Welcome to MATLAB DigComm LAB

1. Matlab Toutrial
   - http://www.math.utah.edu/lab/ms/matlab/matlab.html#starting
2. LAB1 to LAB5 : BASIC WAVES
3. LECTURE: Complex Exponential Function
   - LAB6 to LAB7
4. Channel Modeling
   - LAB8
5. OFDM modeling and Error Rate Measure
   - LAB9 to LAB11
6. REPORT TASK

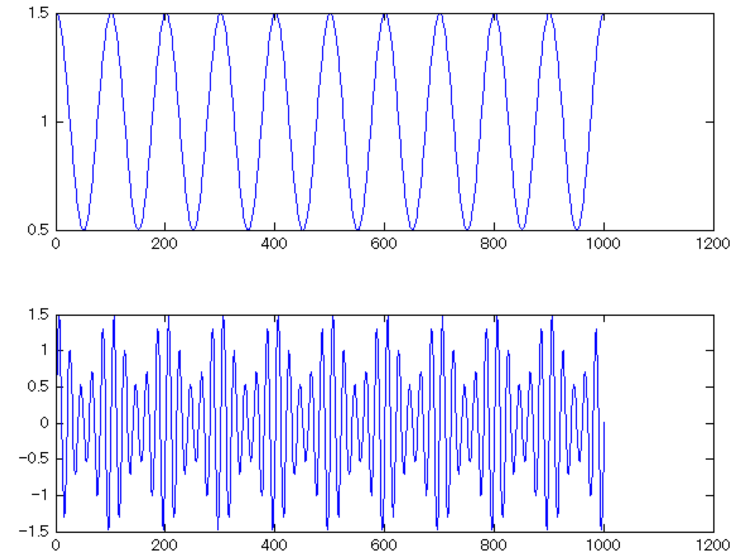
LAB1： AM

- Write Amplitude Modulation (AM) program by MATLAB
- A = 1 + 0.5*cos(2*pi*1*t)
- fc =5Hz
- Use Sampling frequency fs = 100Hz

$$x(t) = A\cos(2\pi f_c t + \phi)$$
$$= A\cos(2\pi f_c n / fs + \phi)$$

LAB1： AM answer

- n=0:1000; % 1001 points
- fc=5;
- fs=100;   % Sampling Frequency
- t = n/fs; % time index
- % INPUT to Modulator
- A = 1 + 0.5*cos(2*pi*1*t);
- % OUTPUT
- x = A .* sin(2*pi*fc*t);
- % FIGURE
- figure(1);
- subplot(2,1,1);
- plot(A);
- subplot(2,1,2);
- plot(x);

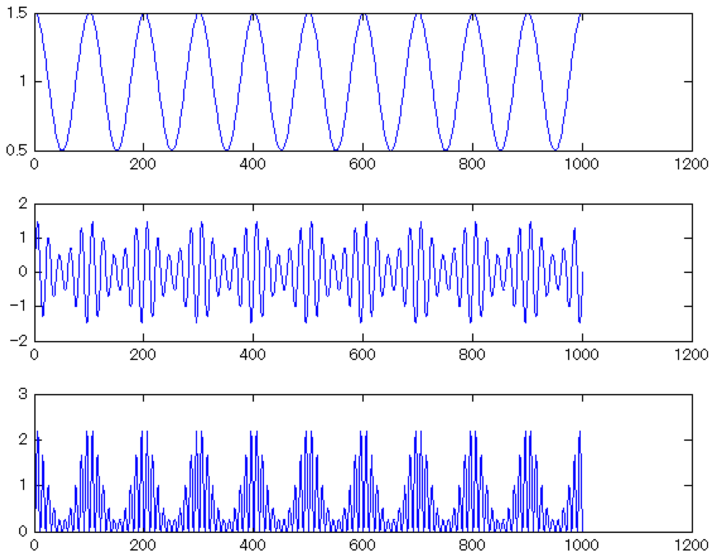


LAB2: AM Demodulation

- Use LAB1 result x and calculate y as each x is squared.
- If you connect each peak of y, you can recover original A.

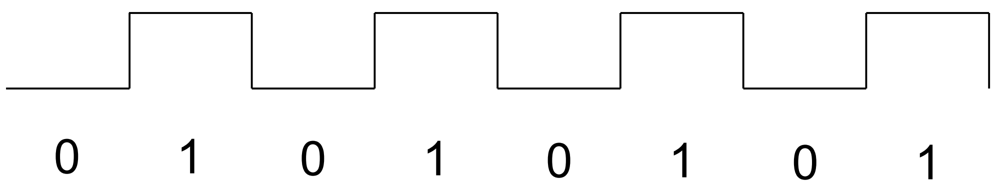
LAB2： AM Demod answer

- n=0:1000; % 1001 points
- fc=5;
- fs=100;   % Sampling Frequency
- t = n/fs; % time index
- % INPUT to Modulator
- A = 1 + 0.5*cos(2*pi*1*t);
- % OUTPUT
- x = A .* sin(2*pi*fc*t);
- %%
- y = x .* x;
- % FIGURE
- figure(2);
- subplot(3,1,1);
- plot(A);
- subplot(3,1,2);
- plot(x);
- subplot(3,1,3);
- plot(y);



LAB3： Spectrum of square wave

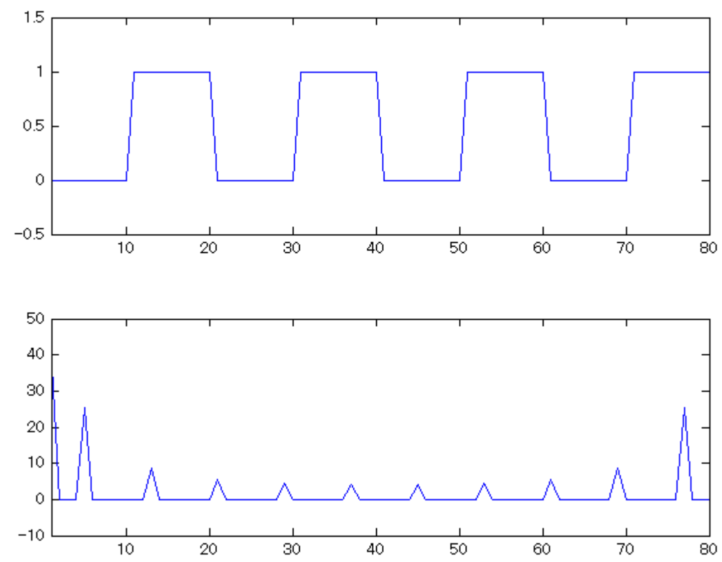
- Analyze below pulse spectrum by Discrete Fourier Transform.



LAB3： Spectrum answer

Assume T = 10 points

- n=1:1:80;
- x = [zeros(1,10), ones(1,10), zeros(1,10), ones(1,10), zeros(1,10), ones(1,10), zeros(1,10), ones(1,10)];
- figure(3)
- subplot(2,1,1);
- plot(x);
- axis([1,80,-0.5, 1.5]);
- %%
- y = fft(x);
- subplot(2,1,2);
- plot(abs(y));
- axis([1,80,-10, 50]);



