Table of Contents


```
clc; close all; clear;

% Setting up required functions
u = @(n)double(n>=0);
del = @(n)double(n==0);
```

Question 1: Record Audio

```
% Done
```

Question 2: Load Audio

```
% Sampling Frequency
Fs = 44100;
T = 1/Fs;
% Audio Data
x = load('audi22o.txt');
x = x(:,1);
x = transpose(x);

% Testing Audio
soundsc(x,Fs);
```

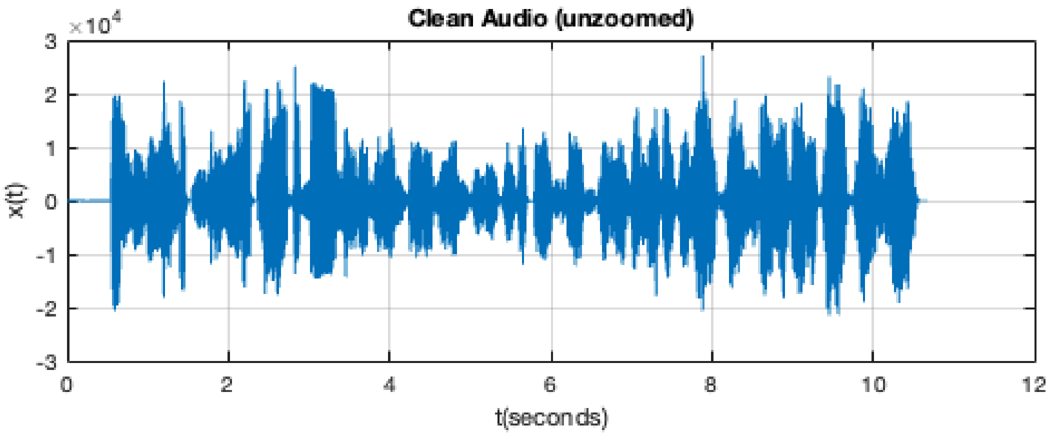
Question 3: Add Noise

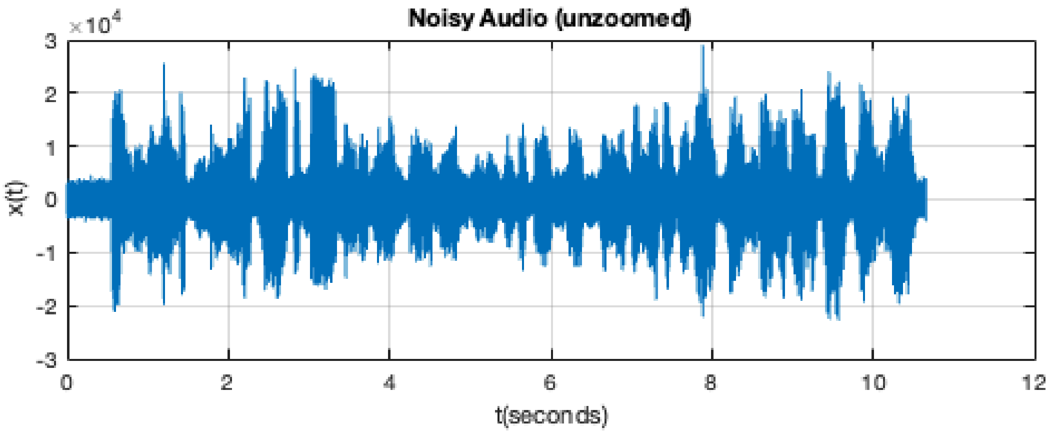
```
sigma = 22323*0.05;
```

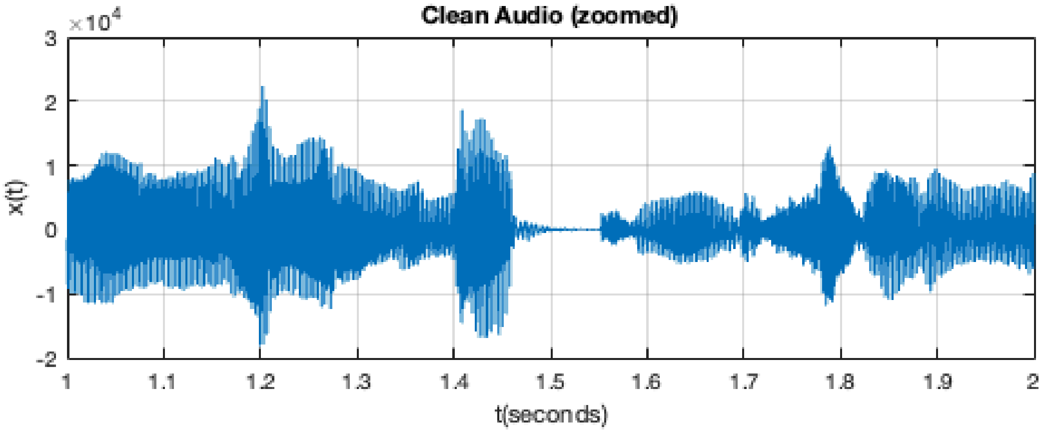
```
noise = sigma*randn(1,length(x));
x_noisy = x + noise;
% Testing Noisy
soundsc(x_noisy,Fs);
```

