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
4. LAB6 to LAB9
5. SINGLE CARRIER figure 3.4/3.5
6. OFDM figure 4.2/4.3
7. REPORT TASK

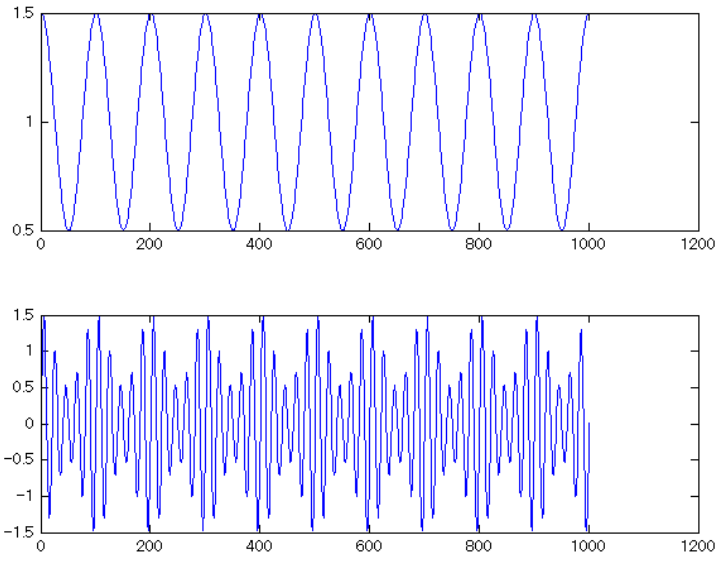
LAB1： AM

- 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);

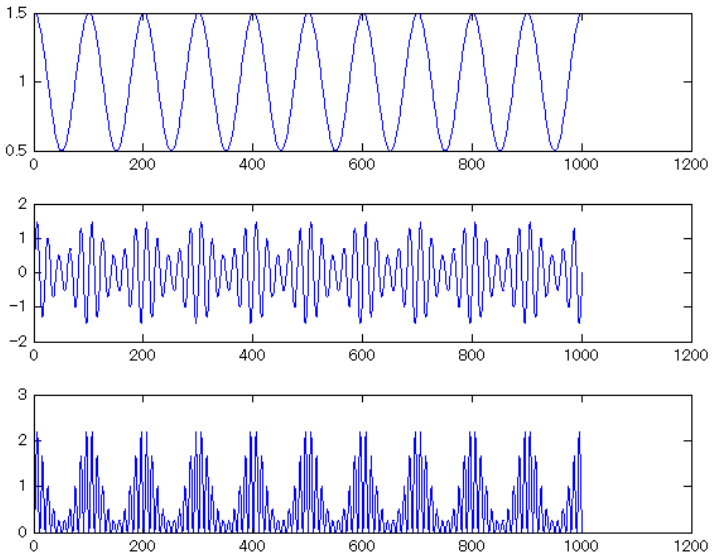


LAB2: AM Demodulation

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

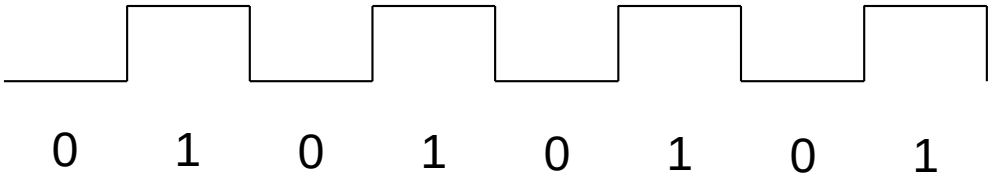
LAB2： AM Demod answer

- 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

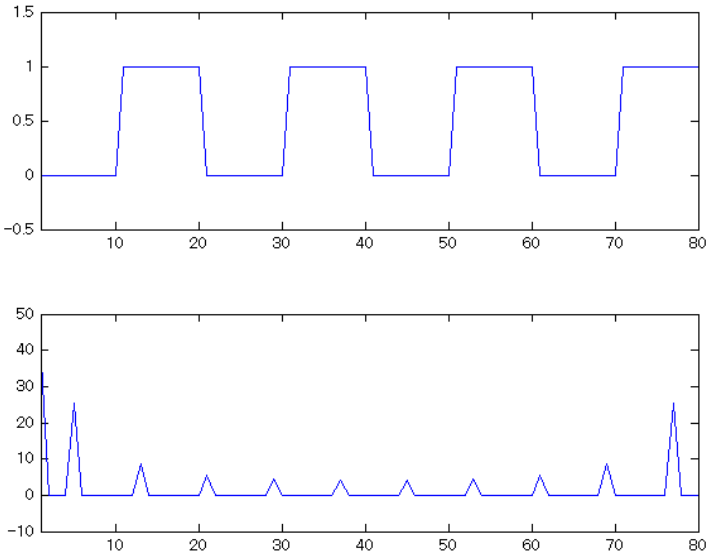
- Analyze below pulse spectrum by Discrete Fourier Transform.



LAB3： Spectrum answer

- 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]);

