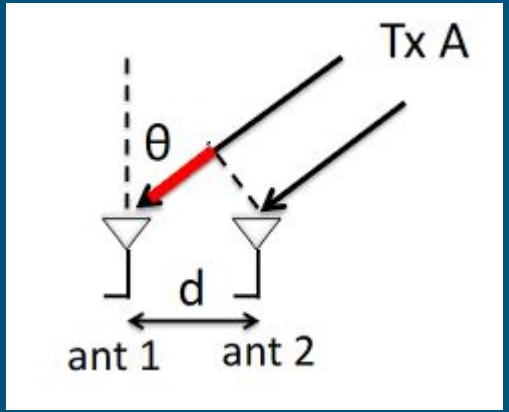
ECSE-6560 - Localization with PLUTO+ & MATLAB *Based on SpotFi*

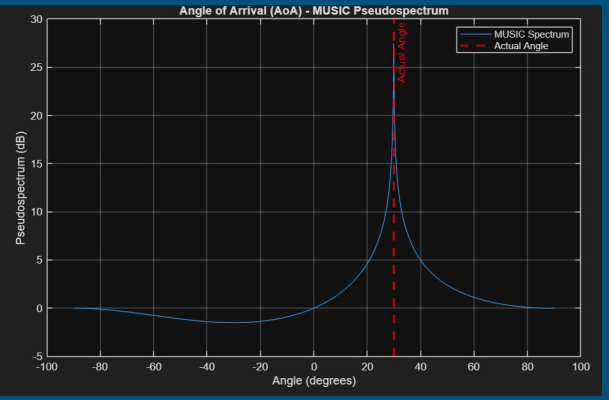
Joseph Pizzimenti

Simulation - AoA Estimation with variable SNR

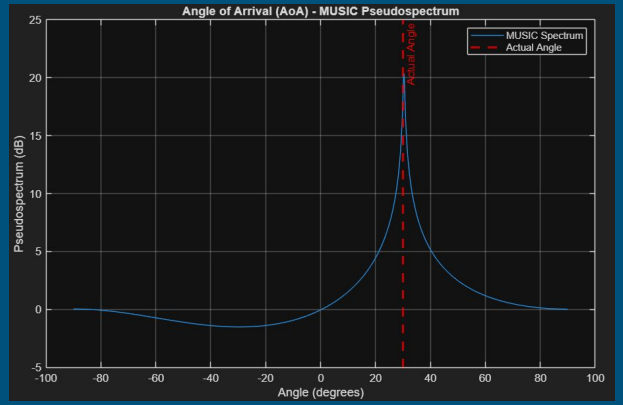
- Uses MATLAB Phased Array Antenna Toolbox
- Created a uniform linear array (ULA) with 2 isotropic antennas spaced at lambda/2
- Tested with 1000 samples
- Added white noise based on SNR simulated
- Applied MUSIC Algorithm for AoA estimation
- Plotted MUSIC spectrum output compared with ground truth angle



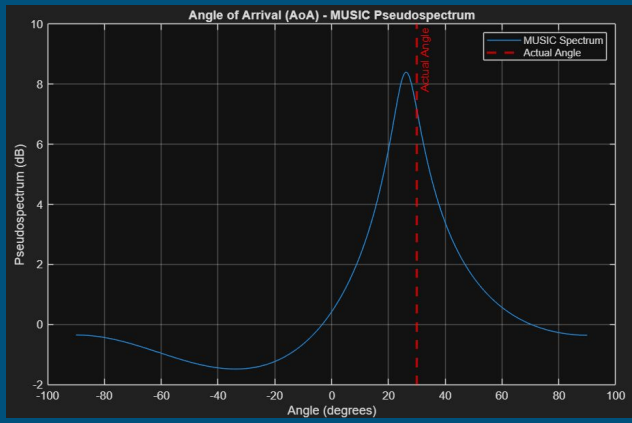
Simulation - AoA Estimation with variable SNR



