EEEN203 Analogue Circuits and Systems
Lab 3
Hi-Fi Audio Circuit Design

Due Thursday, 28 March 2024

Note: this lab requires submission of a formal report, containing all your design decisions and results. Each of Part 1 and Part 2 will be graded for completeness, correctness and clarity.

1 Introduction

One of the most popular and well studied areas of circuit analysis is the design of high fidelity "hi-fi" audio components. Starting from scratch or using one of the many designs available online, circuit analysis allows one to design and build components of comparable quality to any available commercially, sometimes at only a fraction of the retail price. The aim of this assignment is to introduce some of the common sub-circuits seen in hi-fi audio systems and show how they can be manipulated using the skills and techniques you have learnt in EEEN203.

2 Goal

Use the circuit analysis skills you have learnt in EEEN203 to design, model, and test various circuits commonly found in hi-fi audio equipment.

3 Equipment

Resistors, capacitors, op-amps, hook-up wire and breadboards are all available in the lab. The lab is also equipped with oscilloscopes, function generators, and power supplies. The PCs in the lab have Matlab and LTspice installed; alternatively, LTspice is available online as a free download for you to install on your own Windows or OS X system. Octave, an open source alternative to Matlab, is also widely available, as is Python; however, no support is provided for these in EEEN203.

Reporting: Submit an individual, typed report containing results for each task in parts 1 and 2 of this assignment before the deadline listed at the top of this document. You should include all relevant plots, circuit diagrams, photographs, screen captures and calculations. Include a brief conclusion at the end of your report highlighting the key circuit analysis principals and phenomena covered in EEEN203 that you have explored in this report.

3.1 Part 1: Pre-Amp Subwoofer Filter

Many streaming shows and movies come encoded with 5.1 audio, where the audio signal is split into six separate channels: five for general purpose or "tweeter" loudspeakers, and the sixth for a subwoofer, which handles frequencies below about 200 Hz. For audio sources that are not encoded in 5.1, pre-amplifiers typically implement low pass filters to separate out the frequencies required by a subwoofer and send these to a separate output.

Tasks:

1. Design a low pass filter for a subwoofer, subject to the following guidelines:
   - Use LTspice to prototype your filter and guide your design.
   - For simplicity, your initial design should use only resistor(s) and capacitor(s).
   - If you do use capacitors, choose value(s) between 100 nF and 1 μF.
   - The cut-off frequency of your filter should be 200 Hz.
2. Run an AC analysis in LTspice to plot the transfer function of your filter with no load connected.
   - Characterise your filter for frequencies in the range 2 Hz to 20 kHz.
   - Calculate the gain and phase of the filter at its cut-off frequency, $f_c = 200$ Hz, as well as at $f_c/10$ and $10f_c$.
   - Comment on the relevance of the gain and phase values at these frequencies
3. Repeat your AC analysis with a 10 kΩ load connected to your filter, which may be expected when the subwoofer output from the pre-amp is connected to the input of some other component, such as a power amplifier.
   - Re-calculate f_c based on the results of your AC analysis with a 10 kΩ load connected.
   - Explain why f_c has changed and name the phenomenon responsible for this change.
4. Insert a voltage follower between your filter and the 10 kΩ load. Re-run your analysis and calculate f_c based on the plots you generate.
   - Explain your observations.

3.2 Part 2: Audio Effects Unit

Amplifiers typically come with (at least) some way to change or *equalise* the spectral 'shape' of the sound they produce. Many sophisticated models also include effects units that can drastically alter the sound produced to various ends, including removing voice tracks for karaoke, adding reverb or flange, or just making everything sound *different*.

Tasks:

1. Build an integrator effect circuit using one or more resistors and capacitors, and op amps on one of the breadboards in the lab.
   - Refer to your notes on AC analysis if you need inspiration for the design of your integrator.
   - Op amps have data sheets (you should be able to find the LM741 data sheet online) that contain pin out diagrams to help you work out which way to plug them in. The key thing to know is that pin 1 is denoted either with a printed dot on the body of the IC, or with a half-moon indentation at the top end of the chip. (Pin 1 is always to the left of this indentation.)
   - Use a function generator to provide a 1 kHz, zero-mean square wave as input to your integrator. Observe the resulting output on an oscilloscope. **NB:** see next step below if your results are not what you expected.
   - Include screen captures from the oscilloscope and annotated photographs of your breadboard circuit in your report.
2. Be careful not to include a DC offset on your input signal, as this will cause the integrator to slowly 'wind-up', where its output drifts to either one of its power rails. You can prevent wind-up by adding a large (e.g., 100 kΩ) feedback resistor in parallel with the capacitor in your circuit.

