Performance Evaluation of Digital Modulation Schemes Over Diverse Wireless Channel Models

RM IPR PROJECT DETAILS INFO FILE

MAIN PAGES TO REFER

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CONTENTS

Research Paper
Techniques and channels
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Code

Performance Evaluation of Digital Modulation Schemes Over Diverse Wireless Channel Models

Research papers with links

1. Comparisons of PSK, APSK, and QAM over AWGN and fading channels(https://www.ewadirect.com/proceedings/ace/article/view/10070?)

2. A MATLAB Simulink Study on the Performance of QAM Modulation Scheme in AWGN, Rayleigh, and Rician Fading Channels: BER Analysis" (2023)

(https://archive.org/details/5575_20230609?)

3. Evaluating the BER Performance for M-ary QAM in AWGN, Rayleigh, Rician and Nakagami-m Fading Channels" (2023, IEEE ICCCNT)

4. Bit Error Rate Analysis of M-ARY PSK and M-ARY QAM Over Rician Fading Channel(https://arxiv.org/abs/2002.07392)

5. Evaluation of SNR for AWGN, Rayleigh & Rician Fading Channels Under DPSK(https://www.sciencepublishinggroup.com/article/10.11648/j.wcmc.20150301.12?)

Excel performance summary csv file is generated

and

heat map is used for easy visualization as line plot was messy

GUI interface for diff snr value

Recommended (IEEE-style) Logical Order by Complexity & Modulation Type:

🟦 **Phase Shift Keying (PSK):**

1. **BPSK** – baseline, most robust, lowest spectral efficiency
2. **QPSK** – standard in many systems like LTE
3. **OQPSK** – refinement of QPSK for spectral shaping
4. **π/4-QPSK** – differential phase QPSK, used in fading channels
5. **8PSK** – higher spectral efficiency than QPSK
6. **16PSK** – even higher PSK, less common due to BER

🟧 **Quadrature Amplitude Modulation (QAM):**

7. **64QAM** – widely used in LTE/Wi-Fi
8. **256QAM** – higher data rate, lower noise robustness

🟥 **Differential:**

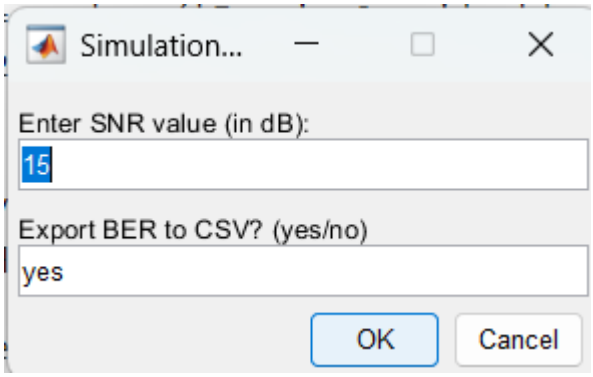
9. **DPSK** – differential encoding without coherent detection

🟪 **Multi-Carrier:**

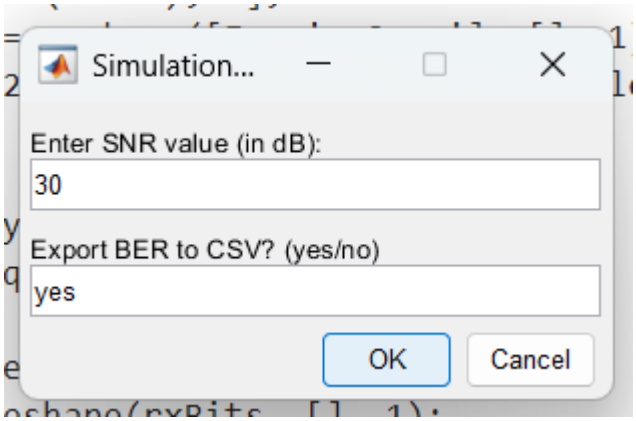
10. **OFDM** – robust multi-carrier scheme (can include QAM inside)

Channel Model	Key Feature	Application Area
AWGN	Noise only	Benchmark / theoretical analysis
Rayleigh	Multipath fading (no LOS)	Urban mobile, deep fading zones
Rician	Multipath + dominant LOS	Suburban, indoor LOS scenarios
Nakagami-m	Flexible multipath fading	Satellite, vehicular, general
Shadowed	Rayleigh + log-normal fading	Outdoor, rural, obstructed areas

Outputs



enter any snr value of choice



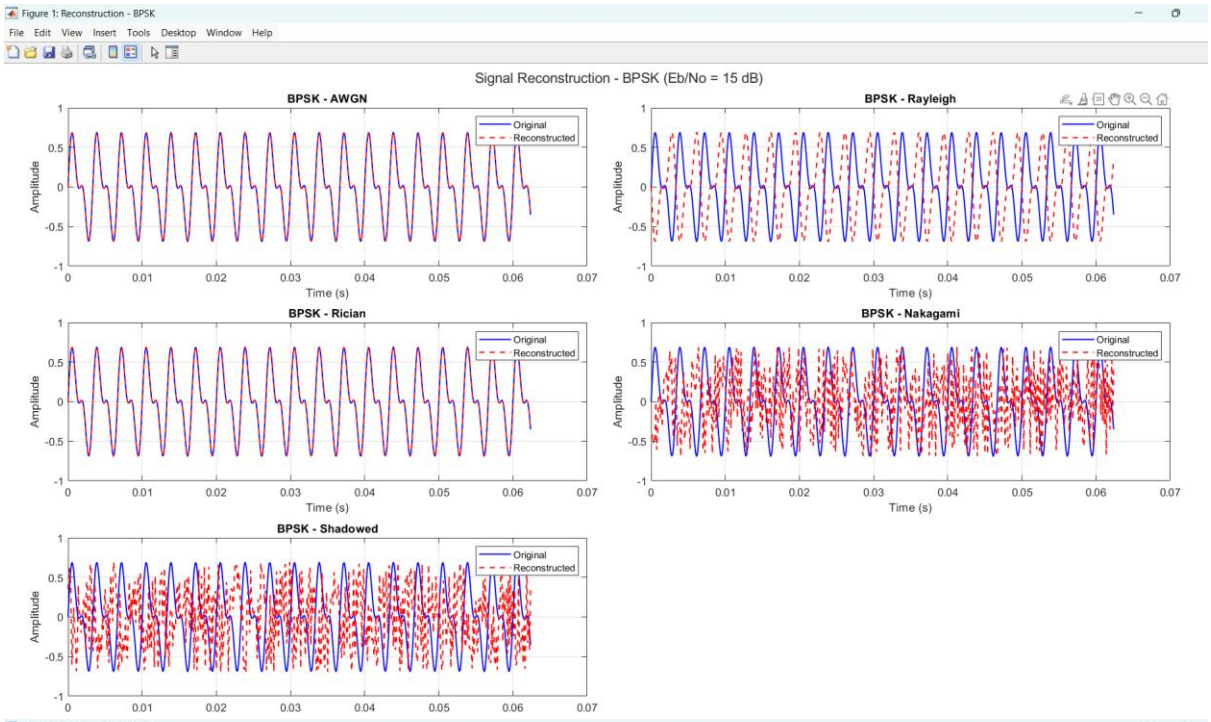


Figure 1: Reconstruction - BPSK
File Edit View Insert Tools Desktop Window Help
Signal Reconstruction - BPSK (Eb/No = 15 dB)
BPSK - AWGN
BPSK - Rayleigh
BPSK - Rician
BPSK - Nakagami
BPSK - Shadowed
Original
Reconstructed
Amplitude
Time (s)

