جامعة الإسكندرية
ALEXANDRIA
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Digital Signal Processing – Final project

Audio equalizer using MATLAB

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Repository address:

https://github.com/XMaroRadoX/Audio_equalizer_using_matlab

1 Code

1.1 Input code

1.2 Filters' implementations and analysis code

Filters implemented and designed using filterDesigner tool at sampling frequency of 44.1 KHz, Following code and table are for the inputs in the tools for each band attached with the exported filter object's name. In the appendix there is a code that do the same task but with less accuracy.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% To load filters in workspace %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% cd 'project location'        %
% load('filters.mat')          %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


% Analysis function
analyze('IIR');

% filters' analysis function
function analyze(type)
    cd 'W:\Projects\Digital Signal
Processing\Audio_equalizer_using_matlab'
    load('filters. Mat');

    if type == 'IIR'
        % IIR Analysis
        % 0-170 Hz band
        analysis(iir170,'4-th order 0-170 Hz BPF');

        % 170-310 Hz band
        analysis(iir170310,'4-th order 170-310 Hz BPF');

        % 310-600 Hz band
        analysis(iir310600,'4-th order 310-600 Hz BPF');

        % 600-1000 Hz band
        analysis(iir6001000,'4-th order 600-1000 Hz BPF');

        % 1-3 KHz band
        analysis(iir13k,'4-th order 1-3 KHz BPF');

        % 3-6 KHz band
        analysis(iir36k,'4-th order 3-6 KHz BPF');

        % 6-12 KHz band
        analysis(iir612k,'4-th order 6-12 KHz BPF');

        % 12-14 KHz band
        analysis(iir1214k,'4-th order 12-14 KHz BPF');

        % 14-16 KHz band
        analysis(iir1416k,'4-th order 14-16 KHz BPF');

    else

        % FIR Analysis
        % 0-170 Hz band
        analysis(fir170,'800-th order 0-170 Hz BPF');

        % 170-310 Hz band
        analysis(fir170310,'800-th order 170-310 Hz BPF');

        % 310-600 Hz band
        analysis(fir310600,'800-th order 310-600 Hz BPF');
```

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```
        % 600-1000 Hz band
        analysis(fir6001000,'800-th order 600-1000 Hz BPF');

        % 1-3 KHz band
        analysis(fir13k,'800-th order 1-3 KHz BPF');

        % 3-6 KHz band
        analysis(fir36k,'800-th order 3-6 KHz BPF');

        % 6-12 KHz band
        analysis(fir612k,'800-th order 6-12 KHz BPF');

        % 12-14 KHz band
        analysis(fir1214k,'800-th order 12-14 KHz BPF');

        % 14-16 KHz band
        analysis(fir1416k,'800-th order 14-16 KHz BPF');
    end
end

function analysis(filter,name)
    figure('name',name);

    [H,wh] = freqz(filter);
    subplot(4,2,1);
    plot(wh/pi,abs(H));grid;
    title('Magnitude response');
    xlabel('Normalized frequency (\times\pi rad/samples)');
    ylabel('Magnitude');

    [P,wp] = phasez(filter);
    subplot(4,2,2);
    plot(wp/pi,P.*180/pi);grid;
    title('Phase response');
    xlabel('Normalized frequency (\times\pi rad/samples)');
    ylabel('Phase (Degrees)');

    [h,nh] = impz(filter);
    subplot(4,2,[3 4]);
    stem(nh,h);grid;
    title('Impulse response');
    xlabel('Samples');
    ylabel('Amplitude');

    [s,ns] = stepz(filter);
    subplot(4,2,[5 6]);
    stem(ns,s);grid;
    title('Step response');
    xlabel('Samples');
    ylabel('Amplitude');

    subplot(4,2,[7 8]);
    [b,a] = tf(filter);
    zplane(b,a);grid;
    title('Pole-Zero plot');

end
```

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	Band (Hz)	Response Type	Design Method & Order	Freq. Specs. (Hz) Fs = 44100 Hz or 44.1 KHz		Filter Name
IIR	0 – 170	Lowpass	Butterworth – 4	Fc = 170		iir170
	170 – 310	Bandpass		Fc1 = 600	Fc2 = 310	iir170310
	310 – 600			Fc1 = 310	Fc2 = 600	iir310600
	600 – 1000			Fc1 = 600	Fc2 = 1000	iir6001000
	1000 – 3000			Fc1 = 1000	Fc2 = 3000	iir13k
	3000 – 6000			Fc1 = 1000	Fc2 = 6000	iir36k
	6000 – 12000			Fc1 = 6000	Fc2 = 12000	iir612k
	12000 – 14000			Fc1 = 12000	Fc2 = 14000	iir1214k
	14000 - 16000			Fc1 = 14000	Fc2 = 16000	iir1416k
FIR	0 – 170	Lowpass	Blackman Window 800	Fc = 170		fir170
	170 – 310	Bandpass		Fc1 = 600	Fc1 = 600	fir170310
	310 – 600			Fc1 = 310	Fc1 = 310	fir310600
	600 – 1000			Fc1 = 600	Fc1 = 600	fir6001000
	1000 – 3000			Fc1 = 1000	Fc1 = 1000	fir13k
	3000 – 6000			Fc1 = 1000	Fc1 = 1000	fir36k
	6000 – 12000			Fc1 = 6000	Fc1 = 6000	fir612k
	12000 – 14000			Fc1 = 12000	Fc1 = 12000	fir1214k
	14000 - 16000			Fc1 = 14000	Fc1 = 14000	fir1416k

