DSP LABORATORY MANUAL

IV Semester

INTEGRATED LAB-[21ET42]

Name	**:**	
Semester/Section	**:**	
USN	**:**	
Batch	**:**	

DAYANANDA SAGAR COLLEGE OF ENGINEERING

Accredited by National Assessment & Accreditation Council (NAAC) with 'A' Grade

(An Autonomous Institution affiliated to Visvesvaraya Technological University, Belagavi & ISO 9001:2008 Certified)

Shavige Malleswara Hills , Kumaraswamy Layout Bengaluru-560078

DEPARTMENT OF ELECTRONICS AND TELECOMMUNICATON ENGINEERING

Vision of the Institute

To impart quality technical education with a focus on Research and Innovation emphasizing on Development of Sustainable and Inclusive Technology for the benefit of society.

Mission of the Institute

1. To provide an environment that enhances creativity and Innovation in pursuit of Excellence.

2. To nurture teamwork in order to transform individuals as responsible leaders and entrepreneurs.

3. To train the students to the changing technical scenario and make them to understand the importance of Sustainable and Inclusive technologies

Vision of the Department

To disseminate quality technical education for achieving Academic Excellence through focused research and innovation encompassing contemporary technologies trends in electronic devices, telecommunication systems and standards for societal needful applications, of country in specific and global at broader perspective.

Mission of the Department

1.By adopting quality curriculum design, associated with standard teaching learning process and assessment techniques; on par with standards for portability of graduates globally.

2.By educating students towards contemporary technologies through consistent interaction with the leading industries based on the current socio-economic conditions of the society.

3.By inculcating research attitude among graduates through lifelong learning in pursuit of academic excellence and career enrichment.

Program Educational Objectives (PEOs)

PEO1: The graduate envisages the vision of the department, on engineering needs of the country at large and industry in specific and thereby contribute services with perspective of self-sustenance through higher studies, and research in the program domain.

PEO2: The graduate enduring the optimally designed curriculum, demonstrates ability to analyze Scientific, Mathematical perspectives of Electronics and Telecommunication Engineering and apply its knowledge with multidisciplinary approach for solving real life problems for a successful career.

PEO3: The graduate possesses professional attitude for career building in the society, ability to work and lead a team with highest integrity and ethical values for managing large corporate projects through suitable research and development.

PEO4: The graduate demonstrates lifelong learning to upgrade knowledge of emerging technologies through training, interaction with professional bodies for finding sustainable solution to changing scenarios of the technology frontiers, emphasizing on security and safety concern of individual and global environment.

Program Specific Outcomes (PSO's)

PSO1: To apply fundamental concepts of electrical, electronic devices and circuits to communication theory and systems on par with the electronics and telecommunication industry domain.

PSO2: To apply the core merits of embedded systems, signal processing and network protocols for electronics and telecommunication standards.

PSO3: To design secured cognitive collaborative solutions related to electronics and telecommunication systems.

DIGIAL SIGNAL PROCESSING (INTEGRATED) LAB

(SYLLABUS)

IV SEMESTER B. E (TCE)

Sub Code : 21ET42	**CIE: 50**
Exam Hours: 02	**SEE: 50**

Course Objectives:

1. To investigate Digital Signal processing techniques with their Properties both in time and frequency domain.
2. To implement Linear and Circular Convolution.
3. To implement FIR and IIR filters

Course Outcomes:

1. Examine the frequency response and impulse response of discrete-time LTI systems (L3).
2. Interpret discrete-time signals using DFT (L3).
3. Apply FFT algorithms for various signal processing operations (L3).
4. Analyse IIR and FIR digital filters (L4).
5. Design IIR and FIR digital filters for real time DSP applications (L5).

Syllabus:

List of Programs to be implemented & executed using any programming languages like C++/Python/Java/Scilab / MATLAB/CC Studio (but not limited to)

1. Computation of N point DFT of a given sequence and to plot magnitude and phase spectrum.
2. Computation of circular convolution of two given sequences and verification of commutative, distributive and associative property of convolution
3. Computation of linear convolution of two sequences using DFT and IDFT
4. Computation of circular convolution of two given sequences using DFT and IDFT
5. Verification of Linearity property, circular time shift property & circular frequency shift

property of DFT.

6. Verification of Parseval's theorem
7. Design and implementation of IIR (Butterworth)low pass filter to meet given specifications
8. Design and implementation of IIR (Butterworth) high pass filter to meet given specifications
9. Design and implementation of low pass FIR filter to meet given specifications.
10. Design and implementation of high pass FIR filter to meet given specifications.

Table of Contents

PROGRAM TITLE: **1a. Computation of N point DFT of a given sequence and to plot magnitude and phase spectrum (Using inbuilt function).**

MATLAB CODE

```
clc;
clear all;

xn = input('Enter the input sequence x(n):  ');
N = length(xn);
n=0:1:N-1;
k=0:1:N-1;

Xk = fft(xn,N);
disp('Xk: ');
disp(Xk);
mag_Xk = abs(Xk);
disp('magnitude values of Xk: ');
disp(Xk);
ang_Xk = angle(Xk);
disp('phase values of Xk: ');
disp(Xk);

subplot(3,1,1);
stem(n,xn);
title('input sequence x(n)')
xlabel('-----> n');
ylabel('-----> xn');


subplot(3,1,2);
stem(k,mag_Xk);
title('Magnitude response of X(k)');
xlabel('-----> k');
ylabel('-----> |Xk|');

subplot(3,1,3);
stem(k,ang_Xk);
title('Phase response of X(k)');
xlabel('-----> k');
ylabel('-----> phase of X(k)');
```

