EEE 321 LAB3 OFFLAB ASSIGMENT REPORT

Name/Surname: Muhammet Melih Çelik ID:22003836

Part 1: DTMF Signal and Transceiver

For the DTMF Transmitter the written function can be seen below:

```
function [x_t_main] = DTMFTRA(input_num,samp_int)  %(Number, deltat)

%Lookup table for DTMFTRA
data = {'0',1336,941;
        '1',1209,697;
        '2',1336,697;
        '3',1477,697;
        '4',1209,770;
        '5',1336,770;
        '6',1477,770;
        '7',1209,852;
        '8',1336,852;
        '9',1477,852;
        '*',1209,941;
        '#',1477,941;
        'A',1633,697;
        'B',1633,770;
        'C',1633,852;
        'D',1633,941};

N = length(input_num);
x_t_main = [];         %Empty Signal

    for i = 1:N

        for element = 1:length(data)
            if data{element,1} == input_num(i)
                f1 = data{element,2};
                f2 = data{element,3};
                %t_i = linspace(0.25*(i-1),0.25*i,0.25/samp_int);
                t_i = 0.25*(i-1):samp_int:(0.25*i)-samp_int;
                x_i = cos(2*pi*f1*t_i) + cos(2*pi*f2*t_i);
                x_t_main = [x_t_main x_i];
            end
        end

    end

end
```

The part of the assignment in which the DTMFTRA function was used was also given below:

```
%--------------------EEE 321 LAB3 OFFLAB-------------------------

%PART 1: DTMF Signal and Tranceiver------------------------------

%DTMF Transmitter
samp_int = 1/16384; %Ts
input_num = '05422158574'; %PhoneNumber
gen_signal = DTMFTRA(input_num,samp_int);
soundsc(gen_signal,1/samp_int);
```

The sound was resembling the sound when a number button of an old cabled home telephone is pressed.

DTMF Receiver

Derivations of Fourier Transforms of some signals:

a) $x(t) = \exp(j2\pi f_0 t)\,, x_0(t) = 1 \Rightarrow X_o(j\omega) = 2\pi\delta(t)$ by the frequency shifting property:

$$x(t) = e^{j\omega_0 t}x_0(t) \Rightarrow X(j\omega) = \; 2\pi\delta(\omega - \omega_0)$$

b) $x(t) = cos(2\pi f_o t) = \frac{1}{2}e^{j\omega_0 t} + \frac{1}{2}e^{-j\omega_0 t} \Rightarrow \pi\delta(\omega - \omega_0) + \pi\delta(\omega + \omega_0)$

c) $x(t) = \begin{cases} 1, & |t| < T_0 \\ 0, & otherwise \end{cases}, X(j\omega) = \int_{-\infty}^{+\infty} x(t)e^{-j\omega t}dt = \int_{-T_0}^{+T_0} x(t)e^{-j\omega t}dt$

$$\int_{-T_0}^{+T_0} x(t)e^{-j\omega t}dt = -\frac{1}{j\omega}\left[e^{-j\omega t}\right]_{-T_0}^{+T_0} = \frac{e^{j\omega T_0} - e^{-j\omega T_0}}{j\omega} = \frac{2\sin(\omega T_0)}{\omega}$$

d) $x(t) = \exp(j2\pi f_0 t)\, x_0(t)\,, x_0(t) = \begin{cases} 1, & |t| < \frac{T_0}{2} \\ 0, & otherwise \end{cases}$ from the properties if two signal are multiplied the Fourier transform of the resulting signal has the convolution of Fourier transforms of those two signals.

$$x(t) = \; \exp(j2\pi f_0 t)\, x_0(t), x_0(t) \; \Rightarrow \frac{1}{2\pi}[X_1(j\omega) * X_0(j\omega)]$$

$$X_1(j\omega) * X_0(j\omega) = \int_{-\infty}^{+\infty} X_1(j\xi)X_0\big(j(\omega - \xi)\big)\, d\xi$$

$$\int_{-\infty}^{+\infty} [\pi\delta(\xi-\omega_0)] \frac{2\sin\left(\frac{(\omega-\xi)T_0}{2}\right)}{(\omega-\xi)} d\xi$$

$$= \frac{\sin\left(\frac{(\omega-\omega_0)T_0}{2}\right)}{(\omega-\omega_0)}$$

e) $x(t) = cos(2\pi f_o t)\, x_0(t), x_0(t) = \begin{cases} 1, & |t| < \frac{T_0}{2} \\ 0, & otherwise \end{cases}$ as mentioned in previous example:

$$x(t) = cos(2\pi f_o t)\, x_0(t), x_0(t) \Rightarrow \frac{1}{2\pi}[X_1(j\omega) * X_0(j\omega)]$$

$$X_1(j\omega) * X_0(j\omega) = \int_{-\infty}^{+\infty} X_1(j\xi) X_0\big(j(\omega-\xi)\big)\, d\xi$$

$$\int_{-\infty}^{+\infty} [\pi\delta(\xi-\omega_0) + \pi\delta(\xi+\omega_0)] \frac{2\sin\left(\frac{(\omega-\xi)T_0}{2}\right)}{(\omega-\xi)} d\xi$$

$$= \frac{\sin\left(\frac{(\omega-\omega_0)T_0}{2}\right)}{(\omega-\omega_0)} + \frac{\sin\left(\frac{(\omega+\omega_0)T_0}{2}\right)}{\pi(\omega+\omega_0)}$$

f) $x(t) = \begin{cases} 1, & |t-t_0| < \frac{T_0}{2} \\ 0, & otherwise \end{cases}$; by the time shifting property of the Fourier transform,

$$X(j\omega) = X_0(j\omega)e^{j\omega t_0} \Rightarrow X(j\omega) = \frac{2\sin\left(\frac{\omega T_0}{2}\right)}{\omega}\, e^{-j\omega t_0}$$

g) $x(t) = \exp(j2\pi f_0 t)\, x_0(t)\,, x_0(t) = \begin{cases} 1, & |t-t_0| \leq \frac{T_0}{2}; \\ 0, & otherwise \end{cases}$ multiplication-convolution property pair can be used again here:

$$x(t) = \exp(j2\pi f_0 t)\, x_0(t), x_0(t) \Rightarrow \frac{1}{2\pi}[X_1(j\omega) * X_0(j\omega)]$$

$$X_1(j\omega) * X_0(j\omega) = \int_{-\infty}^{+\infty} X_1(j\xi) X_0\big(j(\omega-\xi)\big)\, d\xi$$

$$\int_{-\infty}^{+\infty} \pi\delta(\xi-\omega_0)\frac{2\sin\left(\frac{(\omega-\xi)T_0}{2}\right)}{(\omega-\xi)}\,e^{-j(\omega-\xi)t_0}\,d\xi$$

$$=\frac{\sin\left(\frac{(\omega-\omega_0)T_0}{2}\right)}{(\omega-\omega_0)}\,e^{-j(\omega-\omega_0)t_0}$$

h) $x(t) = cos(2\pi f_o t)\,x_0(t), x_0(t) = \begin{cases} 1, & |t-t_0| < \frac{T_0}{2} \\ 0, & otherwise \end{cases}$; the results that were obtained on previous examples can be directly used:

$$x(t) = cos(2\pi f_o t)\,x_0(t), x_0(t) \Rightarrow \frac{1}{2\pi}[X_1(j\omega) * X_0(j\omega)]$$

$$X_1(j\omega) * X_0(j\omega) = \int_{-\infty}^{+\infty} X_1(j\xi)X_0\big(j(\omega-\xi)\big)\,d\xi$$

$$\int_{-\infty}^{+\infty}[\pi\delta(\xi-\omega_0)+\pi\delta(\xi+\omega_0)]\frac{2\sin\left(\frac{(\omega-\xi)T_0}{2}\right)}{(\omega-\xi)}\,e^{-j(\omega-\xi)t_0}\,d\xi$$

$$=\frac{\sin\left(\frac{(\omega-\omega_0)T_0}{2}\right)}{\pi(\omega-\omega_0)}e^{-j(\omega-\omega_0)t_0}+\frac{\sin\left(\frac{(\omega+\omega_0)T_0}{2}\right)}{\pi(\omega+\omega_0)}e^{-j(\omega+\omega_0)t_0}$$

