```
clear all
close all
clc

berarr = zeros(6,1);
for i = 1:6


nfft = 64;
n_fft = 64;


n_cpe = 16;

snr = 20; % in dB



n_taps = 8;

ch_est_method = 'LS'
%ch_est_method = 'none';

mod_methods = {'BPSK', 'QPSK', '8PSK', '16QAM', '32QAM', '64QAM'};
switch(i)
    case 1
       mod_method = 'BPSK';
    case 2
       mod_method = 'QPSK';
    case 3
       mod_method = '8PSK';
    case 4
       mod_method = '16QAM';
    case 5
       mod_method = '32QAM';
    case 6
       mod_method =  '64QAM';
end

mod_order = find(ismember(mod_methods,mod_method));

im = imread('baboon.png');
im_bin = dec2bin(im(:))';
im_bin = im_bin(:);
sym_rem = mod(mod_order-mod(length(im_bin),mod_order),mod_order);
padding = repmat('0',sym_rem,1);
im_bin_padded = [im_bin;padding];
cons_data = reshape(im_bin_padded,mod_order,length(im_bin_padded)/
mod_order)';
cons_sym_id = bin2dec(cons_data);

if mod_order == 1
```

```
    mod_ind = 2^(mod_order-1);
    n = 0:pi/mod_ind:2*pi-pi/mod_ind;
    in_phase = cos(n);
    quadrature = sin(n);
    symbol_book = (in_phase + quadrature*1i);
end

if mod_order == 2 || mod_order == 3
    mod_ind = 2^(mod_order-1);
    n = 0:pi/mod_ind:2*pi-pi/mod_ind;
    in_phase = cos(n+pi/4);
    quadrature = sin(n+pi/4);
    symbol_book = (in_phase + quadrature*1i);
end

if mod_order == 4 || mod_order == 6
    mod_ind = sqrt(2^mod_order);
    in_phase = repmat(linspace(-1,1,mod_ind),mod_ind,1);
    quadrature = repmat(linspace(-1,1,mod_ind)',1,mod_ind);
    symbol_book = (in_phase(:) + quadrature(:)*1i);
end

if mod_order == 5
    mod_ind = 6;
    in_phase = repmat(linspace(-1,1,mod_ind),mod_ind,1);
    quadrature = repmat(linspace(-1,1,mod_ind)',1,mod_ind);
    symbol_book = (in_phase(:) + quadrature(:)*1i);
    symbol_book = symbol_book([2:5 7:30 32:35]);
end

X = symbol_book(cons_sym_id+1);

fft_rem = mod(n_fft-mod(length(X),n_fft),n_fft);
X_padded = [X;zeros(fft_rem,1)];
X_blocks = reshape(X_padded,nfft,length(X_padded)/nfft);
x = ifft(X_blocks);

x_cpe = [x(end-n_cpe+1:end,:);x];
x_s   = x_cpe(:);

data_pwr = mean(abs(x_s.^2));

noise_pwr = data_pwr/10^(snr/10);
noise =
 normrnd(0,sqrt(noise_pwr/2),size(x_s))+normrnd(0,sqrt(noise_pwr/2),size(x_s))*1i;
x_s_noise = x_s + noise;

snr_meas = 10*log10(mean(abs(x_s.^2))/mean(abs(noise.^2)));

g = exp(-(0:n_taps-1));
g = g/norm(g);
x_s_noise_fading = conv(x_s_noise,g,'same');
```

```
x_p = reshape(x_s_noise_fading,nfft+n_cpe,length(x_s_noise_fading)/
(nfft+n_cpe));
x_p_cpr = x_p(n_cpe+1:end,:);

X_hat_blocks = fft(x_p_cpr);

if n_taps > 1
    switch(ch_est_method)
        case 'none'
        case 'LS'
            G = X_hat_blocks(:,1)./X_blocks(:,1);
            X_hat_blocks = X_hat_blocks./
repmat(G,1,size(X_hat_blocks,2));
        case 'normalized Ls'
            G = X_hat_blocks(:,1)./X_blocks(:,1);
            G = G/norm(G);
            X_hat_blocks = X_hat_blocks./
repmat(G,1,size(X_hat_blocks,2));
    end
end


X_hat = X_hat_blocks(:);
X_hat = X_hat(1:end-fft_rem);


A=[real(symbol_book) imag(symbol_book)];
if (size(A,2)>2)
    A=[real(symbol_book)' imag(symbol_book)'];
end
rec_syms = knnsearch(A,[real(X_hat) imag(X_hat)])-1;

rec_syms_cons = dec2bin(rec_syms);
rec_im_bin = reshape(rec_syms_cons',numel(rec_syms_cons),1);
rec_im_bin = rec_im_bin(1:end-sym_rem);
ber = sum(abs(rec_im_bin-im_bin))/length(im_bin);

rec_im = reshape(rec_im_bin,8,numel(rec_im_bin)/8);
rec_im = uint8(bin2dec(rec_im'));
rec_im = reshape(rec_im,size(im));

figure(i);
subplot(2,2,1);
plot(X,'x','linewidth',2,'markersize',10);
xlim([-2 2]);
ylim([-2 2]);
xlabel('In phase')
ylabel('Qudrature')

if n_taps > 1
    title(sprintf('\\bfTransmit Constellation\n\\rm%s Modulation
\nMultipath Channel Taps: %d',mod_method,n_taps));
else
```

