Digital Signal Processing Laboratory
Experiment 3

Harshavardhan Alimi
18EC10021

Problem Statement:

A study and analysis of Dual Tone Multifrequency or TouchTone encoder/ decoder using Digital FIR Filter. A DTMF tone representing a single key press on a telephonic device, consists of two frequencies. The experiment deals with the extraction of those two frequency components using eight bandpass filters. The bandpass filter chosen is $h[n] = \beta\cos(\omega_c * n)$ where $0 \le n < L$. After the two frequencies are extracted, it is decoded to the character it represents.

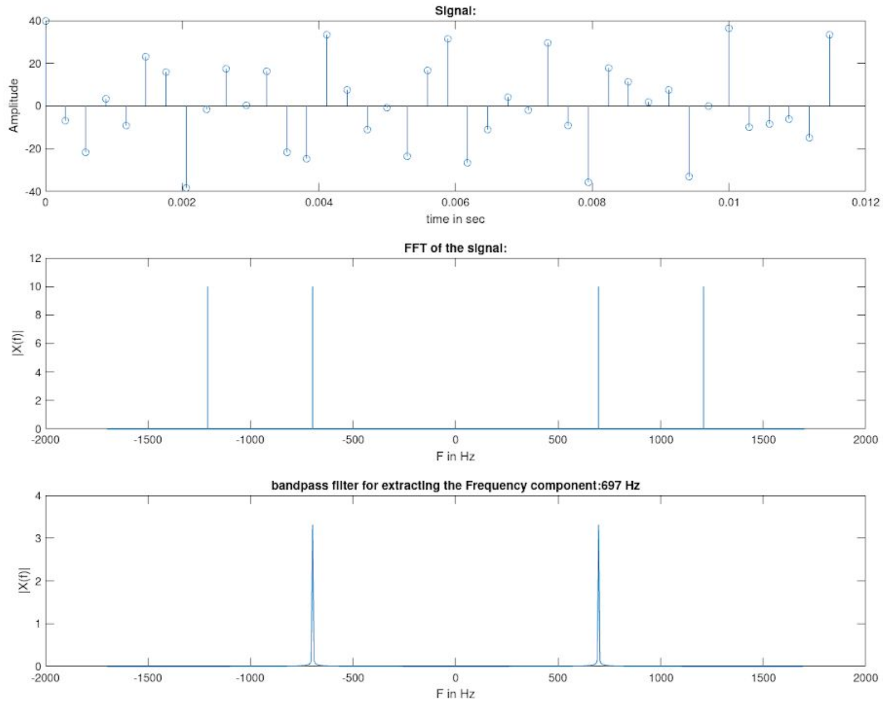
Results :

$h[n] = \beta\cos(\omega_c * n)$,

- Signal :- x=A*cos(2*pi*f1*t)+A*cos(2*pi*f2*t); With Fs=3400 Hz(>2*1633) and N=17000 {to get a signal of length 5sec}.
- Eight filters have been designed using the same equation h[n] and L =512 with the frequencies: - 697 Hz, 770 Hz, 852 Hz, 941 Hz, 1209 Hz, 1336 Hz, 1477 Hz, 1633 Hz. The decoding is done with L = 512 and Beta = (4*N)/(L*A) {to obtain the amplitude of 1 for the filtered output of the signal}.
- Input taken is a character and the output is expected to be the same character. Initially the characters are encoded and the two frequencies chosen are passed through the eight band pass filters and the corresponding frequencies are found out.
- Encoding :- extracting 2 frequency components of a character.
- Decoding :- extracting the character using the 2 frequency components.

A telephone keypad and the DTMF frequencies for each column and row

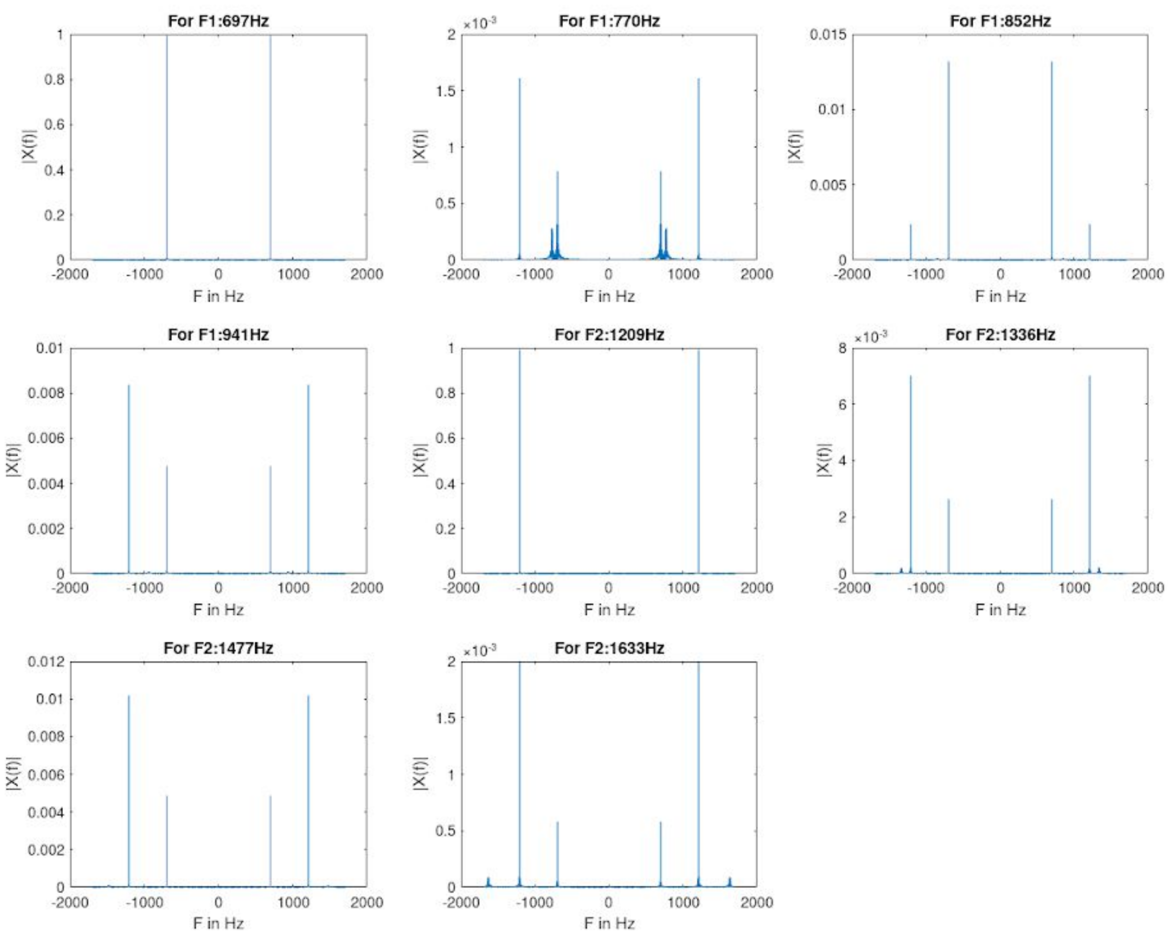
Hz	1209	1336	1477	1633
697	1	2	3	A
770	4	5	6	B
852	7	8	9	C
941	*	0	#	D

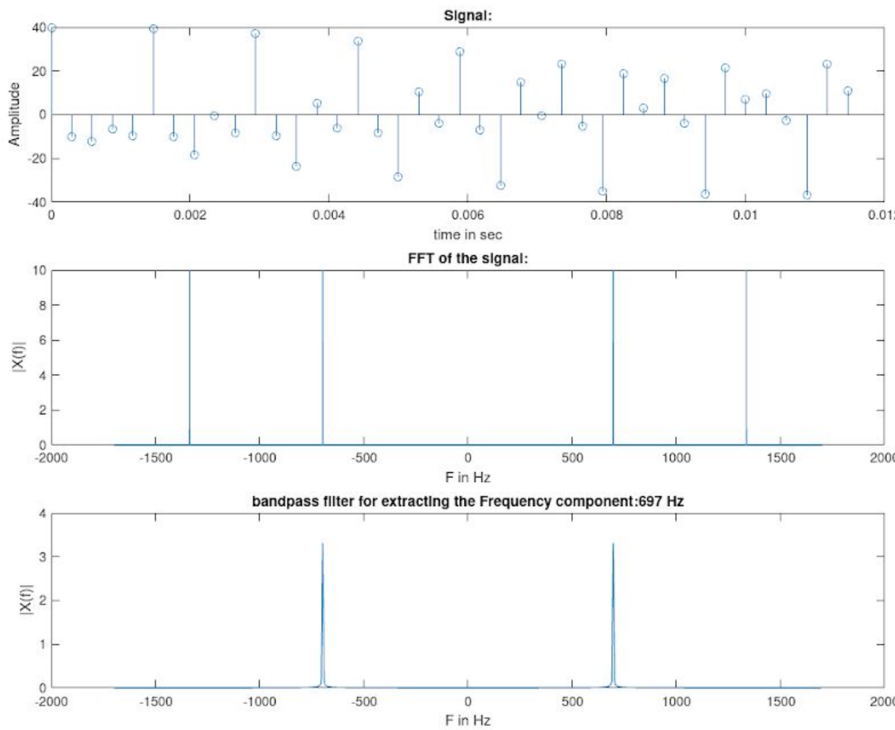


Description :- The below eight plots are those of decoding the character ‘1’

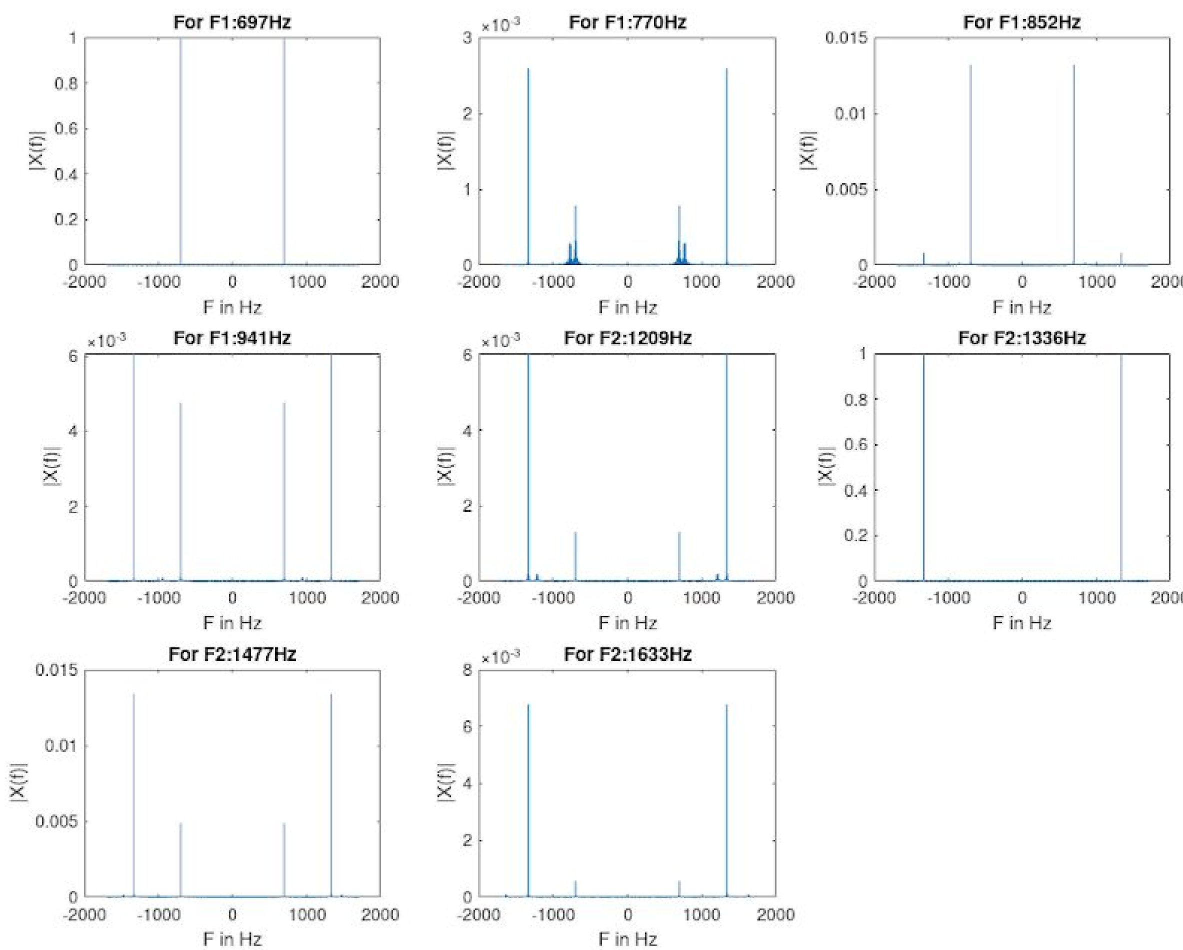
At the command prompt :- Key Pressed :-1