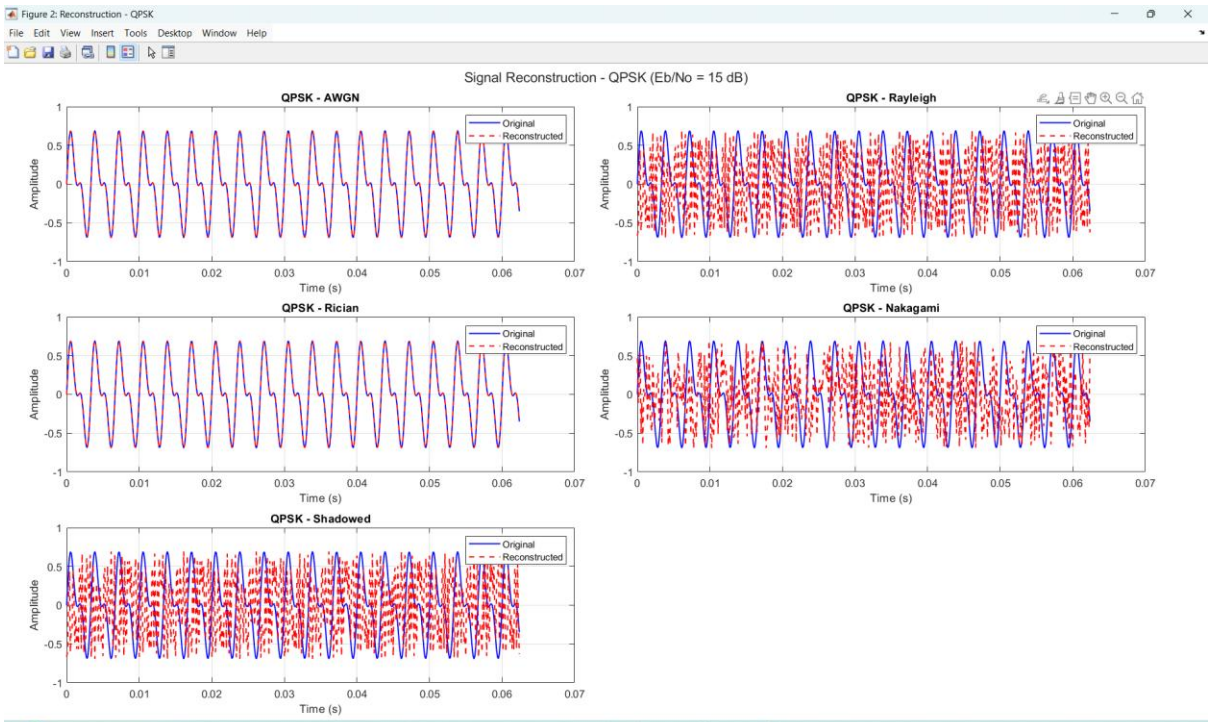


Figure 2: Reconstruction - QPSK
File Edit View Insert Tools Desktop Window Help
Signal Reconstruction - QPSK (Eb/No = 15 dB)
QPSK - AWGN
QPSK - Rayleigh
QPSK - Rician
QPSK - Nakagami
QPSK - Shadowed
Original
Reconstructed
Amplitude
Time (s)


22°C
Mostly clear
Search
ENG
IN
22:50
11-07-2025

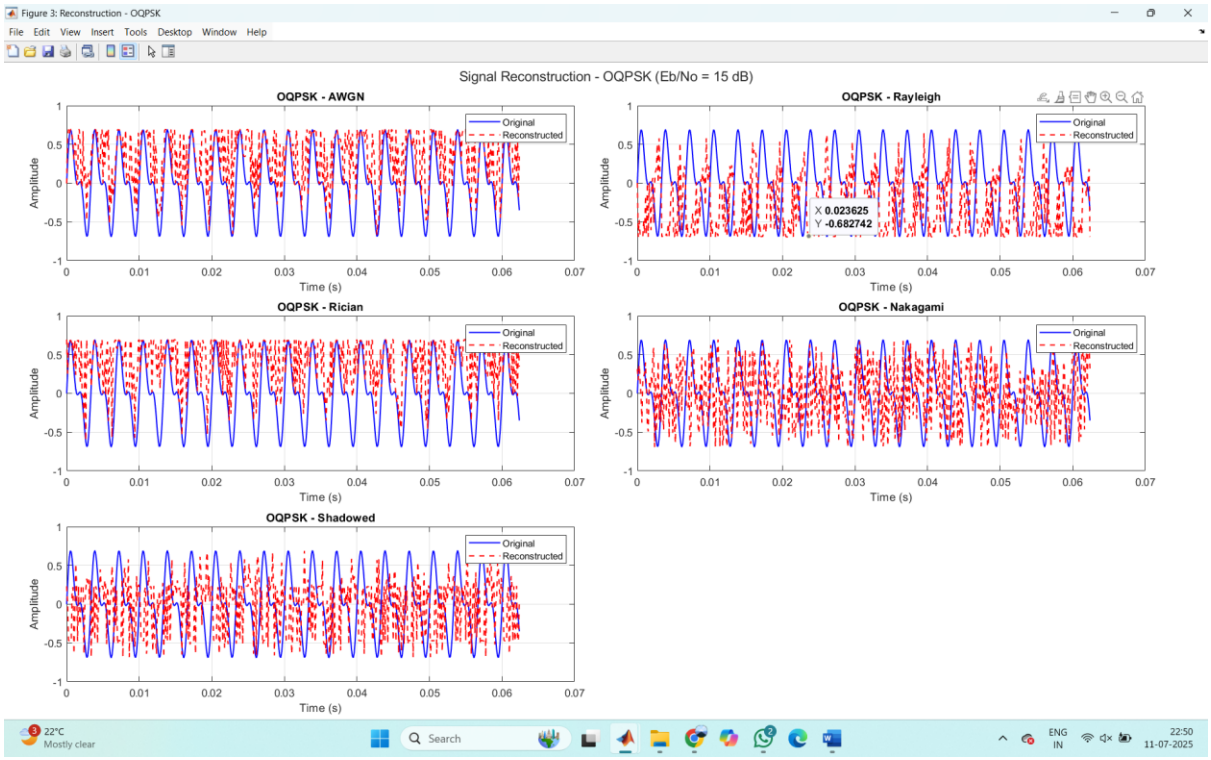


Figure 3: Reconstruction - OQPSK
File Edit View Insert Tools Desktop Window Help
Signal Reconstruction - OQPSK (Eb/No = 15 dB)
OQPSK - AWGN
OQPSK - Rayleigh
OQPSK - Rician
OQPSK - Nakagami
OQPSK - Shadowed
Original
Reconstructed
Amplitude
Time (s)
X 0.023625
Y -0.682742
22°C
Mostly clear
Search
ENG
IN
22:50
11-07-2025

