USAF ACADEMY
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
LESSON 24 LAB - Null Steering
Lab Packet
Fall 2026

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

Learning Objective 3.9: I can calculate null-steering weights and implement pattern nulls on the ADALM-PHASER.

This packet is the L24 Lab, in three parts, and you turn it in once, complete, before Lesson 25. Do **Part 1** on your own before the lab period: the predictions you will test at the bench. **Part 2** is your own measurements, from your own kit, recorded in class. Do **Part 3** on your own after the lab: compare the measurements with the predictions and explain the differences.

Grading. One submission, counted toward your engagement grade and graded as a genuine, documented attempt.

The array is the PHASER's: $N = 8$ elements, E1 to E8, on a $d = 14$ mm pitch. Facing the patches, E1 is on the right and E8 on the left, and $+\theta$ is on the E8 side. The Element Gains sliders are voltage amplitudes in percent of full scale, linear in voltage. Use $c = 3.00 \times 10^8$ m/s, and report every level relative to the frozen uniform trace's peak unless a question asks otherwise.

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

1. **From weights to GUI settings.** A null-steering calculation for a 4-element subarray returns the complex weights

$$w_1 = 0.62 - j0.13, \quad w_2 = 0.88 + j0.05, \quad w_3 = 0.88 - j0.05, \quad w_4 = 0.62 + j0.13$$

The Phaser GUI takes element amplitude as a percentage of the largest weight and element phase as an offset in degrees, entered with its sign.

(a) Compute the four magnitudes and convert them to the percentages you would type into Element Gains.

gains = _____

(b) Compute the four phase offsets in degrees.

phases = _____

(c) A student enters the four gain percentages but forgets the phase offsets. Describe the pattern they will measure and say whether a notch appears.

(d) All four weights are multiplied by e^{j40° before being entered. How does the measured pattern change, and why?

2. Your kit's settings. Use the HB100 frequency your kit reported with **Find HB100** in an earlier lab. If you did not record one, use the nominal 10.525 GHz and say so. Hold the beam at broadside and null an interferer at $\theta_1 = +22.5^\circ$.

(a) Find kd and the element-to-element phase $\psi_1 = kd \sin\theta_1$ at the null angle.

f =

ψ_1 =

(b) Write a short Python script (NumPy) that forms $w_n = 1 - r_\mathrm{n}\, e^{-jn\psi_1}$, $n = 0, \ldots, 7$, with $r_\mathrm{n} = \frac{1}{8}\sum_n e^{jn\psi_1}$, and converts the weights to gains and phases. Fill in the table, and attach the script or its output.

Element	1	2	3	4	5	6	7	8
Gain (%)								
Phase (°)								

(c) Predict the main-lobe loss: the subtraction term $-20\log_{10}(1-|r_\mathrm{n}|^2)$, the rescaling term $20\log_{10}\max|w_n|$, and their total.

loss =

(d) Where does the notch land if every phase is entered with the wrong sign, and why?

3. How deep can the notch go? Lesson 24 estimated the residual of independent, one-step channel errors at the null as

$$\frac{|y(\theta_1)|}{N} \approx \frac{\epsilon_{\text{rms}}}{\sqrt{N}}, \qquad \epsilon_{\text{rms}} = \sqrt{\sigma_\phi^2 + \sigma_a^2}, \qquad \sigma_\phi = \frac{\text{LSB}}{\sqrt{12}}.$$

(a) Estimate the notch depth for the ADAR1000 (2.8125° phase steps, 1% gain steps), first relative to the null-steered peak and then relative to the uniform peak.

depth =

(b) The lab is repeated on a board whose phase shifters have only $B = 2$ bits. Find the LSB and estimate the notch depth the same way, ignoring the gain error.

depth =

(c) Round the four phases of Question 1(b) to the nearest multiple of the 90° LSB. What does the resulting weight vector do?

(d) Explain why holding a deep null is more demanding of phase resolution than holding a beam peak.

4. **Two-channel MVDR by hand.** The PHASER's two digital channels are steered so that a target off boresight presents the real steering vector $s = [1, -1]^T$, while an interferer on boresight presents $u = [1, 1]^T$ with power $P = 9$ relative to a per-channel noise power of 1. The covariance seen by the beamformer is $R = \sigma^2 I + P\,uu^T$.

   (a) Build R.

   R =

   (b) Compute the MVDR weights $w = R^{-1}s/(s^T R^{-1} s)$.

   w =

   (c) Evaluate the beamformer's response to the target, $w^T s$, and to the interferer, $w^T u$.