For the DTMF Receiver part, the number was used as the emergency number of our university which is given below:

```
%DTMF Receiver

samp_int = 1/16384; %delta_t
Number = '03122900666';
x = DTMFTRA(Number,samp_int);%Received signal

X = FT(x); %Fourier transform of the received signal.
omega=linspace(-16384*pi,16384*pi,16384*2.75+1);
omega=omega(1:end-1);

clf;
plot(omega,abs(X),"k");
title ('$Frequency\,\,Components\,\,of\,\,Received\,\,Signal$',...
        'Interpreter','latex','FontSize',14);
ylabel ('$X(j\omega)$','Interpreter','latex','FontSize',14);
xlabel ('$\omega$','Interpreter','latex','FontSize',14);
grid on;
ax = gca;
ax.YLabel.Rotation = 360;
```

The Fourier Transform of the X(jω) can be seen in Figure 1.

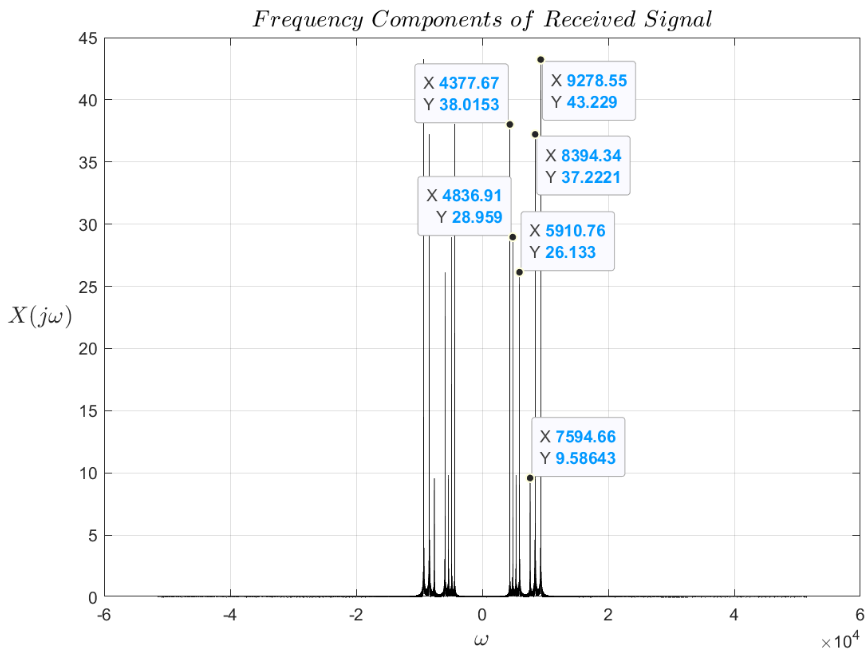

Figure 1: Fourier Transform Plot of the x(t)

The frequency component of the received signal was clearly present in Figure 1.

$$\frac{4377.67}{2\pi} \cong 696.72 \cong 697\ Hz$$

$$\frac{4896.91}{2\pi} \cong 779.36 \Rightarrow 770\ Hz$$

$$\frac{5910.76}{2\pi} \cong 940.72 \cong 941\ Hz$$

$$\frac{7594.66}{2\pi} \cong 1208.62 \cong 1209\ Hz$$

$$\frac{8394.34}{2\pi} \cong 1336\ Hz$$

$$\frac{9278.55}{2\pi} \cong 1476.72 \cong 1477\ Hz$$

So, it is obvious that the peaks give the frequencies that were used by DTMF Transceivers. However, jut by looking at these frequencies, the number dialed cannot be determined as this plot contains all the frequency components of the digits of which the number composed.

For individual digits, firstly $x_6(t)$, was defined as:

$$x_6(t) = \begin{cases} x(t), & for\ 1.25 \leq t < 1.5 \\ 0, & otherwise \end{cases}$$

In the same manner, for digits and $x_t(t)$ was defined to determine the digit. The determination of separate signals and taking the Fourier Transform of each signal were given below:

```
% Investigating and Plotting Seperate Digits

samp_int = 1/16384; %Ts
%Number = input("Bilkent emergency line: ","s");
Number = '03122900666';
x = DTMFTRA(Number,samp_int);

x_1 = zeros(1,length(x));
x_2 = zeros(1,length(x));
x_3 = zeros(1,length(x));
x_4 = zeros(1,length(x));
x_5 = zeros(1,length(x));
x_6 = zeros(1,length(x));
x_7 = zeros(1,length(x));
x_8 = zeros(1,length(x));
x_9 = zeros(1,length(x));
x_10 = zeros(1,length(x));
x_11 = zeros(1,length(x));

x_1(1:(0.25/samp_int)-1)            = x(1:(0.25/samp_int)-1);
x_2(0.25/samp_int:(0.5/samp_int)-1) = x(0.25/samp_int:(0.5/samp_int)-1);
x_3(0.5/samp_int:(0.75/samp_int)-1) = x(0.5/samp_int:(0.75/samp_int)-1);
x_4(0.75/samp_int:(1/samp_int)-1)   = x(0.75/samp_int:(1/samp_int)-1);
x_5(1/samp_int:(1.25/samp_int)-1)   = x(1/samp_int:(1.25/samp_int)-1);
x_6(1.25/samp_int:(1.5/samp_int)-1) = x(1.25/samp_int:(1.5/samp_int)-1);
x_7(1.5/samp_int:(1.75/samp_int)-1) = x(1.5/samp_int:(1.75/samp_int)-1);
x_8(1.75/samp_int:(2/samp_int)-1)   = x(1.75/samp_int:(2/samp_int)-1);
x_9(2/samp_int:(2.25/samp_int)-1)   = x(2/samp_int:(2.25/samp_int)-1);
x_10(2.25/samp_int:(2.5/samp_int)-1) = x(2.25/samp_int:(2.5/samp_int)-1);
x_11(2.5/samp_int:(2.75/samp_int)-1) = x(2.5/samp_int:(2.75/samp_int)-1);

X_1 = FT(x_1);
X_2 = FT(x_2);
X_3 = FT(x_3);
X_4 = FT(x_4);
X_5 = FT(x_5);
X_6 = FT(x_6);
X_7 = FT(x_7);
X_8 = FT(x_8);
X_9 = FT(x_9);
X_10 = FT(x_10);
X_11 = FT(x_11);
```

Each digit’s Fourier transform plot and the frequencies of the digits were given in the figures 2-13 below:

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

Figure 2: Frequencies of Digits

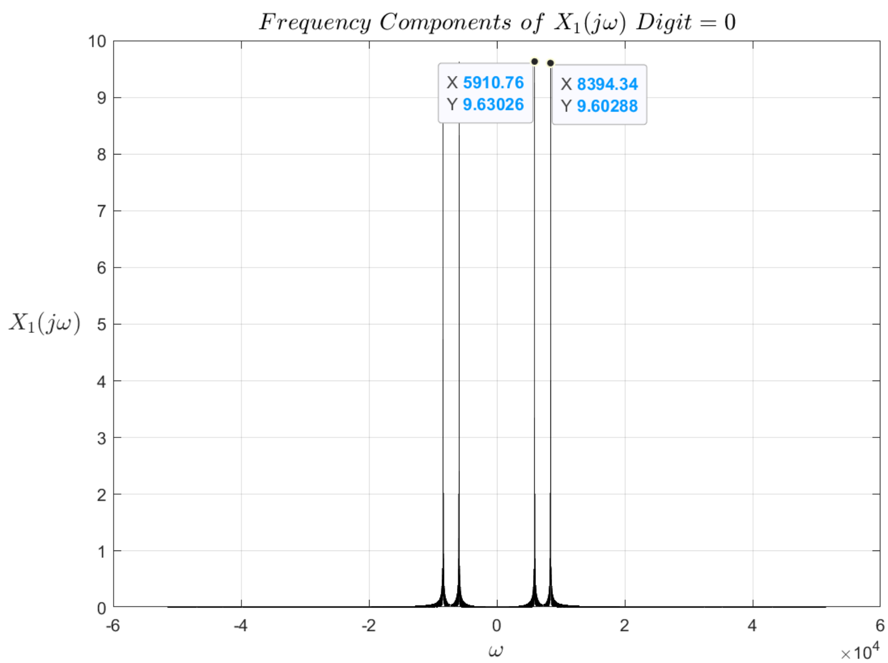

Figure 3: Digit Zero FT

$$\frac{5910.76}{2\pi} \cong 940.72 \cong 941\ Hz, \qquad \frac{8394.34}{2\pi} \cong 1336\ Hz$$

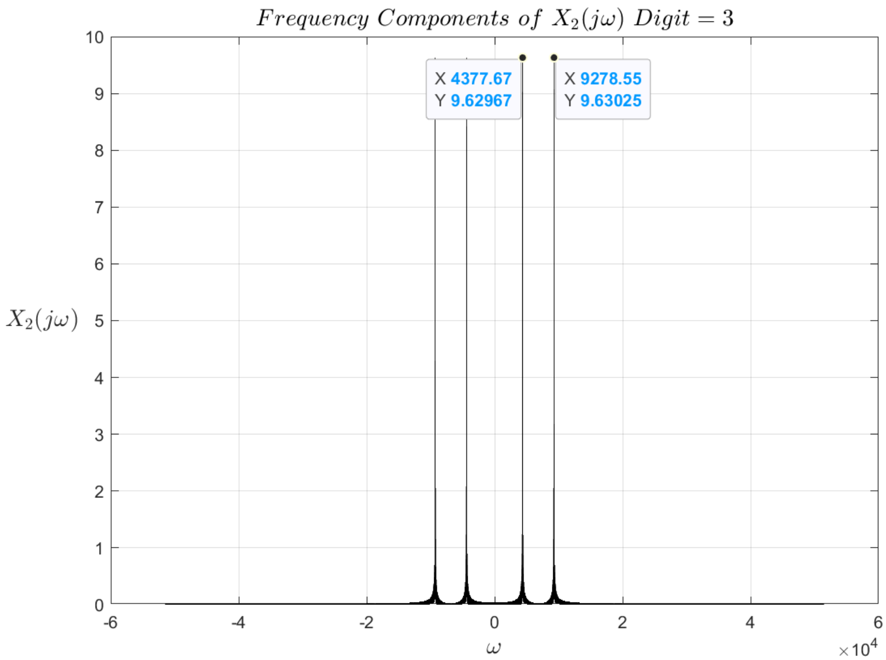

Figure 4: Digit Three FT

$$\frac{4377.67}{2\pi} \cong 696.72 \cong 697\ Hz, \qquad \frac{9278.55}{2\pi} \cong 1476.72 \cong 1477\ Hz$$

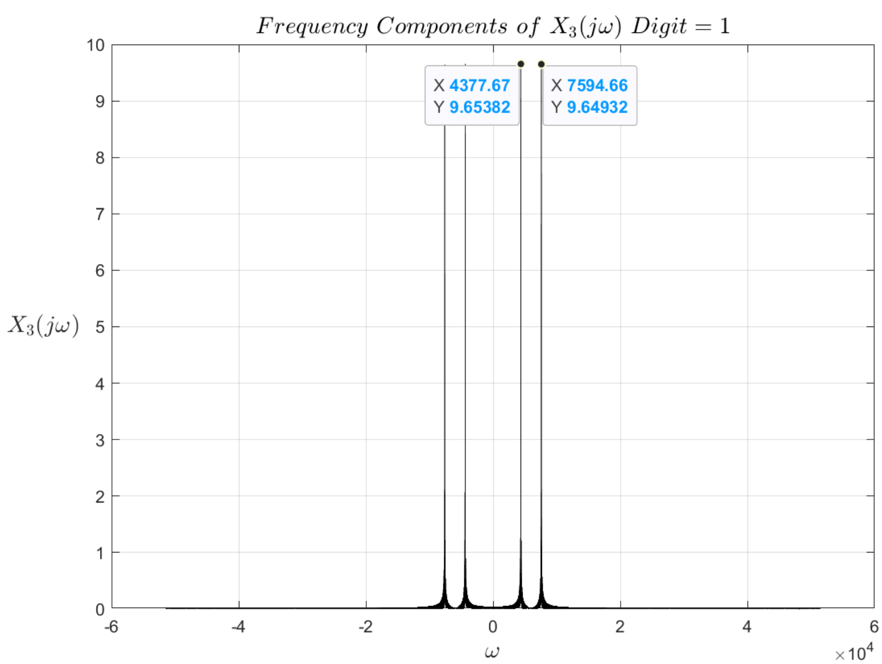

Figure 5: Digit Two FT

$$\frac{4377.67}{2\pi} \cong 696.72 \cong 697\ Hz, \qquad \frac{7594.66}{2\pi} \cong 1209\ Hz$$

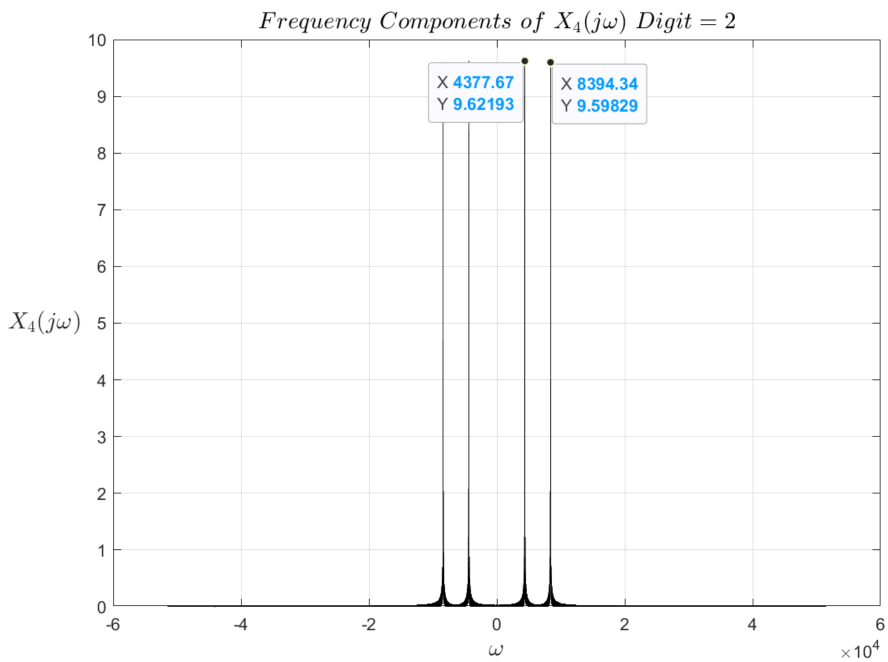

Figure 6: Digit Two in x(t) FT

$$\frac{4377.67}{2\pi} \cong 696.72 \cong 697\ Hz, \qquad \frac{8394.34}{2\pi} \cong 1336\ Hz$$

