Diagnostics - USRP Sensing Subsystem

Configure the configuration to test against

```
clear;
clf;
simulator = Simulator_revB();
kristen_path = "C:\Users\krist\OneDrive\Documents\2022-2023 School Year\Radar Security
windows_file_path = "C:\Users\Operator\Documents\RadarSecurityResearch\MATLAB\Simulink
david_path = "/home/david/Documents/BlackBoxRadarAttacks/MATLAB/config_files/";
% file_path = "20MHz_USRP.json";
% file_path = "20MHz_USRP_revA.json";
file_path = "20MHz_USRP_revB.json";
% file_path = "20MHz.json";
% file_path = "100MHz.json";
% file_path = "100MHz_USRP.json";
% file_path = "1GHz.json";
% file_path = "4GHz.json";
simulator.load_params_from_JSON(david_path + file_path);

%apply timing offsets as desired
simulator.Victim.timing_offset_us = 0;
simulator.Attacker.Subsystem_tracking.timing_offset_us = 0;

%configure the FMCW parameters
simulator.configure_FMCW_Radar_parameters();

%load default attacker, and victim positions and velocities
simulator.load_usrp_attacker_and_victim_position_and_velocity();

%print out key parameters

simulator.Victim.print_radar_parameters;
```

```
Chirp Parameters
     Start Frequency:          3.00 GHz
     Frequency Slope:          0.10 MHz/us
     Idle Time:               11.28 us
     Tx Start Time:           0.00 us
     ADC Valid Start Time:          7.52 us
     ADC Samples:              64
     ADC Sample Rate:          0.27 MSps
     Ramp End Time:           248.12 us
     Chirp Tx Bandwidth:           24.99 MHz
     Chirp Sampling Bandwidth:      24.23 MHz
     ADC Sampling Period:          240.60 us
     Chirp Cycle Time:          259.40 us
     Chirp Wavelength:          99.93 mm
Frame Parameters
     Number of Chirps          256
     FramePeriodicity          100.13 ms
     Active Frame Time          66.41 ms
Performance Specifications
```

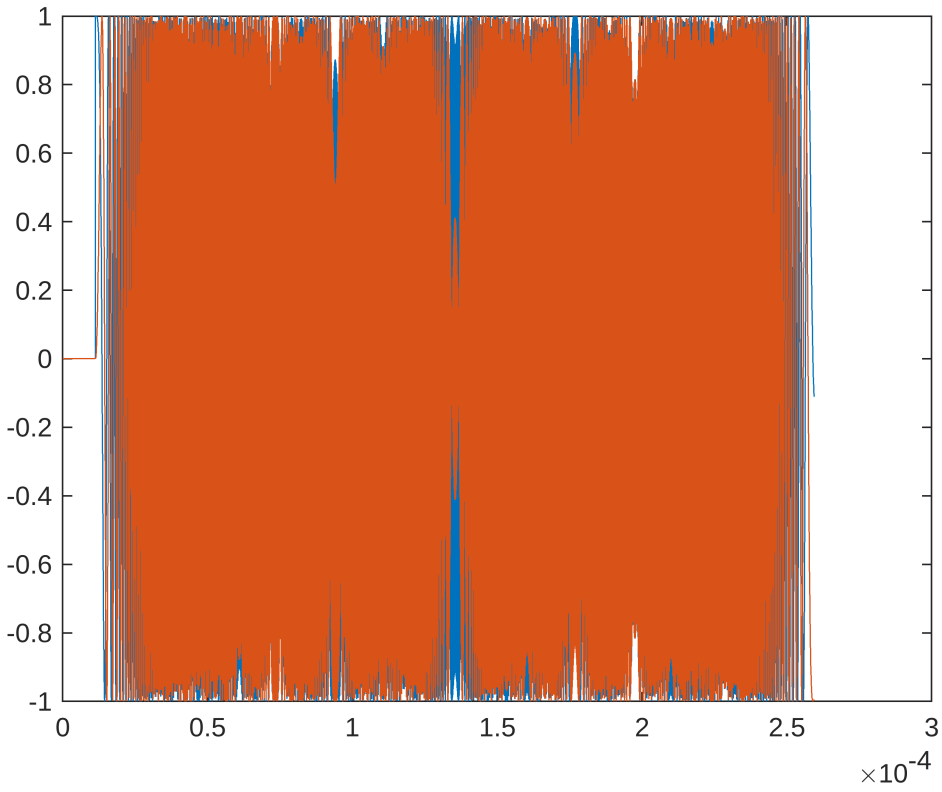
```
      Max Range              395.95 m
      Range Resolution         6.19 m
      Max Velocity            96.31 m/s
      Velocity Resolution      0.75 m/s
FMCW Specifications
      FMCW sampling rate      25.00 MHz
      Downsampling factor      94
      Sweep time             248.12 us
      Samples per chirp         6486.00
CFAR Detection Region
      Range Detection Region          61.868 m to 327.898 m
      Velocity Detection Region          -75.242 m/s to 75.995 m/s
```