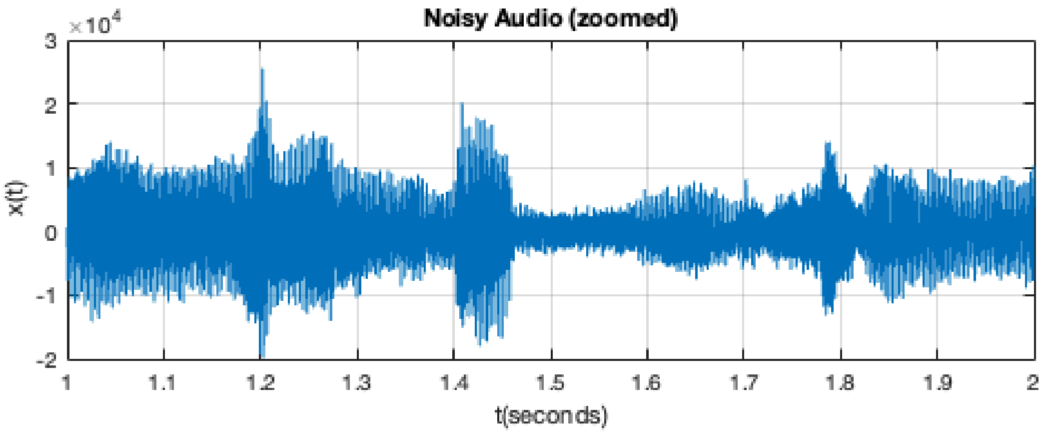
Plotting Audios

```
t = 0:T:(length(x)-1)*(T);
figure;
subplot(2,1,1);
plot(t,x);
xlabel("t(seconds)");
ylabel("x(t)");
title("Clean Audio (unzoomed)");
grid on;
subplot(2,1,2);
plot(t,x_noisy);
xlabel("t(seconds)");
ylabel("x(t)");
title("Noisy Audio (unzoomed)");
grid on;

figure;
t = 0:T:(length(x)-1)*(T);
subplot(2,1,1);
plot(t,x);
xlabel("t(seconds)");
ylabel("x(t)");
title("Clean Audio (zoomed)");
xlim([1.0,2.0]);
grid on;
subplot(2,1,2);
plot(t,x_noisy);
xlabel("t(seconds)");
ylabel("x(t)");
title("Noisy Audio (zoomed)");
xlim([1.0,2.0]);
grid on;
```


Clean Audio (unzoomed)
×10^4
x(t)
t(seconds)


Noisy Audio (unzoomed)
×10^4
x(t)
t(seconds)