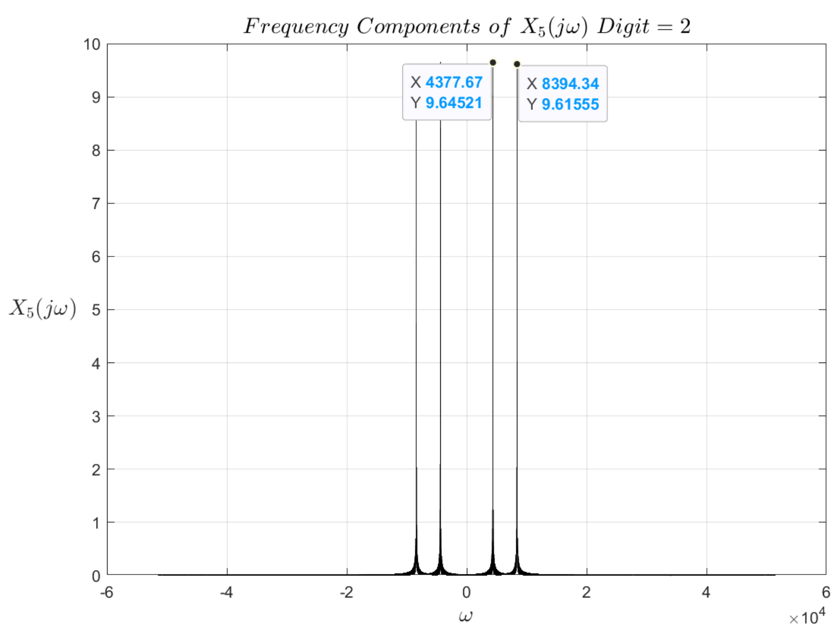

Figure 7: Second Digit Two in x(t) FT

$$\frac{4377.67}{2\pi} \cong 696.72 \cong 697\ Hz, \qquad \frac{8394.34}{2\pi} \cong 1336\ Hz$$

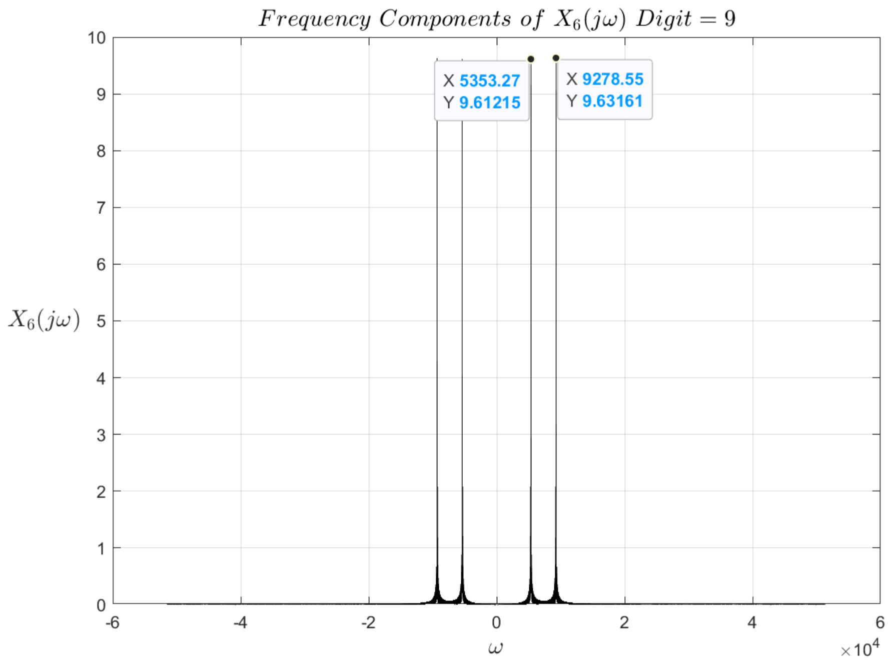

Figure 8: Digit Nine FT

$$\frac{5353.27}{2\pi} \cong 852.04 \cong 852\ Hz, \qquad \frac{9278.55}{2\pi} \cong 1476.72 \cong 1477\ Hz$$

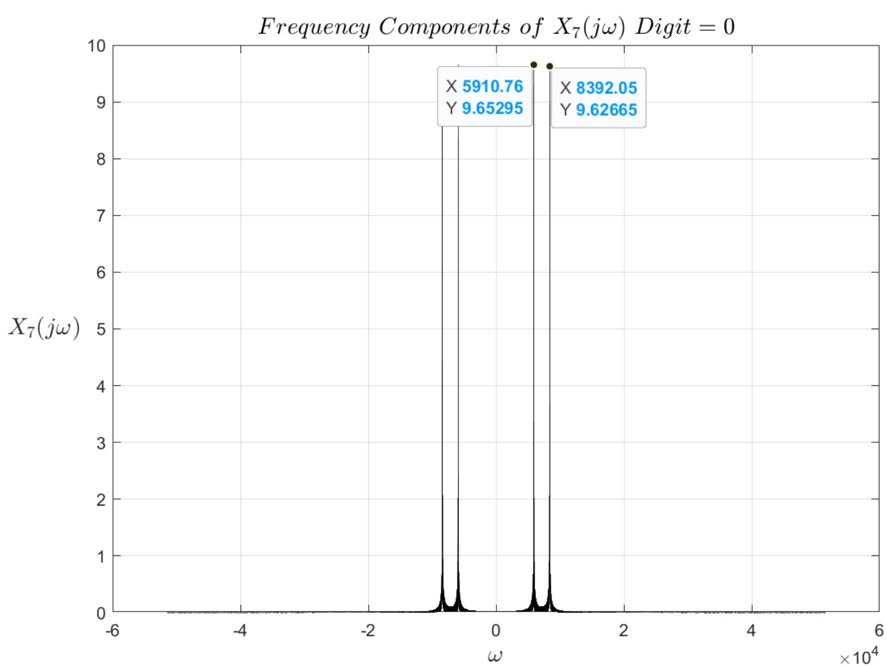

Figure 9: Second Digit Zero in x(t) FT

$$\frac{5910.76}{2\pi} \cong 940.72 \cong 941\ Hz, \qquad \frac{8394.34}{2\pi} \cong 1336\ Hz$$

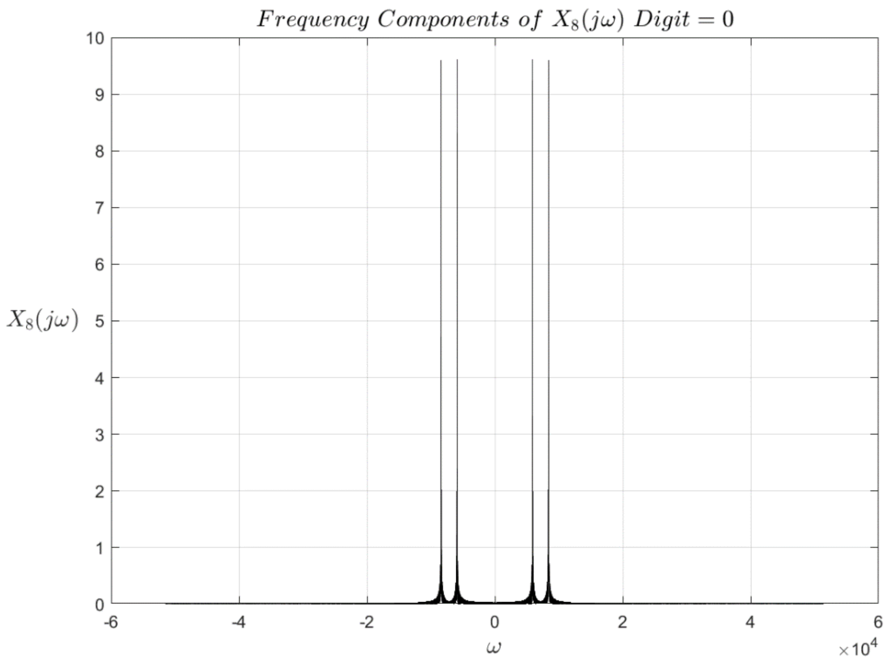

Figure 10: Third Digit Zero in x(t) FT

$$\frac{5910.76}{2\pi} \cong 940.72 \cong 941\ Hz, \qquad \frac{8394.34}{2\pi} \cong 1336\ Hz$$