Assume T = 10 points



LAB4： BPSK waveform

- Make BPSK waveform as follows

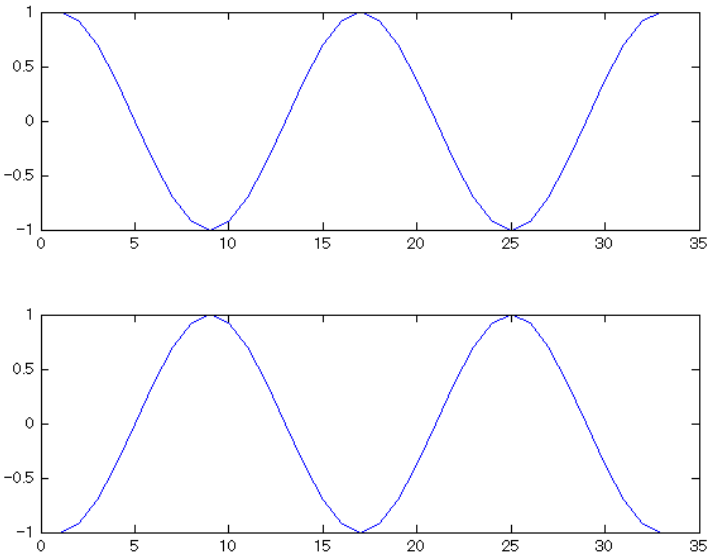
$$x = A\cos(2\pi ft + \phi)$$

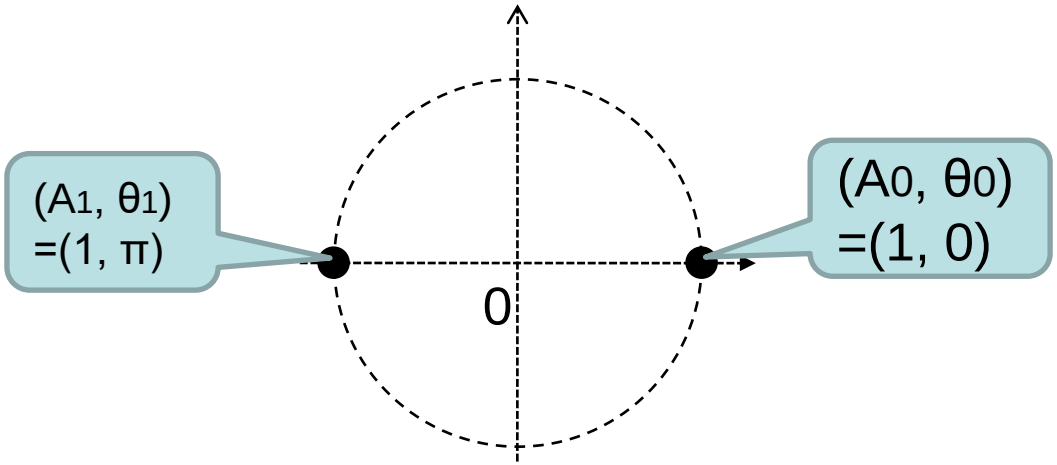
When data=0 $x = A\cos(2\pi ft)$

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);

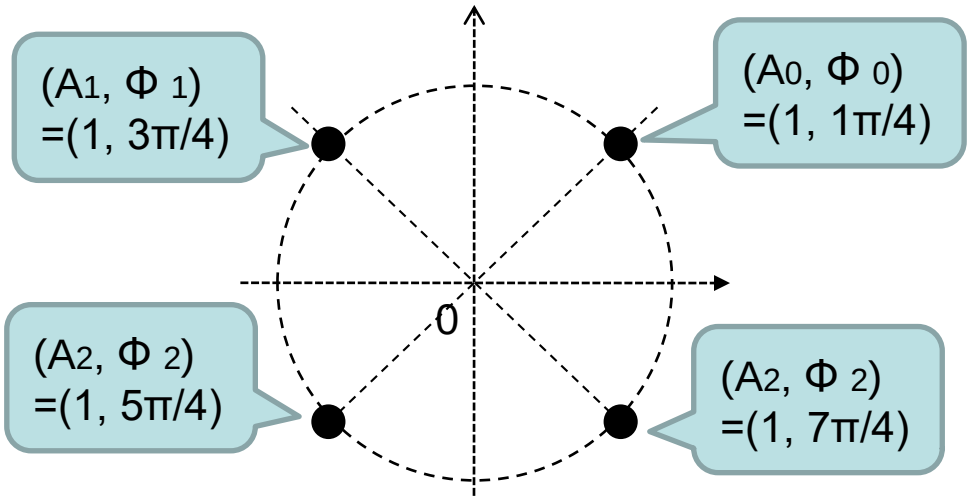




LAB5： QPSK waveform

- Make QPSK waveform as follows

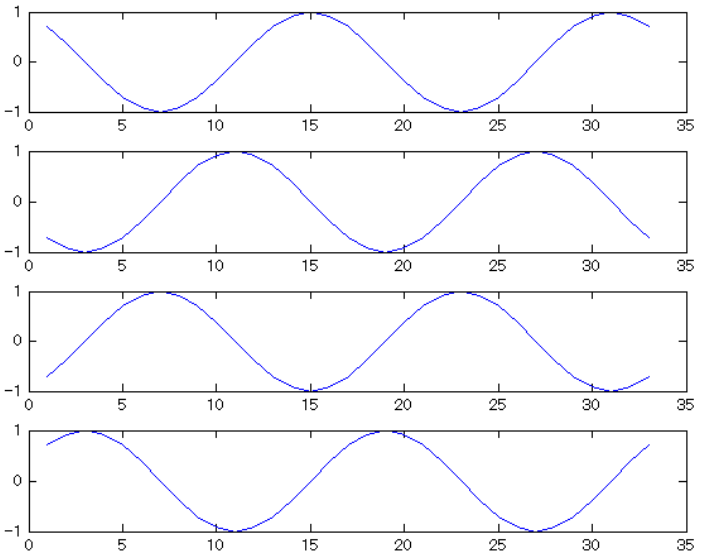
$$x = A\cos(2\pi ft + \phi)$$



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

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.