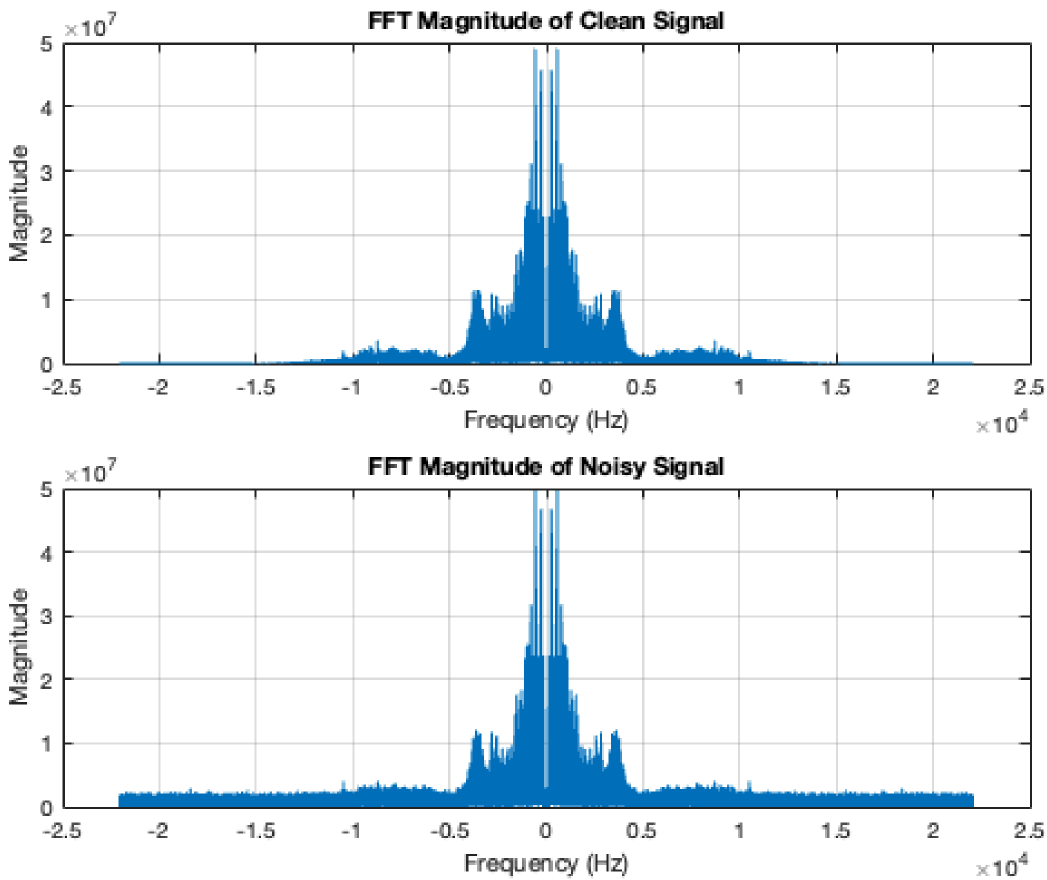


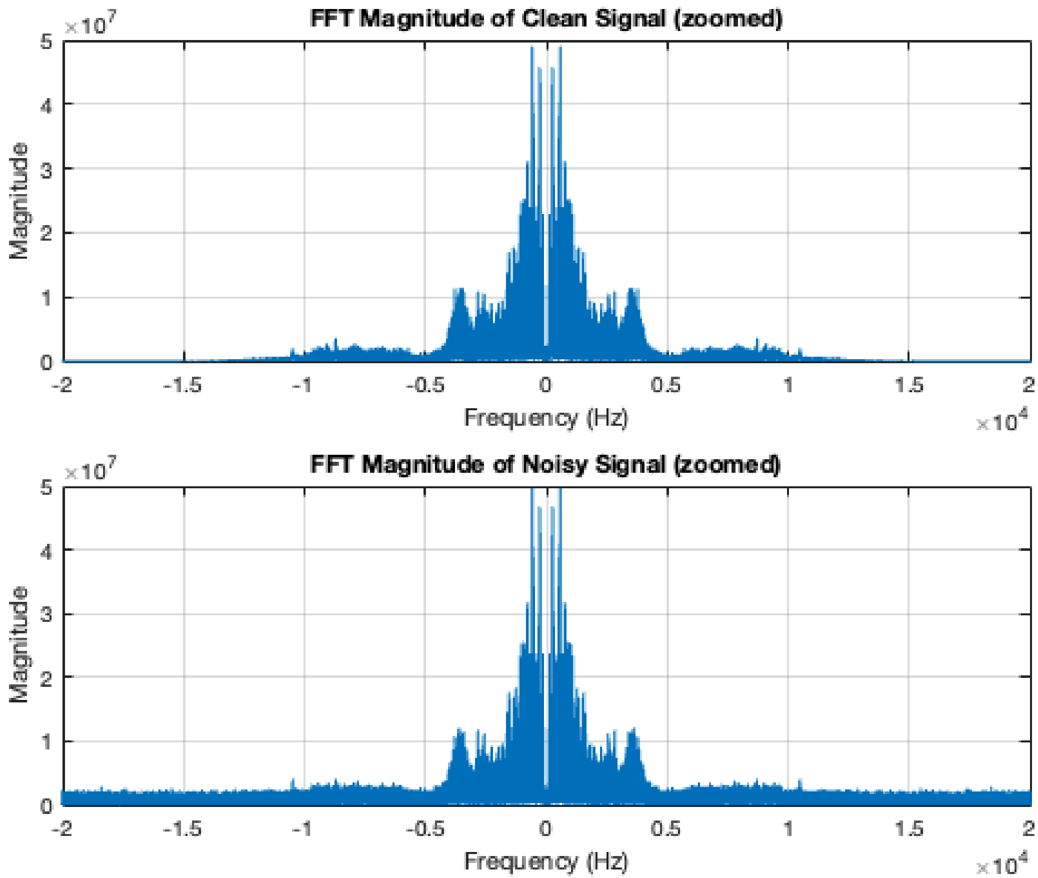


Question 4: dtft Plots

```
% Compute FFT of the clean signal
[clean_fft, clean_fft_freq] = dtft(x,T);

% Compute FFT of the noisy signal
[noisy_fft, noisy_fft_freq] = dtft(x_noisy,T);

% Plotting FFT magnitudes
figure;
subplot(2,1,1);
plot(clean_fft_freq, abs(clean_fft));
xlabel('Frequency (Hz)');
ylabel('Magnitude');
grid on;
title('FFT Magnitude of Clean Signal');

subplot(2,1,2);
plot(noisy_fft_freq, abs(noisy_fft));
xlabel('Frequency (Hz)');
ylabel('Magnitude');
grid on;
```

```
title('FFT Magnitude of Noisy Signal');

% Plotting FFT magnitudes zoomed
figure;
subplot(2,1,1);
plot(clean_fft_freq, abs(clean_fft));
xlabel('Frequency (Hz)');
ylabel('Magnitude');
xlim([-20000,20000]);
grid on;
title('FFT Magnitude of Clean Signal (zoomed)');

subplot(2,1,2);
plot(noisy_fft_freq, abs(noisy_fft));
xlabel('Frequency (Hz)');
ylabel('Magnitude');
xlim([-20000,20000]);
grid on;
title('FFT Magnitude of Noisy Signal (zoomed)');

% Over what range do you see the dominant frequencies in the clean signal?
% 0Hz to 500 Hz
```