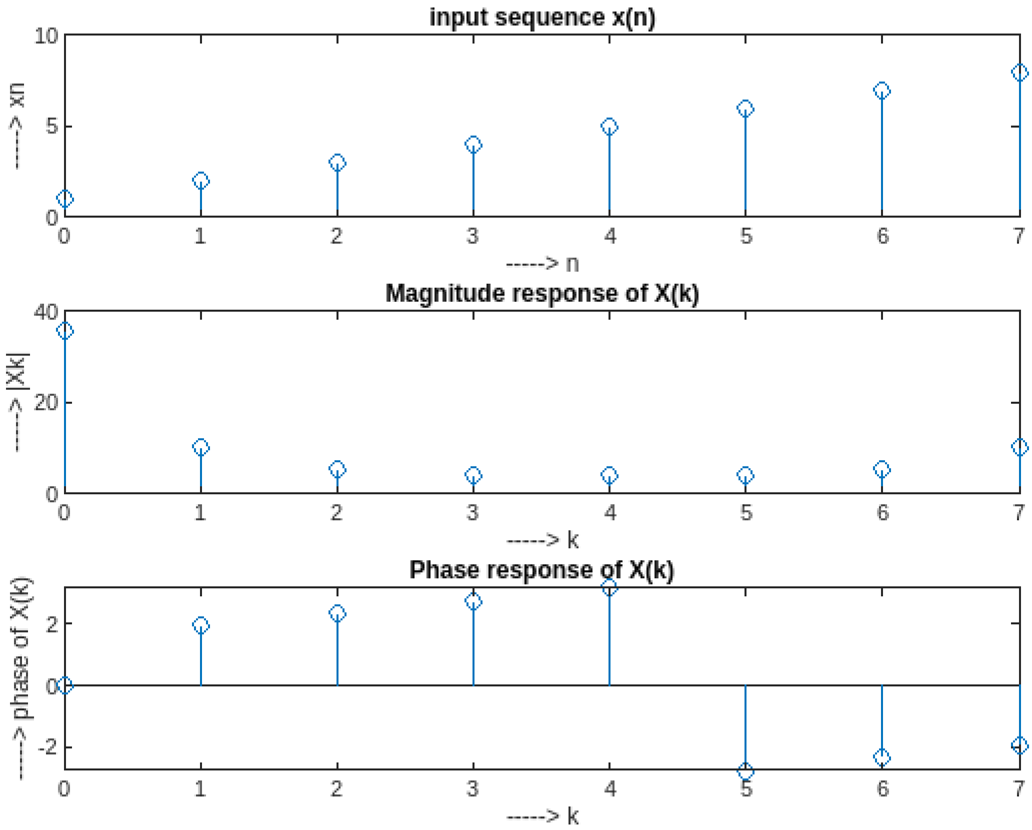
Result:

```
Enter the input sequence x(n):
[1 2 3 4 5 6 7 8]
X(k):
36.0000 + 0.0000i
-4.0000 + 9.6569i
-4.0000 + 4.0000i
-4.0000 + 1.6569i
-4.0000 + 0.0000i
-4.0000 - 1.6569i
```

-4.0000 - 4.0000i
-4.0000 - 9.6569i

magnitude values of Xk:
36.0000 10.4525 5.6569 4.3296 4.0000 4.3296 5.6569 10.4525
phase values of Xk:
0 1.9635 2.3562 2.7489 3.1416 -2.7489 -2.3562 -1.9635

Graph:



PROGRAM TITLE: **1b. Computation of N point DFT of a given sequence and to plot magnitude and phase spectrum (Without Using inbuilt function).**

MATLAB CODE

```
clc;
clear all;

xn = input('Enter the input sequence x(n):  ');
N = length(xn);

Xk = zeros(1,N);

for k=0:N-1
   for n=0:N-1
      Xk(k+1) = Xk(k+1)+xn(n+1)*exp((-i)*2*pi*k*n/N);
   end;
end


disp('X(k): ');
```

```
disp(Xk);
mag_Xk = abs(Xk);
disp('magnitude values of Xk: ');
disp(mag_Xk);
ang_Xk = angle(Xk);
disp('phase values of Xk: ');
disp(ang_Xk);

n=0:N-1;
k=0:N-1;
subplot(3,1,1);
stem(n,xn);
title('input sequence x(n)')
xlabel('-----> n');
ylabel('-----> xn');


subplot(3,1,2);
stem(k,mag_Xk);
title('Magnitude response of X(k)');
xlabel('-----> k');
ylabel('-----> |Xk|');

subplot(3,1,3);
stem(k,ang_Xk);
title('Phase response of X(k)');
xlabel('-----> k');
ylabel('-----> phase of X(k)');
```

Result:

```
Enter the input sequence x(n):
[1 2 3 4 5 6 7 8]
X(k):
36.0000 + 0.0000i
-4.0000 + 9.6569i
-4.0000 + 4.0000i
-4.0000 + 1.6569i
-4.0000 + 0.0000i
-4.0000 - 1.6569i
-4.0000 - 4.0000i
-4.0000 - 9.6569i
```

