Distance and Velocity Measuring Radar

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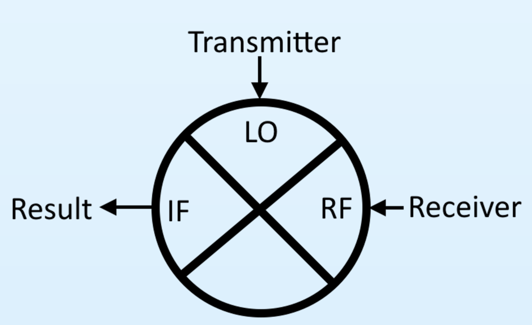
Introduction

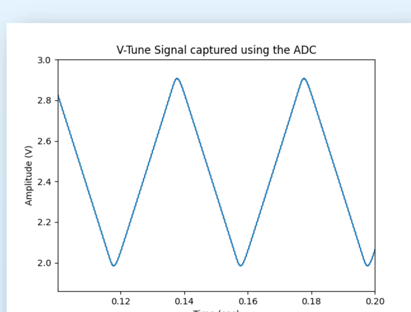
Goal: Design and build a radar system capable of measuring the distance to, and velocity of, a human-sized target.

Constraints:
- Transmission Frequency of 2.4 - 2.5 GHz.
- Transmission Power limited to 20mW.
- Detection Range of 100 meters.
- Fully Integrated on a PCB.
- Powered via USB 5-volt connection.

Design Theory

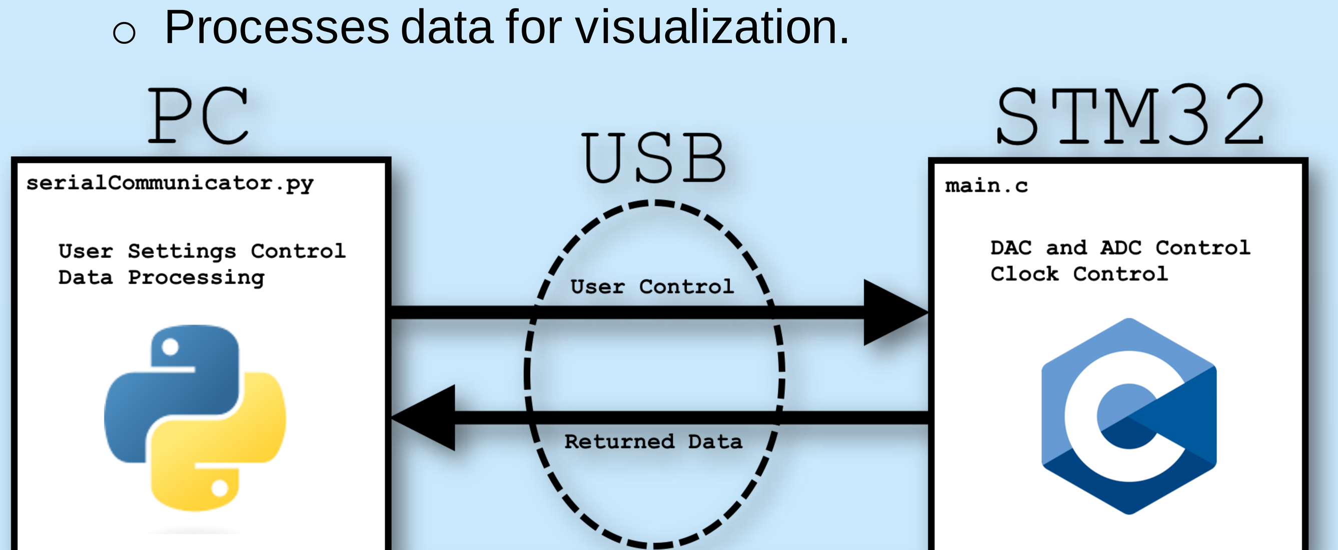
Radar Type: Frequency-Modulated Continuous Wave.
Fundamental Theory:
- Transmission is a continuous wave that is modulated at a known rate using a triangle control wave "V-Tune".
- Transmitter signal is used as the local oscillator (LO) in mixing to produce a base-band signal with a frequency proportional to the difference to the received signal.