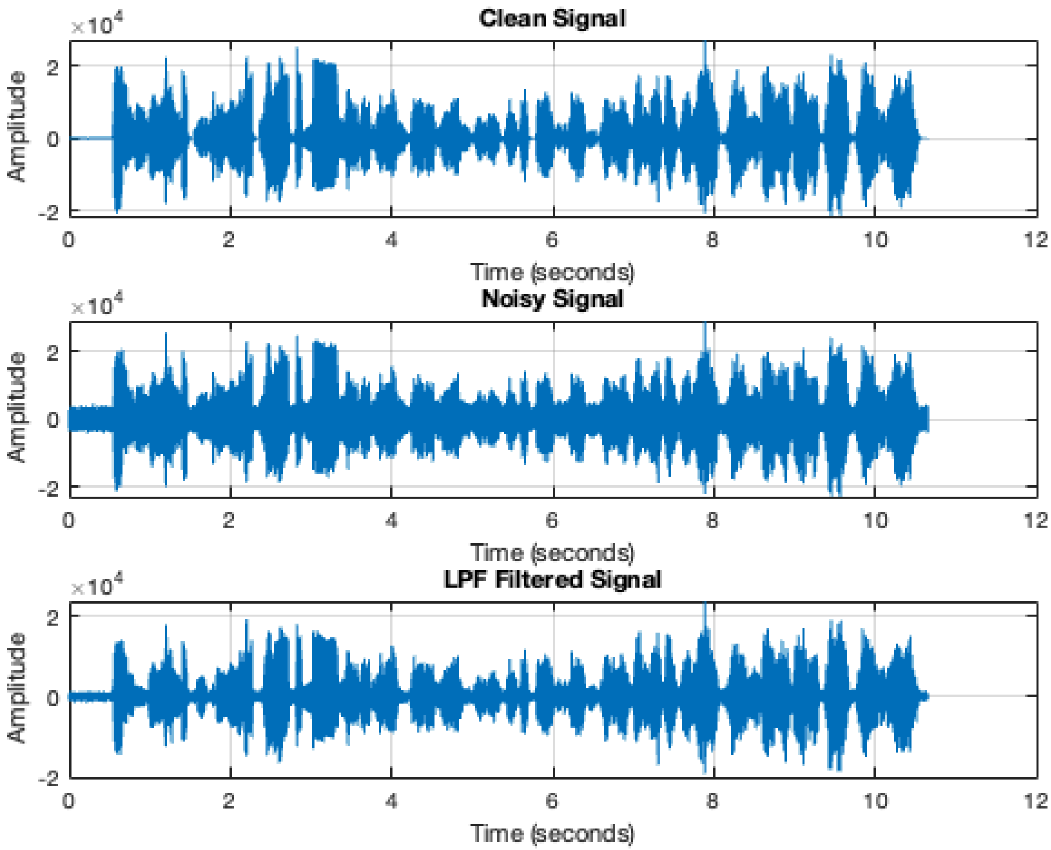


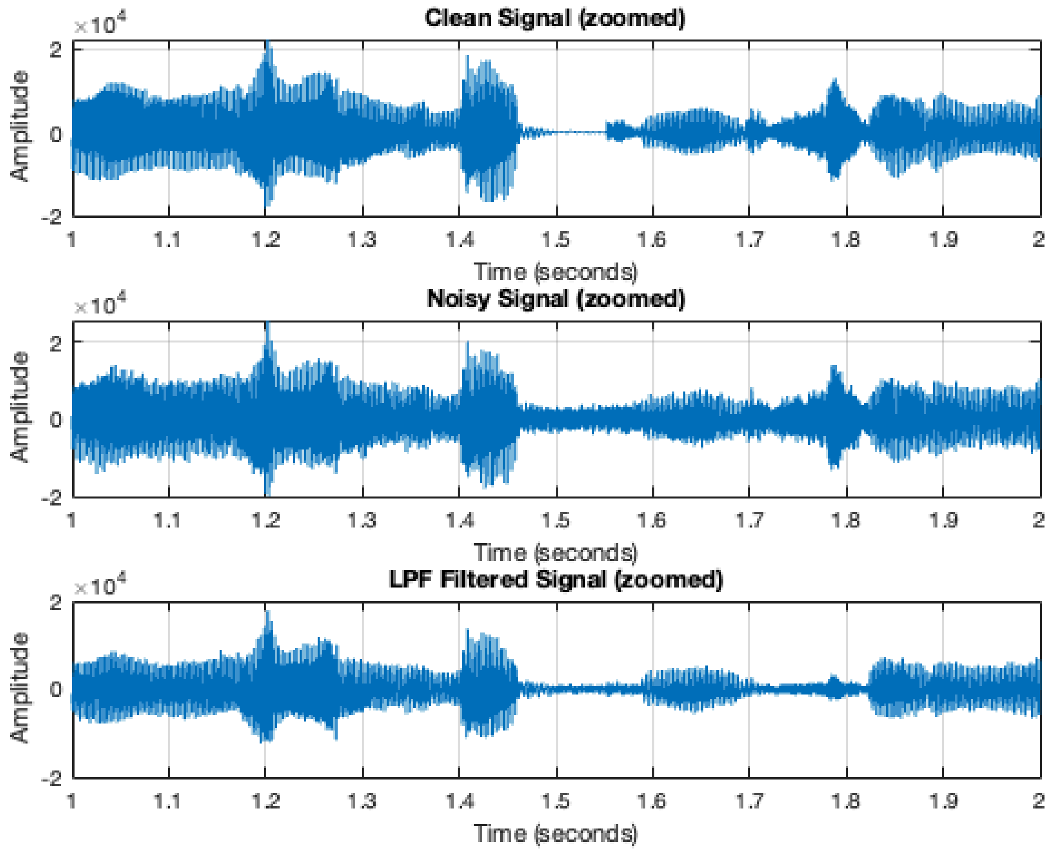
Question 5: Design an appropriate elliptic LPF with the ellip function

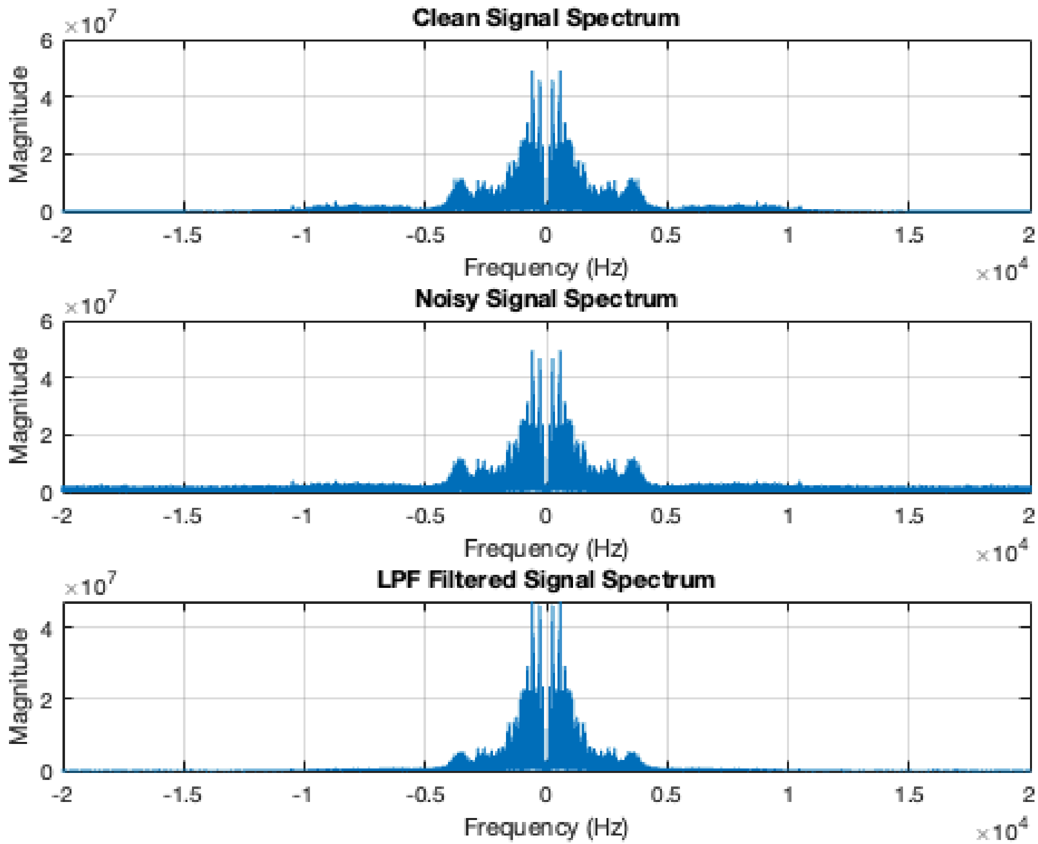
```
pass_band_ripple = 0.20;
stop_band_ripple = 0.30;
cut_off_frequency = 400;

[n, Wn] = ellipord(cut_off_frequency*2/Fs, (cut_off_frequency+500)*2/Fs,
 pass_band_ripple, stop_band_ripple);
[b_ellip, a_ellip] = ellip(n, pass_band_ripple, stop_band_ripple, Wn);

filtered_signal = filter(b_ellip, a_ellip, x_noisy);

soundsc(filtered_signal, Fs);
close all;
figure;
subplot(3,1,1);
plot(t, x);
xlabel('Time (seconds)');
ylabel('Amplitude');
title('Clean Signal');
```

```
grid on;

subplot(3,1,2);
plot(t, x_noisy);
xlabel('Time (seconds)');
ylabel('Amplitude');
title('Noisy Signal');
grid on;

subplot(3,1,3);
plot(t, filtered_signal);
xlabel('Time (seconds)');
ylabel('Amplitude');
title('LPF Filtered Signal');
grid on;

figure;
subplot(3,1,1);
plot(t, x);
xlim([1.0,2.0]);
xlabel('Time (seconds)');
ylabel('Amplitude');
title('Clean Signal (zoomed)');
grid on;

subplot(3,1,2);
plot(t, x_noisy);
xlim([1.0,2.0]);
xlabel('Time (seconds)');
ylabel('Amplitude');
title('Noisy Signal (zoomed)');
grid on;

subplot(3,1,3);
plot(t, filtered_signal);
xlim([1.0,2.0]);
xlabel('Time (seconds)');
ylabel('Amplitude');
title('LPF Filtered Signal (zoomed)');
grid on;

[filtered_fft, filtered_fft_freq] = dtft(filtered_signal,T);

figure;
subplot(3,1,1);
plot(clean_fft_freq, abs(clean_fft));
xlabel('Frequency (Hz)');
ylabel('Magnitude');
title('Clean Signal Spectrum');
xlim([-20000,20000]);
grid on;

subplot(3,1,2);
plot(noisy_fft_freq, abs(noisy_fft));
```

```
xlabel('Frequency (Hz)');
ylabel('Magnitude');
title('Noisy Signal Spectrum');
xlim([-20000,20000]);
grid on;


subplot(3,1,3);
plot(filtered_fft_freq, abs(filtered_fft));
xlabel('Frequency (Hz)');
ylabel('Magnitude');
title('LPF Filtered Signal Spectrum');
xlim([-20000,20000]);
grid on;
```




