USAF ACADEMY
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
LESSON 28 LAB - FMCW Range
Lab Packet
Fall 2026

Name: _____ **Section:** _____ **Date:** _____

Learning Objective 4.2: I can calculate range resolution, unambiguous range, and Doppler shift for a given radar waveform.

Learning Objective 4.4: I can describe FMCW radar operation and configure an FMCW waveform on the ADALM-PHASER.

Learning Objective 4.5: I can process FMCW radar data to produce range, range-waterfall, and range-Doppler results.

This packet is the L28 Lab, in three parts, and you turn it in once, complete. Do **Part 1** before you go to the bench: the predictions you will test. **Part 2** is your own measurements, from your own kit with the Phaser app, and three short tasks in the course's notebook, run on the captures you saved. Do **Part 3** after the bench: compare the measurements with the predictions and explain the differences. You work this lab on your own, outside class, following the procedure on the L28 page.

Due: see Gradescope.

Grading. The packet is checked and returned with feedback. It is the first piece of scaffolding for your final report, not part of the report: the report explains the radar in your own words, and text lifted from this packet earns nothing there.

The radar is the PHASER in the Phaser app's **Range (Basic)** preset: a 12.145 GHz carrier, a chirp of bandwidth $B = 500$ MHz and length $T_s = 1$ ms, and the Pluto sampling the beat at $f_s = 0.6$ MSPS. Use $c = 3.00 \times 10^8$ m/s. Measure range from the array face.

Part 1: Pre-Lab (individual, before the bench)

1. **From range to beat frequency.** A flat plate stands in front of the kit at the settings above.

   (a) Find the chirp slope, in MHz per microsecond.

   slope = ☐

   (b) Find the round-trip delay of the echo from a plate at 1.00 m, and the beat frequency it produces.

   τ = ☐

   f_b = ☐

(c) The kit's 0 m frequency is about $f_0 = 100$ kHz. Predict the frequency of the plate's peak at each range.

Range	1.00 m	2.00 m	3.00 m
Beat above f_0			
Peak frequency			

(d) How many cycles of the beat fit in one chirp for the plate at 1.00 m? Show that the number does not depend on T_s.

2. Changing the waveform. Procedure C changes one setting at a time: the app's **Range (Fast)** preset halves the chirp length and samples at 5 MSPS, and the course's recorded capture halves the bandwidth. Predict each row for the plate at 2.00 m, with $f_0 = 100$ kHz.

Waveform	**kHz per meter**	**Peak frequency**	**Resolution**	**Reach**
Range (Basic): 500 MHz, 1 ms				
Range (Fast): 500 MHz, 0.5 ms				
Recorded: 250 MHz, 1 ms				

(a) Show the work for the resolution and the reach of the Range (Fast) and the 250 MHz rows.

(b) Both changes move the plate's peak. Name two things the bench can show, besides the peak's frequency, that tell the two changes apart.

3. The range FFT. One 1 ms chirp sampled at 0.6 MSPS. The app discards the first 0.1 ms of each chirp, while the ramp settles, and keeps the rest.

(a) Find the number of samples the app keeps of one chirp, the spacing of the FFT's bins in kHz, and that spacing in meters.

N =

Δf =

ΔR =

(b) Two plates stand 0.20 m apart, near 2 m. Does one chirp's FFT show one peak or two? Answer in terms of the beat cycles in the samples the app keeps.

(c) Zero-padding the 540 samples to a 4096-point FFT gives bins 0.146 kHz apart. Does it improve the resolution? Explain.

4. Windows and the echo budget.

(a) A strong target and one 30 dB weaker stand 2.0 m apart, six bins. With a rectangular window the strong target's sidelobes there sit about 25 dB below its peak; with a Hann window, about 54 dB. Which window shows the weak target, and what does it give up to do so?

