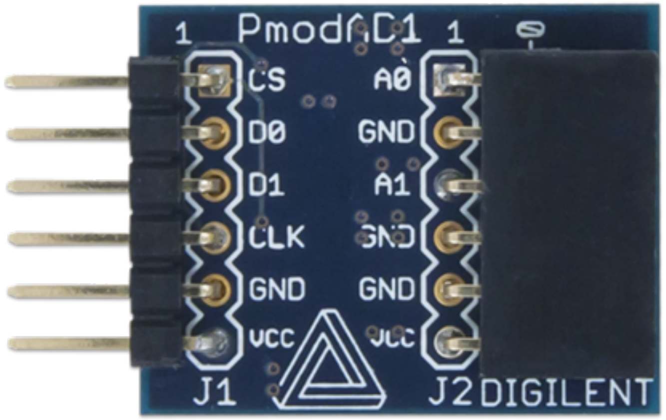
System on Chip (SoC): PYNQ-Z1

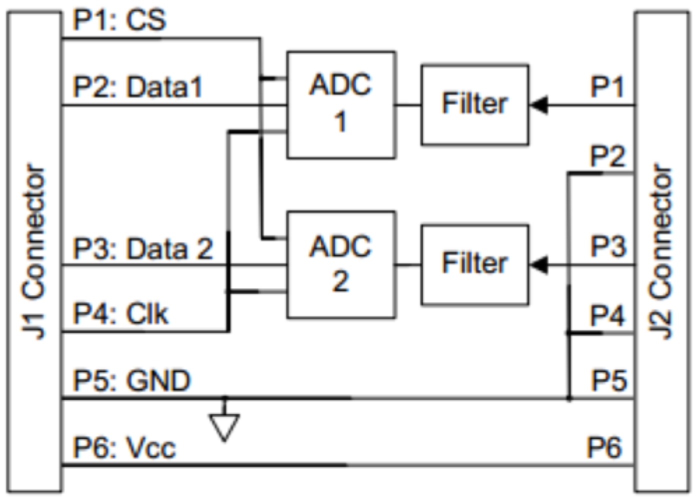
- Two processing units:
  - 650 MHz Dual-Core Cortex A9
  - 100 MHz Artix-7 FPGA
- 512 MB DDR3 Memory
- External interfaces:
  - Arduino shield connector
  - PMOD ports
  - HDMI output



Analog-to-Digital Converter: Pmod AD1

- Features two AD7476A analog-to-digital converters and anti-aliasing filters.
- Two channels, each with 12-bit precision
- 1 MSPS throughput rate
- SPI interface protocol
- The radar signals are expected to be 500 Hz – 10kHz depending on the speed of the drone's propellers
- We will be sampling the ADC at 20 kHz

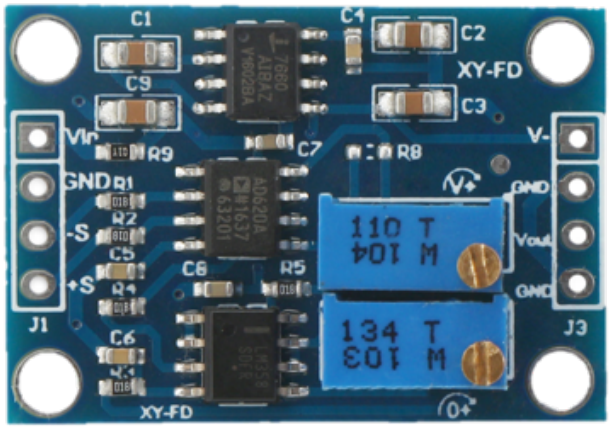


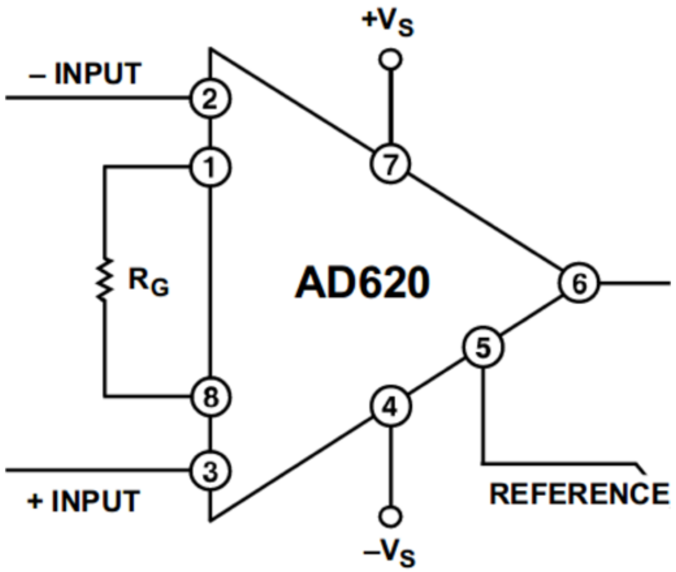


AD1 Circuit Diagram

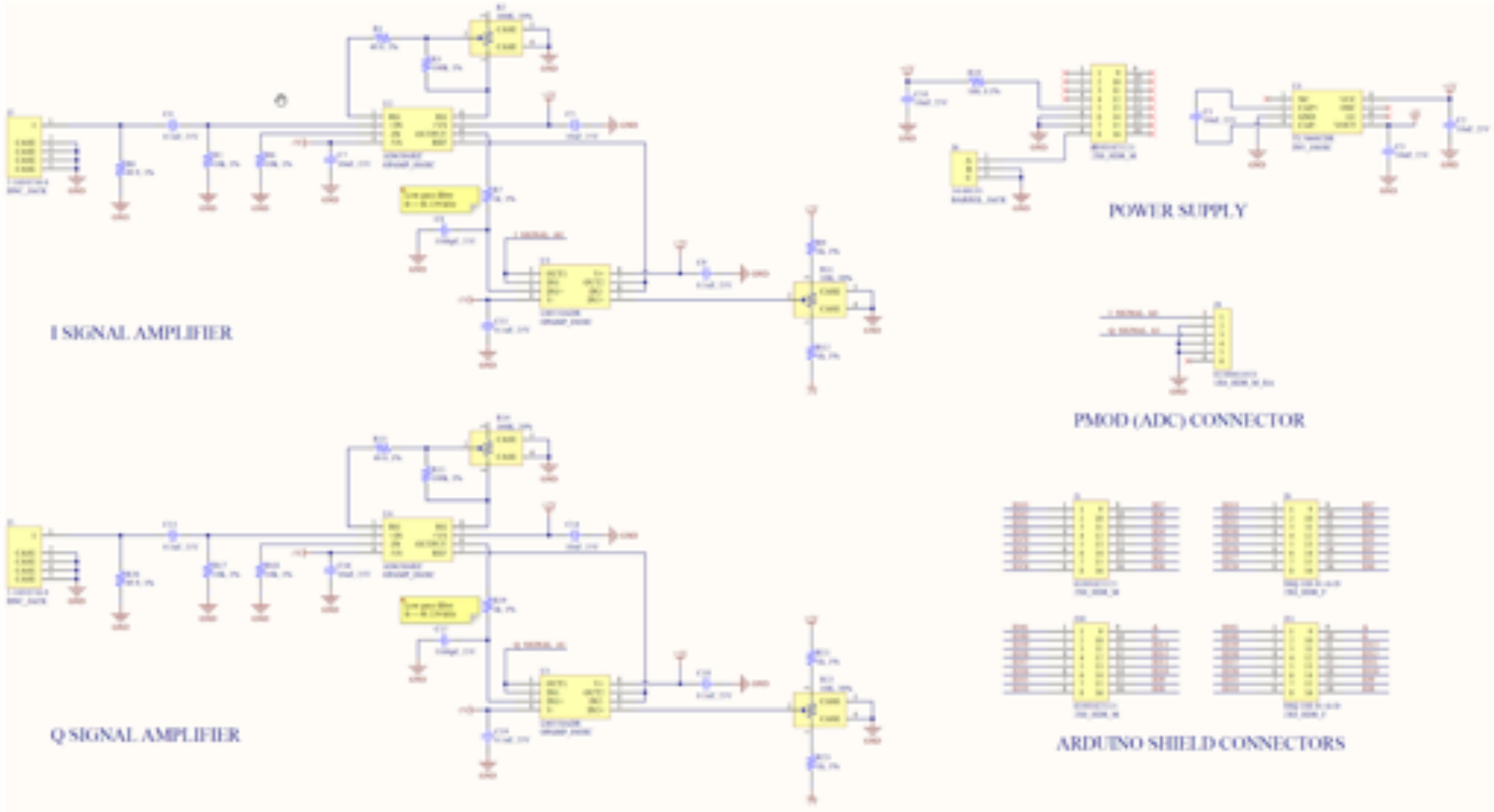
Amplifier: AD620

- Low power instrumentation amplifier
- Gain range of 1 to 10,000
- Adjustable ground reference of the output signal
- Potentiometers set the gain and the DC offset of the amplifier circuit
- Amplifier circuits are implemented on the PCB, one for each channel