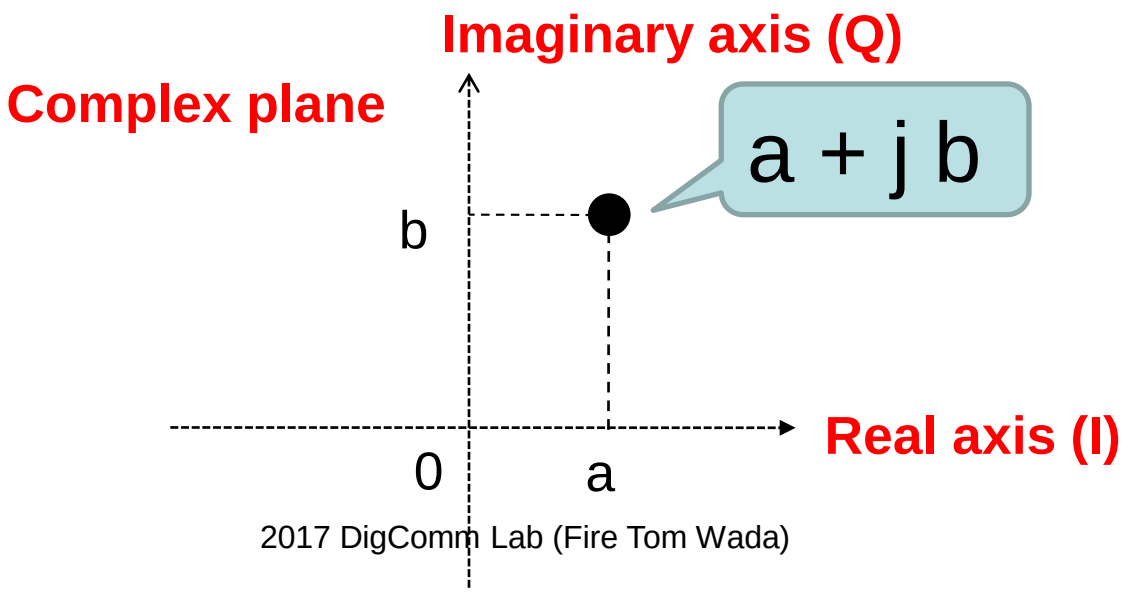
$$\tilde{x}(t) = Ae^{j(2\pi ft+\phi)}$$

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

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

2. Real – Imaginary plane

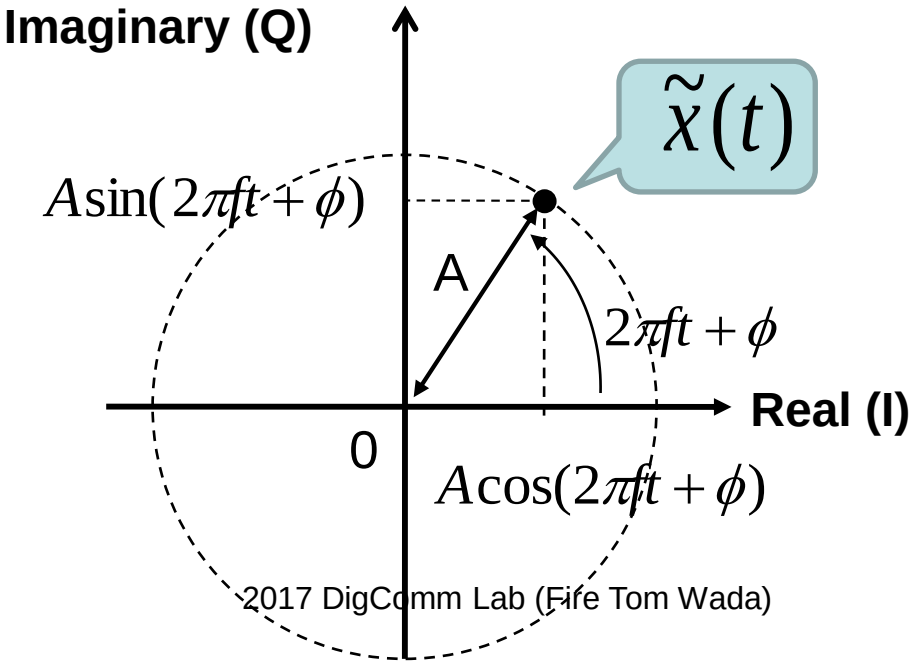
- IQ plane
  - I: In-Phase = Real axis
  - Q: Quadrature-Phase = Imaginary axis
- Real-Imaginary plane (Complex plane)
  - Complex number can be indicated as a point



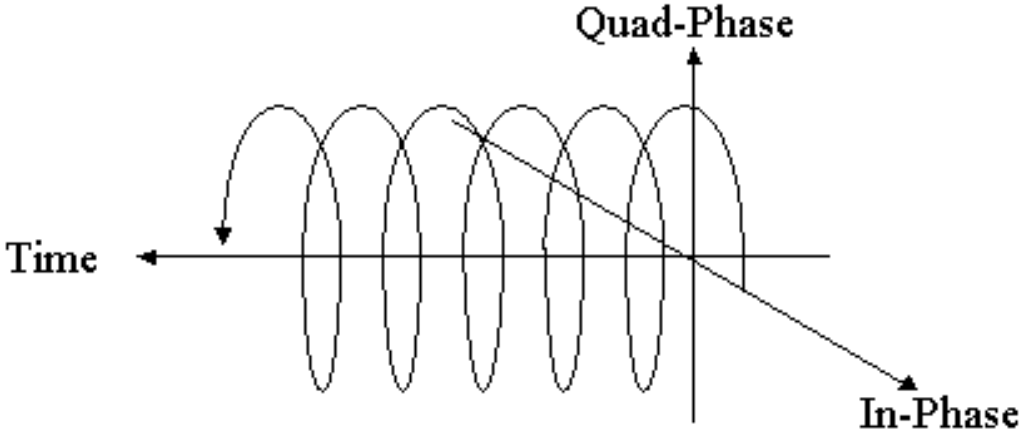
Complex Exponential Function Shows Rotation in I-Q plane

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

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



Complex Exponential Function shows Rotation on TIME!