LAB4： BPSK waveform

- Make BPSK waveform as follows

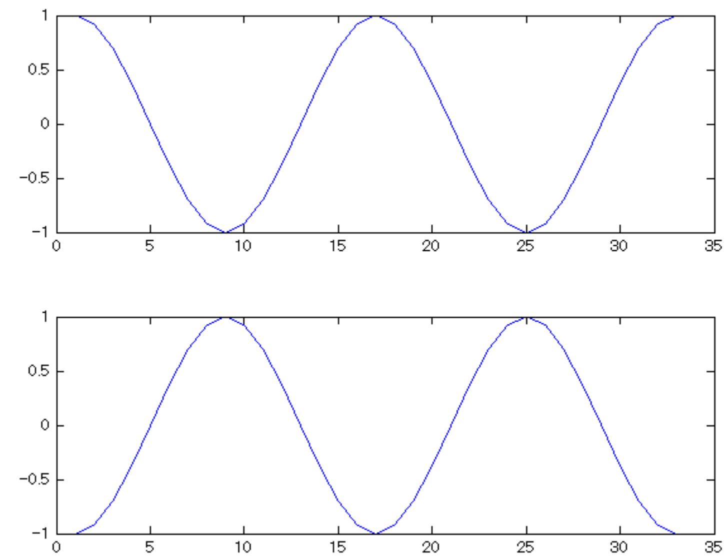
$$x = A\cos(2\pi ft + \phi)$$

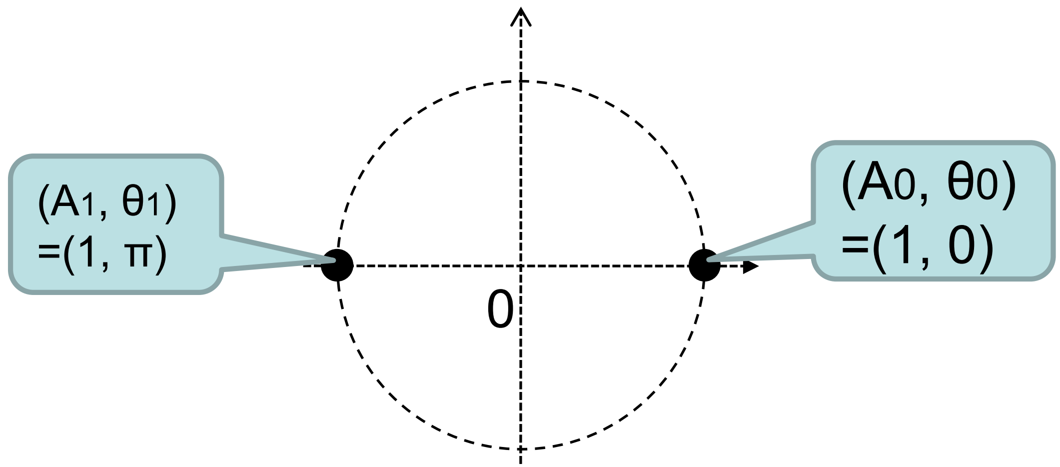
When data=0 $x = A\cos(2\pi ft)$

When data=1 $x = A\cos(2\pi ft + \pi)$

LAB4： BPSK answer

- n=0:32;
- fc=2;
- fs=32; % Sampling Frequency
- t = n/fs; % time index
- % BPSK waveform
- x0 = cos(2*pi*fc*t);
- x1 = cos(2*pi*fc*t + pi);
- % FIGURE
- figure(5);
- subplot(2,1,1);
- plot(x0);
- subplot(2,1,2);
- plot(x1);

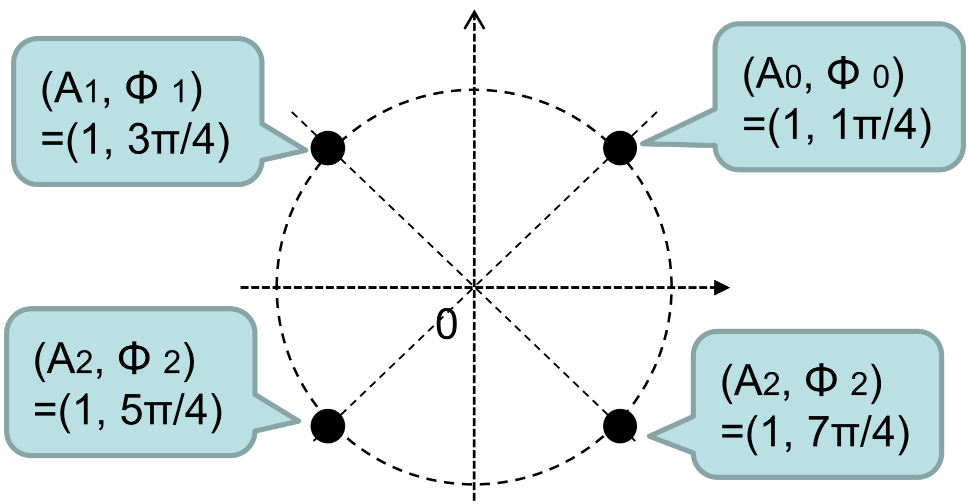




LAB5： QPSK waveform

- Make QPSK waveform as follows

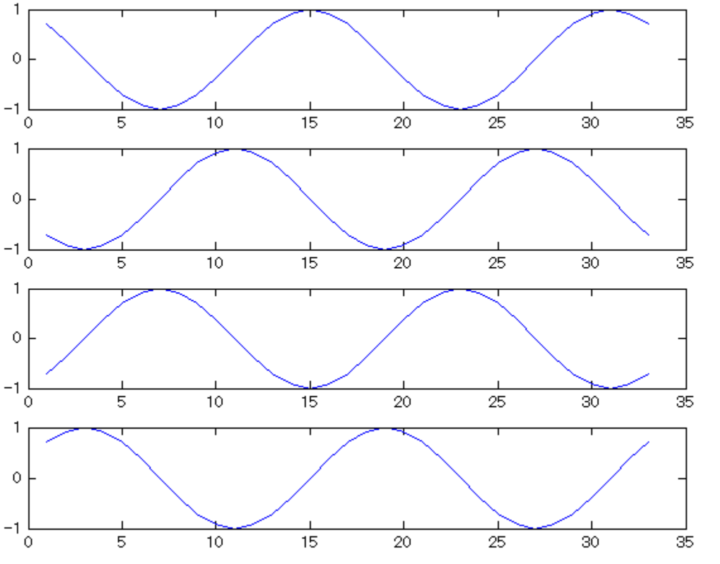
$$x = A\cos(2\pi f t + \phi)$$



$$x = A\cos(2\pi f t + \pi/4)$$
$$x = A\cos(2\pi f t + 3\pi/4)$$
$$x = A\cos(2\pi f t + 5\pi/4)$$
$$x = A\cos(2\pi f t + 7\pi/4)$$

LAB5： QPSK answer

- n=0:32;
- fc=2;
- fs=32;   % Sampling Frequency
- t = n/fs; % time index
- % QPSK waveform
- x0 = cos(2*pi*fc*t + 1*pi/4);
- x1 = cos(2*pi*fc*t + 3*pi/4);
- x2 = cos(2*pi*fc*t + 5*pi/4);
- x3 = cos(2*pi*fc*t + 7*pi/4);
- % FIGURE
- figure(5);
- subplot(4,1,1);
- plot(x0);
- subplot(4,1,2);
- plot(x1);
- subplot(4,1,3);
- plot(x2);
- subplot(4,1,4);
- plot(x3);



LECTURE: COMPLEX EXPONENTIAL FUNCTION

1. Complex Exponential Function

- We will shift from SIN and COS to Complex Exponential Function.

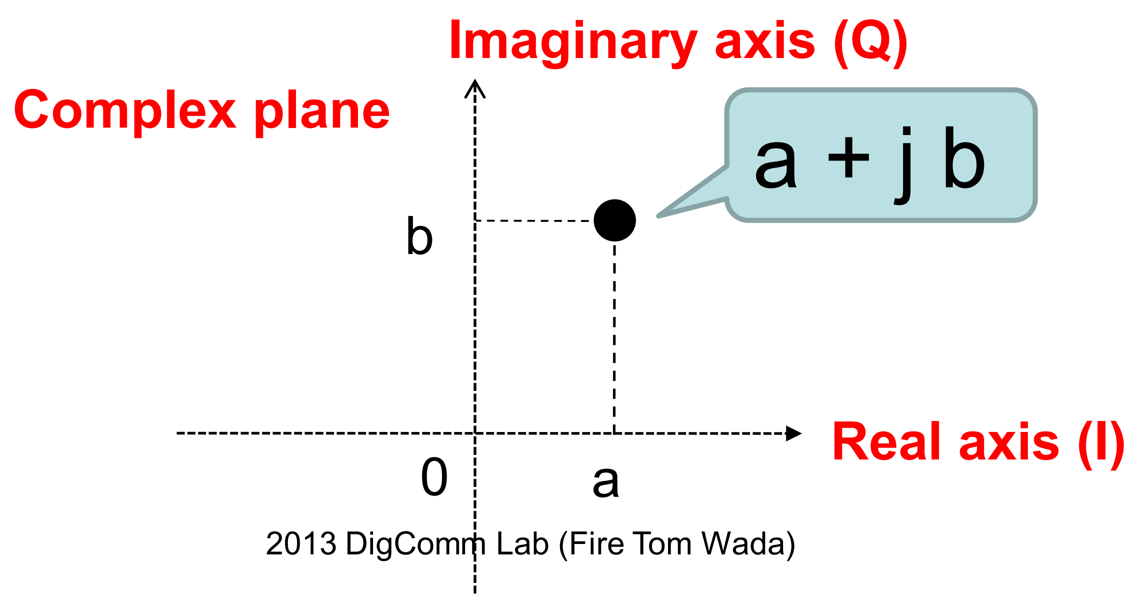
$$\tilde{x}(t) = Ae^{j(2\pi ft+\phi)}$$

$$= \underbrace{A\cos(2\pi ft+\phi)}_{\textbf{Real part}} + \underbrace{j\cdot A\sin(2\pi ft+\phi)}_{\textbf{Imaginary part}}$$

- Real and Imaginary =complex number
- Real part is same as previous cosine wave.