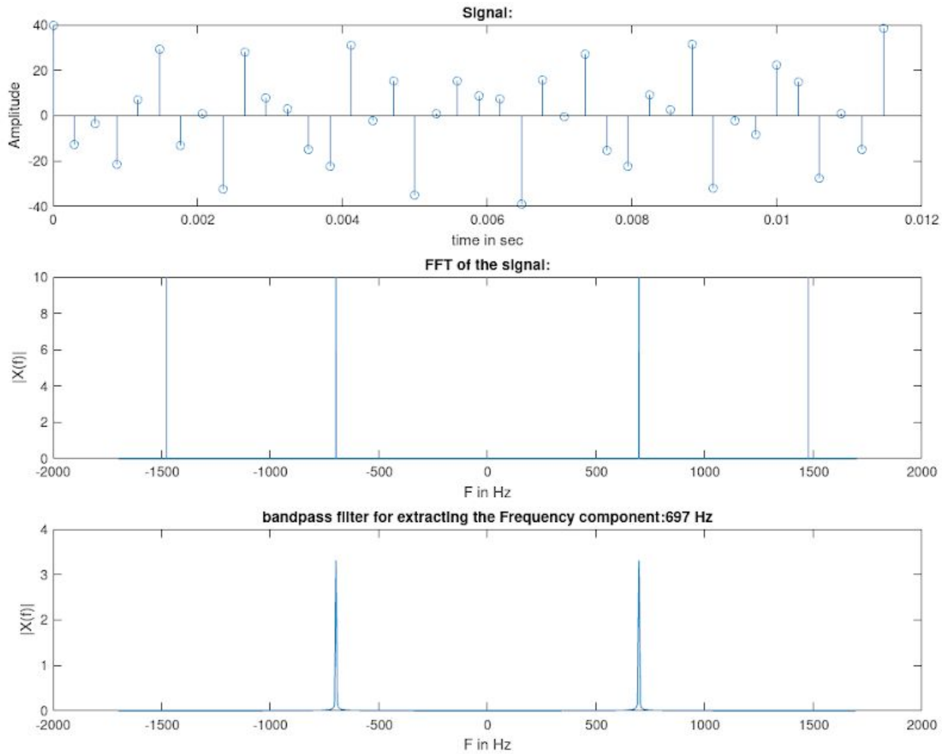
The dialled number is:1





Description :- The below eight plots are those of decoding the character ‘2’
At the command prompt :- Key Pressed :-2
The dialled number is:2

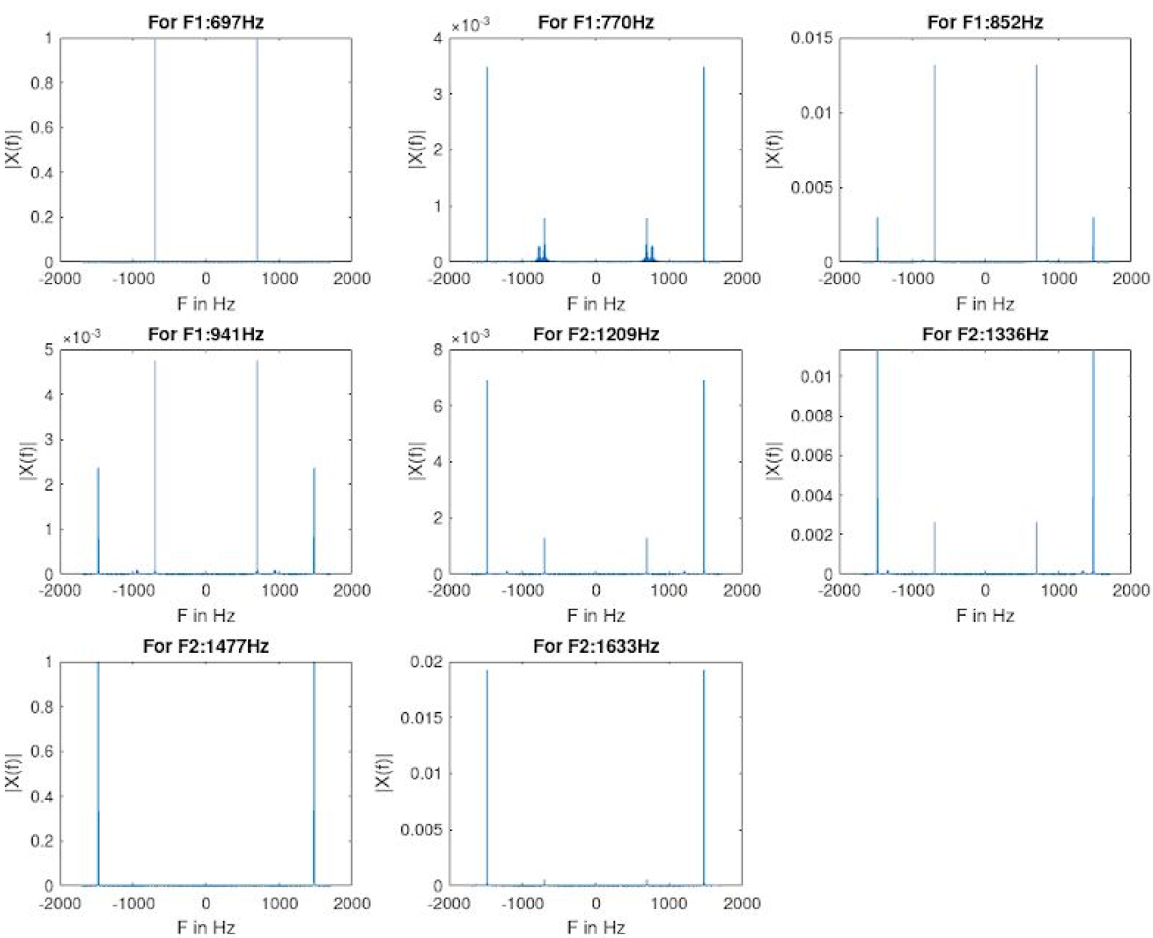


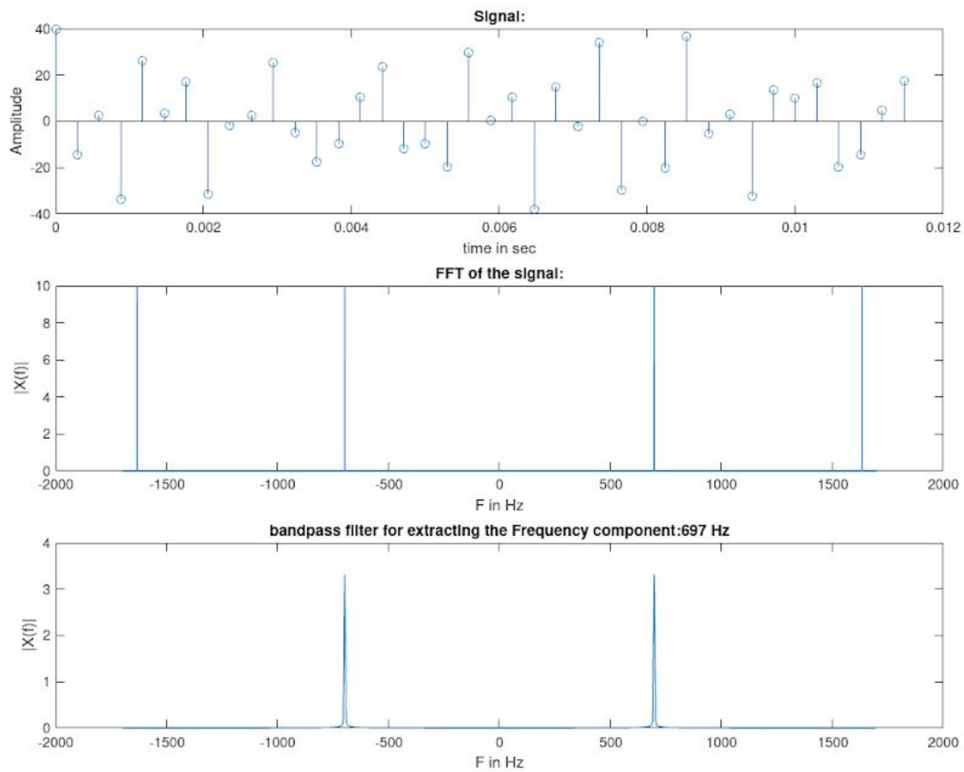


Description :- The below eight plots are those of decoding the character ‘3’

At the command prompt :-   Key Pressed :-3

The dialled number is:3

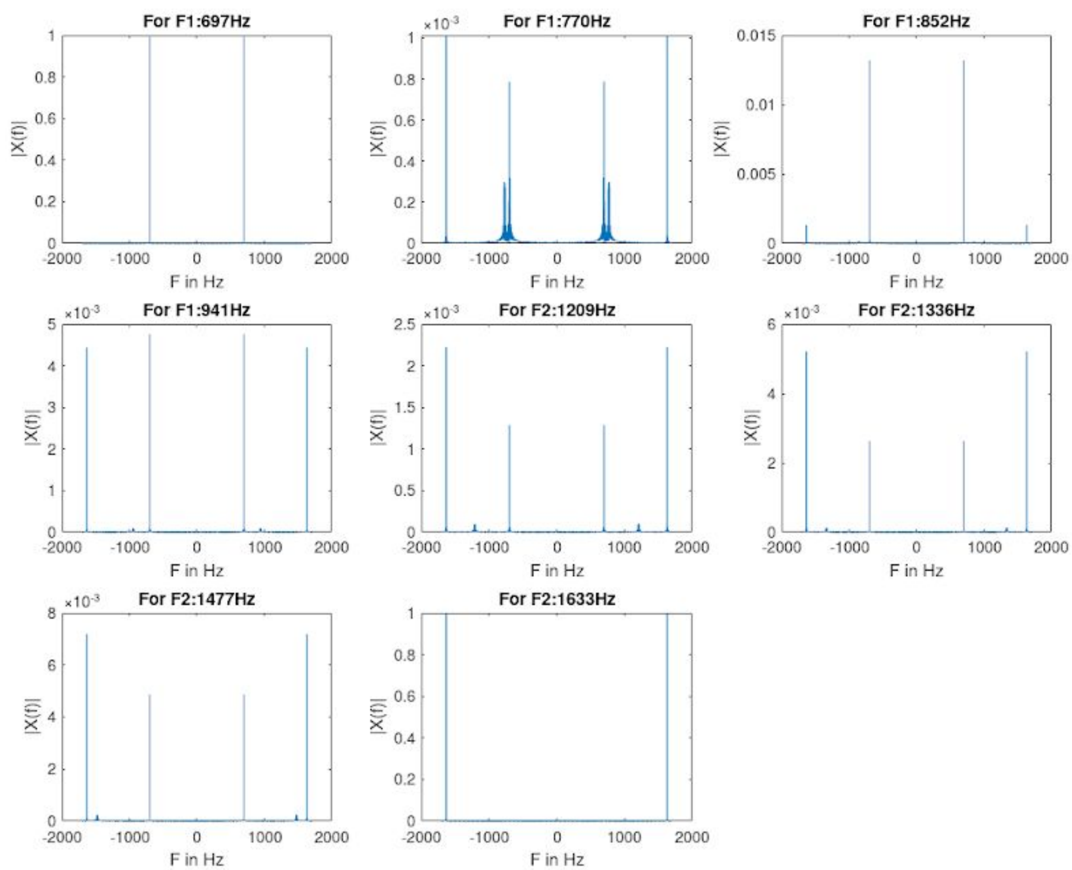


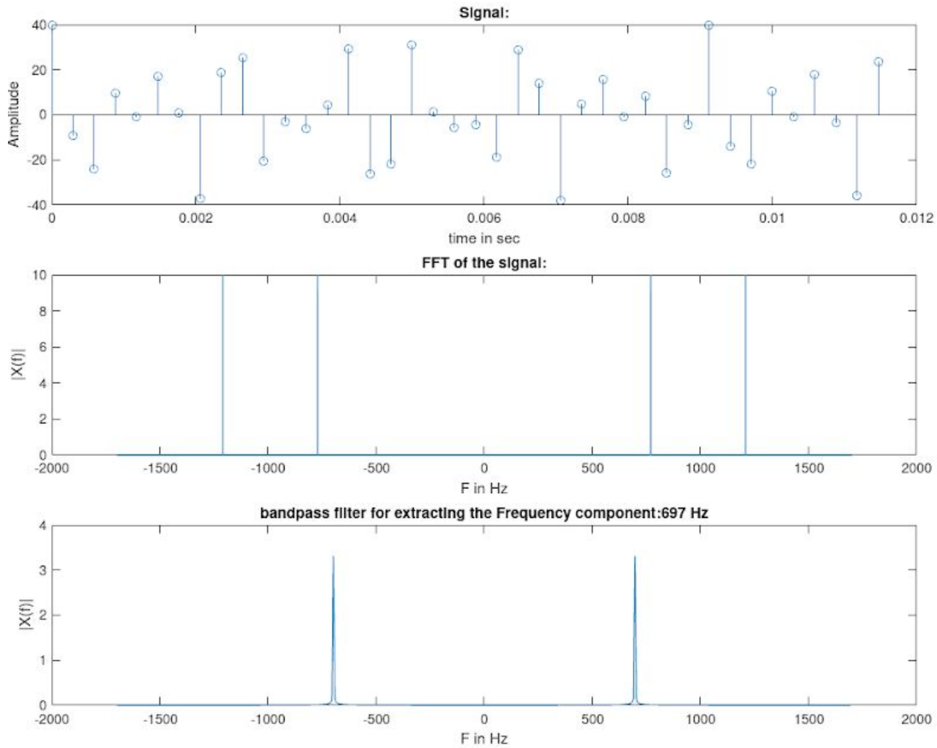


Description :- The below eight plots are those of decoding the character ‘A’

