ESE 351 Case Study #1 Multi-band equalizer

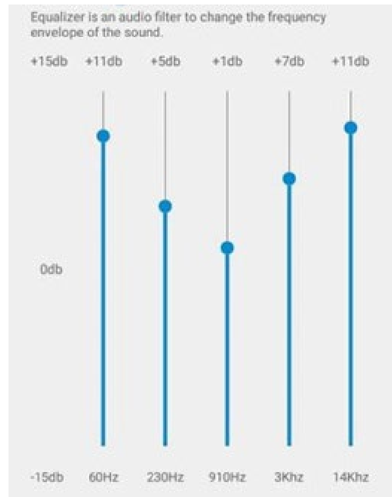
Assigned Tuesday February 16, 2026

Final Report due March 3, 2026.

Submit to gradescope: your final report (pdf) and a zip file containing your video and all files needed to run your code.

You may work in groups of up to 3 students.

Audio recordings can often be improved with basic signal processing by changing signal amplification over different frequency ranges or bands. 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). The objective of this case study is to design an equalizer using RC-equivalent stages then use it to enhance two music recordings and one low-quality recording of bird vocalizations. You'll use the spectrogram to visualize the time-varying frequency content in the signals and identify recurring bird sounds.



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 multi-band equalizer and use it for the following tasks:

1) Design an equalizer to provide variable amplification (gain) over at least 5 frequency bands.
2) Design these 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)
3) 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
4) Use your equalizer to enhance the bird vocalizations in the provided audio recording (~85 seconds from an upper woodland region of Shaw Nature Reserve near Pacific, MO). [Merlin Bird ID](#) by Cornell Lab recognized the following species in the recording: Blue Jay, Carolina Wren, Red-Bellied Woodpecker, Tufted Titmouse, Northern Cardinal, Eastern Bluebird, and Northern Mockingbird. Some of these species are relatively easy to verify and occur several times, and others might be incorrect, e.g., several Blue Jay sounds are present from ~30 seconds.
    a. Adjust your equalizer bands and gain settings as needed to reduce wind and other noise and amplify bird sounds.

b. Demonstrate enhancement and identification of bird vocalizations through audio playback and spectrograms for visualization. Consider the following:
    i. How many distinct bird vocalizations can you find?
    ii. Which vocalizations are recurring?
    iii. What spectrogram parameters give the best visualization of the vocalizations?
    iv. Which bird vocalizations can you isolate from others with your equalizer?

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) and bandwidth (range of frequency over which gain is within some tolerance, e.g., 3dB).
    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, and processing is 'offline'. Your code does not need to process the signals in real time.
2) Implement the system with 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 (1^{st} order LCCDE) filters as in previous homework, but feel free to consider other options such as RLC (2^{nd} order LCCDE) circuits.
    a. For each frequency band filter, analyze its frequency response (magnitude and phase) and impulse response (e.g., to approximate the impulse response, use lsim(b,a,x,t), with x = [1 zeros(1,N)]).
    b. For each overall equalizer setting, 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).
3) Results: Demonstrate enhancement of the provided signals.
    a. Use time- and frequency-domain plots and spectrograms to illustrate.
    b. You can also describe the qualitative change in the signals based on audio playback.
    c. Describe the equalizer band and gain settings used to achieve each result.

The provided demo includes code to produce a spectrogram (a time-varying Fourier series decomposition of the sampled signal). The demo uses syntax *spectrogram(x,window,noverlap,nfft,fs),* which produces a figure showing the spectrogram of signal x, with time-varying fft's of signal segments of length *window*, overlapping by *overlap* samples, and an fft-length of *nfft.* Note that the *clim* command (formerly *caxis*) changes the color limits on the spectrogram visualization.

Document your design in a 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 to illustrate how well you met 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. Note: slides are preferred. Matlab demos are great but best presented within a slide-based presentation. In this case study, audio demonstrations are excellent, but check the results before submitting to ensure the recording sounds as intended.
  - See also the general report guidelines and notes on canvas.

Note: please ensure that your demo code can be run by the grader (include all needed files) and that your code generates all (at least the main) figures in the report. Submit all files as a .zip file.

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 for the overall system
- Results - 25%
  - Demonstration of design objectives
  - Demonstrated enhancement of modified music recordings
  - Demonstrated enhancement and analysis of bird vocalizations
- 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 methods and results.