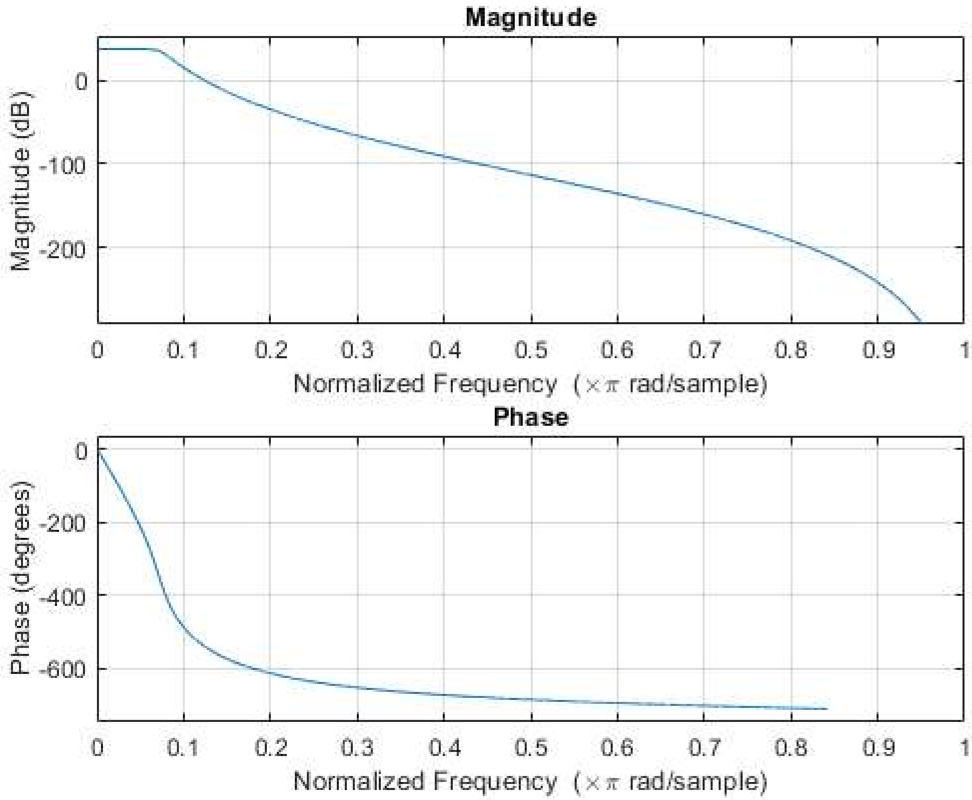
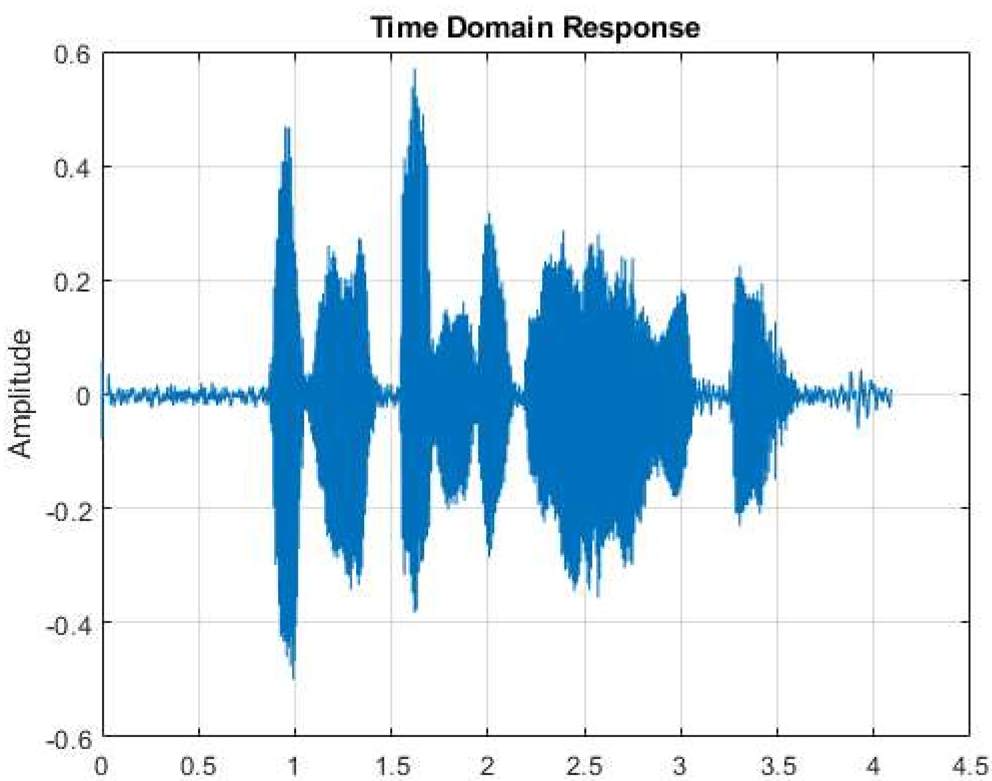
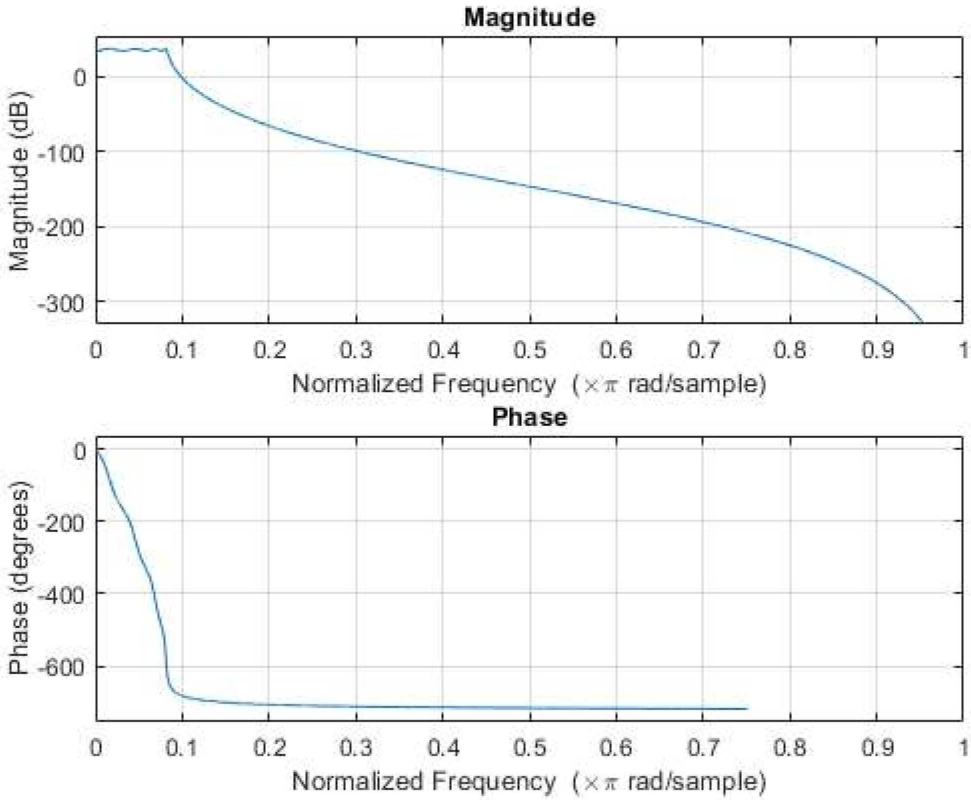
```matlab
% Function to count multiplications
function mult_count = count_multiplies(b, a, is_fir, M)
    if is_fir
        mult_count = ceil((length(b) - 1) / M);
    else
        mult_count = length(b) + length(a) - 1;
    end
end

% Function to find optimal passband frequency
function [is_fir, opt_Fp, opt_b, opt_a] = find_optimal_fp(filter_type, fs_stop, nyq, rp, rs, gain, M)
    Fp_min = 1000;  % Minimum passband frequency
    Fp_max = fs_stop;
    opt_Fp = Fp_min;
    opt_b = [];
    opt_a = [];

    while (Fp_max - Fp_min) > 1
        fp_test = (Fp_min + Fp_max) / 2;
        wp_test = fp_test / nyq;
        ws = fs_stop / nyq;

        % Design filter based on type
        switch filter_type
            case 'Butterworth'
                [n, wn] = buttord(wp_test, ws - 500 / nyq, rp, 55);
                [b, a] = butter(n, wn);
                is_fir = false;
            case 'Chebyshev1'
                [n, wn] = cheb1ord(wp_test, ws, rp, rs);
                [b, a] = cheby1(n, rp, wn);
                is_fir = false;
            case 'Chebyshev2'
                [n, wn] = cheb2ord(wp_test, ws, rp, rs);
                [b, a] = cheby2(n, rs, wn);
                is_fir = false;
            case 'Elliptic'
                [n, wn] = ellipord(wp_test, ws, rp, rs);
                [b, a] = ellip(n, rp, rs, wn);
                is_fir = false;
            case 'Parks-McClellan'
                fp = 100;
                Dpass = 0.10099735734; % Maximum allowable passband deviation
                Dstop = 2.1134890398e-05; % Maximum allowable stopband deviation
                dens = 20; % Grid density for filter optimization
                [n, Fo, Ao, W] = firpmord([fp, fs_stop] / nyq, [1 0], [Dpass, Dstop]);
                b = firpm(n, Fo, Ao, W, {dens});
                opt_Fp = fp;
                opt_a = 1;
                opt_b = b * (gain + 50);
                is_fir = true;
                return;
            case 'Kaiser'
                fp = 100;
                Dpass = 0.17099735734; % Maximum allowable passband deviation
                Dstop = 2.1134890398e-05; % Maximum allowable stopband deviation
```