2. Real – Imaginary plane

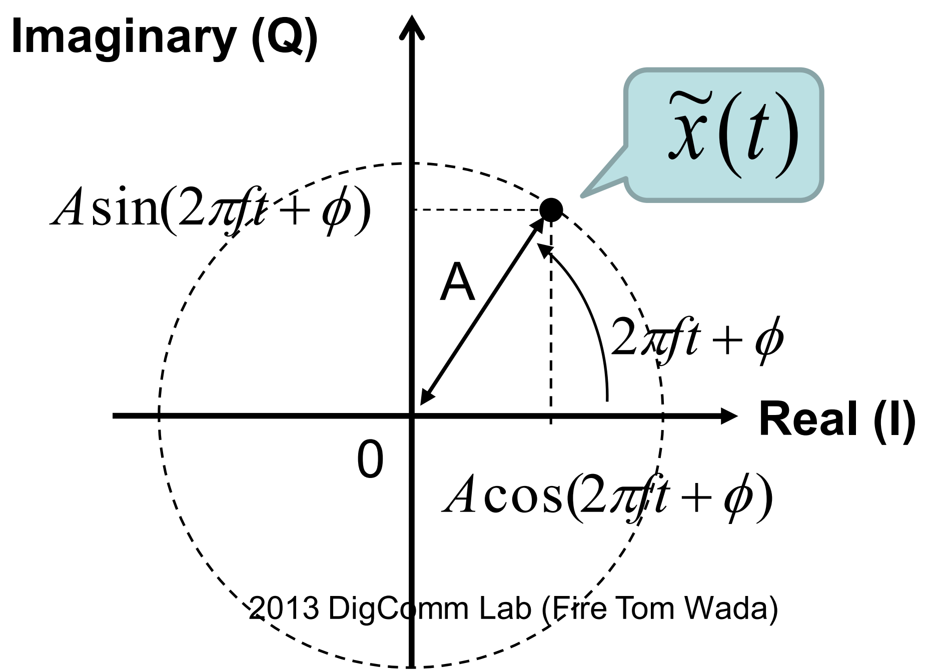
- IQ plane
  - I: In-Phase = Real axis
  - Q: Quadrature-Phase = Imaginary axis
- Real-Imaginary plane (Complex plane)
  - Complex number can be indicated as a point



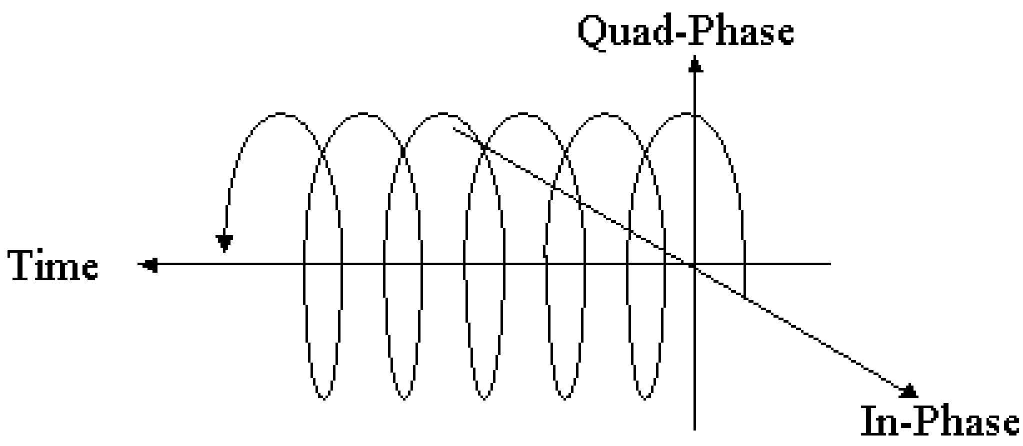
Complex Exponential Function Shows Rotation in I-Q plane

$$\tilde{x}(t) = Ae^{j(2\pi ft+\phi)}$$

$$= \underbrace{A\cos(2\pi ft+\phi)}_{\textbf{Real part}} + j\cdot \underbrace{A\sin(2\pi ft+\phi)}_{\textbf{Imaginary}}$$



Complex Exponential Function shows Rotation on TIME!



Complex Amplitude (Phaser)

$$\tilde{x}(t) = Ae^{j(2\pi ft+\phi)}$$

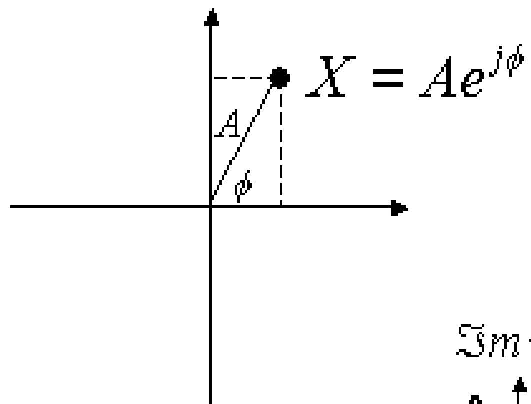
$$= Ae^{j\phi} \cdot e^{j2\pi ft}$$

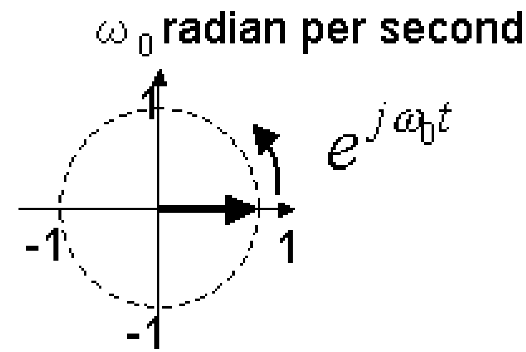
assume

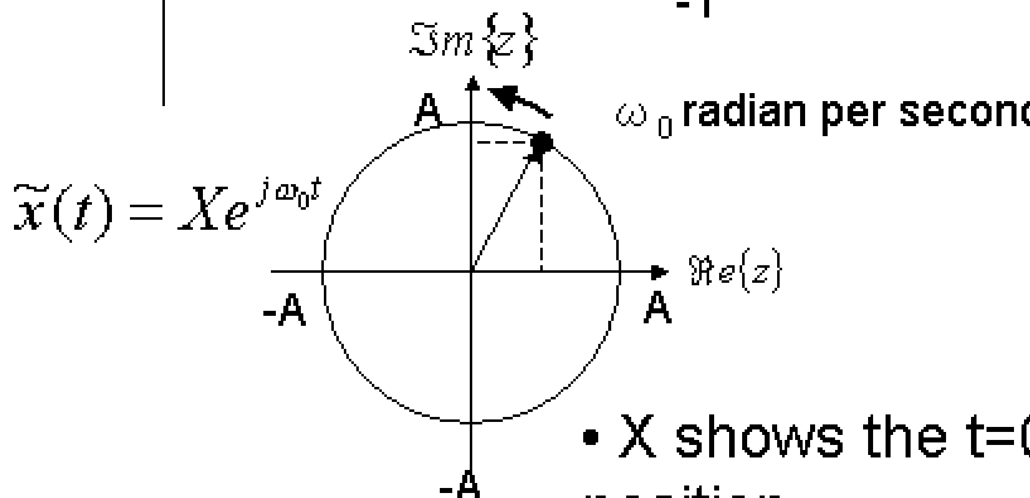
$$X = Ae^{j\phi}$$

$$\omega_0 = 2\pi f$$

$$\tilde{x}(t) = X \cdot e^{j\omega_0 t}$$







- X=x(t=0) shows starting point (t=0) .
- X is called as Complex Amplitude (Phaser)

- X shows the t=0 position.