Tabel 1.1 Input data for filterDesigner tool for both IIR and FIR

1.3 Wave file processing code

```
if type == 'IIR'
    y1=filter(iir170,x);
    analyseFilter(y1,x,info,'0-170 Hz IIR Filter');
    y1 = y1 .* db2mag(gain(1));

    y2=filter(iir170310,x);
    analyseFilter(y2,x,info,'170-310 Hz IIR Filter');
    y2 = y2 .* db2mag(gain(2));

    y3=filter(iir310600,x);
    analyseFilter(y3,x,info,'310-600 Hz IIR Filter');
    y3 = y3 .* db2mag(gain(3));

    y4=filter(iir6001000,x);
    analyseFilter(y4,x,info,'600-1000 Hz IIR Filter');
    y4 = y4 .* db2mag(gain(4));

    y5=filter(iir13k,x);
    analyseFilter(y5,x,info,'1-3 KHz IIR Filter');
    y5 = y5 .* db2mag(gain(5));

    y6=filter(iir36k,x);
    analyseFilter(y6,x,info,'3-6 KHz IIR Filter');
    y6 = y6 .* db2mag(gain(6));

    y7=filter(iir612k,x);
    analyseFilter(y7,x,info,'6-12 KHz IIR Filter');
    y7 = y7 .* db2mag(gain(7));

    y8=filter(iir1214k,x);
    analyseFilter(y8,x,info,'12-14 KHz IIR Filter');
    y8 = y8 .* db2mag(gain(8));

    y9=filter(iir1416k,x);
    analyseFilter(y9,x,info,'14-16 KHz IIR Filter');
    y9 = y9 .* db2mag(gain(9));

else
    y1=filter(fir170,x);
    analyseFilter(y1,x,info,'0-170 Hz FIR Filter');
    y1 = y1 .* db2mag(gain(1));

    y2=filter(fir170310,x);
    analyseFilter(y2,x,info,'170-310 Hz FIR Filter');
    y2 = y2 .* db2mag(gain(2));

    y3=filter(fir310600,x);
```

```
% Doubling Fs
fs = Fs*2;
idx = 1:info.TotalSamples;
t = (idx-1)./fs;
Fvec = linspace(-fs/2,fs/2,length(t));
Y = fftshift(fft(y));

figure('name','Double Sampling');
subplot(3,2,[1 2]);
plot(t,x);grid;
title('Original Signal (Time domain)');
xlabel('Time (seconds)');
ylabel('x(t)');

subplot(3,2,[3 4]);
plot(t,y);grid;
title('Composite Signal (Time domain)');
xlabel('Time (seconds)');
ylabel('x(t)');

subplot(3,2,5);
plot(Fvec,abs(Y));grid;
title('Magnitude spectrum');
xlabel('Frequency (Hz)');
ylabel('|Y(\omega)|');
xlim([-3,3]);

subplot(3,2,6);
plot(Fvec,angle(Y).*180/pi);grid;
title('Phase spectrum');
xlabel('Frequency (Hz)');
ylabel('Phase (degree)');
xlim([-3,3]);

% Decreasing Fs to half
fs = Fs/2;
idx = 1:info.TotalSamples;
t = (idx-1)./fs;
Fvec = linspace(-fs/2,fs/2,length(t));
Y = fftshift(fft(y));

figure('name','Half sampling');
subplot(3,2,[1 2]);
plot(t,x);grid;
title('Original Signal (Time domain)');
xlabel('Time (seconds)');
ylabel('x(t)');
```

```
    analyseFilter(y3,x,info,'310-600 Hz FIR Filter');

    y3 = y3 .* db2mag(gain(3));

    y4=filter(fir6001000,x);
    analyseFilter(y4,x,info,'600-1000 Hz FIR Filter');
    y4 = y4 .* db2mag(gain(4));



    y5=filter(fir13k,x);


    analyseFilter(y5,x,info,'1-3 KHz FIR Filter');
    y5 = y5 .* db2mag(gain(5));

    y6=filter(fir36k,x);
    analyseFilter(y6,x,info,'3-6 KHz FIR Filter');
    y6 = y6 .* db2mag(gain(6));

    y7=filter(fir612k,x);
    analyseFilter(y7,x,info,'6-12 KHz FIR Filter');
    y7 = y7 .* db2mag(gain(7));

    y8=filter(fir1214k,x);
    analyseFilter(y8,x,info,'12-14 KHz FIR Filter');
    y8 = y8 .* db2mag(gain(8));

    y9=filter(fir1416k,x);
    analyseFilter(y9,x,info,'14-16 KHz FIR Filter');
    y9 = y9 .* db2mag(gain(9));
end

y = y1 + y2 + y3 + y4 + y5 + y6 + y7 + y8 + y9;
% output of composite
idx = 1:info.TotalSamples;
t = (idx-1)./Fs;
Fvec = linspace(-Fs/2,Fs/2,length(t));
Y = fftshift(fft(y));

figure('name','Composite Signal');
subplot(3,2,[1 2]);
plot(t,x);grid;
title('Original Signal (Time domain)');
xlabel('Time (seconds)');
ylabel('x(t)');

subplot(3,2,[3 4]);
plot(t,y);grid;
title('Composite Signal (Time domain)');
xlabel('Time (seconds)');
ylabel('x(t)');

subplot(3,2,5);
plot(Fvec,abs(Y));grid;
title('Magnitude spectrum');
xlabel('Frequency (Hz)');
ylabel('|Y(\omega)|');
xlim([-3,3]);

subplot(3,2,6);
plot(Fvec,angle(Y).*180/pi);grid;
title('Phase spectrum');
xlabel('Frequency (Hz)');
ylabel('Phase (degree)');
xlim([-3,3]);



sound(y,Fs);
audiowrite('composite.wav',x,Os);
```

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```
subplot(3,2,[3 4]);
plot(t,y);grid;
title('Composite Signal (Time domain)');
xlabel('Time (seconds)');
ylabel('x(t)');

subplot(3,2,5);
plot(Fvec,abs(Y));grid;
title('Magnitude spectrum');
xlabel('Frequency (Hz)');
ylabel('|Y(\omega)|');
xlim([-3,3]);

subplot(3,2,6);
plot(Fvec,angle(Y).*180/pi);grid;
title('Phase spectrum');
xlabel('Frequency (Hz)');
ylabel('Phase (degree)');
xlim([-3,3]);



% filtered signals analysis
function analyseFilter(y,x,info,name)
    Fs = info.SampleRate;
    idx = 1:info.TotalSamples;
    t = (idx-1)./Fs;
    Fvec = linspace(-Fs/2,Fs/2,length(t));
    Y = fftshift(fft(y));

    figure('name',name);
    subplot(3,2,[1 2]);
    plot(t,x);grid;
    title('Original Signal (Time domain)');
    xlabel('Time (seconds)');
    ylabel('x(t)');

    subplot(3,2,3);
    plot(t,y);grid;
    title('Filtered Signal (Time domain)');
    xlabel('Time (seconds)');
    ylabel('y(t)');

    subplot(3,2,4);
    plot(Fvec,Y);grid;
    title('Filtered Signal (Frequency domain)');
    xlabel('Frequency (Hz)');
    ylabel('Y(\omega)');

    subplot(3,2,5);
    plot(Fvec,abs(Y));grid;
    title('Magnitude spectrum');
    xlabel('Frequency (Hz)');
    ylabel('|Y(\omega)|');
    xlim([-3,3]);

