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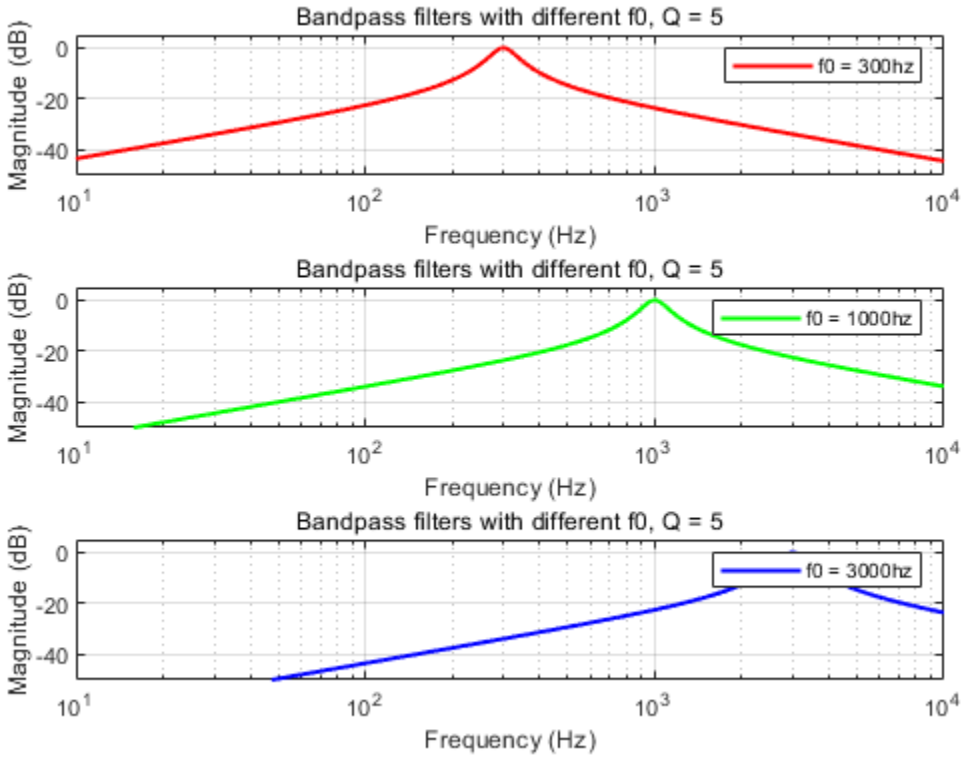
```
clc;
clear;
close all;
```

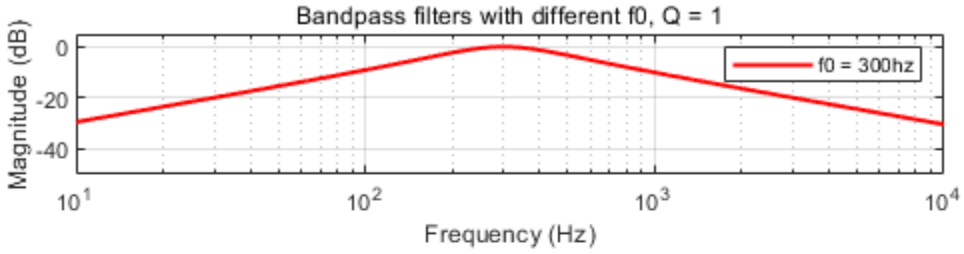
Question 1, Designed 3 second-order band-pass filters centered at 300(bass), 1000(mid), and 3000(treble)