- You can observe integrator wind-up by setting the function generator to intentionally introduce a small (50 mV) offset to your input signal and watching the output change over time.
- Confirm that the 100 kΩ resistor prevents wind-up, even with a significant DC offset on the input signal.
- Explain how the 100 kΩ resistor prevents wind-up. Hint: consider the transfer function of the circuit at high frequencies, where the integrator is expected to work, and at low frequencies, i.e., near DC.

3. Measure the voltage gain of your integrator circuit at 1 kHz. Design an appropriate op-amp-based amplifier to connect to the output of the integrator to give a combined voltage gain of 1×. Save a screen capture from the oscilloscope to confirm that your amplifier gives the desired gain. Also include an annotated photograph of your circuit in your report.

3.3 Part 3: Power Amplifier Output Stage (Optional Extension)

(This section is worth some marks, but not many compared to the previous sections)

A common hi-fi design approach involves a pre-amplifier to provide voltage gain, with a separate[1] power amplifier to provide current (i.e., power) gain. Unfortunately much of this power gain can be lost if the output stage of the power amp is not matched carefully to the expected load from the loudspeakers.

Tasks:

1. Use Matlab to calculate the voltage across, V_L, current through, I_L, and power delivered, P_L, to an 8 Ω load connected to a Thevenin source with resistance, R_S, of 32 Ω (i.e., the power amp output) and voltage of 40 V.
2. Plot V_L, I_L and P_L as R_L is varied from 0.1 Ω to 1 kΩ. Explain your results.
3. Repeat the above for $R_S = 8\,\Omega$, $R_S = 2\,\Omega$, and $R_S = 128\,\Omega$. Plot the curves for different value of R_S on the same graph. Explain your results.
4. Now insert an ideal transformer between the source and the load. Plot V_L, I_L and P_L as the turns ratio varies from 1 : 10 to 10 : 1. Explain your results.
   - Plotting data in Matlab is as simple as typing `plot(x, y);` at the Matlab prompt, where x is an N-length vector of values to appear on the x-axis and y is an N-length vector of the data to be plotted.
   - To plot multiple curves on the same plot, enter `hold on;` once the first variable is plotted, then add more curves using the `plot()` command. To start a new figure, type `figure;`.
   - Be sure to add text labels to your plot axes using the commands `xlabel('text');` and `ylabel('text')`. The `title();` command follows a similar syntax.
   - Finally, you can distinguish between multiple curves on a plot by including line style ("-", "–", ":", "-.") and colour ("r", "g", "b", "y", "m", "c", "w", "k") arguments between single quotes at the end of the plot command, like this: "plot(x, y, 'r:')".
5. Given the results you found, comment on the ideal value for the turns ratio in this power amp application.
6. Model the transformer circuit with the ideal turns ratio in LTspice to confirm your transformer delivers the expected benefits.

[1] The power amplifier may be a physically separate component or box to the pre-amplifier, or may be a separate 'stage' within the same circuit board that implements the pre-amplifier.

4 To hand in

You need to hand in a somewhat more detailed write-up than for the other labs. This will include include an Aim, a Method, and Results.

1. Aim: a short introduction describing and motivating the task (why is it important),
2. Methods: a theoretical section describing in more detail the task at hand and the approach (the methods) taken (this section usually includes equations), and
3. Results: a section that describes the results, and a discussion of what they mean. The results section should have two subsections (one for each of Sections 3.1 and 3.2 of the lab script), and enough of your working to show that you've completed the lab. Most will include photos of the oscilloscope and/or the circuit. The tasks of 3.2 are worth more marks than the tasks of 3.1.

Marking schedule (out of 10):

1.
2. Aim = 1 mark
3. Methods = 2 marks
4. 1/2 mark for each of the 4 tasks of 3.1. 4 x 0.5 = 2 marks
5. 1 mark for each of the 3 tasks of 3.2. 3 x 1 = 3 marks
6. 1 mark for the optional 3.3
7. 1 mark for presentation