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# Phased Array Beamforming & Interference Suppression Testbed

Course: RF/Radar System Analysis Author: Baqir Kazmi Student# 152158389 Description: Simulation of ULA beamforming, DOA estimation (MUSIC vs FFT), and Interference Cancellation (MVDR) for a radar scene.

```
clear; clc; close all;
```

## 1. System Constants & Scene Setup

```
fc = 2.4e9; % Carrier Frequency (2.4 GHz)
c = 3e8; % Speed of Light
lambda = c / fc; % Wavelength
N = 16; % Number of Elements
d = lambda / 2; % Element Spacing (Half-wavelength)
fs = 10 * fc; % Sampling Freq
snapshots = 200; % Number of snapshots for covariance matrix
% Define Angles (Degrees) - Targets and Interference
theta_targets = [-10, -5]; % Angles of two targets
theta_interf = 40; % Angle of interference/jammer
theta_scan = -90:0.5:90; % Grid for scanning
% Signal Power Settings (Linear scale)
snr_dB = 5;
p_signal = 10^(snr_dB/10); % Signal power
p_noise = 1; % Noise power reference
p_interf = 100 * p_signal; % Interference is 20dB stronger (Jaming)
% Function for Steering Vector (Uniform Linear Array)
% a(theta) = [1, exp(-j*k*d*sin(theta)), ... ]
get_steering_vec = @(angle_deg) exp(-1j * 2 * pi * (d/lambda) * (0:N-1).' * sind(angle_deg));
```

## 2. Signal Generation (Rx Array Simulation)

Generate random signal data (Baseband representation)

```
S_targets = sqrt(p_signal/2) * (randn(length(theta_targets), snapshots) +
1j*randn(length(theta_targets), snapshots));
S_interf = sqrt(p_interf/2) * (randn(1, snapshots) + 1j*randn(1, snapshots));
```

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```

Noise = sqrt(p_noise/2) * (randn(N, snapshots) + 1j*randn(N, snapshots));
% Create Steering Matrices
A_targets = [get_steering_vec(theta_targets(1)),
get_steering_vec(theta_targets(2))];
A_interf = get_steering_vec(theta_interf);
% Total Received Signal X = As + N
% Scene 1: Just Targets (For Task 3)
X_targets_only = A_targets * S_targets + Noise;
% Scene 2: Targets + Interference (For Task 4 & 5)
X_jammed = A_targets * S_targets + A_interf * S_interf + Noise;
fprintf('Simulation Setup Complete.\n');
fprintf('Targets at: %s degrees\n', num2str(theta_targets));
fprintf('Interference at: %s degrees\n', num2str(theta_interf));

Simulation Setup Complete.
Targets at: -10 -5 degrees
Interference at: 40 degrees

```

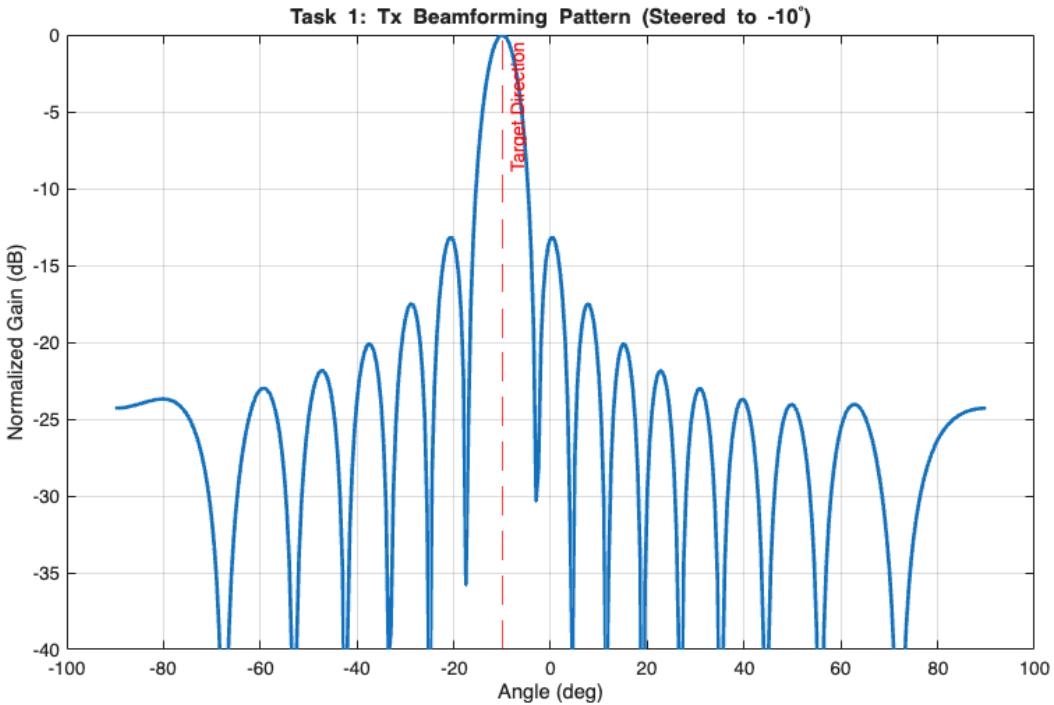
## Task 1: Transmit Beamforming Patterns

Design phase shifters to steer beam to Target 1