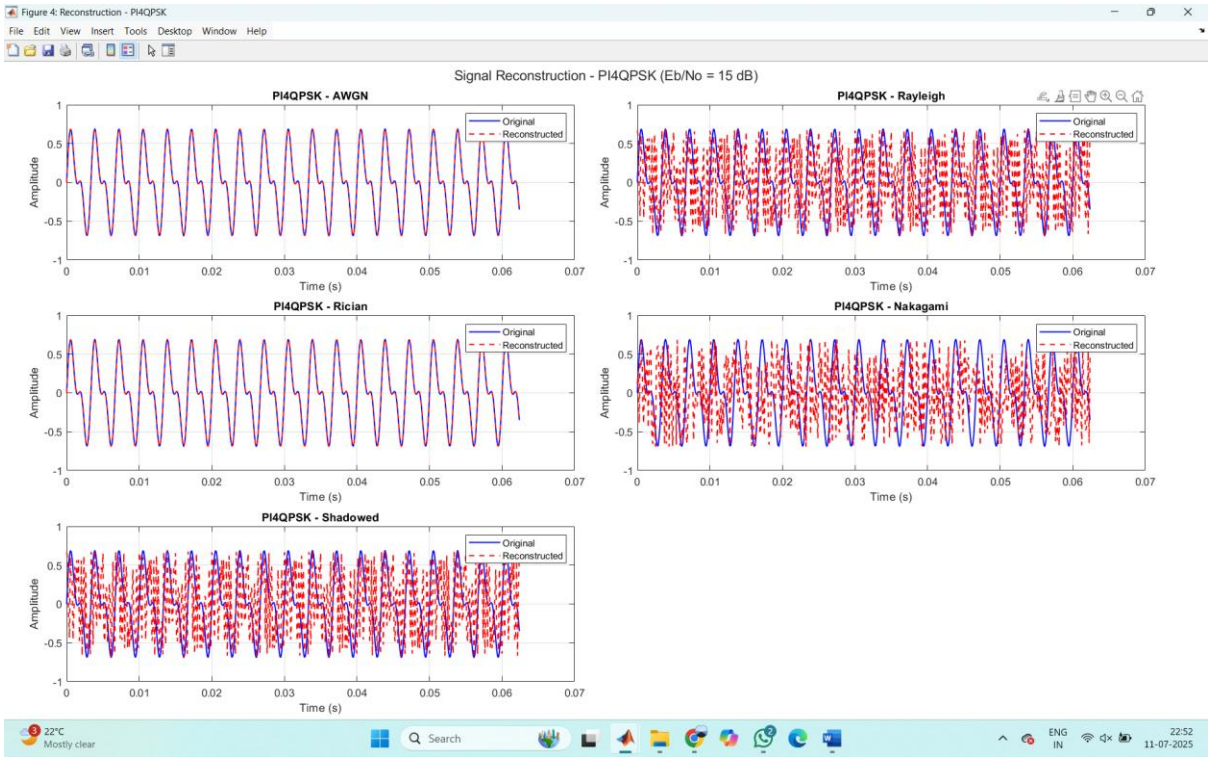


Figure 4: Reconstruction - PI4QPSK
File Edit View Insert Tools Desktop Window Help
Signal Reconstruction - PI4QPSK (Eb/No = 15 dB)
PI4QPSK - AWGN
PI4QPSK - Rayleigh
PI4QPSK - Rician
PI4QPSK - Nakagami
PI4QPSK - Shadowed
Original
Reconstructed
Amplitude
Time (s)
22°C
Mostly clear
Search
ENG
IN
22:52
11-07-2025

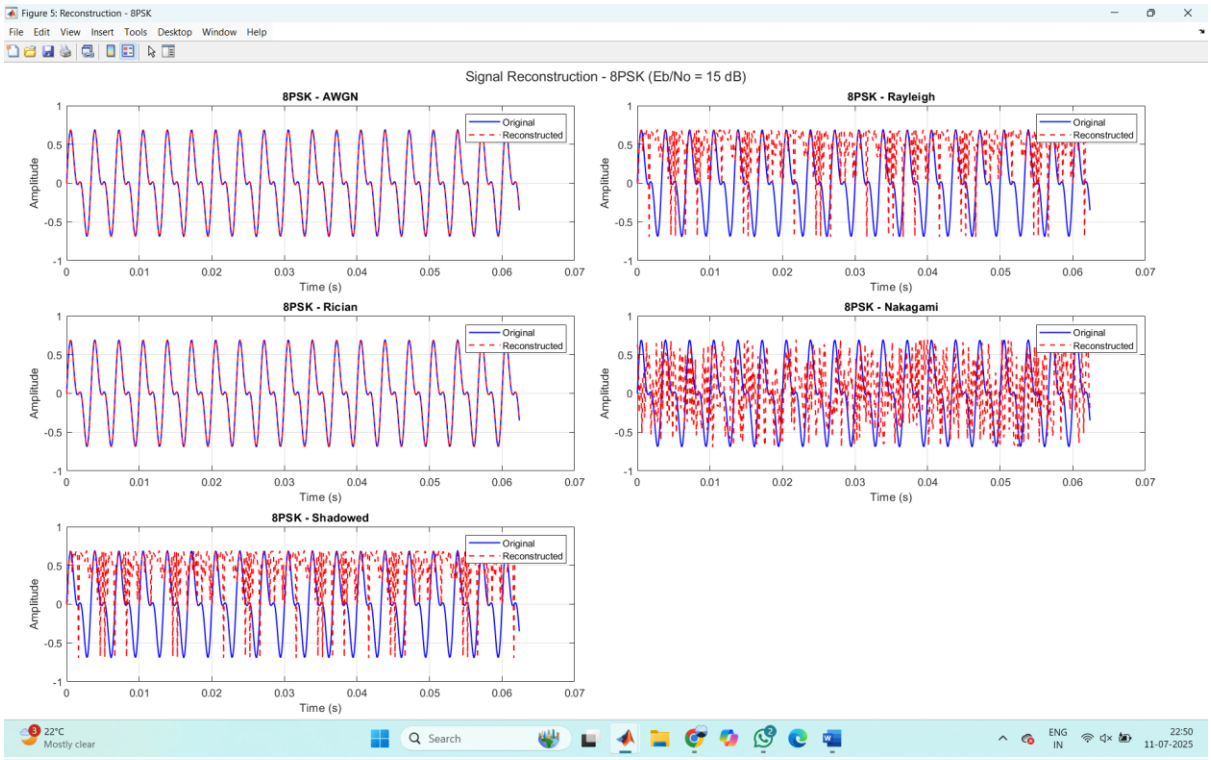


Figure 5: Reconstruction - 8PSK
File Edit View Insert Tools Desktop Window Help
Signal Reconstruction - 8PSK (Eb/No = 15 dB)
8PSK - AWGN
8PSK - Rayleigh
8PSK - Rician
8PSK - Nakagami
8PSK - Shadowed
Original
Reconstructed
Amplitude
Time (s)
22°C
Mostly clear
Search
ENG
IN
22:50
11-07-2025