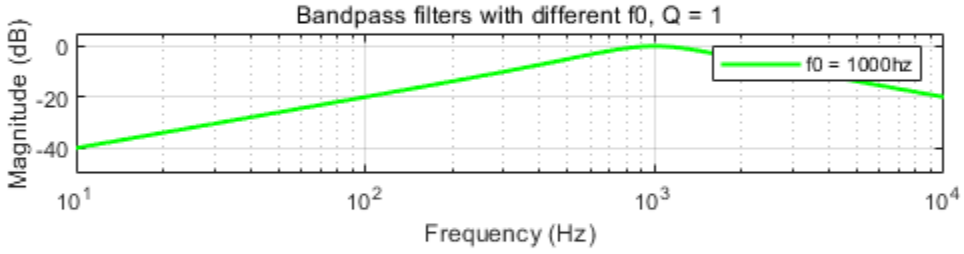
```
f0_list = [300, 1000, 3000];

% case Q=5
Q = 5;
titles = {
    'f0 = 300hz',
    'f0 = 1000hz',
    'f0 = 3000hz'
};
colors = ['r', 'g', 'b'];

freqs_hz = logspace(1, 4, 1000);
w = 2 * pi * freqs_hz;

figure;
hold on;

for i=1:3
    subplot(3, 1, i);
    f0 = f0_list(i);
    w0 = 2 * pi * f0;

    numerator = [w0/Q, 0];
    denominator = [1, w0/Q, w0^2];

    H = freqs(numerator, denominator, w);
    mag = abs(H);
    mag_db = 20 * log10(mag);

    semilogx(freqs_hz, mag_db, colors(i), 'LineWidth', 1.5, 'DisplayName',
titles{i});
    grid on;
```

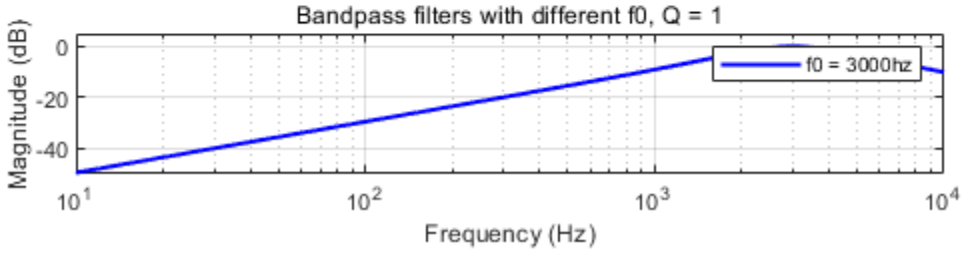
```
    xlabel('Frequency (Hz)');
    ylabel('Magnitude (dB)');
    title('Bandpass filters with different f0, Q = 5');
    legend('show');
    xlim([10, 10000]);
    ylim([-50, 5]);
end


hold off;

figure;
hold on;

% Q2 = 1 case
Q2 = 1;
for i=1:3
    subplot(3, 1, i);
    f0 = f0_list(i);
    w0 = 2 * pi * f0;

    numerator = [w0/Q2, 0];
    denominator = [1, w0/Q2, w0^2];

    H = freqs(numerator, denominator, w);
    mag = abs(H);
    mag_db = 20 * log10(mag);

    semilogx(freqs_hz, mag_db, colors(i), 'LineWidth', 1.5, 'DisplayName',
titles{i});

    grid on;
    xlabel('Frequency (Hz)');
    ylabel('Magnitude (dB)');
    title('Bandpass filters with different f0, Q = 1');
    legend('show');
    xlim([10, 10000]);
    ylim([-50, 5]);
end
hold off;

% case Q=100
figure;
hold on;
Q3 = 100;

for i=1:3
    subplot(3, 1, i);
    f0 = f0_list(i);
    w0 = 2 * pi * f0;

    numerator = [w0/Q3, 0];
    denominator = [1, w0/Q3, w0^2];
```

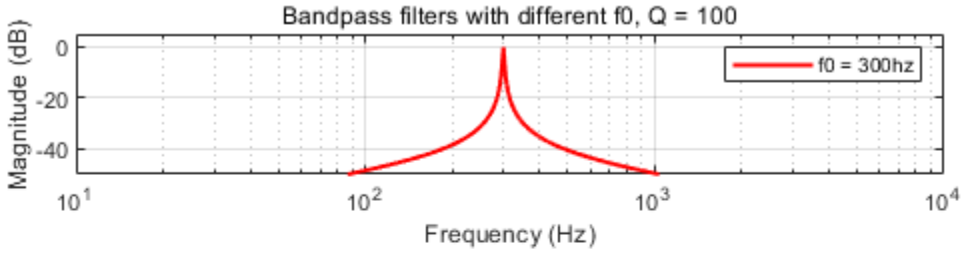
```
    H = freqs(numerator, denominator, w);
    mag = abs(H);
    mag_db = 20 * log10(mag);

    semilogx(freqs_hz, mag_db, colors(i), 'LineWidth', 1.5, 'DisplayName',
titles{i});

    grid on;
    xlabel('Frequency (Hz)');
    ylabel('Magnitude (dB)');
    title('Bandpass filters with different f0, Q = 100');
    legend('show');
    xlim([10, 10000]);
    ylim([-50, 5]);
end
hold off;

% The bandwidth is proportional to the center freq, f0/Q
% The resonance will co-respond with center frequency f0
```