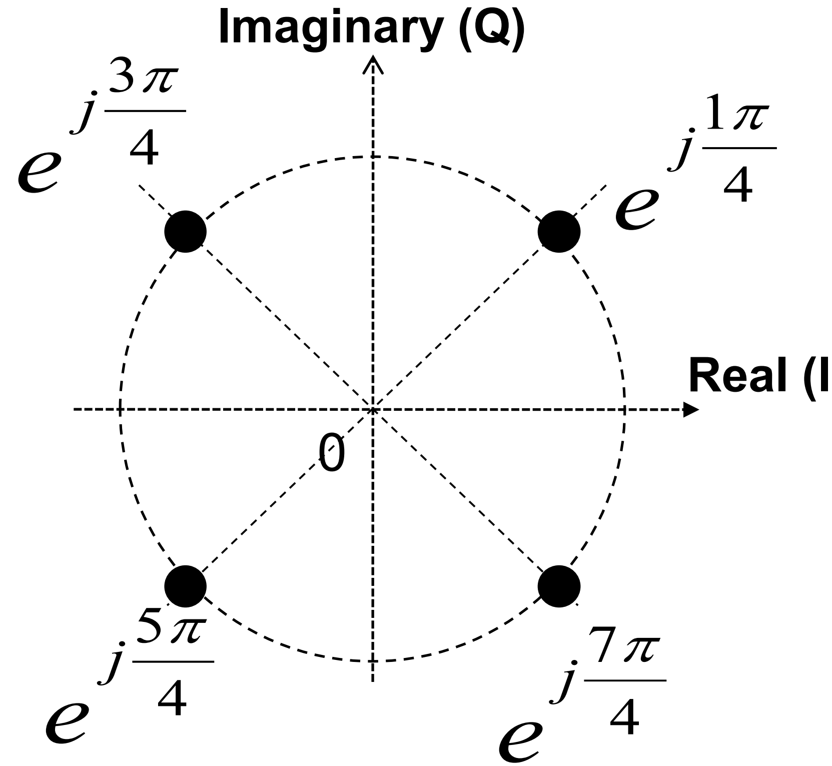
QPSK by Complex Exponential Function

$$\tilde{x}_0(t) = e^{j(2\pi ft + \frac{1\pi}{4})} = e^{j\frac{1\pi}{4}} \cdot e^{j2\pi ft}$$

$$\tilde{x}_1(t) = e^{j(2\pi ft + \frac{3\pi}{4})} = e^{j\frac{3\pi}{4}} \cdot e^{j2\pi ft}$$

$$\tilde{x}_2(t) = e^{j(2\pi ft + \frac{5\pi}{4})} = e^{j\frac{5\pi}{4}} \cdot e^{j2\pi ft}$$

$$\tilde{x}_3(t) = e^{j(2\pi ft + \frac{7\pi}{4})} = e^{j\frac{7\pi}{4}} \cdot e^{j2\pi ft}$$



Complex Amplitude (Phaser) = Constellation point

Conversion from Complex Exponential Function to Real sinusoid.

$$\tilde{x}(t) = Ae^{j(2\pi ft+\phi)}$$
$$= A\cos(2\pi ft+\phi) + j\cdot A\sin(2\pi ft+\phi)$$

Take Real Part
Then
You can convert!

$$\tilde{x}(t) = Ae^{j(2\pi ft+\phi)}$$

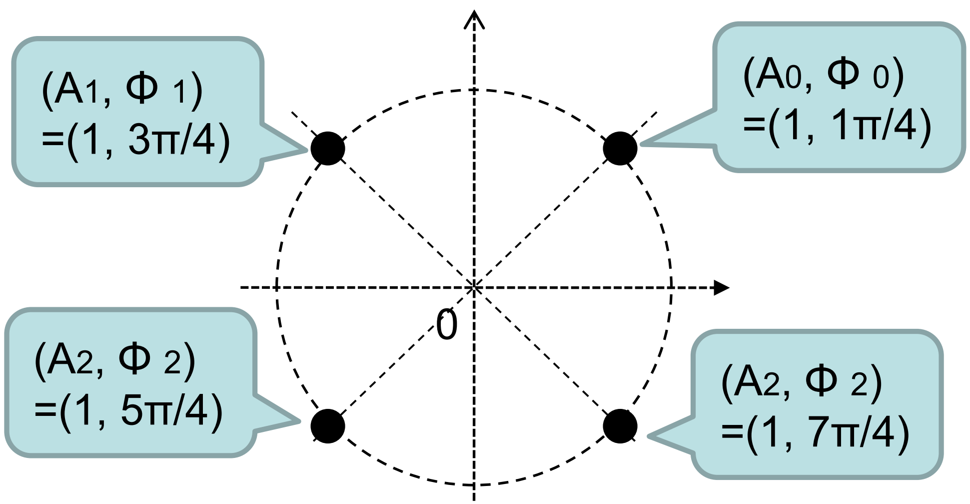
$$A\cos(2\pi ft+\phi) = \mathrm{Re}[\tilde{x}(t)] = \mathrm{Re}[Ae^{j(2\pi ft+\phi)}]$$

LAB6： QPSK waveform

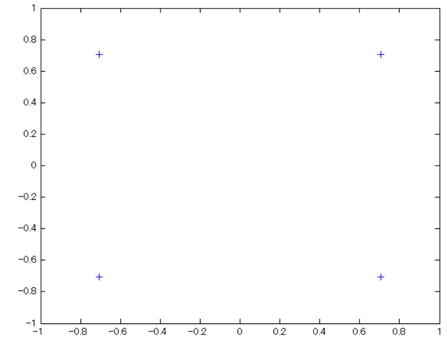
- Make QPSK waveform as follows using

$$\tilde{x}(t) = Ae^{j(2\pi ft+\phi)}$$

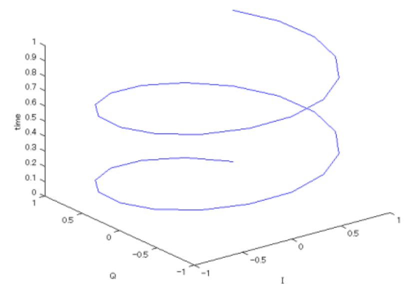
$$= A\cos(2\pi ft+\phi) + j\cdot A\sin(2\pi ft+\phi)$$

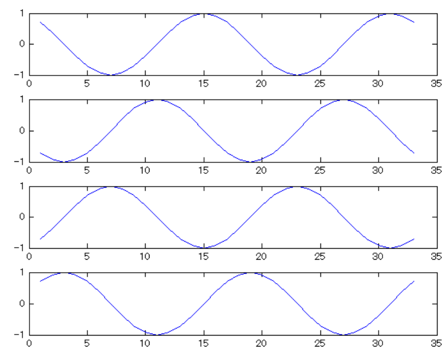


LAB6 : QPSK (2) answer



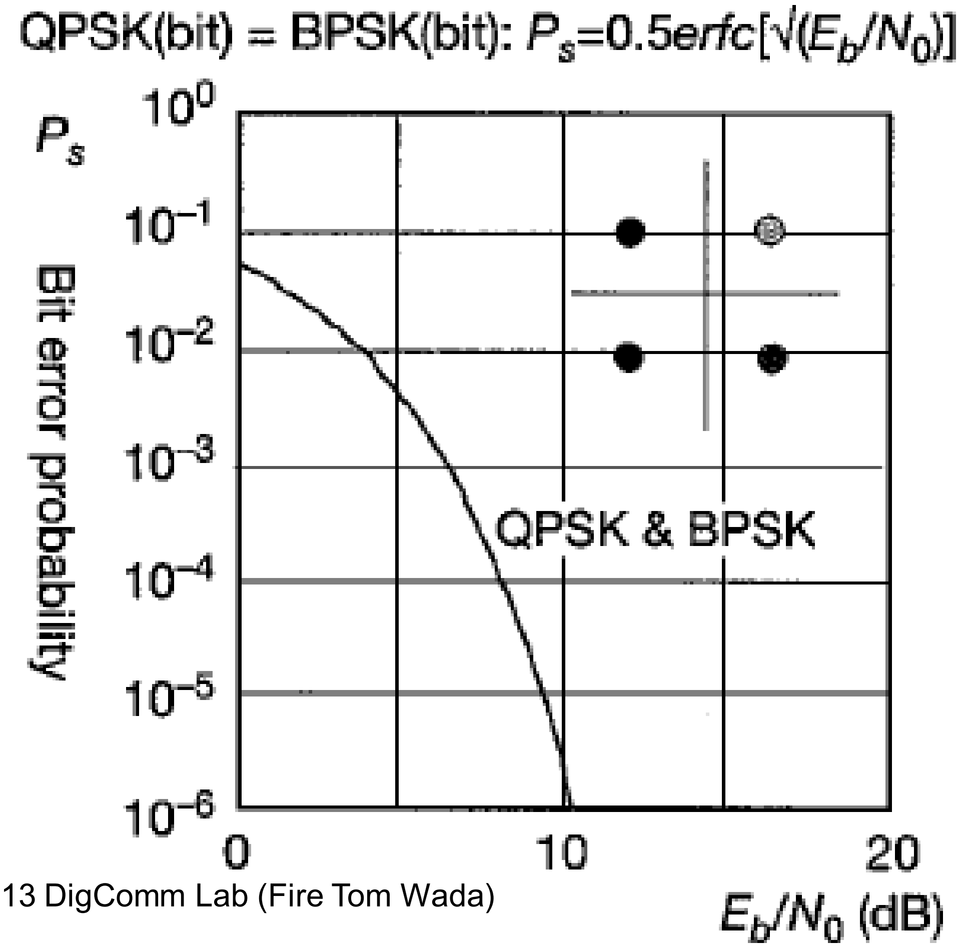
- n=0:32; fc=2;
- fs=32; % Sampling Frequency
- t = n/fs; % time index
- % QPSK Phasers
- X0 = exp(1j*1*pi/4); X1 = exp(1j*3*pi/4);
- X2 = exp(1j*5*pi/4); X3 = exp(1j*7*pi/4);
- % FIGURE
- figure(61); plot([X0, X1, X2, X3], '+');
- axis([-1 1 -1 1]);
- %
- X0wave = X0 * exp(1j*2*pi*fc*t); X1wave = X1 * exp(1j*2*pi*fc*t);
- X2wave = X2 * exp(1j*2*pi*fc*t); X3wave = X3 * exp(1j*2*pi*fc*t);
- %
- figure(62);
- XX=real(X0wave); YY=imag(X0wave); ZZ=t;
- plot3(XX, YY, ZZ); xlabel ('I'); ylabel('Q'); zlabel('time');
- %
- figure(63);
- subplot(4,1,1); plot(real(X0wave));
- subplot(4,1,2); plot(real(X1wave));
- subplot(4,1,3); plot(real(X2wave));
- subplot(4,1,4); plot(real(X3wave));