Save the victim chirp to a file

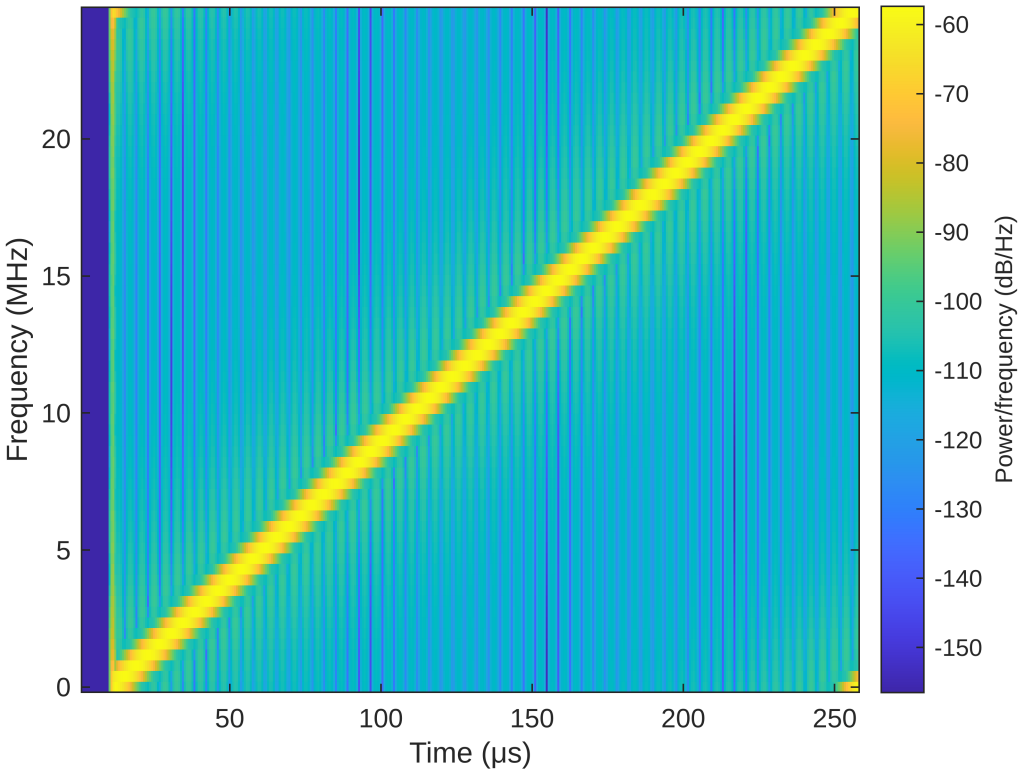
```
%save the full chirp as a binary file
path = "/home/david/Documents/MATLAB_generated/MATLAB_full_chirps/MATLAB_chirp_full.bin
simulator.save_to_file(simulator.Victim.chirp,path,'float32');
```

Plot Tx Chirp to confirm correctness

```
%plot the chirp signal
t = 0:simulator.Victim.FMCW_sampling_period_s:...
    simulator.Victim.ChirpCycleTime_us * 1e-6 - ...
    simulator.Victim.FMCW_sampling_period_s;
data = simulator.Victim.chirp;
plot(t,real(data),t,imag(data))
```



```
spectrogram(data,64,48,64,simulator.Victim.FMCW_sampling_rate_Hz,'yaxis')
```