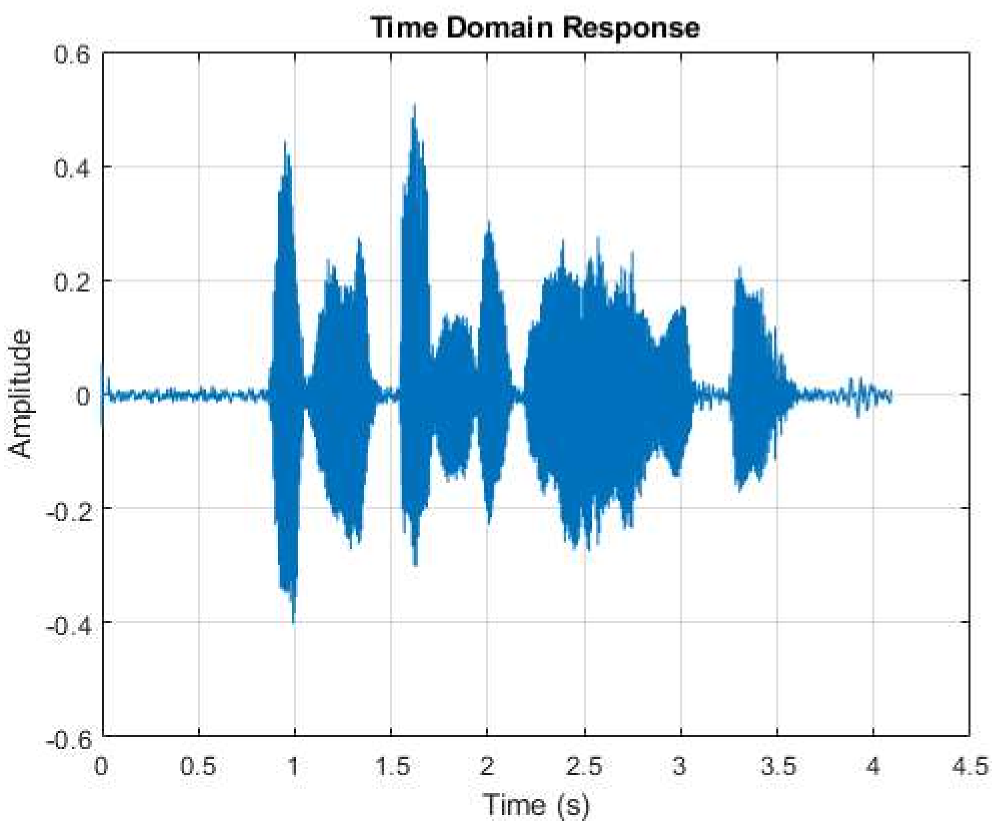
```
                [n, wn, beta, type] = kaiserord([fp fs_stop] / nyq, [1 0], [Dstop Dpass]);
                b = fir1(n, wn, type, kaiser(n + 1, beta));
                opt_Fp = fp;
                opt_a = 1;
                opt_b = b * gain;
                is_fir = true;
                return;
        end

        % Apply gain to filter coefficients
        b = b * gain;

        % Check multiplication constraints
        if count_multiplies(b, a, is_fir, M) <= 17
            Fp_min = fp_test;
            if fp_test > opt_Fp
                opt_Fp = fp_test;
                opt_b = b;
                opt_a = a;
            end
        else
            Fp_max = fp_test;
        end
    end
end
```