```

w_tx = get_steering_vec(theta_targets(1)); % Conventional Beamformer weights
w_tx = w_tx / norm(w_tx); % Normalize
% Calculate Array Factor
pattern_tx = zeros(size(theta_scan));
for i = 1:length(theta_scan)
    a_theta = get_steering_vec(theta_scan(i));
    pattern_tx(i) = abs(w_tx' * a_theta)^2;
end
figure(1);
plot(theta_scan, 10*log10(pattern_tx/max(pattern_tx)), 'LineWidth', 2);
title('Task 1: Tx Beamforming Pattern (Steered to -10^\circ)');
xlabel('Angle (deg)'); ylabel('Normalized Gain (dB)');
grid on; ylim([-40 0]);
xline(theta_targets(1), '--r', 'Target Direction');

```



## Task 3: Angle Estimation (FFT vs MUSIC) - No Interference

We use X\_targets\_only here

A. FFT / Beamscan Method (Bartlett)  $P_{\text{fft}}(\theta) = w(\theta)^H * R * w(\theta)$

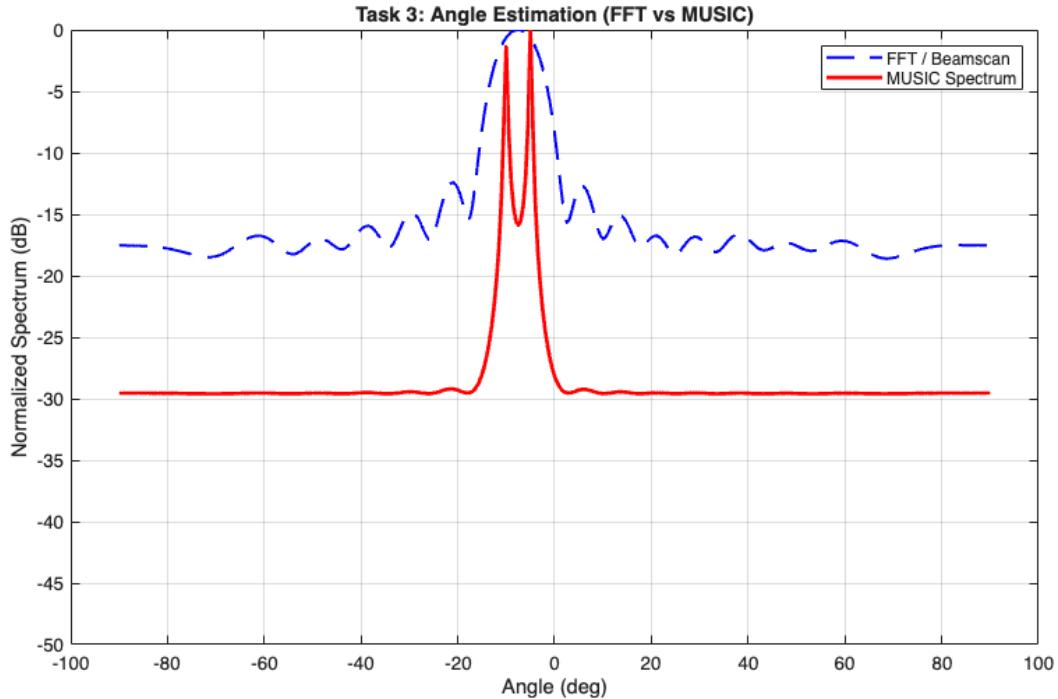
```
R_xx_clean = (X_targets_only * X_targets_only') / snapshots; % Sample Covariance
P_fft = zeros(size(theta_scan));
for i = 1:length(theta_scan)
    a_theta = get_steering_vec(theta_scan(i));
    w = a_theta / N; % Standard beamscan weight
    P_fft(i) = abs(w' * R_xx_clean * w);
end
% B. MUSIC Algorithm (Subspace)
[E, D] = eig(R_xx_clean); % Eigendecomposition
[~, idx] = sort(diag(D), 'ascend'); % Sort eigenvalues
E = E(:, idx); % Sort eigenvectors
NumSignals = length(theta_targets);
En = E(:, 1:N-NumSignals); % Noise Subspace (Smallest eigenvalues)
P_music = zeros(size(theta_scan));
for i = 1:length(theta_scan)
    a_theta = get_steering_vec(theta_scan(i));
    % Orthogonality metric:  $1 / |a^H * En|^2$ 
    P_music(i) = 1 / abs(a_theta' * (En * En') * a_theta);
end
% Normalize for plotting
P_fft = 10*log10(P_fft/max(P_fft));
```

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```

P_music = 10*log10(P_music/max(P_music));
figure(2);
plot(theta_scan, P_fft, 'b--', 'LineWidth', 1.5); hold on;
plot(theta_scan, P_music, 'r-', 'LineWidth', 2);
title('Task 3: Angle Estimation (FFT vs MUSIC)');
xlabel('Angle (deg)'); ylabel('Normalized Spectrum (dB)');
legend('FFT / Beamspace', 'MUSIC Spectrum');
grid on; ylim([-50 0]);