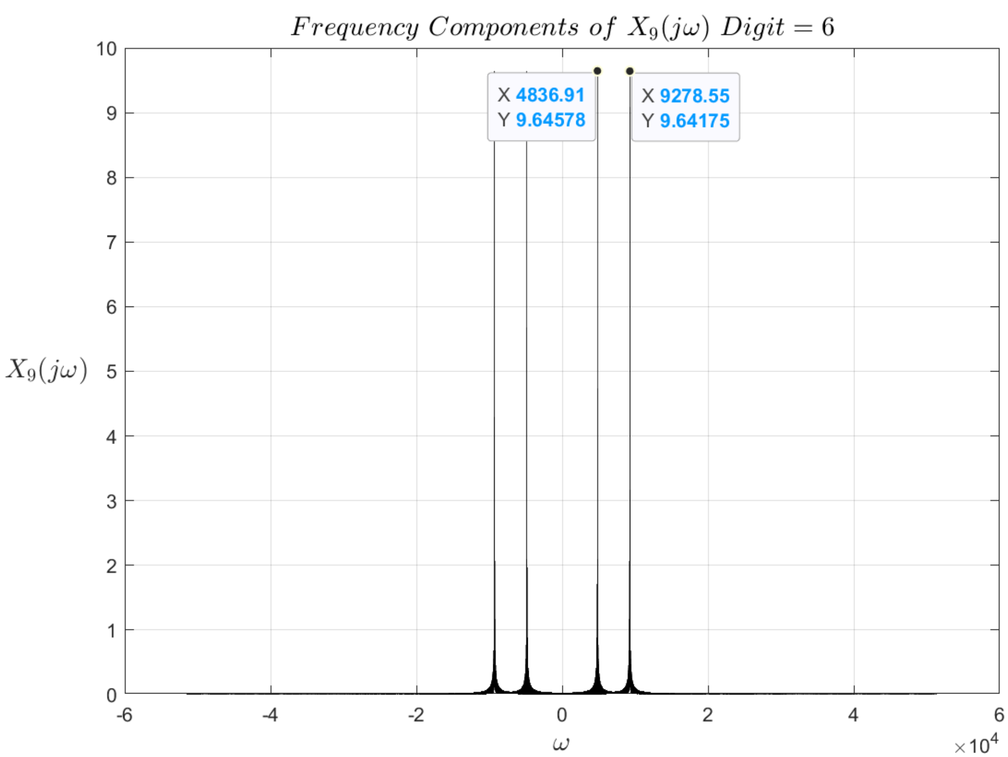

Figure 11: Digit Six FT

$$\frac{4896.91}{2\pi} \cong 779.36 \Rightarrow 770\ Hz, \qquad \frac{9278.55}{2\pi} \cong 1476.72 \cong 1477\ Hz$$

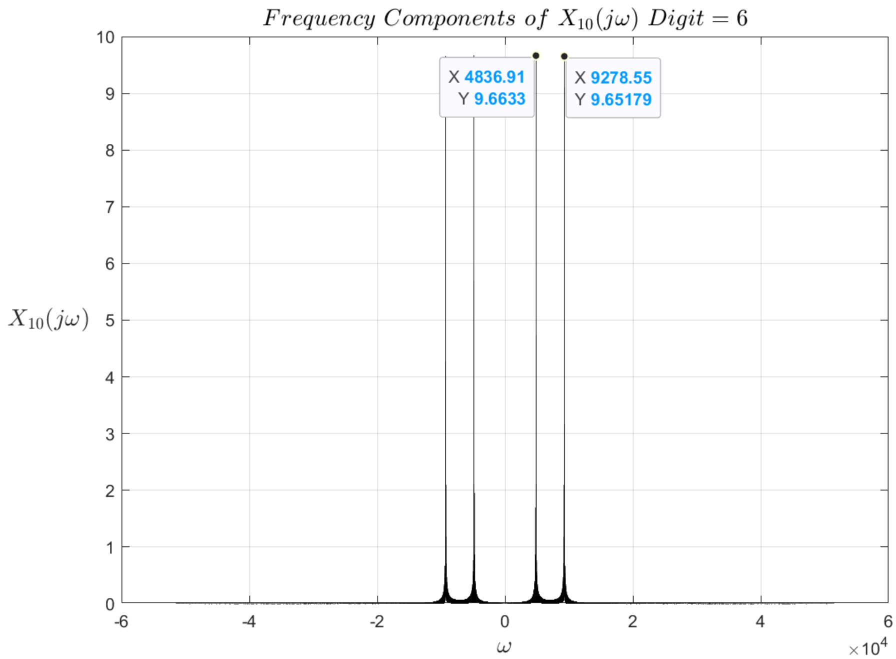

Figure 12: Second Digit Six in x(t) FT

$$\frac{4896.91}{2\pi} \cong 779.36 \Rightarrow 770\ Hz, \qquad \frac{9278.55}{2\pi} \cong 1476.72 \cong 1477\ Hz$$

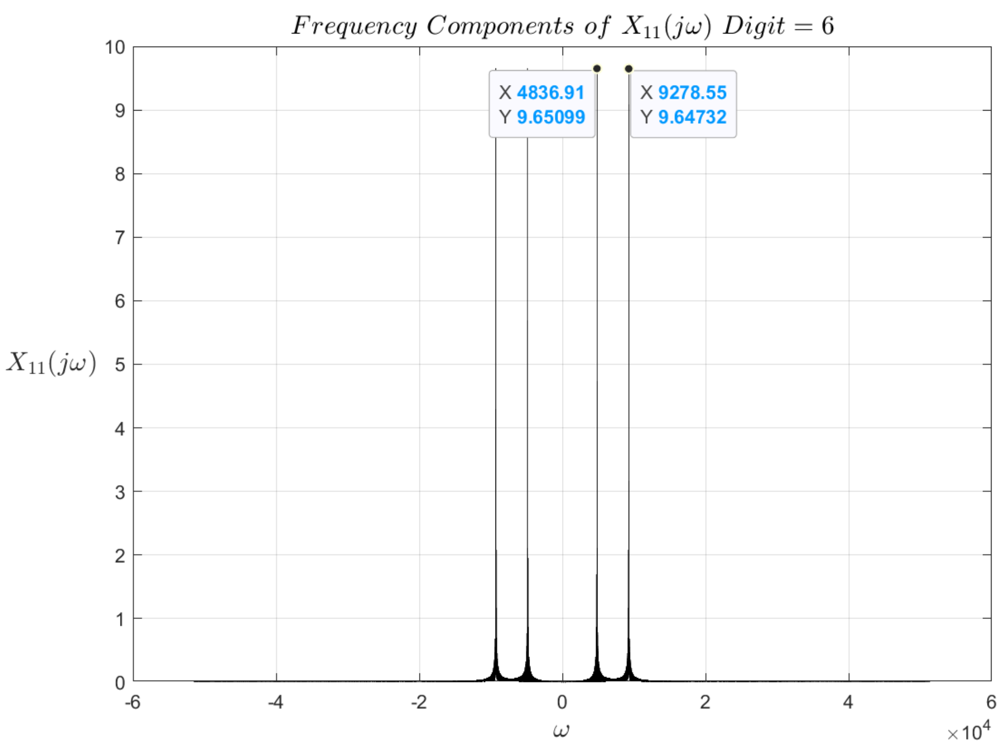

Figure 13: Third Digit Six in x(t) FT

$$\frac{4896.91}{2\pi} \cong 779.36 \Rightarrow 770\ Hz, \qquad \frac{9278.55}{2\pi} \cong 1476.72 \cong 1477\ Hz$$