    subplot(3,2,6);
    plot(Fvec,angle(Y).*180/pi);grid;
    title('Phase spectrum');
    xlabel('Frequency (Hz)');
    ylabel('Phase (degree)');
    xlim([-3,3]);
end
```

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2 Sample runs

A testbench with the following specifications will be used:

- Sampling rate: 44100 Hz
- Duration: 43.4678 seconds
- Number of channels: 2 (stereo)
- Total samples: 1916928
- Bits per sample: 16
- User gain input per band (dB): 4, -10, -9, -8, 1, -4, 9, -2, -1
- Output sampling rate: 44100 Hz

2.1 Using FIR filters

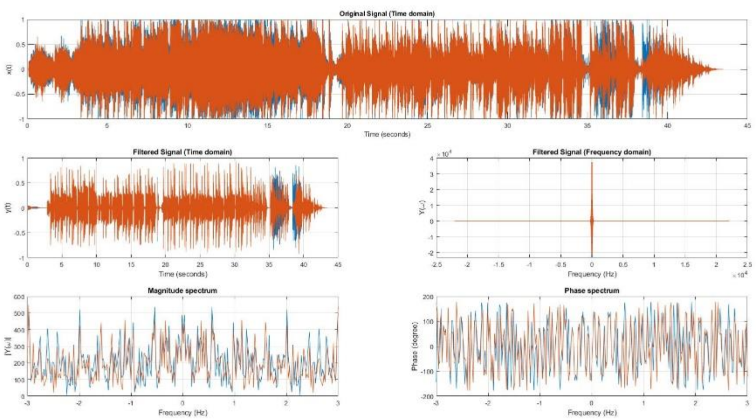

Figure 2.1.1 Filtering input signal with 0 – 170 Hz bandpass FIR filter

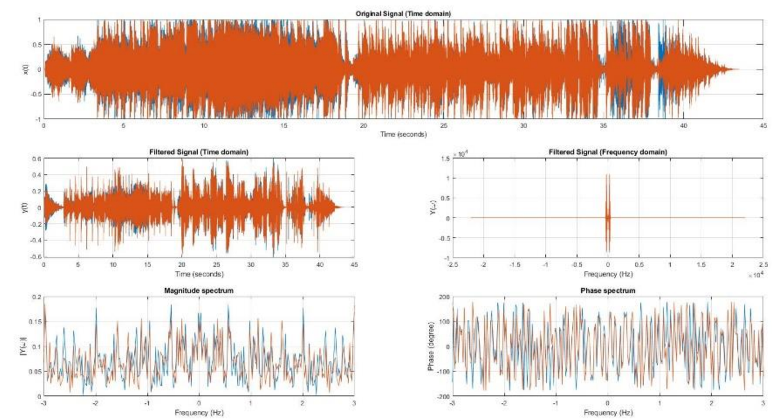

Figure 2.1.2 Filtering input signal with 170 – 310 Hz bandpass FIR filter

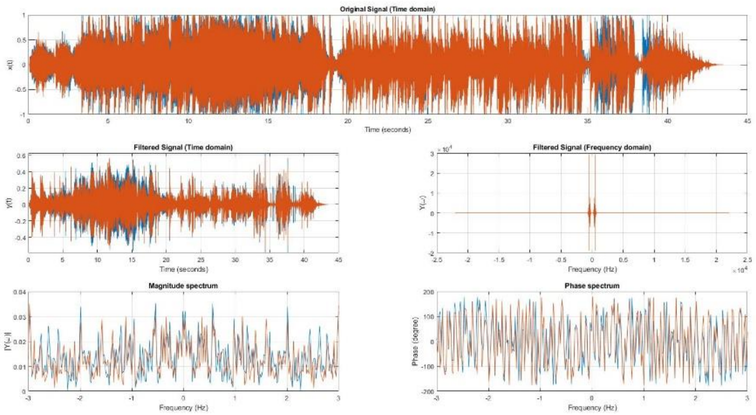