Clean Signal (zoomed)
Noisy Signal (zoomed)
LPF Filtered Signal (zoomed)
×10^4
Amplitude
Time (seconds)
2
0
-2
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2



Clean Signal

```
soundsc(x, Fs);
```

Noisy Signal

```
soundsc(x_noisy, Fs);
```

Filtered Signal

```
soundsc(filtered_signal, Fs);
```

Question 6: Comment on your observations. Can you remove most of the noise from the corrupted

signal? Is the noise reduction quality affected more by the size of passband ripple or by the size of the stopband ripple? What is one more important — that the passband be very close to 1 or that the stopband be very close to 0? You should try different filter designs and listen to the results to find out.

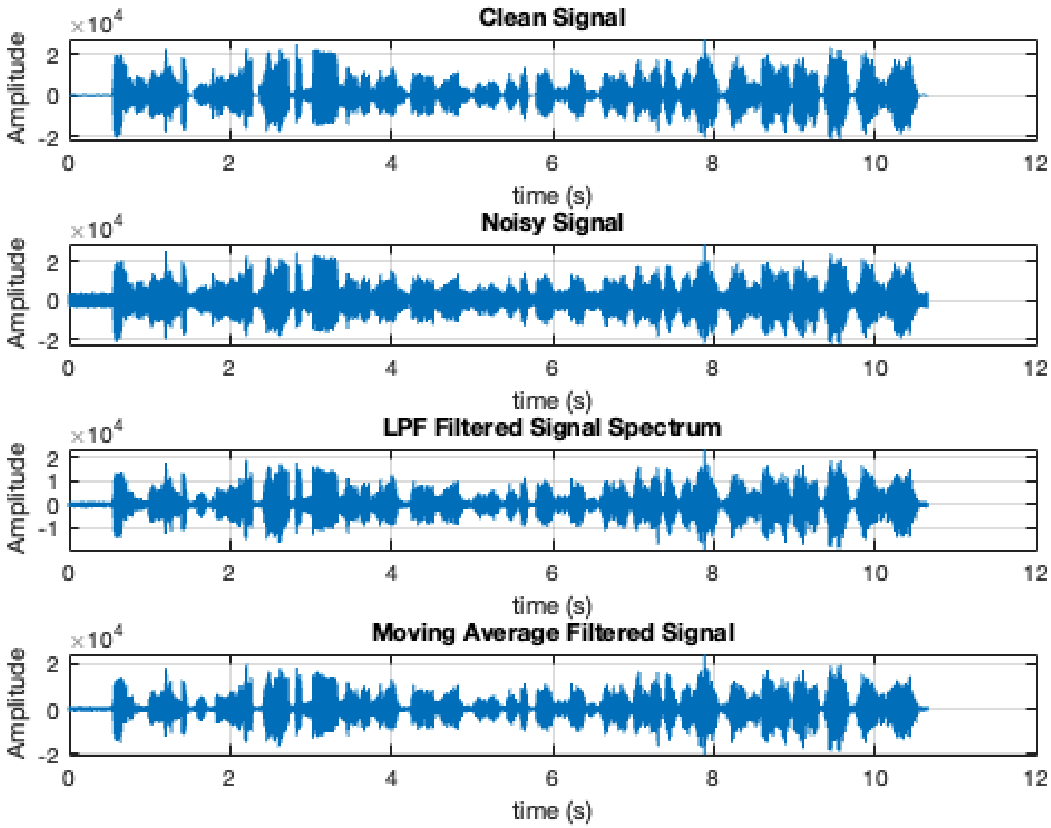
```
% After exploring and changing both the stopband and passband ripples, it
 seemed to me that higher
% passbadn rippled cause less noise to leak into the passband resulting
 however that could come in the cost of losing
% the quality of the signal.  On the other hand, larger stopband ripples seem
 to not attenuate noise
% frequencies as seen through experiemnting and checking the graphs
```