(b) Lesson 25 put a 10 cm corner reflector at 3 m at 31.1 dB above the noise in a 1 MHz bandwidth. One FFT bin is 1.11 kHz wide. Predict the corner's height above the noise floor in the range profile, rectangular window, and then with Hann.

rectangular =

Hann =

Part 2: Measurements (your kit, and the notebook)

Follow the procedure on the L28 page. Transmit antenna on **OUT2**, connected before you power the kit. Step out of the beam while you read a static target. The app shows range; the notebook's peak readout gives each capture's peak frequencies. With no kit, use the app's simulator with **Load Recording** on the course's recorded data, as the page's *No Hardware?* frame describes, and mark which rows are recorded rather than your own. A gray cell is given; you do not fill it.

Kit: _____ Target used: _____ Recorded data? _____

5. **Table A: the 0 m frequency** (Procedure A). The app reads each frequency to the nearest FFT bin, 1.11 kHz; the notebook reads the same capture to 0.01 kHz. *Expected* is the lesson's value, for comparison.

Quantity	App, New 0 m beat	Notebook	Expected
Leakage peak, bench clear			near 100 kHz
f_0, plate against the array			95 to 105 kHz
Capture files			

6. **Table B: static ranges** (Procedure B). Range (Basic). Range in the app from hovering over the plate's peak; peak frequency from the notebook's readout on the capture; beat above your notebook f_0 from Table A.

Tape range	Range in the app	Peak frequency	Beat above f_0	Capture file
1.00 m				
2.00 m				
3.00 m				

Measured beat per meter, the slope of peak frequency against tape range: ____

Its intercept, the line's frequency at 0 m: ____

Optional, the course corner reflector at 3.00 m, from the notebook's readout: peak _____ dBFS, height above the floor _____ dB.

7. **Table C: chirp length and bandwidth** (Procedure C). Plate at 2.00 m. Copy your predictions from Question 2 before you measure; the measured columns come from the notebook's readout.

Waveform	Predicted peak	Measured peak	Width 3 dB down	Height above floor	Capture file
Range (Basic)					
Range (Fast)					
250 MHz, recorded					`L28_corner_2m_B250.npz`

8. **Table D: the waterfall** (Procedure D). Your walk out to about 4 m and back, read from the app's Range Waterfall; and the course's walk, `L28_walker.npz`, from Load Recording or the notebook's waterfall.

Quantity	Your walk	`L28_walker.npz`
Nearest range of the trace		
Farthest range of the trace		
Frames for one leg, out or back		
Frame Rate readout		
Time for one leg		
Walking speed from the slope		
Screenshot file		

9. Table E: the notebook (Procedure E). Run `L28_range.ipynb` with the course's `radar_lab.py` on your 2 m capture. Each task changes the one line its cell names. Upload the saved `.ipynb`, with its edits and plots, with this packet.

Task (a), the window. `WINDOW = "hann"`, then `WINDOW = None`.

Quantity	Hann	Rectangular
Peak range and level		
Strongest sidelobe of the peak		
Floor near 10 m		

Task (b), zero-padding, on `L28_two_corners.npz`, corners 0.20 m apart. In the two-corner cell, `N_FFT = None`, then `N_FFT = 4096`.

Quantity	No padding	4096 points
Peaks between 1.5 and 2.7 m		
Width 3 dB down		

Task (c), range from your own f_0. Your `F0` _____ kHz; `f_peak` _____ kHz; `R` ____

against the tape's _____ m. Your changed line:

_____

Part 3: Writeup (individual, after the bench)

10. Beat per meter. Compare the slope from Table B with the 3.33 kHz/m of Question 1, and the line's intercept with your f_0 from Table A. Name the two largest sources of the differences, and say which one moves every range by the same amount and which one changes the slope.

11. Changing the waveform. Using Table C and your Question 2 predictions, explain why Range (Fast) doubles the plate's beat without changing the width of its peak, while the 250 MHz capture halves the beat and doubles the width. Then explain the change in the peak's height above the floor.

12. The rectangular floor. In Task (a) the floor near 10 m rose by about 30 dB when you changed to the rectangular window. Is that rise noise? Explain from your two plots.

13. **Reading your waterfall.** Identify every line in your waterfall screenshot, and say how you found the walking speed. Why can this waterfall give the speed only from the slope of the trace, and not from the phase of the echo?

14. **What you carry forward.** List what you keep from this lab for the later labs and for the final report.

Documentation: _____