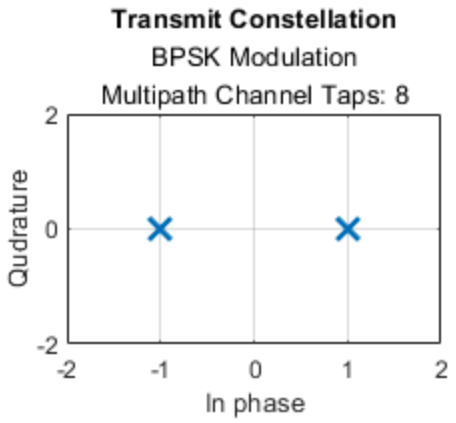
```
    title(sprintf('\\bfTransmit Constellation\n\\rm%s Modulation
\nMultipath Channel Taps: %d',mod_method));
end
grid on

subplot(2,2,2);
plot(X_hat(1:500:end),'x','markersize',3);
xlim([-2 2]);
ylim([-2 2]);
xlabel('In phase')
ylabel('Qudrature')

if n_taps > 1
    title(sprintf('\\bfReceived Constellation\n\\rmMeasured SNR: %.2d
 dB\nChannel Estimation: %s',snr_meas,ch_est_method));
else
    title(sprintf('\\bfReceived Constellation\n\\rmMeasured SNR: %.2d
 dB',snr_meas));
end
grid on

subplot(2,2,3);
imshow(im);
title('\bfTransmit Image');

subplot(2,2,4);
imshow(rec_im);
title(sprintf('\\bfRecovered Image\n \\rmBER: %.2g',ber));

berarr(i) =ber;
end
figure(7)
plot(berarr,'o');

for i = 1:3


nfft = 64;
n_fft = 64;


n_cpe = 16;

snr = 20; % in dB



n_taps = 8;

switch i
    case 1
        ch_est_method = 'LS';
    case 2
        ch_est_method = 'none';
```

