Cochlear Implant Processing MATLAB Simulation Program - Phase-II - Filter Design

A Report Submitted in Partial Fulfillment of the Requirements for BME 252 Project

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1. Introduction

One of the most innovative inventions developed in the field of Biomedical Engineering, a cochlear implant, is an ear prosthesis device worn by people with severe to profound hearing loss. It aims at providing partial hearing to people with sensorineural hearing loss. A typical cochlear implant is composed of a microphone - to pick up sounds from the environment, a signal/speech processor - to transform collected sound signals into electrical signals, a system to transmit electrical signals to implanted electrodes, and a system to transmit electrical signals to the brain for interpretation.

2. Filter Design

Phase-I was a preparatory stage of the project which involved importing audio files (.wav file format) as input to the MATLAB simulation. Stereo signals were summed to mono (1 channel/column), and downsampled to 16 kHz. Arguably the most important aspect of a cochlear implant is its signal-processing technique. The signal processing technique reported here aims at envelope transformation.

The resulting mono, downsampled sound signal was divided into different frequencies by eight bandpass filters (6th-order Butterworth) between 100 Hz to 8 kHz. The MATLAB function includes a loop that generates cutoff frequencies for bandwidths starting at 100 Hz up to 8 kHz with increments of 987.5. The increment of 987.5 Hz is obtained by dividing the entire range of

7900 Hz into 8 channels. For digital filters, the cutoff frequency must lie between 0 and 1. Here, 1 corresponds to the Nyquist rate, which is half the sampling rate (π rad/sample). To convert Hz to normalized frequency, the physical frequency is divided by the Nyquist rate. Following are sample calculations of lower and higher cutoff frequencies for a 100 to 1087.5 Hz bandwidth:

$$Sampling\ Rate\ =\ 16,000\ Hz$$

$$Nyquist\ \ Rate\ =\ Sampling\ Rate\ /\ 2\ =\ 8,000\ Hz$$

$$Lower\ Cutoff\ Frequency\ =\ 100\ Hz\ /\ Nyquist\ Rate\ \ =\ 100/8000\ =\ 0.0125\ Hz$$

$$Higher\ Cutoff\ Frequency\ =\ 1087.5\ Hz\ /\ Nyquist\ Rate\ =\ 1087.5/8000\ =\ 0.1359\ Hz$$

The bandwidths and higher and lower cutoff frequencies for each of the eight channels are listed in Table 1 below:

Table 1: Bandwidths and Lower and Higher Cutoff Frequencies for Bandpass Filters

Bandwidth (Hz)	Lower Cutoff Frequency (Hz)	Higher Cutoff Frequency (Hz)
100 - 1087.5	0.0125	0.1359
1087.5 - 2075	0.1359	0.2594
2075 - 3062.5	0.2594	0.3828
3062.5 - 4050	0.3828	0.5063
4050 - 5037.5	0.5063	0.6297
5037.5 - 6025	0.6297	0.7531
6025 - 7012.5	0.7531	0.8766
7012.5 - 8000	0.8766	0.99 (*)

*Based on sample calculations provided earlier, the calculated value for the higher cutoff frequency is 1. This exceeds of the cutoff frequency range which was normalized to fall between 0-1, i.e. it will have removed any frequencies above the specified bandpass edge of 8 kHz.

The following plots were generated from Task 6:

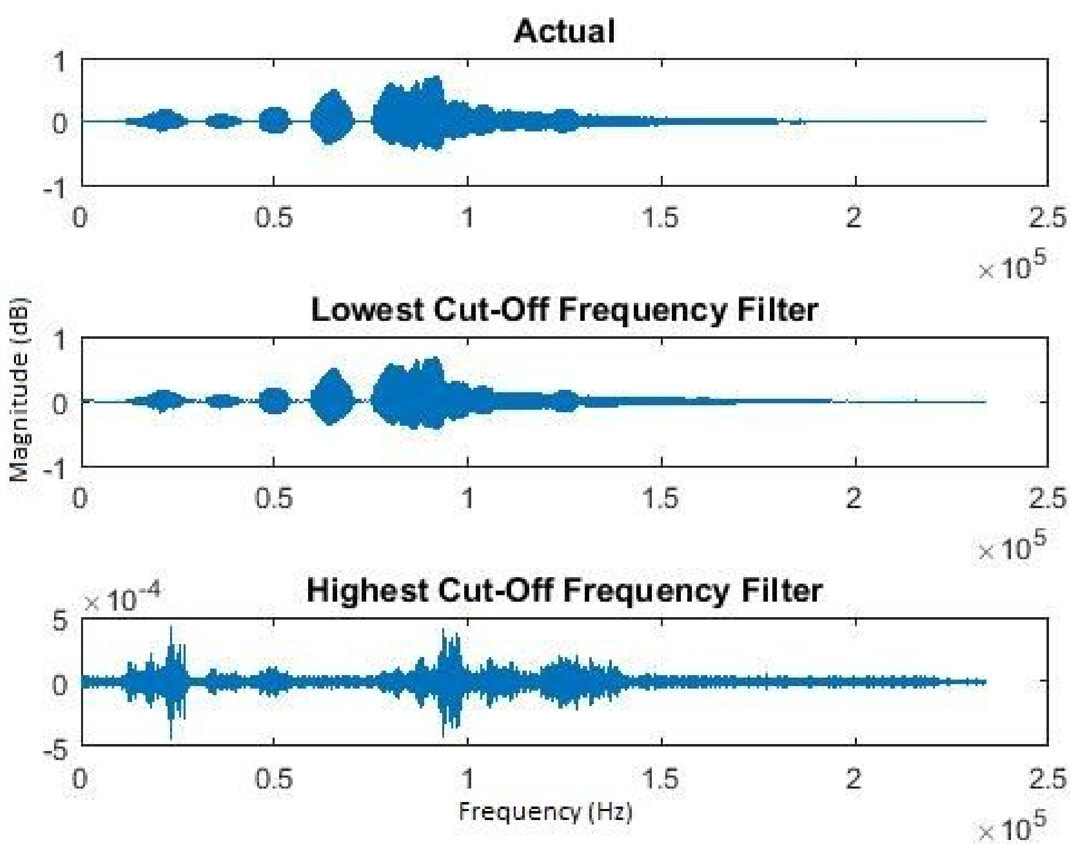

Figure 1: Actual, Lowest and Highest Cutoff Frequency Filter Plots

In order to transform the waveform into envelope signal, the next stage involves rectification and low-pass filtering with a cutoff frequency of 400 Hz. The ‘abs()’ command in

MATLAB is used to rectify the filters. The 'filtfilt()' command is used to filter the rectified signal with a low-pass 6th order Butterworth filter. These commands are repeated for each of the eight channels. The outputs from each channel are full wave rectified. The 'abs()' puts the absolute value on the waveform for full wave rectifier.

The following graph is of the lowest frequency bandpass filter, the rectified low-pass filter and its upper and lower envelopes:

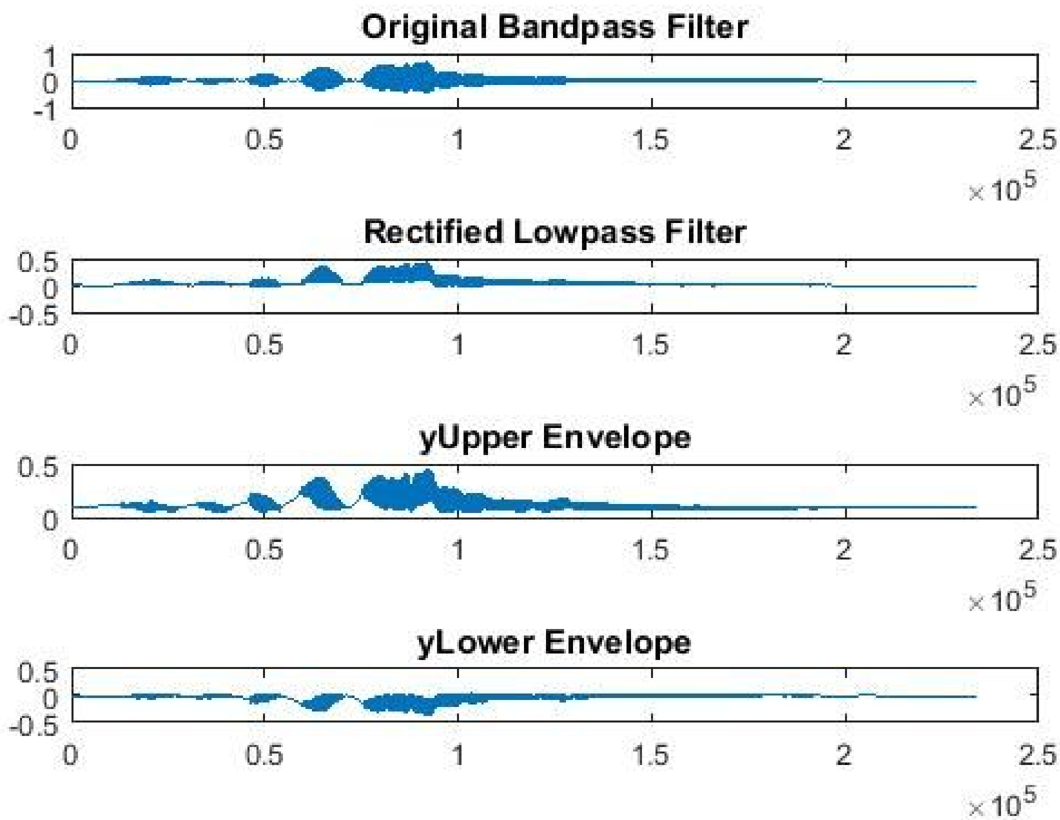

Figure 2: Lowest Cutoff Bandpass Filter, Rectified Low-pass Filter and Envelope of Rectified Time Waveform

The following graph is of the highest frequency bandpass filter, the rectified low-pass filter and its upper and lower envelopes:

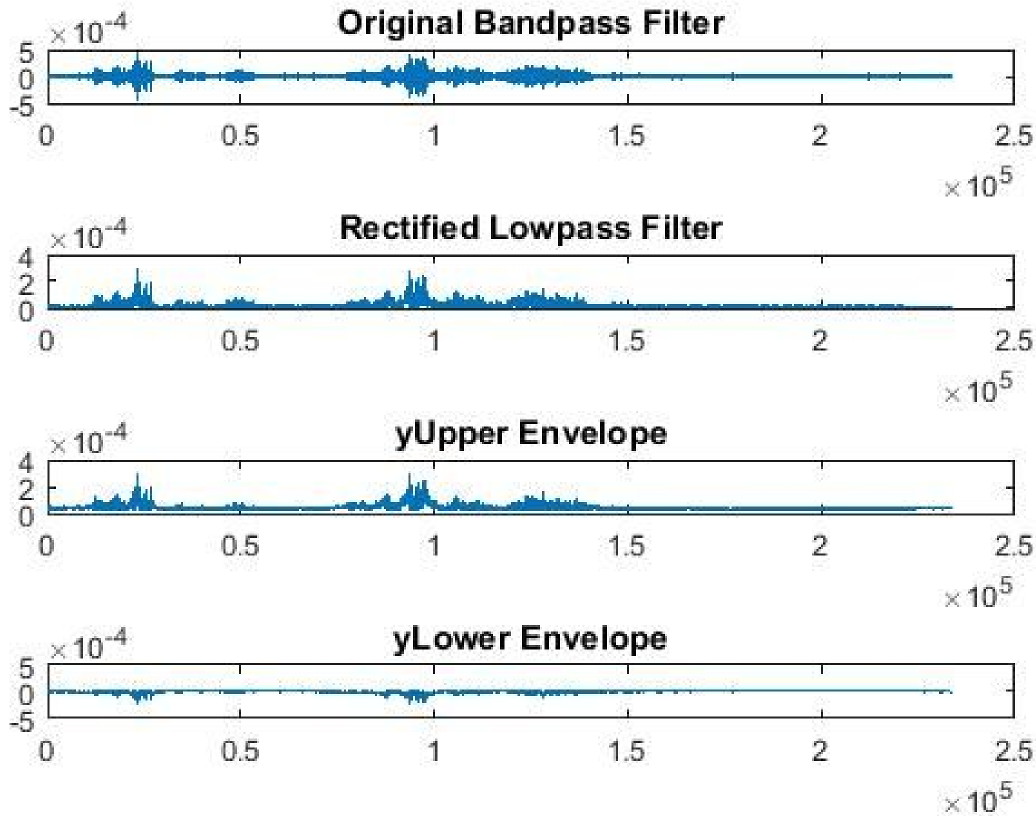

Figure 3: Highest Cutoff Bandpass Filter, Rectified Low-pass Filter and Envelope of Rectified Time Waveform