At the command prompt :- Key Pressed :-A

The dialled number is:A

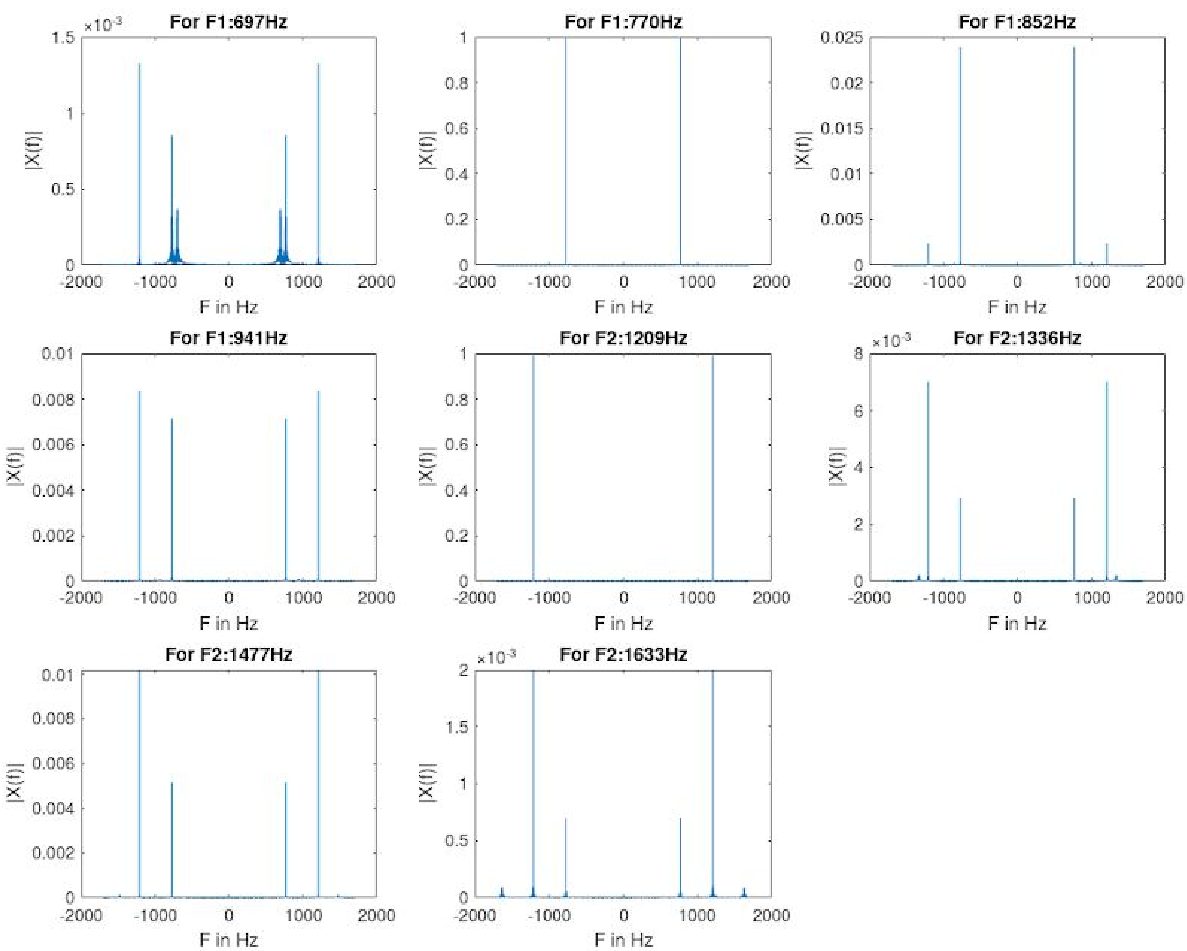


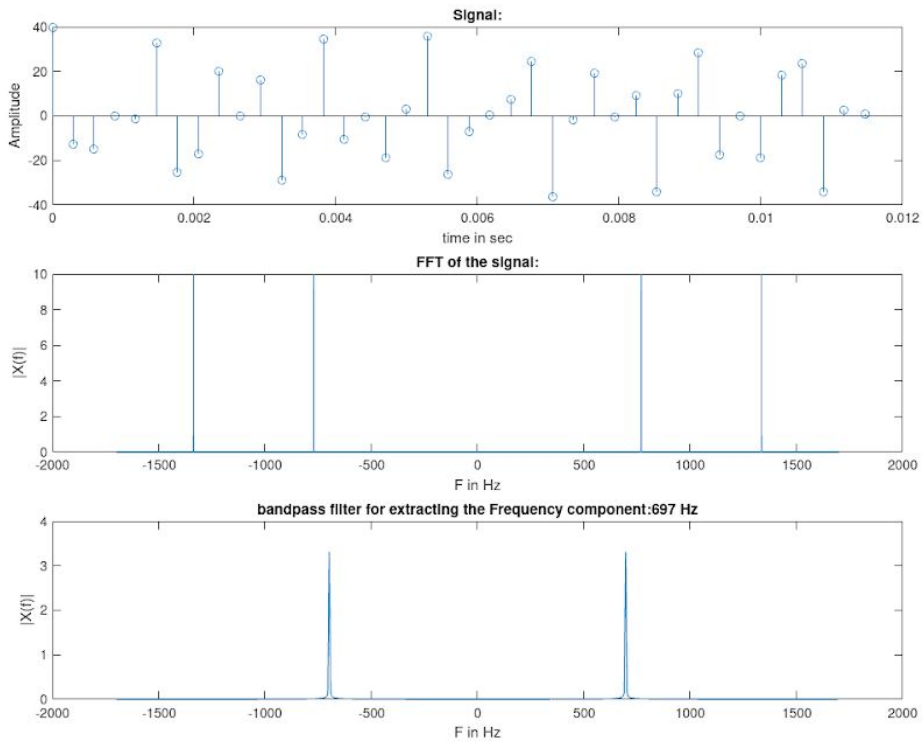


Description :- The below eight plots are those of decoding the character ‘4’

At the command prompt :- Key Pressed :-4

The dialled number is:4

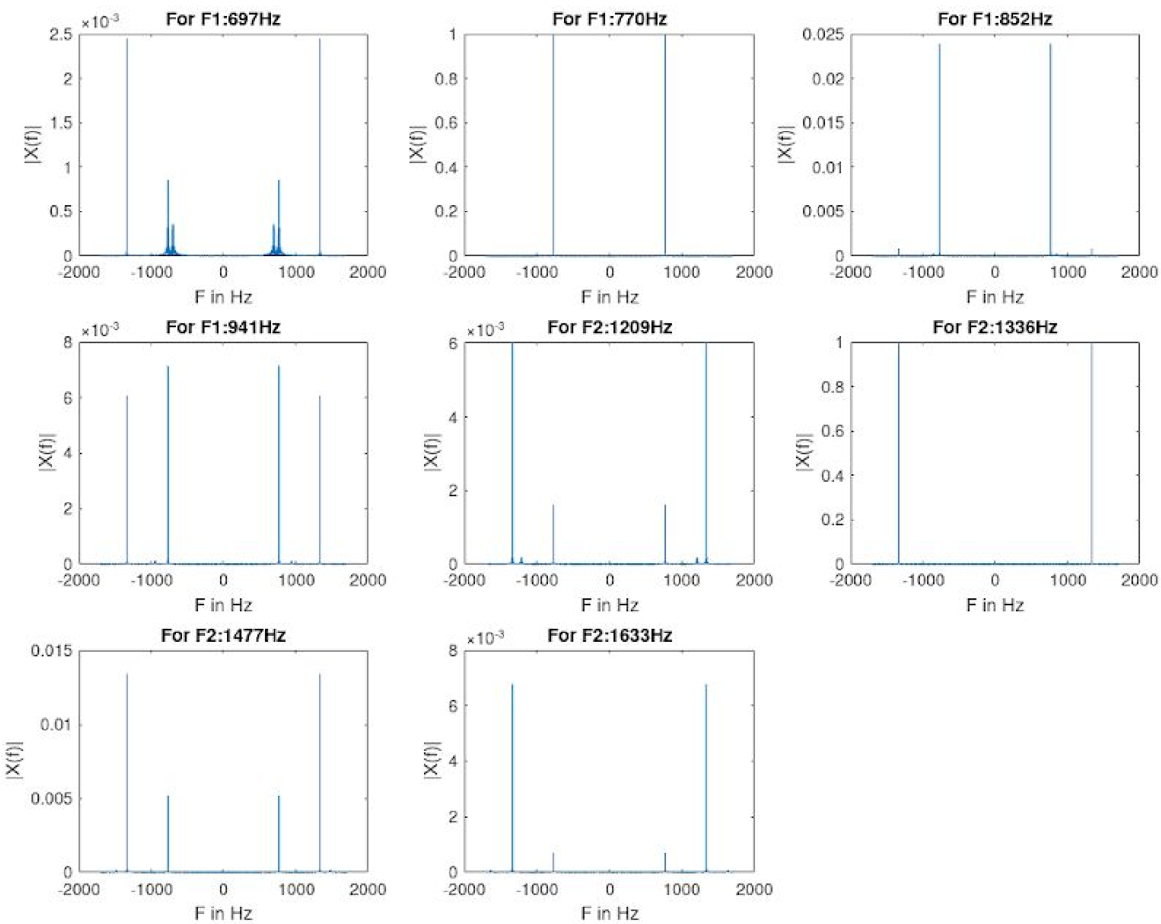


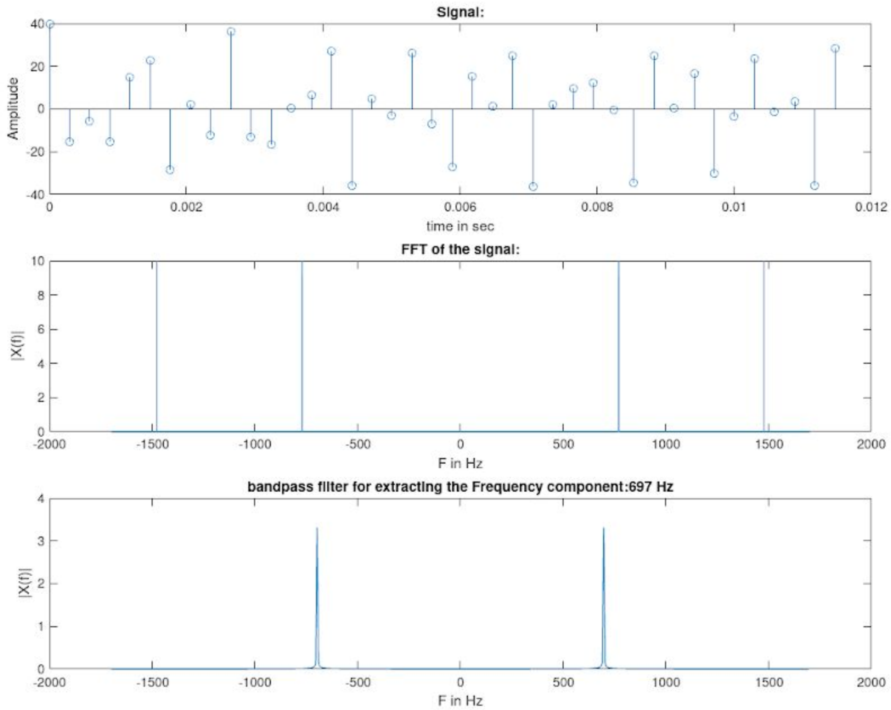


Description :- The below eight plots are those of decoding the character ‘5’