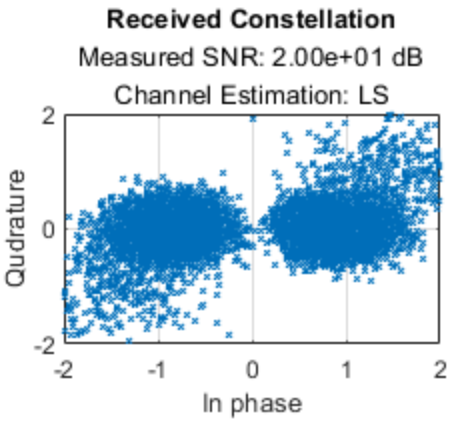
```
    case 3
        ch_est_method = 'normalized Ls'
end

mod_methods = {'BPSK', 'QPSK', '8PSK', '16QAM', '32QAM', '64QAM'};
mod_method = 'BPSK';

mod_order = find(ismember(mod_methods,mod_method));

im = imread('baboon.png');
im_bin = dec2bin(im(:))';
im_bin = im_bin(:);
sym_rem = mod(mod_order-mod(length(im_bin),mod_order),mod_order);
padding = repmat('0',sym_rem,1);
im_bin_padded = [im_bin;padding];
cons_data = reshape(im_bin_padded,mod_order,length(im_bin_padded)/
mod_order)';
cons_sym_id = bin2dec(cons_data);

if mod_order == 1
    mod_ind = 2^(mod_order-1);
    n = 0:pi/mod_ind:2*pi-pi/mod_ind;
    in_phase = cos(n);
    quadrature = sin(n);
    symbol_book = (in_phase + quadrature*1i);
end

if mod_order == 2 || mod_order == 3
    mod_ind = 2^(mod_order-1);
    n = 0:pi/mod_ind:2*pi-pi/mod_ind;
    in_phase = cos(n+pi/4);
    quadrature = sin(n+pi/4);
    symbol_book = (in_phase + quadrature*1i);
end

if mod_order == 4 || mod_order == 6
    mod_ind = sqrt(2^mod_order);
    in_phase = repmat(linspace(-1,1,mod_ind),mod_ind,1);
    quadrature = repmat(linspace(-1,1,mod_ind)',1,mod_ind);
    symbol_book = (in_phase(:) + quadrature(:)*1i);
end

if mod_order == 5
    mod_ind = 6;
    in_phase = repmat(linspace(-1,1,mod_ind),mod_ind,1);
    quadrature = repmat(linspace(-1,1,mod_ind)',1,mod_ind);
    symbol_book = (in_phase(:) + quadrature(:)*1i);
    symbol_book = symbol_book([2:5 7:30 32:35]);
end

X = symbol_book(cons_sym_id+1);

fft_rem = mod(n_fft-mod(length(X),n_fft),n_fft);
X_padded = [X;zeros(fft_rem,1)];
```

```
X_blocks = reshape(X_padded,nfft,length(X_padded)/nfft);
x = ifft(X_blocks);

x_cpe = [x(end-n_cpe+1:end,:);x];
x_s   = x_cpe(:);

data_pwr = mean(abs(x_s.^2));

noise_pwr = data_pwr/10^(snr/10);
noise =
 normrnd(0,sqrt(noise_pwr/2),size(x_s))+normrnd(0,sqrt(noise_pwr/2),size(x_s))*1i;
x_s_noise = x_s + noise;

snr_meas = 10*log10(mean(abs(x_s.^2))/mean(abs(noise.^2)));

g = exp(-(0:n_taps-1));
g = g/norm(g);
x_s_noise_fading = conv(x_s_noise,g,'same');


x_p = reshape(x_s_noise_fading,nfft+n_cpe,length(x_s_noise_fading)/
(nfft+n_cpe));
x_p_cpr = x_p(n_cpe+1:end,:);

X_hat_blocks = fft(x_p_cpr);

if n_taps > 1
    switch(ch_est_method)
        case 'none'
        case 'LS'
            G = X_hat_blocks(:,1)./X_blocks(:,1);
            X_hat_blocks = X_hat_blocks./
repmat(G,1,size(X_hat_blocks,2));
        case 'normalized Ls'
            G = X_hat_blocks(:,1)./X_blocks(:,1);
            G = G/norm(G);
            X_hat_blocks = X_hat_blocks./
repmat(G,1,size(X_hat_blocks,2));
    end
end


X_hat = X_hat_blocks(:);
X_hat = X_hat(1:end-fft_rem);


A=[real(symbol_book) imag(symbol_book)];
if (size(A,2)>2)
    A=[real(symbol_book)' imag(symbol_book)'];
end
rec_syms = knnsearch(A,[real(X_hat) imag(X_hat)])-1;

rec_syms_cons = dec2bin(rec_syms);
rec_im_bin = reshape(rec_syms_cons',numel(rec_syms_cons),1);
```

```
rec_im_bin = rec_im_bin(1:end-sym_rem);
ber = sum(abs(rec_im_bin-im_bin))/length(im_bin);

rec_im = reshape(rec_im_bin,8,numel(rec_im_bin)/8);
rec_im = uint8(bin2dec(rec_im'));
rec_im = reshape(rec_im,size(im));

figure(i+7);
subplot(2,2,1);
plot(X,'x','linewidth',2,'markersize',10);
xlim([-2 2]);
ylim([-2 2]);
xlabel('In phase')
ylabel('Qudrature')

if n_taps > 1
    title(sprintf('\\bfTransmit Constellation\n\\rm%s Modulation
\nMultipath Channel Taps: %d',mod_method,n_taps));
else
    title(sprintf('\\bfTransmit Constellation\n\\rm%s Modulation
\nMultipath Channel Taps: %d',mod_method));
end
grid on

subplot(2,2,2);
plot(X_hat(1:500:end),'x','markersize',3);
xlim([-2 2]);
ylim([-2 2]);
xlabel('In phase')
ylabel('Qudrature')

if n_taps > 1
    title(sprintf('\\bfReceived Constellation\n\\rmMeasured SNR: %.2d
 dB\nChannel Estimation: %s',snr_meas,ch_est_method));
else
    title(sprintf('\\bfReceived Constellation\n\\rmMeasured SNR: %.2d
 dB',snr_meas));
end
grid on

subplot(2,2,3);
imshow(im);
title('\bfTransmit Image');

subplot(2,2,4);
imshow(rec_im);
title(sprintf('\\bfRecovered Image\n \\rmBER: %.2g',ber));

end


ch_est_method =

    'LS'
```