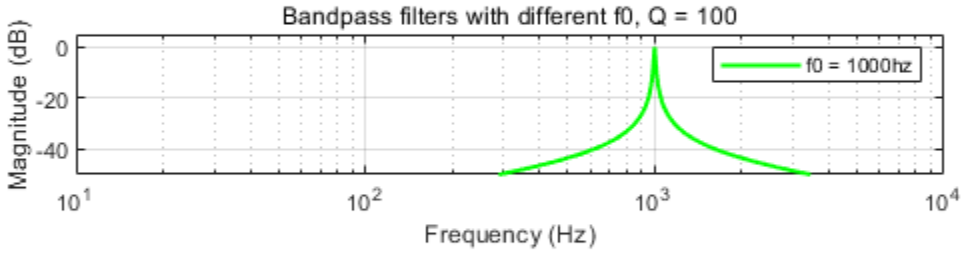


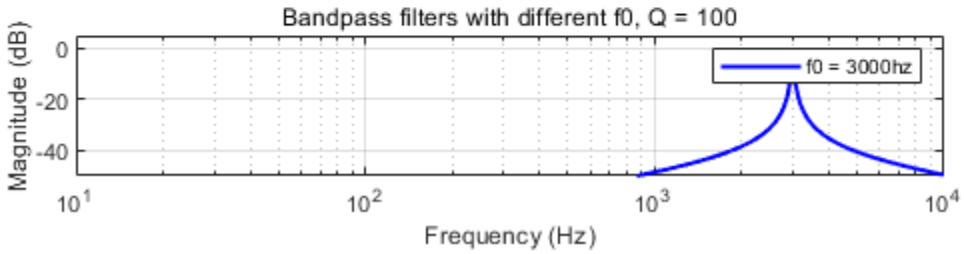

Bandpass filters with different f0, Q = 1
Magnitude (dB)
0
-20
-40
10^1
10^2
10^3
10^4
Frequency (Hz)
f0 = 300hz


Bandpass filters with different f0, Q = 1
Magnitude (dB)
0
-20
-40
10^1
10^2
10^3
10^4
Frequency (Hz)
f0 = 1000hz


Bandpass filters with different f0, Q = 1
Magnitude (dB)
0
-20
-40
10^1
10^2
10^3
10^4
Frequency (Hz)
f0 = 3000hz


Bandpass filters with different f0, Q = 100
Magnitude (dB)
0
-20
-40
10^1
10^2
10^3
10^4
Frequency (Hz)
f0 = 300hz