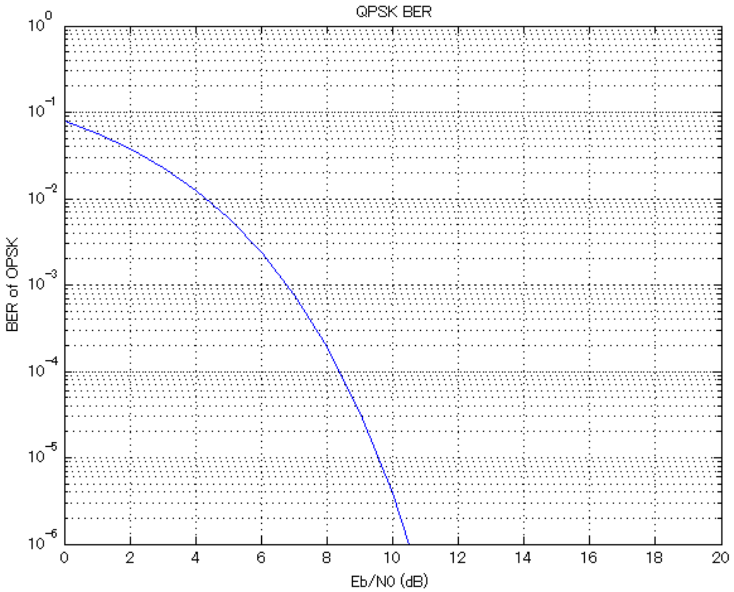
LAB7： Draw BER graph

- Make following graph by MATLAB



LAB7： BER graph answer

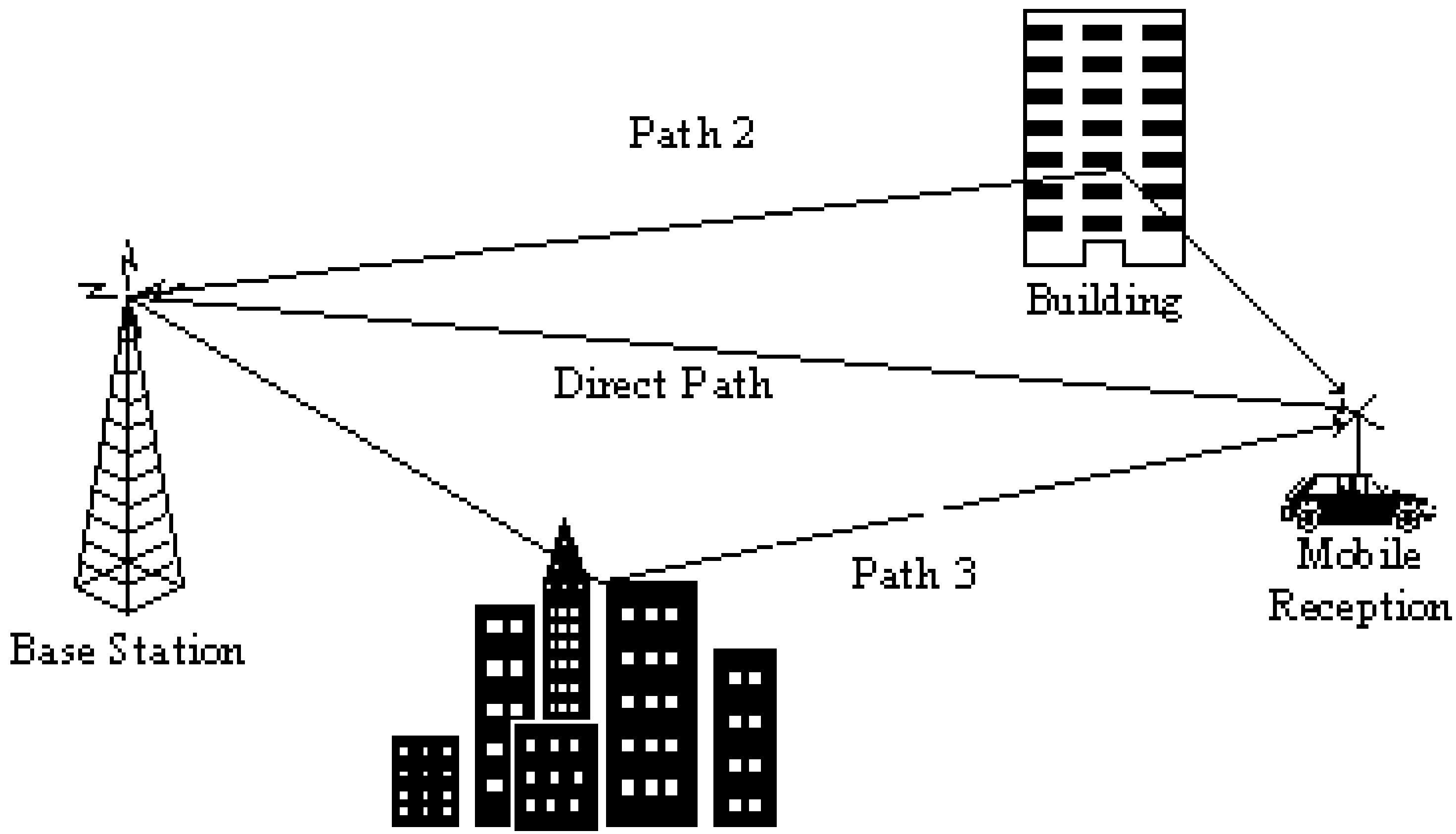
- EBN0dB = 0:1:20; % EbN0 in dB
- EBN0   = 10 .^(EBN0dB/10);
- BER_QPSK = 0.5*erfc(sqrt(EBN0));
- figure(7);
- semilogy(EBN0dB, BER_QPSK);
- axis([0 20 1E-6 1]);
- xlabel(' Eb/N0 (dB) ');
- ylabel(' BER of OPSK');
- grid on;
- title(' QPSK BER');