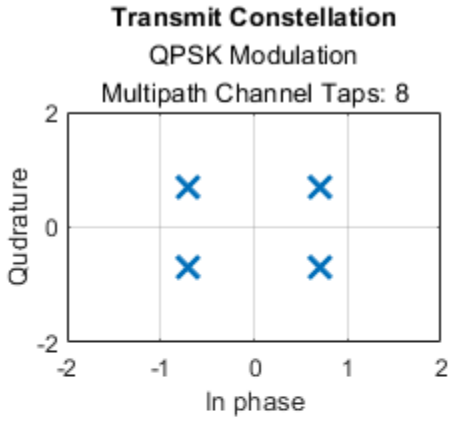
```
ch_est_method =

    'LS'

ch_est_method =

    'LS'

ch_est_method =

    'LS'

ch_est_method =

    'LS'

ch_est_method =

    'LS'

ch_est_method =

    'normalized Ls'
```

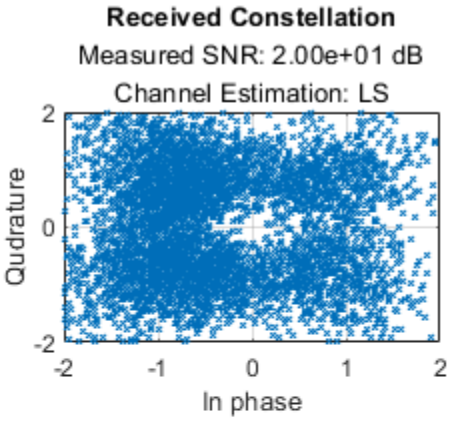

Transmit Constellation
BPSK Modulation
Multipath Channel Taps: 8
Qudrature
In phase
2
0
-2
-1
1


Received Constellation
Measured SNR: 2.00e+01 dB
Channel Estimation: LS
Qudrature
In phase
2
0
-2
-1
1