At the command prompt :- Key Pressed :-5

The dialled number is:5

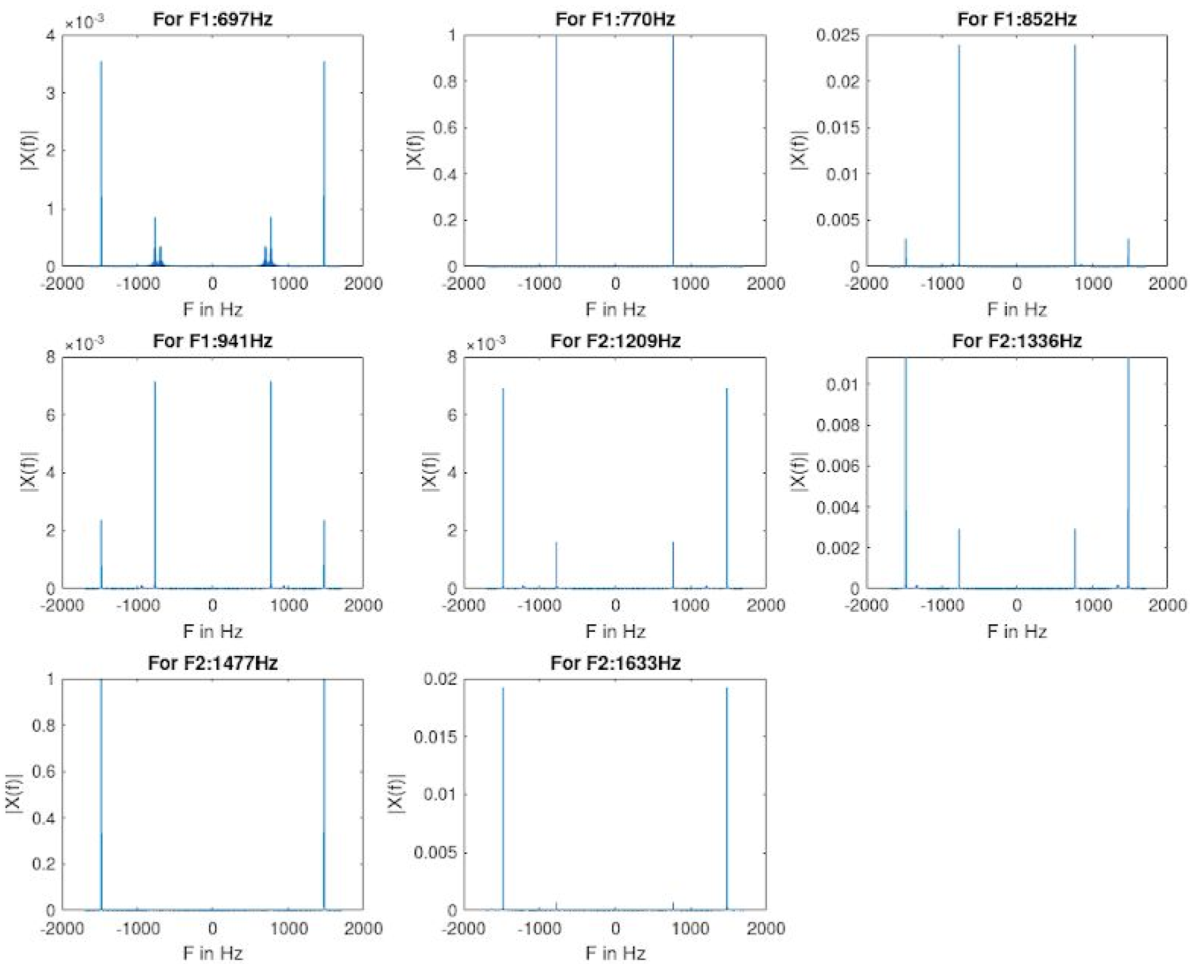


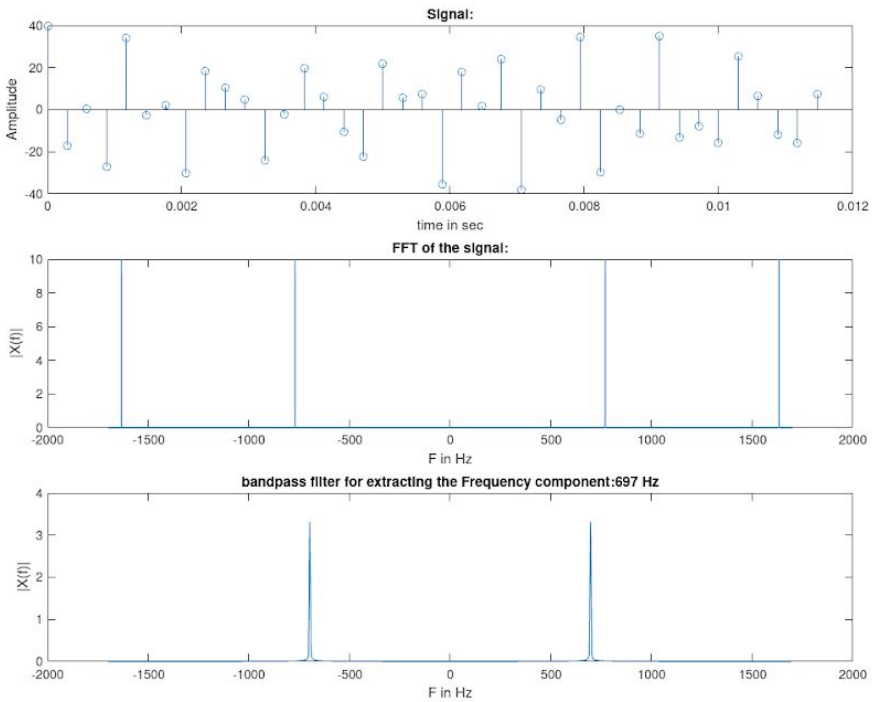


Description :- The below eight plots are those of decoding the character ‘6’

At the command prompt :-   Key Pressed :-6

The dialled number is:6

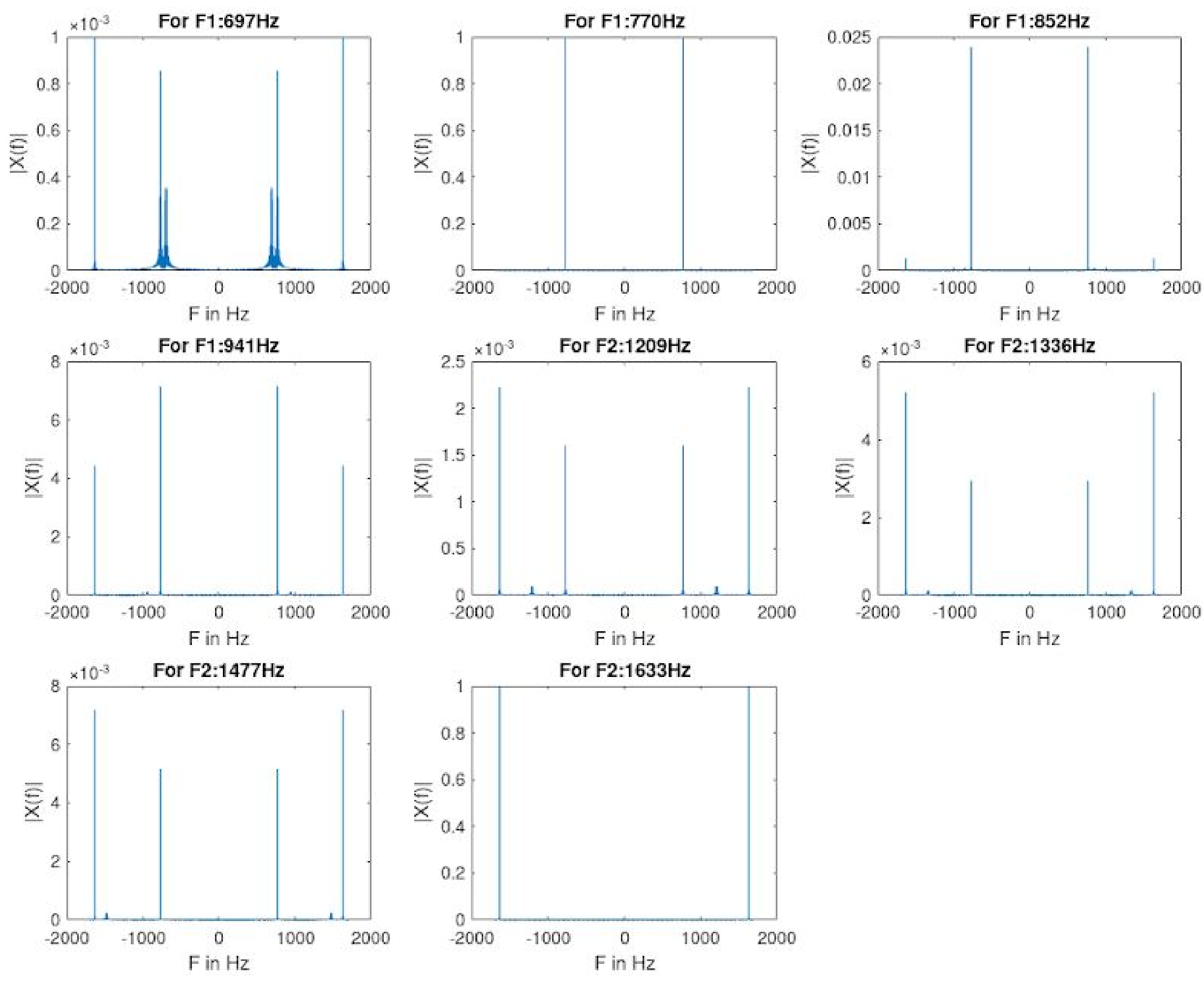


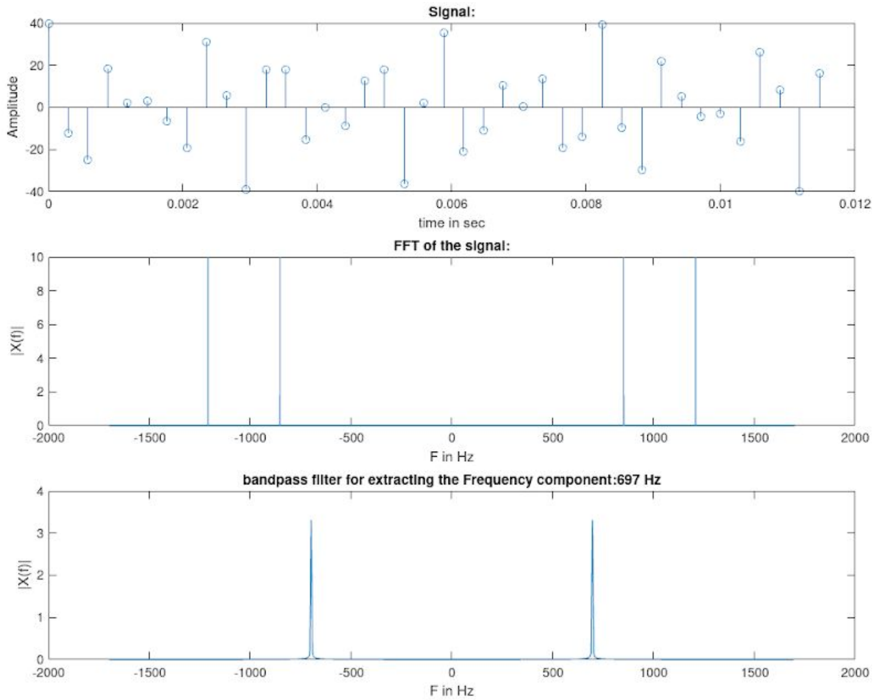


Description :- The below eight plots are those of decoding the character ‘B’