SNR = 10dB



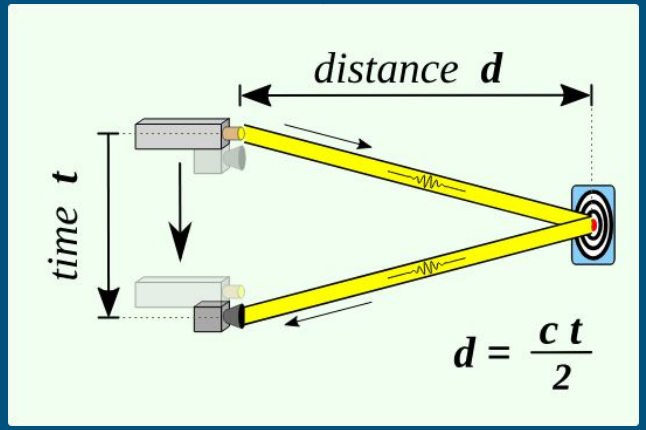
SNR = 0dB



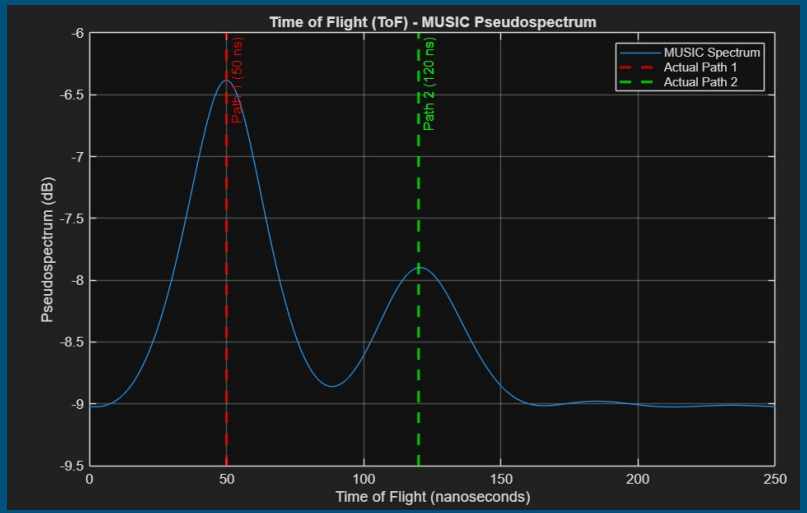
SNR = -10dB

Simulation - ToF Estimation with variable SNR

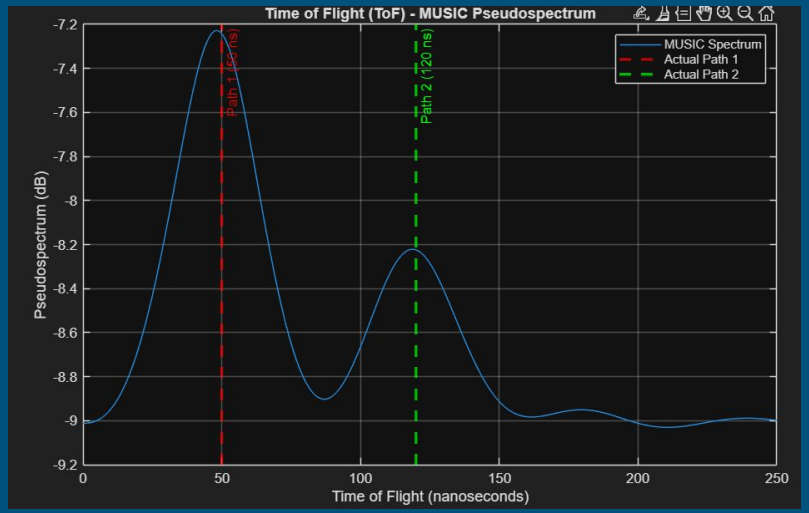
- Generates OFDM signal at standard WiFi spacing (312.5kHz)
- Created ground truth multipath channel with CSI computed from OFDM parameters
- Added white noise based on SNR simulated
- Used MUSIC again to estimate spectrum
- Found multipath delays and approximated ToF