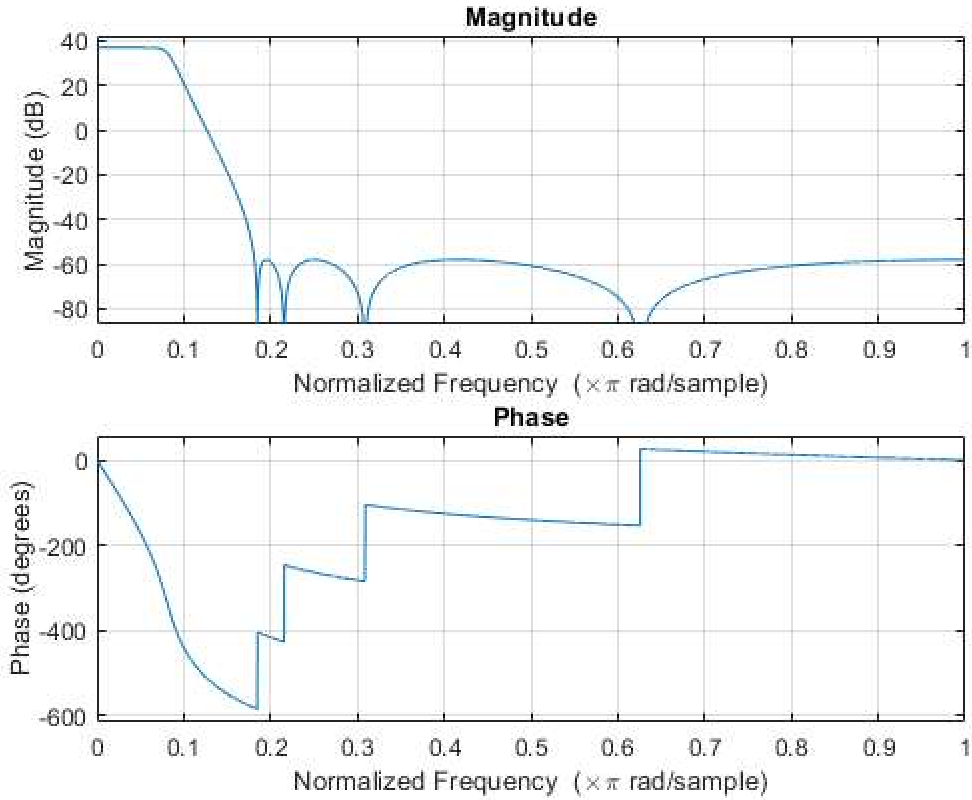
```
Passband frequency: 1611.6 Hz
Number of multiplies: 17.0

Chebyshev1
Passband frequency: 1811.5 Hz
Number of multiplies: 17.0

Chebyshev2
Passband frequency: 1811.5 Hz
Number of multiplies: 17.0

Elliptic
Passband frequency: 2924.8 Hz
Number of multiplies: 17.0

Parks-McClellan
Passband frequency: 100.0 Hz
Number of multiplies: 8.0

Kaiser
Passband frequency: 100.0 Hz
Number of multiplies: 17.0
```