Figure 2.1.3 Filtering input signal with 310 – 600 Hz bandpass FIR filter

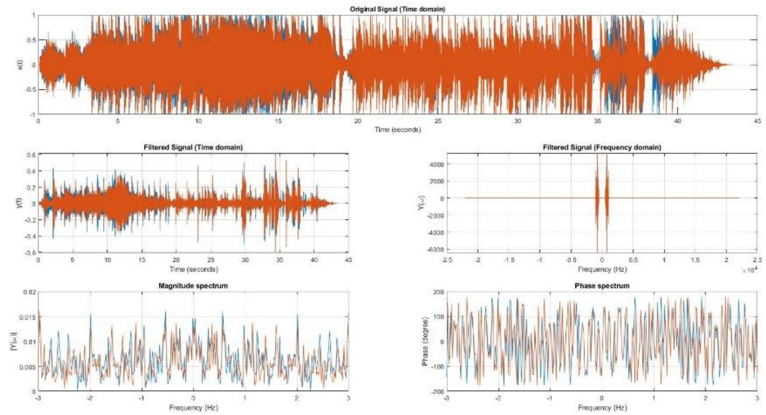

Figure 2.1.4 Filtering input signal with 600 – 1000 Hz bandpass FIR filter

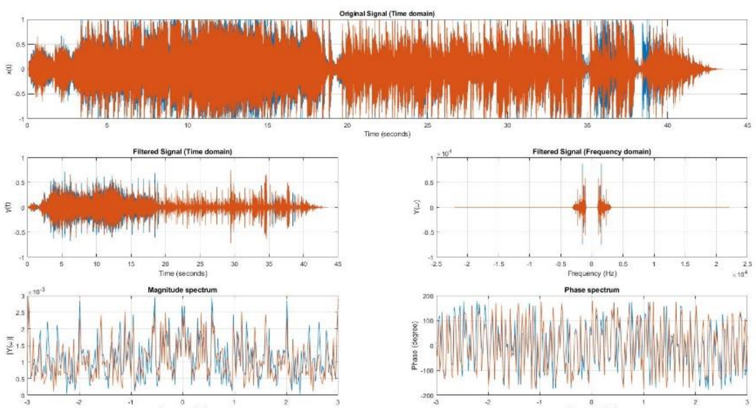

Figure 2.1.5 Filtering input signal with 1 – 3 KHz bandpass FIR filter

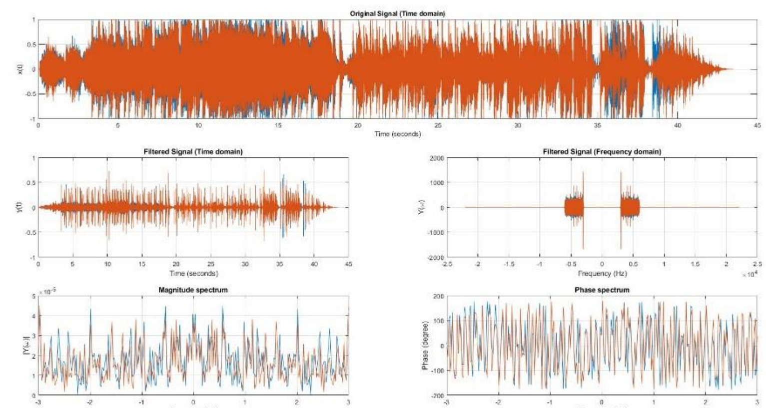

Figure 2.1.6 Filtering input signal with 3 – 6 KHz bandpass FIR filter

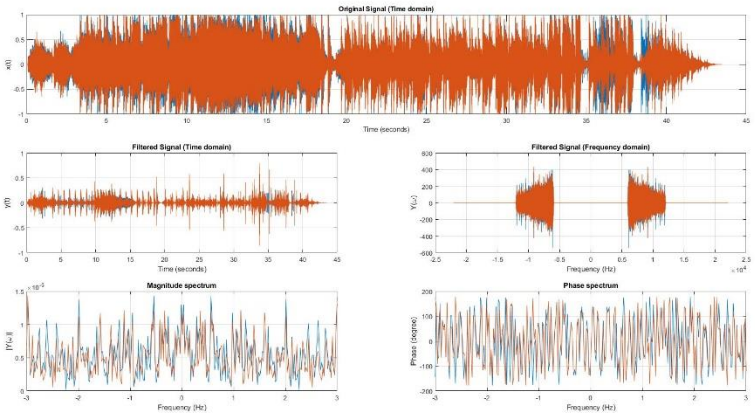

Figure 2.1.7 Filtering input signal with 6 – 12 KHz bandpass FIR filter

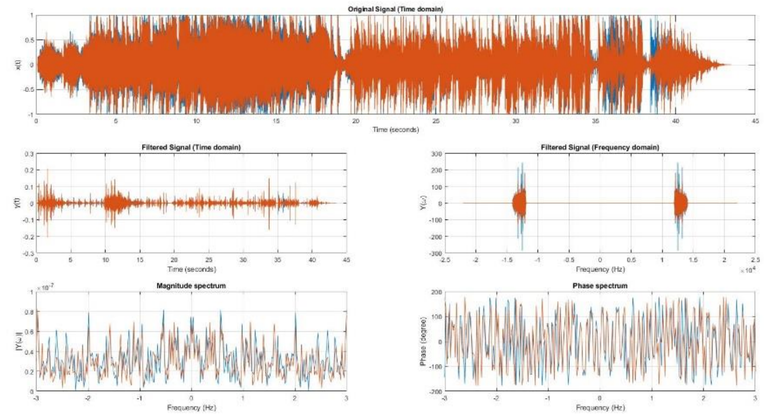

Figure 2.1.8 Filtering input signal with 12 – 14 KHz bandpass FIR filter

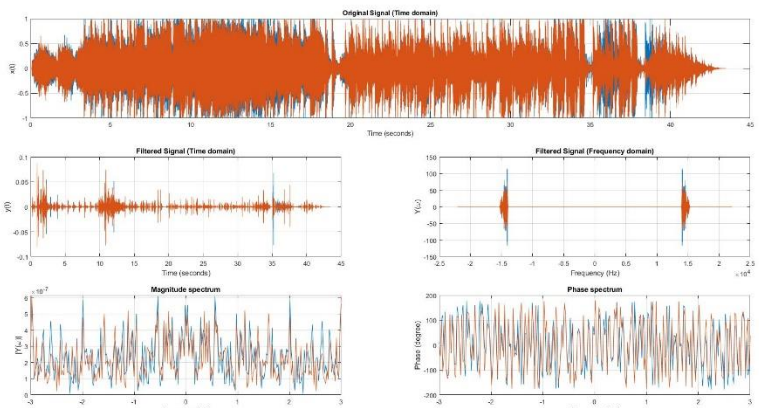

Figure 2.1.9 Filtering input signal with 14 – 16 KHz bandpass FIR filter

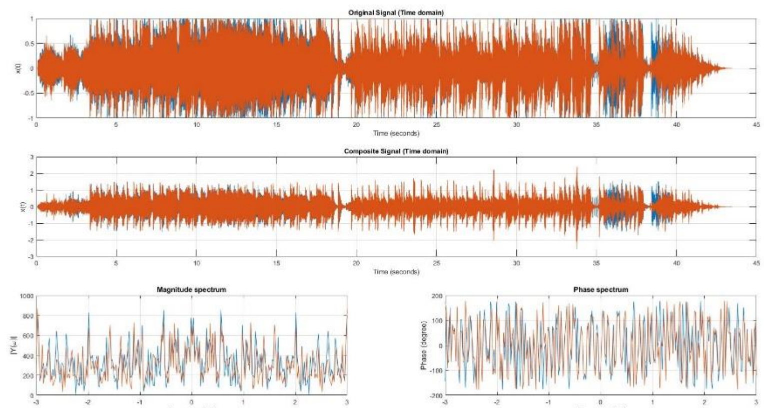