Complex Amplitude (Phaser)

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

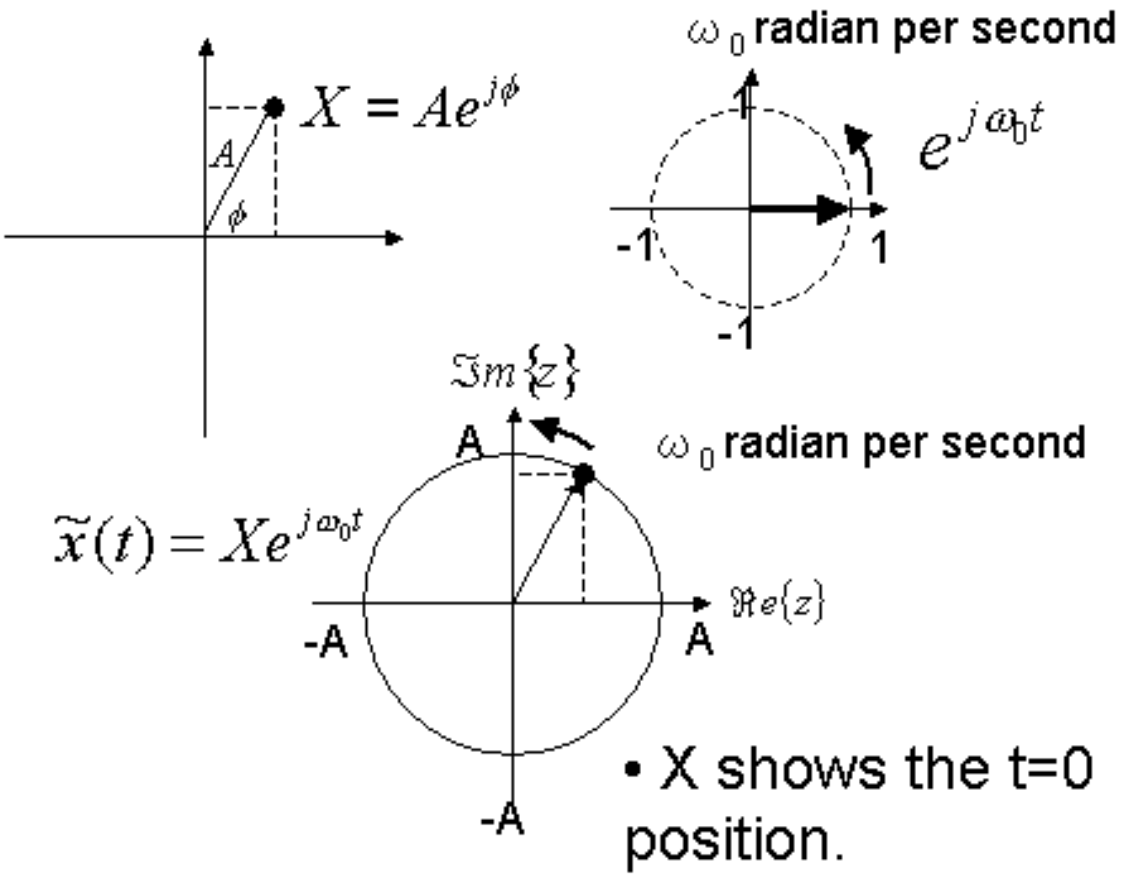
$$= Ae^{j\phi} \cdot e^{j2\pi ft}$$

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.

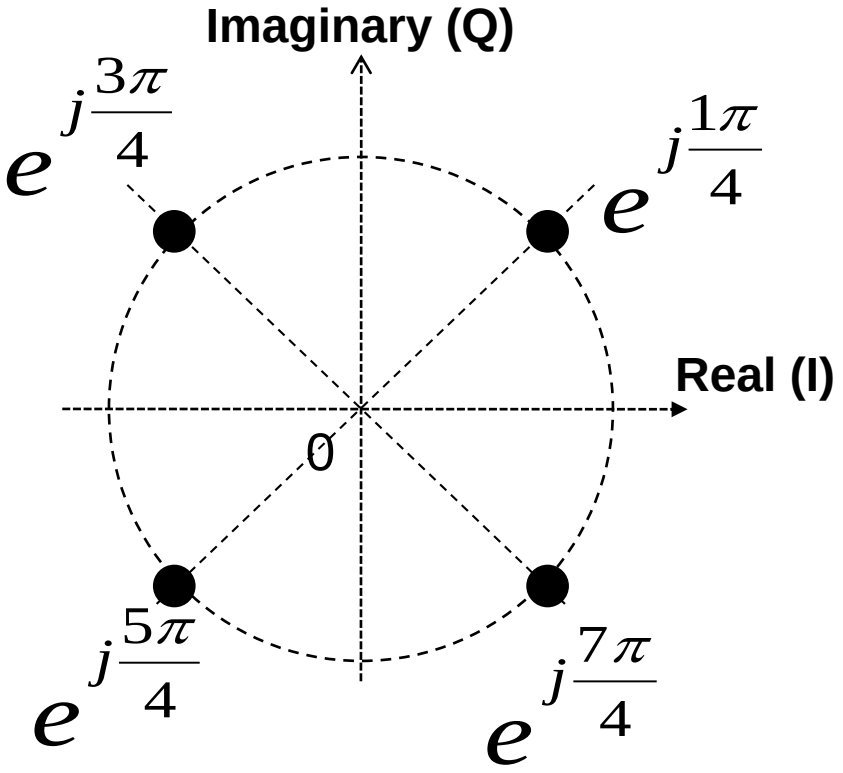
QPSK
by Complex Exponential Function

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

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

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

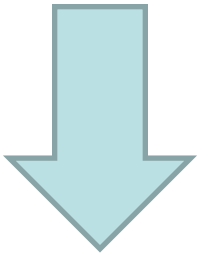
$$\tilde{x}_3(t) = e^{j(2\pi ft+\frac{7\pi}{4})} = e^{j\frac{7\pi}{4}} \cdot e^{j2\pi ft}$$



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!