   $w^T s$, $w^T u$ =

   (d) Which lab procedure did MVDR just reproduce, and what would w become if the interferer were switched off?

Part 2: Measurements (your kit, in class)

Follow the procedure on the L24 Lab page. Open the **Lab Presets** section before you press a preset. Press **Calibrate**, then **Find HB100**. Set **Rx Gain** so that the uniform main-lobe peak, source at boresight, reads -10 ± 3 dBFS on the FFT, and leave it there. Check **Signal BW**, which Calibrate and Find HB100 reset. Keep the source 1.2 m from the array, and keep $\pm 40^\circ$ of the bench clear of walls and people. Record each reading as you take it.

Signal Freq from **Find HB100**: _____ Rx Gain: _____ Distance: _____

5. **Table A: the static notch** (Procedure A). Freeze the uniform trace first. If its two first sidelobes differ by more than about 2 dB, recalibrate before you go on. Read peaks with **Peak Gain** and angles with **Angle** set to **Peak**.

Quantity	**Measured**	**Predicted**
Uniform sidelobe nearest $+22.5^\circ$		
Null-steered main-lobe peak		
Notch bottom, below the uniform peak		
Notch angle		

6. **Table B: the difference null** (Procedure B). Beam 1 Phase at 180°, Mode Manual, uniform taper.

Quantity	**Measured**	**Predicted**
Null depth		
Null angle		
Left peak angle		
Right peak angle		

7. **Table C: MVDR against an interferer** (Procedure C). Simulated interferer at $+20^\circ$, Power 0 dBFS, about 10 dB above the target; target your HB100 at boresight; beam held at 0° in Signal vs Time; MVDR with $K = 1024$ snapshots. Each entry is the median of ten readings.

Mode	**Interferer vs Target**	**Peak Gain**	**MVDR Suppression**
Manual			
MVDR, load 0.1			

Adaptive tab	**Null angle**	**Null depth**	**Conventional at null**
MVDR, load 0.1			

Interferer at $+30^\circ$	**Manual**	**MVDR, load** 0.001	**MVDR, load** 0.1
Peak Gain			

8. **Table D: monopulse** (Procedure D). Lab preset 8 Tracking, with the taper set to Uniform by hand.

Quantity	**Measured**	**Predicted**
Delta null depth		
Delta null angle		
Error-function zero crossing		

Tracking: how far across the arc did it follow the source, and how did it behave when it lost the source?

_____

_____

Part 3: Writeup (individual, after the lab)

9. The notch you measured. A short paragraph each.

(a) Compare Table A with your Question 3(a) estimate. What sets the depth of the notch on your bench?

(b) Rounding the weights to the ADAR1000's steps is not what limits the depth. Explain why, using the symmetry of your Question 2(b) table.

10. Reading a null-steered sweep. A student freezes the uniform trace, loads the null-steering table, and sweeps again. The null-steered peak reads -1.8 dB and the notch reads -48 dB, both relative to the uniform peak.

(a) Express the notch depth relative to the null-steered array's own peak, which is the number an interference calculation needs.

depth = ____

(b) A second student, with the same table, finds the level at $+22.5^\circ$ still near -13 dBc and a deep notch near -22.5° instead. Give the cause and what they should check.

(c) The notch appears centered at $+25.7^\circ$ rather than $+22.5^\circ$. Rank these causes by size: rounding the weights, using the nominal 10.525 GHz instead of the kit's frequency, the sweep's angle grid, and aligning the kit by eye.

11. Choosing an approach. Each situation below uses the same 8-element PHASER.

(a) A fixed ground emitter sits at a surveyed bearing of $+35^\circ$ from the array face and does not move. The array must keep its beam on a target at -10°. Which approach would you use, and why?

(b) An airborne jammer of unknown and changing bearing appears during a mission. Which approach would you use, and why?

(c) A requirement calls for a 33 dB notch on a board whose 3-bit phase shifters allow a notch only about 22 dB deep (Lesson 24). Taking about 6 dB of improvement per added bit, how many phase bits are needed?

$B =$ ____

(d) Two jammers now illuminate the array from different bearings. State what happens when MVDR is asked to handle both on this hardware.

12. The monopulse pair. Two or three sentences each, using your Table D.

(a) The error function's slope near boresight is about 0.11 per degree. What reading does a target 2° off boresight produce, and why is the delta beam, not the sum beam, what makes that reading large?

(b) Your delta null and your error-function zero both sit a degree or two off 0°. What does that offset tell you about the kit, and does it matter to a tracker?

Documentation: _____