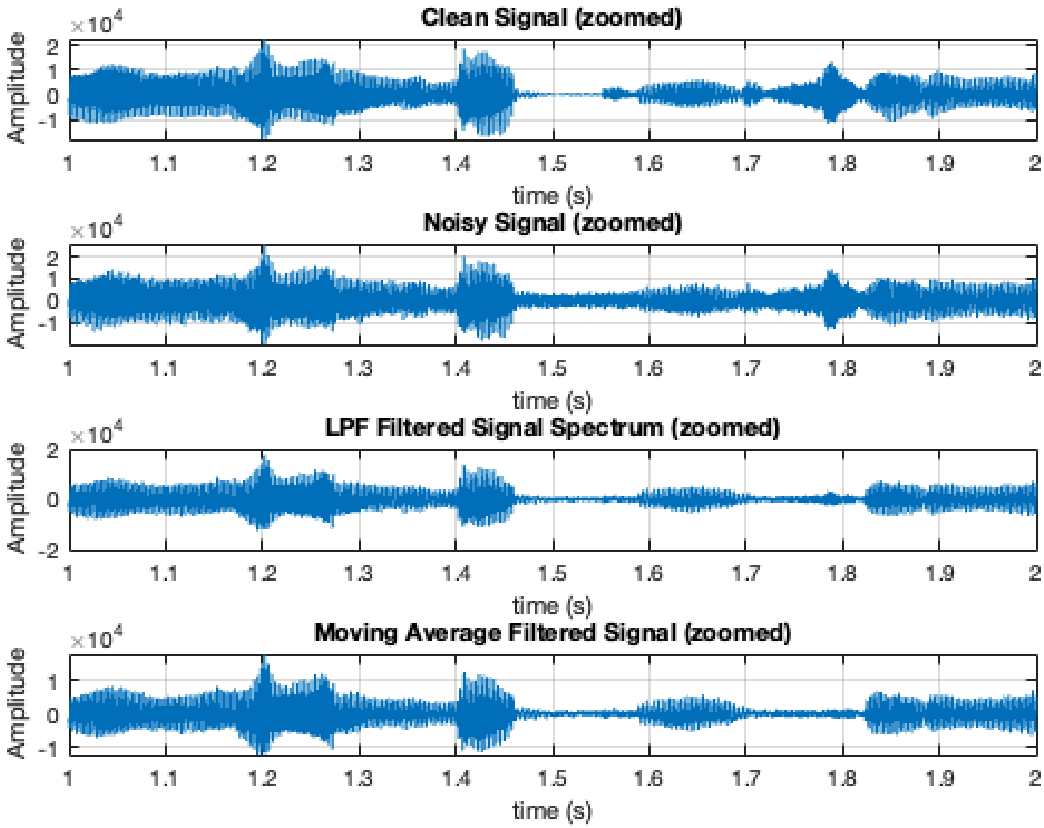
Question 7: Moving Average Filter

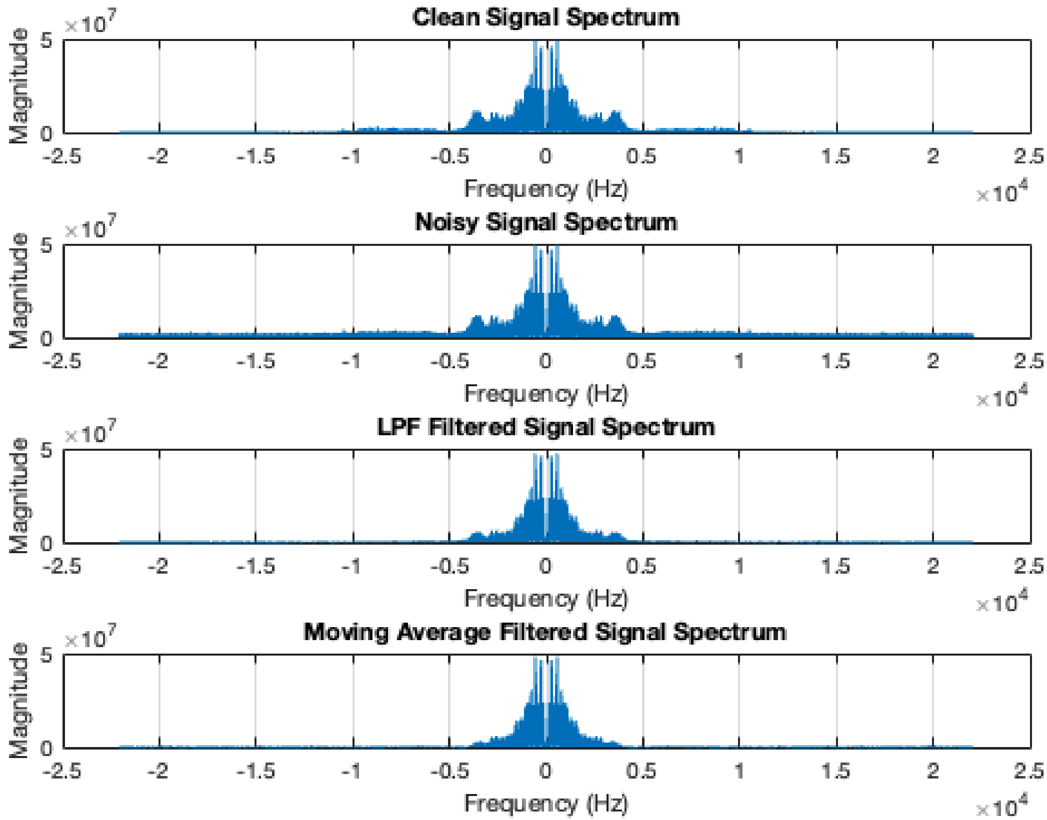
```
r = 10;
h_ma = ones(1, r) / r;
filtered_signal_ma = filter(h_ma, 1, x_noisy);
[filtered_fft_ma, filtered_fft_ma_freq] = dtft(filtered_signal_ma,T);

figure;
subplot(4,1,1);
plot(t, x);
xlabel('time (s)');
ylabel('Amplitude');
title('Clean Signal');
grid on;

subplot(4,1,2);
plot(t, x_noisy);
title('Noisy Signal');
grid on;
xlabel('time (s)');
ylabel('Amplitude');

subplot(4,1,3);
plot(t, filtered_signal);
title('LPF Filtered Signal Spectrum');
grid on;
xlabel('time (s)');
ylabel('Amplitude');

subplot(4,1,4);
plot(t, filtered_signal_ma);
title('Moving Average Filtered Signal');
grid on;
xlabel('time (s)');
ylabel('Amplitude');


figure;
subplot(4,1,1);
plot(t, x);
title('Clean Signal (zoomed)');
xlabel('time (s)');
ylabel('Amplitude');
grid on;
xlim([1.0,2.0]);
```