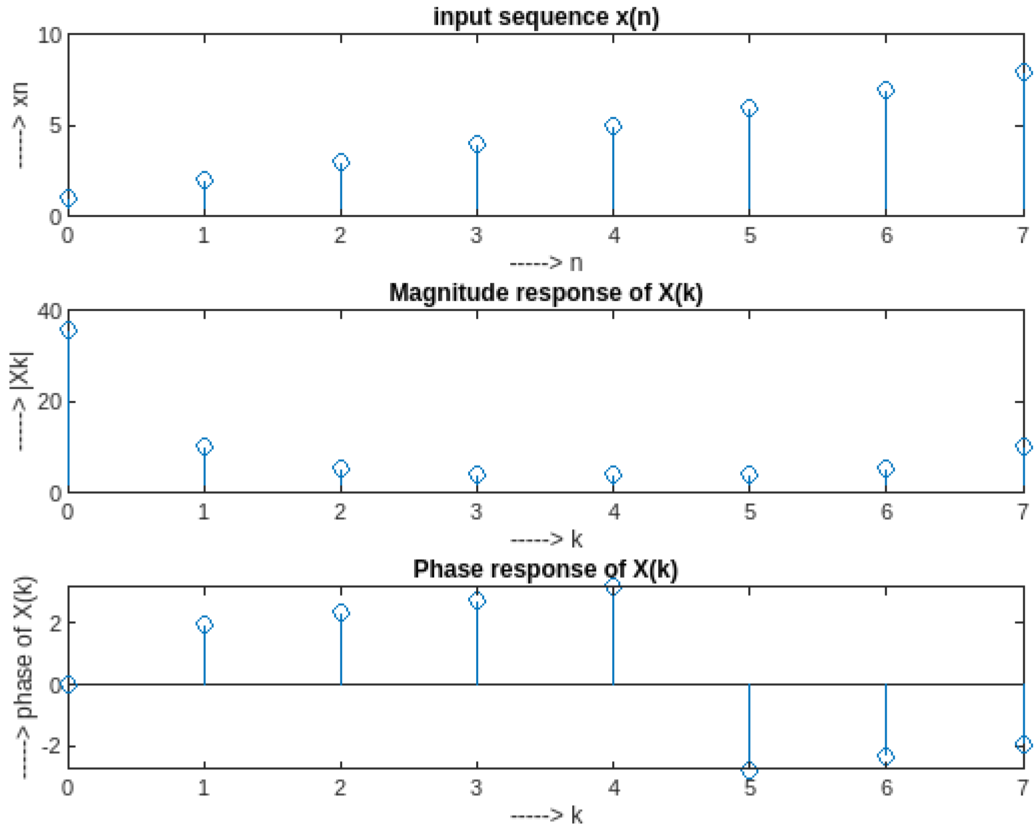
magnitude values of Xk:

36.0000 10.4525 5.6569 4.3296 4.0000 4.3296 5.6569 10.4525

phase values of Xk:

0 1.9635 2.3562 2.7489 3.1416 -2.7489 -2.3562 -1.9635

Graph:


input sequence x(n)
-----> xn
-----> n
Magnitude response of X(k)
-----> |Xk|
-----> k
Phase response of X(k)
-----> phase of X(k)
-----> k

PROGRAM TITLE: **2a. Matlab code to Linear and Circular convolution of given sequences.**

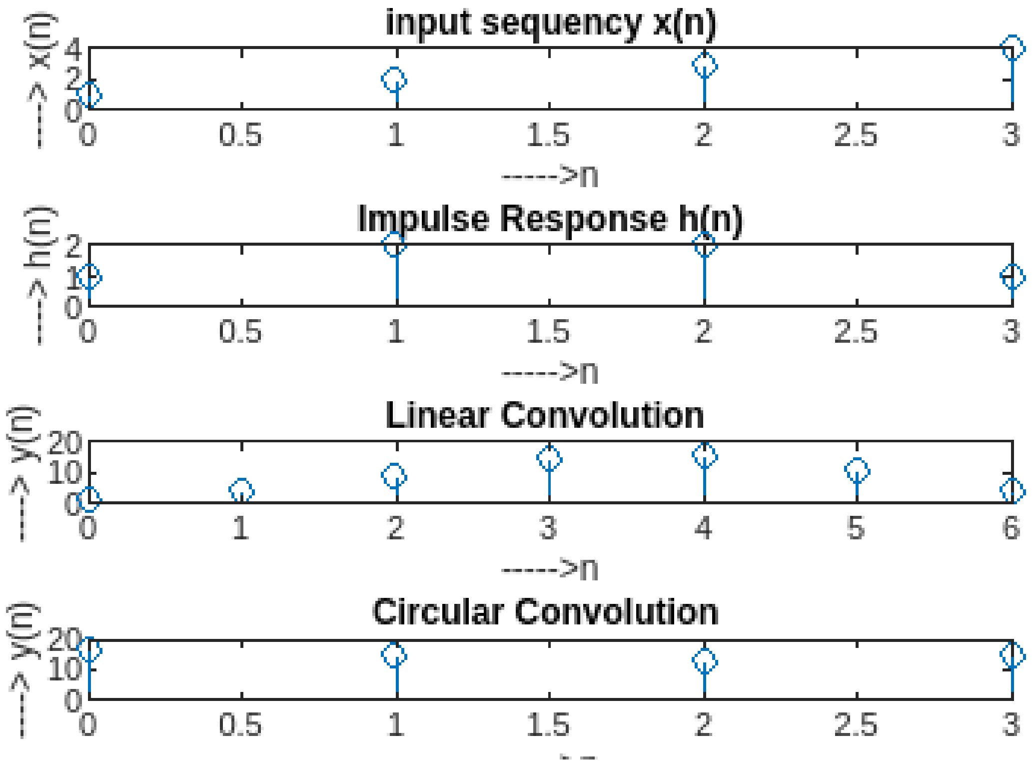
MATLAB CODE

```
clc
clear;

x=input('Enter the input signal x(n):  ');
h=input('Enter the impulse response h(n): ');
N = max(length(x),length(h));

y1=conv(x,h);
disp('The Linear convolution of x(n) and h(n) is : ')
disp(y1);

y2=cconv(x,h,N);
disp('The circular convolution of x(n) and h(n) is : ')
disp(y2);


subplot(4,1,1);
stem(0:length(x)-1, x);
title('input sequency x(n)');
xlabel('----->n');
ylabel('----> x(n)')


subplot(4,1,2);
stem(0:length(h)-1, h);
title('Impulse Response h(n)');
xlabel('----->n');
ylabel('----> h(n)')

subplot(4,1,3);
stem(0:length(y1)-1, y1);
title('Linear Convolution ');
xlabel('----->n');
ylabel('----> y(n)');

subplot(4,1,4);
stem(0:length(y2)-1, y2);
title('Circular Convolution ');
xlabel('----->n');
ylabel('----> y(n)');
```