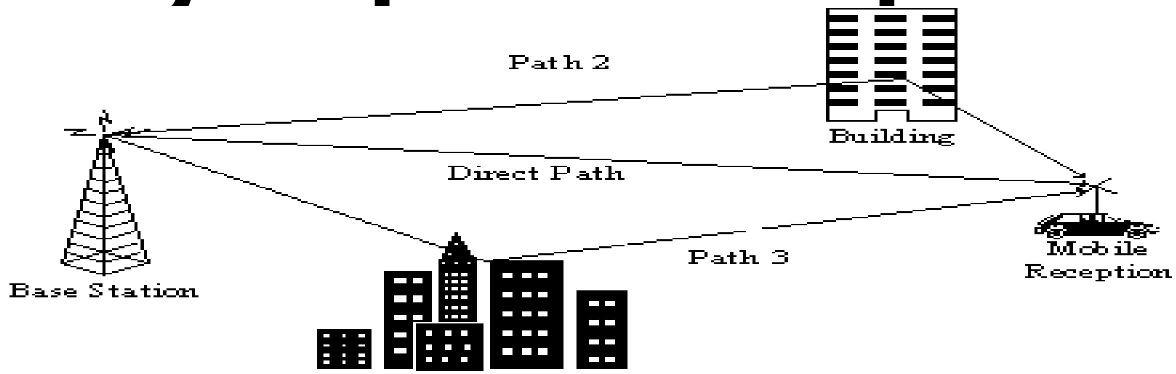
LECTURE: CHANNEL MODELING

Multipath Channel

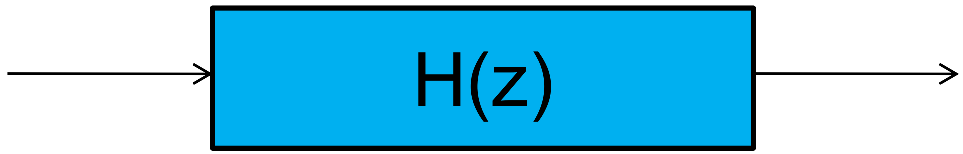
- Direct path and Delayed paths



Channel Modeling by Impulse Response

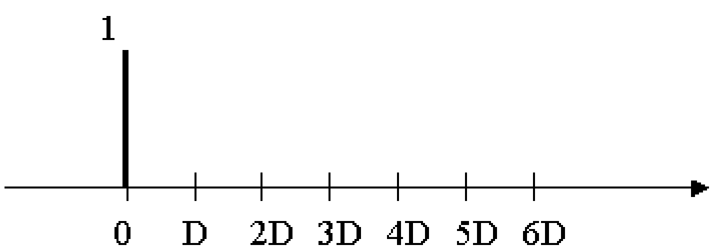


Sending Signal

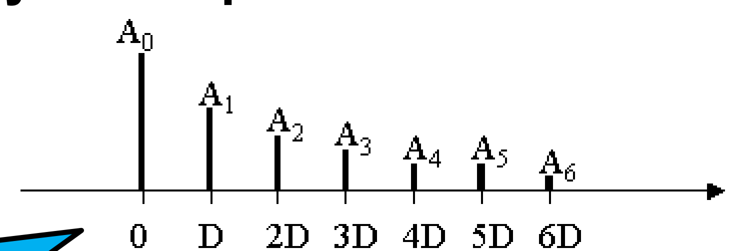


Receiving Signal

If sending signal is Impulse



then, Received signal has many delayed components.



This outputs shows
CHANEL IMPULSE RESPONSE

Convolution operation

- If you multiply two polynomial

$$x(z) = 1 + 1z^{-1} + 1z^{-2} + 1z^{-3} + 1z^{-4}$$

$$H(z) = 1 + 0.5z^{-1} + 0.2z^{-2}$$

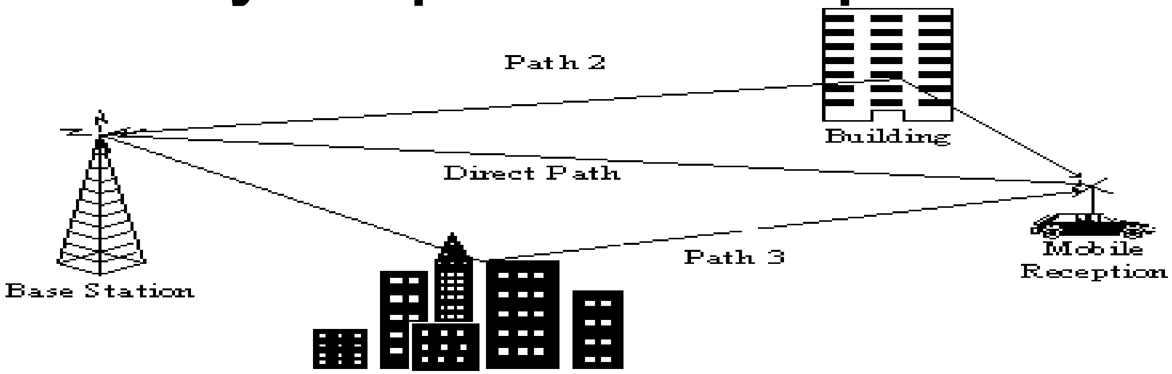
$$y(z) = H(z) \cdot x(z)$$

$$= \left(1 + 0.5z^{-1} + 0.2z^{-2}\right)\left(1 + 1z^{-1} + 1z^{-2} + 1z^{-3} + 1z^{-4}\right)$$

$$= (1 + 1.5z^{-1} + 1.7z^{-2} + 1.7z^{-3} + 1.7z^{-4} + 0.7z^{-5} + 0.2z^{-6})$$

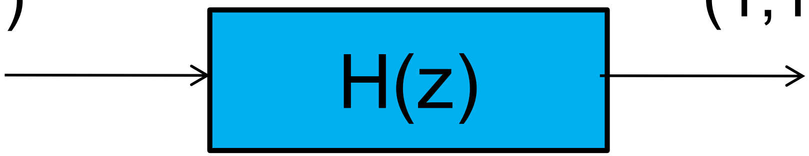
- Channel Impulse Response=(1, 0.5, 0.2)
- Send (1, 1, 1, 1, 1) signal
- Then Received Signal is (1,1.5,1.7,1.7,1.7,0.7,0.2)

Channel Modeling by Impulse Response



(1, 1, 1, 1, 1)

Sending Signal



(1,1.5,1.7,1.7,1.7,0.7,0.2)

Receiving Signal

H(z) =(1, 0.5, 0.2)

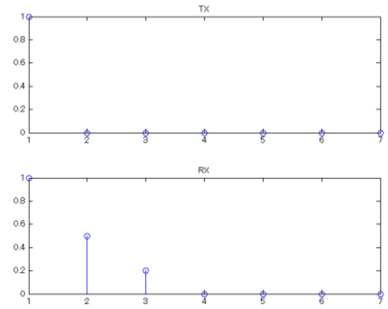
This can be calculated by CONVOLUTION.

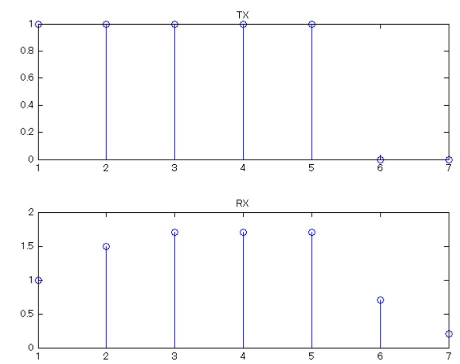
LAB8： CHANNEL

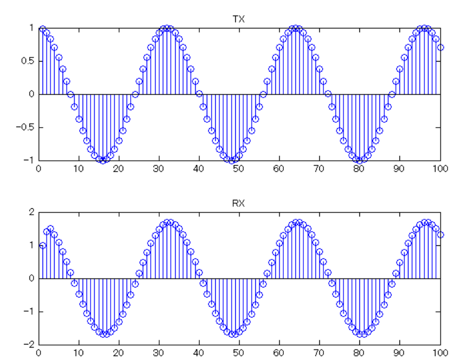
- Assume Channel Impulse Response = (1, 0.5, 0.2)
- Show each received signal for
  1. x1 = [1,0,0,0,0,0,0];
  2. x2 = [1,1,1,1,1,0,0];
  3. n = 1:100; x3 = cos(2*pi*n/32);

LAB8： CHANNEL answer

- %% CHANNEL
- h = [1, 0.5, 0.2];
- %% INPUT signal 1
- x1 = [1,0,0,0,0,0,0];
- y1 =conv(h, x1); % OUTPUT signal
- figure(81)% FIGURE
- xa=1:7;
- subplot(2,1,1); stem(xa, x1(1:7)); title('TX');
- subplot(2,1,2); stem(xa, y1(1:7)); title('RX');
- %% INPUT signal 2
- x2 = [1,1,1,1,1,0,0];
- y2 =conv(h, x2); % OUTPUT signal
- figure(82)% FIGURE
- xa=1:7;
- subplot(2,1,1); stem(xa, x2(1:7)); title('TX');
- subplot(2,1,2); stem(xa, y2(1:7)); title('RX');
- %% INPUT signal 3
- n = 1:100; x3 = cos(2*pi*n/32);
- y3 =conv(h, x3);% OUTPUT signal
- figure(83)% FIGURE
- xa=1:100;
- subplot(2,1,1); stem(xa, x3(1:100)); title('TX');
- subplot(2,1,2); stem(xa, y3(1:100)); title('RX');