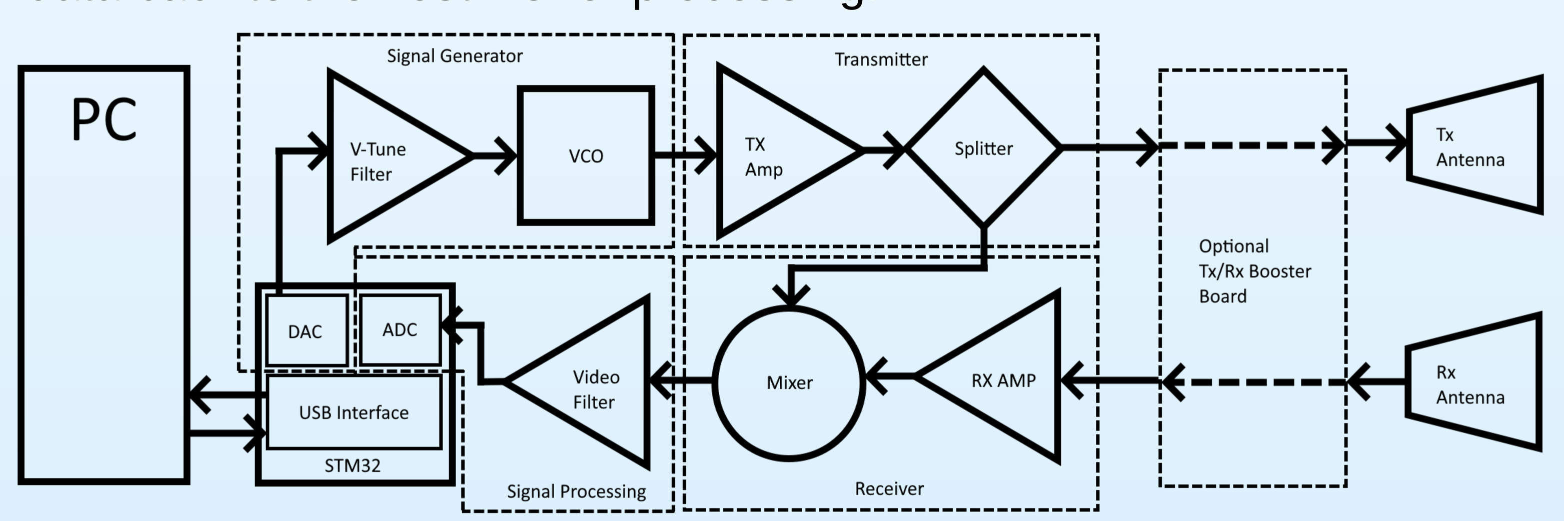
Software Design

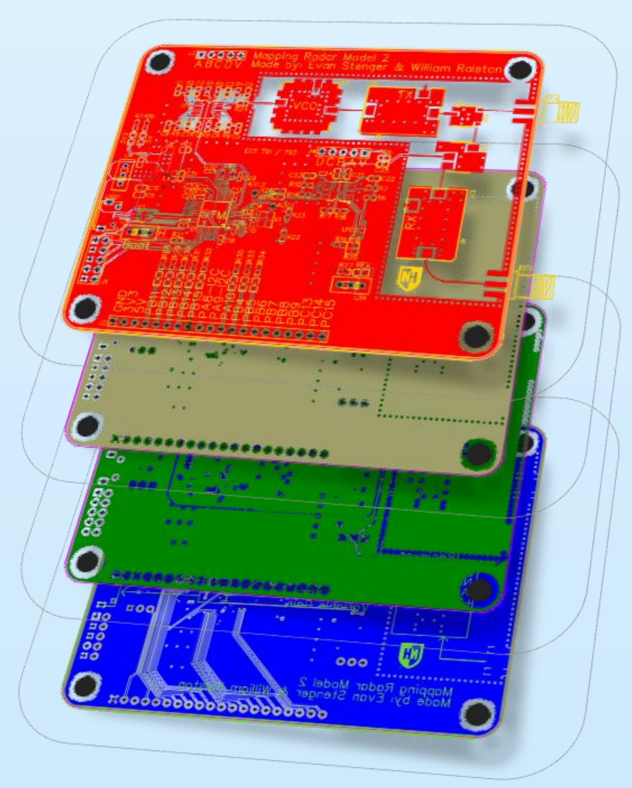
Two Primary Software Domains:
- Embedded software control in STM32 microcontroller
  - Written in C.
  - Creates and controls clocks.
  - Direct control of DAC, ADC, and USB.
- Control and Processing Software
  - Written in Python.
  - Passes configurations to STM32.
  - Records data output from radar board via COM port.
  - Processes data for visualization.