Result:

```
Enter the input signal x(n):
[1 2 3 4]
Enter the impulse response h(n):
[1 2 2 1]
The Linear convolution of x(n) and h(n) is :
     1     4     9    15    16    11     4

The circular convolution of x(n) and h(n) is :
    17    15    13    15
```

Graph:


input sequency x(n)
------> x(n)
------>n
Impulse Response h(n)
------> h(n)
------>n
Linear Convolution
------> y(n)
------>n
Circular Convolution
------> y(n)

PROGRAM TITLE: **2a. Matlab code to Verify the Properties of Linear convolution.**

MATLAB CODE

```
clc
clear;

x=input('Enter the input signal x(n):  ');
h1=input('Enter the impulse response h1(n): ');
h2=input('Enter the impulse response h2(n): ');


%Commutative Property: x(n) * h(n) = h(n) * x(n)

LHS1 = conv(x,h1);
RHS1 = conv(h1,x);
disp('LHS:   ');
disp(LHS1);
disp('RHS:   ');
disp(RHS1);

if(LHS1 == RHS1)
    disp('Commutatuve Property Verified');
else
     disp('Commutatuve Property Not Verified');
end


%Distributive Property: x(n) * [h1(n)+h2(n)] = [x(n) * h1(n)] + [x(n) *
h2(n)]

LHS2 = conv(x,(h1+h2));
RHS2 = conv(x,h1) + conv(x,h2);
disp('LHS:   ');
disp(LHS2);
disp('RHS:   ');
disp(RHS2);

if(LHS2 == RHS2)
    disp('Distributive Property Verified');
else
     disp('Distributive Property Not Verified');
end

%Associative Property: [ x(n) * h1(n) ] * h2(n) = x(n) * [ h1(n)] * h2(n)]

LHS3 = conv(conv(x,h1),h2);
RHS3 = conv(x, conv(h1,h2));
disp('LHS:   ');
disp(LHS3);
disp('RHS:   ');
disp(RHS3);

if(LHS3 == RHS3)
    disp('Associative Property Verified');
else
     disp('Associative Property Not Verified');
end
```

Result:

```
Enter the input signal x(n):
[1 2 1]
Enter the impulse response h1(n):
[1 2 2]
Enter the impulse response h2(n):
[2 1 1]
LHS:
     1     4     7     6     2

RHS:
     1     4     7     6     2

Commutatuve Property Verified
LHS:
     3     9    12     9     3

RHS:
     3     9    12     9     3

Distributive Property Verified
LHS:
     2     9    19    23    17     8     2

RHS:
     2     9    19    23    17     8     2

Associative Property Verified
```

PROGRAM TITLE: **3. MATLAB PROGRAM TO FIND LINEAR CONVOLUTION USING DFT AND IDFT**

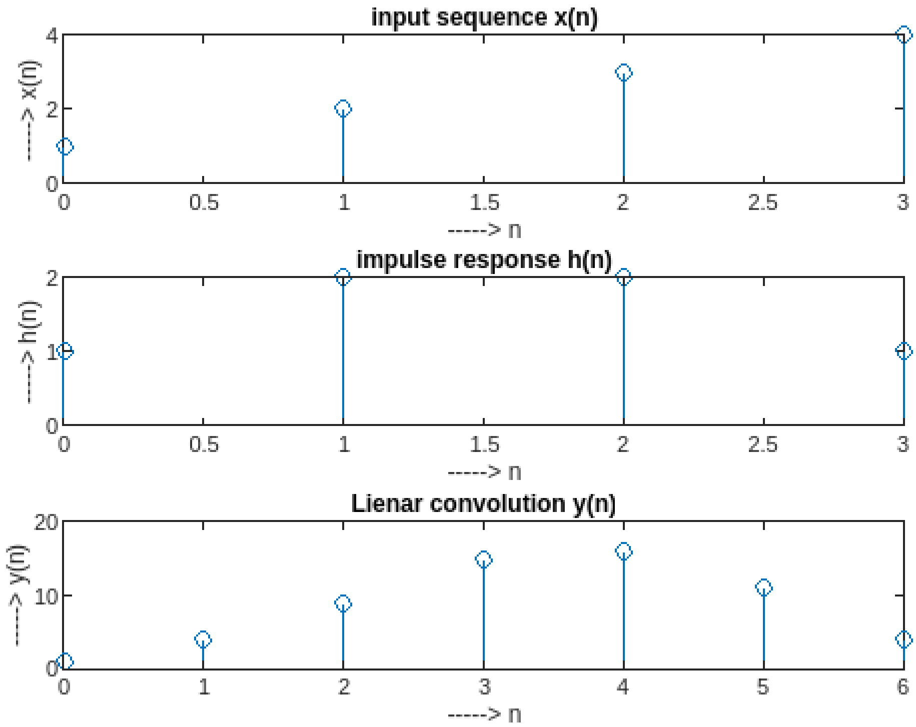
MATLAB CODE

```
clc;
clear all;

xn = input('Enter the input sequence x(n):  ');
hn = input('Enter the impulse response h(n): ');
N = length(xn)+length(hn)-1

Xk = fft(xn,N);
Hk = fft(hn,N);

Yk = Xk.* Hk

yn = ifft(Yk.');

disp('yn: ');
disp(yn);

subplot(3,1,1);
stem(0:length(xn)-1, xn);
xlabel('-----> n');
ylabel('-----> x(n)');
title('input sequence x(n)');

subplot(3,1,2);
stem(0:length(hn)-1, hn);
xlabel('-----> n');
ylabel('-----> h(n)');
title('impulse response h(n)');

subplot(3,1,3);
stem(0:length(yn)-1, yn);
xlabel('-----> n');
ylabel('-----> y(n)');
title('Lienar convolution y(n)');
```

