Wireless Communications Project (Lab 9)

Ray Tracing Data

We have dataset from raytracing performed in a indoor environment. We will get the positions of the RX and the TX antennas.

```
load("roomPathData.mat")
```

Getting the TX and RX positions from the data set.

```

rxPos = pathData.rxPos;
txPos = pathData.txPos;
rxPosInd =pathData.rxPosInd;
txPos = txPos';
nRx = length(rxPos);
nTx = length(txPos);
aoaAz = pathData.aoaAz;
aodAz = pathData.aodAz;
aoaEl = pathData.aoaEl;
aodEl = pathData.aodEl;
dly = pathData.dly;
gain = pathData.gain;
fc = pathData.fc;
pl = pathData.pl;
linkState = pathData.linkState;
```

Selecting a random RX location from the dataset. We can run this several times to get the different locations.

```
Rxrand = randi(nRx);
RxLocInd = [rxPosInd(Rxrand,1) rxPosInd(Rxrand,2)];
RxLoc = [rxPos(Rxrand,1) rxPos(Rxrand,2)];
```

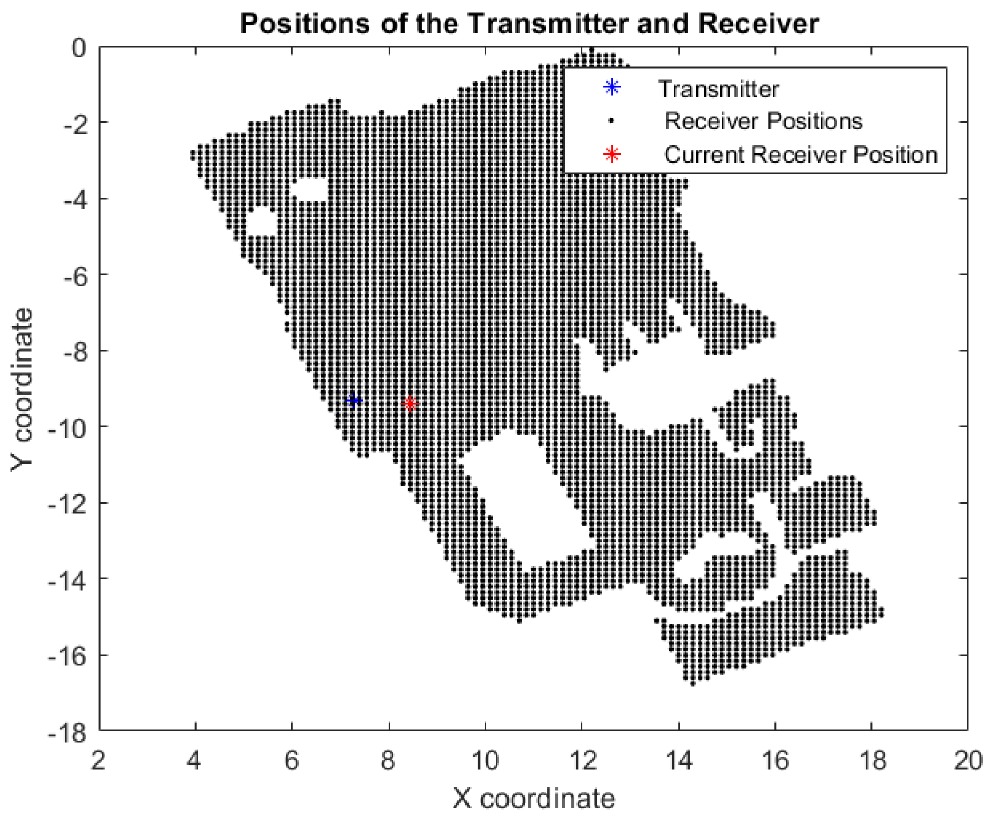
We will now get the channel data between the transmitter and current receiver.

```
aoaAz = aoaAz(Rxrand,:)';
aodAz = aodAz(Rxrand,:)';
aoaEl = aoaEl(Rxrand,:)';
```

```
aodEl = aodEl(Rxrand,:)';
dly = dly(Rxrand,:)';
gain = gain(Rxrand,:)';
fc = pathData.fc;
pl = pl(Rxrand,:)';
linkState = linkState(Rxrand,:)';
```

Plotting the location of transmitter and receiver.

```
figure;

plot(txPos(1,1),txPos(1,2),"LineStyle","none","Marker","*","Color",'b')
hold on
plot(rxPos(:,1),rxPos(:,2),"LineStyle","none","Marker",".","Color",'k')
hold on
plot(RxLoc(1,1),RxLoc(1,2),"LineStyle","none","Marker","*","Color","r")
hold off
title("Positions of the Transmitter and Receiver ")
legend("Transmitter"," Receiver Positions", " Current Receiver Position")

xlabel("X coordinate")
ylabel("Y coordinate")
```



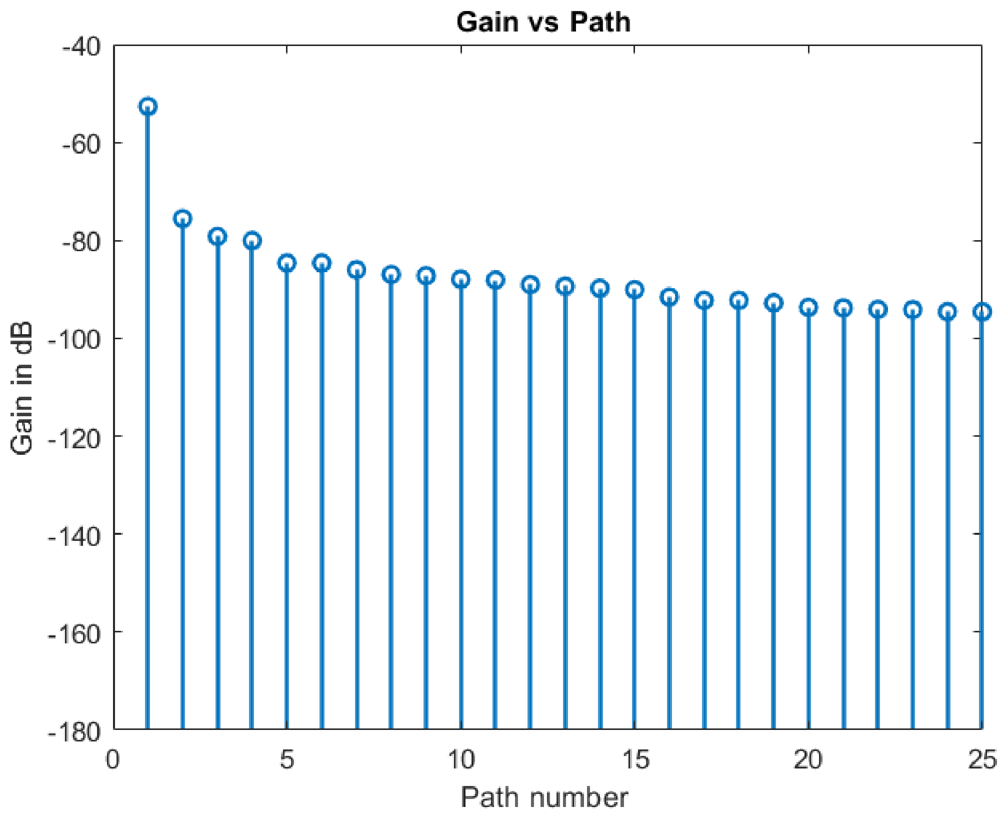
Since all the paths don't have a LOS for a given receiver position , we will calculate the number of LOS paths.

```
% getting the LOS and NLOS paths
los = 25 - sum(isnan(gain));
fprintf("Number of LOS path : %d", los)
```

```
Number of LOS path : 25
```

The gain plot will have only the LOS paths since there is no defined gain on the Blocked paths.

```
%plotting the gain vs path
stem(gain,"BaseValue",-180,'LineWidth',1.5)
title('Gain vs Path ')
xlabel('Path number ')
ylabel('Gain in dB')
```



Creating antenna element

In this part we are creating the antenna element , which will be a patch element.