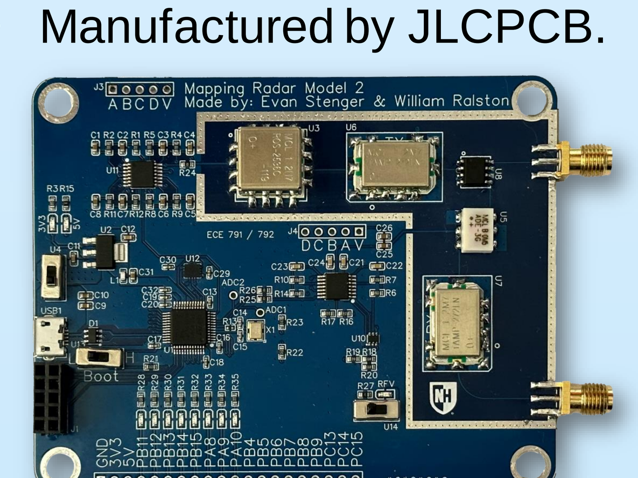
Hardware Design

Hardware Functional Loop:
- STM32 microcontroller provides digital-to-analog signal generation of "V-Tune" triangle ramp.
- V-Tune ramp is filtered with four-stages of two-pole active low-pass filter with a unity gain and cut-off frequency of 1KHz to remove DAC artifacts.
- VCO produces the frequency-modulated RF signal that is amplified by the TX Amplifier.
- Transmitter output is split for emitting and used as LO for down-mixing with received signal.
- Received and Transmitter LO signal are down-mixed to base-band result.
- Resulting low-frequency signal is filtered through a two-stage, two pole active low-pass filter with a cut-off frequency of 20KHz to remove high-frequency harmonics.
- STM32's analog-to-digital converter samples the signal and transfers the data back to the host PC for processing.





Fully integrated on a single PCB.
- Designed with EasyEDA.
- Four-layered PCB with impedance-controlled traces for USB and RF components.
- Manufactured by JLCPCB.

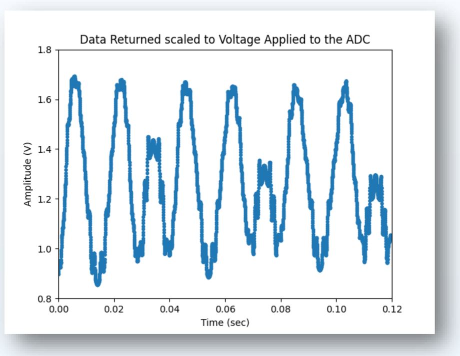


High-Gain Yagi Antenna
- Provides 18dBi of gain which contributes to >100-meter detection range with optional Tx/Rx Booster Board and a high level of antenna-to-antenna isolation.