Result:

```
Enter the input sequence x(n):
[1 2 3 4]
Enter the impulse response h(n):
[1 2 2 1]

yn:
    1.0000
    4.0000
    9.0000
   15.0000
   16.0000
   11.0000
    4.0000
```

Graph:


input sequence x(n)
----> x(n)
----> n
impulse response h(n)
----> h(n)
----> n
Lienar convolution y(n)
----> y(n)
----> n

PROGRAM TITLE: **4. MATLAB PROGRAM TO FIND CIRCULAR CONVOLUTION USING DFT AND IDFT**

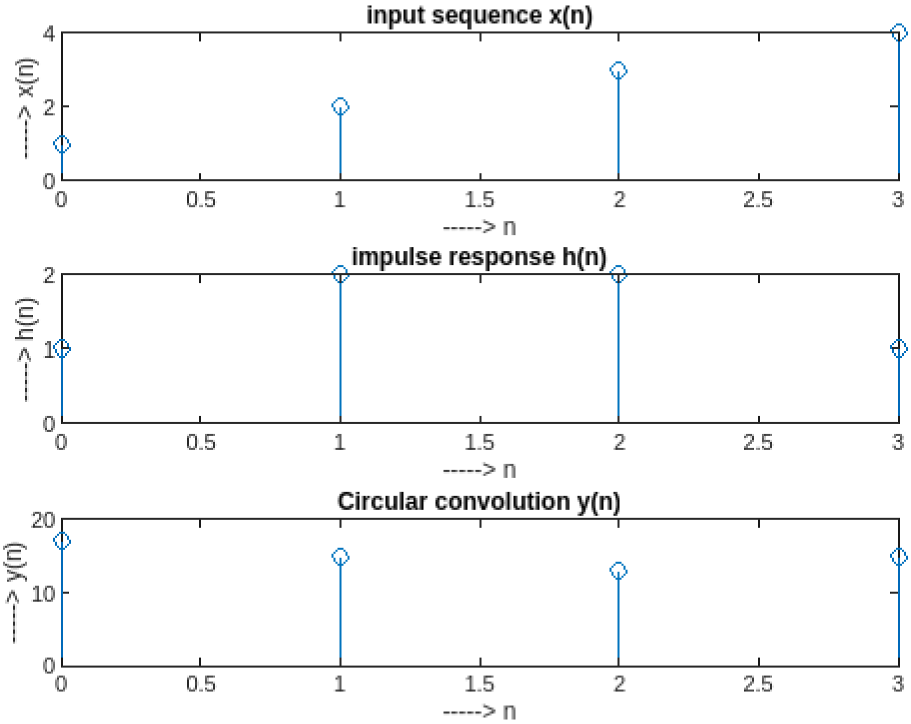
MATLAB CODE

```
clc;
clear all;

xn = input('Enter the input sequence x(n):  ');
hn = input('Enter the impulse response h(n): ');
N = max(length(xn),length(hn))

Xk = fft(xn,N);
Hk = fft(hn,N);

Yk = Xk.* Hk

yn = ifft(Yk.');

disp('yn: ');
disp(yn);

subplot(3,1,1);
stem(0:length(xn)-1, xn);
xlabel('-----> n');
ylabel('-----> x(n)');
title('input sequence x(n)');

subplot(3,1,2);
stem(0:length(hn)-1, hn);
xlabel('-----> n');
ylabel('-----> h(n)');
title('impulse response h(n)');

subplot(3,1,3);
stem(0:length(yn)-1, yn);
xlabel('-----> n');
ylabel('-----> y(n)');
title('Circular convolution y(n)');
```

Result:

```
Enter the input sequence x(n):
[1 2 3 4]
Enter the impulse response h(n):
[1 2 2 1]

yn:
    17
    15
    13
    15
```

Graph:


input sequence x(n)
----> x(n)
----> n
impulse response h(n)
----> h(n)
----> n
Circular convolution y(n)
----> y(n)
----> n

PROGRAM TITLE: **5A. MATLAB PROGRAM FOR linearity Property Verification DFT{ a1*x1(n) + a2*x2(n) } = a1*X1(k) + a2*X2(k)**