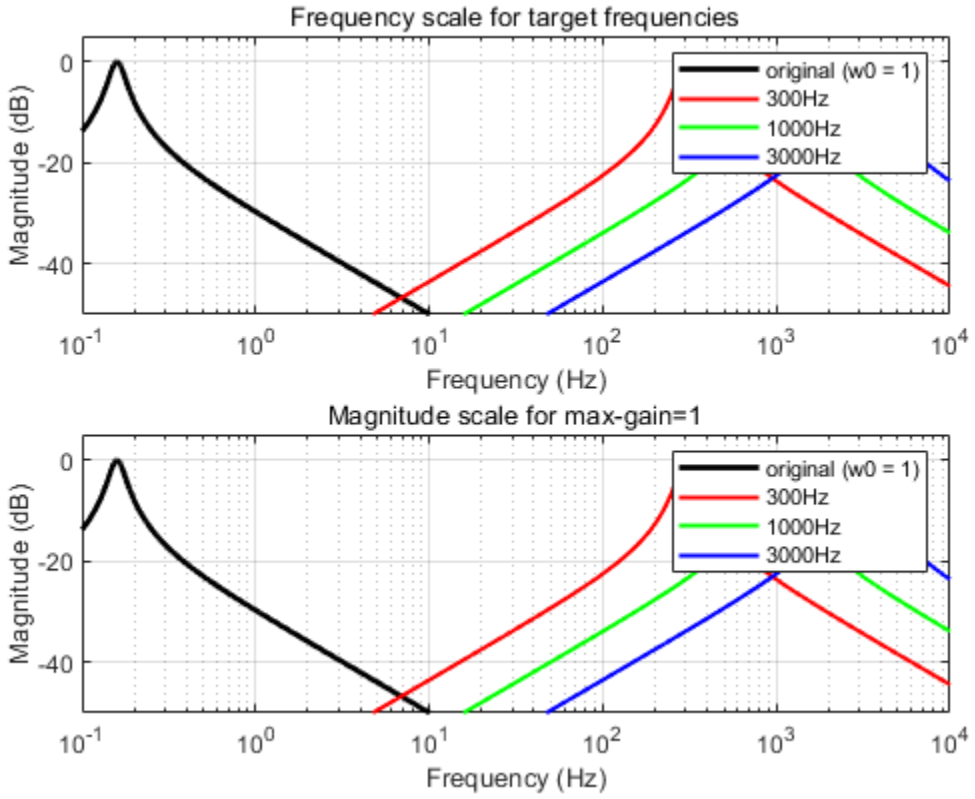

Bandpass filters with different f0, Q = 100
Magnitude (dB)
0
-20
-40
10^1
10^2
10^3
10^4
Frequency (Hz)
f0 = 1000hz


Bandpass filters with different f0, Q = 100
Magnitude (dB)
0
-20
-40
10^1
10^2
10^3
10^4
Frequency (Hz)
f0 = 3000hz