Figure 2.2.10 Output composite signal after applying user defined amplifications

2.2 Using IIR filters

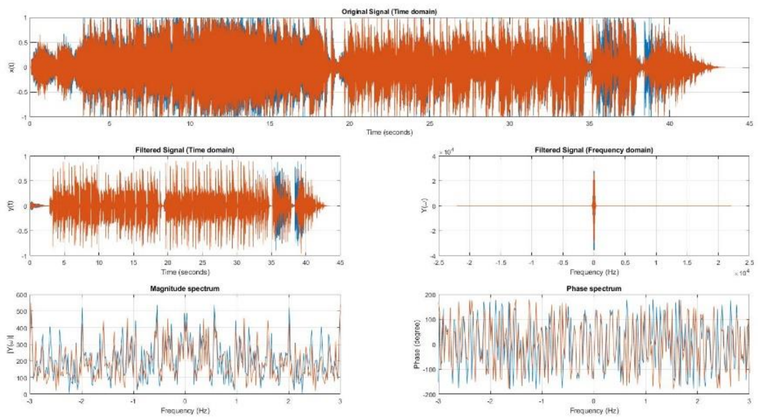

Figure 2.2.1 Filtering input signal with 0 – 170 Hz bandpass IIR filter

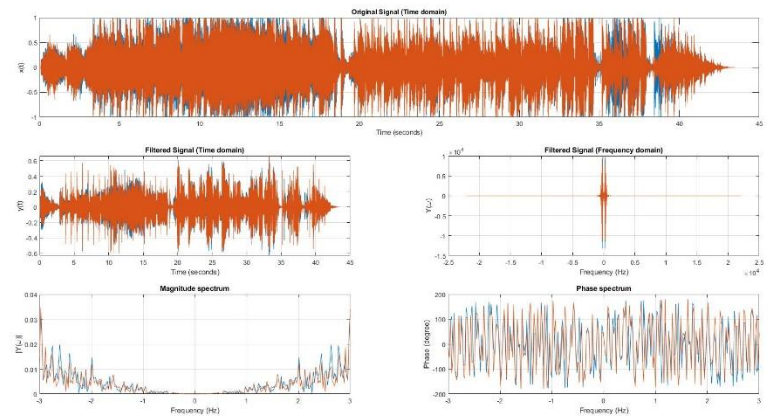

Figure 2.2.2 Filtering input signal with 170 – 310 Hz bandpass IIR filter

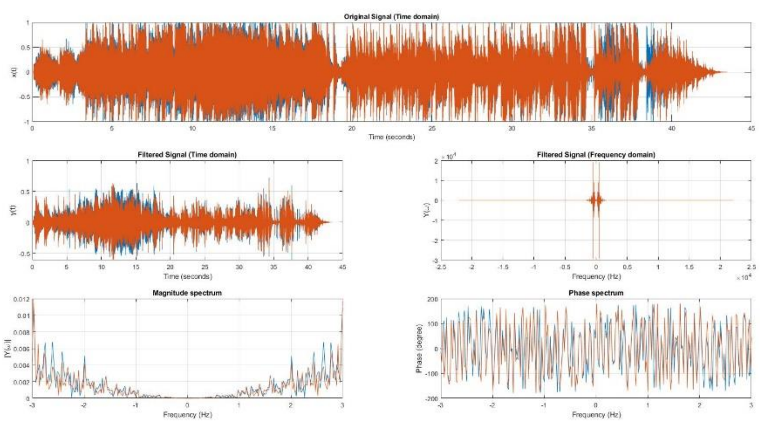

Figure 2.2.3 Filtering input signal with 310 – 600 Hz bandpass IIR filter

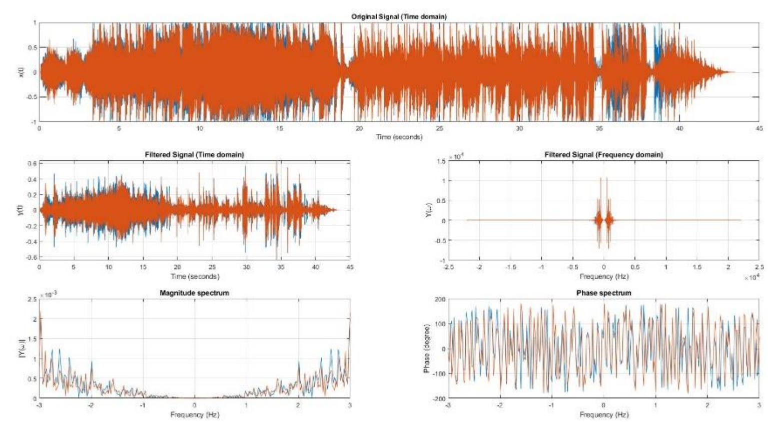

Figure 2.2.4 Filtering input signal with 600 – 1000 Hz bandpass IIR filter

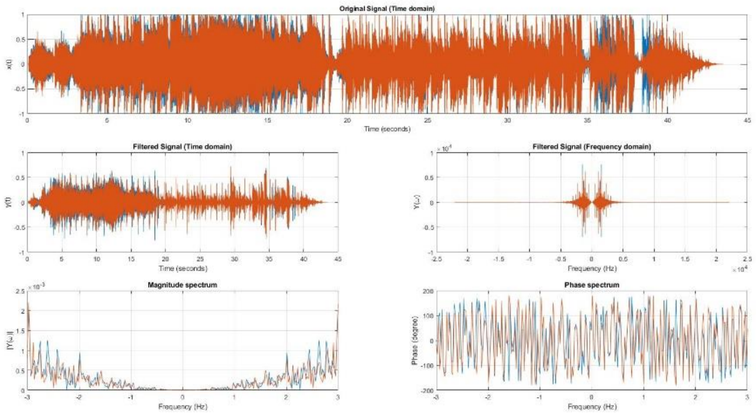

Figure 2.2.5 Filtering input signal with 1 – 3 KHz bandpass IIR filter

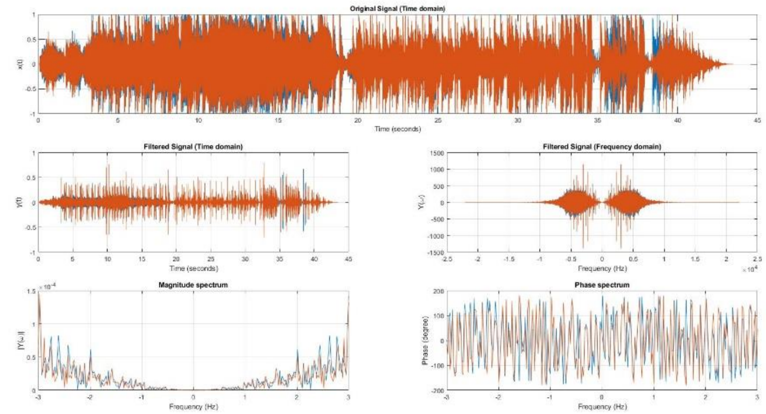

Figure 2.2.6 Filtering input signal with 3 – 6 KHz bandpass IIR filter