MATLAB CODE

```
clc;
clear all;

x1n = input('x1(n):  ' );
x2n = input('x2(n):  ' );
N = max(length(x1n), length(x2n));
a1 = input('a1:  ' );
a2 = input('a2:  ' );


% code for DFT{ a1*x1(n) + a2*x2(n) }
yn = a1*x1n + a2*x2n;
LHS = fft(yn,N);
disp('LHS : ')
disp(LHS.');


% code for a1*X1(k) + a2*X2(k)
X1k = fft(x1n,N);
X2k = fft(x2n,N);
RHS = a1*X1k + a2*X2k;
disp('RHS :')
disp(RHS.');

if LHS == RHS
    disp('Lineartiy Property Verified');
else
    disp('Lineartiy Property not Verified');

end
```

Result:

```
Enter the input sequence x(n):
[1 2 3 4]
Enter the impulse response h(n):
[1 2 2 1]

yn:
    17
    15
    13
    15
```

PROGRAM TITLE: **5B. Matlab Program for Circular Time Shift Property DFT(x((n-m))N) = e(-j*2*pi*m*k)*X(k)**

MATLAB CODE

```
clc;
clear all;

xn = input('xn:    ');
N = length(xn);
m = 4;
yn = circshift(xn,[0,m]);


LHS = int32(fft(yn,N));
disp('LHS: ');
disp(LHS.');


Xk = fft(xn,N);
RHS = zeros(1,N);
for k=0:N-1
    RHS(k+1) =int32(exp(-2*pi*i*m*k/N)*Xk(k+1));
end
disp('RHS');
disp(RHS.');

if LHS == RHS
    disp('The circular Time Shift Property verified');
else
    disp('The circular Time Shift property not Verified')

end
```

Result:

```
xn:
[1 2 3 4]
LHS:
    10 +     0i
    -2 +     2i
    -2 +     0i
    -2 -     2i

RHS
  10.0000 + 0.0000i
  -2.0000 + 2.0000i
  -2.0000 + 0.0000i
  -2.0000 - 2.0000i

The circular Time Shift Property verified
```

PROGRAM TITLE: **5C. Matlab Program for Circular Frequency Shift Property DFT{e(j*2*pi*m*n)*x(n)} = X((k-m))N**

MATLAB CODE

```
%Circular freq shift Property
%DFT{e(j*2*pi*m*n)*x(n)} = X((k-m))N

clc;
clear all;

xn = input('xn:    ');
N = length(xn)
m = 2
yn = zeros(1,N)
for n=0:N-1
    yn(n+1)=exp(2*pi*i*n*m/N)*xn(n+1);
end
LHS = int32(fft(yn,N));
disp('LHS: ');
disp(LHS.');



RHS = fft(xn,N)
RHS = int32(circshift(RHS,[0 m]));
disp('RHS: ');
disp(RHS.');



if LHS == RHS
    disp('The circular Frequecny Shift Property verified');
else
    disp('The circular Frequency Shift property not Verified')

end
```

Result:

```
xn:
[1 2 3 4]

LHS:
    -2 +      0i
    -2 -      2i
    10 +      0i
    -2 +      2i


RHS =

  10.0000 + 0.0000i  -2.0000 + 2.0000i  -2.0000 + 0.0000i  -2.0000 -
2.0000i

RHS:
    -2 +      0i
    -2 -      2i
    10 +      0i
    -2 +      2i
```

```
The circular Frequecny Shift Property verified
```

PROGRAM TITLE: **6. Matlab Program for Parsvels theorm verification (Energy Verification)**

MATLAB CODE

```
clc;
clear all;

xn = input('xn: ');
N = length(xn);

LHS = 0;
for n=0:N-1
    LHS = LHS + (abs(xn(n+1)).*abs(xn(n+1)));
end

RHS = 0;
Xk = fft(xn,N);
for k=0:N-1
    RHS = RHS + (abs(Xk(k+1)).*abs(Xk(k+1)));
end
RHS = RHS/N;

disp('RHS:');
disp(RHS);
disp('LHS:');
disp(LHS);

if LHS == RHS
    disp('The Parsvels Theorm verified');
else
    disp('The Parsvels Theorm not Verified')
```

Result:

```
[1 2 3 4]
RHS:
    30

LHS:
    30

The Parsvels Theorm verified
```

PROGRAM TITLE: **7. Design and implementation of IIR (Butterworth)low pass filter to meet given specifications.**
Passband attenuation ≤1.25db,stopband attenuation ≥ 15db fpass=200Hz, fstop=300Hz fsample=2KHz