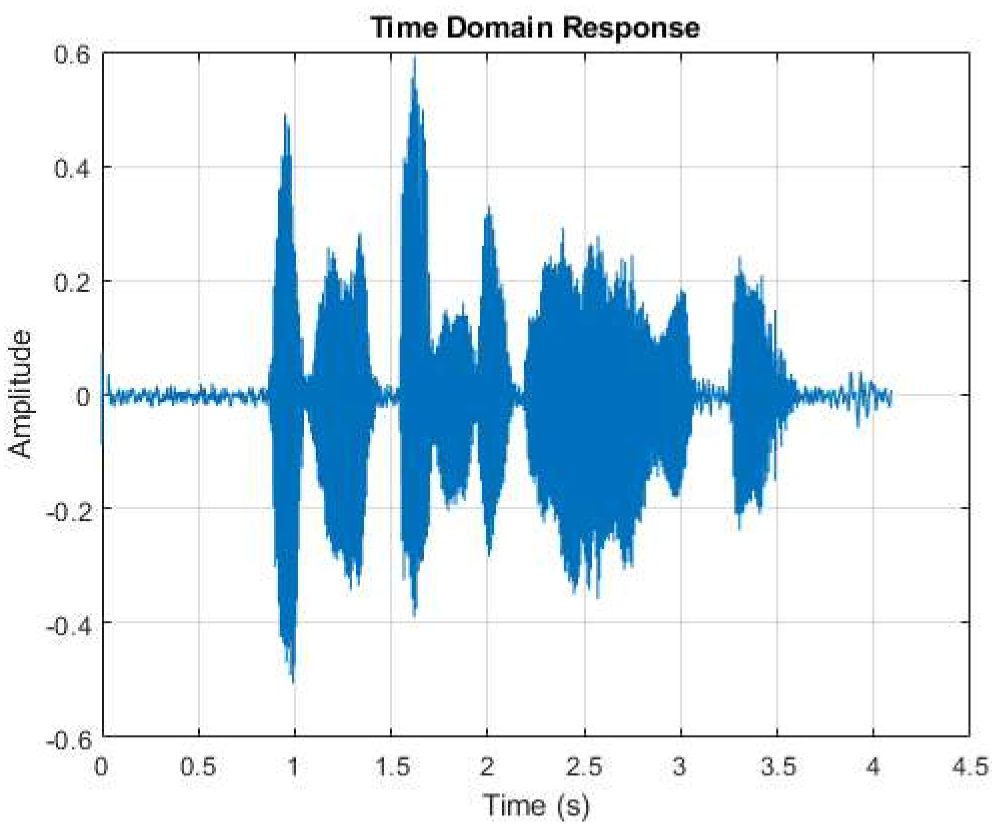

Magnitude
Magnitude (dB)
0
-100
-200
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Normalized Frequency (×π rad/sample)
Phase
Phase (degrees)
0
-200
-400
-600
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Normalized Frequency (×π rad/sample)