RUN EXPERIMENT ON USRP DEVICE - SESING ONLY (enable debug on sensing subsystem)

Load key sensing subsystem parameters from USRP Implementation

Spectrogram Generation

Get key initialization parameters

```
num_rows = 722;
fft_size = 128;
samples_per_sampling_window = 175;
samp_freq = 25.004 * 1e6;

%load the times/frequencies used for spectrogram generation in the cpp code
path = "/home/david/Documents/MATLAB_generated/cpp_sensed_parameters/cpp_spectrogram_ti
spectrogram_times = simulator.read_from_file(path,false,"double");

path = "/home/david/Documents/MATLAB_generated/cpp_sensed_parameters/cpp_spectrogram_fr
spectrogram_frequencies = simulator.read_from_file(path,false,"double");

fprintf(" rows: %d \n samples per sampling window: %d \n fft size: %d \n samp freq: %d'
    num_rows,samples_per_sampling_window,fft_size,samp_freq);
```

```
rows: 722
samples per sampling window: 175
fft size: 128
samp freq: 25004000
```

Verify Hanning Window

```
%get the hanning window
path = "/home/david/Documents/MATLAB_generated/cpp_sensed_parameters/cpp_hanning_windo
read_data = simulator.read_from_file(path,true,"float");

%compare with the computed hanning window
compare = all(abs(read_data - hann(fft_size)) < 1e-5);
if compare
    fprintf("Hanning window matches")
else
    fprintf("Hanning window doesn't match")
end
```

```
Hanning window matches
```

Reshape Received Signal - read and verify

```
%get the reshaped for fft signal
path = "/home/david/Documents/MATLAB_generated/cpp_sensed_parameters/cpp_reshaped_and_w

read_data = simulator.read_from_file(path,true,"float");
read_data_reshaped = reshape(read_data,fft_size,num_rows);
```

Generated Spectrogram

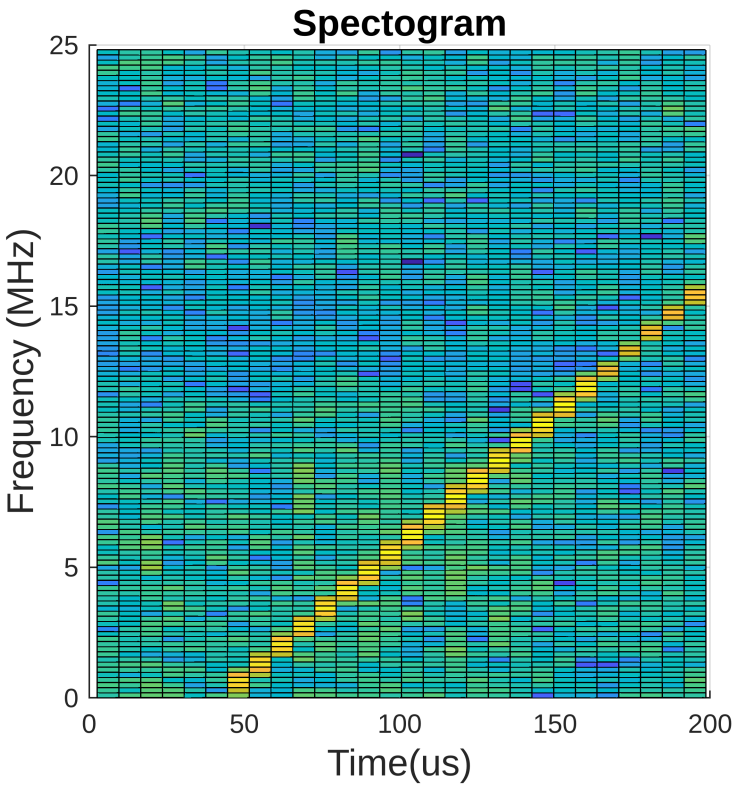
```
path = "/home/david/Documents/MATLAB_generated/cpp_sensed_parameters/cpp_generated_spec

read_data = simulator.read_from_file(path,false,"float");
read_data_reshaped = reshape(read_data,fft_size,num_rows);

max_time_to_plot_us = 200;
idx_to_plot = spectrogram_times < max_time_to_plot_us;

clf;
set(gcf,'Position',[100 100 400 400])
font_size = 14;
ax = gca;
ax.FontSize = font_size;
surf(spectrogram_times(idx_to_plot),...
    spectrogram_frequencies,...
    read_data_reshaped(:,idx_to_plot));
title_str = sprintf('Spectogram');
title(title_str,"FontSize",font_size);
xlabel('Time(us)',"FontSize",font_size)
```

```
ylabel('Frequency (MHz)',"FontSize",font_size)
view([0,90.0])
```