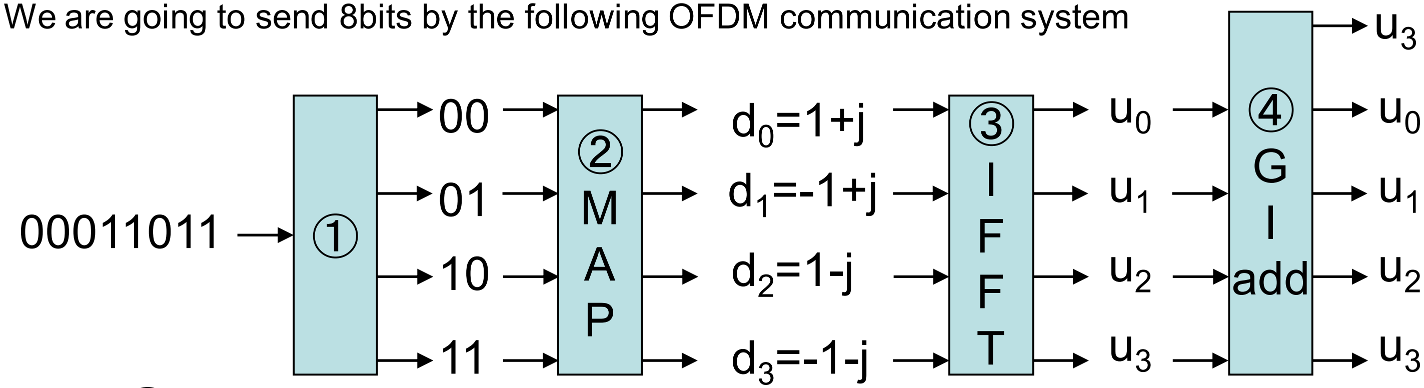


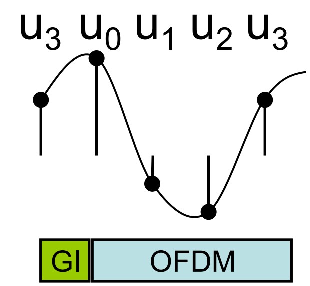


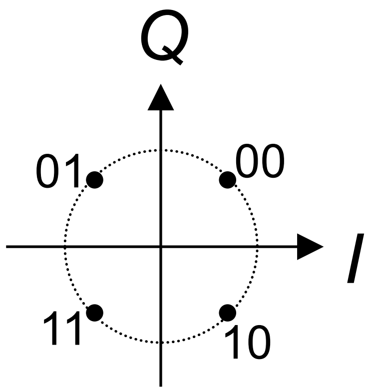
LECTURE:
OFDM MODELING

OFDM digital communication WORK SHEET

We are going to send 8bits by the following OFDM communication system







$$u_k = \frac{1}{4}\sum_{n=0}^{3} d_n \cdot \left(e^{j\frac{2\pi}{4}}\right)^{nk} = IFFT(d_n) \quad (k = 0,1,2,\cdots,3)$$

$$u_0 = \frac{1}{4}(d_0 + d_1 + d_2 + d_3)$$

$$u_1 = \frac{1}{4}(d_0 + d_1 \cdot (j) + d_2 \cdot (-1) + d_3 \cdot (-j))$$

$$u_2 = \frac{1}{4}(d_0 + d_1 \cdot (-1) + d_2 + d_3 \cdot (-1))$$

$$u_3 = \frac{1}{4}(d_0 + d_1 \cdot (-j) + d_2 \cdot (-1) + d_3 \cdot (j))$$

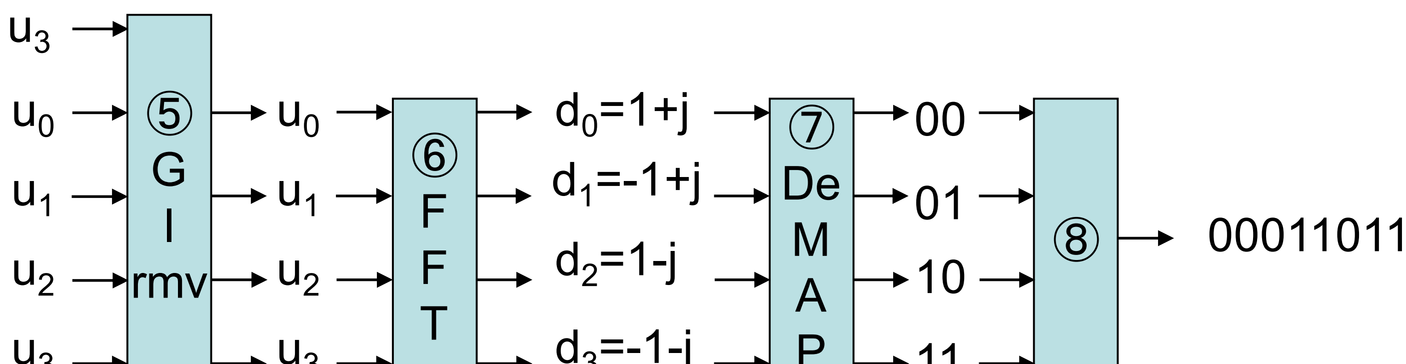
$$d_n = \sum_{k=0}^{3} u_k \cdot \left(e^{-j\frac{2\pi}{4}}\right)^{nk} = FFT(u_k) \quad (n = 0,1,2,\cdots,3)$$

$$d_0 = u_0 + u_1 + u_2 + u_3$$

$$d_1 = u_0 + u_1 \cdot (-j) + u_2 \cdot (-1) + u_3 \cdot (+j)$$

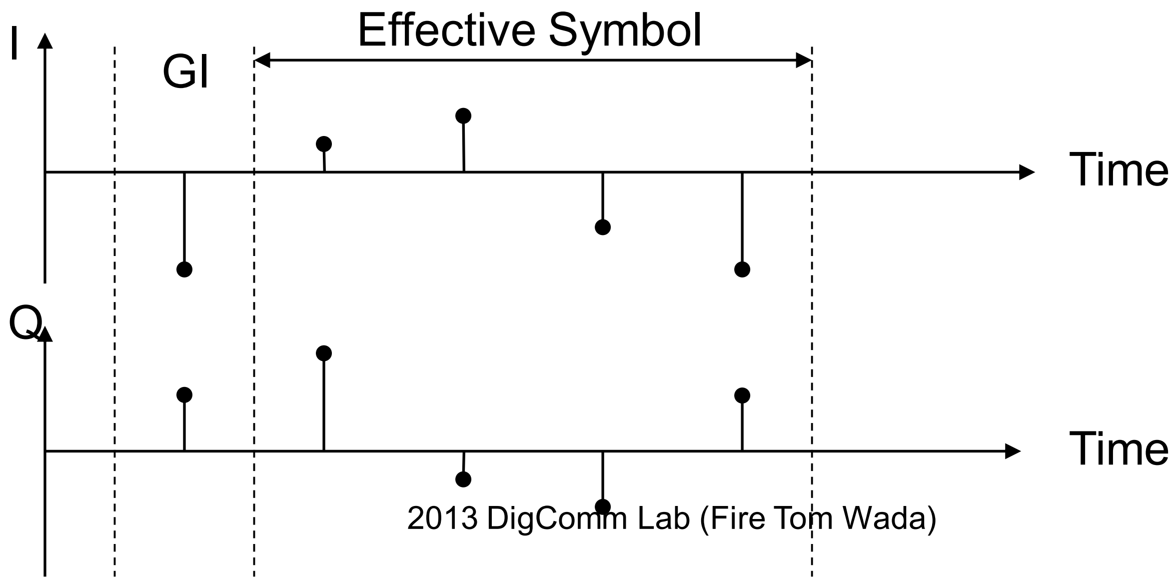
$$d_2 = u_0 + u_1 \cdot (-1) + u_2 + u_3 \cdot (-1)$$

$$d_3 = u_0 + u_1 \cdot (j) + u_2 \cdot (-1) + u_3 \cdot (-j)$$



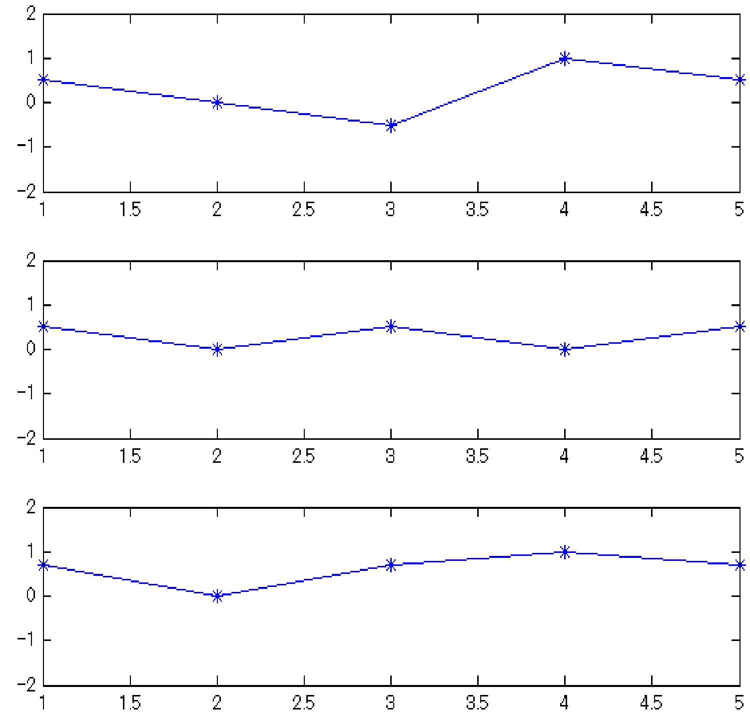
LAB9 OFDM

1. Please draw OFDM symbol complex wave form including GI when you send “00011011”.
2. Please draw OFDM symbol complex wave form including GI when you send “10010011”.
3. Please draw OFDM symbol complex wave form including GI when you send “00000000”.
4. Compare those 3 waveform. Then Did you find any problem? If yes, please state the problem.