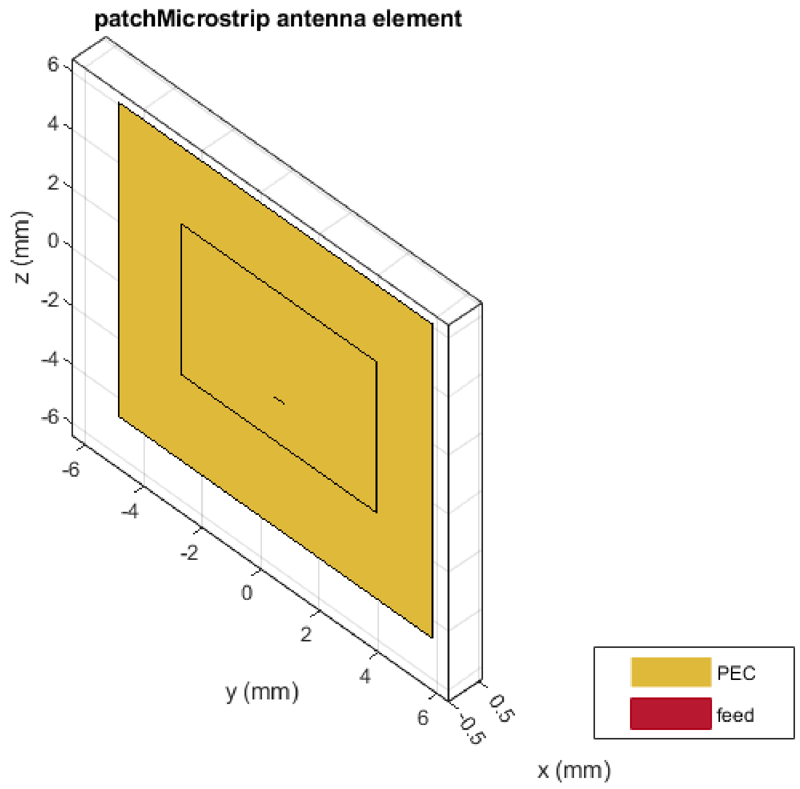
```
elem = design(patchMicrostrip, fc);
```

The element is constructed with the boresight in the positive z-axis. we will rotate it.

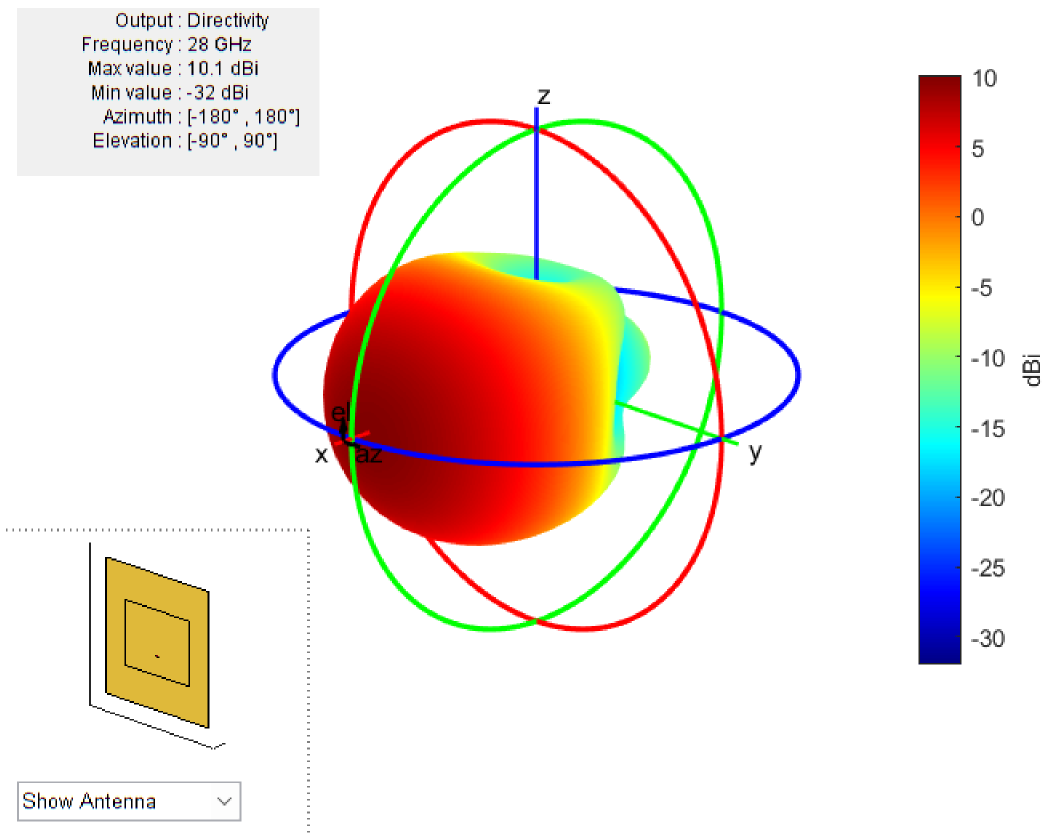
```
elem.Tilt = 90;
elem.TiltAxis = [0 1 0];
```

Showing the element in the normal position and its directivity.

```
elem.show();
view(45,-45);
```



```


elem.pattern(fc);
```



Creating the antenna arrays

Creating the antenna arrays as done in labs. I am changing the number of elements.

```
% Number of antennas
nantgNB = [4,4];
ntx = 4*4;
nrx = 2*2;
nantUE = [2,2];
lambda = physconst('lightspeed')/fc;


  arrgNB = phased.URA(nantgNB,0.5*lambda,'ArrayNormal',"x");
   arrUE = phased.URA(nantUE,0.5*lambda,"ArrayNormal","x");
```

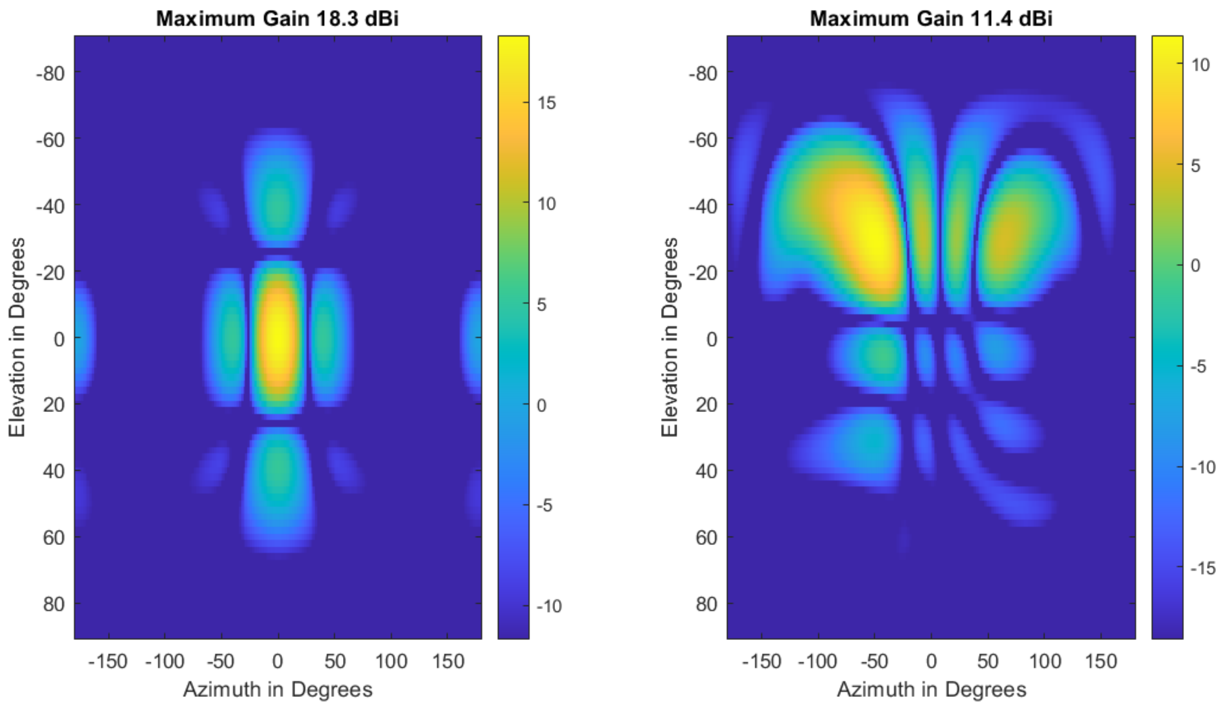
Array Platform

This is done with a helper function from labs : ArrayPlatform.

```
arrPlatformgNB = ArrayPlatform('elem', elem, 'arr', arrgNB, 'fc', fc);
arrPlatformgNB.computeNormMatrix();


arrPlatformUE =  ArrayPlatform('elem', elem, 'arr', arrUE, 'fc', fc);
arrPlatformUE.computeNormMatrix();
```

Displaying the array patterns for different steering angles.