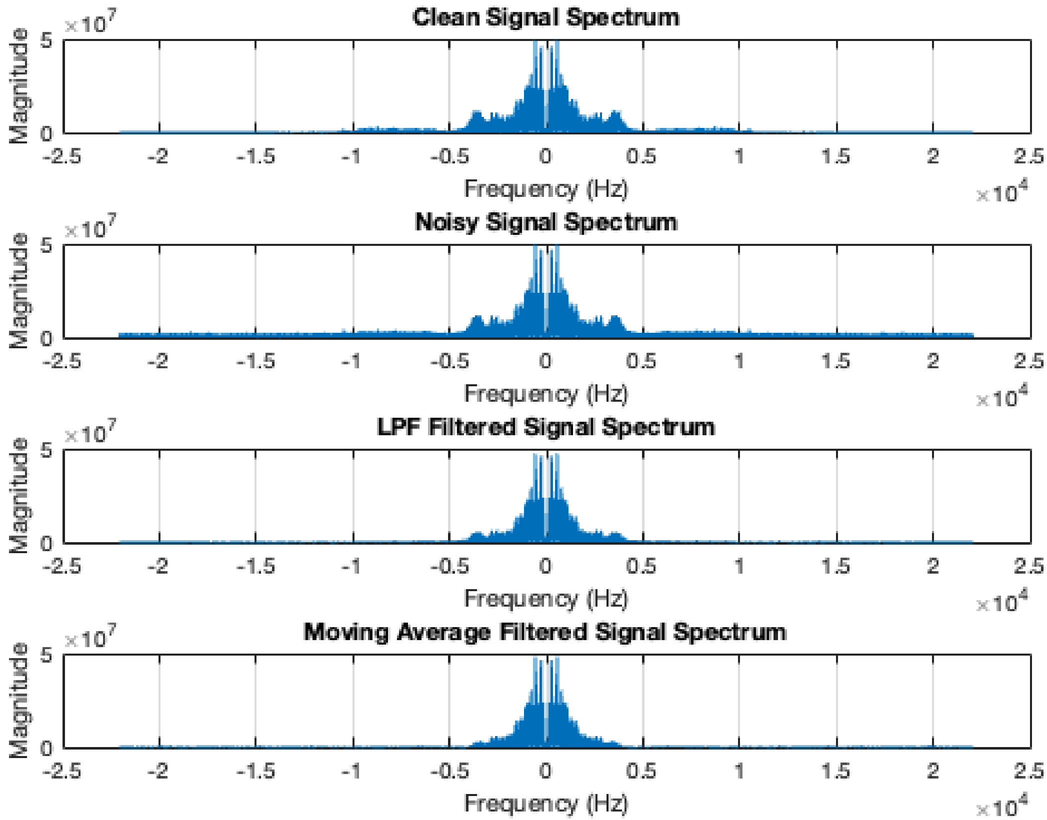
```
subplot(4,1,2);
plot(t, x_noisy);
title('Noisy Signal (zoomed)');
grid on;
xlabel('time (s)');
ylabel('Amplitude');
xlim([1.0,2.0]);

subplot(4,1,3);
plot(t, filtered_signal);
title('LPF Filtered Signal Spectrum (zoomed)');
grid on;
xlabel('time (s)');
ylabel('Amplitude');
xlim([1.0,2.0]);

subplot(4,1,4);
plot(t, filtered_signal_ma);
title('Moving Average Filtered Signal (zoomed)');
grid on;
xlabel('time (s)');
ylabel('Amplitude');
xlim([1.0,2.0]);

figure;
subplot(4,1,1);
plot(clean_fft_freq, abs(clean_fft));
xlabel('Frequency (Hz)');
ylabel('Magnitude');
title('Clean Signal Spectrum');
grid on;

subplot(4,1,2);
plot(noisy_fft_freq, abs(noisy_fft));
xlabel('Frequency (Hz)');
ylabel('Magnitude');
title('Noisy Signal Spectrum');
grid on;

subplot(4,1,3);
plot(filtered_fft_freq, abs(filtered_fft));
xlabel('Frequency (Hz)');
ylabel('Magnitude');
title('LPF Filtered Signal Spectrum');
grid on;

subplot(4,1,4);
plot(filtered_fft_ma_freq, abs(filtered_fft_ma));
xlabel('Frequency (Hz)');
ylabel('Magnitude');
title('Moving Average Filtered Signal Spectrum');
grid on;
```

```
figure;
subplot(4,1,1);
plot(clean_fft_freq, abs(clean_fft));
xlabel('Frequency (Hz)');
ylabel('Magnitude');
title('Clean Signal Spectrum');
grid on;

subplot(4,1,2);
plot(noisy_fft_freq, abs(noisy_fft));
xlabel('Frequency (Hz)');
ylabel('Magnitude');
title('Noisy Signal Spectrum');
grid on;

subplot(4,1,3);
plot(filtered_fft_freq, abs(filtered_fft));
xlabel('Frequency (Hz)');
ylabel('Magnitude');
title('LPF Filtered Signal Spectrum');
grid on;

subplot(4,1,4);
plot(filtered_fft_ma_freq, abs(filtered_fft_ma));
xlabel('Frequency (Hz)');
ylabel('Magnitude');
title('Moving Average Filtered Signal Spectrum');
grid on;


soundsc(filtered_signal_ma, Fs);

% Compare the performance of the moving average with the elliptic filter you
% created. Is one clearly better than the other?

% No, I think both of them were not able to complelety or to a decent
% extent remove the noise. However, and in my opinion, the low pass filter
% perforemd better as it kept the sound crispier. The noise level seems to
% be higher in the moving average
```