Transmit Image

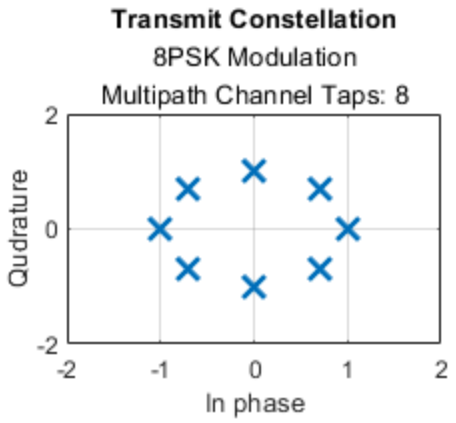

Recovered Image
BER: 0.00041

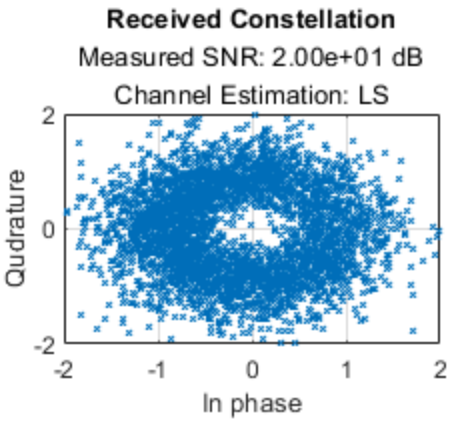

Transmit Constellation
QPSK Modulation
Multipath Channel Taps: 8
Qudrature
In phase
2
0
-2
-1
1


Received Constellation
Measured SNR: 2.00e+01 dB
Channel Estimation: LS
Qudrature
In phase
2
0
-2
-1
1


Transmit Image

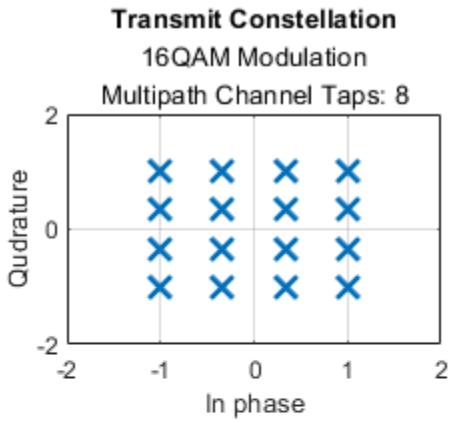

Recovered Image
BER: 0.031

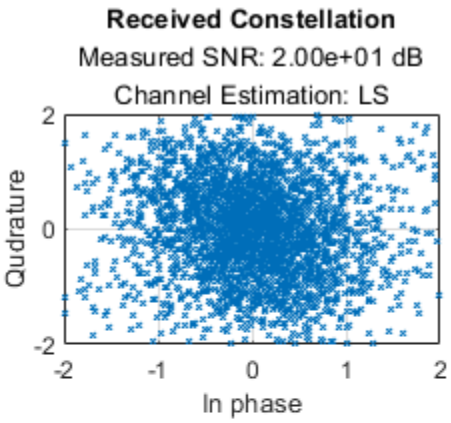

Transmit Constellation
8PSK Modulation
Multipath Channel Taps: 8
Qudrature
In phase
2
0
-2
-2
-1
0
1
2


Received Constellation
Measured SNR: 2.00e+01 dB
Channel Estimation: LS
Qudrature
In phase
2
0
-2
-2
-1
0
1
2