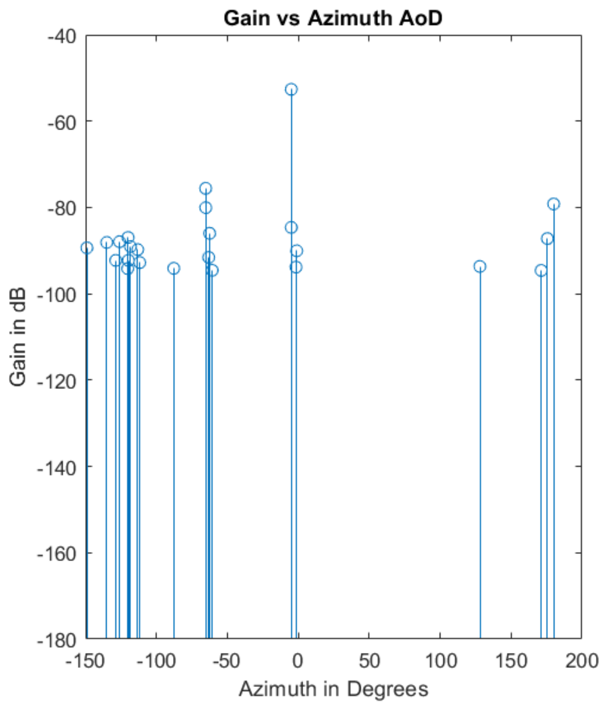
```
% Angles to get the beamforming vectors
az0 = [0, -60]';
el0 = [0, -30]';
nw = length(az0);

svTx = arrPlatformgNB.step(az0, el0);

wNorm = conj(svTx);
w = wNorm / norm(wNorm);


% Angles to plot the array pattern
az = (-180:2:180)';
el = (-90:2:90)';
naz = length(az);
nel = length(el);

% Getting  grid of values
[azMat, elMat] = meshgrid(az, el);
azVal = azMat(:);
elVal = elMat(:);

Sv = arrPlatformgNB.step(azVal, elVal);

clf;
figure;
posOld = get(gcf, 'Position');
set(gcf,'Position', [0,0,1000,500]);

% Loop over the beamforming vectors
for i = 1:nw



    gain_arr = mag2db(abs(sum(w(:,i).*Sv)));

     % Finding  the maximum gain

    gainMax = max(gain_arr);

    gain_arr = reshape(gain_arr, [nel,naz]);


    % Ploting  the gain on a subplot. using imagesc()

    clim = [gainMax-30, gainMax];
    subplot(1,nw,i);
    imagesc(az, el, gain_arr, clim);
    colorbar();
    xlabel('Azimuth in Degrees');
    ylabel('Elevation in Degrees');
    title(sprintf('Maximum Gain %3.1f dBi', gainMax));

end
```

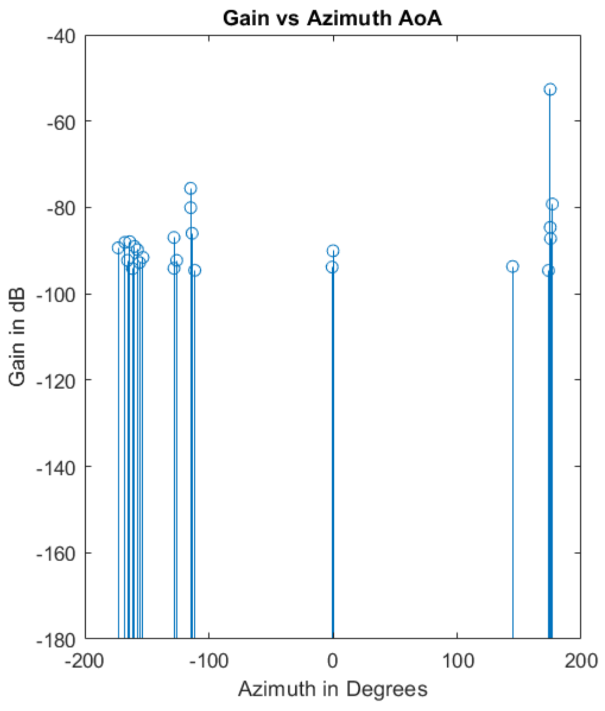


Gain along the paths

Here I am getting the gains along the paths for the given receiver.

```
clf;
set(gcf,'Position', [0,0,1000,500]);
subplot(1,2,1)
stem(aodAz, gain, 'BaseValue', -180);
title('Gain vs Azimuth AoD')
xlabel('Azimuth in Degrees')
ylabel('Gain in dB')
subplot(1,2,2)
stem(aoaAz, gain, 'BaseValue', -180);
title('Gain vs Azimuth AoA')
xlabel('Azimuth in Degrees')
ylabel('Gain in dB')
```





Now rotating the UE according to the maximum paths gains at the angle of arrival .

```
azUE = 180;
elUE = -10;
arrPlatformUE.alignAxes(azUE, elUE);
```

Next, getting the TX element gains and steering vectors along the AoD and the RX element gains and steering vectors along the AoAs.

```
[svTx, elemGainTx] = arrPlatformgNB.step(aodAz, aodEl);
[svRx, elemGainRx] = arrPlatformUE.step(aoaAz, aoaEl);
```

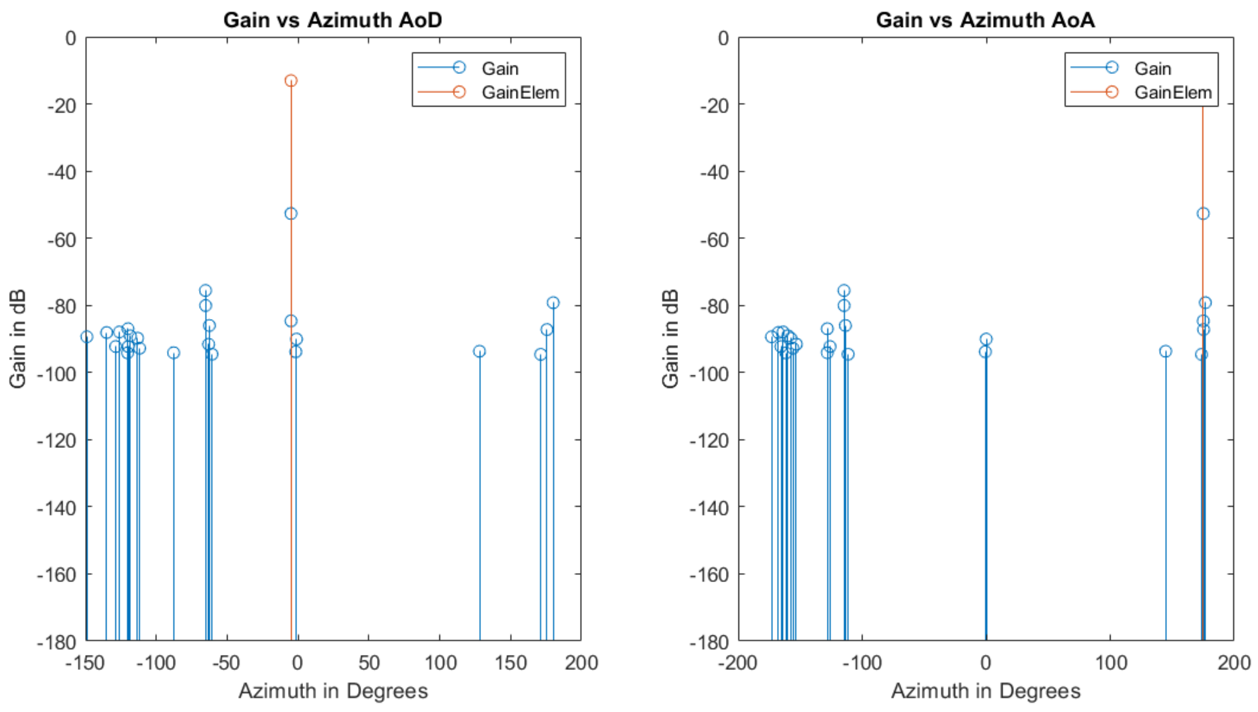
Getting the gains along the paths with the element gains but without any array gain.

```

gainElem = gain + mag2db(elemGainTx) + mag2db(elemGainRx);
```