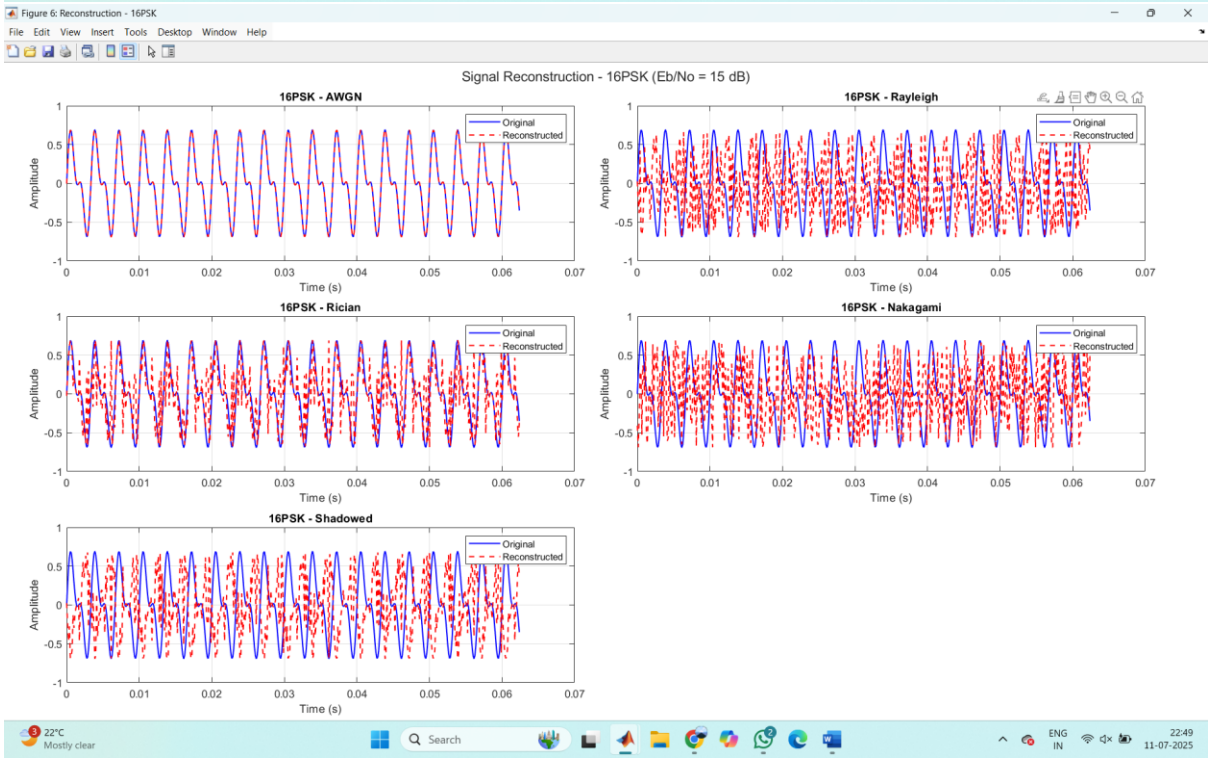


Figure 6: Reconstruction - 16PSK
File Edit View Insert Tools Desktop Window Help
Signal Reconstruction - 16PSK (Eb/No = 15 dB)
16PSK - AWGN
16PSK - Rayleigh
16PSK - Rician
16PSK - Nakagami
16PSK - Shadowed
Original
Reconstructed
Amplitude
Time (s)
22°C
Mostly clear
Search
ENG
IN
22:49
11-07-2025

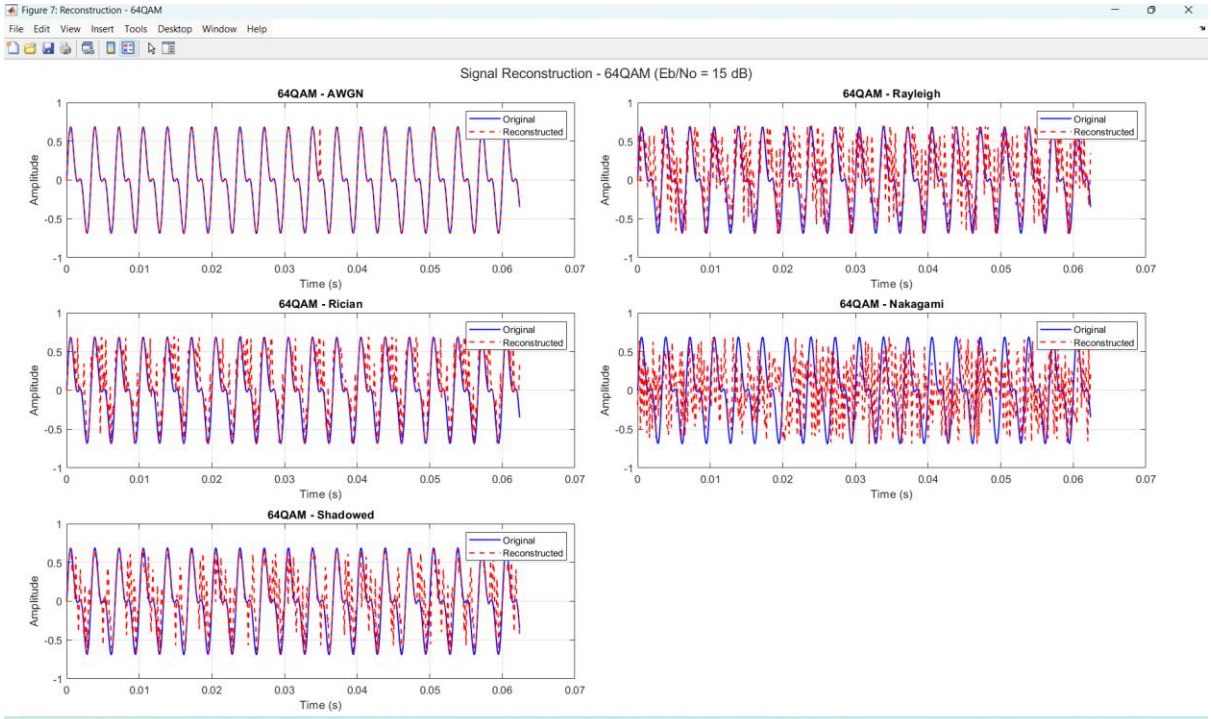


Figure 7: Reconstruction - 64QAM
File Edit View Insert Tools Desktop Window Help
Signal Reconstruction - 64QAM (Eb/No = 15 dB)
64QAM - AWGN
64QAM - Rayleigh
64QAM - Rician
64QAM - Nakagami
64QAM - Shadowed
Original
Reconstructed
Amplitude
Time (s)