Transmit Image

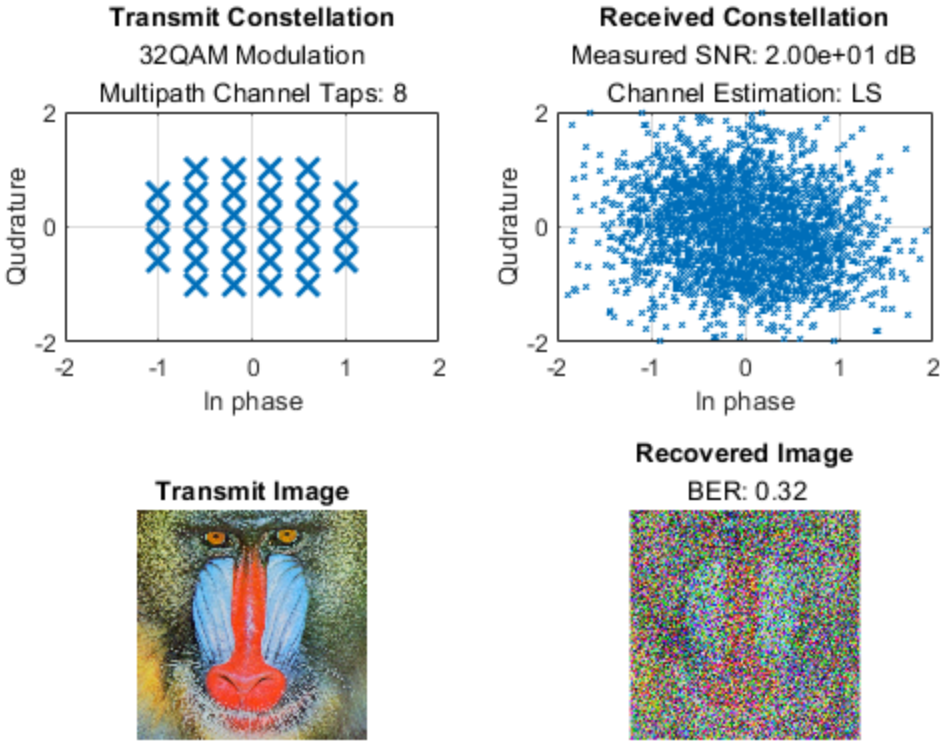

Recovered Image
BER: 0.15

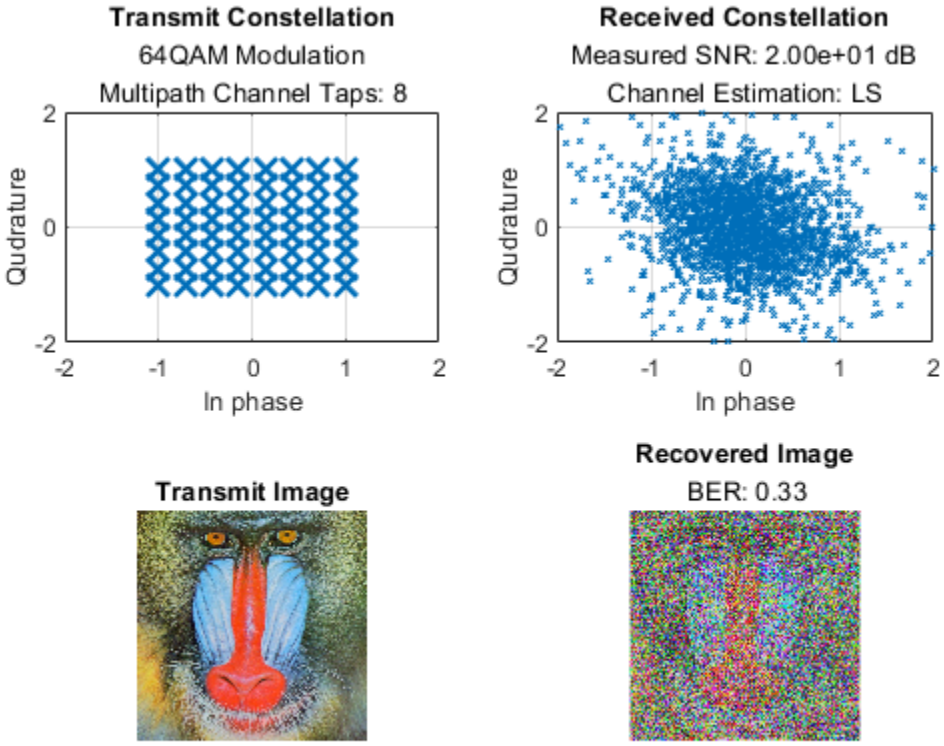

Transmit Constellation
16QAM Modulation
Multipath Channel Taps: 8
Qudrature
In phase
2
0
-2
-2
-1
0
1
2

