

Section 6-9.3: Lowpass Filtering the Noisy Trumpet Signal.

Purpose:

Given that the trumpet signal is bandlimited to 3952 Hz, we shall use a fifth-order ($n = 5$) Butterworth lowpass filter with cutoff frequency $f_c = 4000$ Hz.

Inputs:

Signal of an actual trumpet playing note B from the file `trumpet.mat`.

n =order of Butterworth filter.

f_c =Butterworth cutoff frequency in Hz.

f_s =sampling rate in samples per s used.

Outputs:

Plot and sound of noiseless trumpet signal.

Plot and sound of noisy trumpet signal.

Plot and sound of filtered noisy trumpet.

Spectrum of noisy trumpet signal.

Frequency response of Butterworth filter.

Impulse response of Butterworth filter.

Comments:

- The first sound is the noisy trumpet signal. Hit any key to hear the filtered signal.
- The trumpet signal is an actual trumpet playing note B, which has a fundamental frequency of 494 Hz and period $\frac{1}{494} \approx 2$ ms. This is apparent in its waveform plot.
- The sampling rate used is the standard CD sampling rate of 44100 samples per s. Time is discretized to integer multiples of $1/44100$
- White noise is generated using `randn`.
- The filtered signal seems to have most of its noise removed. But it doesn't sound much better. This is because the filtered noise is mostly inaudible! This motivates the resonator filter used in the next example.
- The Butterworth filter is designed to have cutoff frequency one radian/s. Then it is scaled by a factor of $S = 2\pi 4000$.

Program:

```
clear;load 'trumpet.mat'
n=5;fc=4000;fs=44100;
L=length(X);dt=1/fs;t=[0:L-1]*dt;
Y=X+0.1*randn(1,L);
%GOAL: Recover X from Y.
%Design Butterworth filter:
D=poly(exp(j*pi*[3:7]'/5));
[R P K]=residue([1],D);
S=2*pi*fc;%Scale factor.
%Butterworth impulse response:
h=real(R.'*exp(P*S*t));
figure,subplot(211),plot(t(1:50),h(1:50))
%Compute frequency response of
%Butterworth filter from h:
Fh=S*fft(h)*dt;%Scale factor.
%Convolve signal and filter
%using Fourier transforms.
FY=fft(Y);Z=real(ifft(FY.*Fh));
%Plot spectrum of FY of Y and
%Frequency response Fh of h.
%See Chapter 8 for details.
%Frequencies for plotting:
FY=2*FY/L;%To plot spectrum of Y.
Iy=[1:3300];fy=(Iy-1)*fs/L;
Ih=[1:8000];fh=(Ih-1)*fs/L;
figure,subplot(211),plot(fy,abs(FY(Iy)))
figure,subplot(211),plot(fh,abs(Fh(Ih)))
%Plot time waveforms of signals:
I=[4601:4900];%Display interval.
figure,subplot(211),plot(t(I),X(I))
figure,subplot(211),plot(t(I),Y(I))
figure,subplot(211),plot(t(I),Z(I))
soundsc(Y,fs),pause,soundsc(Z,fs)
```

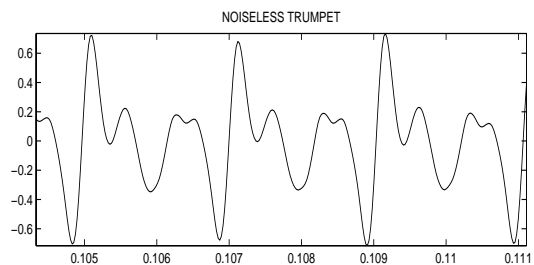


Figure 1: Noiseless trumpet.

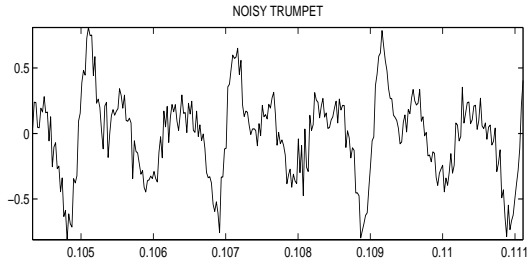


Figure 2: Noisy trumpet signal.

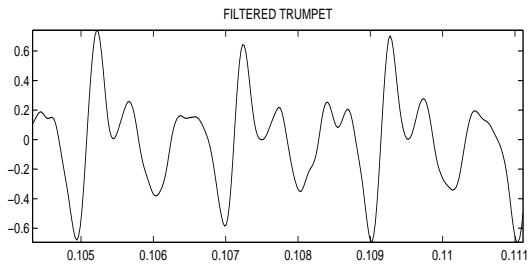


Figure 3: Filtered noisy trumpet.

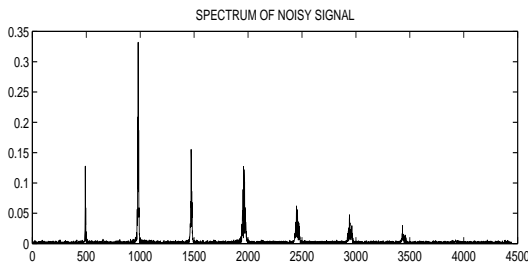


Figure 4: Spectrum of noisy trumpet signal.

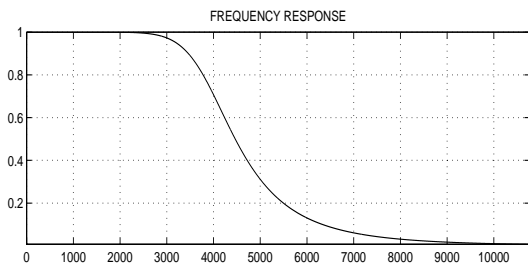


Figure 5: Frequency response of the Butterworth filter.

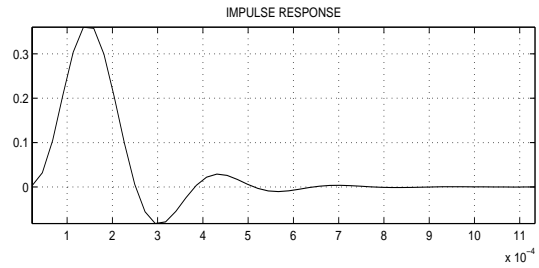


Figure 6: Impulse response of Butterworth filter.