PCB: Radar-PYNQ Interface



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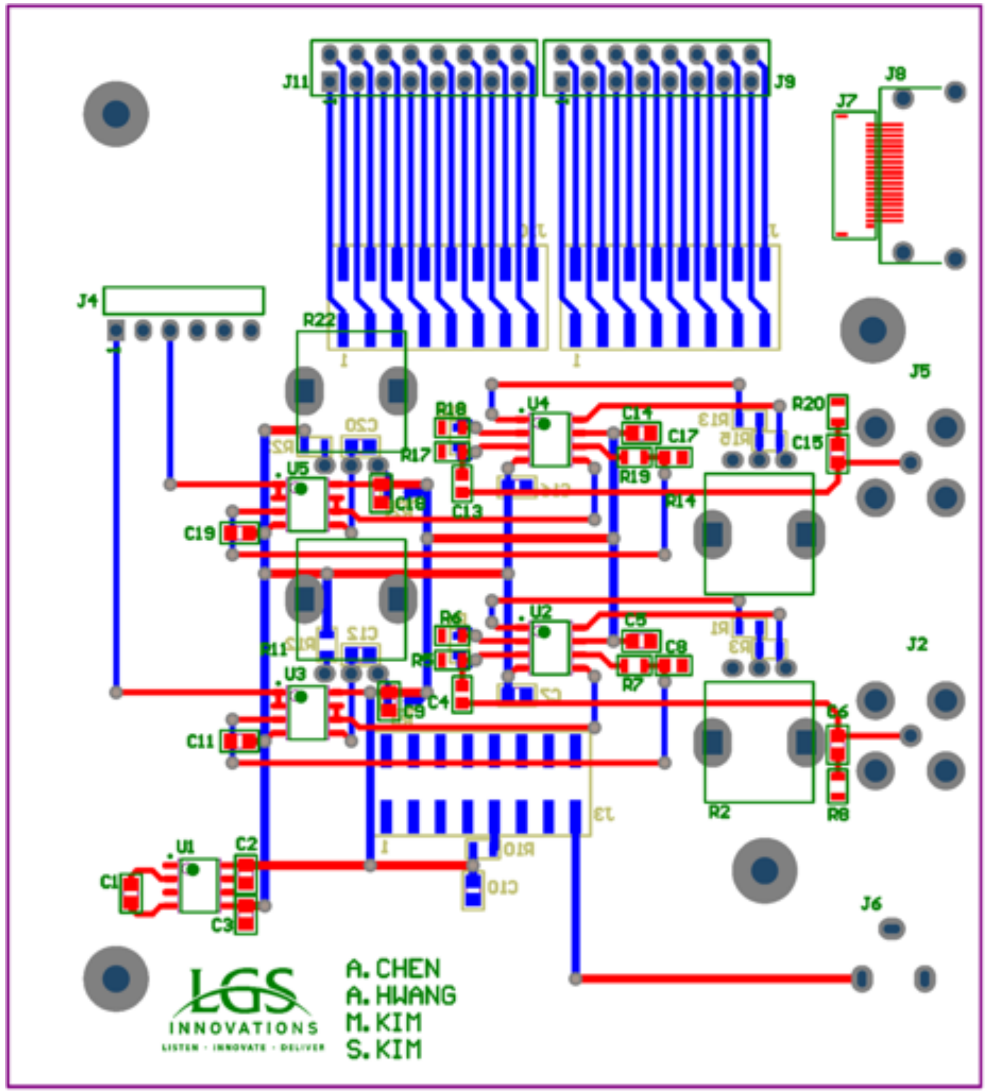

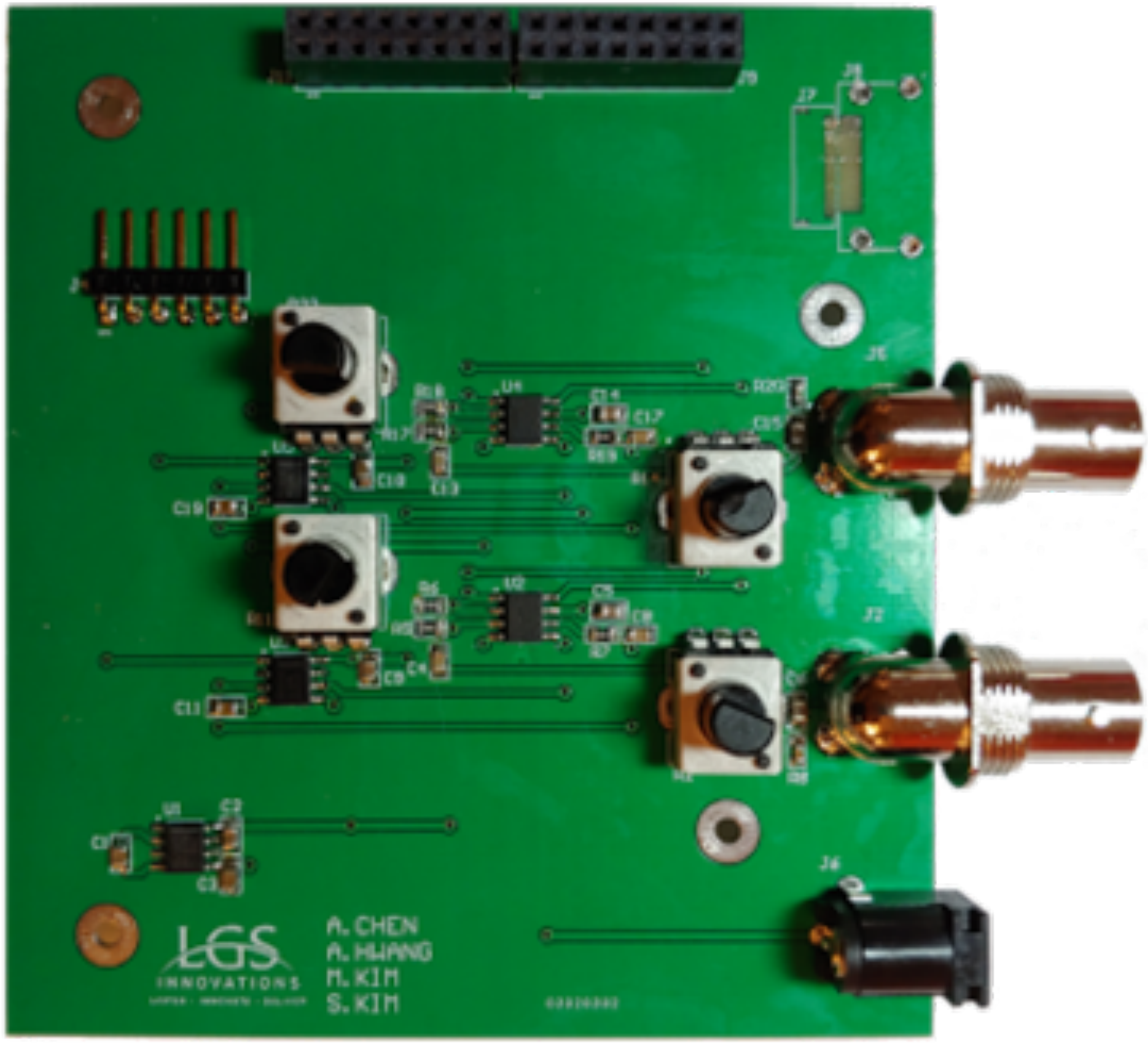

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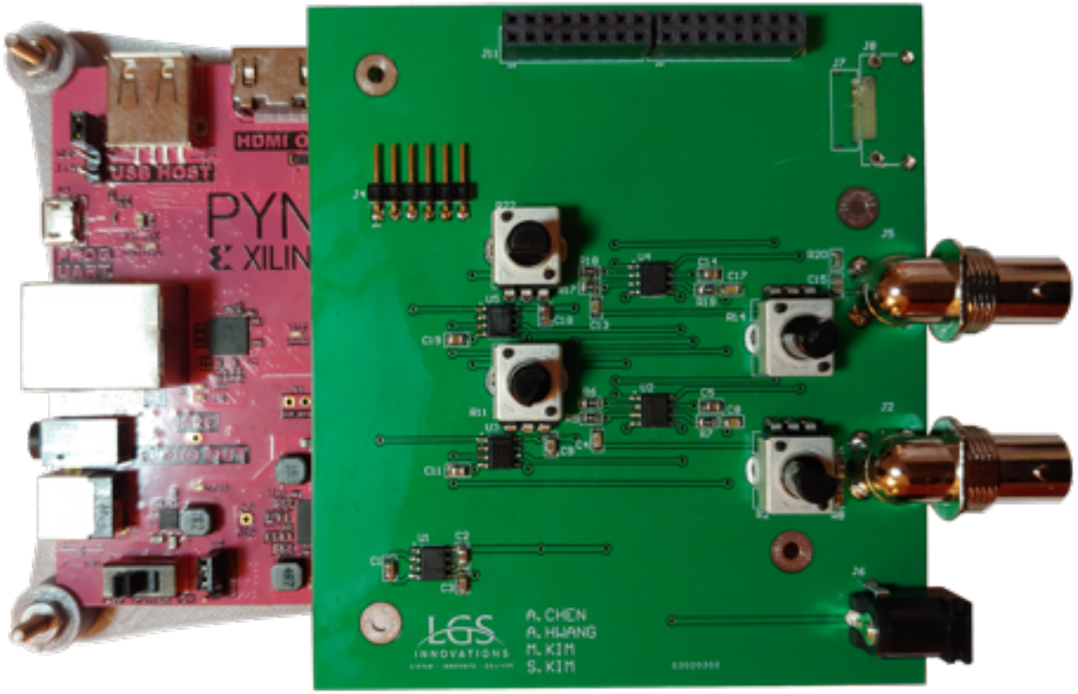
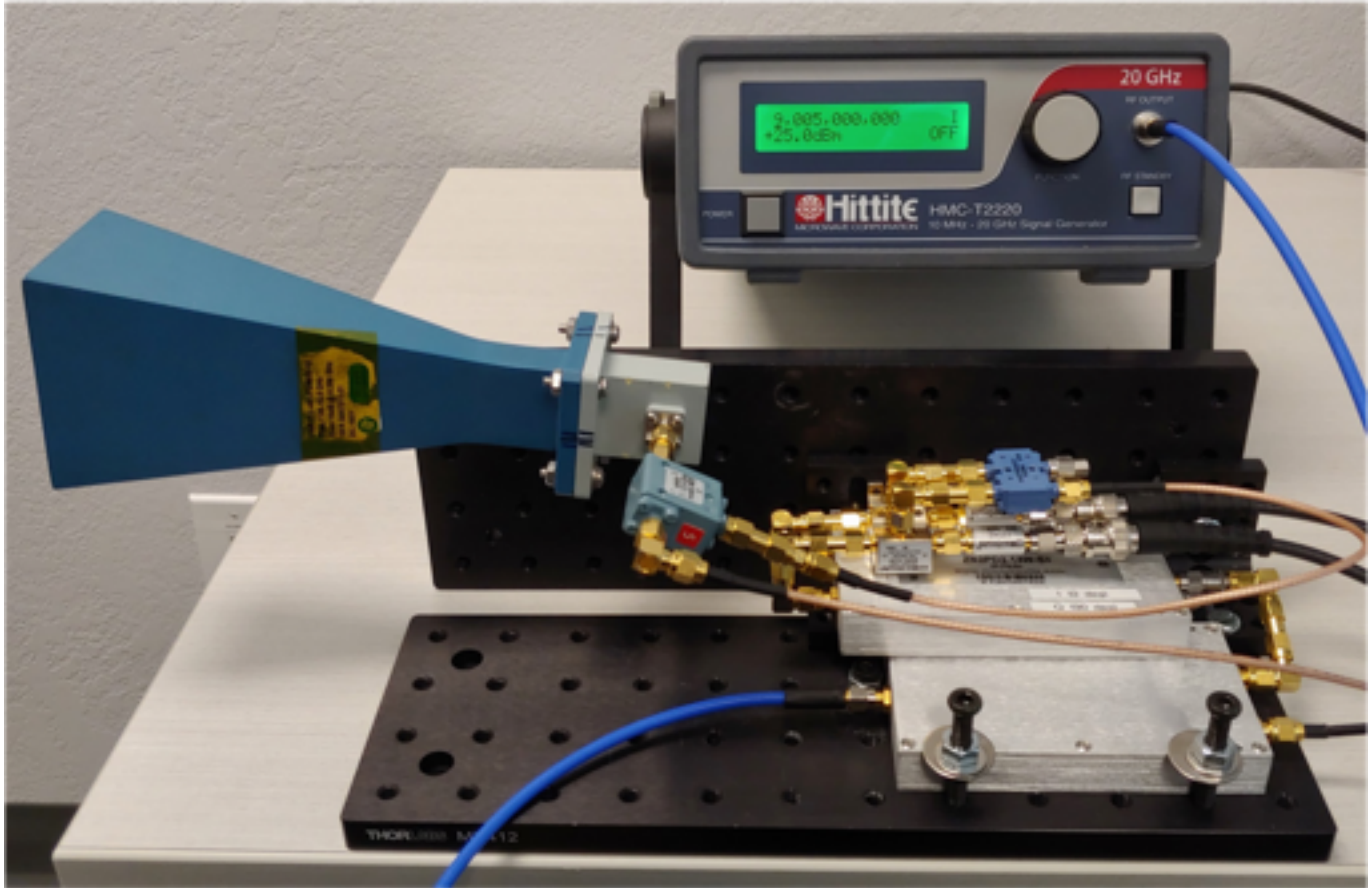
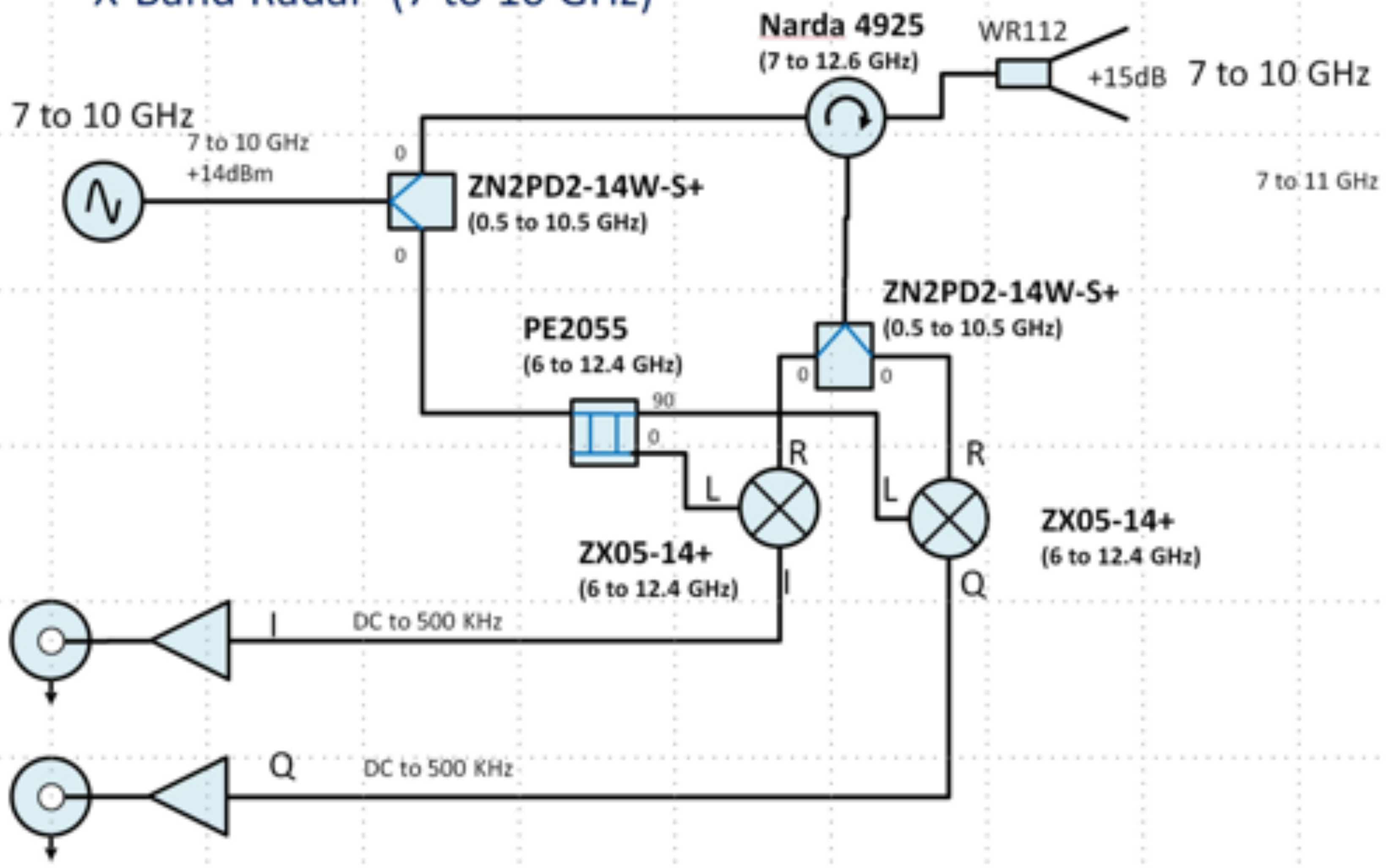


LGS X-Band Radar (7-10 GHz)



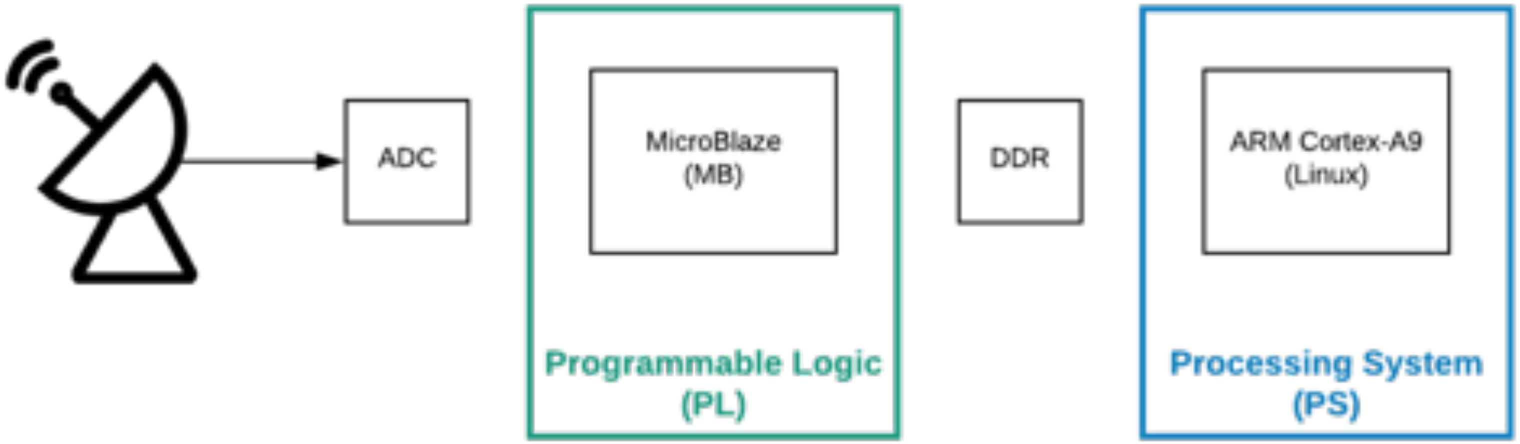
LGS X-Band Radar: Block Diagram

- X-Band Radar (7 to 10 GHz)



Software

Data Acquisition



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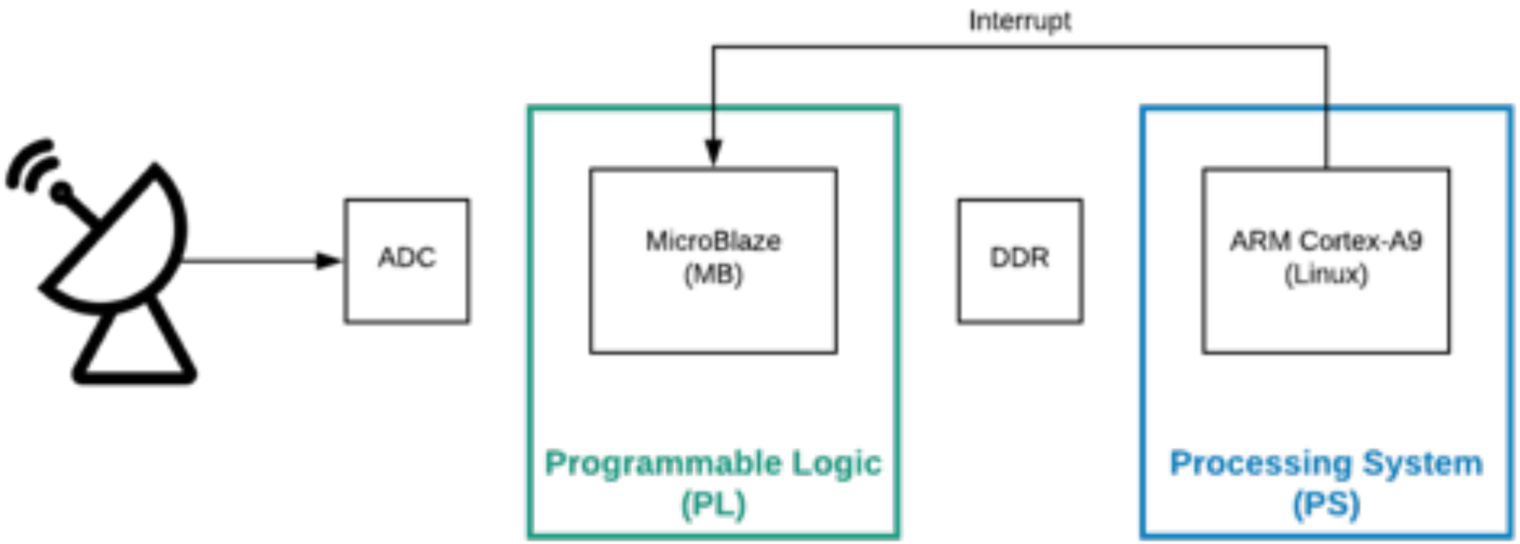
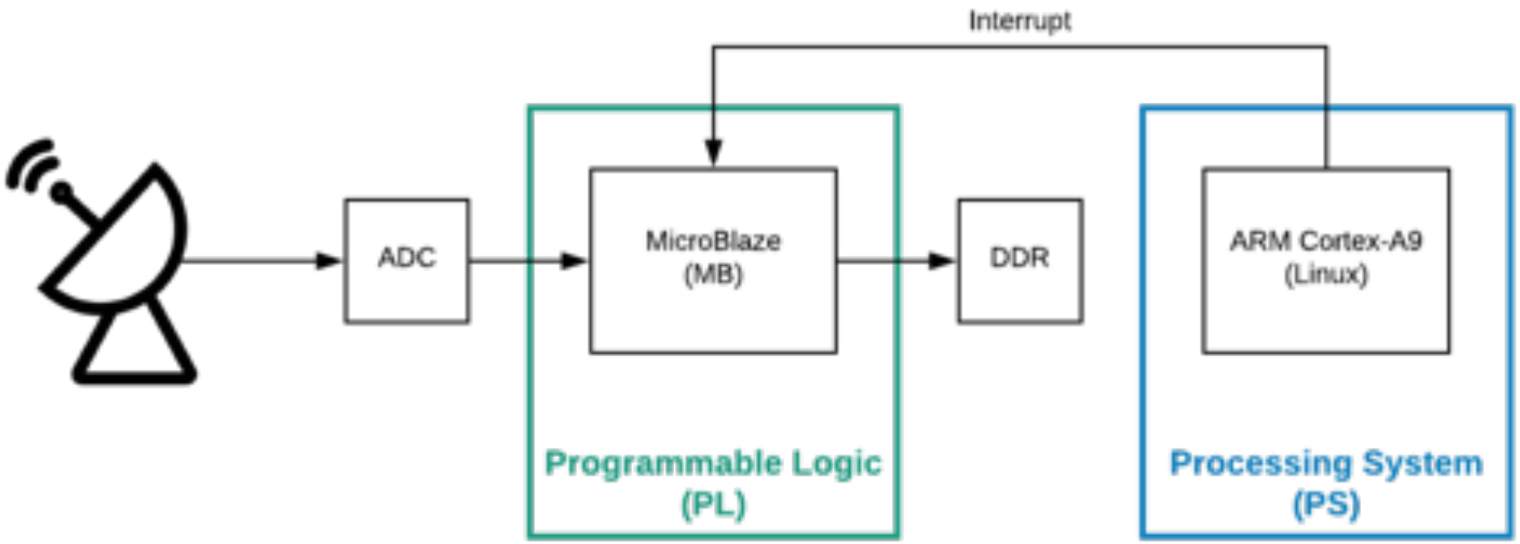


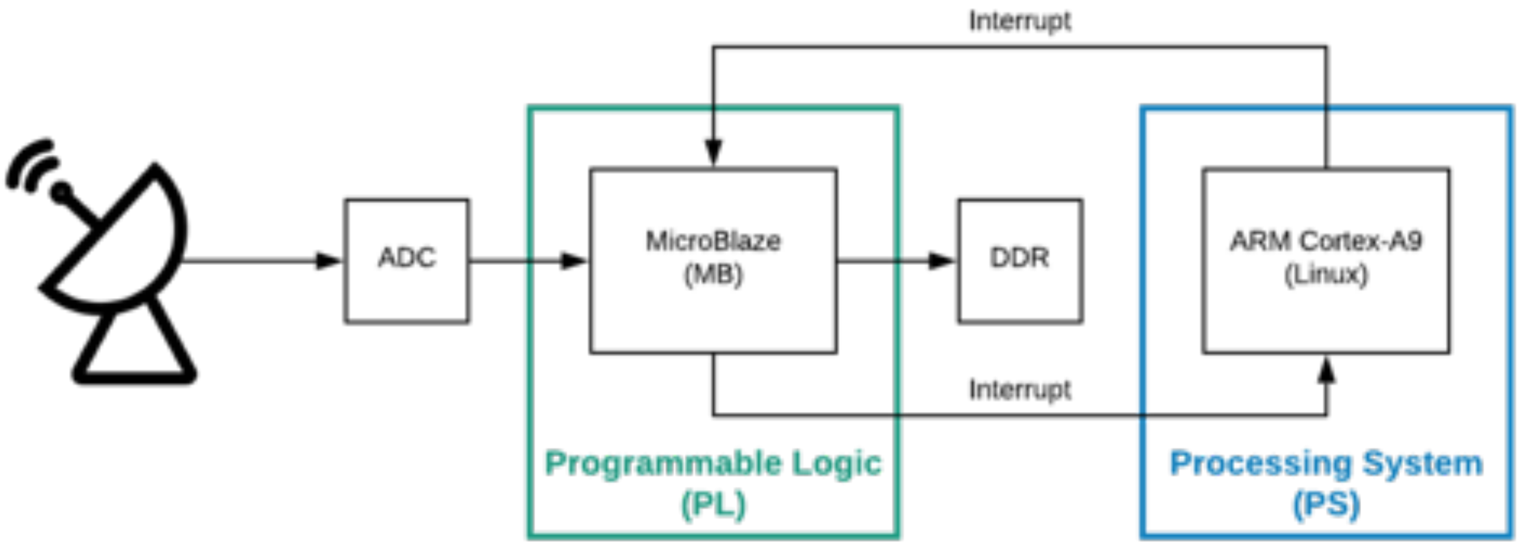
1. Main program interrupts the MicroBlaze telling it to record N samples with a sampling frequency of FS

Data Acquisition



1. Main program interrupts the MicroBlaze telling it to record N samples with a sampling frequency of FS.
2. The MB writes these samples to a reserved section of the DDR memory

Data Acquisition



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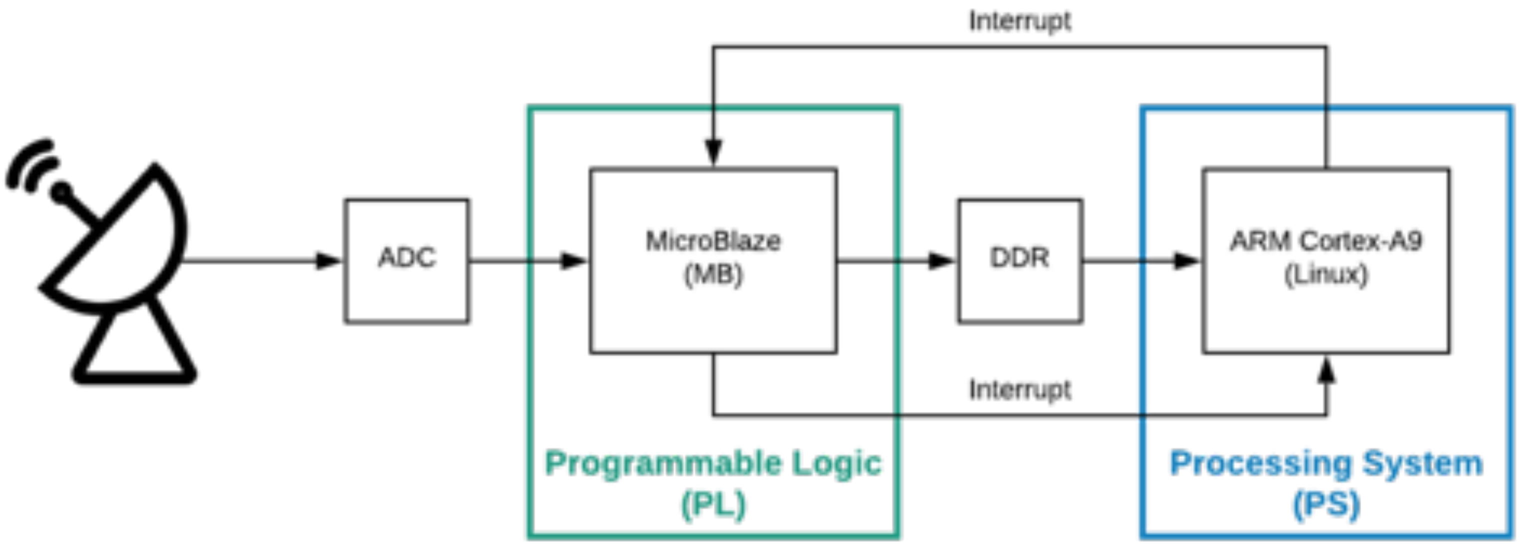
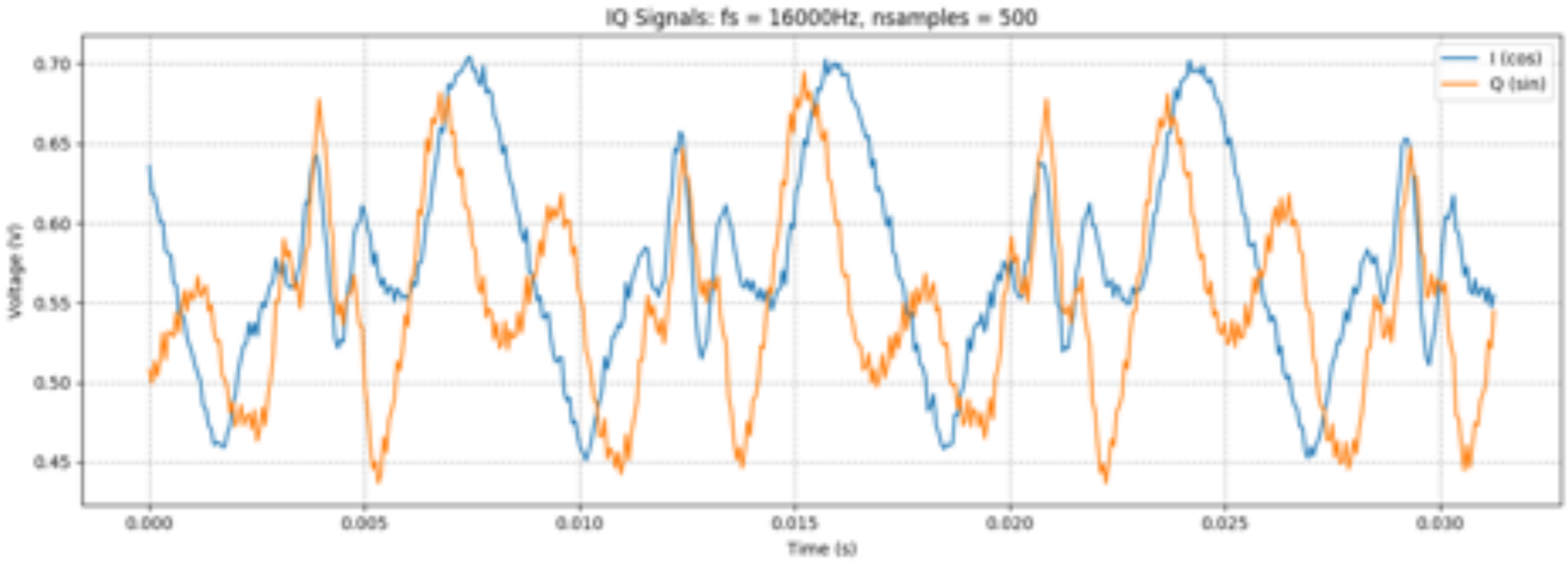


1. Main program interrupts the MicroBlaze telling it to record N samples with a sampling frequency of FS
2. The MB writes these samples to a reserved section of the DDR memory
3. Another interrupt is sent to main program as an alert that all N samples have been written to memory
4. Now our Python program can read the samples from DDR and analyze them

Signal Processing: STFT

- Short-time Fourier Transform (STFT) is used to determine the frequency and phase of a signal as it changes over time
- Procedure: Divide a time-domain signal into “frames” of equal length and then computes the FFT on each frame separately



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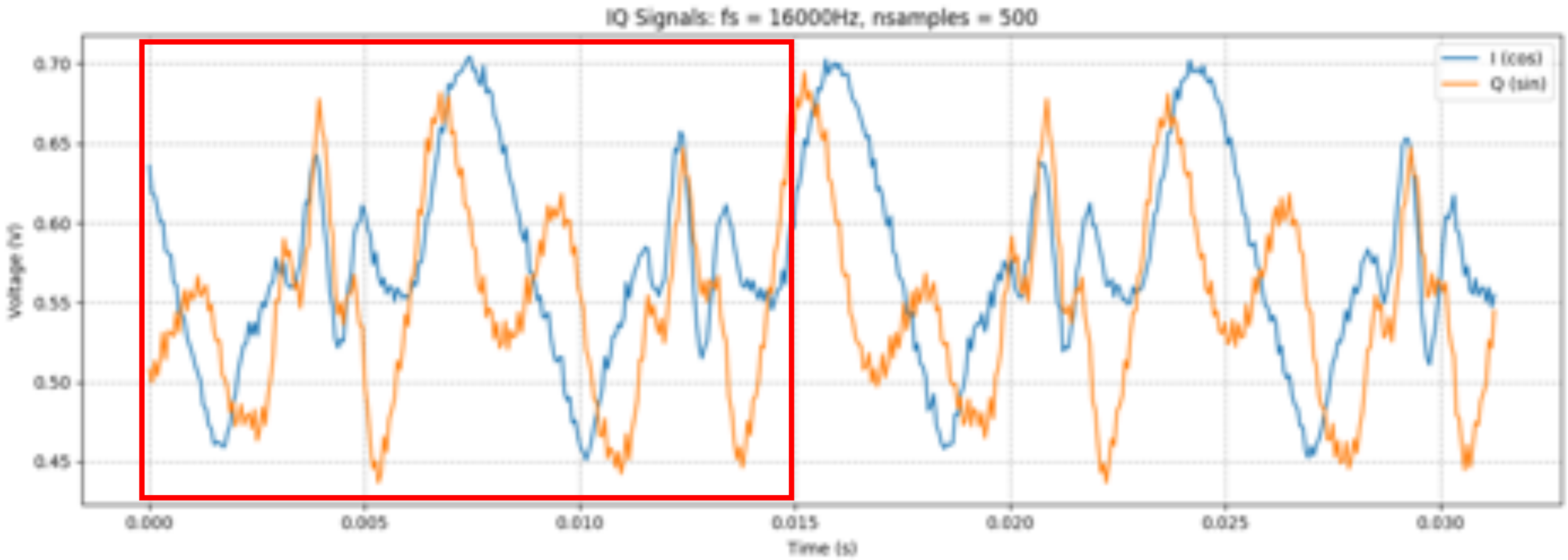

FFT: Frame 1

Signal Processing: STFT

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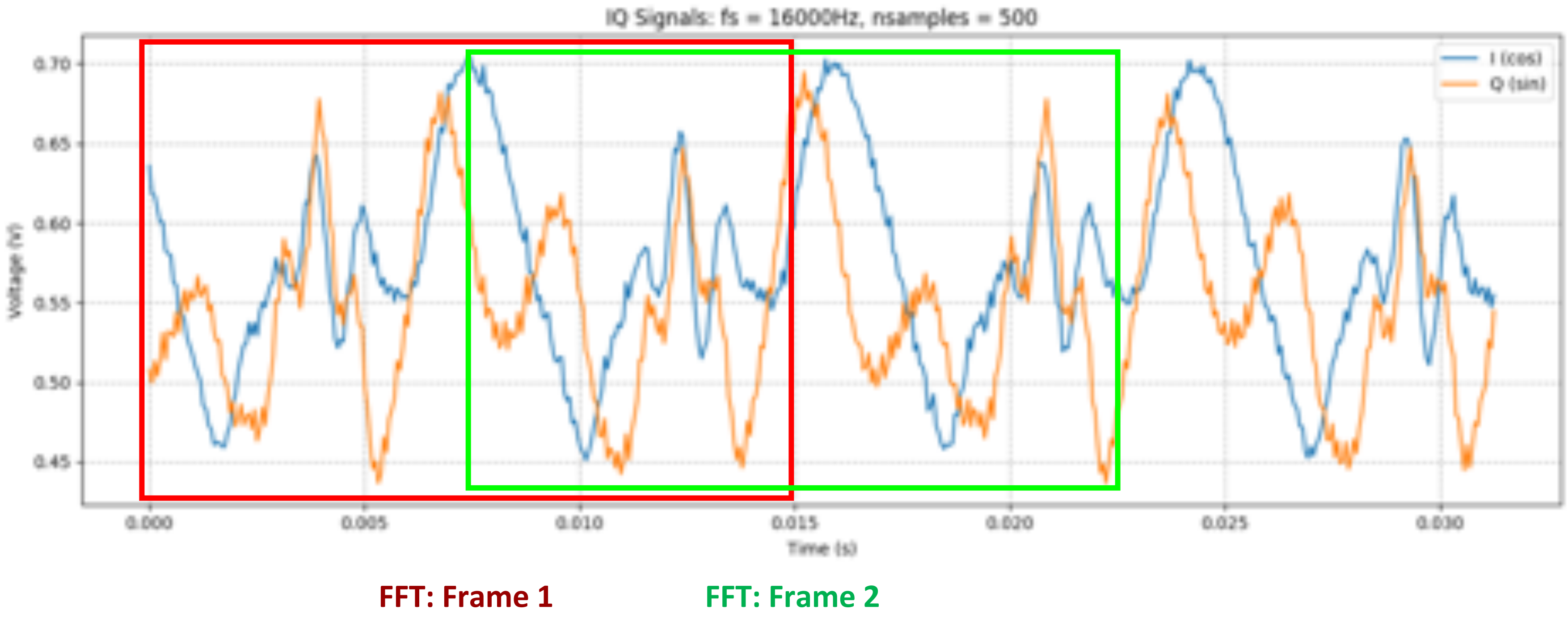

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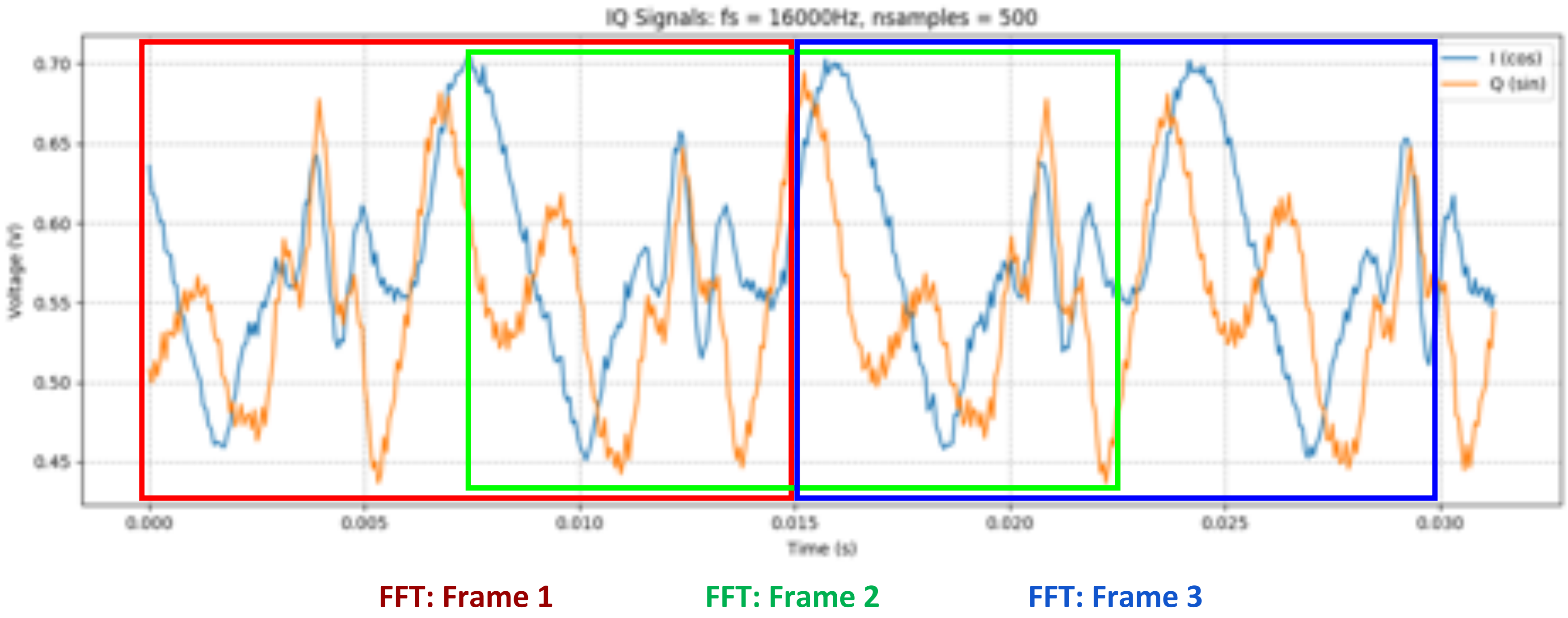

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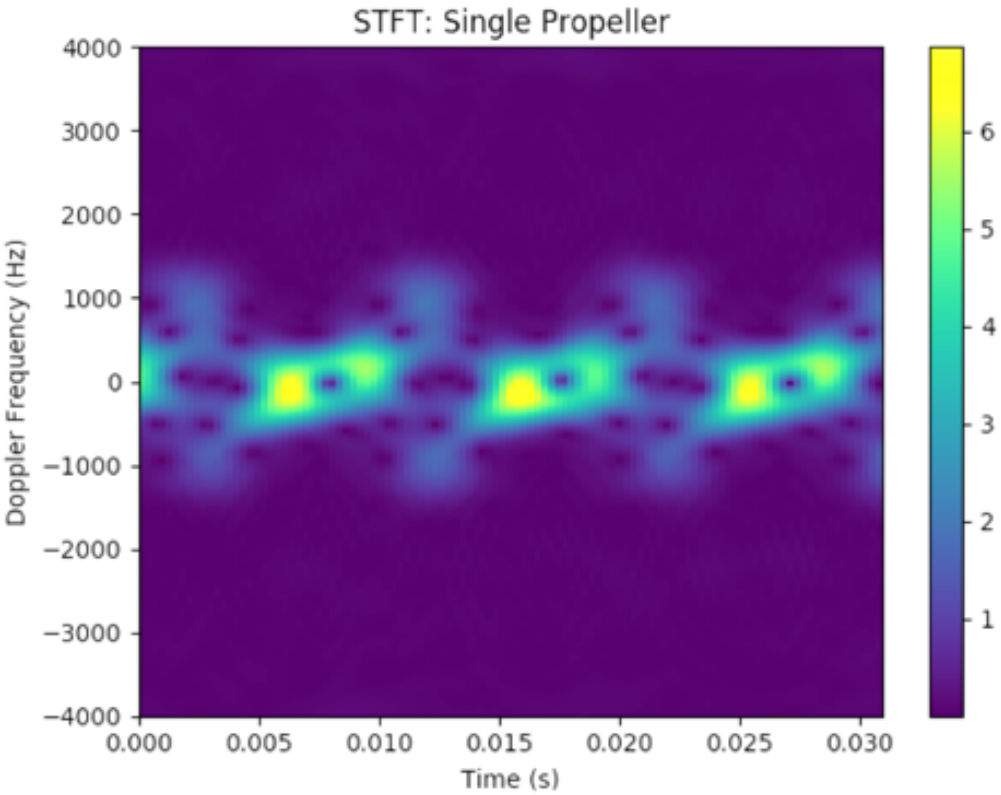
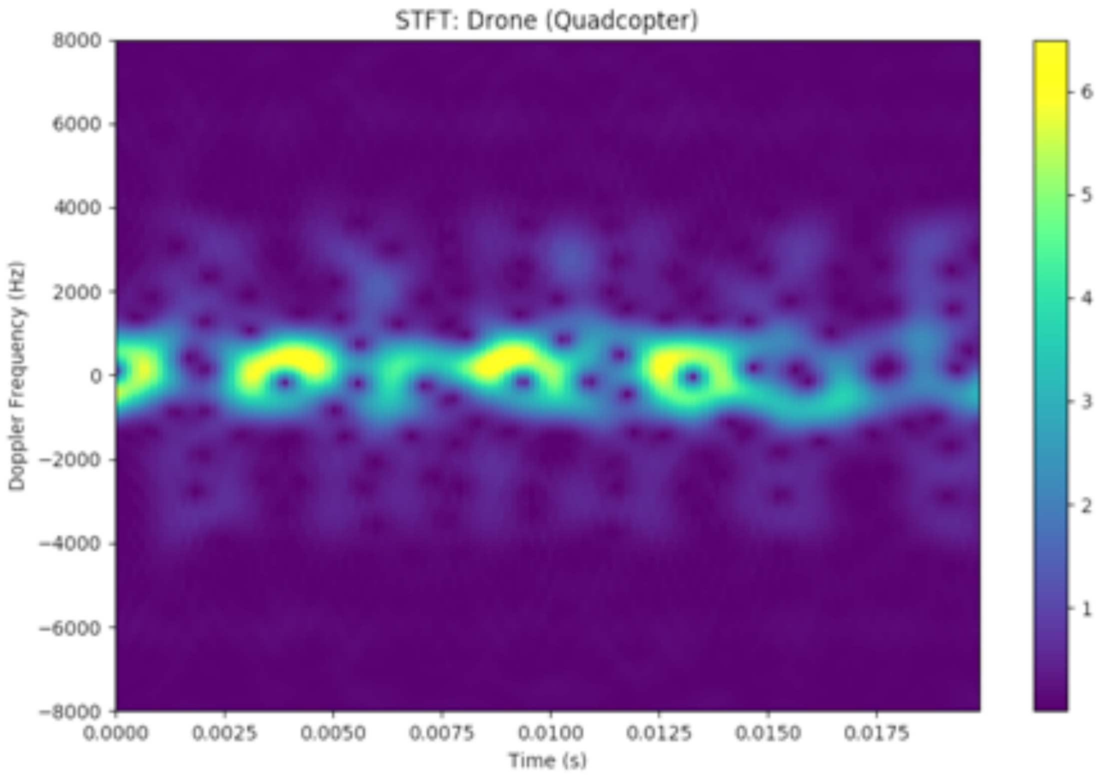
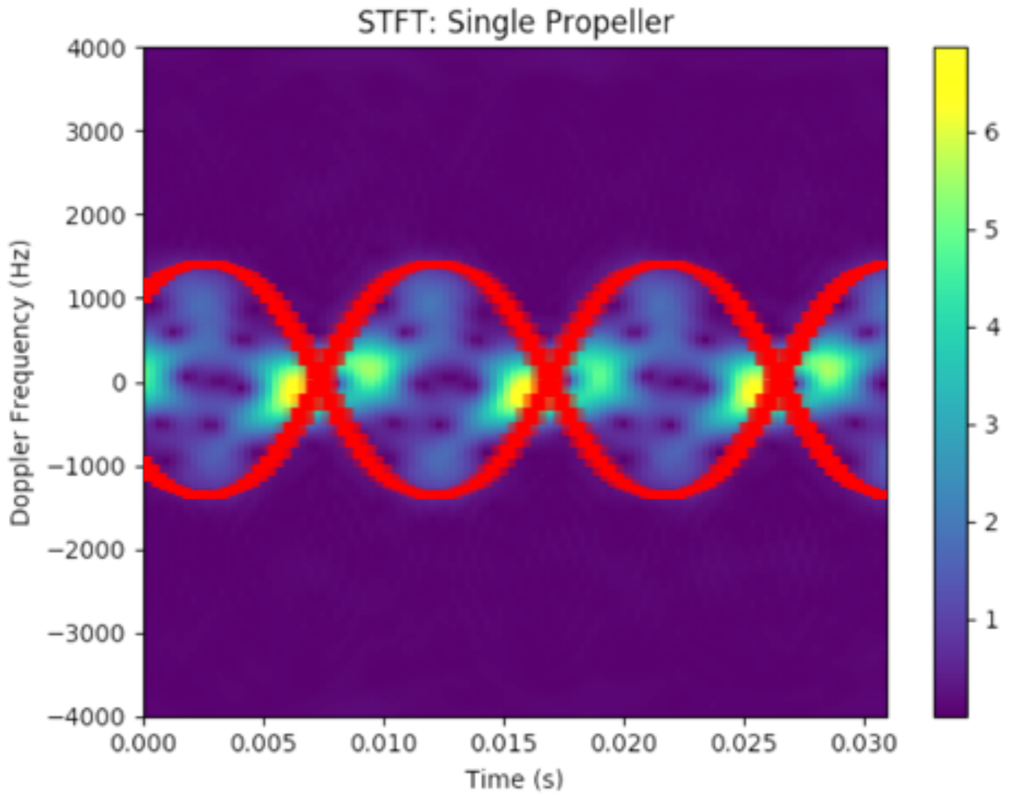
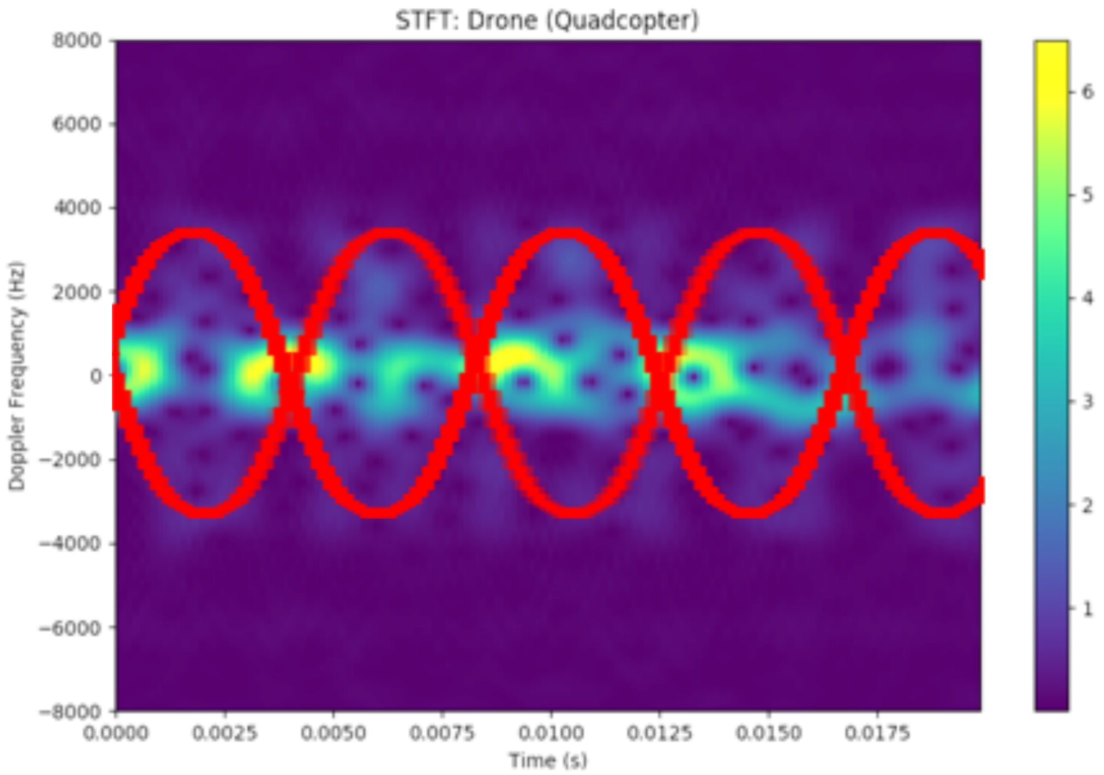




- These results will be processed further to characterize the area captured by the radar

Signal Processing: STFT





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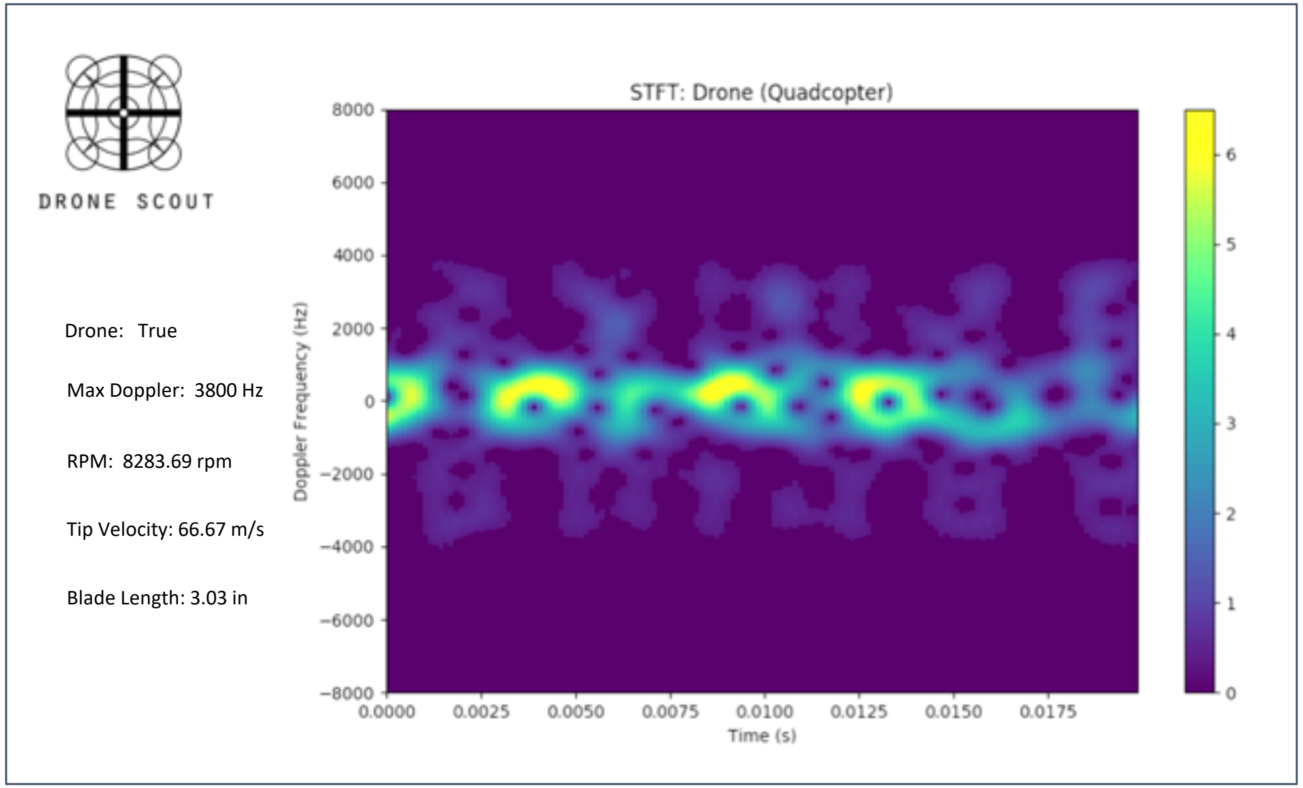
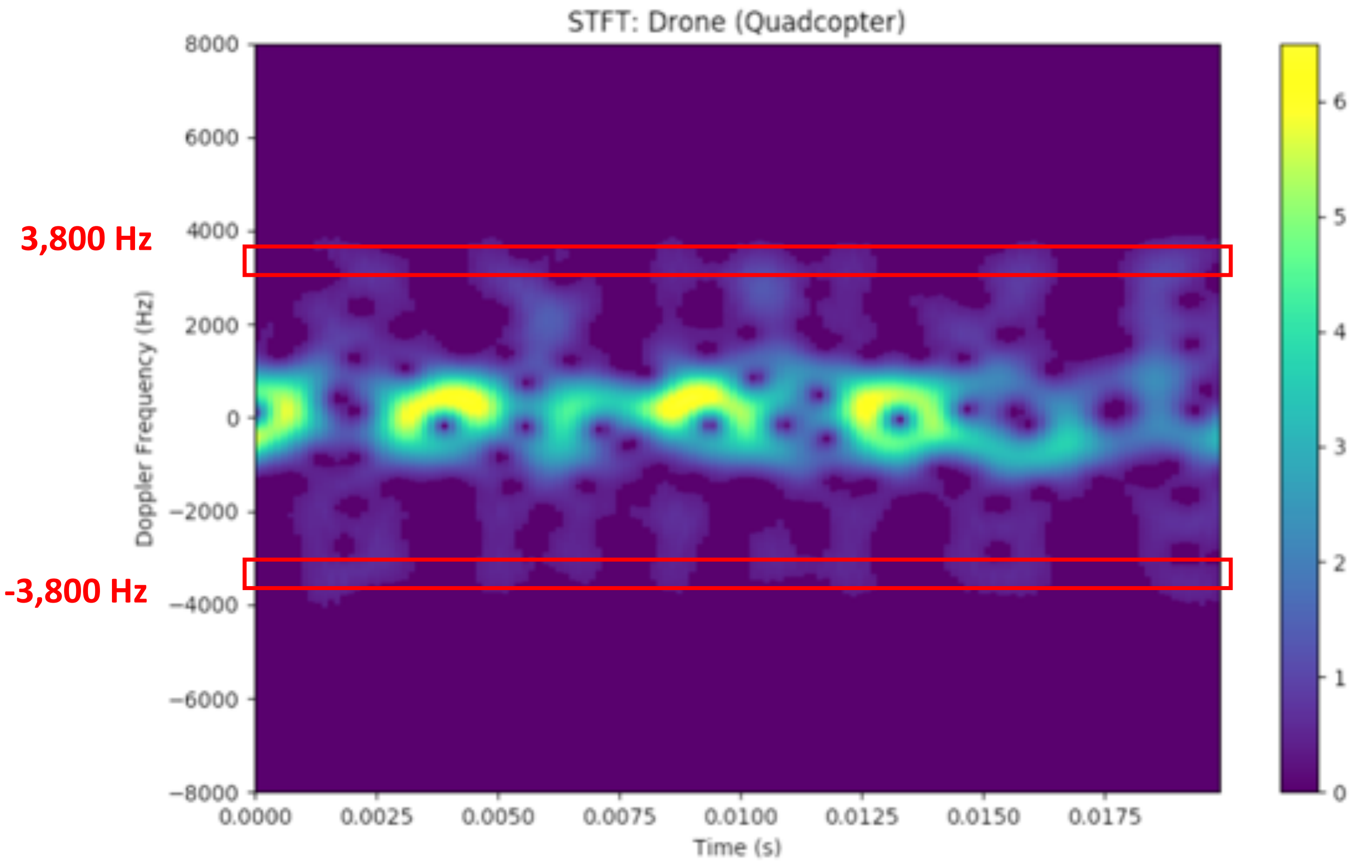
Feature Extraction

- STFT features:
  - Maximum doppler frequency shift
- Drone features:
  - Presence of a drone or UAV
  - Propeller tip velocity
  - Rotations per minute (RPM)
  - Propeller blade length