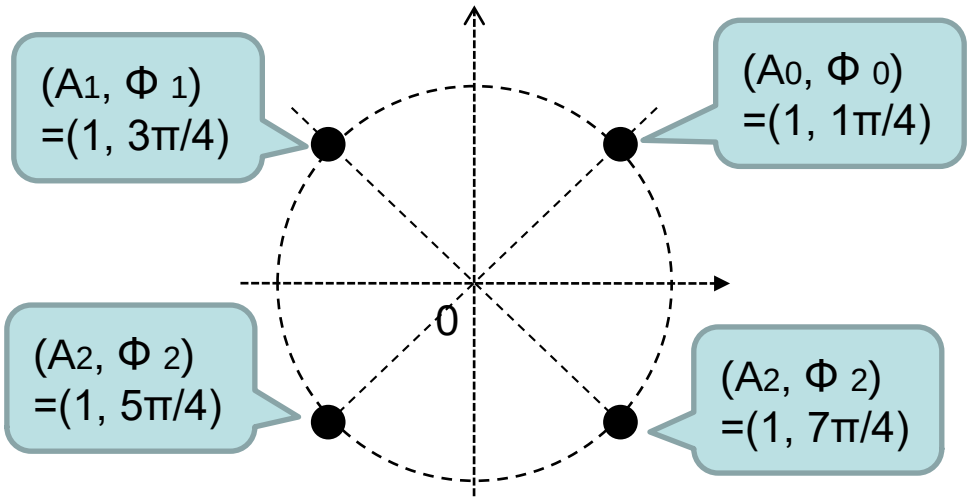
$$\tilde{x}(t) = Ae^{j(2\pi ft+\phi)}$$

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

LAB6： QPSK waveform

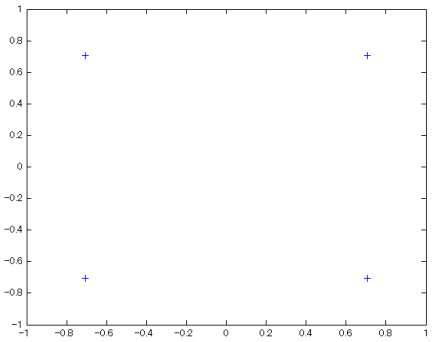
- Make QPSK waveform as follows using

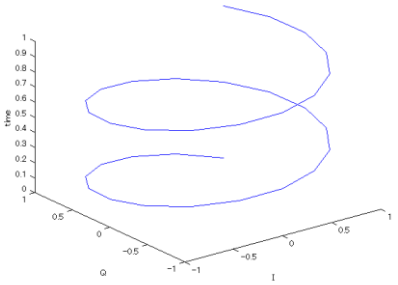
$$\tilde{x}(t) = Ae^{j(2\pi ft+\phi)}$$
$$= A\cos(2\pi ft + \phi) + j \cdot A\sin(2\pi ft + \phi)$$

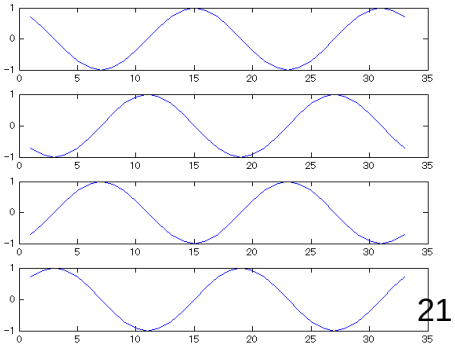


LAB6： QPSK (2) answer

- 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));

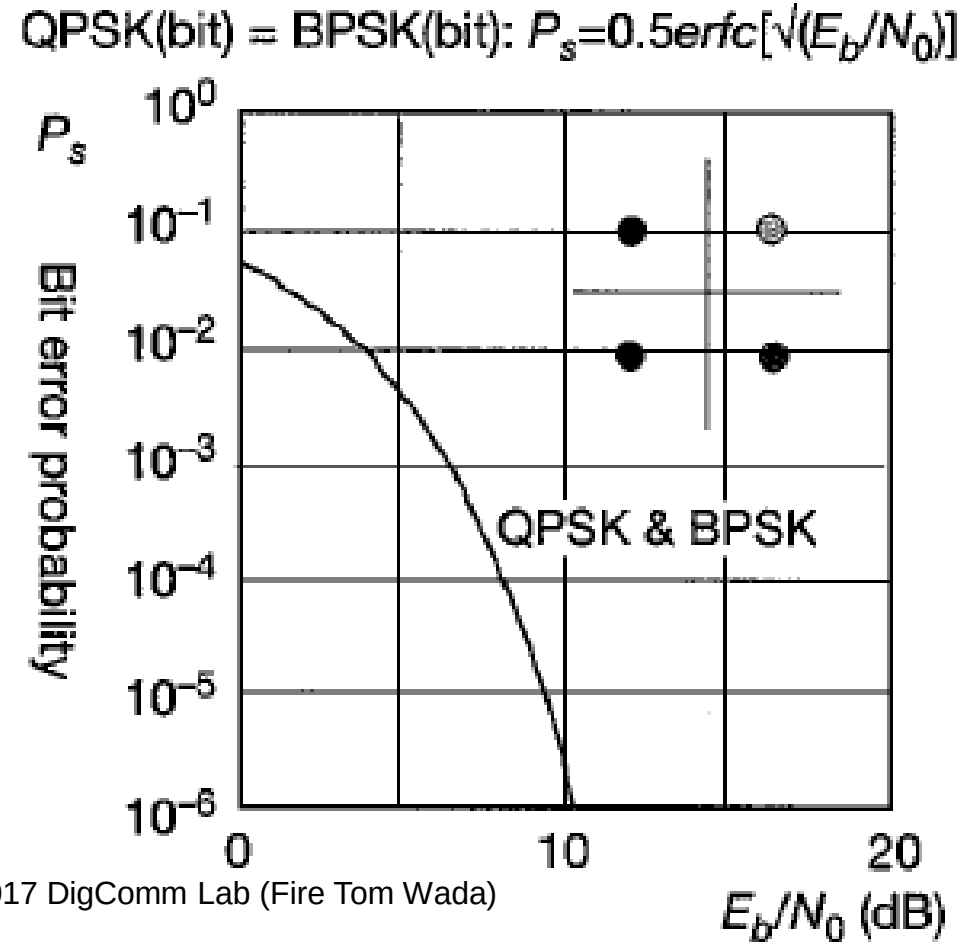






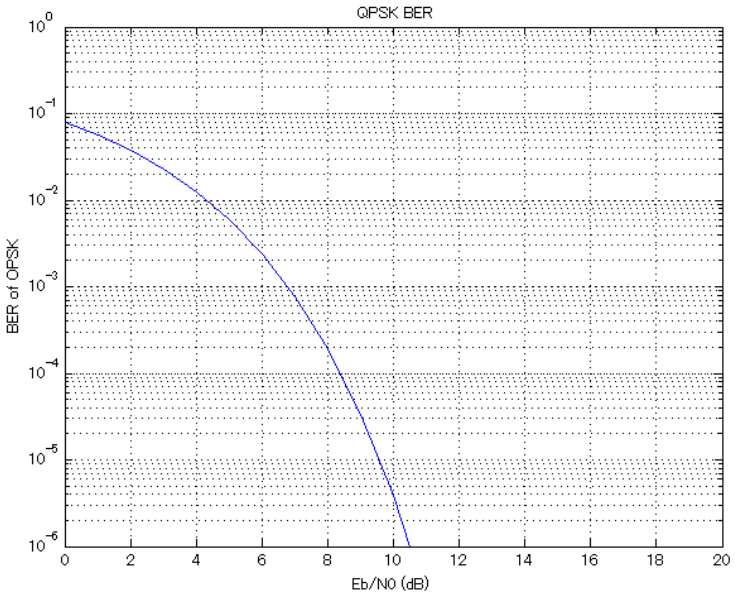
LAB7： Draw BER graph

- 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');



LAB8 OFDM

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

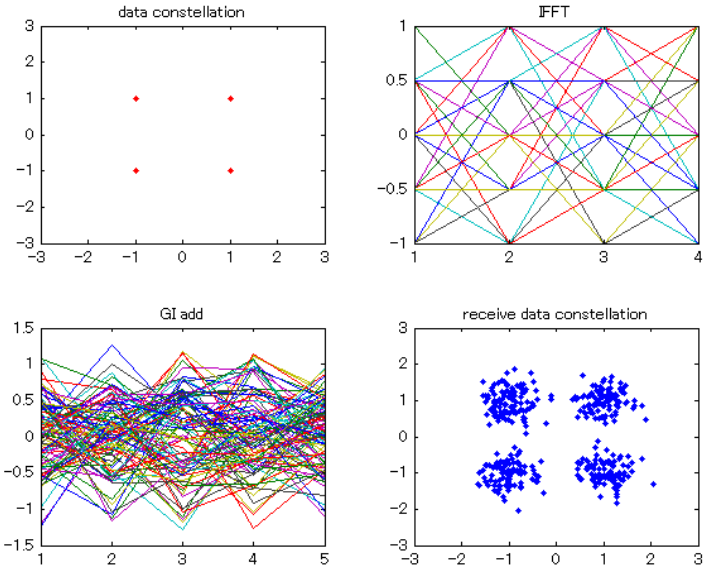
Add noise of SNR=10dB

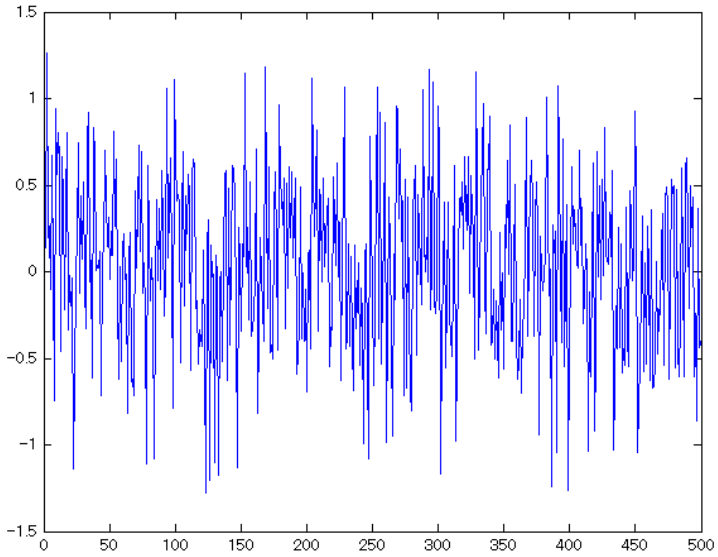
LAB8 OFDM answer

```
% 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)));
```

LAB8 OFDM answer





LAB9 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
```

LAB9 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);
```

Single Carrier Fig 3.4

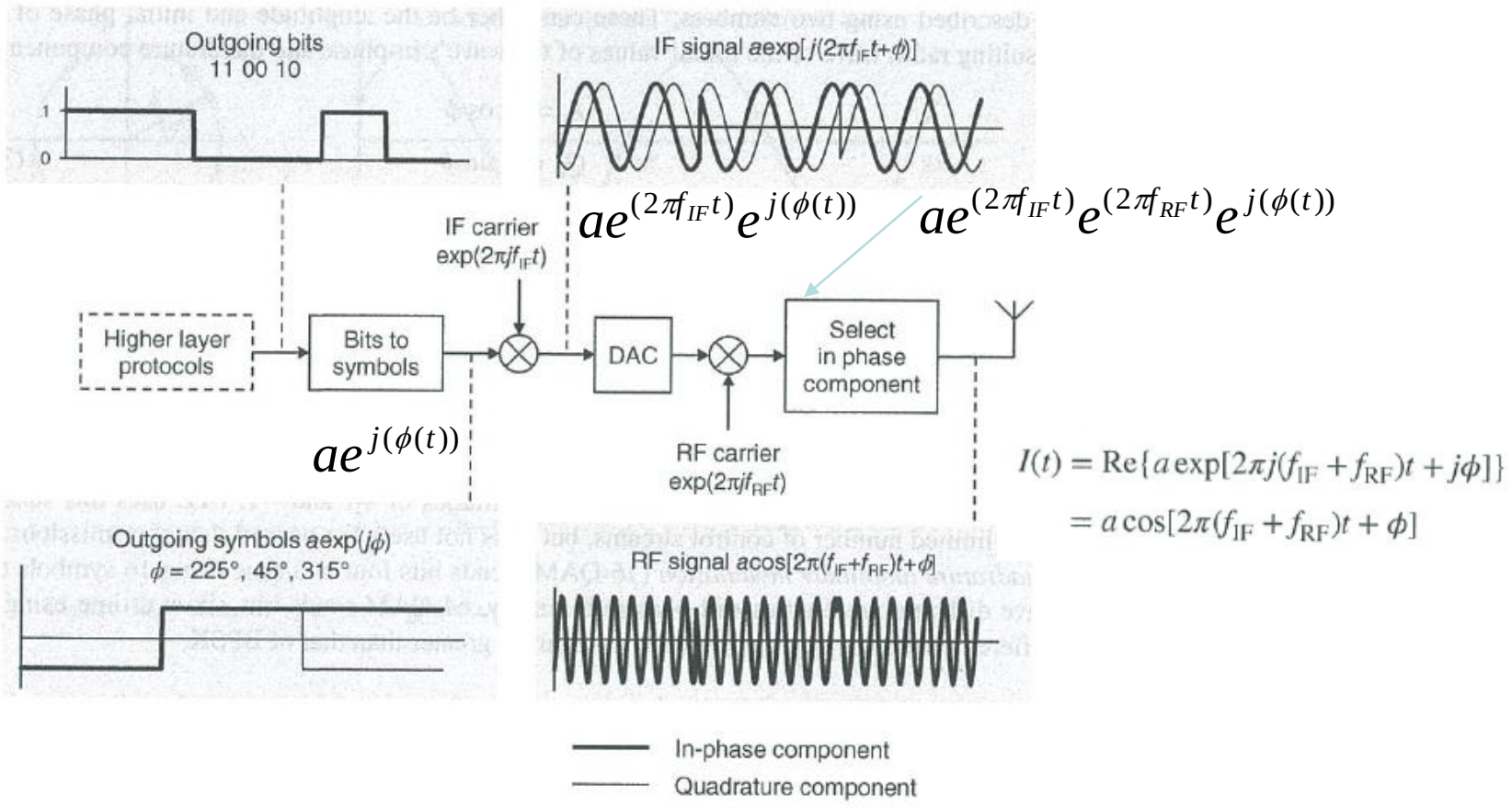


Figure 3.4 Block diagram of the modulator in a wireless communication system

Single Carrier Fig 3.5

$$a \cdot \cos(2\pi(f_{IF} + f_{RF})t + \phi + \psi) + noise$$

$$I(t) = a\cos[2\pi(f_{IF} + f_{RF})t + \phi + \psi]$$
$$= \frac{a\exp\{j[2\pi(f_{IF} + f_{RF})t + \phi + \psi]\} + a\exp\{-j[2\pi(f_{IF} + f_{RF})t + \phi + \psi]\}}{2} \quad (3.8)$$