Simulation - ToF Estimation with variable SNR



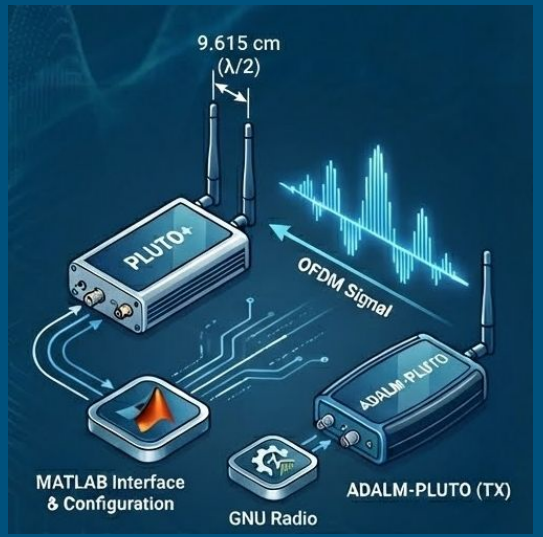
SNR = 0dB



SNR = -20dB

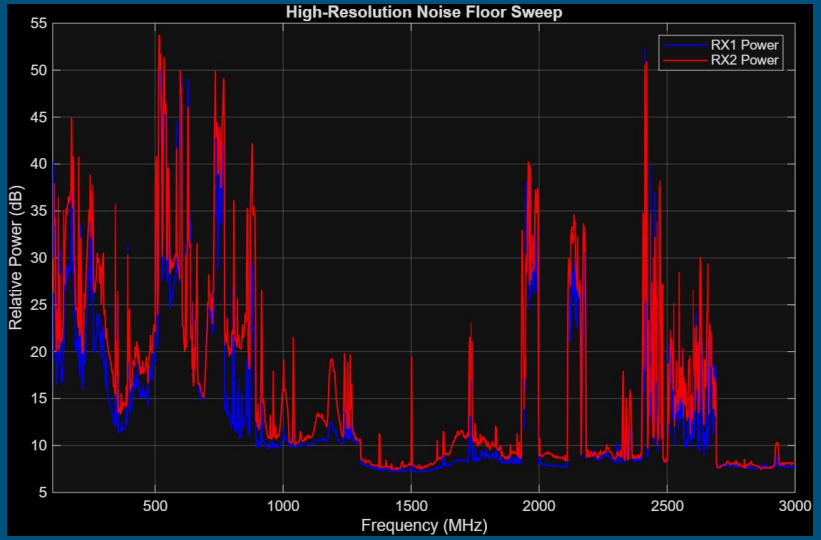
Hardware Experiment

- PLUTO+ as receiver with 2*rx (custom PLUTO+ firmware)
  - Interfaced with MATLAB
  - Required lots of special configuration and to interface with MATLAB
- Spaced 2*RX at about 9.615 centimeters/3.78 inches apart (wavelength/2)
- ADALM-PLUTO as constant OFDM Transmitter
- Used fixed RNG seed between receiver and transmitter



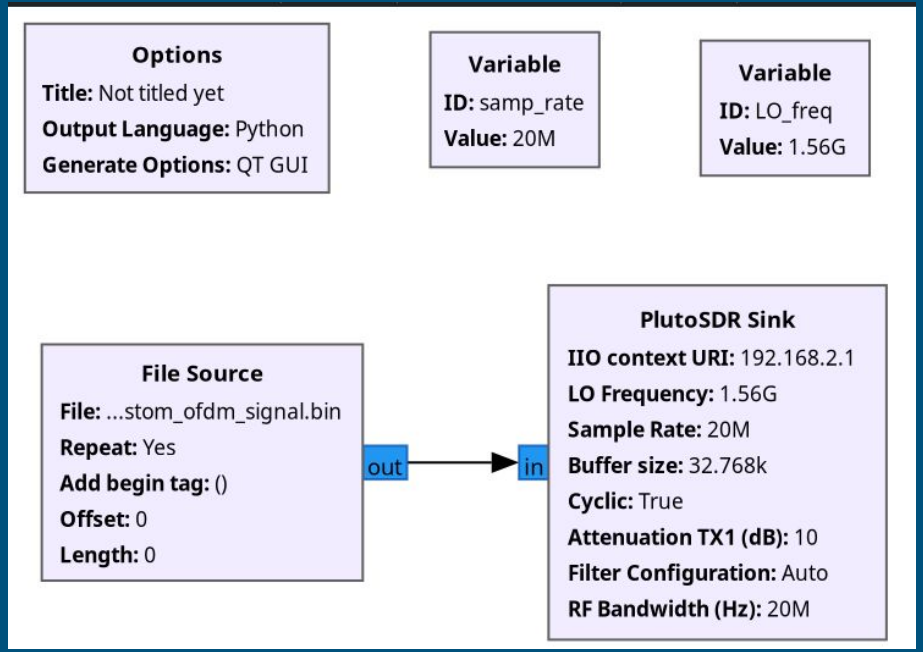
Reading the Noise Floor

- 2.4 GHz was way too noisy for any localization tests
- Performed wideband spectrum sweep on environment
- Decided on a center frequency of 1.56 GHz from this experiment