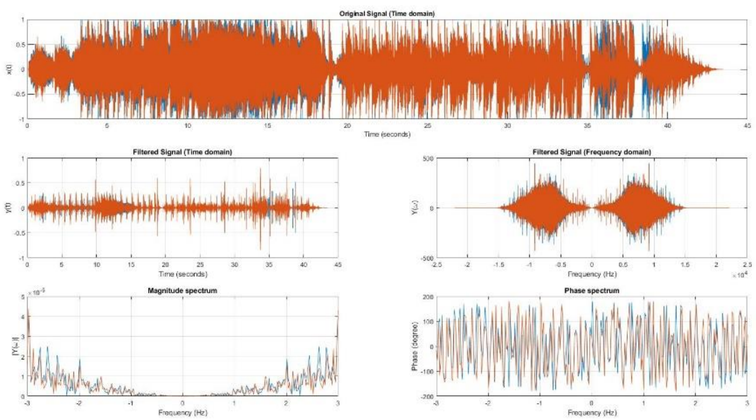

Figure 2.2.7 Filtering input signal with 6 – 12 KHz bandpass IIR filter

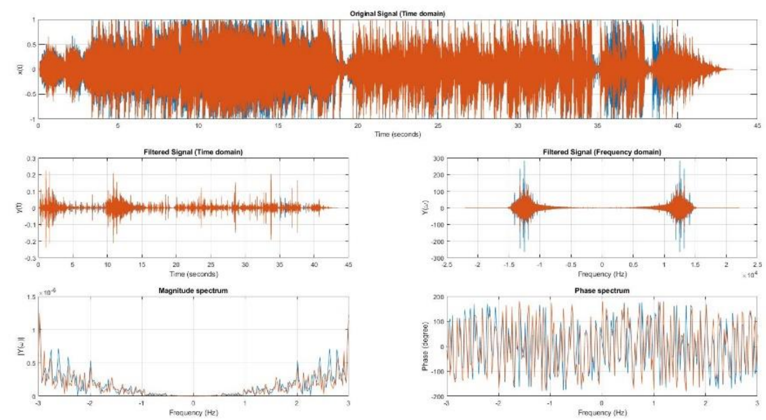

Figure 2.2.8 Filtering input signal with 12 – 14 KHz bandpass IIR filter

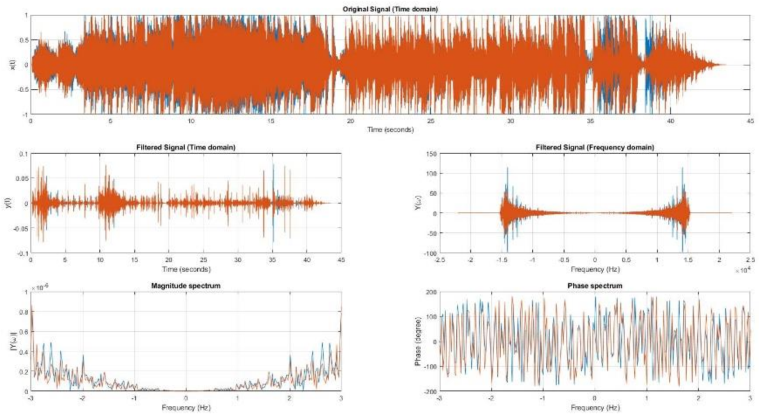

Figure 2.2.9 Filtering input signal with 14 – 16 KHz bandpass IIR filter

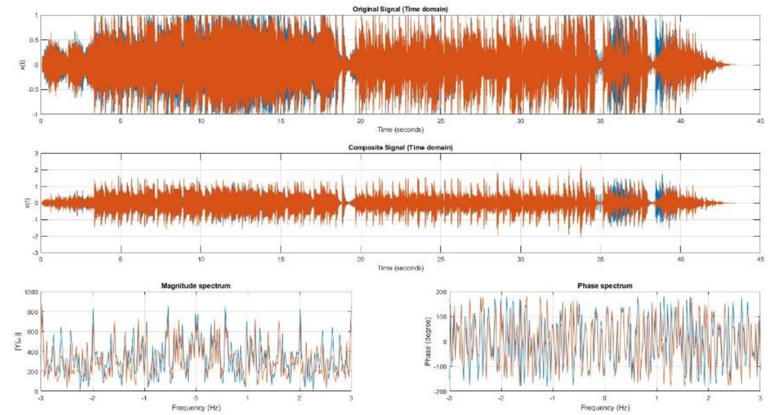

Figure 2.2.10 Output composite signal after applying user defined amplifications

2.3 Doubling output sampling rate

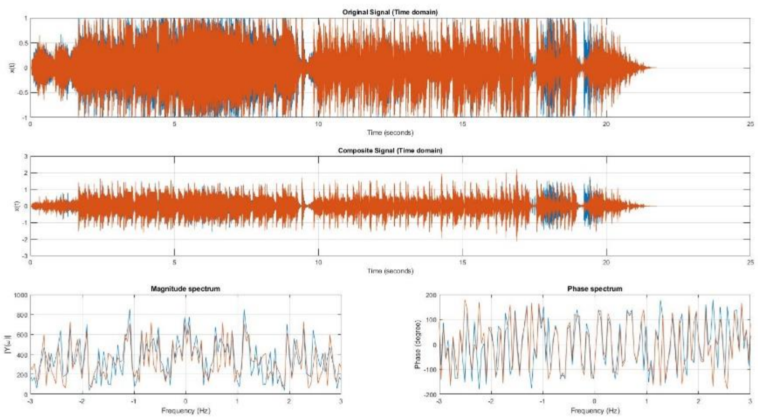

Figure 2.3.1 Output composite signal after doubling the output sample rate

2.4 Decreasing output sampling rate to the half

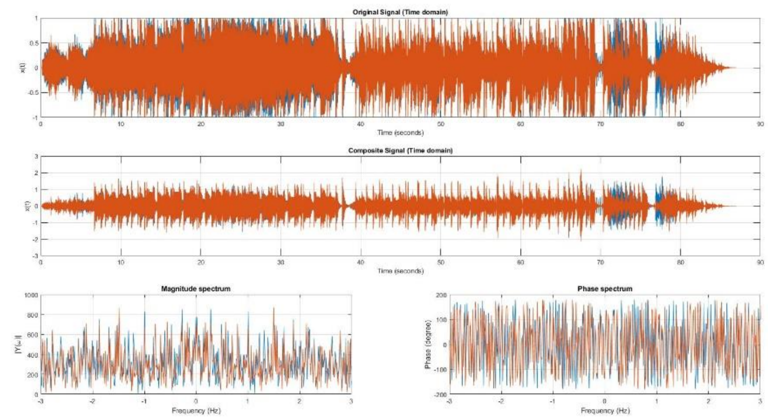

Figure 2.4.1 Output composite signal after decreasing output sample rate to the half

3 Filters' Analysis

