ESE 351 SP22 Case Study #1 Multi-band equalizer

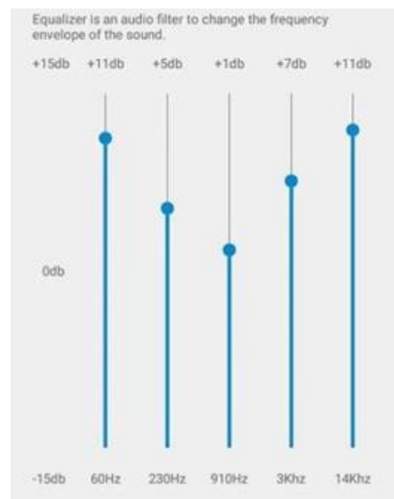
Assigned Thursday February 17, 2022

Final Report due Tuesday March 8.

Interim report (optional) due Thursday 2/24. Include group members, current progress, and plans for the open portion of the project. It would be good but not required to use the IEEE style for this interim report.

You may work in groups of up to 3 students. **Sign up with your project group in canvas** (People->Groups->Case Study 1).

You now have extensive experience with RC circuit models in both lowpass and highpass forms, with analytic and computational solutions for the impulse, step, and frequency response. Combinations of lowpass and highpass filters allow for a wide range of frequency-selective filters (bandpass and band-reject, in addition to lowpass and highpass). In this case study, you'll design a system to modify frequencies in multiple bands, or frequency ranges, to improve or enhance a signal. Typical modern smartphones include this capability, with variable gain over multiple frequency bands (e.g., the screenshot at right shows bands with five center frequencies and gain from -15 to +15 dB).



In this case study, you'll design a multi-band equalizer and use it for the following tasks:

1) Design the following audio presets (fixed gain settings for each band) to process the sound of arbitrary signals:
   a. Treble Boost
   b. Bass Boost
   c. Unity (Create a preset to approximate a flat frequency response)
2) Use your presets to process the following signals:
   a. A modified clip of "Giant Steps" by John Coltrane
   b. A modified clip of "Space Station" by Art Farmer
3) Use your equalizer (presumably with custom gain settings) to filter out unintentional background noise in the following recording
   a. A modified clip of "Blue in Green" by Miles Davis
4) Choose a signal to enhance or improve with your system. It could be an audio or music recording, or you could also consider some other time series, e.g., financial data, non-human biological sounds, etc. Design a new 'preset' for this signal to enhance it in whatever way you see fit.

The main objective of this case study is the design and implementation of a digital audio processing system. Specific design objectives are below.

1) Design a system to provide variable amplification (gain) over at least 5 frequency bands

    a. Specify the frequency range for each band. In an equalizer, this band is typically specified by its approximate center frequency (as in the figure above).
    b. Gain can be varied manually in your code, i.e., you do not need to implement a GUI for adjusting gain over each band.
    c. Processing is 'offline', i.e., it does not need to process the signals in real time.
2) Implement the system with combinations of continuous-time frequency-selective filters. Your system should process the original signal with a frequency-selective filter for each band (e.g., processing in parallel), then apply an independent gain to each filtered signal, then sum the filtered results. For the individual filters, you can use RC filters as in previous homework, but feel free to consider other options such as RLC circuits.
    a. For each frequency band filter, analyze its frequency response (magnitude and phase).
    b. For each set of equalizer settings, evaluate the total system frequency response (magnitude and phase). You can use, e.g., the sweep of complex exponential inputs through the frequency range (as in Homework 3 Matlab).
    c. To assess the time-domain impact of each frequency band filter, analyze its impulse response, e.g., to approximate the impulse response, use lsim(b,a,x,t), with x = [1 zeros(1,N)].
    d. For each equalizer setting, analyze the impulse response of the overall system.
3) Results: Demonstrate the overall impact of each filter on the provided signals and your custom signal. Use plots in the time and/or frequency domains to illustrate. You can also describe the qualitative change in the signals based on audio playback. Describe the gain settings used to achieve each result.

You can inspect the frequency content of signals using the demo code provided to produce a spectrogram (essentially a time-varying Fourier series decomposition of the sampled signal).

Document your design in a 2-4 page report using the IEEE journal template (here for Microsoft Word and here for LaTeX, a typesetting system that is particularly useful for academic publications). Your final case study submission will include:

- A writeup in IEEE style which includes all of the following sections, as well as any other sections you decide to include. (Each section can be as long or as brief as it needs to be)
    - An Abstract describing your findings in brief
    - A Background section describing the context of your work
    - A Methods section describing your filter design and implementation
    - A Results section including figures that illustrate how well you accomplished the above objectives
    - A Conclusion section summarizing what you learned
- Your MATLAB code and any dependent functions
- A published pdf of your MATLAB output
- A 2-3 minute video demonstrating your results, e.g., slides plus audio demonstration

Projects will be graded based on the following items

- Study design - 20%
  - Strategy and rationale for system design
- MATLAB implementation - 25%
  - Processing of signals and demonstration of design
  - Characterization of frequency response and impulse response for each band and overall system
- Results - 25%
  - Demonstration of design objectives
  - Demonstration with given signals and custom signal
- Report - 25%
  - Report is well-organized, concise, and clearly written.
  - Plots are easy to read and interpret, with appropriate font sizes, line widths, labels, etc.
  - Results are interpreted relative to the design objectives.
- Video - 5%
  - Create a 2-3 minute video demonstrating your results