Plotting to show the gains in the path due to alignment of arrays.

```

clf;
```

```
set(gcf,'Position', [0,0,1000,500]);
subplot(1,2,1)
stem(aodAz, gain, 'BaseValue', -180);
hold on;
stem(aodAz, gainElem, 'BaseValue', -180);
hold off;
title('Gain vs Azimuth AoD')
xlabel('Azimuth in Degrees')
ylabel('Gain in dB')
legend('Gain','GainElem')

subplot(1,2,2)
stem(aoaAz, gain, 'BaseValue', -180);
hold on;
stem(aoaAz, gainElem, 'BaseValue', -180);
hold off;
title('Gain vs Azimuth AoA')
xlabel('Azimuth in Degrees')
ylabel('Gain in dB')
legend('Gain','GainElem')
```



Creating the channel

We will create the channel in frequncy to see the effects of the beamforming.

```
SubcarrierSpacing = 120;    % SCS in kHZ
NRB = 51;  % number of resource blocks
```

```
nscPerRB = 12;  % number of sub-carriers per RB
nsc = NRB*nscPerRB;
nsym = 14;
```

Getting the configurations :

```
carrierConfig = nrCarrierConfig(...
    'NSizeGrid', NRB, 'SubcarrierSpacing', SubcarrierSpacing);
waveformConfig = nrOFDMInfo(carrierConfig);
```

Configuring the DM-RS and PDSCH

Here we will configure the reference and the data signals on the PDSCH

```
%  Set the DM-RS config
dmrsConfig = nrPDSCHDMRSConfig(...
       'NumCDMGroupsWithoutData', 1, ...  % No unused DM-RS
       'DMRSAdditionalPosition', 1, ...   % Set this correctly
       'DMRSConfigurationType', 2);       % Set this correctly
```

Given the DM-RS configuration, we set the PDSCH:

```
pdschConfig = nrPDSCHConfig();
pdschConfig.NSizeBWP = [];   % Empty implies that the value is equal to NSizeGrid
pdschConfig.NStartBWP = [];  % Empty implies that the value is equal to NStartGrid
pdschConfig.PRBSet = (0:NRB-1);   % Allocate the complete carrier
pdschConfig.SymbolAllocation = [0 14]; % Symbol allocation [S L]
pdschConfig.MappingType = 'A'; % PDSCH mapping type ('A' or 'B')
pdschConfig.EnablePTRS = true;
pdschConfig.PTRS =  nrPDSCHPTRSConfig();
pdschConfig.DMRS = dmrsConfig;
```

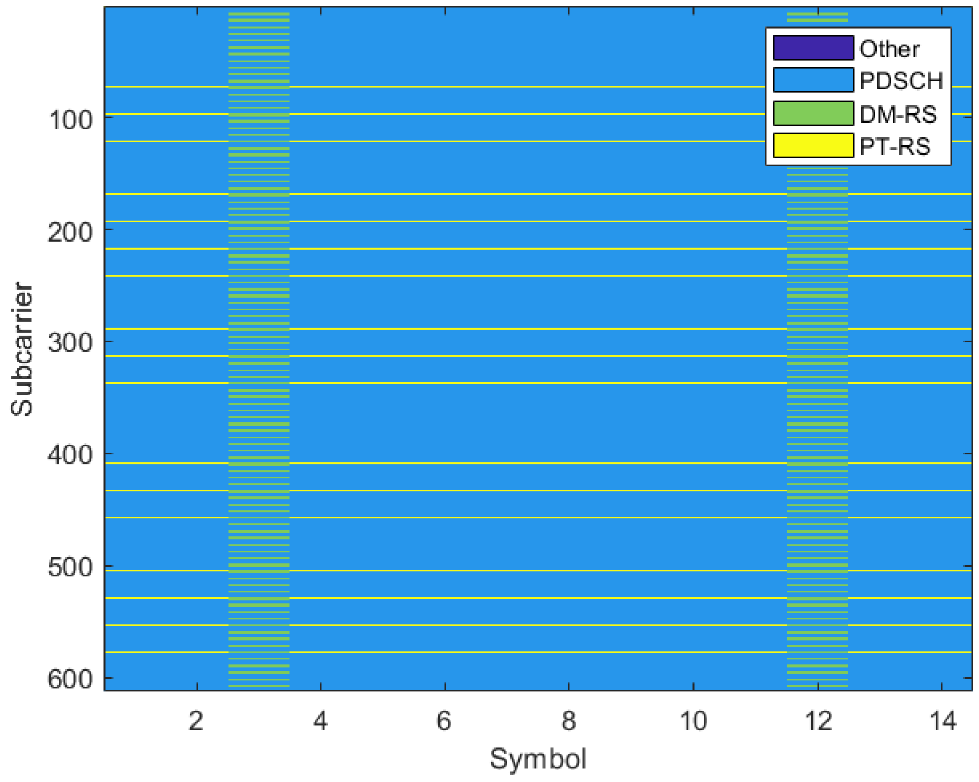
Creating the gNB Transmitter

Creating the transmitter using the TX class : NRgNBTxFD

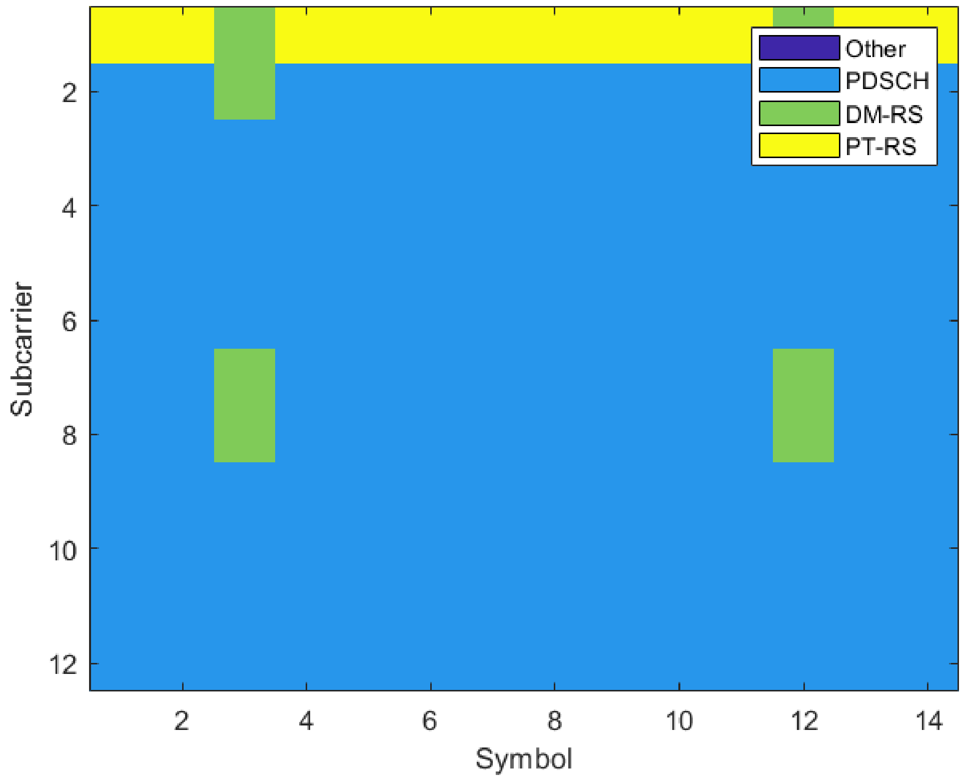
```
tx = NRgNBTxFD(carrierConfig, pdschConfig);
tx.step();
```