3.1 800th order FIR filters (Blackman window)

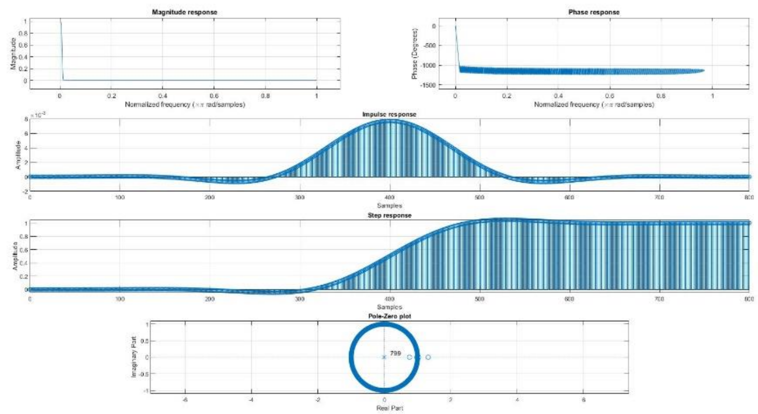

Figure 3.1.1 Analysis for 0 – 170 Hz band

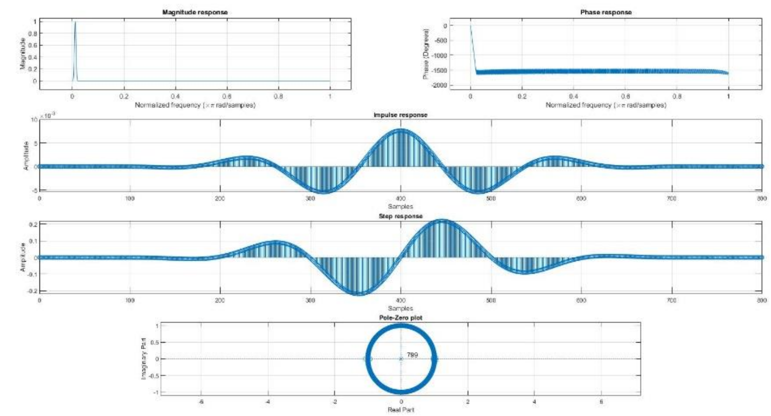

Figure 3.1.2 Analysis for 170 – 310 Hz band

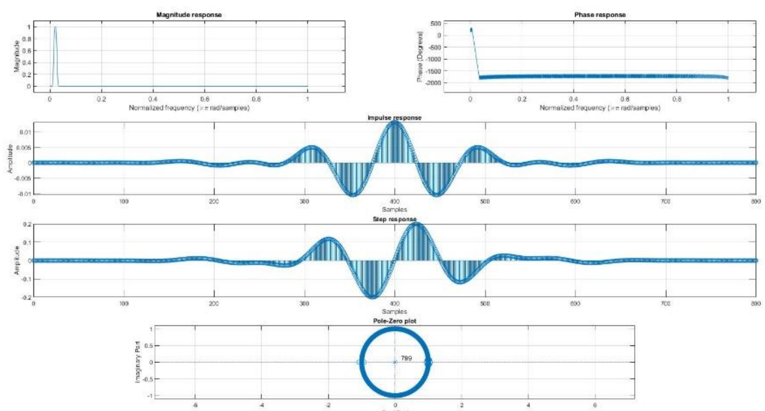

Figure 3.1.3 Analysis for 310 – 600 Hz band

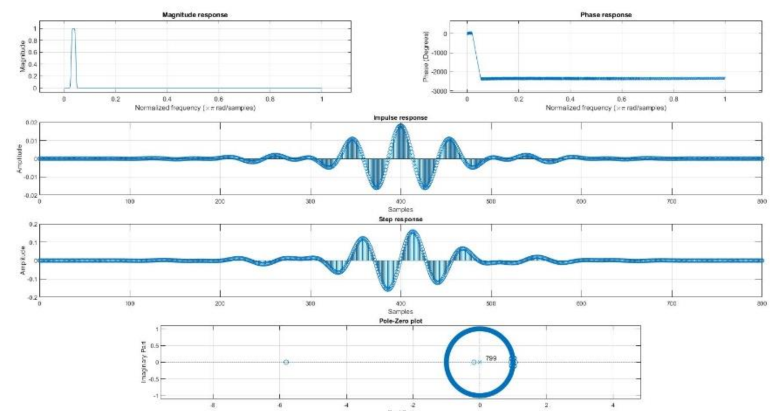

Figure 3.1.4 Analysis for 600 – 1000 Hz band

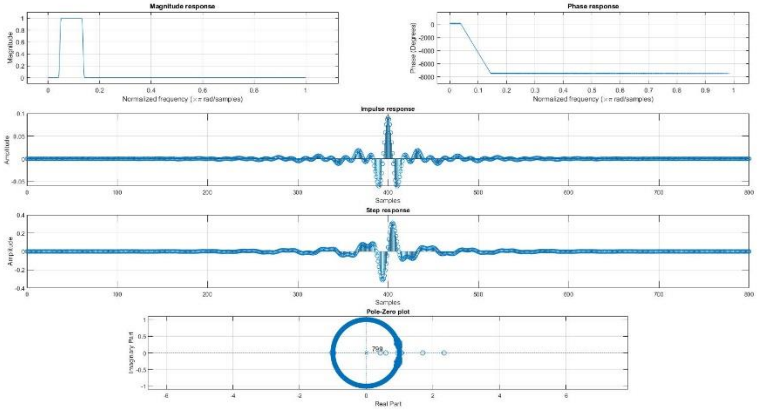

Figure 3.1.5 Analysis for 1 – 3 KHz band

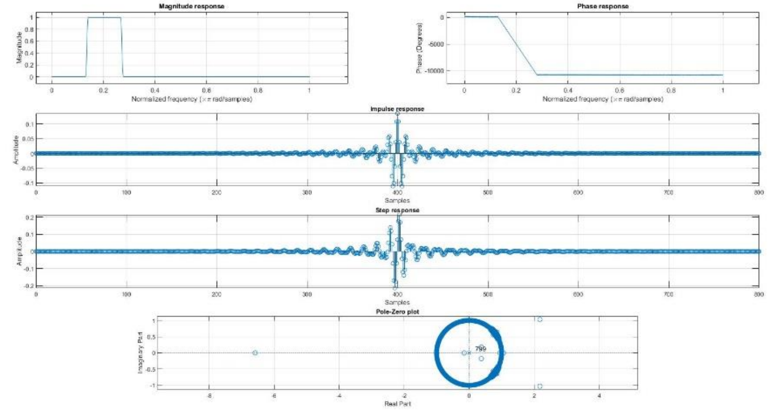

Figure 3.1.6 Analysis for 3 – 6 KHz band

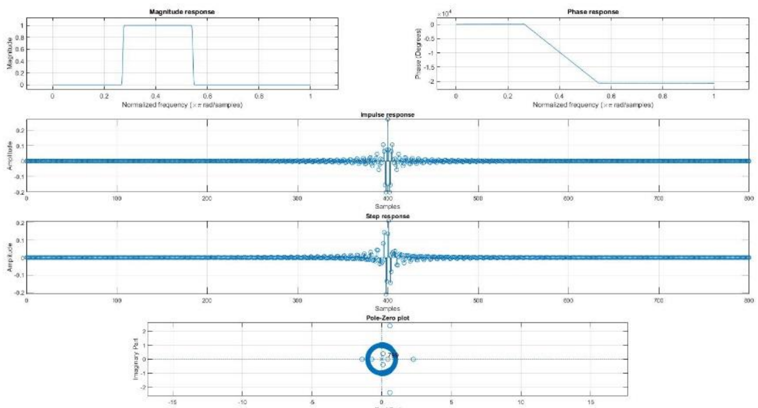

Figure 3.1.7 Analysis for 6 – 12 KHz band

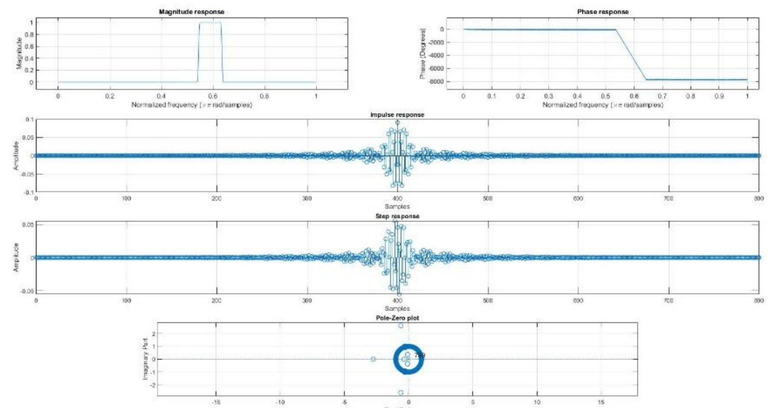

Figure 3.1.8 Analysis for 12 – 14 KHz band

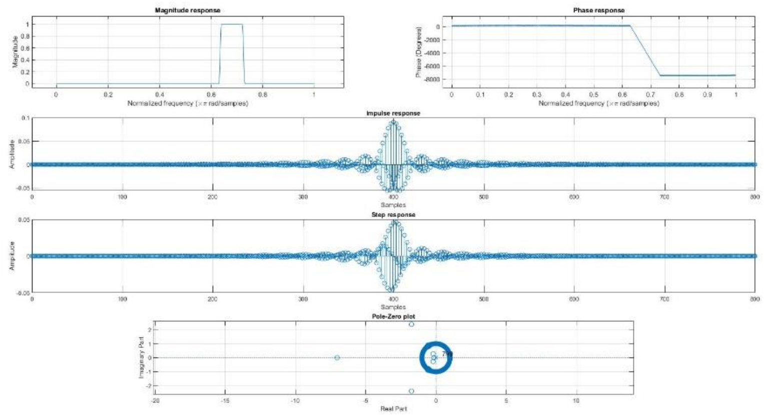

Figure 3.1.9 Analysis for 14 – 16 Hz band