At the command prompt :- Key Pressed :-B

The dialled number is:B

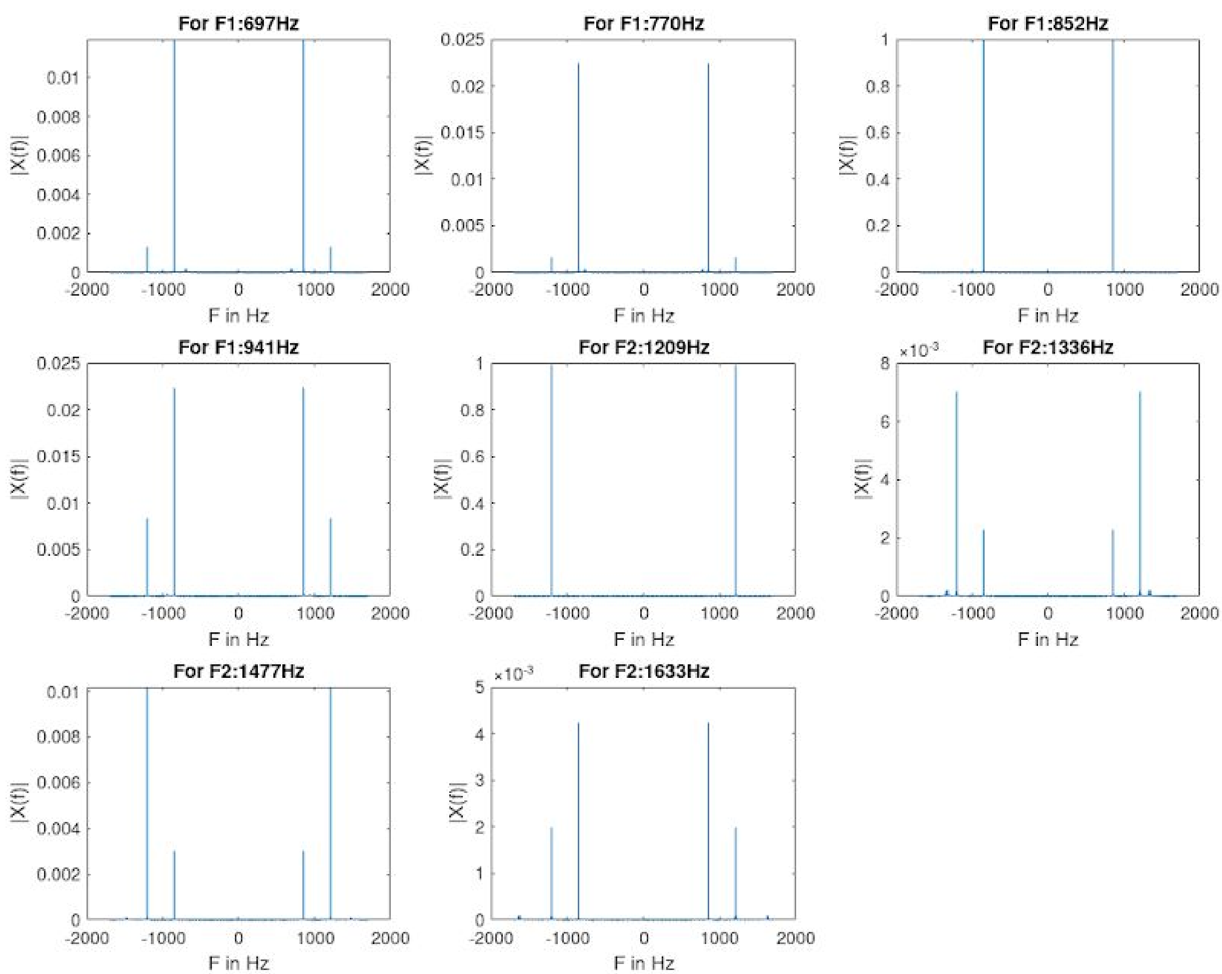


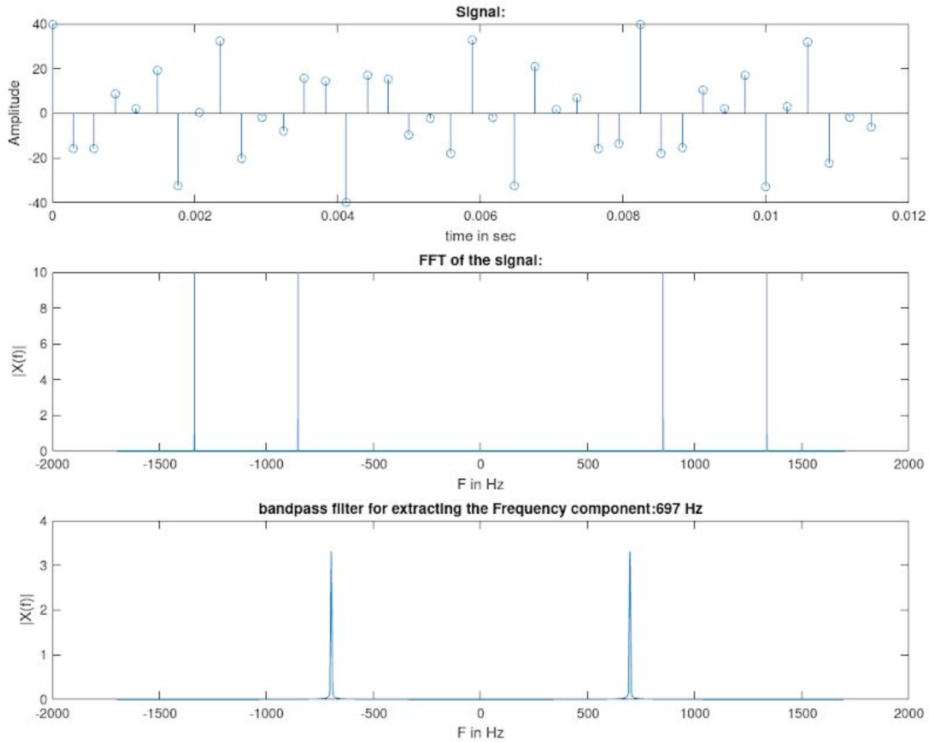


Description :- The below eight plots are those of decoding the character ‘7’

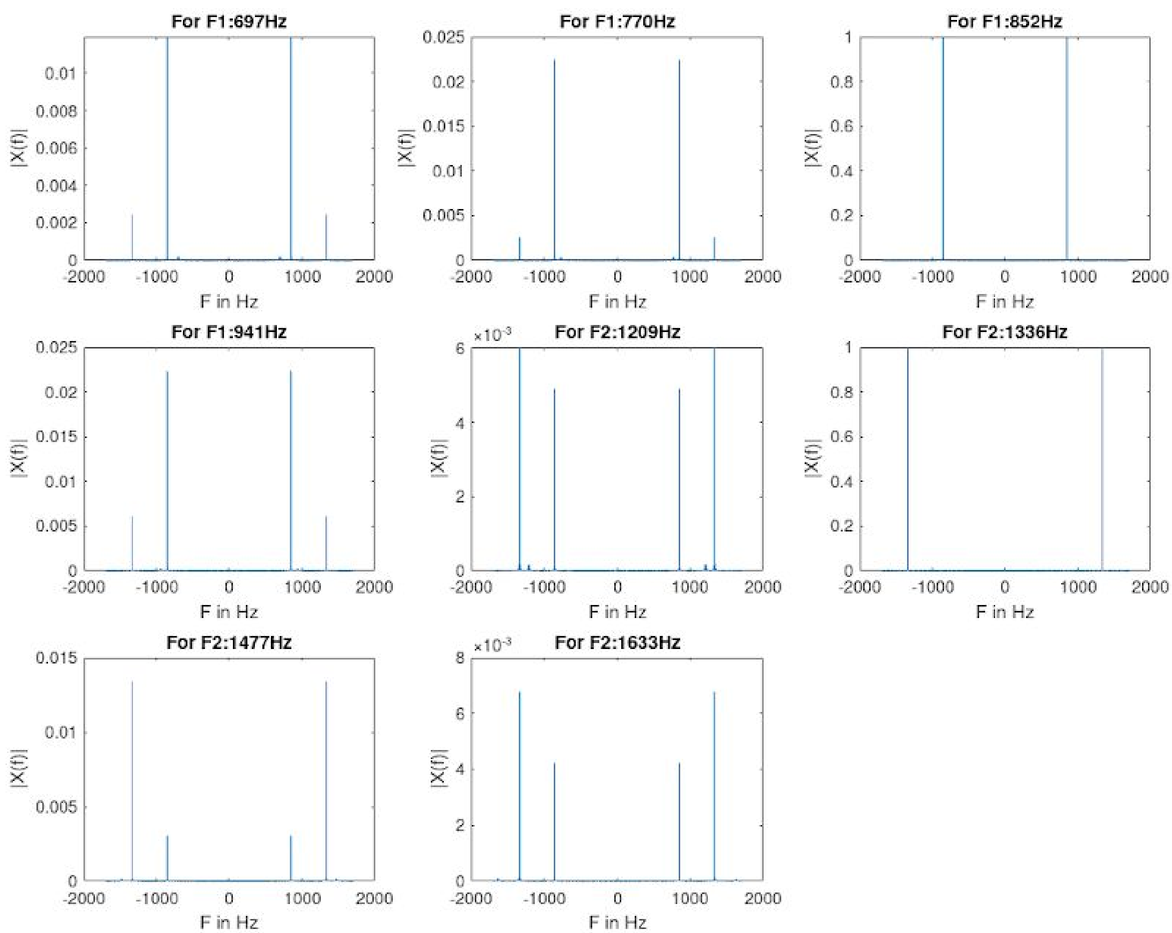
At the command prompt :- Key Pressed :-7

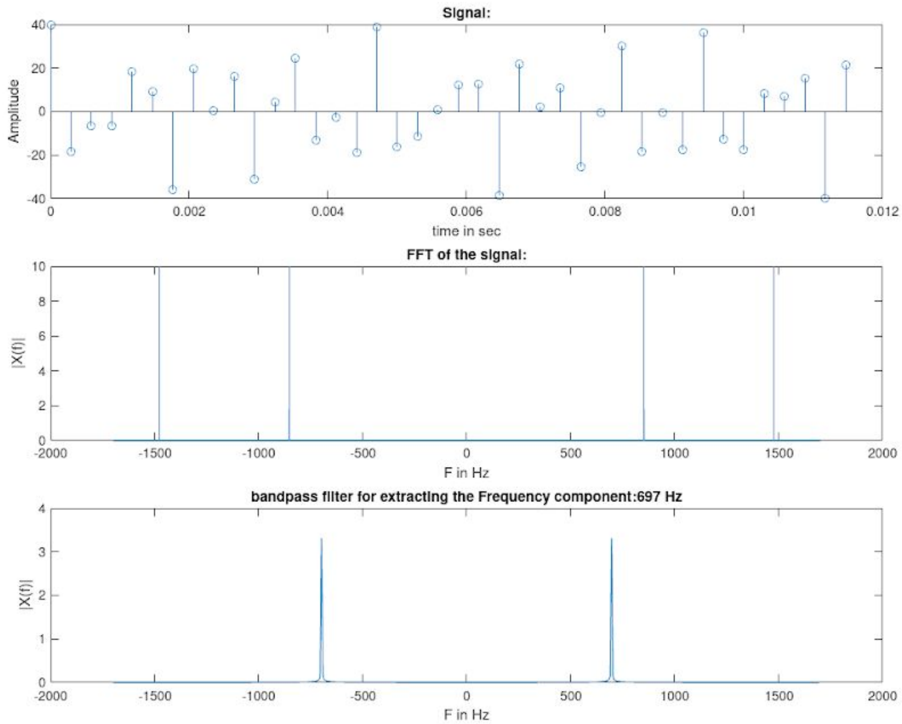
The dialled number is:7





Description :- The below eight plots are those of decoding the character ‘8’
At the command prompt :- Key Pressed :-8
The dialled number is:8