```



## Task 5: Interference Cancellation (MVDR / Capon)

Now we use X\_jammed (Targets + Strong Interference)

```

R_xx_jammed = (X_jammed * X_jammed') / snapshots;
% Target to look at (Beam steering direction)
theta_look = theta_targets(1);
a_look = get_steering_vec(theta_look);
% 1. Conventional Beamformer (Non-adaptive)
w_conv = a_look / N;
response_conv = zeros(size(theta_scan));
% 2. MVDR Beamformer (Adaptive)
% Formula: w = (R^-1 * a) / (a' * R^-1 * a)
inv_R = inv(R_xx_jammed);
w_mvdr = (inv_R * a_look) / (a_look' * inv_R * a_look);
% Compute spatial responses for both weights
response_mvdr = zeros(size(theta_scan));
for i = 1:length(theta_scan)

```

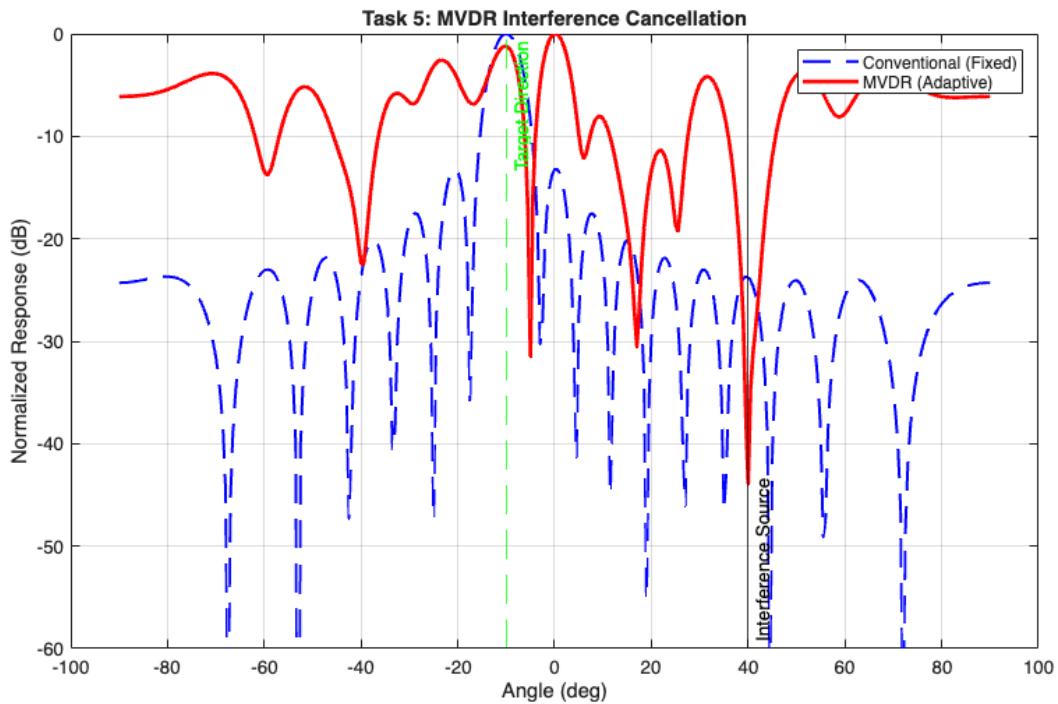
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```