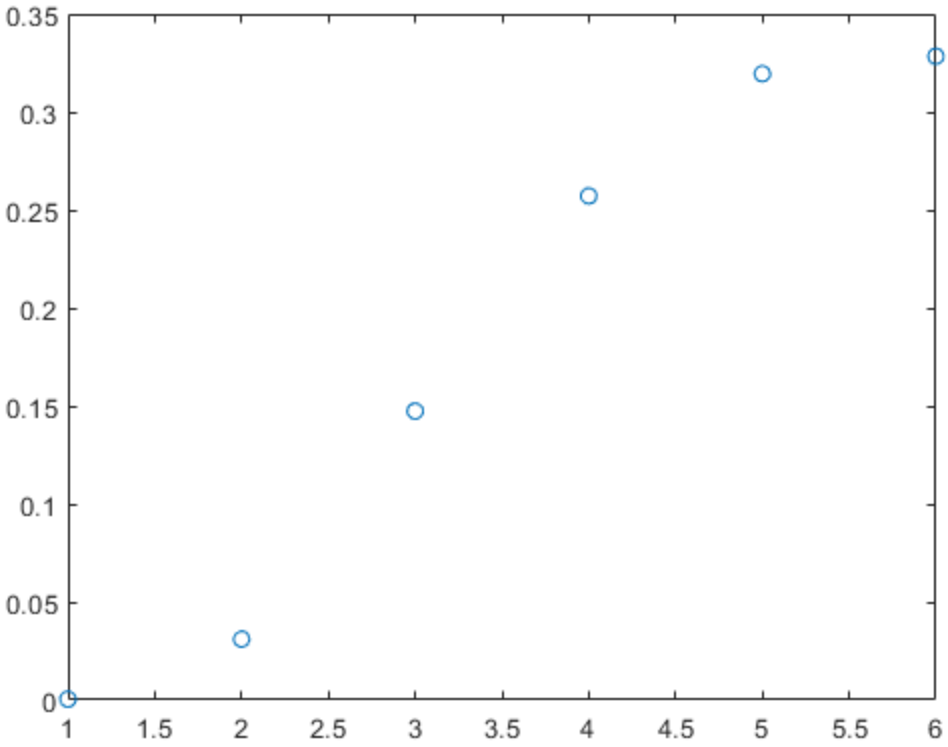

Received Constellation
Measured SNR: 2.00e+01 dB
Channel Estimation: LS
Qudrature
In phase
2
0
-2
-2
-1
0
1
2

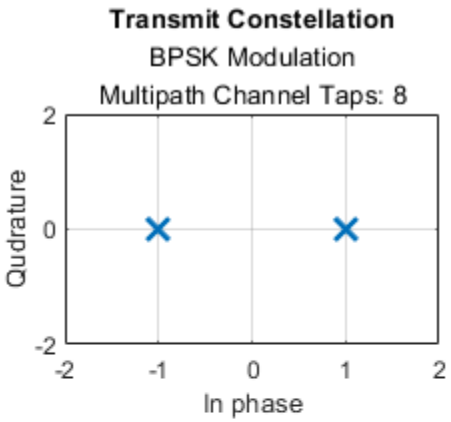

Transmit Image

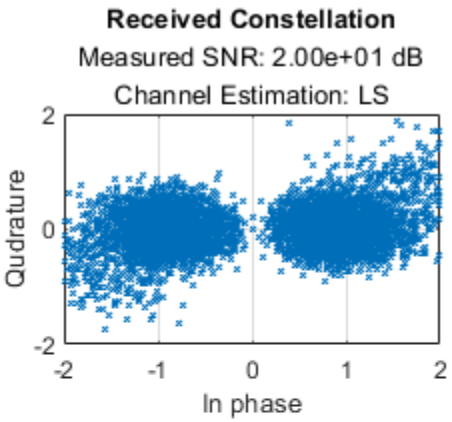

Recovered Image
BER: 0.26


Transmit Constellation
32QAM Modulation
Multipath Channel Taps: 8
Qudrature
In phase
Received Constellation
Measured SNR: 2.00e+01 dB
Channel Estimation: LS
Qudrature
In phase
Transmit Image
Recovered Image
BER: 0.32


Transmit Constellation
64QAM Modulation
Multipath Channel Taps: 8
Qudrature
In phase
Received Constellation
Measured SNR: 2.00e+01 dB
Channel Estimation: LS
Qudrature
In phase
Transmit Image
Recovered Image
BER: 0.33



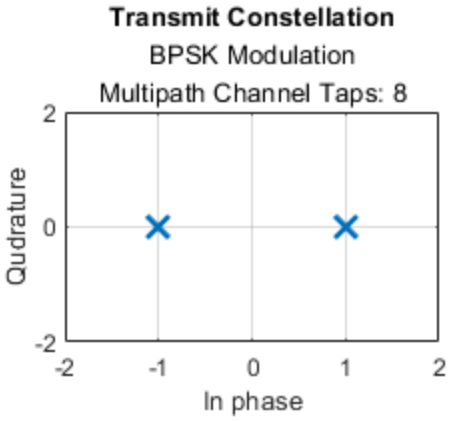


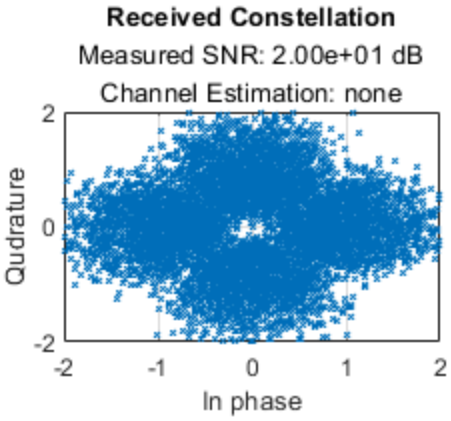


Transmit Image

Recovered Image

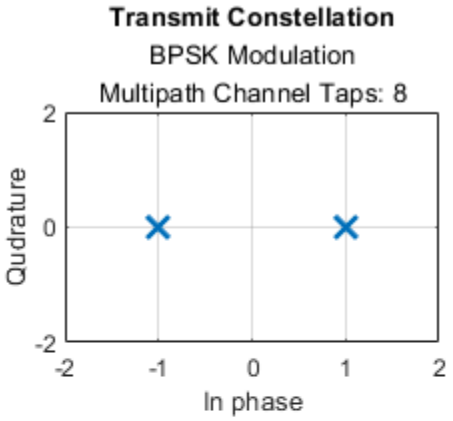
BER: 0.00043

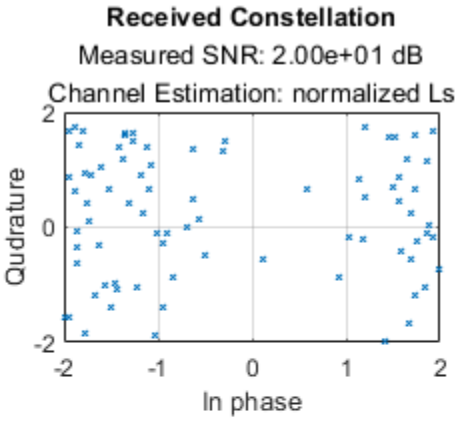

Transmit Constellation
BPSK Modulation
Multipath Channel Taps: 8
Qudrature
In phase
2
0
-2
-2
-1
0
1
2


Received Constellation
Measured SNR: 2.00e+01 dB
Channel Estimation: none
Qudrature
In phase
2
0
-2
-2
-1
0
1
2


Transmit Image


Recovered Image
BER: 0.5


Transmit Constellation
BPSK Modulation
Multipath Channel Taps: 8
Qudrature
In phase
2
0
-2
-2
-1
0
1
2


Received Constellation
Measured SNR: 2.00e+01 dB
Channel Estimation: normalized Ls
Qudrature
In phase
2
0
-2
-2
-1
0
1
2


Transmit Image


Recovered Image
BER: 0.00043

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