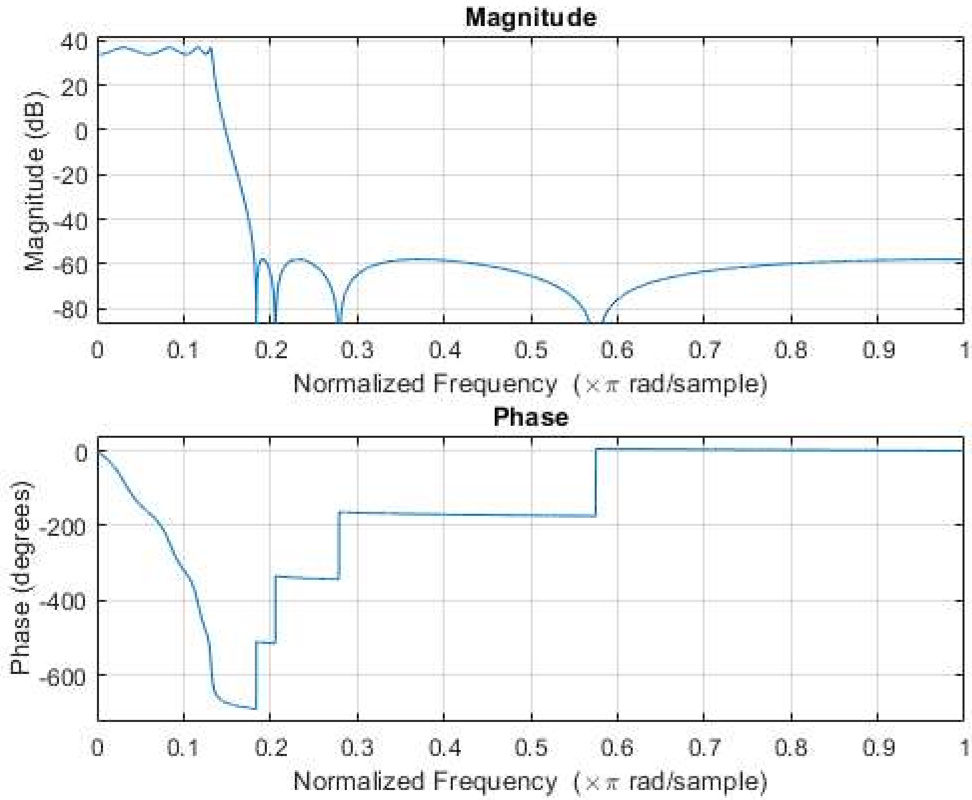

Time Domain Response
Amplitude
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Time (s)

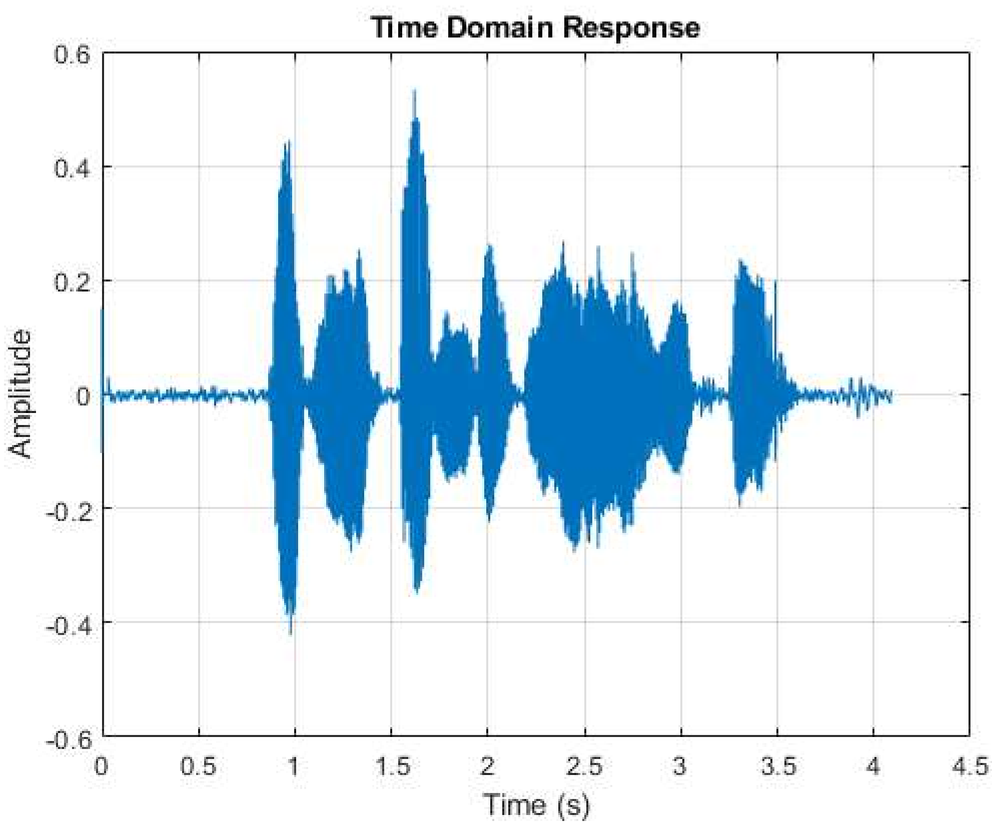

Magnitude
Magnitude (dB)
0
-100
-200
-300
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Normalized Frequency (×π rad/sample)
Phase
Phase (degrees)
0
-200
-400
-600
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Normalized Frequency (×π rad/sample)

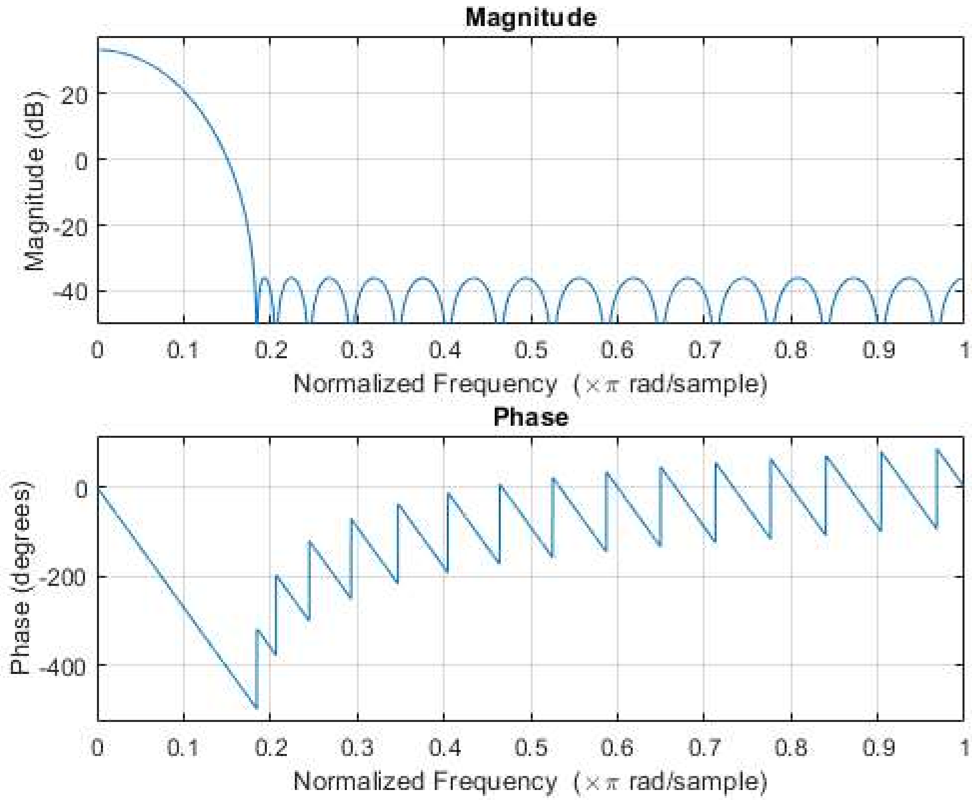

Time Domain Response
Amplitude
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5
Time (s)

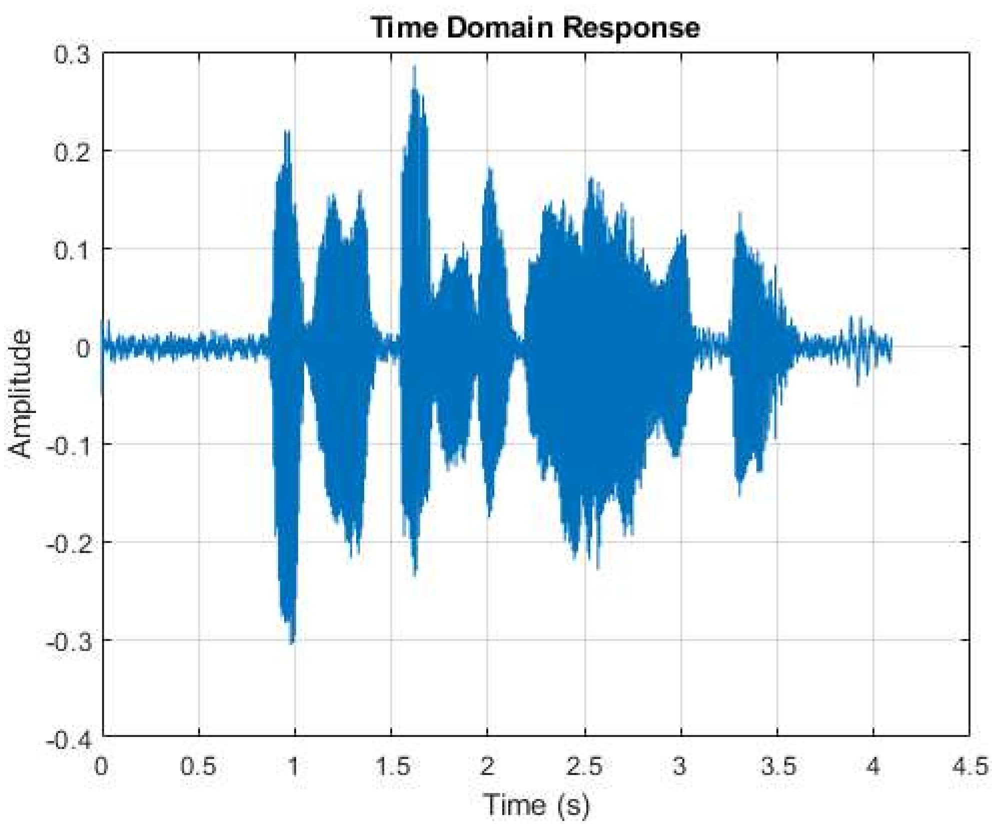

Magnitude
Magnitude (dB)
Normalized Frequency (×π rad/sample)
Phase
Phase (degrees)
Normalized Frequency (×π rad/sample)

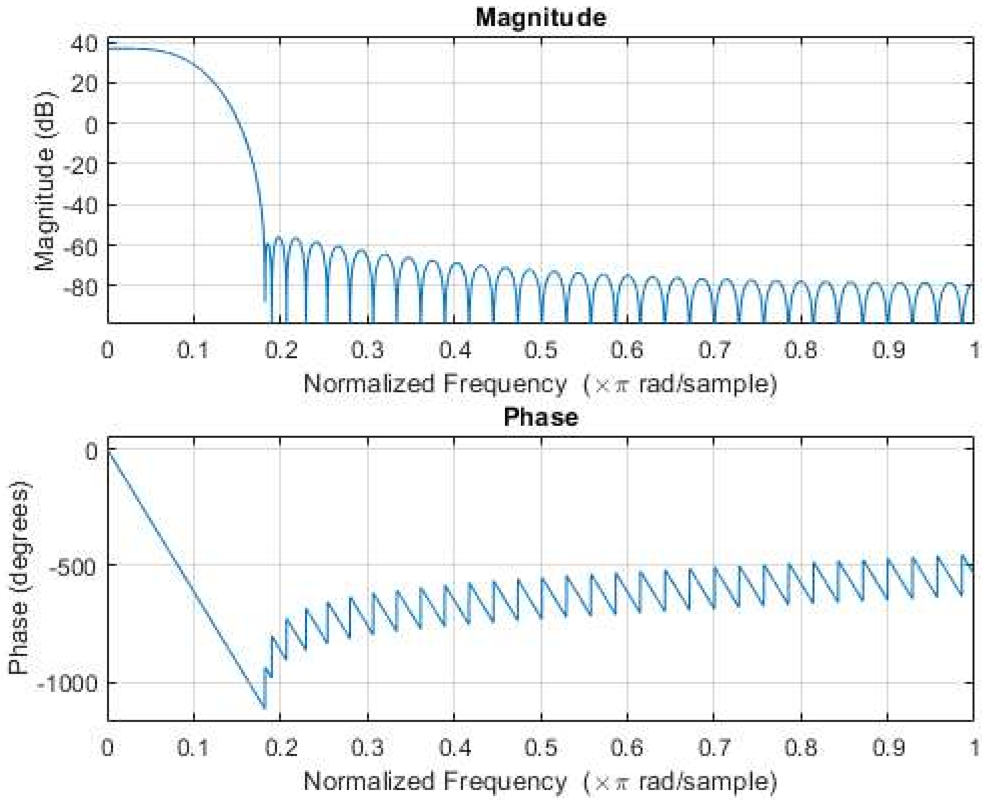

Time Domain Response
Amplitude
Time (s)