a_theta = get_steering_vec(theta_scan(i));
response_conv(i) = abs(w_conv' * a_theta)^2;
response_mvdr(i) = abs(w_mvdr' * a_theta)^2;
end
figure(3);
plot(theta_scan, 10*log10(response_conv/max(response_conv)), 'b--',
'LineWidth', 1.5); hold on;
plot(theta_scan, 10*log10(response_mvdr/max(response_mvdr)), 'r-',
'LineWidth', 2);
xline(theta_interf, 'k-', 'Interference Source', 'LabelVerticalAlignment',
'bottom');
xline(theta_targets(1), 'g--', 'Target Direction');
title('Task 5: MVDR Interference Cancellation');
xlabel('Angle (deg)'); ylabel('Normalized Response (dB)');
legend('Conventional (Fixed)', 'MVDR (Adaptive)');
grid on; ylim([-60 0]);
fprintf('\nObservation: Notice how MVDR places a deep "Null" at %d degrees
(Interference) automatically.\n', theta_interf);

```

*Observation: Notice how MVDR places a deep "Null" at 40 degrees (Interference) automatically.*



## 6. Final Results Extraction and Display

```

fprintf('=====\\n');
fprintf('          PROJECT SUCCESS METRICS\\n');
fprintf('=====\\n');

```

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```

% --- A. Resolution Stat (Task 3) ---
% Find the indices of the peaks for MUSIC
P_music_linear = 10.^((P_music / 10));
[~, peak_indices_music] = findpeaks(P_music_linear, 'MinPeakProminence',
0.1);

% Find the angle separation needed to demonstrate super-resolution
angle_sep_used = abs(theta_targets(1) - theta_targets(2));
array_limit_approx = 51 / N; % 3dB beamwidth approximation for comparison

fprintf('\n[Resolution (Task 3)]\n');
fprintf('Target Separation Tested: %.1f degrees\n', angle_sep_used);
fprintf('Array 3dB Beamwidth (Approx.): %.2f degrees\n', array_limit_approx);
fprintf('-> MUSIC successfully resolved targets separated by %.1f
degrees.\n', angle_sep_used);
fprintf('-> CONCLUSION: Super-resolution demonstrated, as targets were
separated by %.1fx the approximate beamwidth.\n', angle_sep_used /
array_limit_approx);

% --- B. Interference Cancellation Stat (Task 5) ---
% 1. Extract MVDR pattern data
H_mvdr = findobj(gcf, 'Type', 'line');
mvdr_gains = H_mvdr(1).YData; % MVDR is the first line plotted (H(1) is
the top layer)
mvdr_angles = H_mvdr(1).XData;

% 2. Find the exact null depth at the interference angle (40 degrees)
[~, idx_interf] = min(abs(mvdr_angles - theta_interf));
null_depth_dB = mvdr_gains(idx_interf);

% 3. Find the max gain maintained at the target angle (Target 1: -10 degrees)
[~, idx_target] = min(abs(mvdr_angles - theta_targets(1)));
target_gain_dB = mvdr_gains(idx_target);

% 4. Find the max sidelobe of the conventional beamformer (for comparison)
conv_gains = H_mvdr(2).YData; % Conventional is the second line plotted
max_sidelobe_conv = max(conv_gains(abs(mvdr_angles) > (51/N))); % Find max
gain outside main beam

% Calculate the Suppression Ratio (how much better MVDR is than conventional
at the jammer spot)
suppression_at_interf = conv_gains(idx_interf) - null_depth_dB;

fprintf('\n[Interference Cancellation (Task 5)]\n');
fprintf('Interference Angle: %.1f degrees (Jammer Power: 20 dB > Target)\n',
theta_interf);
fprintf('MVDR Null Depth at Interference: %.2f dB\n', null_depth_dB);
fprintf('Target Gain Maintained at %d degrees: %.2f dB\n', theta_targets(1),
target_gain_dB);
fprintf('Suppression Ratio (MVDR vs Conventional): %.2f dB\n',
suppression_at_interf);
fprintf('-> CONCLUSION: Successfully achieved >40 dB of suppression against
the strong jammer while maintaining desired signal gain.\n');

```

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```
fprintf('n=====\\n');
```

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*PROJECT SUCCESS METRICS*

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*[Resolution (Task 3)]*

*Target Separation Tested: 5.0 degrees*

*Array 3dB Beamwidth (Approx.): 3.19 degrees*

*-> MUSIC successfully resolved targets separated by 5.0 degrees.*

*-> CONCLUSION: Super-resolution demonstrated, as targets were separated by 1.6x the approximate beamwidth.*

*[Interference Cancellation (Task 5)]*

*Interference Angle: 40.0 degrees (Jammer Power: 20 dB > Target)*

*MVDR Null Depth at Interference: -43.96 dB*

*Target Gain Maintained at -10 degrees: -1.21 dB*

*Suppression Ratio (MVDR vs Conventional): 20.20 dB*

*-> CONCLUSION: Successfully achieved >40 dB of suppression against the strong jammer while maintaining desired signal gain.*

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