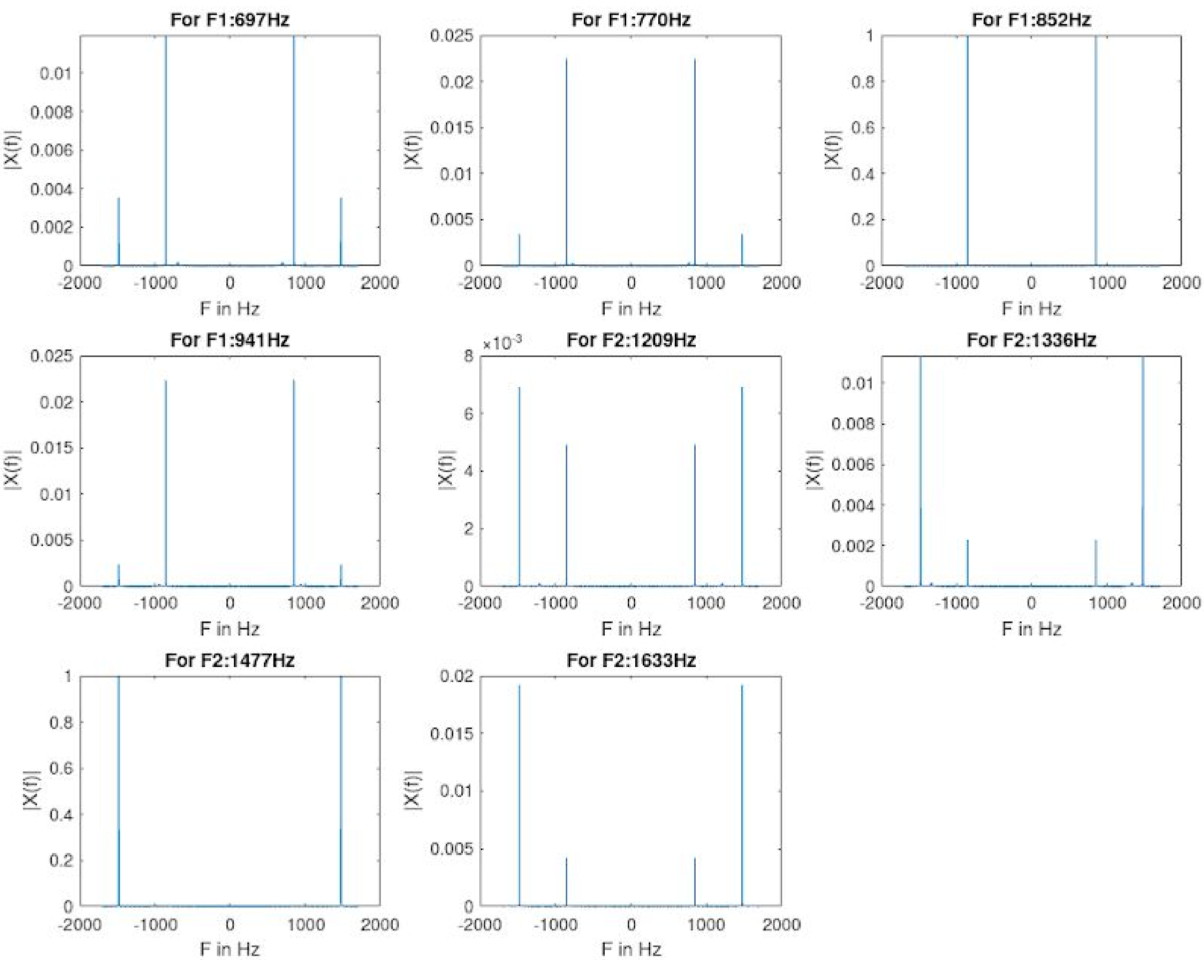


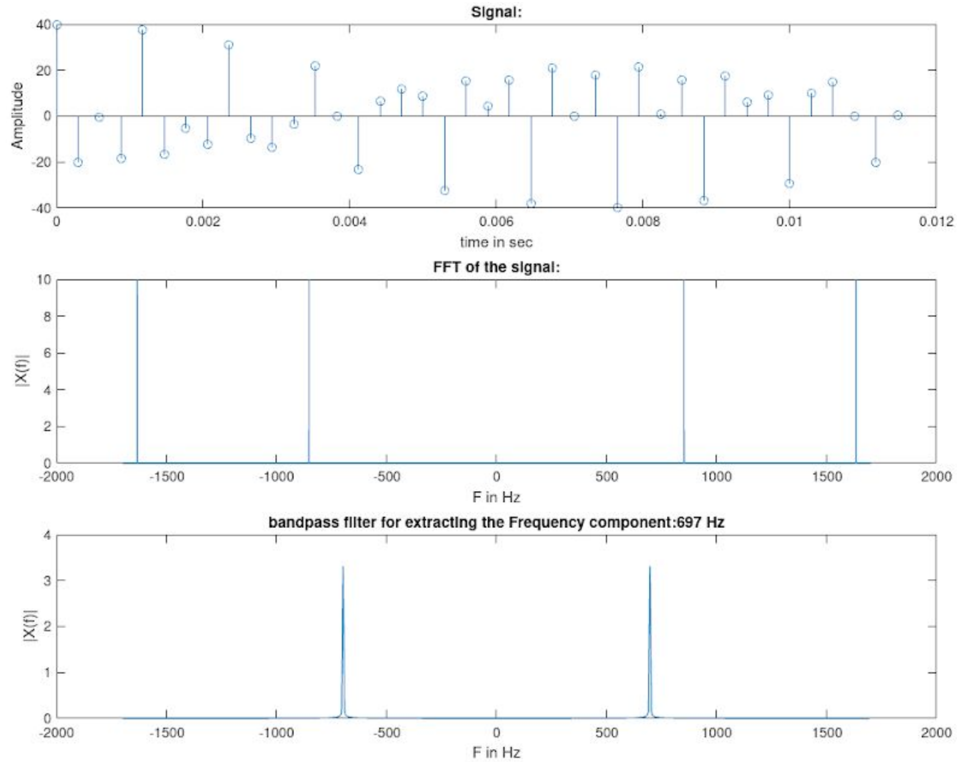


Description :- The below eight plots are those of decoding the character ‘9’

At the command prompt :- Key Pressed :-9

The dialled number is:9

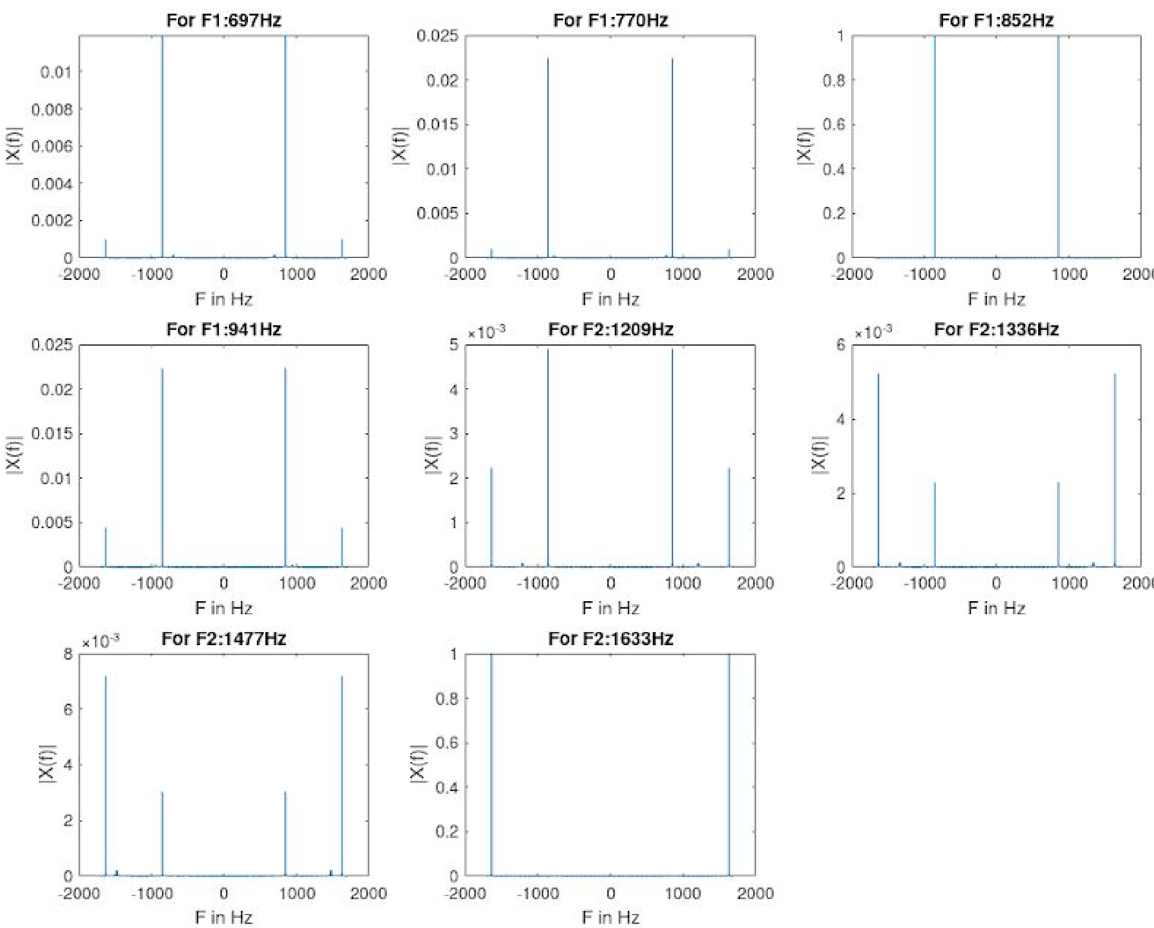


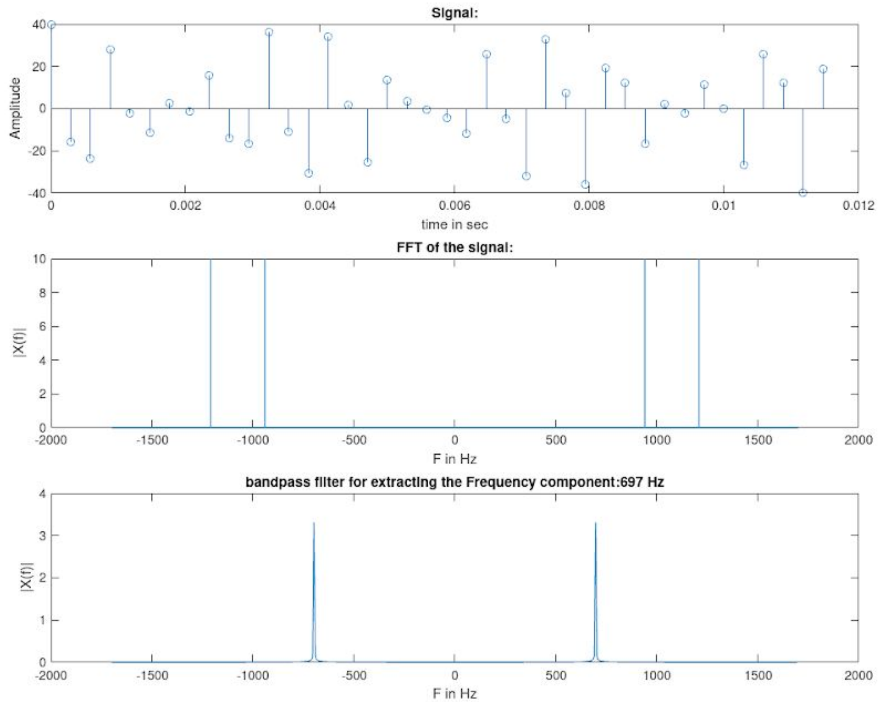


Description :- The below eight plots are those of decoding the character ‘C’

At the command prompt :- Key Pressed :-C

The dialled number is:C

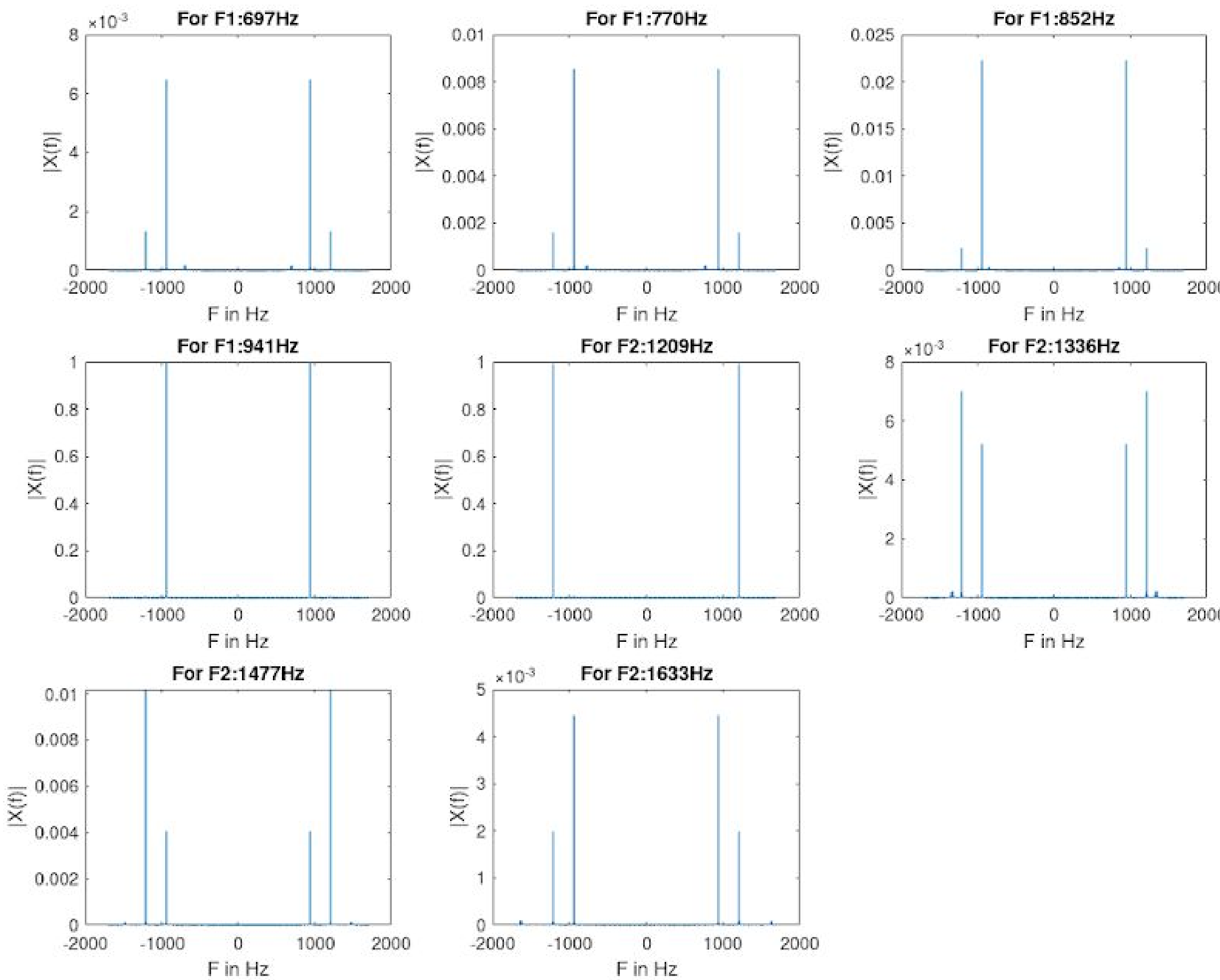


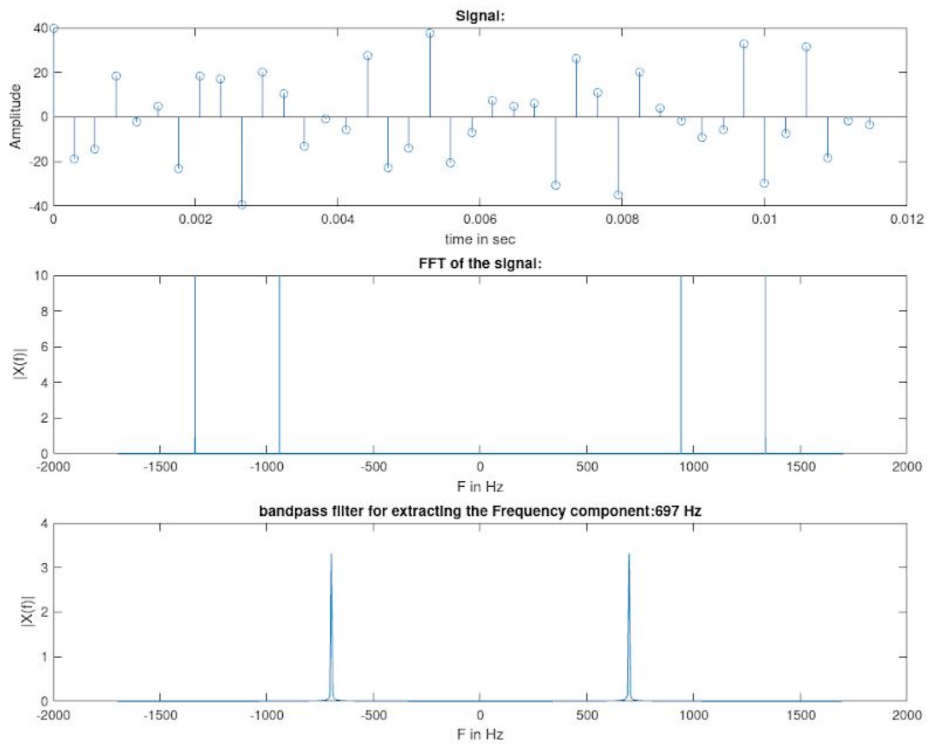


Description :- The below eight plots are those of decoding the character ‘*’