MATLAB CODE

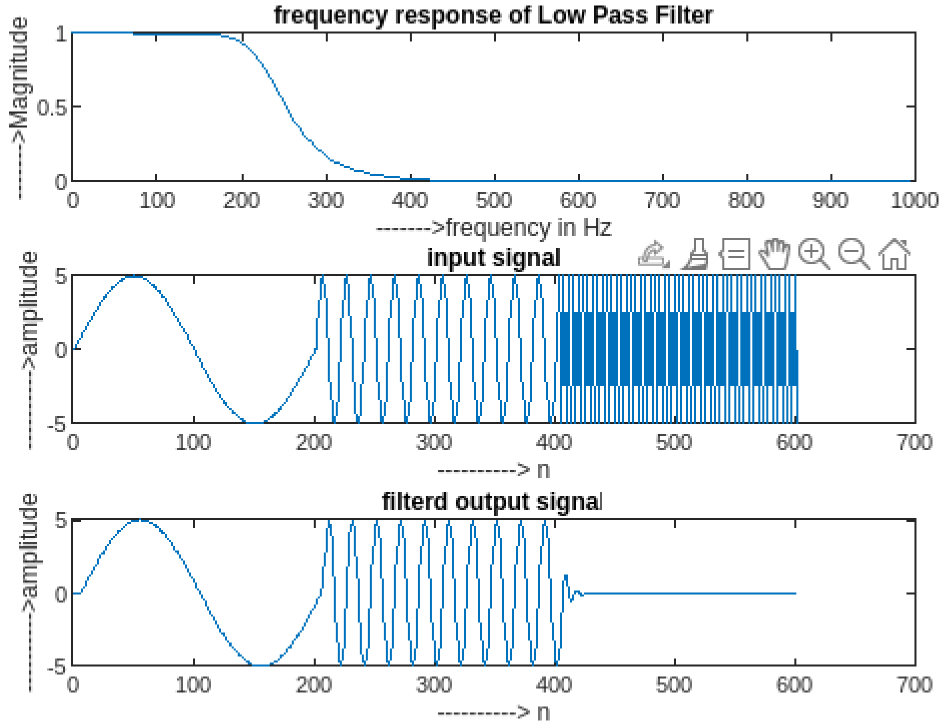
```
clc;
clear all;

%given specifications
Ap=1.25;As=15;
fpb=200; fsb=300; fs = 2000;

%to find Order(N) and cutoff frequency (fc)
fpbn = fpb /(fs/2); fsbn = fsb /(fs/2);

[N,fc]=buttord(fpbn,fsbn,Ap,As);
disp('order of the filter is =');
disp(N);
disp('cutoff frequency is = ');
disp(fc*fs/2);

%to compute frequency response of an IIR digital filter
[b,a]=butter(N,fc);
[H,f] = freqz(b,a,256,fs);

subplot(3,1,1);
plot(f,abs(H));
title('frequency response of Low Pass Filter');
xlabel('------->frequency in Hz');
ylabel('------->Magnitude');



%filtering operation on input singal having frequency 10Hz,100Hz,500Hz
n = 0:1/fs:0.1;
s1=5*sin(2*pi*10*n);
s2=5*sin(2*pi*100*n);
s3=5*sin(2*pi*500*n);

x = [s1 s2 s3];
subplot(3,1,2);
plot(x);
title('input signal');
xlabel('----------> n');
ylabel('---------->amplitude');

y = filter(b,a,x);
subplot(3,1,3); plot(y);
title('filterd output signal');
xlabel('----------> n');
ylabel('---------->amplitude')
```

Result:

```
order of the filter is =
     6
```

```
cutoff frequency is =
  232.9175
```

Graph:



PROGRAM TITLE: **8. Design and implementation of IIR (Butterworth)High pass filter to meet given specifications.*Passband attenuation ≤1.25db,stopband attenuation ≥ 15db fpass=300Hz, fstop=200Hz fsample=2KHz***

MATLAB CODE

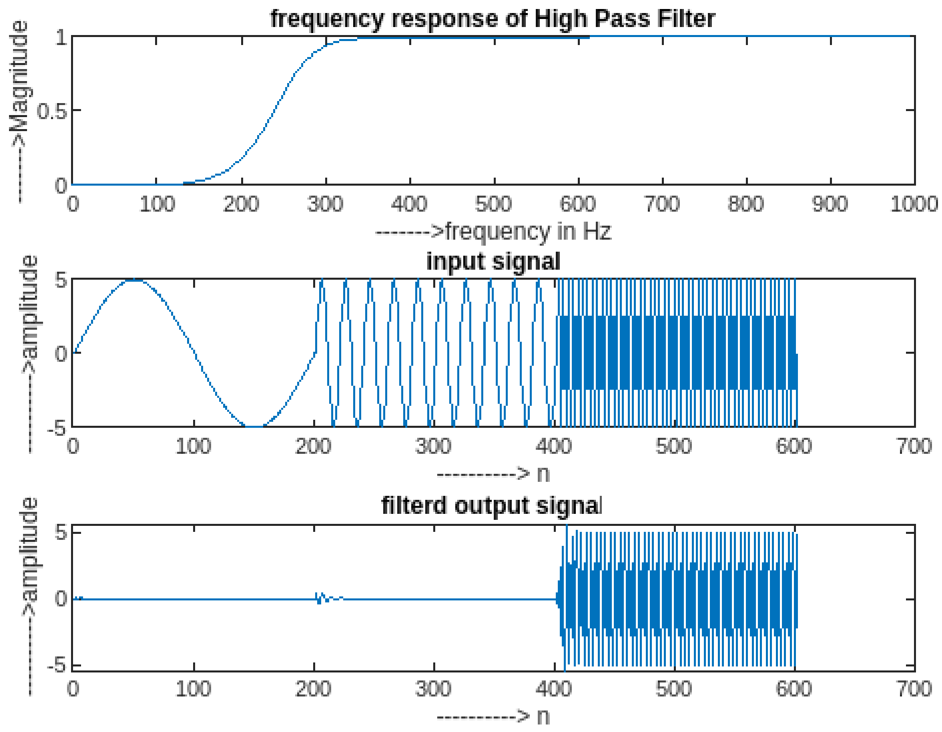
```
clc;
clear all;

%given specifications
Ap=1.25;As=15;
fpb=300; fsb=200; fs = 2000;

%to find Order(N) and cutoff frequency (fc)
fpbn = fpb /(fs/2); fsbn = fsb /(fs/2);

[N,fc]=buttord(fpbn,fsbn,Ap,As);
disp('order of the filter is =');
disp(N);
disp('cutoff frequency is = ');
disp(fc*fs/2);

%to compute frequency response of an IIR digital filter
[b,a]=butter(N,fc,'high');
[H,f] = freqz(b,a,256,fs);

subplot(3,1,1);
plot(f,abs(H));
title('frequency response of High Pass Filter');
xlabel('------->frequency in Hz');
ylabel('------->Magnitude');



%filtering operation on input singal having frequency 10Hz,100Hz,500Hz
n = 0:1/fs:0.1;
s1=5*sin(2*pi*10*n);
s2=5*sin(2*pi*100*n);
s3=5*sin(2*pi*500*n);

x = [s1 s2 s3];
subplot(3,1,2);
plot(x);
title('input signal');
xlabel('----------> n');
ylabel('---------->amplitude');

y = filter(b,a,x);
subplot(3,1,3); plot(y);
title('filterd output signal');
xlabel('----------> n');
ylabel('---------->amplitude')
```