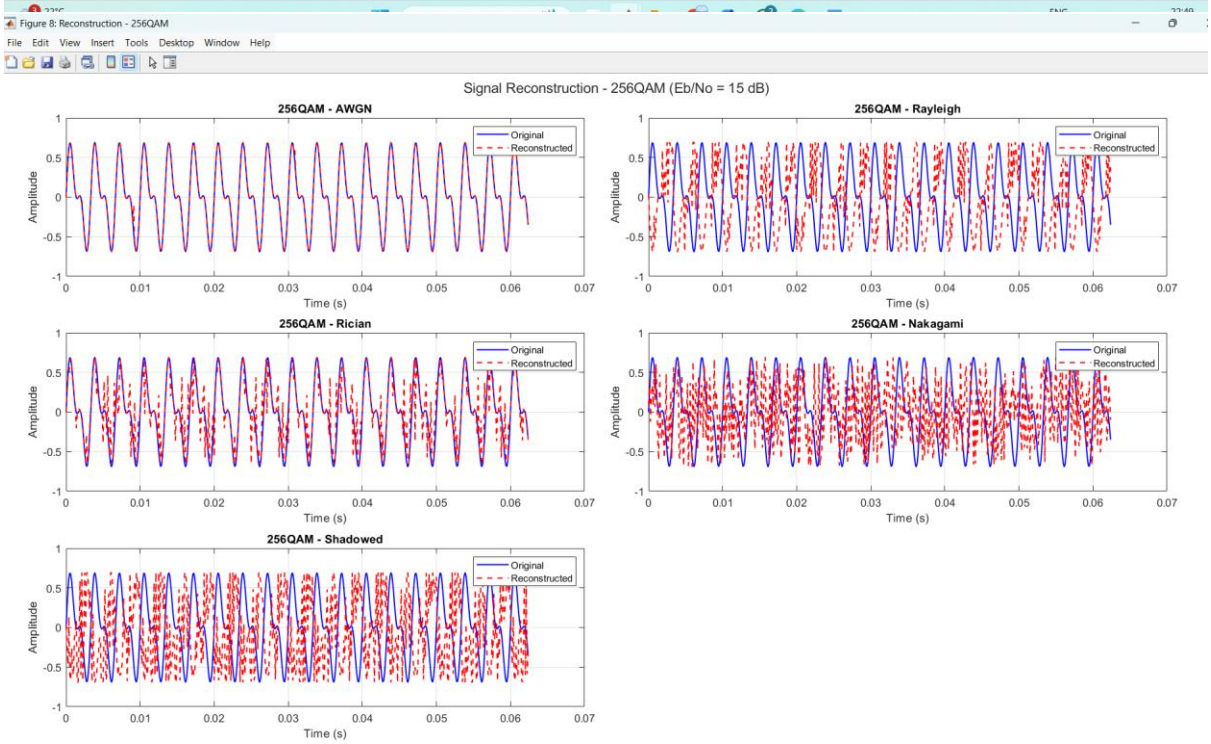


Figure 8: Reconstruction - 256QAM
File Edit View Insert Tools Desktop Window Help
Signal Reconstruction - 256QAM (Eb/No = 15 dB)
256QAM - AWGN
256QAM - Rayleigh
256QAM - Rician
256QAM - Nakagami
256QAM - Shadowed
Original
Reconstructed
Amplitude
Time (s)

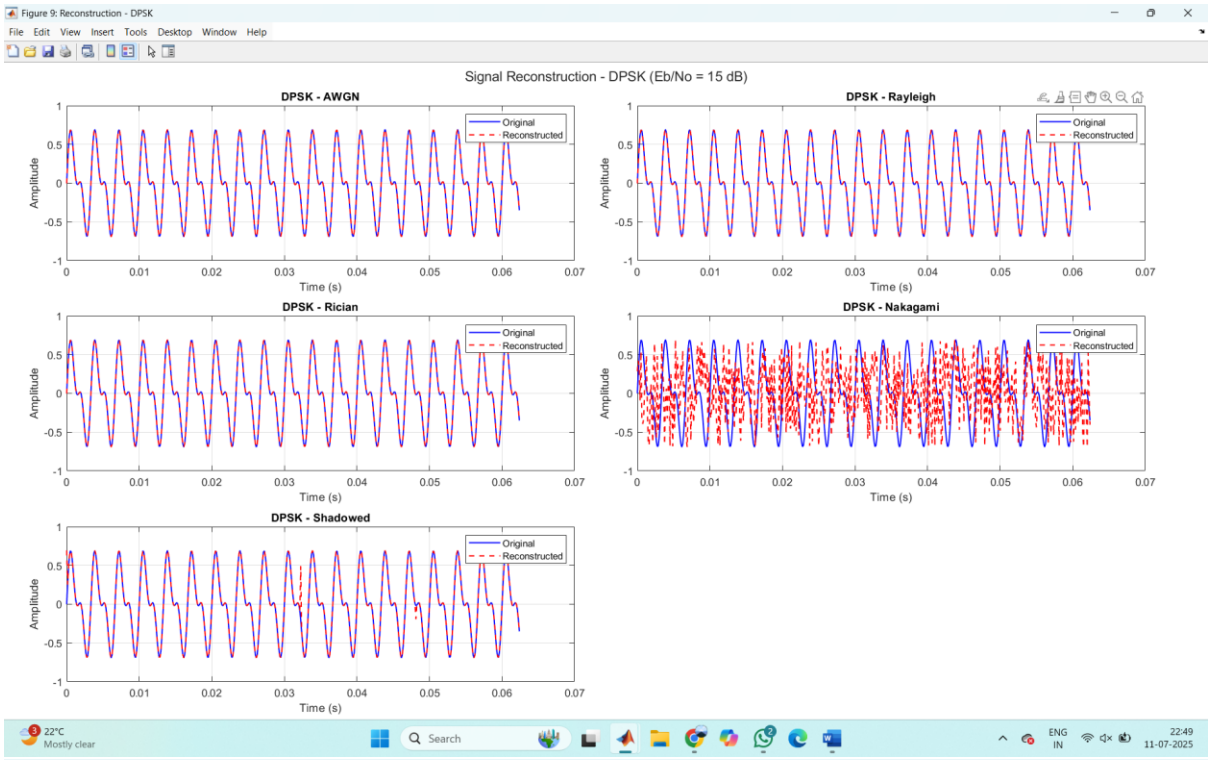


Figure 9: Reconstruction - DPSK
File Edit View Insert Tools Desktop Window Help
Signal Reconstruction - DPSK (Eb/No = 15 dB)
DPSK - AWGN
DPSK - Rayleigh
DPSK - Rician
DPSK - Nakagami
DPSK - Shadowed
Original
Reconstructed
Amplitude
Time (s)
22°C
Mostly clear
Search
ENG
IN
22:49
11-07-2025

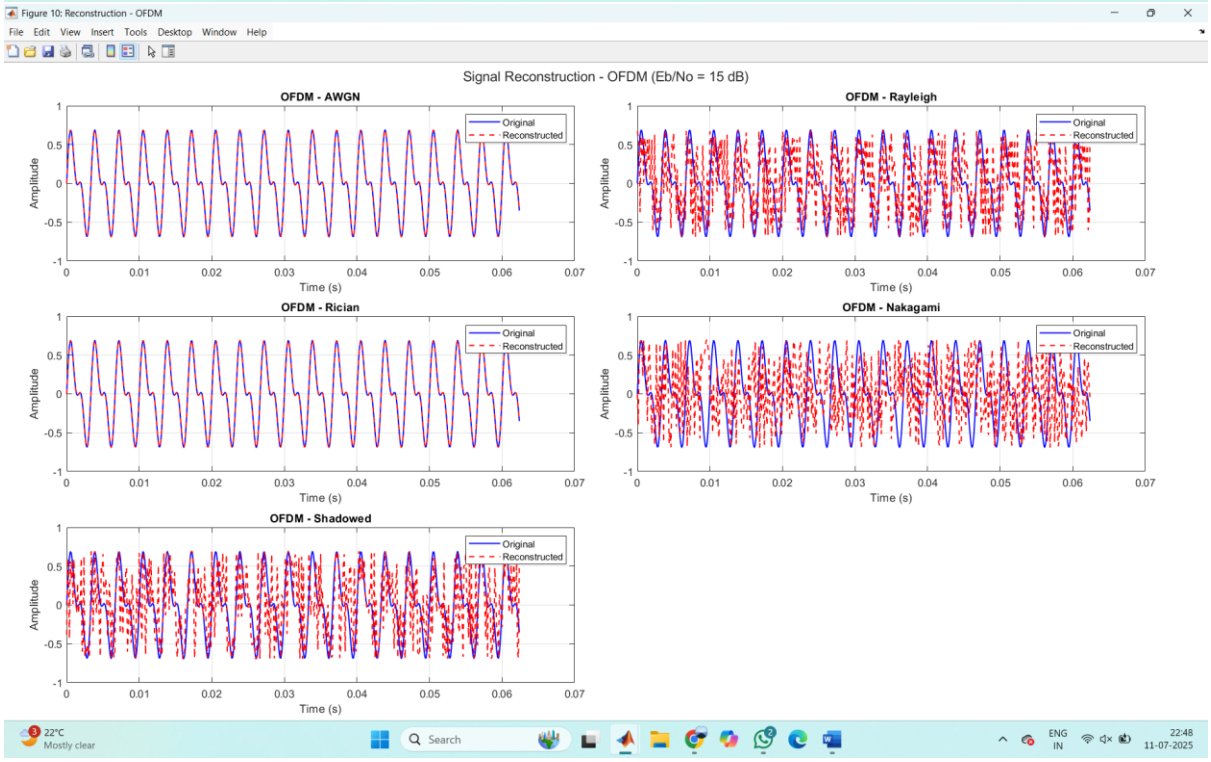


Figure 10: Reconstruction - OFDM
File Edit View Insert Tools Desktop Window Help
Signal Reconstruction - OFDM (Eb/No = 15 dB)
OFDM - AWGN
OFDM - Rayleigh
OFDM - Rician
OFDM - Nakagami
OFDM - Shadowed
Original
Reconstructed
Amplitude
Time (s)
22°C
Mostly clear
Search
ENG
IN
22:48
11-07-2025

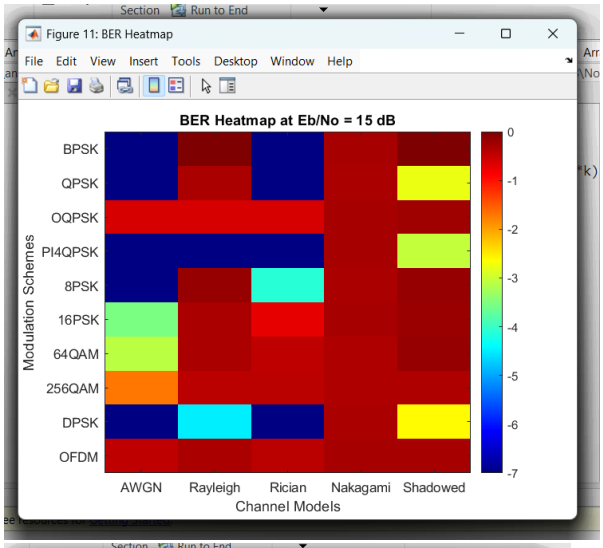


Figure 11: BER Heatmap
File Edit View Insert Tools Desktop Window Help
BER Heatmap at Eb/No = 15 dB
BPSK
QPSK
OQPSK
PI4QPSK
8PSK
16PSK
64QAM
256QAM
DPSK
OFDM
Modulation Schemes
AWGN Rayleigh Rician Nakagami Shadowed
Channel Models
0 -1 -2 -3 -4 -5 -6 -7

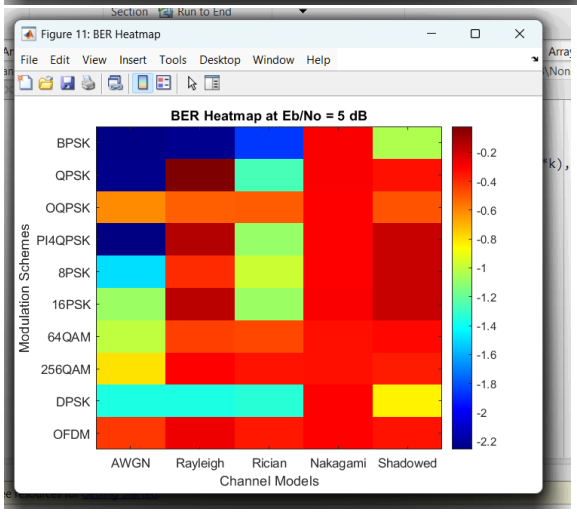


Figure 11: BER Heatmap
File Edit View Insert Tools Desktop Window Help
BER Heatmap at Eb/No = 5 dB
BPSK
QPSK
OQPSK
PI4QPSK
8PSK
16PSK
64QAM
256QAM
DPSK
OFDM
Modulation Schemes
AWGN Rayleigh Rician Nakagami Shadowed
Channel Models
-0.2 -0.4 -0.6 -0.8 -1 -1.2 -1.4 -1.6 -1.8 -2 -2.2