At the command prompt :- Key Pressed :-*

The dialled number is:*

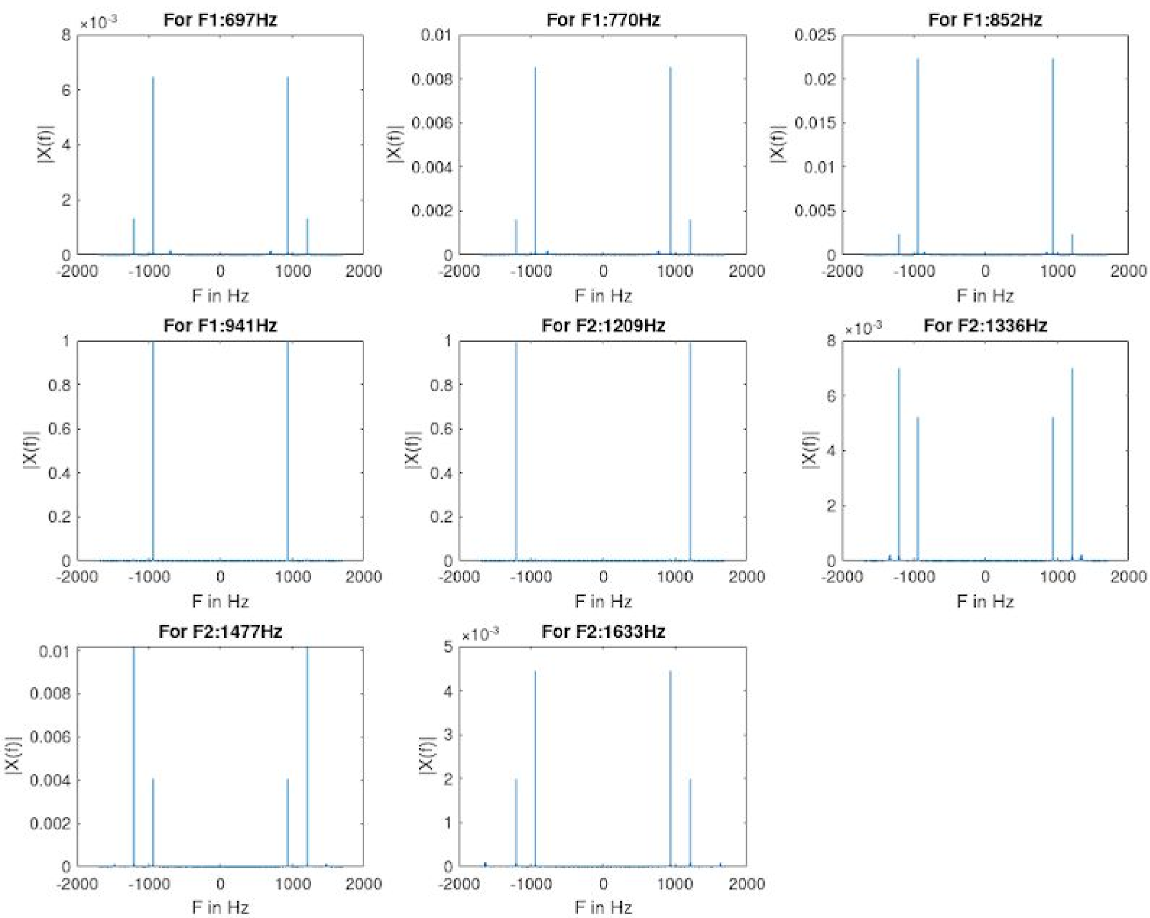


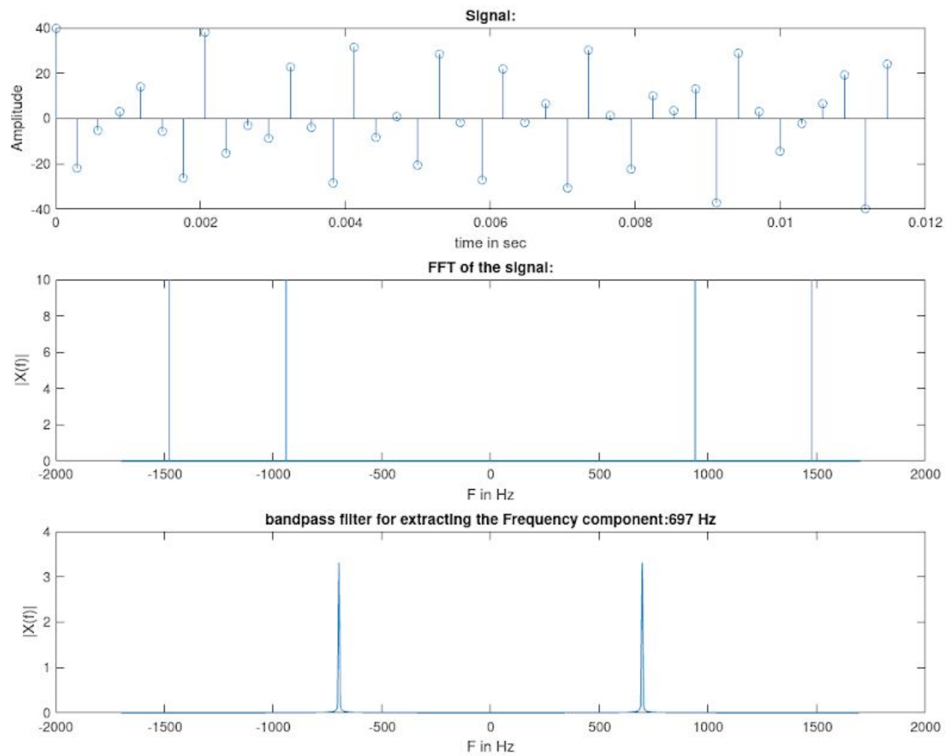


Description :- The below eight plots are those of decoding the character ‘0’

At the command prompt :- Key Pressed :-0

The dialled number is:0

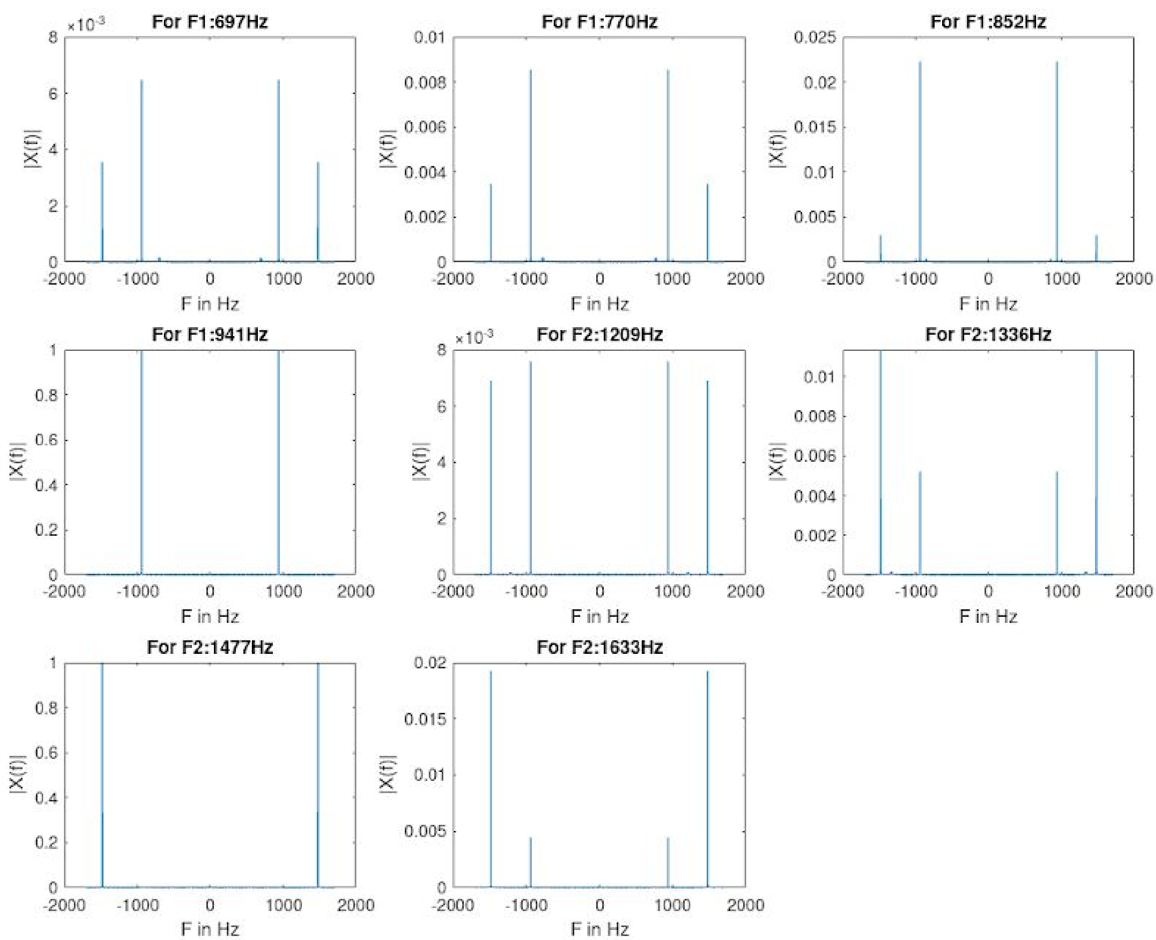


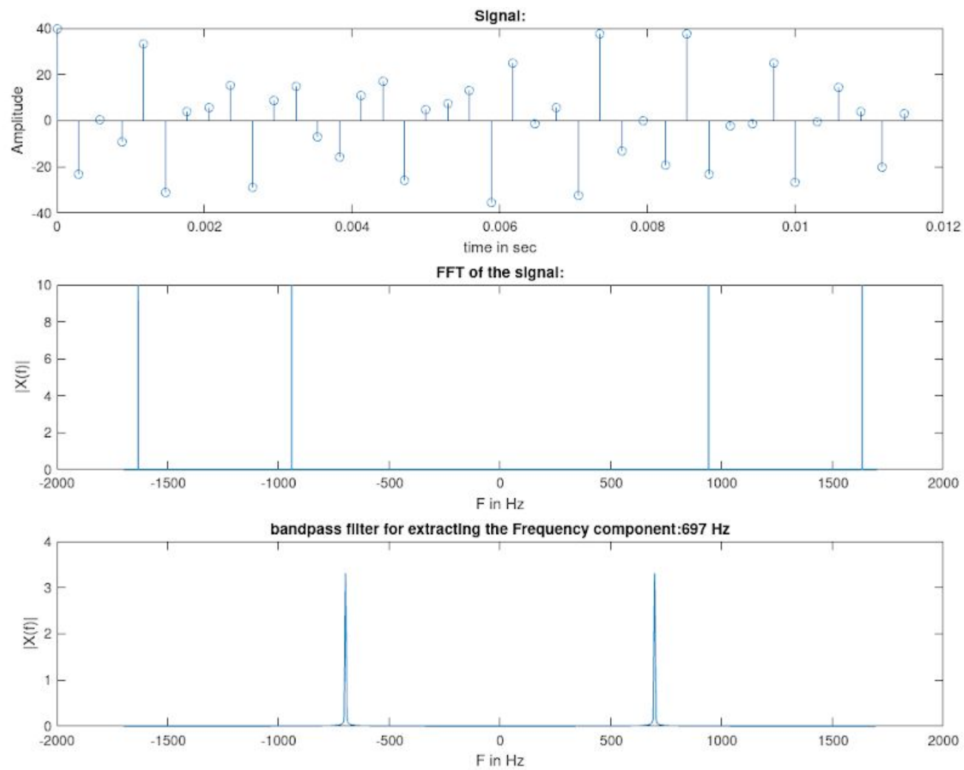


Description :- The below eight plots are those of decoding the character ‘#’