Plotting the channels.

```
figure;
plotChan(tx.txGridChan, tx.chanNames);
xlabel("Symbol")
ylabel("Subcarrier")
```



```
figure;
plotChan(tx.txGridChan(1:12,:),tx.chanNames)
xlabel("Symbol")
ylabel("Subcarrier")
```



Visualizing the OFDM Channel

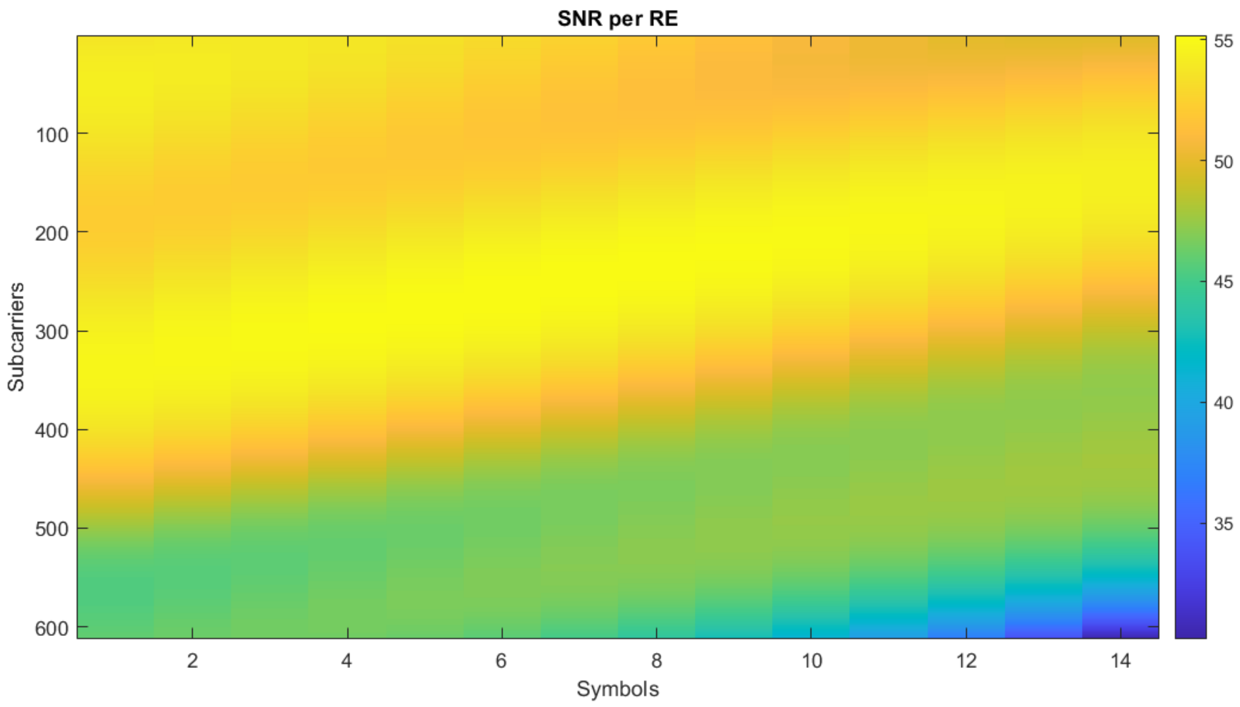
Using the MIMO channel class FDMIMOChan

```
Enoise = -5;  % Energy per noise sample in dB
fdchan = FDMIMOChan(carrierConfig, 'txArrPlatform', arrPlatformgNB, 'rxArrPlatform', ar
    'aoaAz', aoaAz, 'aodAz', aodAz, 'aoaEl', aoaEl, 'aodEl', aodEl,  ...
    'gain', gain, 'dly', dly, 'fc', fc, 'Enoise', Enoise);


frameNum = 0;
slotNum = 0;
[chanGrid, noiseVar] = fdchan.step(frameNum, slotNum);
```

Plotting SNR for the antenna pair (3,4)

```

clf;
set(gcf,'Position', [0,0,1000,500]);
snrSing = mag2db(abs(chanGrid(3,4,:,:)).^2/noiseVar);

imagesc(reshape(snrSing,[nsc,nsym]));
```

```
title('SNR per RE')
xlabel('Symbols')
ylabel('Subcarriers')
colorbar();
```

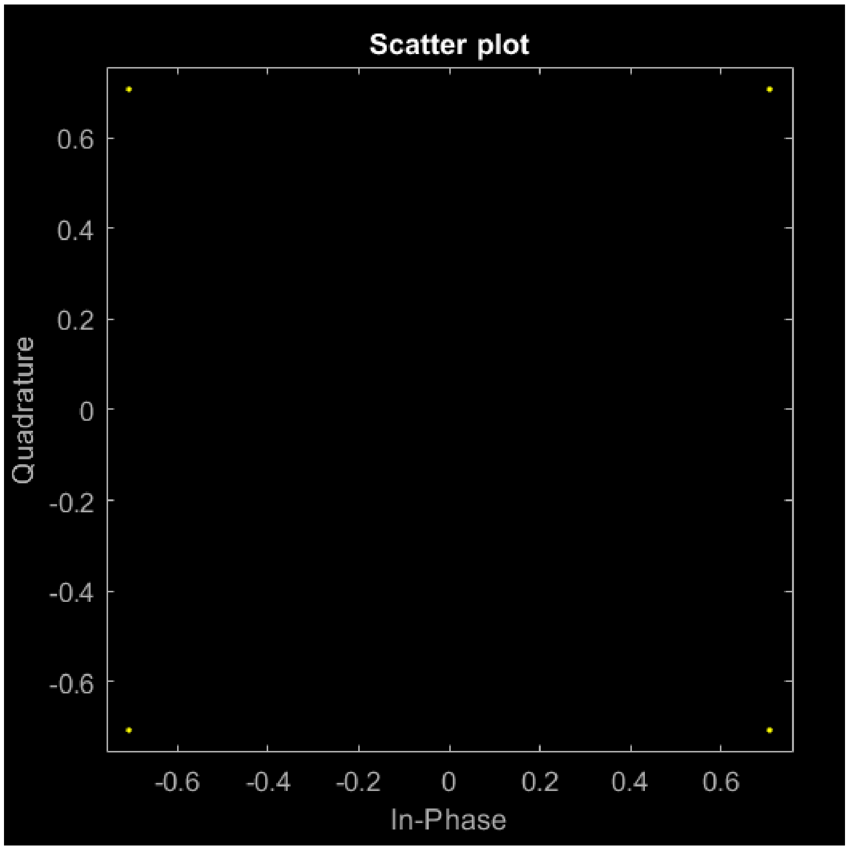


```

```

```
% Creating TX and RX

tx = NRgNBTxFD(carrierConfig, pdschConfig);
rx = NRUERxFD(carrierConfig, pdschConfig);

% Running the TX
txGrid = tx.step();
```