3.2 4th order IIR filters (Butterworth)

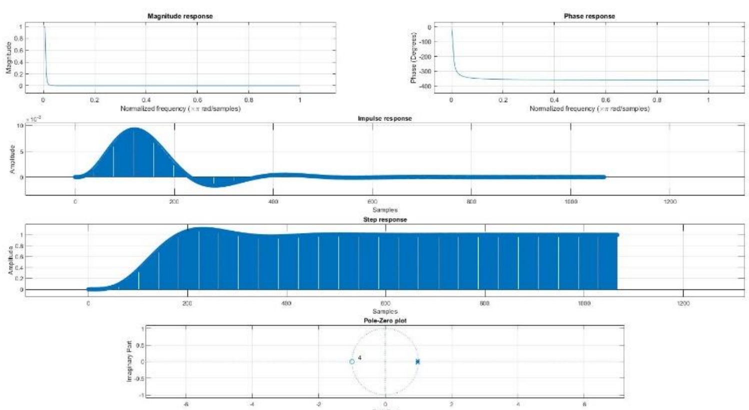

Figure 3.2.1 Analysis for 0 – 170 Hz band

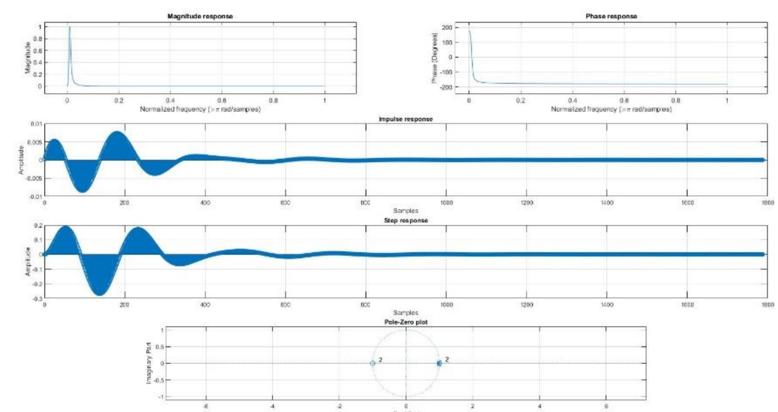

Figure 3.2.2 Analysis for 170 – 310 Hz band

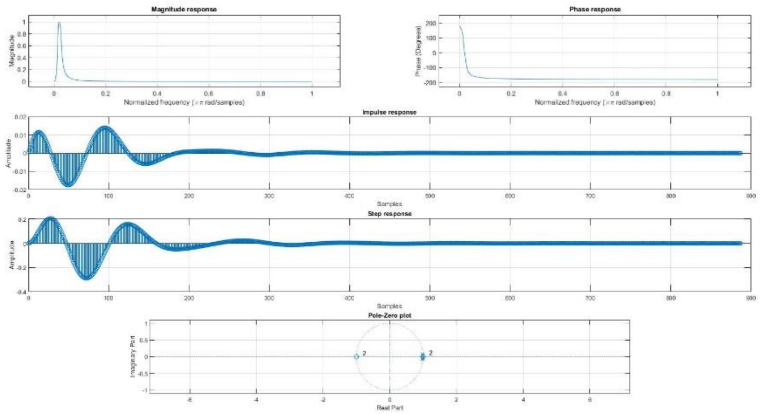

Figure 3.2.3 Analysis for 310 – 600 Hz band

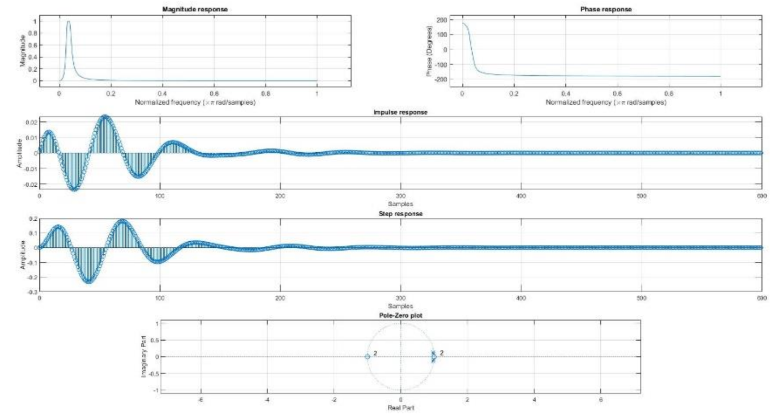

Figure 3.2.4 Analysis for 600 – 1000 Hz band

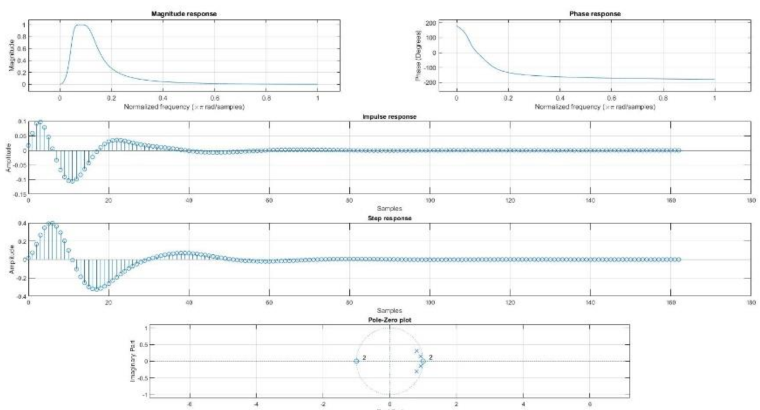

Figure 3.2.5 Analysis for 1 – 3 KHz band

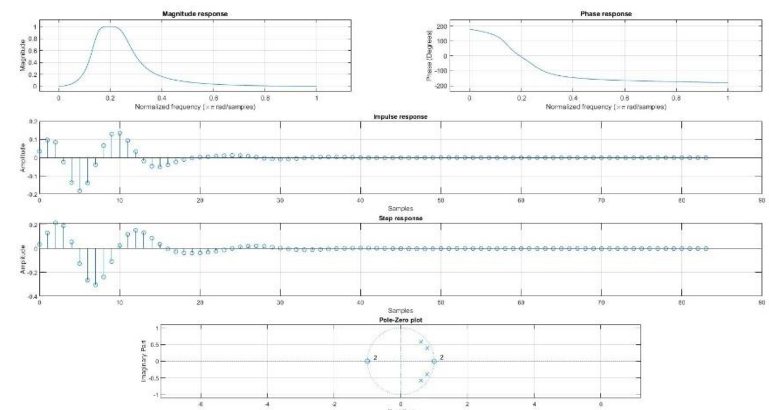

Figure 3.2.6 Analysis for 3 – 6 KHz band

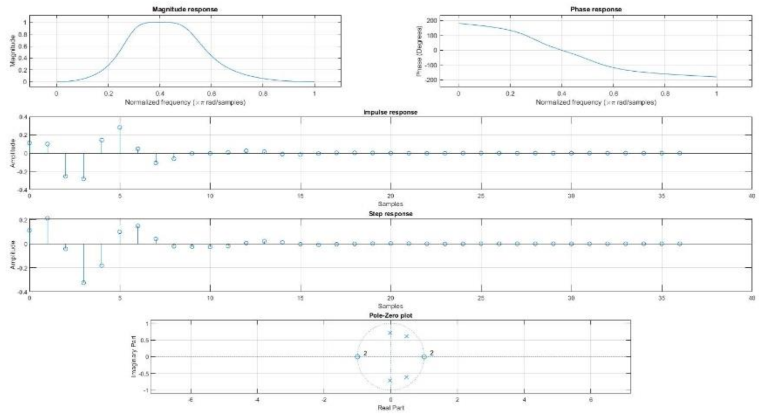

Figure 3.2.7 Analysis for 6 – 12 KHz band

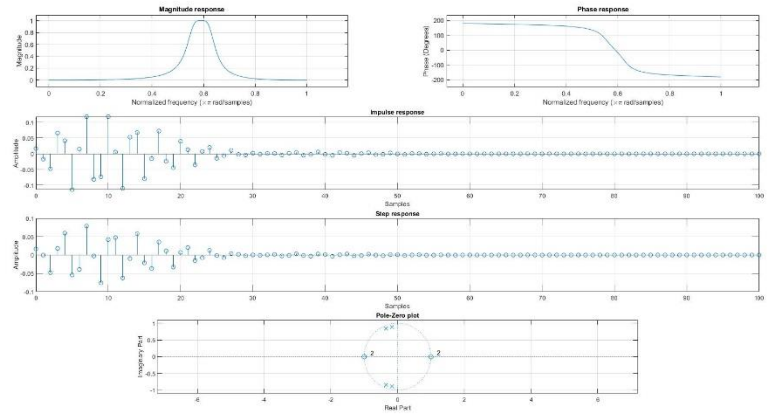

Figure 3.2.8 Analysis for 12 – 14 KHz band

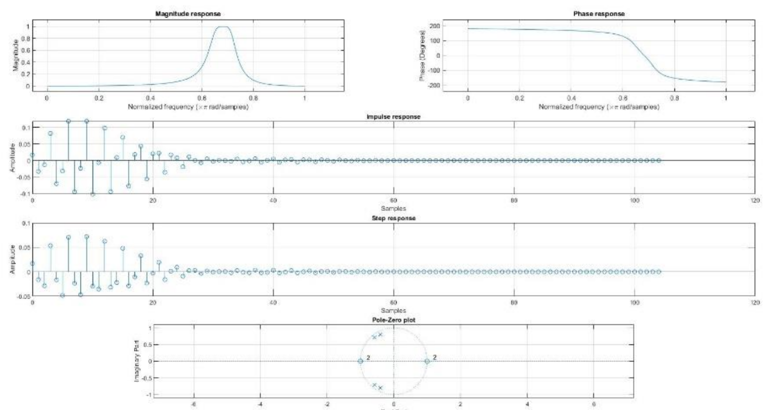

Figure 3.2.9 Analysis for 14 – 16 Hz band