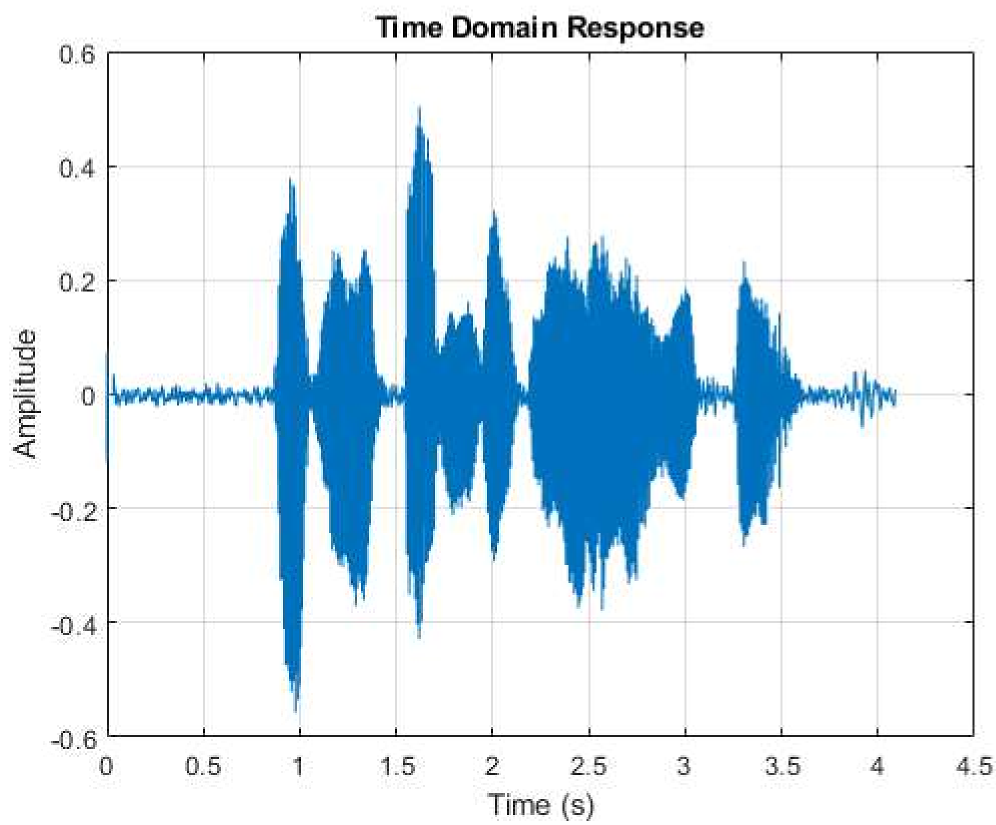

Magnitude
Magnitude (dB)
40
20
0
-20
-40
-60
-80
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Normalized Frequency (×π rad/sample)
Phase
Phase (degrees)
0
-200
-400
-600
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Normalized Frequency (×π rad/sample)


Time Domain Response
Amplitude
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Time (s)


Magnitude
Magnitude (dB)
20
0
-20
-40
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Normalized Frequency (×π rad/sample)
Phase
Phase (degrees)
0
-200
-400
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Normalized Frequency (×π rad/sample)


Time Domain Response
Amplitude
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Time (s)






```
clc; clear; close all;
load projIB.mat

FsIn = 44100; % Input Sampling frequency
```

```
% Filter Specifications
max_multiplications = 17;
% Fp = 4000; % Passband edge (Hz)
Fst = 4000; % Stopband edge (Hz)
max_gain_passband = 40; % (dB)
min_gain_passband = 37; % (dB)
max_gain_stopband = -55; % (dB)

Ast = max_gain_passband - max_gain_stopband; % Stopband Attenuation (dB)
Rp = max_gain_passband - min_gain_passband; % Passband Ripple (dB)

gain = 10^(min_gain_passband/20); % Minimum Linear Gain
nyq = FsIn / 2; % Nyquist frequency
M = 4; % Downsampling factor

filter_types = {'Butterworth', 'Chebyshev1', 'Chebyshev2', 'Elliptic', 'Parks-McClellan', 'Kaiser'};

for i = 1:length(filter_types)
    fprintf('\n%s\n', filter_types{i});

    % Find optimal filter parameters
    [is_fir, fp, b, a] = find_optimal_fp(filter_types{i}, Fst, nyq, Rp, Ast, gain, M);
    if is_fir
        current_filter = dsp.FIRFilter(b);
    else
        current_filter = dsp.IIRFilter(b,a);
    end

    % Frequency response
    figure; freqz(current_filter);

    % Apply filtering and downsampling
    output = current_filter(noisy);
    downsampled_signal = downsample(output,M);

    % Count multiplications
    mults = count_multiplies(b, a, is_fir, M);
    fprintf('Passband frequency: %.1f Hz\n', fp);
    fprintf('Number of multiplies: %.1f\n', mults);
    % cost(current_filter)
    % measure(current_filter)

    % Plot time-domain response
    figure;
    plot((1:length(downsampled_signal)) / (FsIn/M), downsampled_signal);
    grid on;
    title('Time Domain Response');
    xlabel('Time (s)');
    ylabel('Amplitude');

    % Play output
    soundsc(downsampled_signal, FsIn/M);
    pause(length(downsampled_signal) / (FsIn/M) + 1);
end
```

```
Butterworth
```

Published with MATLAB® R2024b