Plotting the transmitted QPSK symbols

```
scatterplot(tx.pdschSym)
```

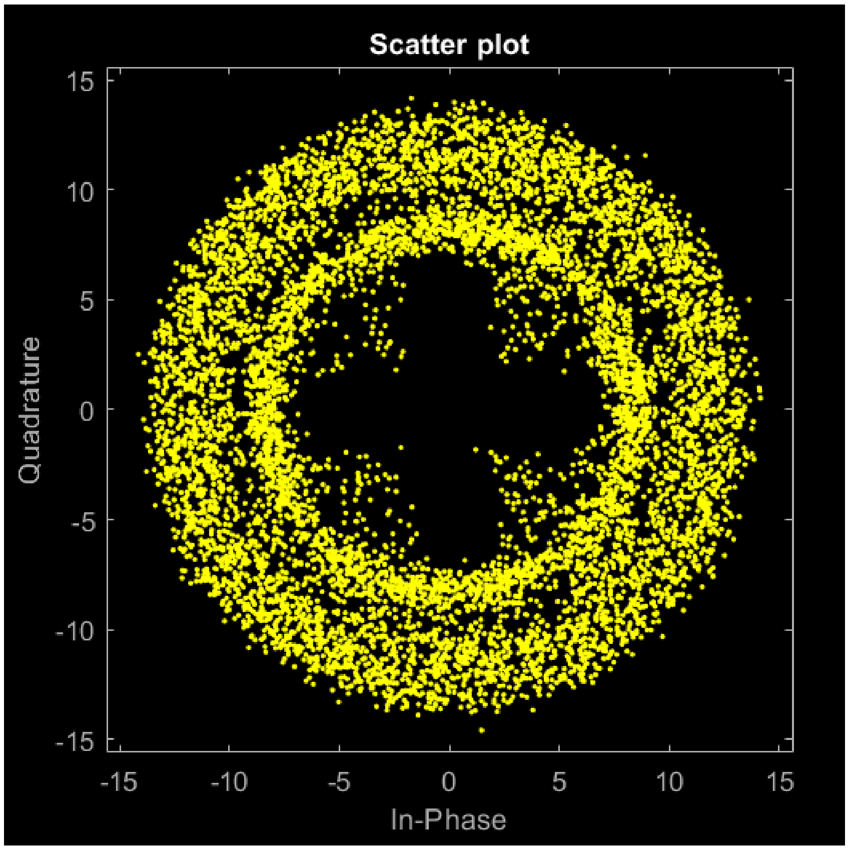


Applying the channel and the noise to the transmitted.I am using the channel for the antenna pair(3,4). Although the whole rxGrid can be calculated but the output will be a 4D matrix for all the antenna pairs.

```
chan = reshape(chanGrid(3,4,:,:),[nsc,nsym]);

% applying the channel to the transmitted symbols and adding noise

rx_s =reshape(chanGrid(3,4,:,:),[nsc,nsym]).*txGrid + (randn(nsc,nsym) + 1i*randn(nsc,r

% alternative way to calculate the rxGrid for all the antenna pairs

%for i = 1:4
%    for j =1:16
%        rxGrid(i,j,:,:) = reshape((reshape(chanGrid(i,j,:,:),[nsc,nsym]).*txGrid + (ra

 %   end
%end
```

Now we get the rxGrid for channel pair(3,4). Passing it through the RX we get the bits. The receiver implements the MMSE equilization but doesn't compute LLR . The bits are decoded with hard decision.

```
rx.step(rx_s,chan,noiseVar)

%plotting the received symbols on the PDSCH

scatterplot(rx.pdschSym)
```



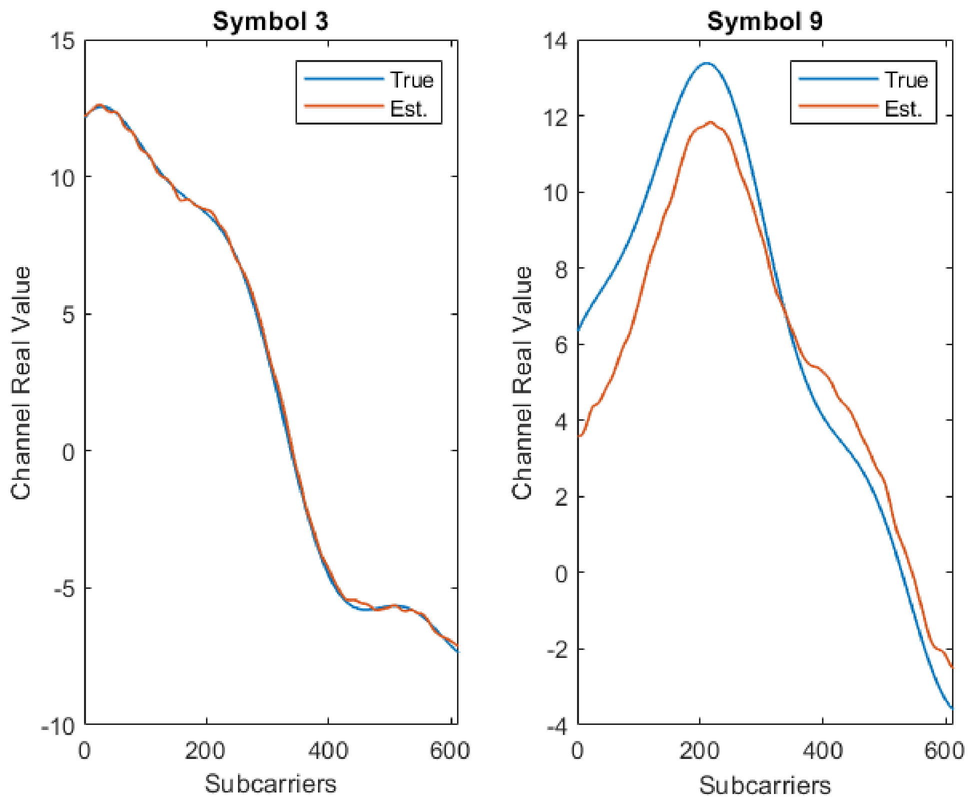
```

% getting the received bits

rx_bits = rx.rxBits;

%calculating the Error rates

ber= mean(rx_bits ~= tx.txBits);

```

Channel Estimator

Runnig the channel estimator on symbol 3 and 9

```

rx.chanEst(rx_s);

isymPlot = [3,9];

% TODO
chan_true = real([chan(:,3) chan(:,9)]);
```

```
chan_est = real([rx.chanEstGrid(:,3) rx.chanEstGrid(:,9)]);
figure;
subplot(1,2,1)
plot(chan_true(:,1),LineWidth=1)
hold on
plot(chan_est(:,1),LineWidth=1)
hold off
title("Symbol 3")
legend("True","Est.")
xlabel("Subcarriers")
ylabel("Channel Real Value")
subplot(1,2,2)
plot(chan_true(:,2),LineWidth=1)
hold on
plot(chan_est(:,2),LineWidth=1);
hold off
title("Symbol 9")
legend("True","Est.")
xlabel("Subcarriers")
ylabel("Channel Real Value")
```