Question 2, simulation in Frequency and Magnitude Scaling

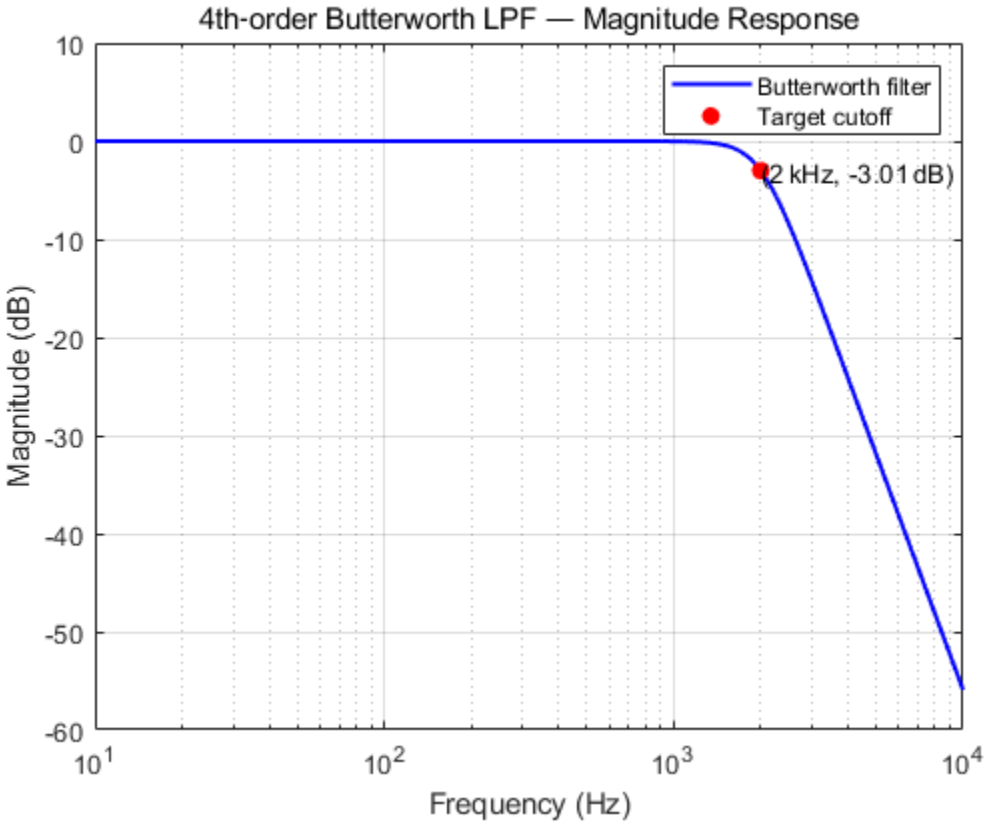
```
Q = 5;
w0_origin = 1;
f0_origin = w0_origin/(2*pi);

num_origin = [w0_origin/Q, 0];
den_origin = [1, w0_origin/Q, w0_origin^2];

f_targets = [300, 1000, 3000];
colors = ['r', 'g', 'b'];
labels = {'300Hz', '1000Hz', '3000Hz'};

freqs_hz = logspace(-1, 4, 1000);
w = 2*pi*freqs_hz;

H_origin = freqs(num_origin, den_origin, w);
mag_origin = abs(H_origin);
mag_db_origin = 20*log10(mag_origin);

% frequency scaling
figure;
subplot(2, 1, 1);
semilogx(freqs_hz, mag_db_origin, 'k', 'LineWidth', 2, 'DisplayName',
'original (w0 = 1)');
hold on;

for i=1:3
    kf = 2*pi*f_targets(i);
    km = 1;
    num_scale = [kf/Q, 0];
    den_scale = [1, kf/Q, kf^2];

    H_scale = freqs(num_scale, den_scale, w);
    mag_scale = abs(km*H_scale);
    mag_db_scale = 20*log10(mag_scale);

    semilogx(freqs_hz, mag_db_scale, colors(i), 'LineWidth', 1.5,
'DisplayName', labels{i});
end

grid on;
xlabel('Frequency (Hz)');
ylabel('Magnitude (dB)');
title('Frequency scale for target frequencies');
legend('show');
xlim([0.1, 10000]);
ylim([-50, 5]);
hold off;

% magnitude scaling
```

```
subplot(2, 1, 2);
semilogx(freqs_hz, mag_db_origin, 'k', 'LineWidth', 2, 'DisplayName',
'original (w0 = 1)');
hold on;
for i=1:3
    kf = 2*pi*f_targets(i);
    num_scale = [kf/Q, 0];
    den_scale = [1, kf/Q, kf^2];
    H_scale = freqs(num_scale, den_scale, w);
    peakMag  = max(abs(H_scale));
    km = 1/peakMag;
    mag_scale = abs(km * H_scale);
    mag_db_scale = 20*log10(mag_scale);
    semilogx(freqs_hz, mag_db_scale, colors(i), 'LineWidth', 1.5,
'DisplayName', labels{i});
end

grid on;
xlabel('Frequency (Hz)');
ylabel('Magnitude (dB)');
title('Magnitude scale for max-gain=1')
legend('show');
xlim([0.1, 10000]);
ylim([-50, 5]);
hold off;
```



Question 3 Butterworth Lowpass Filter

```
order = 4;
fc = 2000;
wc = fc*2*pi;
[num, den] = butter(order, wc, 's');

freq_hz = logspace(1, 4, 1000);
w = freq_hz*2*pi;
H = freqs(num,den,w);

mag_db   = 20*log10(abs(H));

figure;
semilogx(freq_hz, mag_db, 'b', 'LineWidth', 1.5, 'DisplayName', 'Butterworth
filter');
grid on;
xlabel('Frequency (Hz)');
ylabel('Magnitude (dB)');
title('4th-order Butterworth LPF — Magnitude Response');
legend('show');
xlim([min(freq_hz) max(freq_hz)])

magTarget = interp1(freq_hz, mag_db, 2000);
hold on;
plot(2000, magTarget, 'ro','MarkerFaceColor','r', 'DisplayName', 'Target
cutoff');
text(2000,magTarget, sprintf('(2 kHz, %.2f dB)',magTarget));
hold off;
```