Part 2: Echo Cancellation

$$y(t) = x(t) + \sum_{i=1}^{M} A_i x(t - t_i)$$

a) The impulse response of the system was derived by taking CTFT of both sides of the equation above:

$$Y(j\omega) = X(j\omega) + A_1 X(j\omega) e^{-j\omega t_1} + \cdots + A_M X(j\omega) e^{-j\omega t_M}$$

$$Y(j\omega) = X(j\omega)(1 + A_1 e^{-j\omega t_1} + \cdots + A_M e^{-j\omega t_M})$$

$$H(j\omega) = \frac{Y(j\omega)}{X(j\omega)} = (1 + A_1 e^{-j\omega t_1} + \cdots + A_M e^{-j\omega t_M})$$

$$h(t) = \delta(t) + A_1 \delta(t - t_1) + \cdots + A_M \delta(t - t_M)$$

b) The Fourier Transform of the system H(jω) was given again in the below:

$$H(j\omega) = \frac{Y(j\omega)}{X(j\omega)} = (1 + A_1 e^{-j\omega t_1} + \cdots + A_M e^{-j\omega t_M})$$

c) The relation between H(jω), Y(jω) and X(jω) can be seen below:

$$Y(j\omega) = X(j\omega) H(j\omega)$$

d) X(jω) can be found by dividing Y(jω) by the system's Fourier transform H(jω):

$$X(j\omega) = \frac{Y(j\omega)}{H(j\omega)}$$

The input signal and the output signal can be seen below, also the sound was given at the end of the report as well.

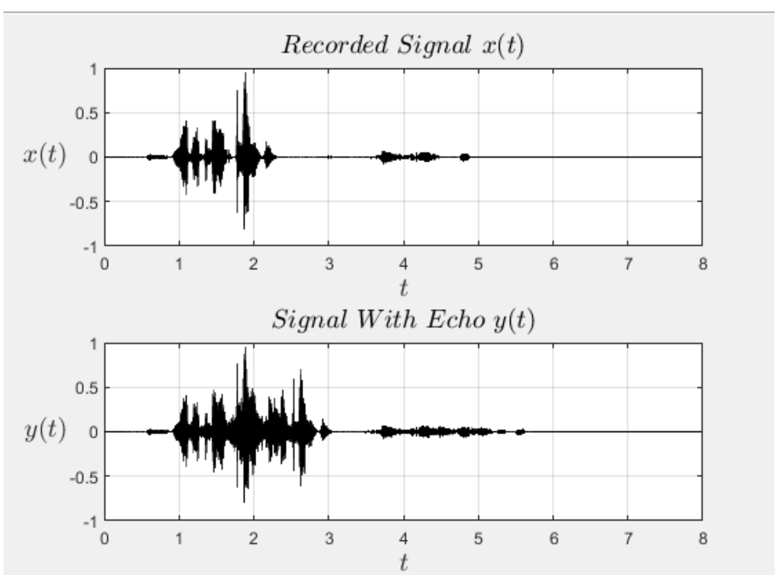

Figure 14: Input and Output of the Echo System

The MATLAB code for the adding echo to the input signal was given below:

```
%-------------------------------------------------------------------------

%PART 2: Echo Cancellation
Fs = 16384;
samp_int = 1/Fs; %delta_t
x = audioread('recorded_audio2.wav');
%soundsc(x,Fs);
x = x(1:5/samp_int,1);

x_0 = zeros(8*Fs,1);
x_1 = zeros(8*Fs,1);
x_2 = zeros(8*Fs,1);
x_3 = zeros(8*Fs,1);
x_4 = zeros(8*Fs,1);

t_main = 0:samp_int:8-samp_int;

A_i = [0.75 0.5 0.25 0.1];      %Amplitudes of the delay
t_i = [0.5 1 2 3];              %amount of delays

x_0(1:5/samp_int,1) = x;
x_1(0.75/samp_int:(5.75/samp_int)-1,1) = x;
x_2(0.5/samp_int:(5.5/samp_int)-1,1) = x;
x_3(0.25/samp_int:(5.25/samp_int)-1,1) = x;
x_3(0.1/samp_int:(5.1/samp_int)-1,1) = x;

y = x_0 +A_i(1)*x_1 + A_i(2)*x_2 + A_i(3)*x_3 + A_i(4)*x_4;
soundsc(y,Fs);

subplot(2,1,1);
plot(t_main,x_0,"k");
title ('$Recorded\,\,Signal\,\,x(t)$','Interpreter','latex','FontSize',14);
ylabel ('$x(t)$','Interpreter','latex','FontSize',14);
xlabel ('$t$','Interpreter','latex','FontSize',14);
grid on;
ax = gca;
ax.YLabel.Rotation = 360;

subplot(2,1,2);
plot(t_main,y,"k");
title ('$Signal\,\,With\,\,Echo\,\,y(t)$',...
       'Interpreter','latex','FontSize',14);
ylabel ('$y(t)$','Interpreter','latex','FontSize',14);
xlabel ('$t$','Interpreter','latex','FontSize',14);
grid on;
ax = gca;
ax.YLabel.Rotation = 360;
```

The impulse response of the system and the Fourier transform of it can be seen in Figure 15 below (to see the DTFT of H(jω) the frame was zoomed in):

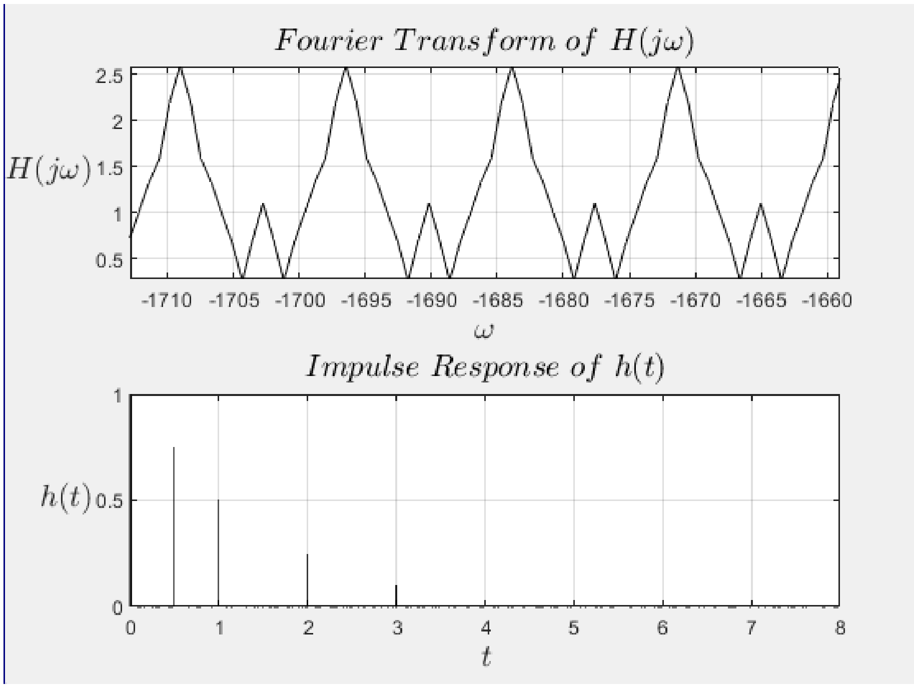

Figure 15: Impulse Response of the Echo System and DTFT of the System's Response

Finally, the echo subtracted (or approximated x(t)) can be seen below:

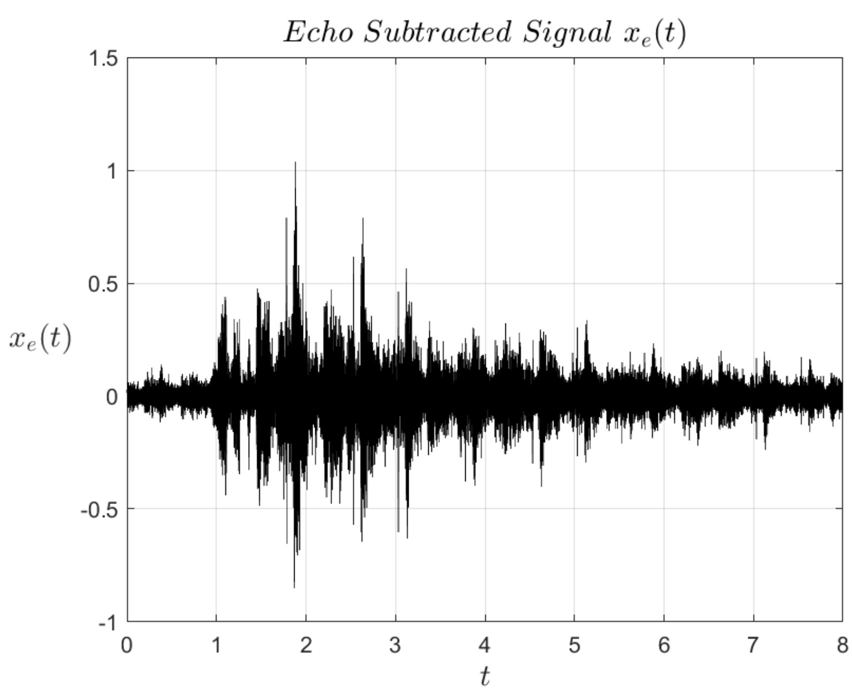

Figure 16: Echo Subtracted Signal

```
function [x_t_main] = DTMFTRA(input_num,samp_int)  %(Number, deltat)

%Lookup table for DTMFTRA
data = {'0',1336,941;
        '1',1209,697;
        '2',1336,697;
        '3',1477,697;
        '4',1209,770;
        '5',1336,770;
        '6',1477,770;
        '7',1209,852;
        '8',1336,852;
        '9',1477,852;
        '*',1209,941;
        '#',1477,941;
        'A',1633,697;
        'B',1633,770;
        'C',1633,852;
        'D',1633,941};

N = length(input_num);
x_t_main = [];          %Empty Signal

    for i = 1:N

        for element = 1:length(data)
            if data{element,1} == input_num(i)
                f1 = data{element,2};
                f2 = data{element,3};
                %t_i = linspace(0.25*(i-1),0.25*i,0.25/samp_int);
                t_i = 0.25*(i-1):samp_int:(0.25*i)-samp_int;
                x_i = cos(2*pi*f1*t_i) + cos(2*pi*f2*t_i);
                x_t_main = [x_t_main x_i];
            end
        end

    end

end
```

Published with MATLAB® R2023b

```
%--------------------EEE 321 LAB3 OFFLAB-----------------------------------
%PART 1: DTMF Signal and Tranceiver----------------------------------------

%DTMF Transmitter
samp_int = 1/16384; %Ts
input_num = '05422158574'; %PhoneNumber
gen_signal = DTMFTRA(input_num,samp_int);
soundsc(gen_signal,1/samp_int);

%DTMF Receiver
samp_int = 1/16384; %delta_t
Number = '03122900666';
x = DTMFTRA(Number,samp_int);              %Received signal

X = FT(x); %Fourier transform of the received signal.
omega=linspace(-16384*pi,16384*pi,16384*2.75+1);
omega=omega(1:end-1);

clf;
plot(omega,abs(X),"k");
title ('$Frequency\,\,Components\,\,of\,\,Received\,\,Signal$',...
        'Interpreter','latex','FontSize',14);
ylabel ('$X(j\omega)$','Interpreter','latex','FontSize',14);
xlabel ('$\omega$','Interpreter','latex','FontSize',14);
grid on;
ax = gca;
ax.YLabel.Rotation = 360;
```