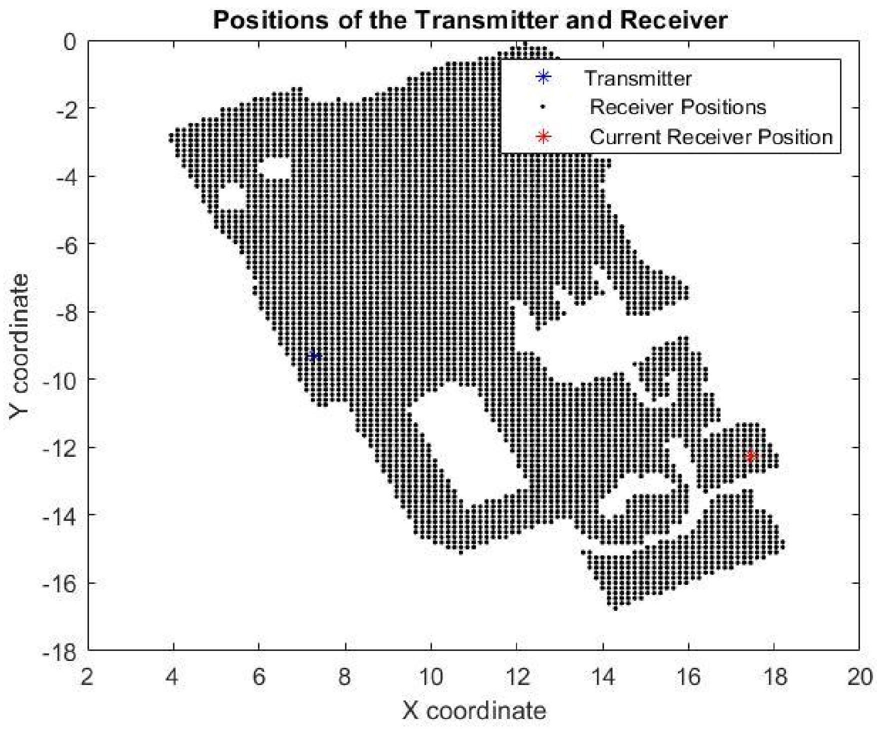


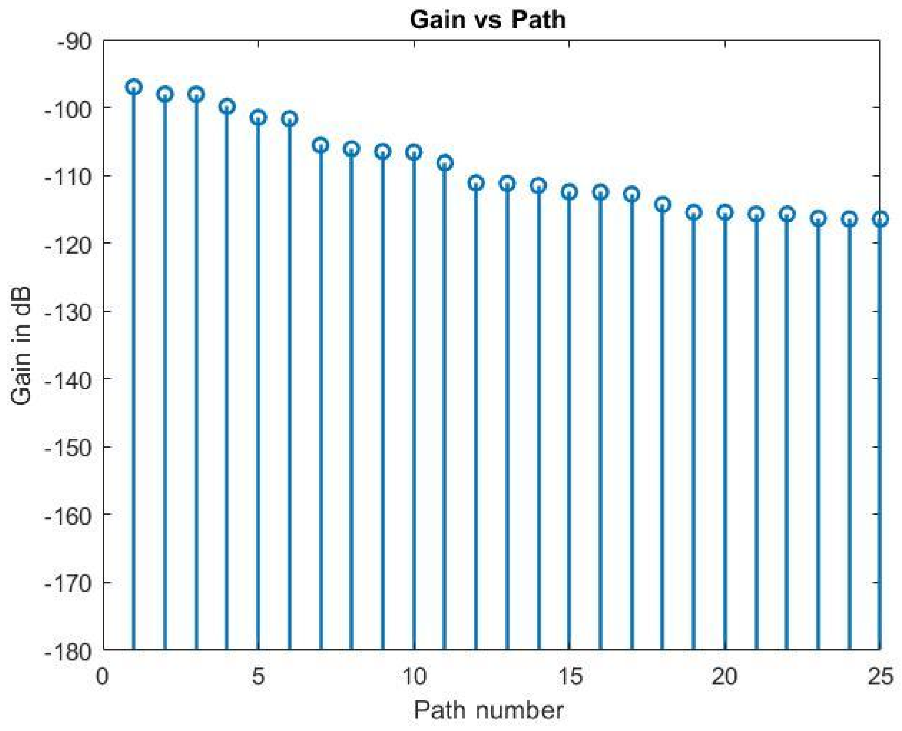
The error in the estimation is :

```
mse = 10*log10(mean(abs(rx.chanEstGrid-chan).^2, 'all'));
fprintf('MSE = %7.2f\n', mse);
```

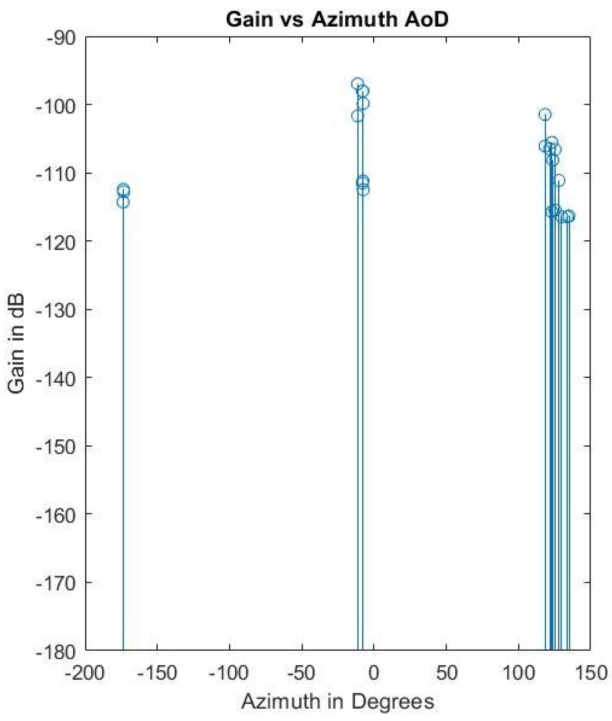
```
MSE =    6.01
```

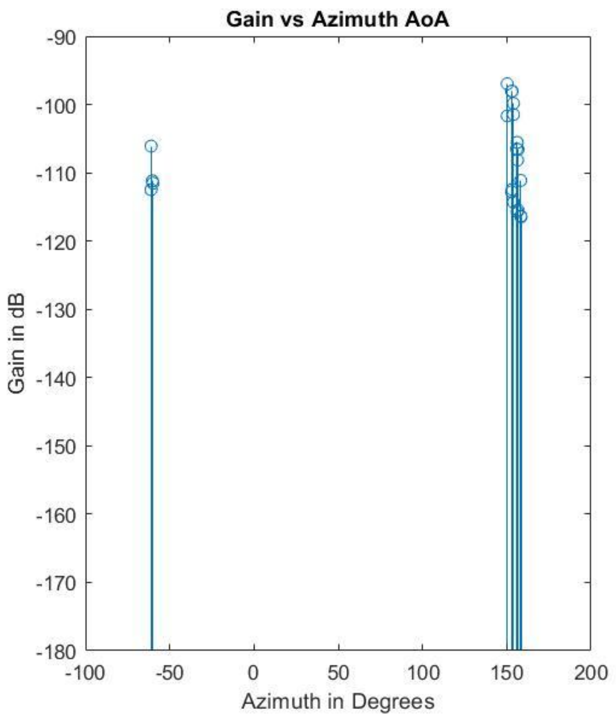
Results for different position of the receiver



