**Filter Design Project**

A segment of a real-time audio signal with increasing loudness is represented by the following equation for the time interval $t : -40 \rightarrow 40 ms$:

$$x(t_n) = 0.20e^{200t_n}\cos(2\pi \cdot 200t_n + 0.20) + 0.50e^{100t_n}\cos(2\pi \cdot 250t_n - 0.20)$$

$$+ 1.00e^{100t_n}\cos(2\pi \cdot 900t_n + 0.90) + 0.60e^{50t_n}\cos(2\pi \cdot 1500t_n + 0.9)$$

$$+ 0.60\cos(2\pi \cdot 2500(1 + \text{rand})t_n - 0.30) + 1.00\cos(2\pi \cdot 4000(1 + \text{rand})t_n - 0.50)$$

$$+ 0.75\cos(2\pi \cdot 5000(1 + \text{rand})t_n + 0.40)$$

where MATLAB’s rand function is used to produce uniformly distributed random numbers between zero and one. In the formula for $x(t_n)$, rand is used to simulate a pitch variation in the high frequency tones. The formula will give different numbers every time the MATLAB script is started and, therefore, you should save your results on a separate file to re-use the same data in the various filter comparisons.

The signal is to be filtered in real-time for time interval between 0 and 32 ms to eliminate noisy components beyond 2kHz. Assume that the sampling rate is 40kHz.

**Problem Statements**

1. Design an optimized FIR filter with 200 taps using Parks McClellan algorithm (remez function in MATLAB) and state the filter specifications that you have used. Plot and compare the ideal output containing only signal components and the filtered output of this optimized FIR filter. Estimate the group delay of the filter by visual inspection.

1.A. Explore the sensitivity of the filter designed in 1. with respect to the finite precision effects. Namely, consider that filter coefficients were quantized and represented using fixed point number format. Explore the effect of using the fixed point filter coefficient representation with [16 15] and [8 7] formats on the magnitude response of the filter as well as on the quality of the filtered signal. In both cases, assume that the input and the output signal and the multiplicands are represented in [16 15] format, while the products and sums are represented in [32 31] format. You may use fdatool Matlab utility or qfilt command to perform these tasks.

1.B. For two fixed point coefficient formats outlined in 1.A. visually compare and comment the outputs of a Direct Form I and Direct Form II implementations of such filters (use filter function to obtain the filter output).
2. In order to take the advantage of the speed of the FFT algorithm, design also a 128-tap optimized (with remez) FIR filter and perform processing on a 256-point overlapping window. Perform filtering using overlap and add method and estimate the group delay of such filter implementation. What is the maximum length of the speech data segments that can be used with such processing?

Also, measure the total computational times for the overlap and add method and the ‘conventional’ convolution-based filtering method (use Matlab commands tic and toc to measure computational times).

3. Design an LMS trained FIR filter for the given speech signal using Simulink with following specifications. Train the 200th order FIR filter coefficients on the time interval $[-40ms, 0ms]$ assuming that appropriately delayed ideal output signal is available to the LMS filter. Perform the speech signal filtering on the interval $[0, 32ms]$ assuming that no training is done (error signal is equal to zero). Assume that step-size coefficient $\mu$ is equal to 0.1. Plot the LMS filter output and the squared error signal on the time interval $[-40ms, 32ms]$. If coefficient $\mu$ is changed to 0.5, how would that change the quality of the output and the squared error signal?

**Report**

The results of this project must be presented in report form (typed or handwritten) and must provide comments, conclusions and answers to the posed questions. For each designed filter, explain the specifications that you have used (e.g. pass band and stop band frequency, ripple factor ...), plot the magnitude filter response and filtered output signal. In the report, please include the Matlab programs and Simulink models that you have developed.