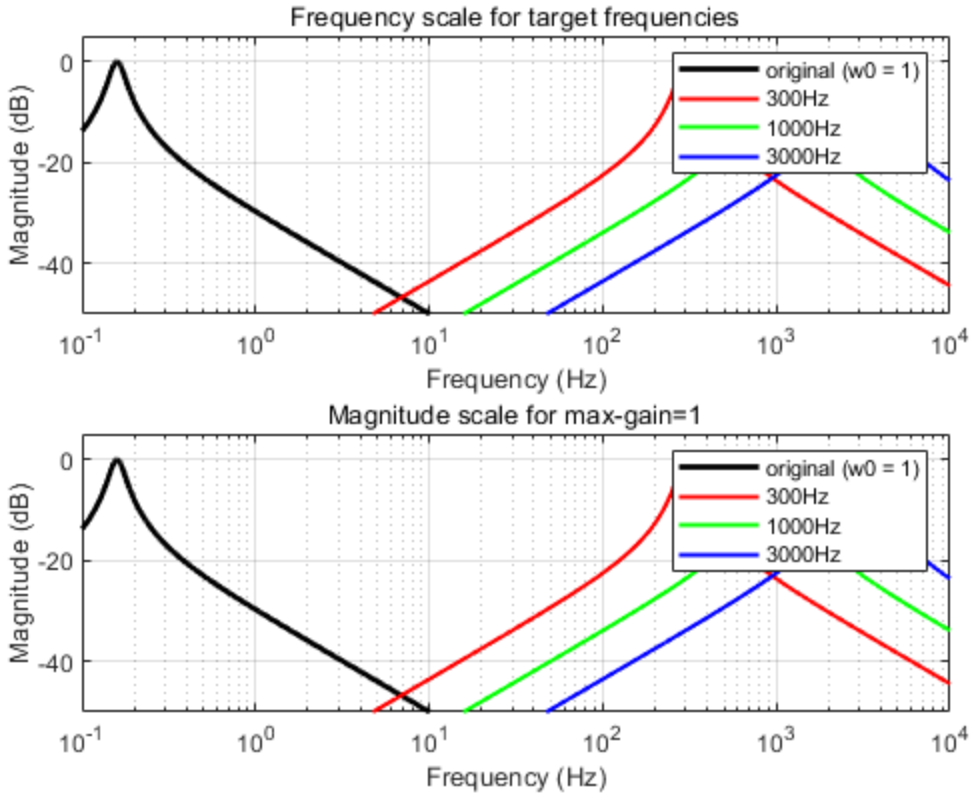
Question 4, Filter the audio

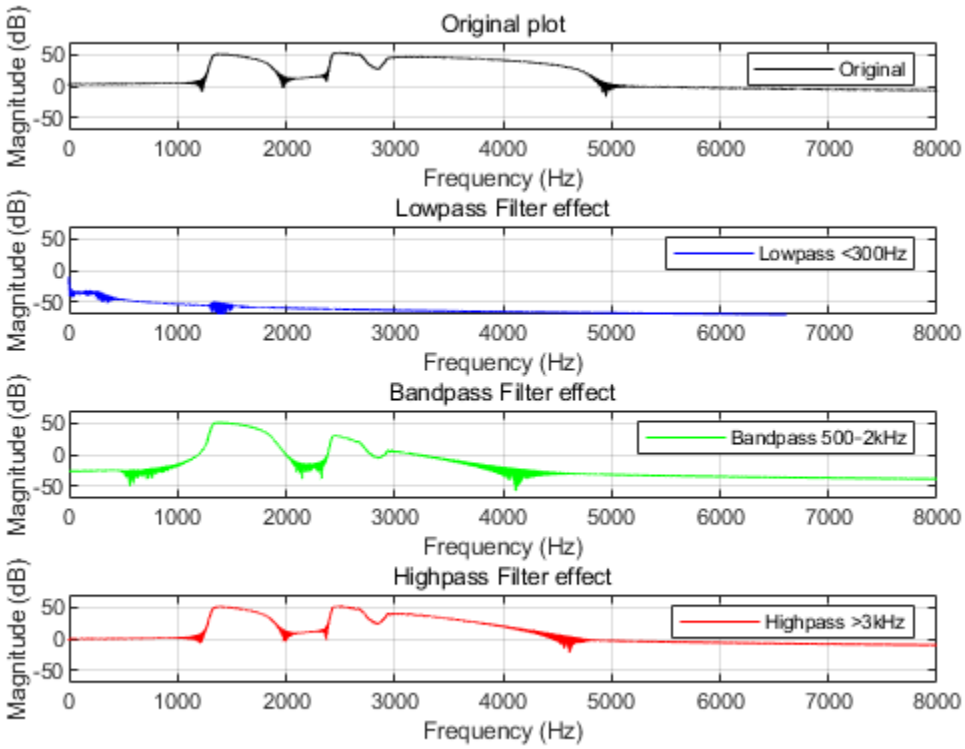
```
[x, fs] = audioread('input.wav');
nyq = fs/2;

lpf = 300/nyq;
[num_lpf, den_lpf] = butter(order, lpf, 'low');

bpf = [500 2000]/nyq;
[num_bpf, den_bpf] = butter(order, bpf, 'bandpass');

hpf = 3000/nyq;
[num_hpf, den_hpf] = butter(order, hpf, 'low');

out_lpf = filtfilt(num_lpf, den_lpf, x);
out_bpf = filtfilt(num_bpf, den_bpf, x);
out_hpf = filtfilt(num_hpf, den_hpf, x);

disp('Playing original…');
soundsc(x, fs);
pause(length(x)/fs + 0.5);

disp('Playing low-pass < 300 Hz…');
soundsc(out_lpf, fs);
pause(length(out_lpf)/fs + 0.5);
```

```
disp('Playing band-pass 500–2 kHz…');
soundsc(out_bpf, fs);
pause(length(out_bpf)/fs + 0.5);

disp('Playing high-pass >3 kHz…');
soundsc(out_hpf, fs);
pause(length(out_hpf)/fs + 0.5);

audiowrite('output_low300.wav',  out_lpf, fs);
audiowrite('output_band500_2k.wav', out_bpf, fs);
audiowrite('output_high3k.wav',  out_hpf, fs);

% map to frequency domain
Nfft = 2^15;
f = linspace(0, nyq, Nfft/2);

X  = fft(x,  Nfft);
outlp= fft(out_lpf, Nfft);
outbp= fft(out_bpf, Nfft);
outhp= fft(out_hpf, Nfft);