Result:

```
order of the filter is =
     6
```

```
cutoff frequency is =
  259.6729
```

Graph:



PROGRAM TITLE: **9. Design and implementation of FIR Low pass filter to meet given specifications.** ***fpass=100Hz, fstop=200Hz fsample=2KHz, hamming window***

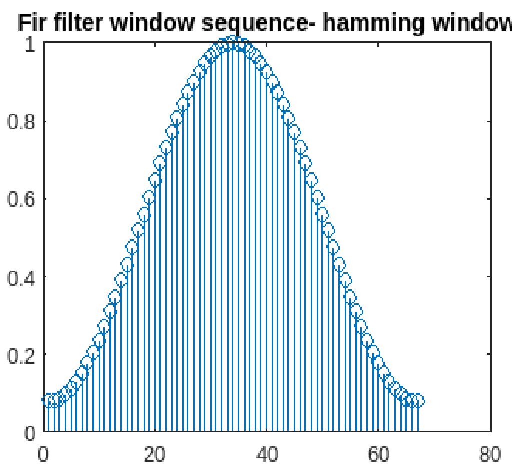
MATLAB CODE

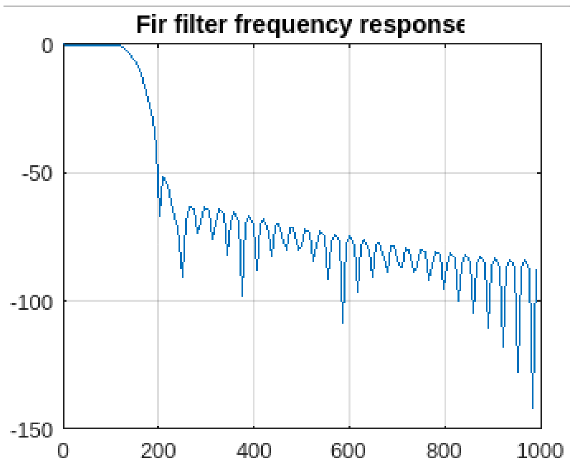
```
clc;
clear all;
wpa=input('Enter passband edge frequency in Hz');
wsa= input('Enter stopband edge frequency in Hz');
ws1= input('Enter sampling frequency in Hz');

%Calculate transmission BW,Transition band tb,order of the filter
wpd=2*pi*wpa/ws1;
wsd=2*pi*wsa/ws1;
tb=wsd-wpd;
N=ceil(6.6*pi/tb) ;
wc=(wsd+wpd)/2;

%compute the normalized cut off frequency
wc=wc/pi;

%calculate & plot the window
hw=hamming(N+1);
stem(hw);
title('Fir filter window sequence- hamming window');

%find h(n) using FIR
h=fir1(N,wc,hamming(N+1));

%plot the frequency response
figure(2);
[m,w]=freqz(h,1,128);
mag=20*log10(abs(m));
plot(ws1*w/(2*pi),mag);
title('Fir filter frequency response');
grid;
```

Result:

```
Enter passband edge frequency in Hz
100
Enter stopband edge frequency in Hz
200
Enter sampling frequency in Hz
2000
```

Graph:





PROGRAM TITLE: **10. Design and implementation of FIR High pass filter to meet given specifications.** ***fpass=200Hz, fstop=100Hz fsample=2KHz, hamming window***

MATLAB CODE

```
clc;
clear all;
wpa=input('Enter passband edge frequency in Hz');
wsa= input('Enter stopband edge frequency in Hz');
ws1= input('Enter sampling frequency in Hz');

%Calculate transmission BW,Transition band tb,order of the filter
wpd=2*pi*wpa/ws1;
wsd=2*pi*wsa/ws1;
tb=wpd-wsd;
N=ceil(6.6*pi/tb) ;
wc=(wsd+wpd)/2;

%compute the normalized cut off frequency
wc=wc/pi;

%calculate & plot the window
hw=hamming(N+1);
stem(hw);
title('Fir filter window sequence- hamming window');

%find h(n) using FIR
h=fir1(N,wc,'high');

%plot the frequency response
figure(2);
[m,w]=freqz(h,1,128);
mag=20*log10(abs(m));
plot(ws1*w/(2*pi),mag);
title('Fir filter frequency response');
grid;
```

Result:

```
Enter passband edge frequency in Hz
200
Enter stopband edge frequency in Hz
100
Enter sampling frequency in Hz
2000
```

Graph: