Digital Modulation (ASK, FSK, BPSK and QAM)

Lab Exercises on July 21, 2021

Department of Electronics and Computer Engineering

Pulchowk Campus, Lalitpur

Ashlesh Pandey

PUL074BEX007

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1 Objectives

- Perform and visualize amplitude shift keying, frequency shift keying, binary phase shift keying, quadrature amplitude modulation.

2 Background Theory

2.1 Amplitude Shift Keying (ASK)

ASK system is a digital modulation method where the bit '1' is represented by transmitting a sinusoidal carrier wave with fixed amplitude and frequency as A_c and f_c respectively for a bit duration of T_b seconds, and the bit '0' is represented by turning off the carrier signal for T_b seconds, which is why this method is also called *On-Off Keying*. For a sinusoidal carrier wave $s_c(t) = A_c \cos(2\pi f_c t)$, the ASK signal is represented as,

$$s(t) = \begin{cases} A_c \cos(2\pi f_c t) & : \text{for bit } 1 \\ 0 & : \text{for bit } 0 \end{cases} \tag{1}$$

A generalized form of Equation 1 for $x(t) = 1$ or 0 is,

$$s(t) = x(t) A_c \cos(2\pi f_c t) \quad [0 \leq t \leq T_b] \tag{2}$$

We have, the signal power is given as, $P = \frac{A_c^2}{2}$. For energy contained in a bit duration $E_b = PT_b$, Equation 2 can be rewritten for bit '1' in the signal space diagram of ASK as,

$$\begin{aligned} s(t) &= \sqrt{2P} \cos(2\pi f_c t) \\ s(t) &= \sqrt{PT_b} \sqrt{\frac{2}{T_b}} \cos(2\pi f_c t) \\ s(t) &= \sqrt{E_b} \sqrt{\frac{2}{T_b}} \cos(2\pi f_c t) \\ s(t) &= \sqrt{E_b} \Phi_1(t) \end{aligned} \tag{3}$$

Equation 3 shows that there is only one carrier function and the signal space diagram has two points on x-axis that are $\sqrt{E_b}$ apart.

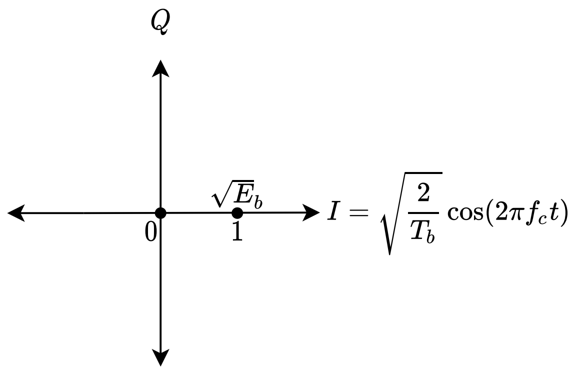

Figure 1: Constellation diagram of ASK signal

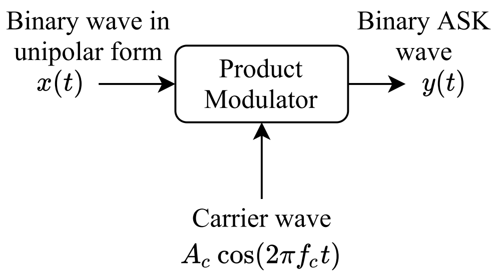

Figure 2: Block diagram for generation of ASK signal

2.2 Frequency Shift Keying (FSK)

FSK system is a digital modulation method where two sinusoidal carrier waves of the same amplitude A_c but different frequencies f_{c1} and f_{c2} are used to represent bits '1' and '0' respectively. For a sinusoidal carrier waves $s_{c1}(t) = A_c \cos(2\pi f_{c1} t)$ and $s_{c2}(t) = A_c \cos(2\pi f_{c2} t)$, the FSK signal is represented as,

$$s(t) = \begin{cases} A_c \cos(2\pi f_{c1} t) & : \text{for bit } 1 \\ A_c \cos(2\pi f_{c2} t) & : \text{for bit } 0 \end{cases} \tag{4}$$

A generalized form of Equation 4 is,

$$s_i(t) = \begin{cases} \sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_{ci} t) & [0 \le t \le T_b] \\ 0 & \text{elsewhere} \end{cases} \tag{5}$$

For FSK system the signal space diagram has two message points and is two dimensional.

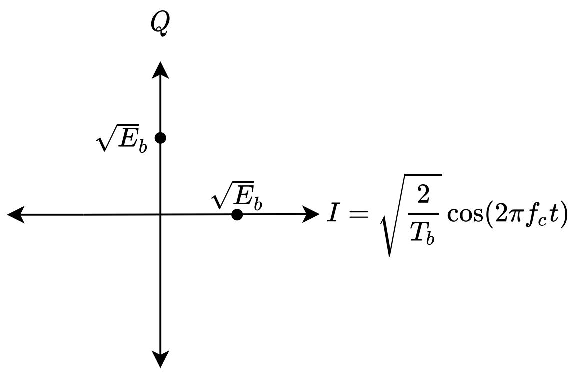

Figure 3: Constellation diagram of FSK signal

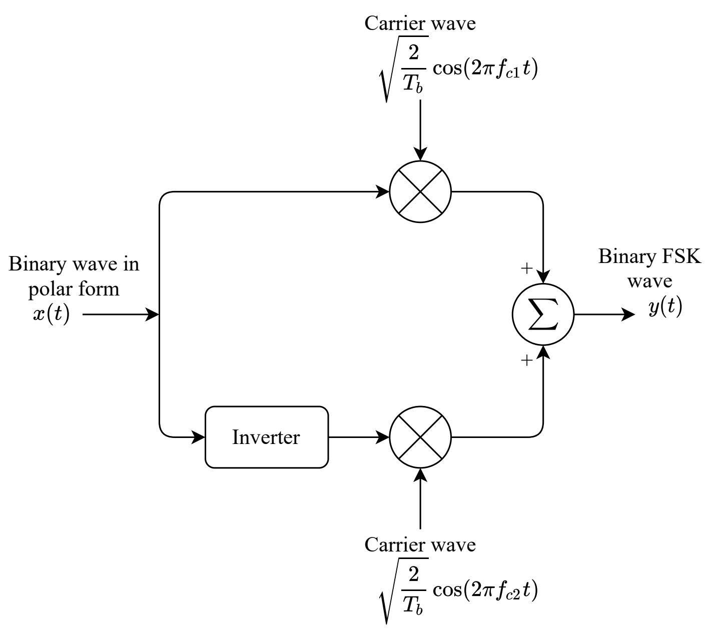

Figure 4: Block diagram for generation of FSK signal

2.3 Binary Phase Shift Keying (BPSK)

BPSK system is a digital modulation method where both the bits '1' and '0' are represented by transmitting a sinusoidal carrier wave with fixed amplitude and frequency as A_c and f_c, except the carrier phase of each bit differs bt π. For a sinusoidal carrier wave $s_c(t) = A_c \cos(2\pi f_c t)$, the BPSK signal is represented as,

$$s(t) = \begin{cases} A_c \cos(2\pi f_c t) & : \text{for bit } 1 \\ A_c \cos(2\pi f_c t + \pi) & : \text{for bit } 0 \end{cases} \tag{6}$$

A generalized form of Equation 6 for

$$b(t) = \begin{cases} +1 & \text{when binary '1' is to be transmitted} \\ -1 & \text{when binary '0' is to be transmitted} \end{cases}$$

is given as,

$$s(t) = b(t) A_c \cos(2\pi f_c t) \quad [0 \le t \le T_b] \tag{7}$$

We have, the signal power is given as, $P = \frac{A_c^2}{2}$. For energy contained in a bit duration $E_b = PT_b$, Equation 7 can be rewritten as,

$$\begin{aligned} s(t) &= \pm\sqrt{2P} \cos(2\pi f_c t) \\ s(t) &= \pm\sqrt{PT_b}\sqrt{\frac{2}{T_b}} \cos(2\pi f_c t) \\ s(t) &= \pm\sqrt{E_b}\sqrt{\frac{2}{T_b}} \cos(2\pi f_c t) \\ s(t) &= \left\{[\sqrt{E_b}\Phi_1(t)], [-\sqrt{E_b}\Phi_1(t)]\right\} \end{aligned} \tag{8}$$

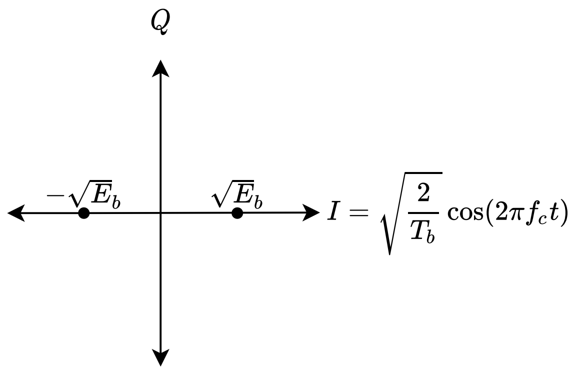

Figure 5: Constellation diagram of BPSK signal

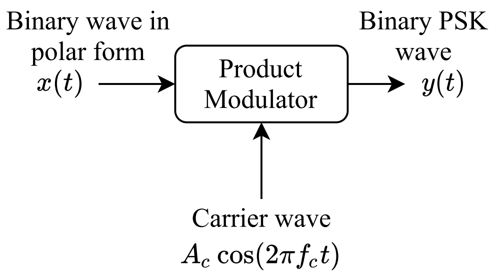

Figure 6: Block diagram for generation of BPSK signal

2.4 Quadrature Amplitude Modulation (QAM)

QAM system is a digital modulation method where variation in phase (similar to M-ary PSK) as well as amplitude is used to carry information of the message signal.

$$s(t) = \begin{cases} \sqrt{\frac{2E_b}{T_b}} a_i \cos(2\pi f_c t) + \sqrt{\frac{2E_b}{T_b}} b_i \sin(2\pi f_c t) & [0 \leq t \leq T_b] \\ 0 & \text{elsewhere} \end{cases} \tag{9}$$

where, E_b is the energy of the lowest amplitude signal, a_i and b_i are pair of independent integers that are chosen based on the position of message points. The coordinates of the i^{th} message point are $a_i\sqrt{E_b}$ and $b_i\sqrt{E_b}$ where (a_i, b_i) is an element of the $L \times L$ matrix, where

$L = \sqrt{M}$, and M is the number of symbols used.

$$(a_i, b_i) = \begin{bmatrix} (-L+1, L-1) & (-L+3, L-1) & \dots & (L-1, L-1) \\ (-L+1, L-3) & (-L+3, L-3) & \dots & (L-1, L-3) \\ \vdots & \vdots & \vdots & \vdots \\ (-L+1, -L+1) & (-L+3, -L+1) & \dots & (L-1, -L+1) \end{bmatrix} \tag{10}$$

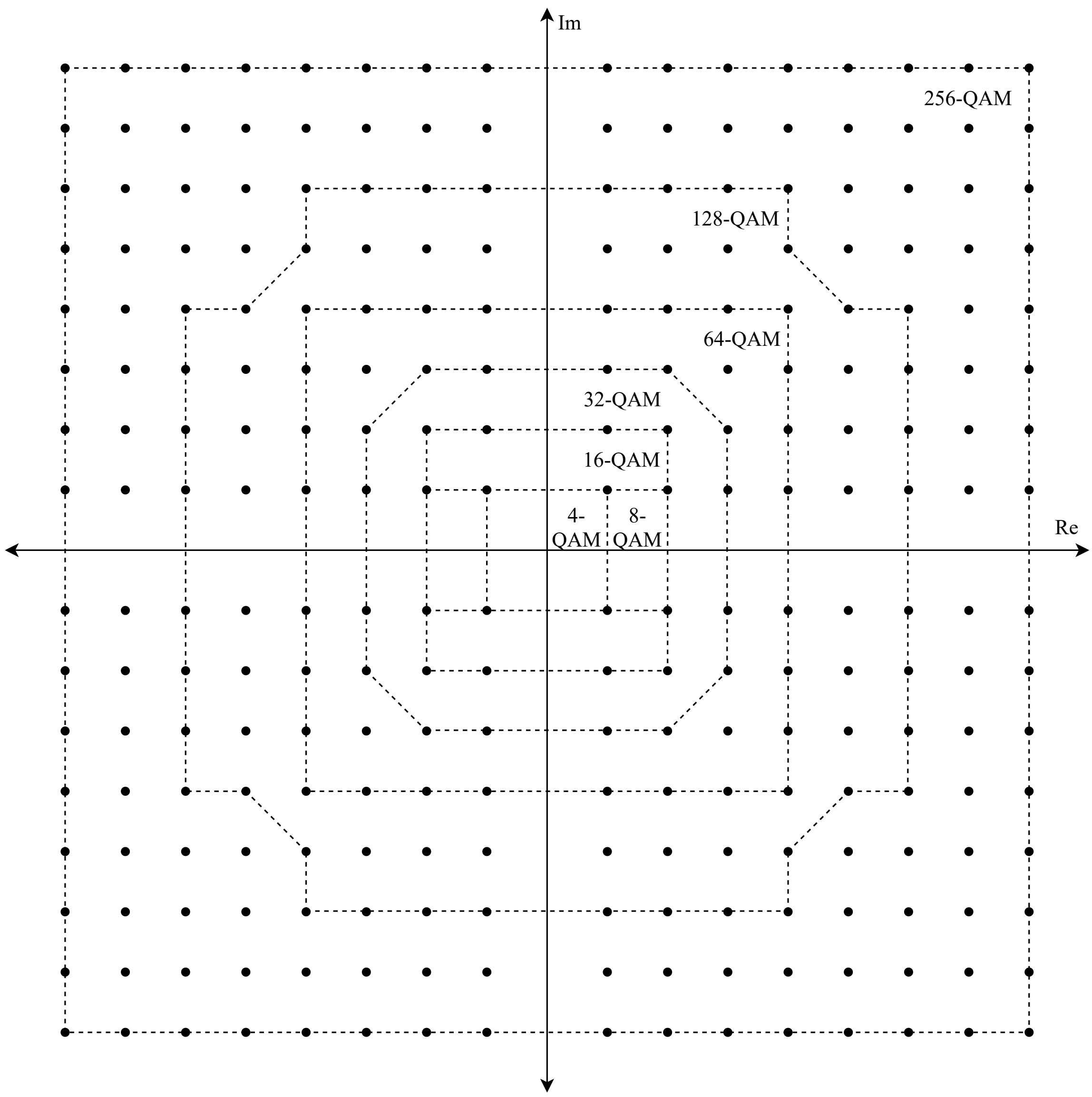

Figure 7: Constellation diagram of M-ary QAM signal

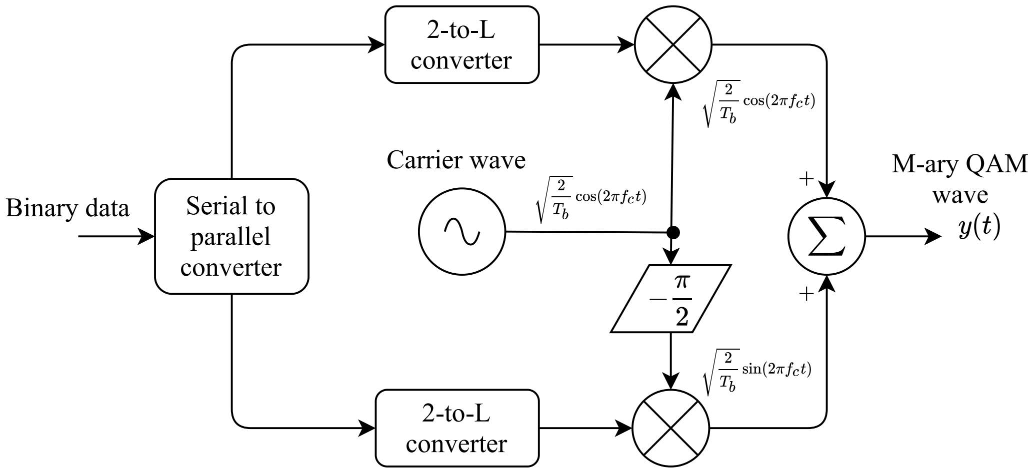

Figure 8: Block diagram for generation of M-ary QAM signal

3 Exercises

```
n=8;
x=randi([0,1],1,n)
Tb=.000001;
N = length(x);
nb = 100;
bit = [];
for n = 1:N
    if x(n) == 1
        sig = ones(1,nb);
    else
        sig = zeros(1,nb);
    end
    bit = [bit sig];
end
disp('Generated bit pattern');
disp(x);
```

Listing 1: Matlab script for generating bit sequence

Problem 1

Perform and visualize ASK modulation.

```
%Generate digital input signal
bitgenerator;
t1 = Tb/nb:Tb/nb:nb*N*(Tb/nb);
%Layout setup
l= tiledlayout(2, 1);
title(l, 'Amplitude Shift Keying (
    PUL074BEX007)')
%Display digital input signal
nexttile;
plot(t1,bit,'lineWidth',2.5);
grid on;
axis([0 Tb*N -0.5 1.5]);
xlabel('Time(Sec)');
ylabel({'Amplitude','(Volts)'});
```

```matlab
title('Digital Input Signal');
%ASK modulation
Ac1 = 12;
Ac2 = 0;
br = 1/Tb;
fc = br*10;
t2 = Tb/nb:Tb/nb:Tb;
mod = [];
for i = 1:1:N
    if x(i) == 1
        y = Ac1*cos(2*pi*fc*t2);
    else
        y = Ac2*cos(2*pi*fc*t2);
    end
    mod = [mod y];
end
t3 = Tb/nb:Tb/nb:Tb*N;
%Display ASK modulated signal
nexttile;
plot(t3,mod);
xlabel('Time(Sec)');
ylabel({'Amplitude','(Volts)'});
title('ASK modulated signal coresponding to binary information at the transmitter');
print('-depsc', 'ask-obs');
```

Listing 2: Matlab script for amplitude shift keying digital modulation

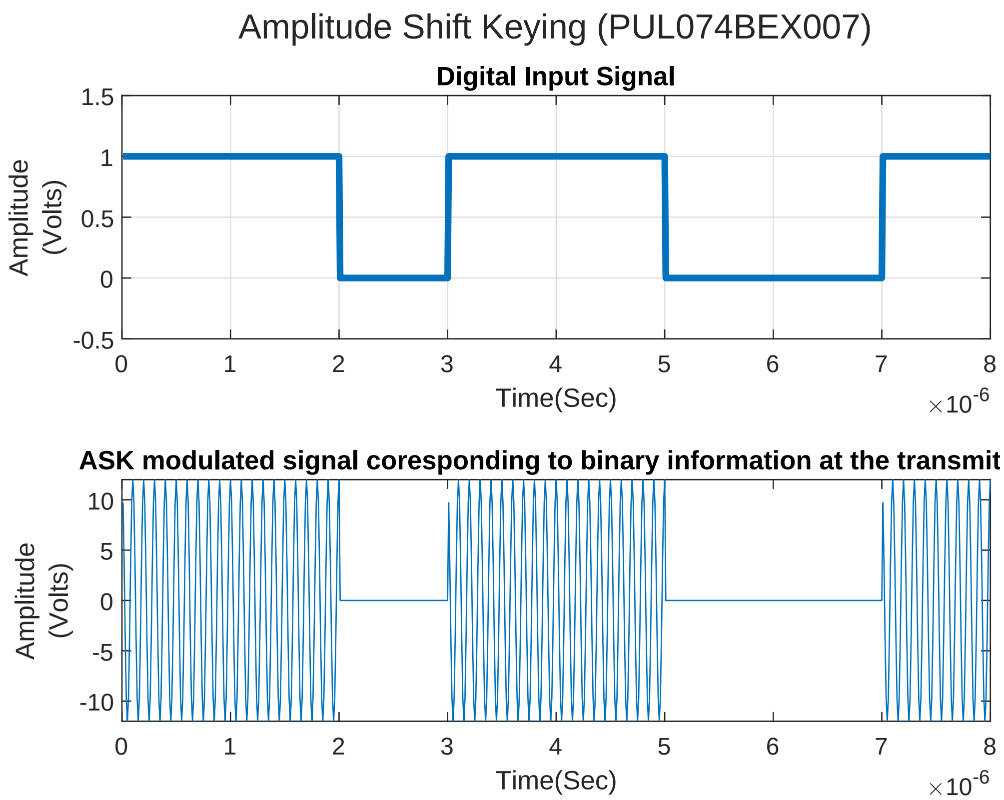

Figure 9: Observation for ASK digital modulation

Problem 2

Perform and visualize FSK modulation.

```
fc1=10 ;
fc2=30 ;
fp=5 ;
amp=1;
t=0:0.001:1;
c1=amp.*sin(2*pi*fc1*t);
c2=amp.*sin(2*pi*fc2*t);
%Layout setup
l= tiledlayout(4, 1);
title(l, 'Frequency Shift Keying (
    PUL074BEX007)')
%Display carrier wave 1
nexttile;
plot(t,c1)
xlabel('Time(Sec)');
ylabel({'Amplitude','(Volts)'});
title('Carrier wave 1')
%Display carrier wave 1
nexttile;
plot(t,c2)
xlabel('Time(Sec)');
ylabel({'Amplitude','(Volts)'});
title('Carrier wave 2')
%Generate amd display digital input signal
m=amp.*square(2*pi*fp*t)+amp;
nexttile;
plot(t,m)
xlabel('Time(Sec)');
ylabel({'Amplitude','(Volts)'});
title('Digital Input Signal')
%FSK modulation
for i=0:1000
    if m(i+1)==0
        mm(i+1)=c1(i+1);
    else
        mm(i+1)=c2(i+1);
    end
end
%Display FSK modulated signal
nexttile;
plot(t,mm)
xlabel('Time(Sec)');
ylabel({'Amplitude','(Volts)'});
title('BPSK modulated signal coresponding
    to binary information at the
    transmitter');
print('-depsc', 'fsk-obs');
```

Listing 3: Matlab script for frequency shift keying digital modulation

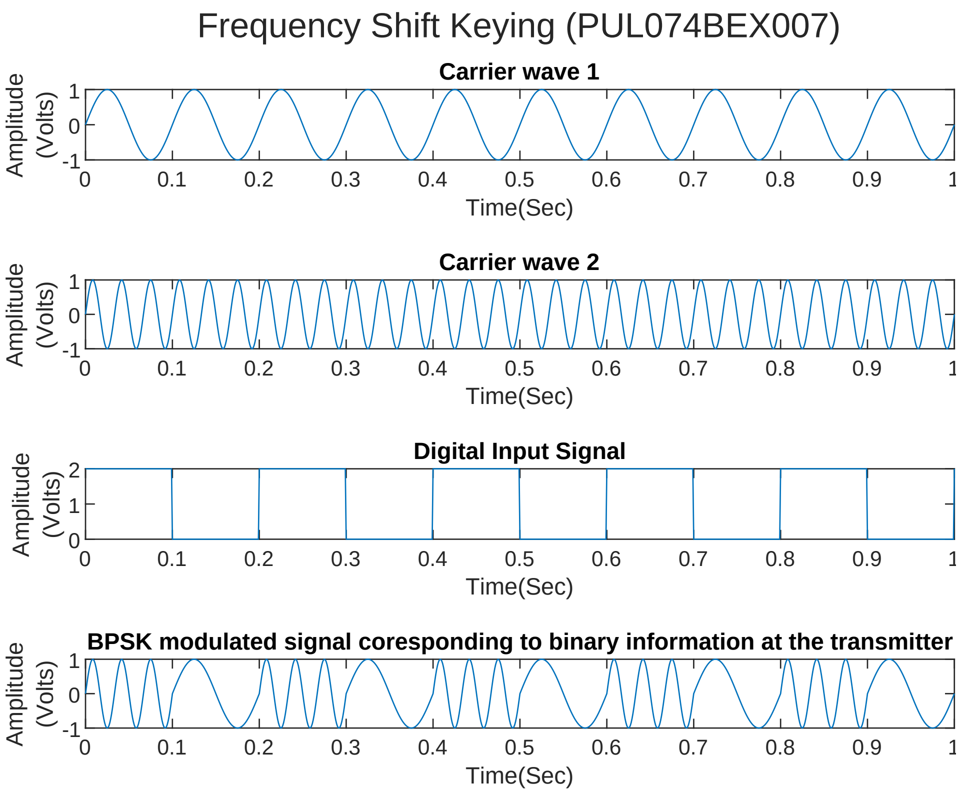

Figure 10: Observation for FSK digital modulation

Problem 3

Perform and visualize BPSK modulation.

```
%Generate digital input signal
bitgenerator;
t1 = Tb/nb:Tb/nb:nb*N*(Tb/nb);
%Layout setup
l= tiledlayout(3, 1);
title(l, 'Binary Phase Shift Keying (
    PUL074BEX007)')
%Display digital input signal
nexttile;
plot(t1,bit,'lineWidth',2.5);
grid on;
axis([0 Tb*N -0.5 1.5]);
xlabel('Time(Sec)');
ylabel({'Amplitude','(Volts)'});
title('Digital Input Signal');
%BPSK modulation
A=5;
br = 1/Tb;
fc = br;
t2 = Tb/nb:Tb/nb:Tb;
mod = [];
kl=[];
for i=1:1:N
    wave=A*sin(2*pi*fc*t2);
    kl=[kl wave];
end
```

```
for i=1:1:N
    if (x(i)==1)
        y=A*sin(2*pi*3*fc*t2);
    else
        y=A*sin(2*pi*3*fc*t2+pi);
    end
mod = [mod y];
end
t3 = Tb/nb:Tb/nb:Tb*N;
%Display carrier signal
nexttile;
plot(t3,kl);
grid on;
xlabel('Time(sec)');
ylabel({'Amplitude','(Volts)'});
title('Carrier Signal');
%Display BPSK modulated signal
nexttile;
plot(t3,mod);
grid on;
xlabel('Time(Sec)');
ylabel({'Amplitude','(Volts)'});
title('BPSK modulated signal coresponding to binary information at the transmitter');
print('-depsc', 'psk-obs');
```

Listing 4: Matlab script for binary phase shift keying digital modulation

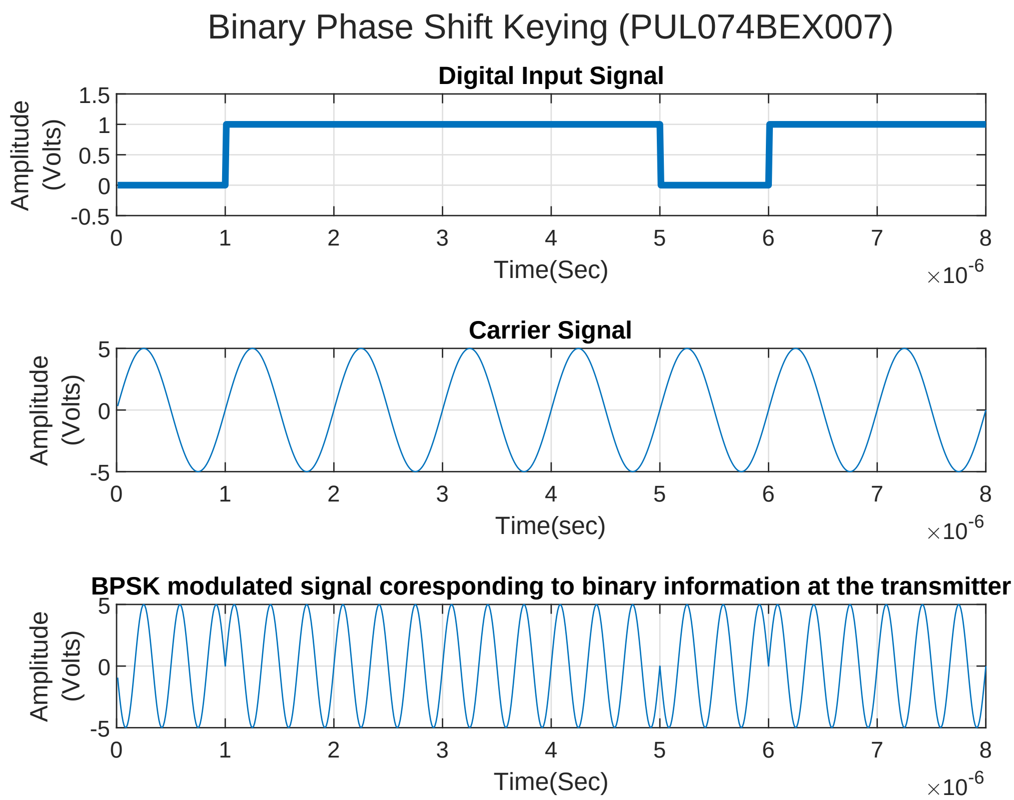

Figure 11: Observation for BPSK digital modulation

Problem 4

Perform and visualize QAM.

```
%Generate digital input signal
M=256;
nbit=64;
msg=randi([0,1],1,nbit);
x=msg;
Tb=0.1;
N = length(x);
nb = 100;
bit = [];
for n = 1:N
    if x(n) == 1
        sig = ones(1,nb);
    else
        sig = zeros(1,nb);
    end
    bit = [bit sig];
end
t1 = Tb/nb:Tb/nb:nb*N*(Tb/nb);
%Layout setup
l= tiledlayout(3, 1);
title(l, 'Quadrature Amplitude Modulation (
    PUL074BEX007)')
%Display digital input signal
nexttile;
plot(t1,bit,'lineWidth',2.5);
grid on;
axis([0 Tb*N -0.5 1.5]);
xlabel('Time(Sec)');
ylabel({'Amplitude','(Volts)'});
title('Digital Input Signal');
%Reshape message into matrix
msg_reshape=reshape(msg,log2(M),nbit/log2(M
    ))';
disp('Information reshaped as:');
disp(msg_reshape);
%Convert binary rows to decimal
for j=1:nbit/log2(M)
    for i=1:log2(M)
        a(j,i)=num2str(msg_reshape(j,i));
    end
end
as=bin2dec(a);
%Display serial symbol
nexttile;
stem(as);
xlabel('n(discrete time)');
ylabel({'Amplitude','(Volts)'});
title('Serial symbol for M-ary QAM
    modulation at transmitter');
%QAM modulation
p=qammod(as,M);
RR=real(p);
II=imag(p);
sr=1/Tb;
f=sr*5;
t=Tb/nb:Tb/nb:Tb;
mod=[];
for k=1:1:length(RR)
    yr=RR(k)*cos(2*pi*f*t);
    yim=II(k)*sin(2*pi*f*t);
    y=yr+yim;
    mod=[mod y];
end
t3 = Tb/nb:Tb/nb:Tb*length(RR);
%Display QAM modulated signal
nexttile;
plot(t3,mod);
xlabel('Time(Sec)');
ylabel({'Amplitude','(Volts)'});
title('QAM modulated signal coresponding to
     binary information at the transmitter'
    );
print('-depsc', 'qam-obs');
```

Listing 5: Matlab script for quadrature amplitude modulation

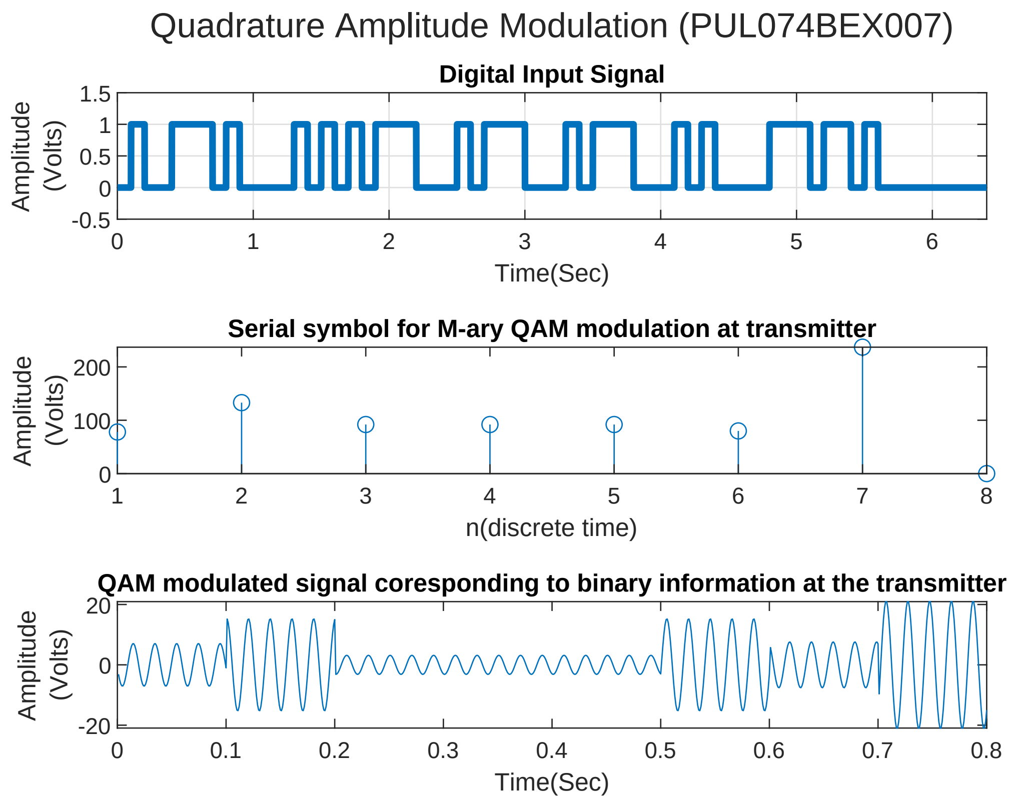

Figure 12: Observation for QAM (256-ary)

4 Discussion and Conclusion

This lab experiment dealt with the implementation and visualization of different digital modulation schemes like amplitude shift keying, frequency shift keying, binary phase shift keying, and quadrature amplitude modulation.

A single bit generator script was used for ASK and BPSK modulation, whereas a different method to generate the input digital signal was implemented for FSK modulation. This was done solely for experimental purposes. Likewise, for the QAM scheme, a digital signal represented by 64 bits was generated for 256-ary QAM scheme using a technique similar to the script for ASK and BPSK. Moreover, the serial symbol conversion was performed using `reshape` command. The reshaped information provided the serial symbol which was converted from the rows of the reshaped matrix into decimal system. `qammod` command was

used to perform QAM scheme which gave back the real and imaginary parts, using which the QAM signal was represented and plotted as shown in the observation above.
Hence the objectives of the lab experiment were fulfilled with the implementation and visualization of ASK, FSK, BPSK and QAM.