Detected Times and Frequencies - read and verify

```
path = "/home/david/Documents/MATLAB_generated/cpp_sensed_parameters/cpp_detected_frequ

read_data_detected_frequencies = simulator.read_from_file(path,false,"double");

path = "/home/david/Documents/MATLAB_generated/cpp_sensed_parameters/cpp_detected_times
read_data_detected_times = simulator.read_from_file(path,false,"double");
```

Clusters - read and verify

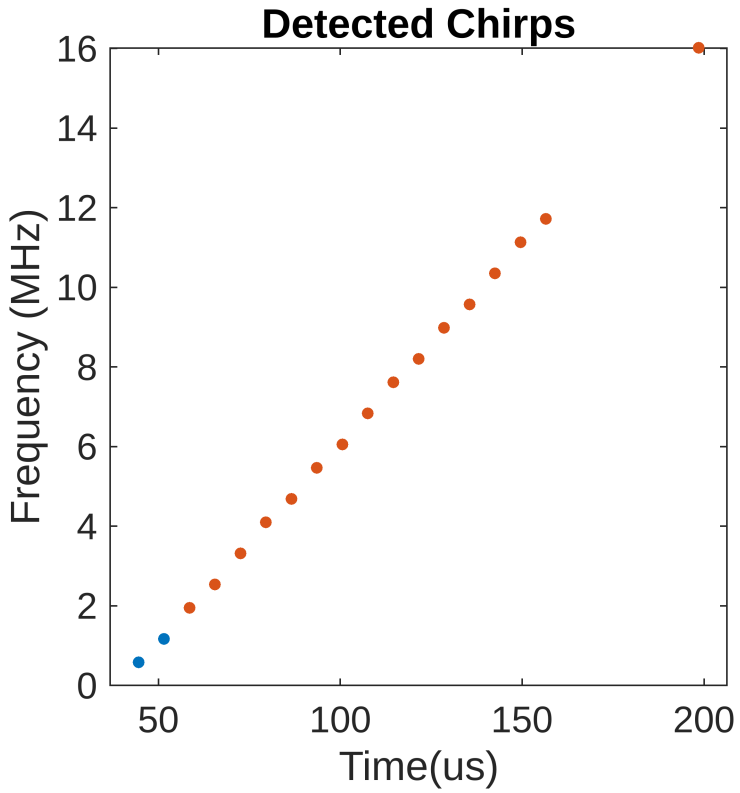
```
path = "/home/david/Documents/MATLAB_generated/cpp_sensed_parameters/cpp_computed_clust
read_data = simulator.read_from_file(path,false,"int");
read_data_idx = read_data(read_data ~= 0);

idx_to_plot = read_data_detected_times < max_time_to_plot_us;

clf;

gscatter(read_data_detected_times(idx_to_plot), ...
    read_data_detected_frequencies(idx_to_plot), ...
    read_data_idx(idx_to_plot));
set(gcf,'Position',[100 100 400 400])
font_size = 14;
```

```
title_str = sprintf('Detected Chirps');
title(title_str,"FontSize",font_size);
xlabel('Time(us)',"FontSize",font_size)
ylabel('Frequency (MHz)',"FontSize",font_size)
ax = gca;
ax.FontSize = font_size;
legend off;
```