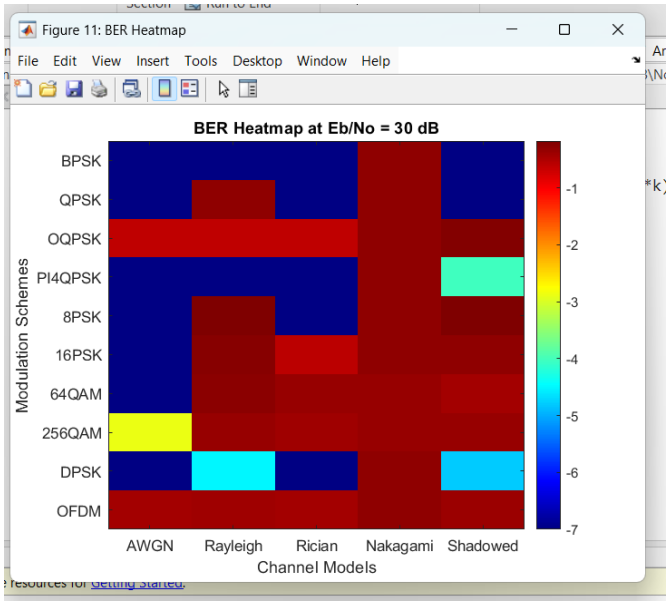
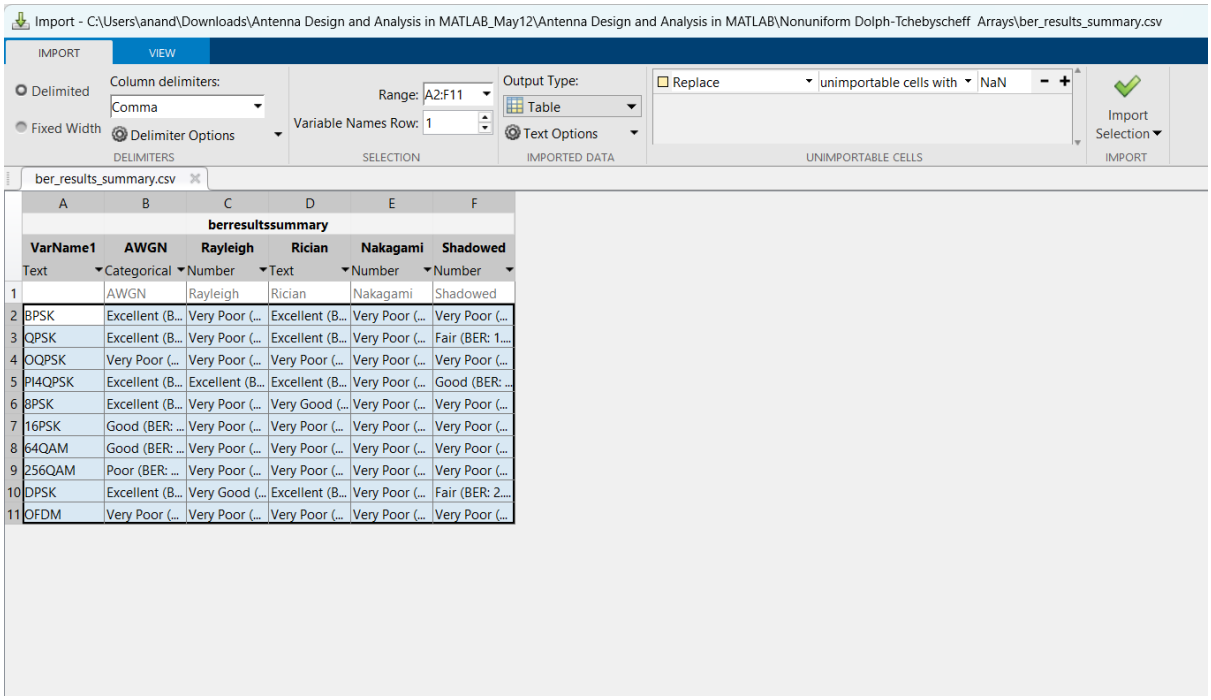


Figure 11: BER Heatmap
File Edit View Insert Tools Desktop Window Help
BER Heatmap at Eb/No = 30 dB
BPSK
QPSK
OQPSK
PI4QPSK
8PSK
16PSK
64QAM
256QAM
DPSK
OFDM
Modulation Schemes
AWGN Rayleigh Rician Nakagami Shadowed
Channel Models
-1 -2 -3 -4 -5 -6 -7



	A	B	C	D	E	F
	berresultssummary					
	VarName1	AWGN	Rayleigh	Rician	Nakagami	Shadowed
	Text	Categorical	Number	Text	Number	Number
1		AWGN	Rayleigh	Rician	Nakagami	Shadowed
2	BPSK	Excellent (B...	Very Poor (...	Excellent (B...	Very Poor (...	Very Poor (...
3	QPSK	Excellent (B...	Very Poor (...	Excellent (B...	Very Poor (...	Fair (BER: 1....
4	OQPSK	Very Poor (...	Very Poor (...	Very Poor (...	Very Poor (...	Very Poor (...
5	PI4QPSK	Excellent (B...	Excellent (B...	Excellent (B...	Very Poor (...	Good (BER: ...
6	8PSK	Excellent (B...	Very Poor (...	Very Good (...	Very Poor (...	Very Poor (...
7	16PSK	Good (BER: ...	Very Poor (...	Very Poor (...	Very Poor (...	Very Poor (...
8	64QAM	Good (BER: ...	Very Poor (...	Very Poor (...	Very Poor (...	Very Poor (...
9	256QAM	Poor (BER: ...	Very Poor (...	Very Poor (...	Very Poor (...	Very Poor (...
10	DPSK	Excellent (B...	Very Good (...	Excellent (B...	Very Poor (...	Fair (BER: 2....
11	OFDM	Very Poor (...	Very Poor (...	Very Poor (...	Very Poor (...	Very Poor (...