LAB9 1) answer

- %%
- data=[0,1,2,3]; % 0->00, 1->01, 2->10, 3->11
- % MAP
- modqpsk= [1+i, -1+i, 1-i, -1-i];
- const =modqpsk(data+1);
- % IFFT
- uu = ifft(const);
- % GI ADD
- uu_g =[uu(4), uu];
- % FIGURE
- figure(81)
- subplot(3,1,1); plot(real(uu_g),'*-'); axis([1 5 -2 2]);
- subplot(3,1,2); plot(imag(uu_g),'*-'); axis([1 5 -2 2])
- subplot(3,1,3); plot(abs(uu_g),'*-'); axis([1 5 -2 2]);



LAB10 OFDM

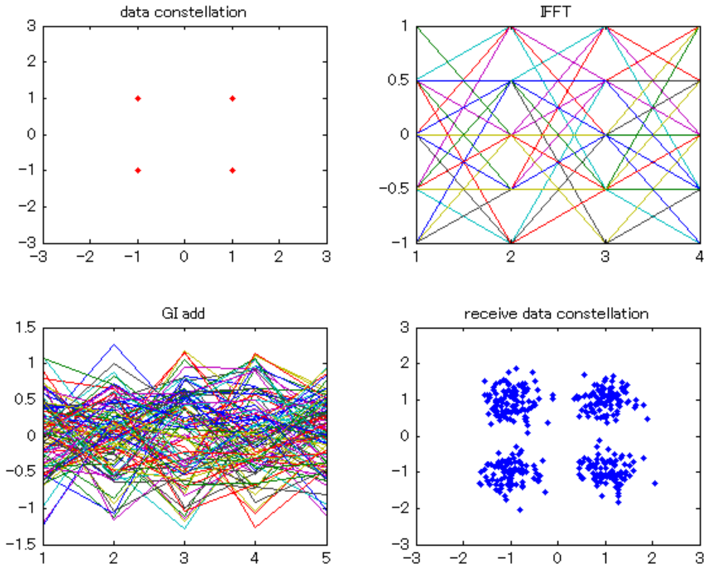
MAKE 100 symbol OFDM signal based on previous 4 point OFDM + 1 point GI.

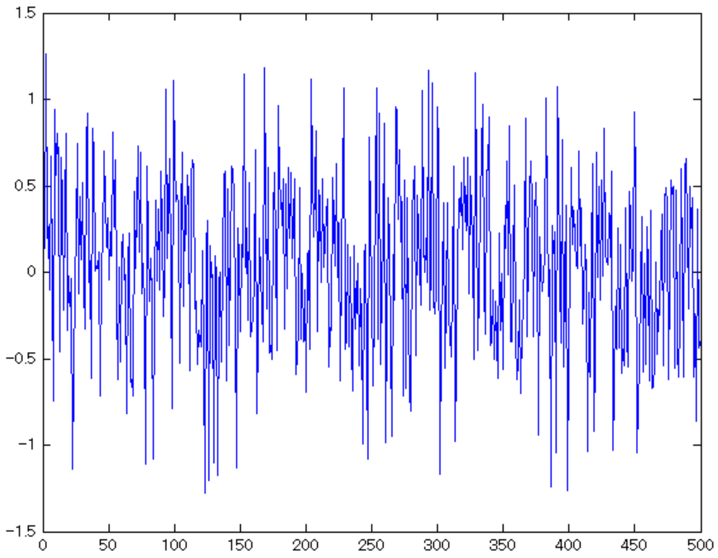
Add noise of SNR=10dB

LAB10 OFDM answer

```
% Simple OFDM system (send 8 bits/symbol * 100 symbol)
% Fire Wada
clear all;
num_symbol = 100;   % number of symbols
n_symbol = 4;       % points in symbol
M = 4;              %  size of signal constellation
modqpsk= [1+i, -1+i, 1-i, -1-i];

%% 1 . create random data
data = floor(rand(n_symbol,num_symbol)*M);

%% 2. mapping into I-Q constellation
data_1 = modqpsk(1+data);

figure(100);
subplot(2,2,1);
plot(data_1,'r.');
axis([-3 3 -3 3])
title('data constellation')

data_2 = data_1;

%% 3. IFFT
data_3 = ifft(data_2);
subplot(2,2,2);
plot((real(data_3)),'-');
title('IFFT');
%% 4. GI add
data_4 = [data_3(n_symbol,:);data_3];

%%4.1 Add Noise
sigpower=mean(mean(abs(data_4).^2));
sn= 10; %% 10dB
awgn = (randn(n_symbol+1,num_symbol)+i*randn(n_symbol+1,num_symbol));
awgnpower=mean(mean(abs(awgn).^2));
awgn = awgn/sqrt(awgnpower)*10^(-sn/20)*sqrt(sigpower);
data_4=data_4+awgn;

subplot(2,2,3);
plot(real(data_4),'-');
title('GI add');

%% 5. GI remove
data_5 = data_4(2:n_symbol+1,:);

%% 6. FFT
data_6 = fft(data_5);

subplot(2,2,4);
plot(data_6,'b.');
axis([-3 3 -3 3])
title('receive data constellation')
figure(200)
plot(real(reshape(data_4,(n_symbol+1)*num_symbol,1)));
```

LAB10 OFDM answer





LAB11 Symbol Error Rate

Measure Symbol Error Rate for LAB10.
Add noise of SNR=0dB, 5dB, 10dB.
Use 'demapQPSK.m' function.
Put the m-file in same directory.

```
% demapQPSK.m
% The program demap to Complex to Numerical data.

function graycode = demapQPSK(comp)

re = real(comp);
im = imag(comp);

if      (re >= 0 & im >= 0 ) graycode=0;
elseif  (re <  0 & im >= 0 ) graycode=1;
elseif  (re >= 0 & im <  0 ) graycode=2;
else graycode=3;
end
```

LAB11 Symbol Error Rate

```
% Simple OFDM system (send 8 bits/symbol * 100 symbol)
% Fire Wada
clear all;
num_symbol = 100;   % number of symbols
n_symbol = 4;       % points in symbol
M = 4;              %  size of signal constellation
modqpsk= [1+i, -1+i, 1-i, -1-i];

%% 1 . create random data
data = floor(rand(n_symbol,num_symbol)*M);

%% 2. mapping into I-Q constellation
data_1 = modqpsk(1+data);

data_2 = data_1;

%% 3. IFFT
data_3 = ifft(data_2);

%% 4. GI add
data_4 = [data_3(n_symbol,:);data_3];

%%4.1 Add Noise
sigpower=mean(mean(abs(data_4).^2));
sn= 5; %% 10dB
awgn = (randn(n_symbol+1,num_symbol)+i*randn(n_symbol+1,num_symbol));
awgnpower=mean(mean(abs(awgn).^2));
awgn = awgn/sqrt(awgnpower)*10^(-sn/20)*sqrt(sigpower);
data_4=data_4+awgn;
%% 5. GI remove
data_5 = data_4(2:n_symbol+1,:);

%% 6. FFT
data_6 = fft(data_5);

figure(11)
plot(data_6,'b.');
axis([-3 3 -3 3])
title('receive data constellation')

%% 7. recover data

rdata=zeros(n_symbol,num_symbol);
for sym = 1: num_symbol
   for index = 1:n_symbol
      rdata(index, sym) = demapQPSK(data_6(index,sym));
   end
end

%% 8. measure Symbol Error Rate by compare data and rdata

Total_data= n_symbol*num_symbol;
diff = rdata - data;
% count how many not zero in diff
notZero = (diff ~= 0);
Total_error=sum(sum(notZero));
fprintf('*** SNR =%4.2f,   *** SYMBOL ERROR RATE = %8.5f *** ¥n', sn, Total_error/Total_data);
```

TASK1

- Make a Matlab program to measure Symbol Error Rate vs SN ratio
  in 1K OFDM with QPSK modulation
  - FFT size = 1024 points in 1 symbol
  - GI length = 1/8*FFT size = 128 points
  - Total 100 symbol

- Write Mid Report to explain OFDM simulation including

1. Your Matlab program
2. Total 100 symbol waveform
3. Consternation with SNR=0, 3, 6, 9dB
4. Symbol Error Rate vs SNR Graph
   - Vertical: SER in log scale
   - Horizontal: SN ratio 0dB, 1dB … to 10dB