Computed Linear Models

```
path = "/home/david/Documents/MATLAB_generated/cpp_sensed_parameters/cpp_detected_slope
read_data_detected_slopes = simulator.read_from_file(path,false,"double")
```

```
read_data_detected_slopes = 20×1
    0.1007
    0.1006
    0.1007
    0.1008
    0.1004
    0.1005
    0.1006
    0.1007
    0.1006
    0.1007
     ⋮
```

```
path = "/home/david/Documents/MATLAB_generated/cpp_sensed_parameters/cpp_detected_inter
```

```
read_data_intercepts = simulator.read_from_file(path,false,"double")
```

```
read_data_intercepts = 20×1
10^6 ×
    6.0501
    6.0504
    6.0506
    6.0509
    6.0511
    6.0514
    6.0517
    6.0519
    6.0522
    6.0524
     ⋮
```

```
%captured chirps buffer
path = "/home/david/Documents/MATLAB_generated/cpp_sensed_parameters/cpp_chirp_estimate
captured_chirps_buffer = simulator.read_from_file(path,false,"double")
```

```
captured_chirps_buffer = 393×1
  259.1019
  259.1289
  259.1888
  259.2000
  259.2353
  259.2415
  259.2423
  259.2434
  259.2434
  259.2453
     ⋮
```

Captured Frames Array

```
path = "/home/david/Documents/MATLAB_generated/cpp_sensed_parameters/cpp_captured_frame
read_data = simulator.read_from_file(path,false,"double");
captured_frames = reshape(read_data,6,[]).'
```

```
captured_frames = 30×6
10^6 ×
         0         0         0         0    0.2501         0
         0         0         0         0    0.4501    0.6504
         0         0         0         0    0.6501    0.8504
         0         0         0         0    0.8501    1.0504
         0         0         0         0    1.0501    1.2504
         0         0         0         0    1.2501    1.4504
         0         0         0         0    1.4501    1.6504
         0         0         0         0    1.6501    1.8504
         0         0         0         0    1.8501    2.0504
         0         0         0         0    2.0501    2.2504
     ⋮
```

```
estimation_errors_ns = (captured_frames(2:end - 1,6) - captured_frames(3:end,5) ...
    - simulator.Victim.ChirpCycleTime_us) * 1e3
```

```
estimation_errors_ns = 28×1
  142.0221
 -478.8832
 -266.1137
  196.2949
  -74.1292
   62.3917
  -98.3812
   36.8666
   37.6182
   38.2195
      ⋮
```

```
average_error_ns = mean(estimation_errors_ns(3:end))
```

```
average_error_ns = 17.7483
```

```
error_stdev_ns_squared = sqrt(var(estimation_errors_ns(3:end)))
```

```
error_stdev_ns_squared = 79.8278
```

Get the estimated parameters

```
path = "/home/david/Documents/MATLAB_generated/cpp_sensed_parameters/cpp_estimated_para
read_data = simulator.read_from_file(path,false,"double");
estimated_frame_duration_ms = read_data(1);
estimated_chirp_duration_us = read_data(2);
estimated_chirp_slope_MHz_us = read_data(3);

% %print out the relevant information
fprintf("Average Frame Duration: %3.7f ms",estimated_frame_duration_ms);
```

```
Average Frame Duration: 199.9996919 ms
```

```
fprintf("Average Chirp Duration: %3.3f us",estimated_chirp_duration_us);
```

```
Average Chirp Duration: 259.442 us
```

```
fprintf("Average Slope: %1.3f MHz/us",estimated_chirp_slope_MHz_us);
```

```
Average Slope: 0.101 MHz/us
```

Estimation Errors

```
% %print out the relevant information
actual_frame_duration_ms = 100;
fprintf("Frame Duration Error: %3.5f ns",(estimated_frame_duration_ms - actual_frame_du
```

```
Frame Duration Error: 99999691.92698 ns
```

```
fprintf("Chirp Duration Error: %3.5f ns",(estimated_chirp_duration_us - simulator.Victi
```