CODE

```
clc; clear; close all;


%% Parameters
fs = 8000;
t = 0:1/fs:1;
signal = 0.5*sin(2*pi*300*t) + 0.3*sin(2*pi*600*t); % Synthetic analog signal
signal_norm = (signal - min(signal)) / (max(signal) - min(signal));
quantized = uint8(signal_norm * 255);
bits_orig = reshape(de2bi(quantized, 8, 'left-msb')', [], 1);


% GUI prompt with error handling
defs = {'15','yes'};
answer = inputdlg({'Enter SNR value (in dB):','Export BER to CSV? (yes/no)'}, 'Simulation Parameters', [1 40], defs);
if isempty(answer) || numel(answer) < 2
    errordlg('Simulation canceled or invalid input.','Input Error');
    return;
end
EbNodB_plot = str2double(answer{1});
if isnan(EbNodB_plot)
    errordlg('Invalid Eb/No value. Please enter a numeric value.','Input Error');
    return;
end
saveCSV = strcmpi(answer{2},'yes');


EbNodB = EbNodB_plot;
channels = {'AWGN','Rayleigh','Rician','Nakagami','Shadowed'};
modSchemes = {'BPSK','QPSK','OQPSK','PI4QPSK','8PSK','16PSK','64QAM','256QAM','DPSK','OFDM'};
ber = zeros(length(modSchemes), length(channels), length(EbNodB));
```

```
rayleigh = comm.RayleighChannel('SampleRate',fs);
rician = comm.RicianChannel('SampleRate',fs,'KFactor',4);
nakagami_m = 2; shadow_sigma = 4;

summary = strings(length(modSchemes)+1, length(channels)+1);
summary(1,2:end) = string(channels);
summary(2:end,1) = string(modSchemes);

for m = 1:length(modSchemes)
    modType = modSchemes{m};
    useOFDM = strcmp(modType, 'OFDM');

    switch modType
        case 'BPSK', M = 2; phaseOffset = 0;
        case 'QPSK', M = 4; phaseOffset = pi/4;
        case 'OQPSK', M = 4;
        case 'PI4QPSK', M = 4; phaseOffset = pi/8;
        case '8PSK', M = 8; phaseOffset = 0;
        case '16PSK', M = 16; phaseOffset = 0;
        case '64QAM', M = 64;
        case '256QAM', M = 256;
        case 'DPSK', M = 4;
        case 'OFDM', M = 16; numSubcarriers = 64; cpLen = 16;
    end

    k = log2(M);
    snr = EbNodB + 10*log10(k);
    numBits = floor(length(bits_orig)/k)*k;
    if numBits == 0
        warning(['Skipping modulation scheme ' modType ' due to invalid k.']); continue;
```

```
end
bits = bits_orig(1:numBits);
symbols = bi2de(reshape(bits, [], k), 'left-msb');

if useOFDM
    modData = qammod(symbols, M, 'gray');
    padLen = mod(numel(modData), numSubcarriers);
    if padLen ~= 0
        modData(end+1:numel(modData)+numSubcarriers-padLen) = 0;
    end
    modData = reshape(modData, numSubcarriers, []);
    ifftSig = ifft(modData, numSubcarriers);
    modSig = [ifftSig(end-cpLen+1:end,:); ifftSig];
    modSig = modSig(:);
elseif ismember(modType, {'64QAM','256QAM'})
    modSig = qammod(symbols, M, 'gray');
elseif ismember(modType, {'BPSK','QPSK','8PSK','16PSK','PI4QPSK'})
    modSig = pskmod(symbols, M, phaseOffset, 'gray');
elseif strcmp(modType, 'DPSK')
    modSig = dpskmod(symbols, M);
elseif strcmp(modType, 'OQPSK')
    I = 2*bits(1:2:end)-1;
    Q = 2*bits(2:2:end)-1;
    Q = [0; Q(1:end-1)];
    modSig = double(I) + 1j*double(Q);
end

figure('Name',['Reconstruction - ' modType],'Color','w');
tiledlayout(3,2,'Padding','compact','TileSpacing','compact');

for c = 1:length(channels)
```

```
chType = channels{c};
switch chType
    case 'AWGN'
        rx = awgn(modSig, snr, 'measured');
    case 'Rayleigh'
        release(rayleigh);
        faded = rayleigh(modSig);
        faded = faded / sqrt(mean(abs(faded).^2));
        rx = awgn(faded, snr, 'measured');
    case 'Rician'
        release(rician);
        faded = rician(modSig);
        faded = faded / sqrt(mean(abs(faded).^2));
        rx = awgn(faded, snr, 'measured');
    case 'Nakagami'
        m_int = round(nakagami_m);
        g = sum(randn(m_int*2, numel(modSig)).^2, 1) / (2 * m_int);
        h = sqrt(g) .* exp(1j * 2 * pi * rand(1, numel(modSig)));
        faded = modSig .* h.';
        rx = awgn(faded, snr, 'measured');
    case 'Shadowed'
        release(rayleigh);
        shadow_dB = shadow_sigma * randn(size(modSig));
        faded = rayleigh(modSig) .* 10.^(shadow_dB/20);
        faded = faded / sqrt(mean(abs(faded).^2));
        rx = awgn(faded, snr, 'measured');
end

if useOFDM
    try
        rx = reshape(rx, numSubcarriers+cpLen, []);
```

```
        rx = rx(cpLen+1:end, :);
        rxFFT = fft(rx, numSubcarriers);
        demod = qamdemod(rxFFT(:), M, 'gray');
    catch
        continue;
    end
elseif ismember(modType, {'64QAM','256QAM'})
    demod = qamdemod(rx, M, 'gray');
elseif ismember(modType, {'BPSK','QPSK','8PSK','16PSK','PI4QPSK'})
    demod = pskdemod(rx, M, phaseOffset, 'gray');
elseif strcmp(modType, 'DPSK')
    demod = dpskdemod(rx, M);
elseif strcmp(modType, 'OQPSK')
    I_rx = real(rx) > 0;
    Q_rx = imag(rx) > 0;
    Q_rx = [Q_rx(2:end); 0];
    oqpskBits = reshape([I_rx'; Q_rx'], [], 1);
    demod = bi2de(reshape(oqpskBits(1:floor(length(oqpskBits)/k)*k), [], k), 'left-msb');
end

if strcmp(modType,'OQPSK')
    rxBits = oqpskBits;
else
    rxBits = de2bi(demod, k, 'left-msb');
    rxBits = reshape(rxBits, [], 1);
end

minLen = min(length(bits), length(rxBits));
berVal = mean(bits(1:minLen) ~= rxBits(1:minLen));
if berVal == 0, berVal = 1e-7; end
ber(m,c,1) = berVal;
```

```
        if berVal < 1e-5
            level = "Excellent";
        elseif berVal < 1e-4
            level = "Very Good";
        elseif berVal < 1e-3
            level = "Good";
        elseif berVal < 1e-2
            level = "Fair";
        elseif berVal < 1e-1
            level = "Poor";
        else
            level = "Very Poor";
        end
        summary(m+1,c+1) = level + " (BER: " + sprintf('%.2e', berVal) + ")";

        rxBits = rxBits(1:floor(length(rxBits)/8)*8);
        if isempty(rxBits), continue; end
        rxQuant = bi2de(reshape(rxBits, 8, [])', 'left-msb');
        signalRec = double(rxQuant)/255;
        signalRec = signalRec*(max(signal)-min(signal)) + min(signal);
        L = min(500,length(signalRec));
        nexttile;
        plot(t(1:L),signal(1:L),'b-', 'LineWidth',1.2); hold on;
        plot(t(1:L),signalRec(1:L),'r--','LineWidth',1.2);
        title([modType ' - ' chType],'Interpreter','none','FontWeight','bold');
        xlabel('Time (s)'); ylabel('Amplitude');
        legend('Original','Reconstructed'); grid on;
    end
    sgtitle(['Signal Reconstruction - ' modType ' (Eb/No = ' num2str(EbNodB_plot) ' dB)']);
end
```

```
if saveCSV
    writecell(cellstr(summary), 'ber_results_summary.csv');
end

figure('Name','BER Heatmap','Color','w');
logBER = log10(squeeze(ber(:,:,1)));
imagesc(logBER);
colormap(jet); colorbar;
xticks(1:length(channels)); xticklabels(channels);
yticks(1:length(modSchemes)); yticklabels(modSchemes);
xlabel('Channel Models'); ylabel('Modulation Schemes');
title(['BER Heatmap at Eb/No = ' num2str(EbNodB_plot) ' dB']);
```