Clean Signal
×10^4
Amplitude
time (s)
Noisy Signal
LPF Filtered Signal Spectrum
Moving Average Filtered Signal
0
2
4
6
8
10
12
-2
-1
1

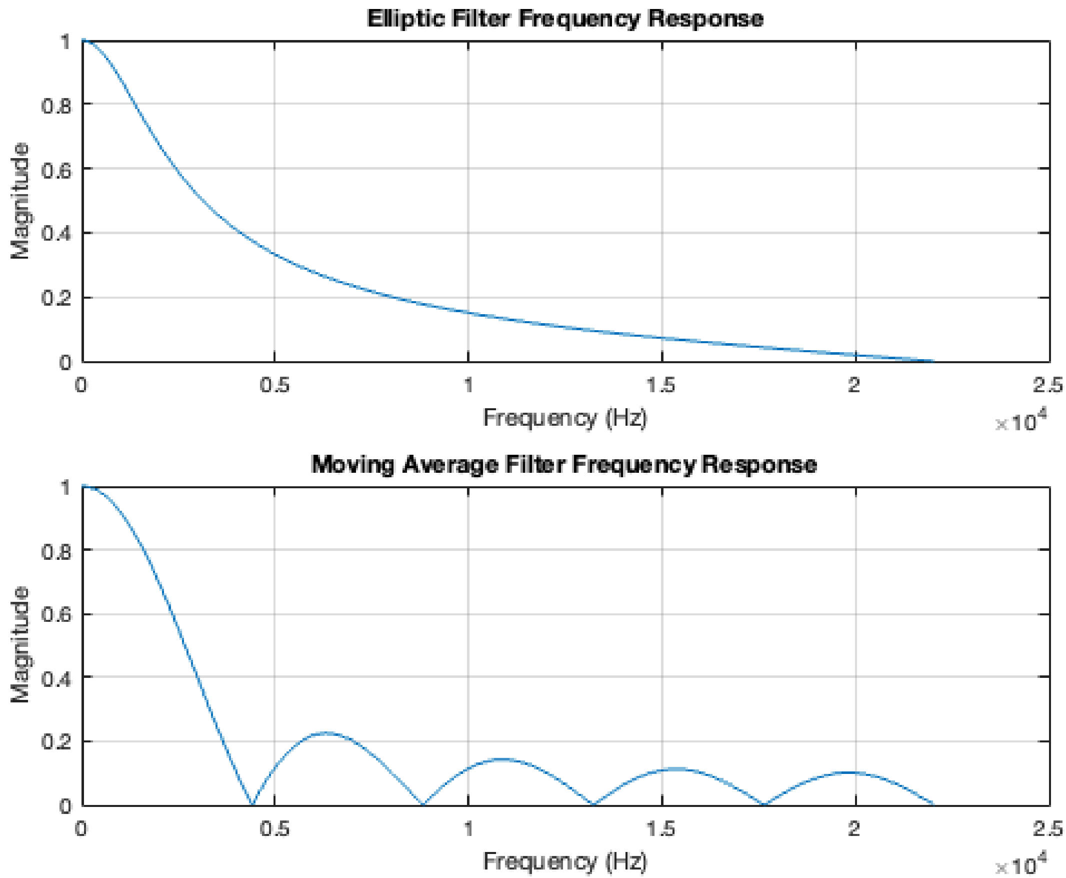

Clean Signal (zoomed)
Noisy Signal (zoomed)
LPF Filtered Signal Spectrum (zoomed)
Moving Average Filtered Signal (zoomed)
Amplitude
time (s)
×10^4


Clean Signal Spectrum
Noisy Signal Spectrum
LPF Filtered Signal Spectrum
Moving Average Filtered Signal Spectrum
Magnitude
Frequency (Hz)
×10^7
×10^4
-2.5 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2 2.5



Plotting the frequency response of both filters

```
[H_ellip, w_ellip] = freqz(b_ellip, a_ellip, 1024, Fs);
[H_ma, w_ma] = freqz(h_ma, 1, 1024, Fs);

figure;
subplot(2,1,1);
plot(w_ellip, abs(H_ellip));
xlabel('Frequency (Hz)');
ylabel('Magnitude');
title('Elliptic Filter Frequency Response');
grid on;

subplot(2,1,2);
plot(w_ma, abs(H_ma));
xlabel('Frequency (Hz)');
ylabel('Magnitude');
title('Moving Average Filter Frequency Response');
grid on;
```



Clean Signal

```
soundsc(x, Fs);
```

Noisy Signal

```
soundsc(x_noisy, Fs);
```

LPF Filtered Signal

```
soundsc(filtered_signal,Fs);
```

MA Filtered Signal

```
soundsc(filtered_signal_ma,Fs);
```

Extra: Applying both filters together

```
filtered_signal_both = filter(h_ma, 1, filtered_signal);
```

```
soundsc(filtered_signal_both, Fs);
```

Question 8: Why did we specifically use LPFs for denoising and not other kinds of filters?

Noise often occupy higher frequencies compared to the signal of interest, and low pass filters (LPFs) are designed to attenuate and eliminate high-frequency noise components while letting lower-frequency signal components pass through, resulting in a noise reduction without significantly affecting the essential components of the signal.

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