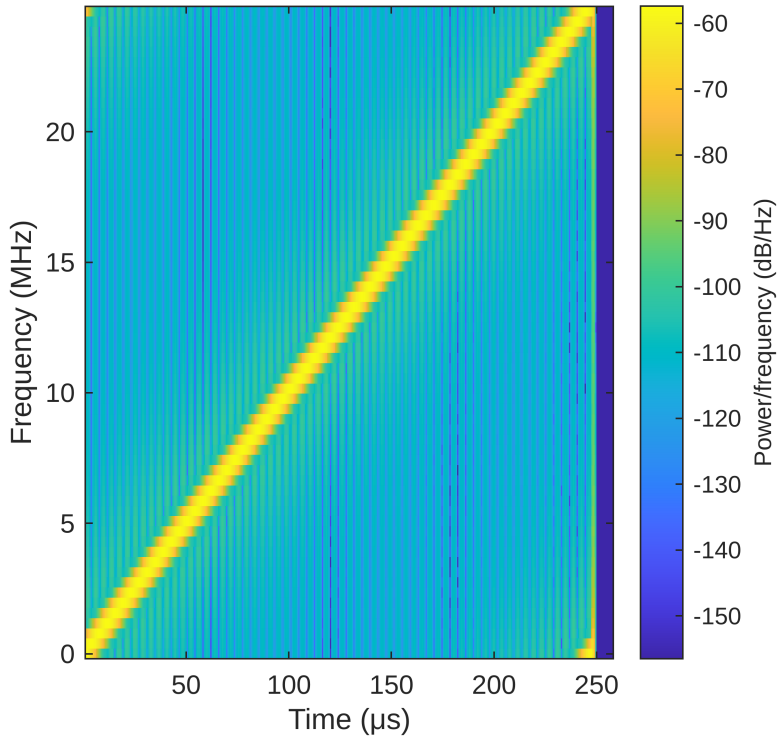
```
Chirp Duration Error: 43.63127 ns
```

```
fprintf("Slope Error: %1.5f MHz/us",estimated_chirp_slope_MHz_us - simulator.Victim.Fre
```

```
Slope Error: -0.00004 MHz/us
```

Computed Victim Waveform from Attacker

```
clf;
path = "/home/david/Documents/MATLAB_generated/cpp_sensed_parameters/cpp_computed_victi
estimated_waveform = simulator.read_from_file(path,true,"float32");
spectrogram(estimated_waveform,64,48,64,simulator.Victim.FMCW_sampling_rate_Hz,'yaxis')
```

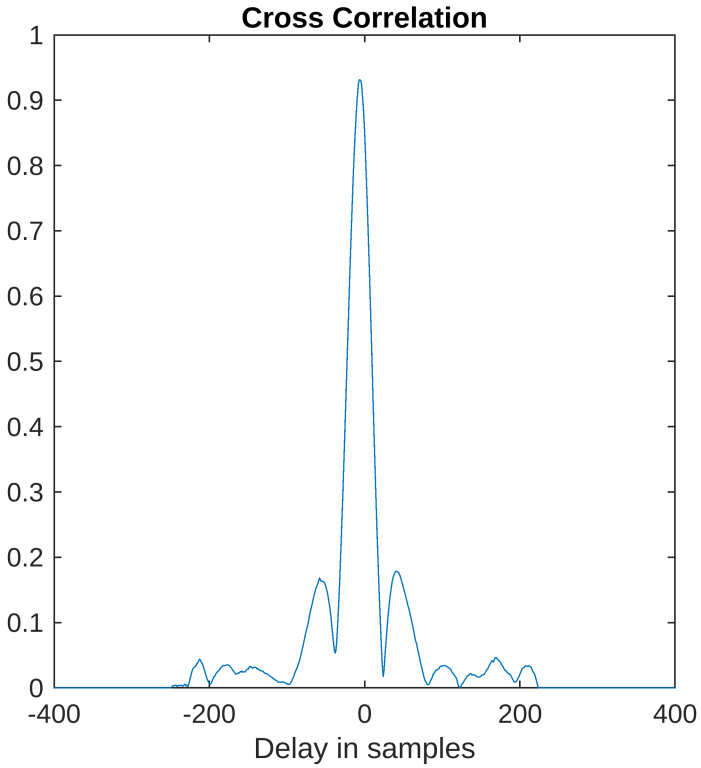


Computed Cross-Correlation

```
path = "/home/david/Documents/MATLAB_generated/cpp_sensed_parameters/cross_correlation_
result = simulator.read_from_file(path,true,"float32");

path = "/home/david/Documents/MATLAB_generated/cpp_sensed_parameters/cross_correlation_
lags = simulator.read_from_file(path,false,"int");

%plot the computed cross correlation
clf;
plot(lags,abs(result));
xlabel("Delay in samples")
title("Cross Correlation")
```


Cross Correlation
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-400
-200
0
200
400
Delay in samples