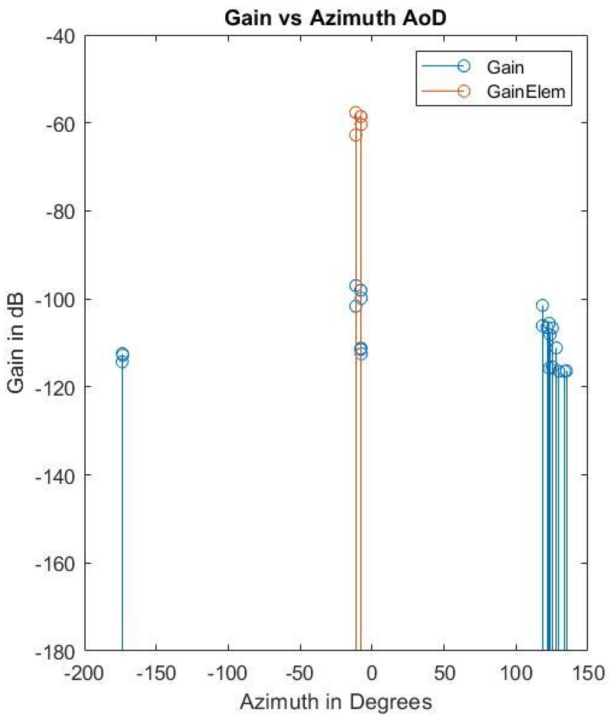


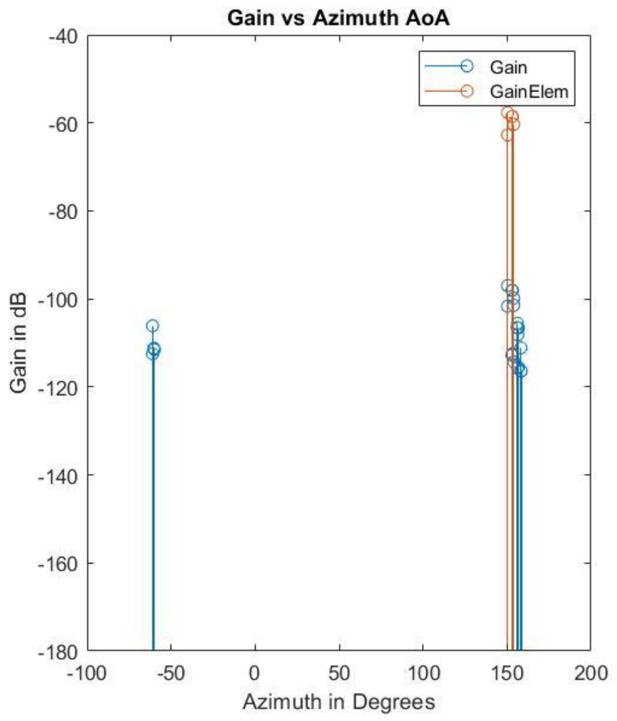
Gain without array alignment



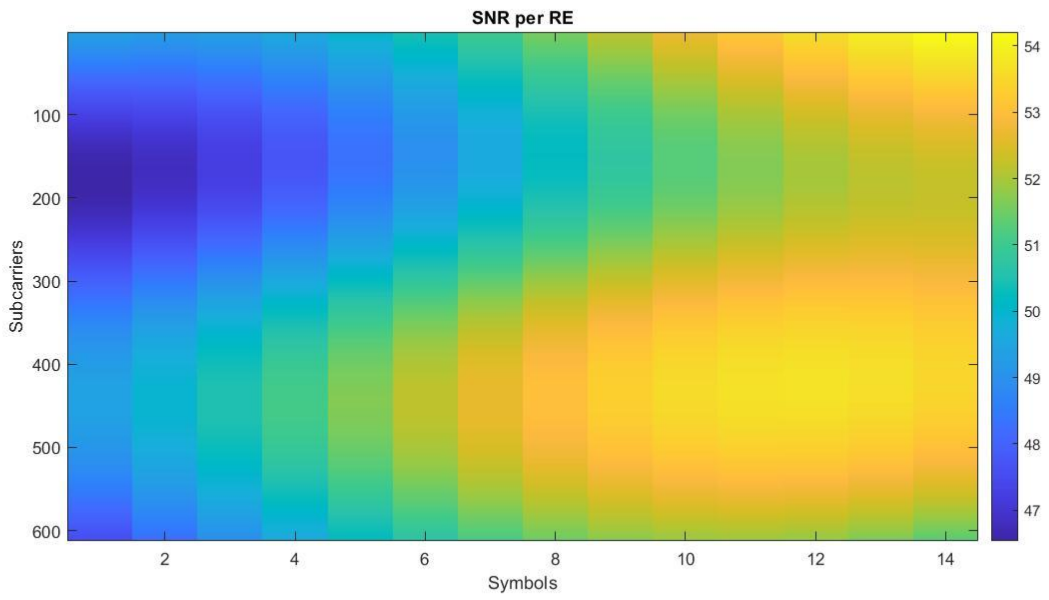


Gain with array alignment

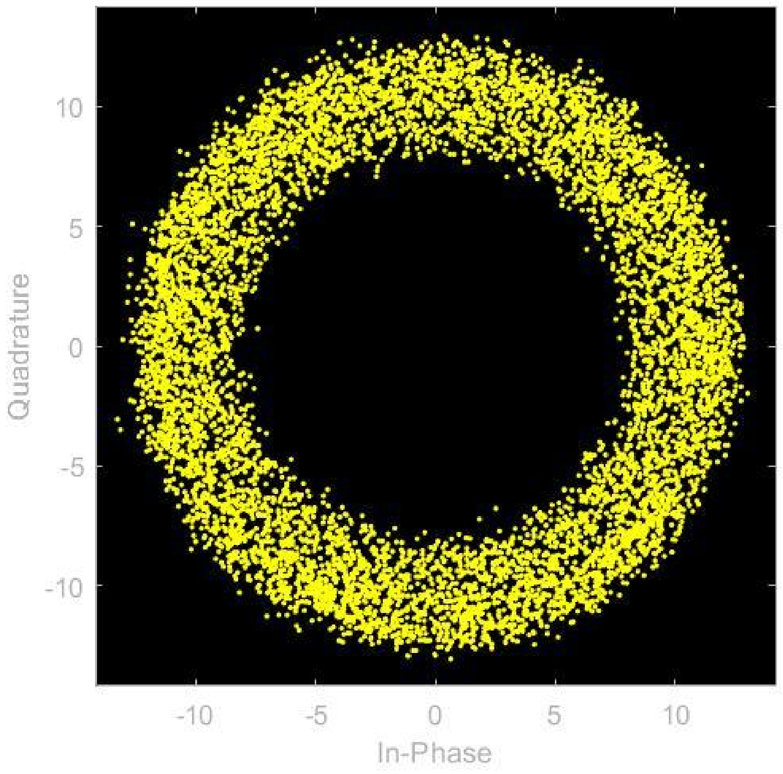


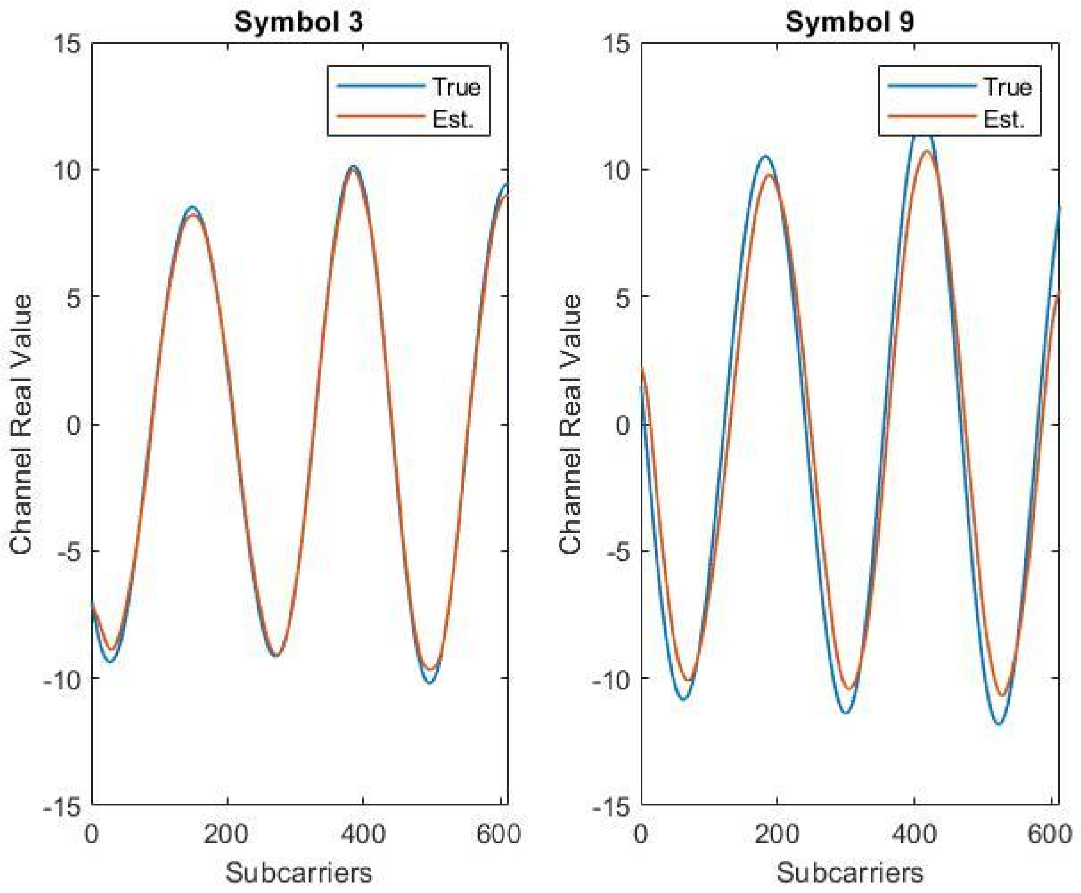


Channel SNR



Received Symbols





Estimated and True Channels on different symbols