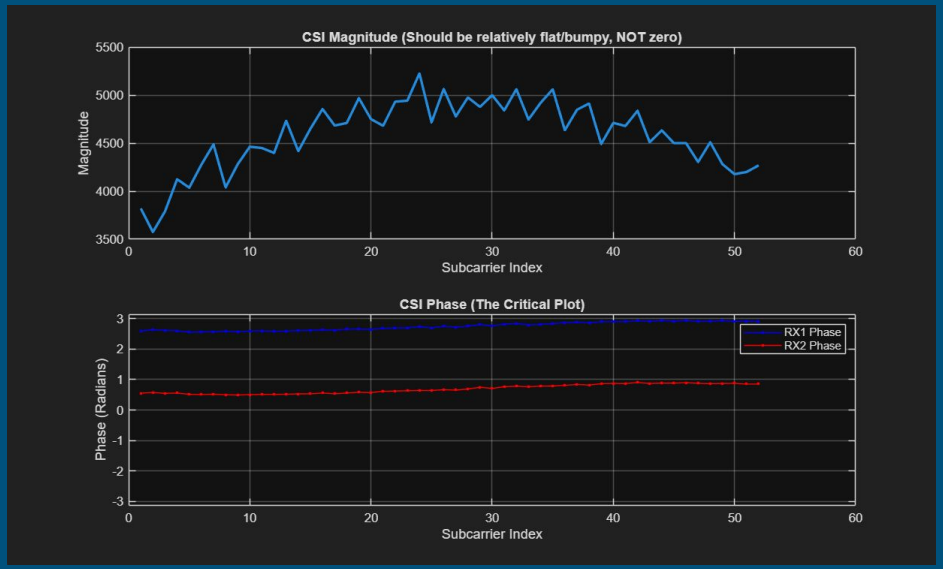
Generating & Transmitting the OFDM Signal

```
%% Generate OFDM Signal for ADALM-PLUTO Transmitter
% Creates a custom OFDM signal with 64 subcarriers.
% It saves the I/Q samples to a binary file for use in GNU Radio.

clear; clc;

rng(42); %FIXED SEED - used for randn() used in signal generator
filename = 'custom_ofdm_signal.bin';
nSubcarriers = 64;
scSpacing = 312.5e3;    % Standard WiFi spacing
cpLen = 16;             % Cyclic Prefix length (16 samples)

%% Create Frequency Domain Symbols
% Using the known preamble 52 subcarriers (standard for WiFi) are used and
% I zeroed out the edges/DC
known_symbol = zeros(nSubcarriers, 1);
active_indices = [7:32 34:59]; % Skip DC (33) and guard bands
known_symbol(active_indices) = sign(randn(length(active_indices), 1));

%% OFDM Modulation
tx_time = ifft(ifftshift(known_symbol)) * sqrt(nSubcarriers);

tx_cp = [tx_time(end-cpLen+1:end); tx_time]; % Add CP

tx_packet = repmat(tx_cp, 10, 1); % Repeat the symbol 10 times to make a "packet"

% Add a little silence (gap) between packets
silence = zeros(100, 1);
final_signal = [tx_packet; silence];

final_signal = final_signal / max(abs(final_signal)) * 0.5; % Normalized to prevent clipping

%% Save to Binary File for use in GNU Radio
interleaved = [real(final_signal) imag(final_signal)].';
interleaved = interleaved(:);

fileID = fopen(filename, 'w');
fwrite(fileID, interleaved, 'float32');
fclose(fileID);

disp(['Successfully saved ' filename]);
```



Hardware Experiment - AoA Only

- CSI Extraction
- Switched from MUSIC to Bartlett Beamformer
  - More accurate for this 2 antenna scenario
- Used weighted averaging to generate a plot
  - 2 antenna case here suffered HEAVILY from multipath



Results

Why no ToF? - Challenges & Next Steps

Challenges:

- Absolute ToF estimation was not functional with 2 antennas.
- Relative multipath was very visible on phase difference vs. subcarrier plot
- Not stable enough for ToF estimation
  - MATLAB showed a “steady state” AoA, but would jump around every once in a while
  - Could experiment with other estimation algorithms
  - 2 antenna AoA estimation with MUSIC was not very good, Bartlett Beamformer was slightly better

Next Steps:

- Maybe would be possible if I implemented Two-Way Ranging
  - CFO/SFO correction for clock synchronization would’ve allowed for two-way ranging
- Could have used RSSI to approximate distance from transmitter
- Test in an emptier environment
  - Testing room was very cluttered, too many multipaths could interfere with this algorithm

References

[1] M. Kotaru, K. Joshi, D. Bharadia, and S. Katti, “SpotFi,” in Proceedings of the 2015 ACM Conference on Special Interest Group on Data Communication, New York, NY, USA: ACM, Aug. 2015, pp. 269–282. Accessed: Dec. 11, 2025. [Online]. Available: https://web.stanford.edu/~skatti/pubs/sigcomm15-spotfi.pdf

[2] Analog Devices Inc., “Analog Devices, Inc. Transceiver Toolbox,” MATLAB Central. Accessed: Dec. 11, 2025. [Online]. Available: https://www.mathworks.com/matlabcentral/fileexchange/72645-analog-devices-inc-transceiver-toolbox

[3] X. Li, Y. Xing, and Z. Zhang, “A Hybrid AOA and TDOA-Based Localization Method Using Only Two Stations,” Wiley Online Library. Accessed: Dec. 11, 2025. [Online]. Available: https://onlinelibrary.wiley.com/doi/10.1155/2021/5512395