At the command prompt :- Key Pressed :-#

The dialled number is:#

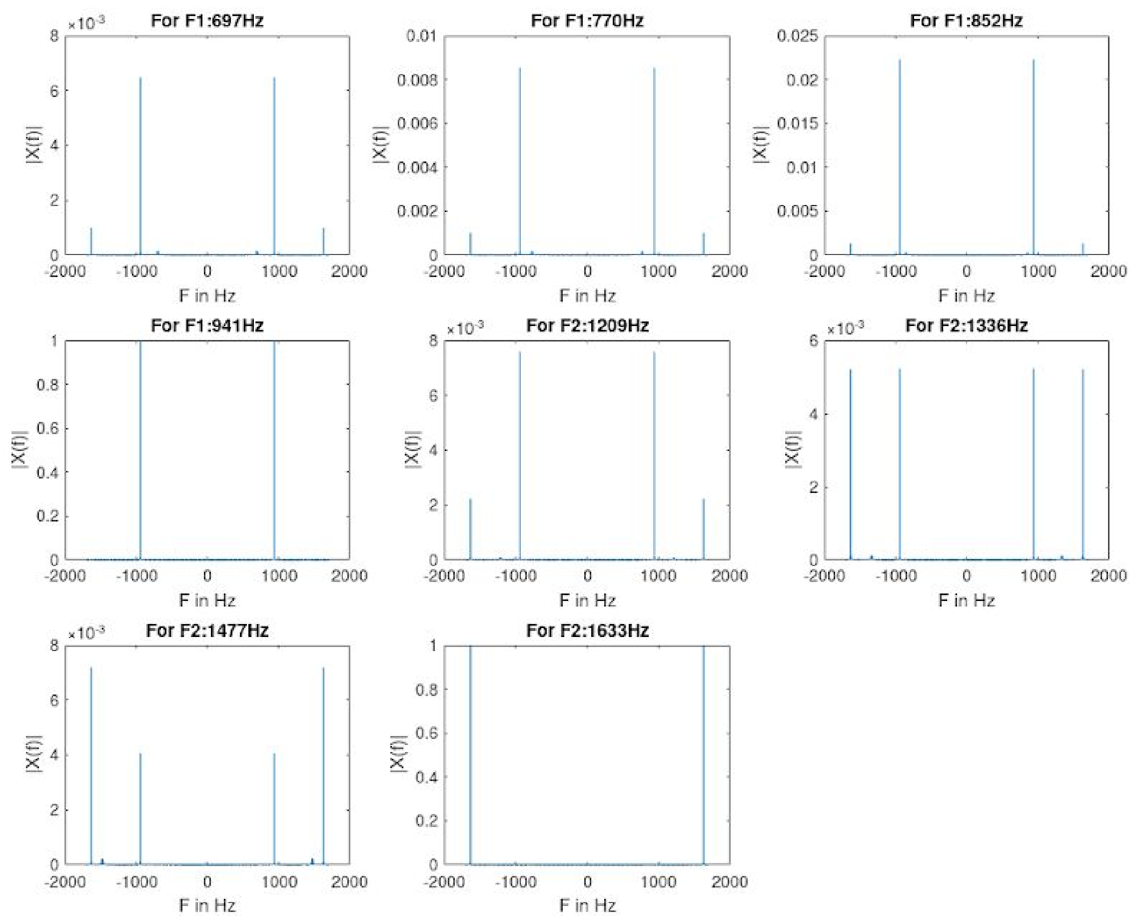




Description :- The below eight plots are those of decoding the character 'D'

At the command prompt :- Key Pressed :-D

The dialled number is:D



Observations and Discussion:

- DTMF (Dual Tone Multifrequency or TouchTone) is a system intended to transmit keys pressed on a keyboard through an audio channel. Every time a key is pressed two audio frequencies are transmitted, one corresponds to the column in which the key is in and the other one corresponds to the row.
- The input taken in the code is a character and it was encoded into cosine signals with their corresponding column and row frequencies.
- Fs (sampling frequency) chosen is 3400 Hz > 2*max(all row and column frequencies) (3266 Hz).
- The N is taken to be 17000 so as to get the 5 sec of signal.
- The row and column frequencies are chosen such that no frequency is an integer multiple of the other and the difference or sum of any two frequencies does not equal to any of the frequencies.
- The L-point FIR filter is chosen as the bandpass filter with L = 512.
- It can be observed that for L =100, the bandwidth increased compared to that of L =512. If the time domain is limited by a finite window width, there will be a spread of peaks in frequency domain and vice versa.
- The β of the filter is chosen in such a way to get unity gain at the required frequency and <1 everywhere else so as to attenuate unwanted frequency components.
- The above summation of cosine signals is passed through eight band pass filters centred at the eight mentioned frequencies and their peaks are compared to extract the frequencies corresponding to that of the top two.
- The above two frequencies are used to output the required character from the table in Page 1.
- The lower case letters ‘a’, ‘b’, ‘c’, ‘d’ have been also taken as a valid input in the program.
- Code for the implementation is given in the next page-APPENDIX.

MATLAB Code:-

```
clear;
Fs=3400; %%sampling frequency
Ts=1/Fs;
N=17000; %%signal length
L=512; %%filter length
time=N/Fs; %%signal is observed till this time from 0 sec
A=20; %%Amplitude of the signal
freq=-(1*Fs)/2:Fs/N:(N-1)*Fs/(2*N); %%sampling frequency
di=['1' '2' '3' 'A' ; '4' '5' '6' 'B' ; '7' '8' '9' 'C' ; '*' '0' '#' 'D']; %%defining the matrix
%% Taking inputs
key=input("Key Pressed :-",'s'); %%the input key
%% The Encoding part
switch (key)
        case {1 2 3 'a' 'A' '1' '2' '3'}
                f1=697;
        case {4 5 6 'b' 'B' '4' '5' '6'}
                f1=770;
        case {7 8 9 'c' 'C' '7' '8' '9'}
                f1=852;
        case {'*' 0 '0' '#' 'D' 'd'}
                f1=941;
end
switch (key)
        case {1 4 7 '*' '1' '4' '7'}
                f2=1209;
        case {2 5 8 0 '0' '2' '5' '8'}
                f2=1336;
        case {3 6 9 '#' '3' '6' '9'}
                f2=1477;
        case {'a' 'b' 'c' 'd' 'A' 'B' 'C' 'D'}
                f2=1633;
end
%% The Decoding part
t=0:Ts:(N-1)*Ts; %%sampling the time till (N-1)*Ts=5sec
x=A*cos(2*pi*f1*t)+A*cos(2*pi*f2*t); %%signal:X(t)
y=fft(x); %%fft of the signal
y=fftshift(y); %%fftshift of the signal
%% For the frequency component:697Hz
h1 = zeros(1,L);
for i=1:L %%defining the impulse response
        h1(i)= ((4*N)/(A*L))*cos(2*pi*Ts*697*(i-1)); %amplitude of cos function is such that fft of output is equal to 1
end
h1_filter=abs(fftshift(fft(h1)))/L;
freq_h1_filter=-(1*Fs)/2:Fs/L:(L-1)*Fs/(2*L); %%sampling frequency
hd1=conv(x,h1,'same'); %%convolving the impulse response with the main signal
y1=fft(hd1);
y1=fftshift(y1);
%% For the frequency component:770Hz
h2 = zeros(1,L);
for i=1:L
        h2(i)= ((4*N)/(A*L))*cos(2*pi*Ts*770*(i-1));
end
hd2=conv(x,h2,'same');
y2=fft(hd2);
y2=fftshift(y2);
```

```
%% For the frequency component:852Hz
h3 = zeros(1,L);
for i=1:L
        h3(i)= ((4*N)/(A*L))*cos(2*pi*Ts*852*(i-1));
end
hd3=conv(x,h3,'same');
y3=fft(hd3);
y3=fftshift(y3);
%% For the frequency component:941Hz
h4 = zeros(1,L);
for i=1:L
        h4(i)= ((4*N)/(A*L))*cos(2*pi*Ts*941*(i-1));
end
hd4=conv(x,h4,'same');
y4=fft(hd4);
y4=fftshift(y4);
%% For the frequency component:1209Hz
h5 = zeros(1,L);
for i=1:L
        h5(i)= ((4*N)/(A*L))*cos(2*pi*Ts*1209*(i-1));
end
hd5=conv(x,h5,'same');
y5=fft(hd5);
y5=fftshift(y5);
%% For the frequency component:1336Hz
h6 = zeros(1,L);
for i=1:L
        h6(i)= ((4*N)/(A*L))*cos(2*pi*Ts*1336*(i-1));
end
hd6=conv(x,h6,'same');
y6=fft(hd6);
y6=fftshift(y6);
%% For the frequency component:1477Hz
h7 = zeros(1,L);
for i=1:L
        h7(i)= ((4*N)/(A*L))*cos(2*pi*Ts*1477*(i-1));
end
hd7=conv(x,h7,'same');
y7=fft(hd7);
y7=fftshift(y7);
%% For the frequency component:1633Hz
h8 = zeros(1,L);
for i=1:L
        h8(i)= ((4*N)/(A*L))*cos(2*pi*Ts*1633*(i-1));
end
hd8=conv(x,h8,'same');
y8=fft(hd8);
y8=fftshift(y8);
%% Plotting the signals:
figure(1)
subplot(311)
stem(t(1:40),x(1:40)); %%considering the only first 20 points of the signal
xlabel('time in sec');
ylabel('Amplitude');
title('Signal:');
subplot(312)
plot(freq,abs(y)/N);
xlabel('F in Hz');
```

```
ylabel('|X(f)|');
title('FFT of the signal:');
subplot(313)
plot(freq_h1_filter,h1_filter);
xlabel('F in Hz');
ylabel('|X(f)|');
title('bandpass filter for extracting the Frequency component:697 Hz');
%% FFT of all the output functions:
figure(2)
subplot(331)
plot(freq,abs(y1)/(N*N));
xlabel('F in Hz');
ylabel('|X(f)|');
title('For F1:697Hz');
subplot(332)
plot(freq,abs(y2)/(N*N));
xlabel('F in Hz');
ylabel('|X(f)|');
title('For F1:770Hz');
subplot(333)
plot(freq,abs(y3)/(N*N));
xlabel('F in Hz');
ylabel('|X(f)|');
title('For F1:852Hz');
subplot(334)
plot(freq,abs(y4)/(N*N));
xlabel('F in Hz');
ylabel('|X(f)|');
title('For F1:941Hz');
subplot(335)
plot(freq,abs(y5)/(N*N));
xlabel('F in Hz');
ylabel('|X(f)|');
title('For F2:1209Hz');
subplot(336)
plot(freq,abs(y6)/(N*N));
xlabel('F in Hz');
ylabel('|X(f)|');
title('For F2:1336Hz');
subplot(337)
plot(freq,abs(y7)/(N*N));
xlabel('F in Hz');
ylabel('|X(f)|');
title('For F2:1477Hz');
subplot(338)
plot(freq,abs(y8)/(N*N));
xlabel('F in Hz');
ylabel('|X(f)|');
title('For F2:1633Hz');
%% Display Part
z1=abs(y1)/(N*N);
z2=abs(y2)/(N*N);
z3=abs(y3)/(N*N);
z4=abs(y4)/(N*N);
z5=abs(y5)/(N*N);
z6=abs(y6)/(N*N);
z7=abs(y7)/(N*N);
z8=abs(y8)/(N*N);
```

```
%% Assigning the corresponding values for row number(r) and column number(c) for the given signal
z=0.9; %% cut-off value
for i=1:length(z1) %%iterate over fft of Y1 and ensure if it has that particular frequency component
        if(z1(i)>=z)
                r=1;
                Continue;
        end
end
for i=1:length(z2)
        If(z2(i)>=z)
                r=2;
                Continue;
        end
end
for i=1:length(z3)
        if(z3(i)>=z)
                r=3;
                Continue;
        end
end
for i=1:length(z4)
        if(z4(i)>=z)
                r=4;
                Continue;
        end
end
for i=1:length(z5)
        if(z5(i)>=z)
                c=1;
                Continue;
        end
end
for i=1:length(z6)
        if(z6(i)>=z)
                c=2;
                Continue;
        end
end
for i=1:length(z7)
        if(z7(i)>=z)
                c=3;
                Continue;
        end
end
for i=1:length(z8)
        if(z8(i)>=z)
                c=4;
                Continue;
        end
end
disp("The dialled number is:");
disp(di(r,c)); %%Display at the output
```