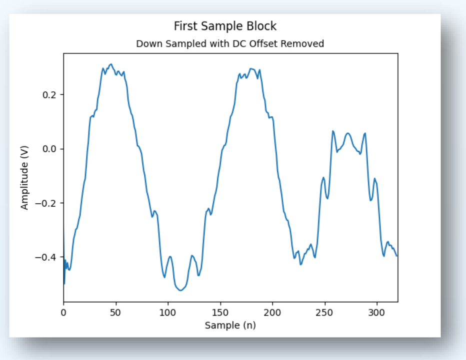
APA-M25 Compact Directional Antenna
- Provides 8dBi of gain in a compact size that allows the entire radar system to be held and used in a single hand.

Signal Processing

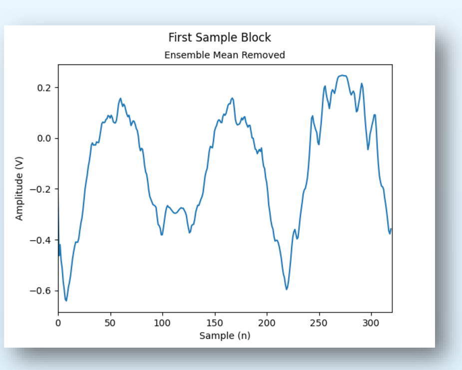
Goal: Use the sampled returns to generate an image showing the distance or speed over time.



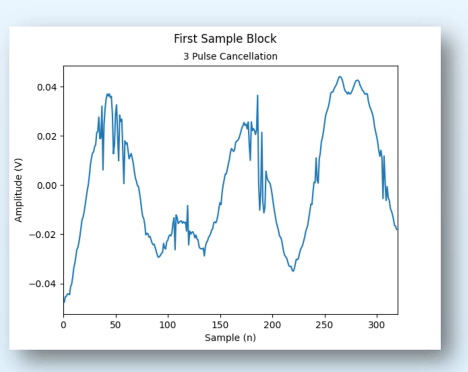
Processing Steps:
1. Down sampling by a factor of 5.
2. Remove DC offset
3. Samples divided into smaller 40ms blocks.



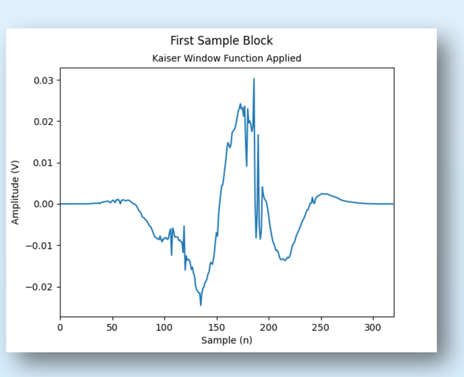
4. Ensemble mean is subtracted from each of the sample blocks.



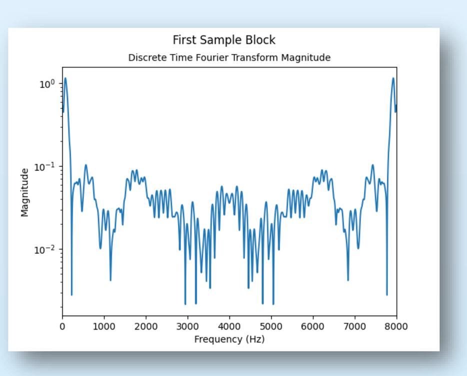
5. Pulse cancellation of 3 sample blocks.



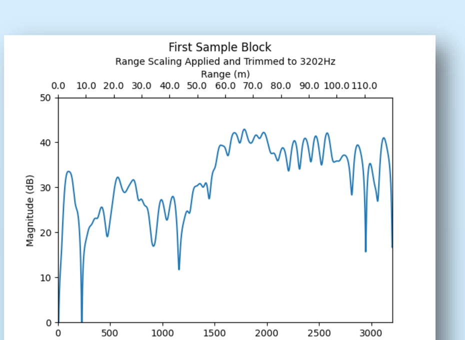
6. A Kaiser window is applied to each sample block.



7. A Discrete-time Fourier transform is performed on each sample block.



8. The frequency magnitude of each block is scaled to account for range losses.



9. The scaled values are plotted as an image, in which the frequency values are proportional to speed or distance and the color scale shows the magnitude at that frequency.