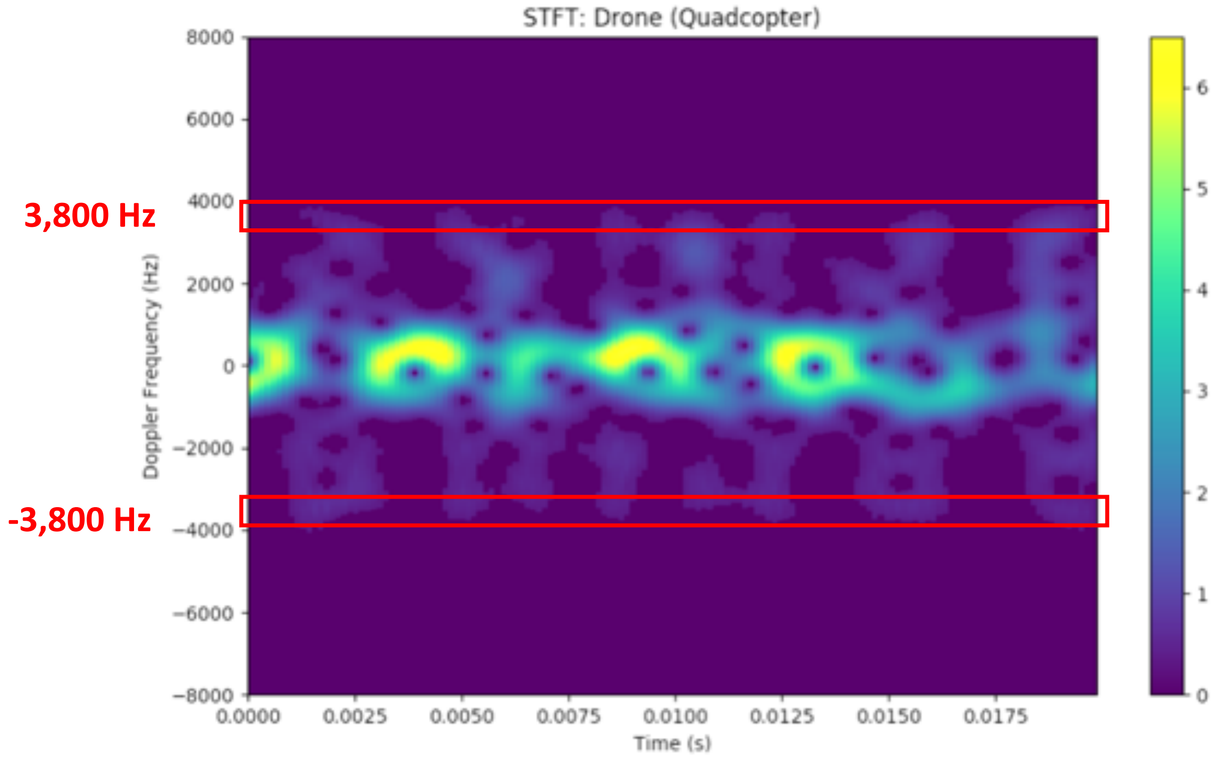


Maximum Doppler Frequency



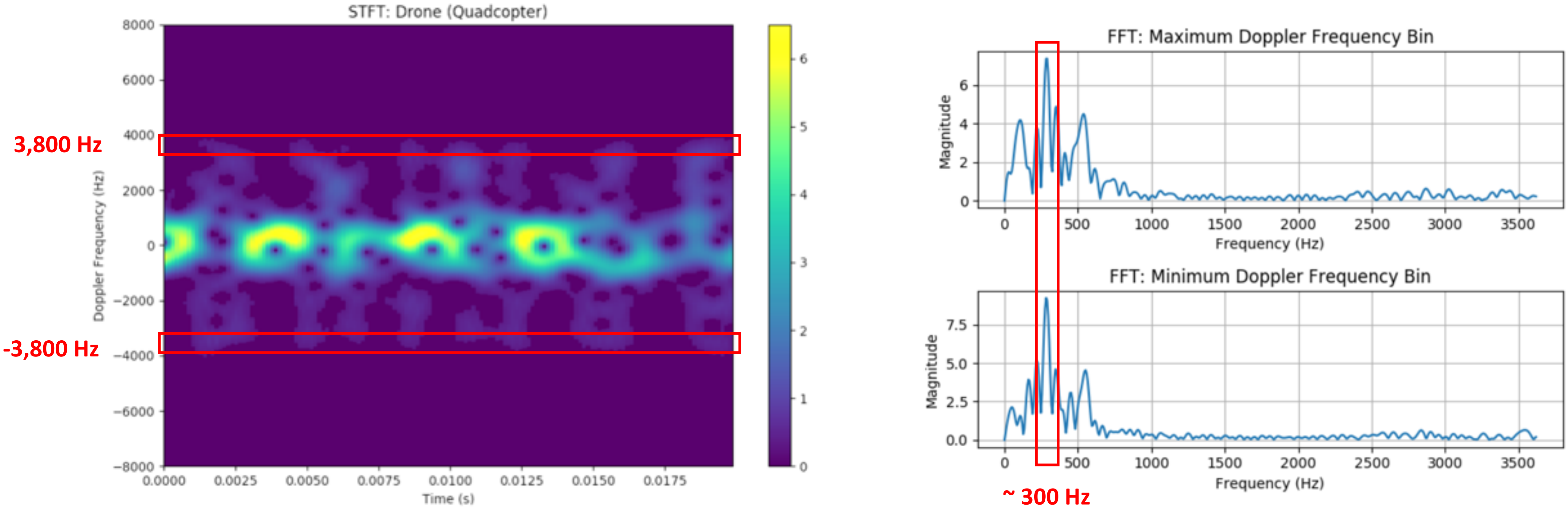
- Represents the maximum difference between the transmitted and reflected signal frequencies
- Positive frequency shifts show the effect of a propeller blade approaching the radar, while the negative frequency shifts show the effect of it receding

Drone Presence



- Presence of a drone is determined by the maximum doppler frequency, periodicity, and symmetry in the STFT

Drone Features



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- RPM depends on the frequency of the local maxima and minima along the time axis

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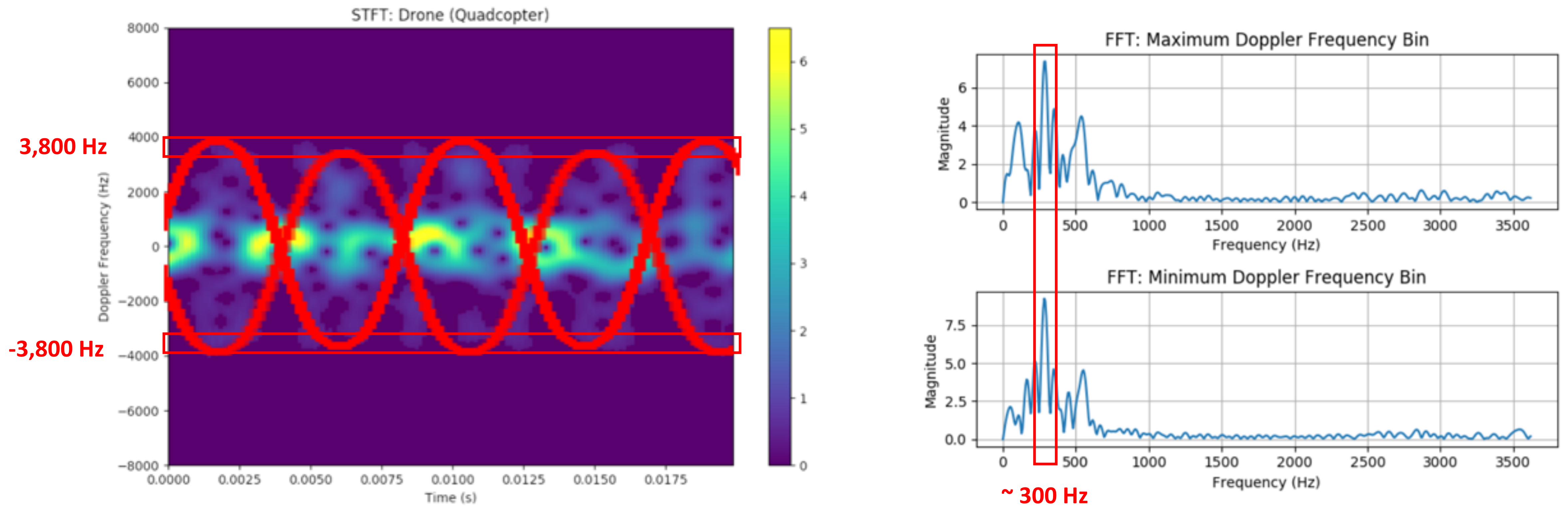

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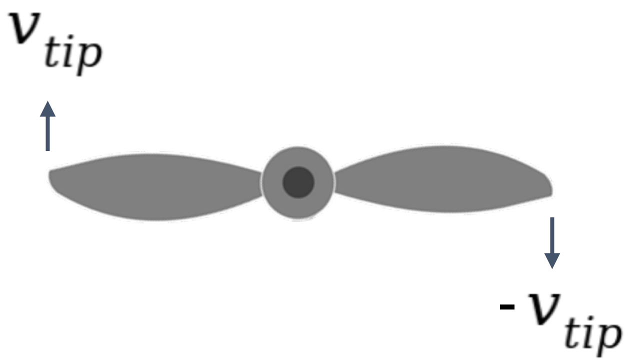
Drone Features

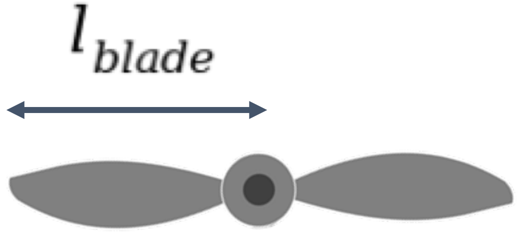
- Propeller tip velocity (m/s):

$$v_{tip} = \frac{1}{2} * f_{doppler,max} * \lambda_{carrier} \; [m/s]$$



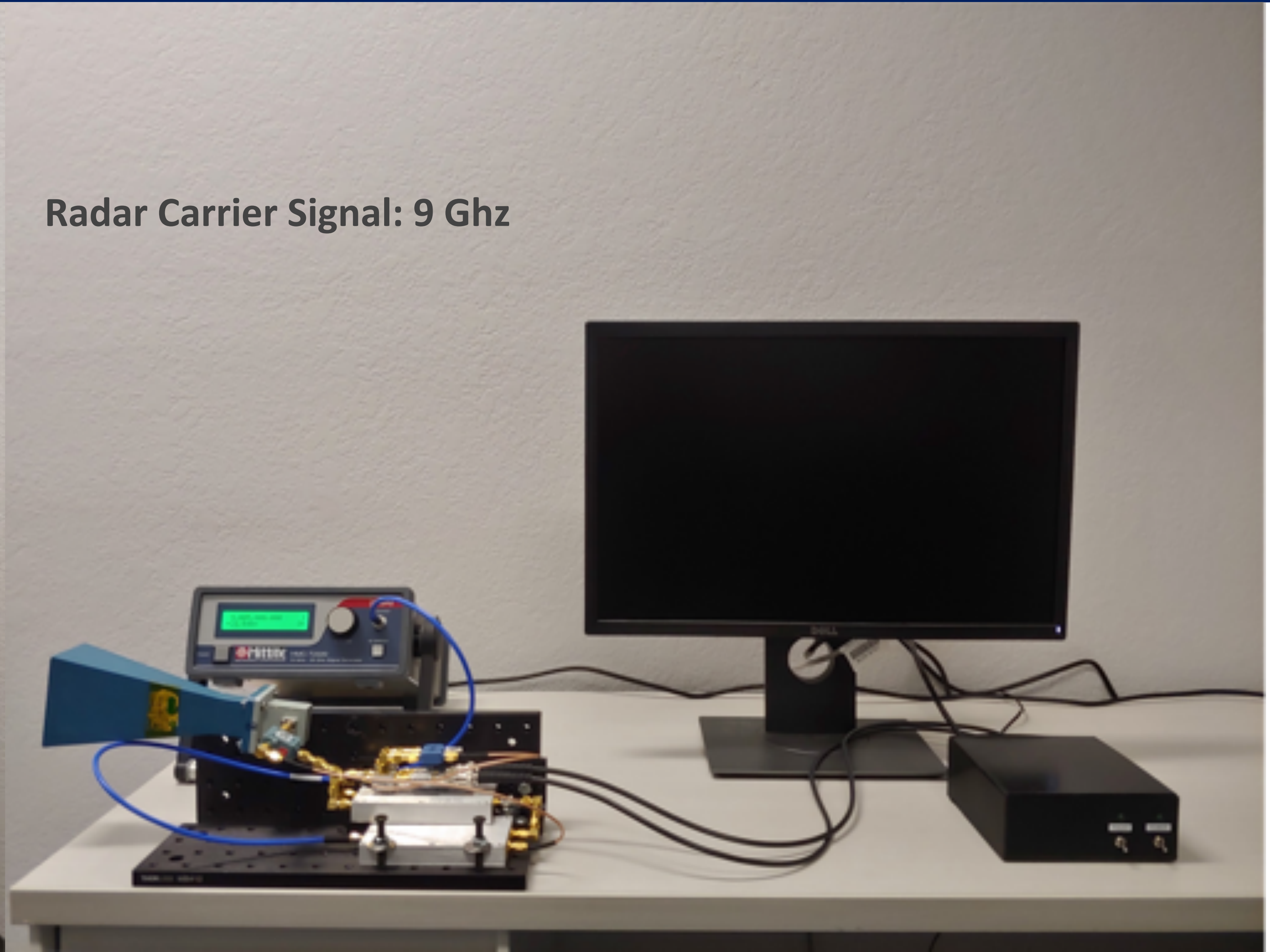
- Blade length (radius):

$$l_{blade} = \frac{60 * v_{tip}}{2\pi * RPM * 0.0254} \; [in]$$



Demo

Demo Video Setup



Acknowledgments

- LGS
  - Duane Gardner
  - Martin Fay
  - Rory McCarthy
- UCSB
  - Dr. Yogananda Isukapalli
  - Brandon Pon
  - Carrie Segal