Investigating and Plotting Seperate Digits

```
samp_int = 1/16384; %Ts
%Number = input("Bilkent emergency line: ","s");
Number = '03122900666';
x = DTMFTRA(Number,samp_int);

x_1 = zeros(1,length(x));
x_2 = zeros(1,length(x));
x_3 = zeros(1,length(x));
x_4 = zeros(1,length(x));
x_5 = zeros(1,length(x));
x_6 = zeros(1,length(x));
x_7 = zeros(1,length(x));
x_8 = zeros(1,length(x));
x_9 = zeros(1,length(x));
x_10 = zeros(1,length(x));
x_11 = zeros(1,length(x));

x_1(1:(0.25/samp_int)-1)            = x(1:(0.25/samp_int)-1);
x_2(0.25/samp_int:(0.5/samp_int)-1) = x(0.25/samp_int:(0.5/samp_int)-1);
x_3(0.5/samp_int:(0.75/samp_int)-1) = x(0.5/samp_int:(0.75/samp_int)-1);
x_4(0.75/samp_int:(1/samp_int)-1)   = x(0.75/samp_int:(1/samp_int)-1);
x_5(1/samp_int:(1.25/samp_int)-1)   = x(1/samp_int:(1.25/samp_int)-1);
x_6(1.25/samp_int:(1.5/samp_int)-1) = x(1.25/samp_int:(1.5/samp_int)-1);
```

```
x_7(1.5/samp_int:(1.75/samp_int)-1) = x(1.5/samp_int:(1.75/samp_int)-1);
x_8(1.75/samp_int:(2/samp_int)-1)   = x(1.75/samp_int:(2/samp_int)-1);
x_9(2/samp_int:(2.25/samp_int)-1)   = x(2/samp_int:(2.25/samp_int)-1);
x_10(2.25/samp_int:(2.5/samp_int)-1) = x(2.25/samp_int:(2.5/samp_int)-1);
x_11(2.5/samp_int:(2.75/samp_int)-1) = x(2.5/samp_int:(2.75/samp_int)-1);

X_1 = FT(x_1);
X_2 = FT(x_2);
X_3 = FT(x_3);
X_4 = FT(x_4);
X_5 = FT(x_5);
X_6 = FT(x_6);
X_7 = FT(x_7);
X_8 = FT(x_8);
X_9 = FT(x_9);
X_10 = FT(x_10);
X_11 = FT(x_11);

clf;
plot(omega,abs(X_1),"k");
title ('$Frequency\,\,Components\,\,of\,\,X_1(j\omega)\,\,Digit = 0$',...
        'Interpreter','latex','FontSize',14);
ylabel ('$X_1(j\omega)$','Interpreter','latex','FontSize',14);
xlabel ('$\omega$','Interpreter','latex','FontSize',14);
grid on;
ax = gca;
ax.YLabel.Rotation = 360;

plot(omega,abs(X_2),"k");
title ('$Frequency\,\,Components\,\,of\,\,X_2(j\omega)\,\,Digit = 3$',...
        'Interpreter','latex','FontSize',14);
ylabel ('$X_2(j\omega)$','Interpreter','latex','FontSize',14);
xlabel ('$\omega$','Interpreter','latex','FontSize',14);
grid on;
ax = gca;
ax.YLabel.Rotation = 360;

plot(omega,abs(X_3),"k");
title ('$Frequency\,\,Components\,\,of\,\,X_3(j\omega)\,\,Digit = 1$',...
        'Interpreter','latex','FontSize',14);
ylabel ('$X_3(j\omega)$','Interpreter','latex','FontSize',14);
xlabel ('$\omega$','Interpreter','latex','FontSize',14);
grid on;
ax = gca;
ax.YLabel.Rotation = 360;

plot(omega,abs(X_4),"k");
title ('$Frequency\,\,Components\,\,of\,\,X_4(j\omega)\,\,Digit = 2$',...
        'Interpreter','latex','FontSize',14);
ylabel ('$X_4(j\omega)$','Interpreter','latex','FontSize',14);
xlabel ('$\omega$','Interpreter','latex','FontSize',14);
grid on;
ax = gca;
ax.YLabel.Rotation = 360;
```

```
plot(omega,abs(X_5),"k");
title ('$Frequency\,\,Components\,\,of\,\,X_5(j\omega)\,\,Digit = 2$',...
        'Interpreter','latex','FontSize',14);
ylabel ('$X_5(j\omega)$','Interpreter','latex','FontSize',14);
xlabel ('$\omega$','Interpreter','latex','FontSize',14);
grid on;
ax = gca;
ax.YLabel.Rotation = 360;

plot(omega,abs(X_6),"k");
title ('$Frequency\,\,Components\,\,of\,\,X_6(j\omega)\,\,Digit = 9$',...
        'Interpreter','latex','FontSize',14);
ylabel ('$X_6(j\omega)$','Interpreter','latex','FontSize',14);
xlabel ('$\omega$','Interpreter','latex','FontSize',14);
grid on;
ax = gca;
ax.YLabel.Rotation = 360;

plot(omega,abs(X_7),"k");
title ('$Frequency\,\,Components\,\,of\,\,X_7(j\omega)\,\,Digit = 0$',...
        'Interpreter','latex','FontSize',14);
ylabel ('$X_7(j\omega)$','Interpreter','latex','FontSize',14);
xlabel ('$\omega$','Interpreter','latex','FontSize',14);
grid on;
ax = gca;
ax.YLabel.Rotation = 360;

plot(omega,abs(X_8),"k");
title ('$Frequency\,\,Components\,\,of\,\,X_8(j\omega)\,\,Digit = 0$',...
        'Interpreter','latex','FontSize',14);
ylabel ('$X_8(j\omega)$','Interpreter','latex','FontSize',14);
xlabel ('$\omega$','Interpreter','latex','FontSize',14);
grid on;
ax = gca;
ax.YLabel.Rotation = 360;

plot(omega,abs(X_9),"k");
title ('$Frequency\,\,Components\,\,of\,\,X_9(j\omega)\,\,Digit = 6$',...
        'Interpreter','latex','FontSize',14);
ylabel ('$X_9(j\omega)$','Interpreter','latex','FontSize',14);
xlabel ('$\omega$','Interpreter','latex','FontSize',14);
grid on;
ax = gca;
ax.YLabel.Rotation = 360;

plot(omega,abs(X_10),"k");
title ('$Frequency\,\,Components\,\,of\,\,X_{10}(j\omega)\,\,Digit = 6$',...
        'Interpreter','latex','FontSize',14);
ylabel ('$X_{10}(j\omega)$','Interpreter','latex','FontSize',14);
xlabel ('$\omega$','Interpreter','latex','FontSize',14);
grid on;
ax = gca;
ax.YLabel.Rotation = 360;

plot(omega,abs(X_11),"k");
title ('$Frequency\,\,Components\,\,of\,\,X_{11}(j\omega)\,\,Digit = 6$',...
```

```
        'Interpreter','latex','FontSize',14);
ylabel ('$X_{11}(j\omega)$','Interpreter','latex','FontSize',14);
xlabel ('$\omega$','Interpreter','latex','FontSize',14);
grid on;
ax = gca;
ax.YLabel.Rotation = 360;

%--------------------------------------------------------------------------
%PART 2: Echo Cancellation
Fs = 16384;
samp_int = 1/Fs; %delta_t
x = audioread('recorded_audio2.wav');
%soundsc(x,Fs);
x = x(1:5/samp_int,1);

x_0 = zeros(8*Fs,1);
x_1 = zeros(8*Fs,1);
x_2 = zeros(8*Fs,1);
x_3 = zeros(8*Fs,1);
x_4 = zeros(8*Fs,1);

t_main = 0:samp_int:8-samp_int;

A_i = [0.75 0.5 0.25 0.1];      %Amplitudes of the delay
t_i = [0.5 1 2 3];              %amount of delays

x_0(1:5/samp_int,1) = x;
x_1(0.75/samp_int:(5.75/samp_int)-1,1) = x;
x_2(0.5/samp_int:(5.5/samp_int)-1,1) = x;
x_3(0.25/samp_int:(5.25/samp_int)-1,1) = x;
x_3(0.1/samp_int:(5.1/samp_int)-1,1) = x;

y = x_0 +A_i(1)*x_1 + A_i(2)*x_2 + A_i(3)*x_3 + A_i(4)*x_4;
soundsc(y,Fs);

subplot(2,1,1);
plot(t_main,x_0,"k");
title ('$Recorded\,\,Signal\,\,x(t)$','Interpreter','latex','FontSize',14);
ylabel ('$x(t)$','Interpreter','latex','FontSize',14);
xlabel ('$t$','Interpreter','latex','FontSize',14);
grid on;
ax = gca;
ax.YLabel.Rotation = 360;

subplot(2,1,2);
plot(t_main,y,"k");
title ('$Signal\,\,With\,\,Echo\,\,y(t)$',...
       'Interpreter','latex','FontSize',14);
ylabel ('$y(t)$','Interpreter','latex','FontSize',14);
xlabel ('$t$','Interpreter','latex','FontSize',14);
grid on;
ax = gca;
ax.YLabel.Rotation = 360;
```

```
%Subtraction  of the echo
Y_jw = fft(y);
omega = linspace(-Fs*pi,Fs*pi,8*Fs+1);
omega = omega(1:end-1);

H_jw = 1 + A_i(1)*exp(-j*omega*t_i(1))+A_i(2)*exp(-j*omega*t_i(2))+...
           A_i(3)*exp(-j*omega*t_i(3))+A_i(4)*exp(-j*omega*t_i(4));

H_jw = transpose(H_jw);

X_jw = Y_jw./H_jw;
x_sub = ifft(X_jw,131072);
x_sub = real(x_sub);
h_t = ifft(H_jw);
%soundsc(x_sub,Fs);

clf;
subplot(2,1,1);
plot(omega,abs(H_jw),"k");
title ('$Fourier\,\,Transform\,\,of\,\,H(j\omega)$',...
       'Interpreter','latex','FontSize',14);
ylabel ('$H(j\omega)$','Interpreter','latex','FontSize',14);
xlabel ('$\omega$','Interpreter','latex','FontSize',14);
grid on;
ax = gca;
ax.YLabel.Rotation = 360;

subplot(2,1,2);
plot(t_main,h_t,"k");
title ('$Impulse\,\,Response\,\,of\,\,h(t)$',...
       'Interpreter','latex','FontSize',14);
ylabel ('$h(t)$','Interpreter','latex','FontSize',14);
xlabel ('$t$','Interpreter','latex','FontSize',14);
grid on;
ax = gca;
ax.YLabel.Rotation = 360;

%Echo subtracted
plot(t_main,x_sub,"k");
title ('$Echo\,\,Subtracted\,\,Signal\,\,x_e(t)$',...
       'Interpreter','latex','FontSize',14);
ylabel ('$x_e(t)$','Interpreter','latex','FontSize',14);
xlabel ('$t$','Interpreter','latex','FontSize',14);
grid on;
ax = gca;
ax.YLabel.Rotation = 360;
```

Published with MATLAB® R2023b