$$\frac{1}{2} ae^{(2\pi f_{IF} t + \phi + \psi)} + noise'$$

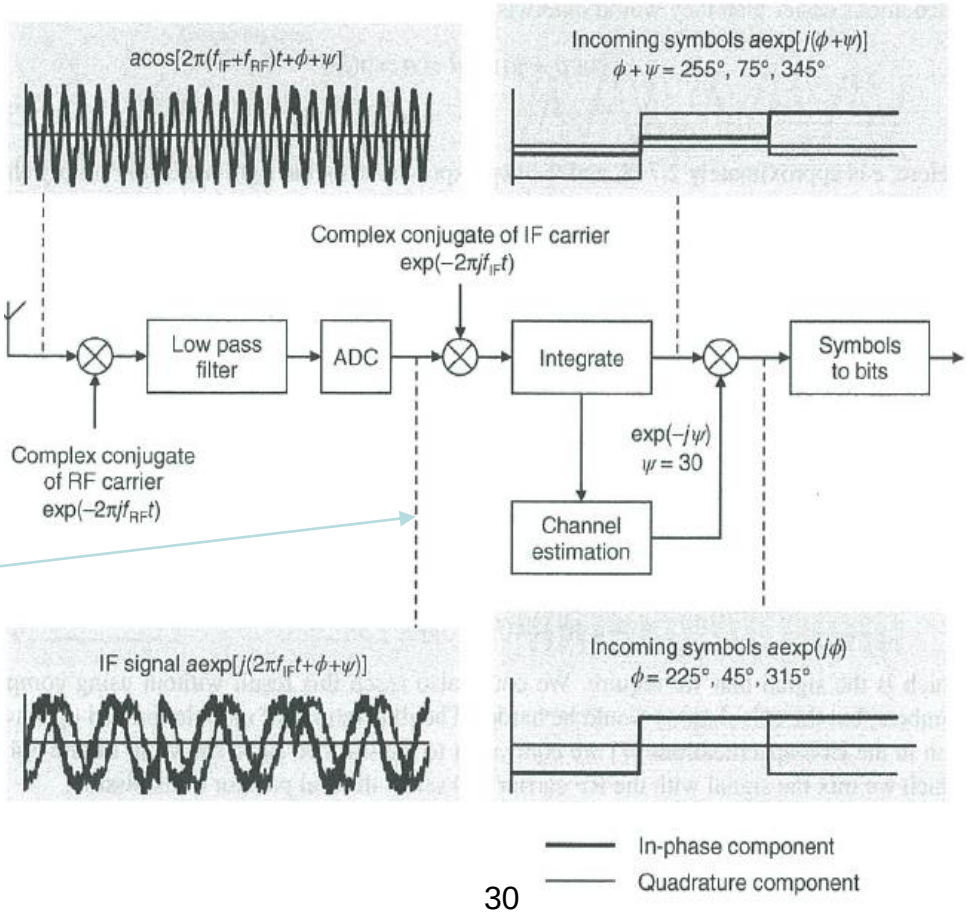


Figure 3.5 Block diagram of the demodulator in a wireless communication system

OFDM Transmitter Fig 4.2

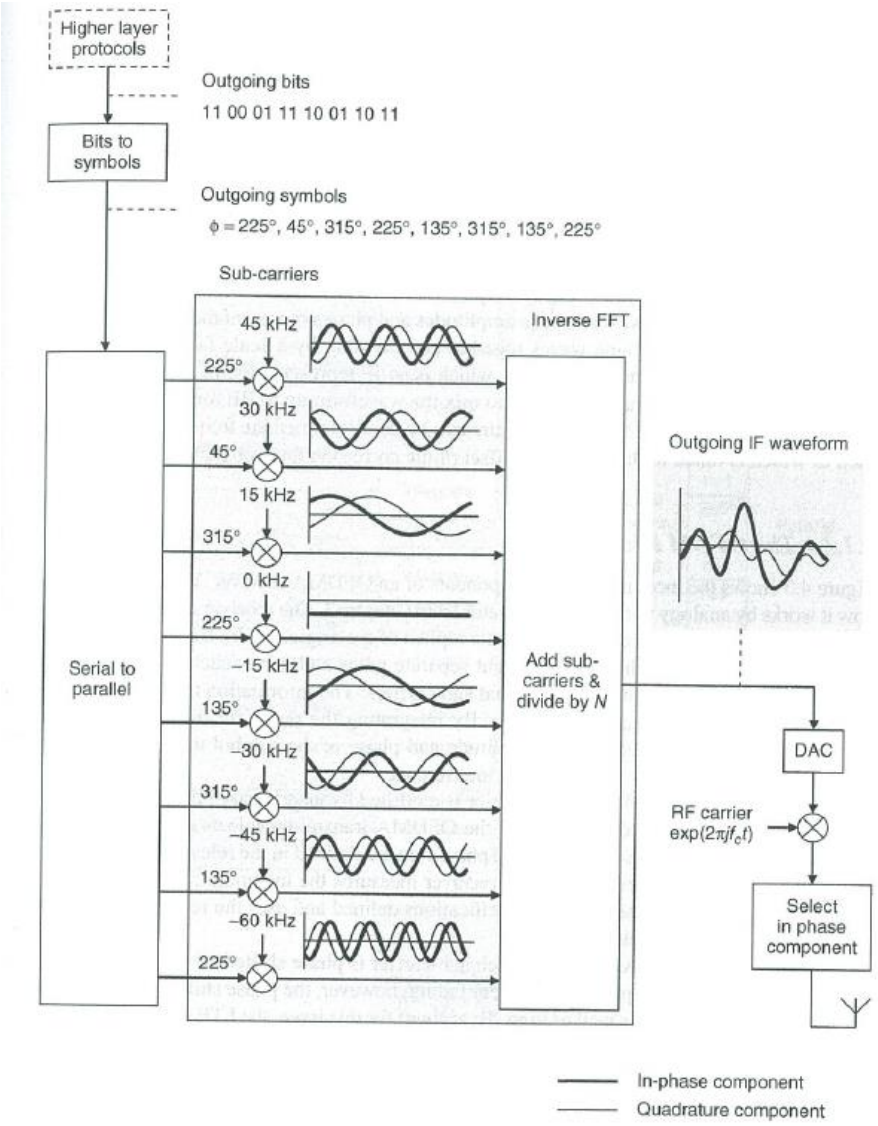


Figure 4.2 Processing steps in an OFDM transmitter

OFDM Receiver Fig 4.3

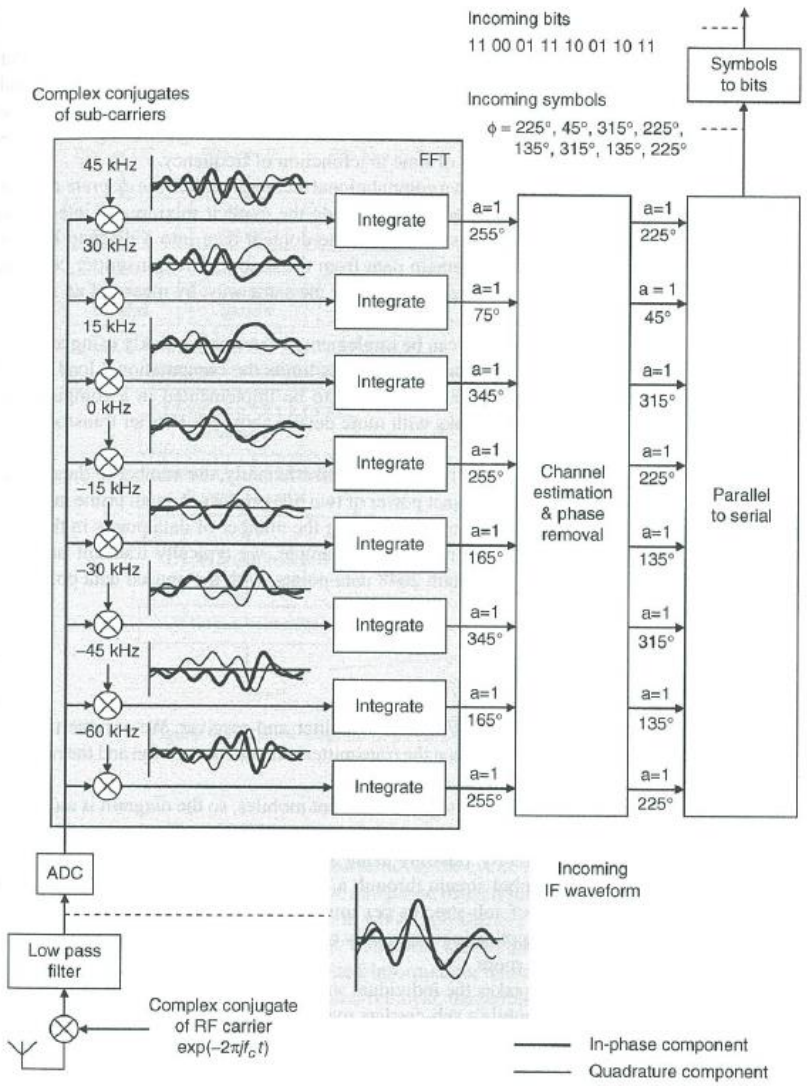


Figure 4.3 Processing steps in an OFDM receiver

Final Report Task

- To be announced