magX  = 20*log10(abs(X(1:Nfft/2)) );
magLp = 20*log10(abs(outlp(1:Nfft/2)) );
magBp = 20*log10(abs(outbp(1:Nfft/2)) );
magHp = 20*log10(abs(outhp(1:Nfft/2)) );

figure;
subplot(4, 1, 1);
plot(f, magX,  'k','DisplayName','Original');
title('Original plot');
xlabel('Frequency (Hz)');
ylabel('Magnitude (dB)');
xlim([0 8000]);
ylim([-70, 70]);
legend('show');
grid on;
subplot(4, 1, 2);
plot(f, magLp, 'b','DisplayName','Lowpass <300Hz');
title('Lowpass Filter effect');
xlabel('Frequency (Hz)');
ylabel('Magnitude (dB)');
xlim([0 8000]);
ylim([-70, 70]);
legend('show');
grid on;
subplot(4, 1, 3);
plot(f, magBp, 'g','DisplayName','Bandpass 500-2kHz');
title('Bandpass Filter effect');
xlabel('Frequency (Hz)');
ylabel('Magnitude (dB)');
xlim([0 8000]);
ylim([-70, 70]);
legend('show');
```

```
grid on;
subplot(4, 1, 4);
plot(f, magHp, 'r','DisplayName','Highpass >3kHz');
xlabel('Frequency (Hz)');
ylabel('Magnitude (dB)');
title('Highpass Filter effect');
xlim([0 8000]);
ylim([-70, 70]);
legend('show');
grid on;
```

```
Playing original…
Playing low-pass < 300 Hz…
Playing band-pass 500-2 kHz…
Playing high-pass >3 kHz…
```





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