ELEN E4215 Instructor: T. Dickson
Fall 2023
Mel-Spaced Filter Bank for Audio Feature Extraction (v 1.0)
Due Date: Tuesday December 12, 2023

1 Project Background

You are an analog circuit design engineer for an integrated circuit design company. Your company has developed a general purpose artificial neural network processing engine, and is eager to showcase this new product to customers and demonstrate its capabilities across a wide variety of applications including speech recognition. To accomplish this, the company would like to ship demonstration boards to potential customers consisting of the system depicted in Figure 1. This system includes an audio feature extractor followed by the neural network processor. In the audio feature extractor, the sound signal is amplified and sent to a bank of bandpass filters with center frequencies spaced linearly on the logarithmic mel frequency scale. The short-term power in each band is detected and digitized using an analog-to-digital converter (ADC) before sending digital information to the neural network processor.

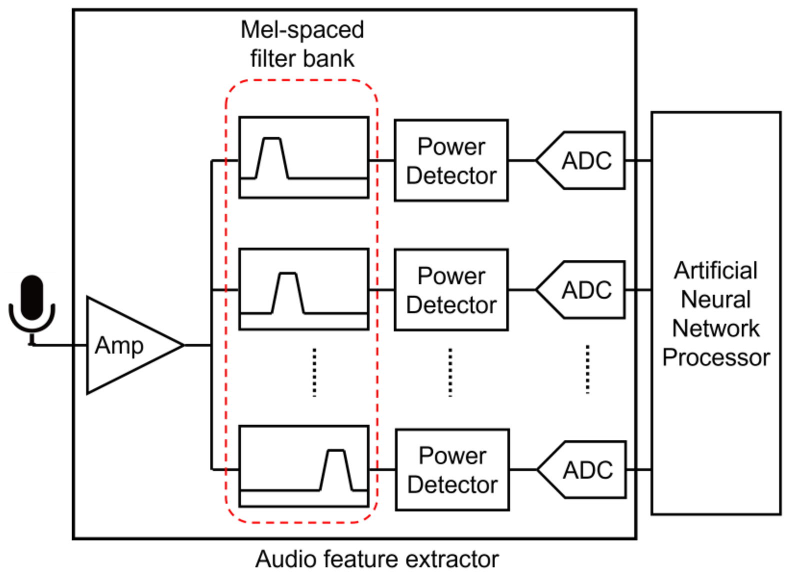

Figure 1

Speech classification can be accomplished through examination of the mel frequency cepstrum, which computes the short-term power spectrum of a sound on a logarithmic mel frequency scale. One can convert cyclical frequency f to the logarithmic mel scale m using the following formula:

$$m = 1127 \ln\left(1 + \frac{f}{700}\right)$$

To illustrate the concept of mel-spaced bandpass filters, Figure 2 shows the ideal response of 16 mel-spaced bandpass filters with center frequencies ranging from 1kHz to 8kHz. Each bandpass filter has a response of 1 at its center frequency, a response of 0 at frequencies less than or equal to the center frequency of the previous bandpass filter, and a response of 0 at frequencies greater than or equal to the center frequency of the subsequent bandpass filter. Thus, the ideal filter response looks triangular when plotted on a linear vertical axis. Figure 3 shows the ideal response of the same bank of 16 bandpass filters plotted on a logarithmic horizontal axis, to clearly illustrate the linear spacing of the center frequencies on a logarithmic axis.

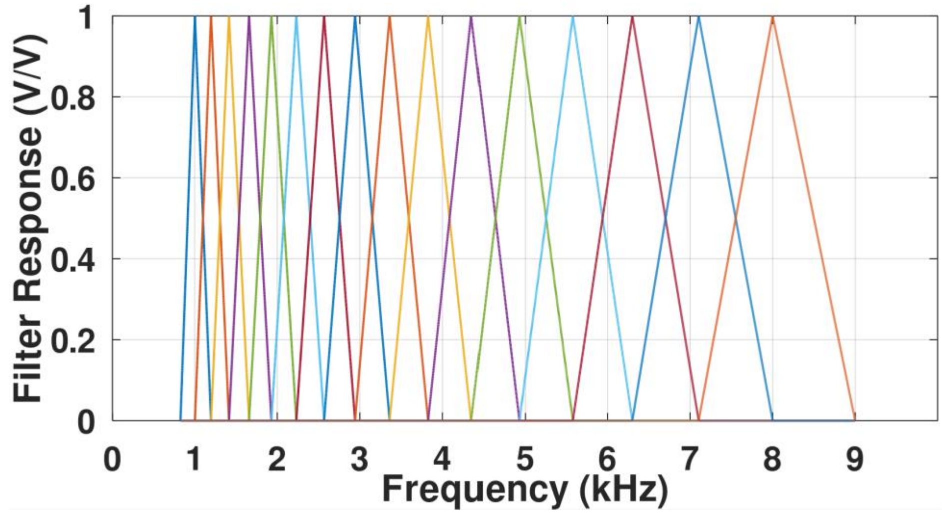

Figure 2

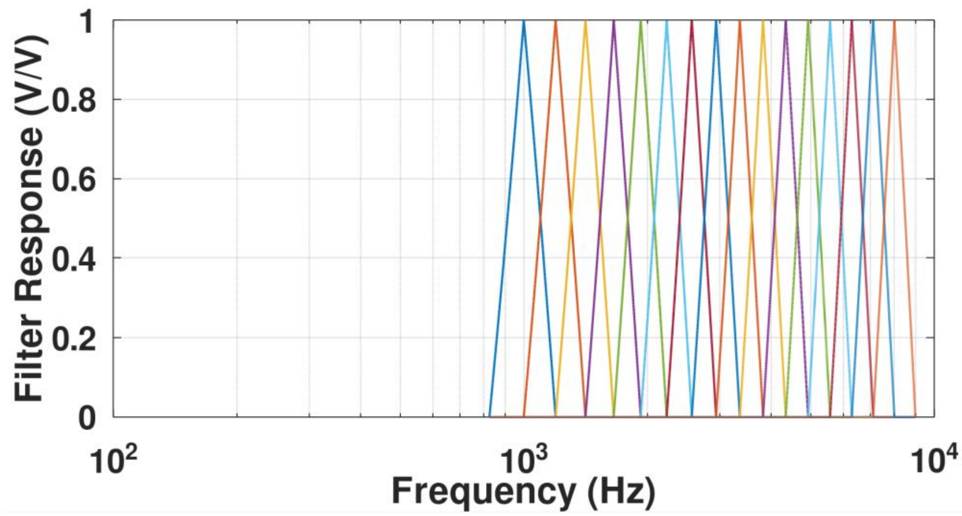

Figure 3

Your company has asked you to design the mel-spaced filter bank for the audio feature extractor of Figure 1. The filter bank should consist of 10 bandpass filters spaced across the audio range from 100 Hz to 4 kHz (<u>note</u>: this is <u>*not*</u> the same as the frequency range or number of filters illustrated in Figures 2 and 3). You are only responsible for the design of the filter bank, not other components in the audio feature extractor. The company needs to ship demo boards to customers quickly, and plans to implement the audio feature extractor on a printed circuit board (PCB) with commonly available surface mount devices. While the power consumption of the feature extractor is not critical for the purpose of the customer demonstration, the company does wish to keep down the cost of the PCB. To this end, it is desirable to minimize the number of components (resistors, capacitors, and operational amplifiers) used in your filter bank.

The lead system designer is aware that triangular bandpass responses of an ideal mel-spaced filter bank (i.e., responses seen in Figures 2 and 3) are not practical for a low-cost implementation. However for the intended application, it is noted that the neural network can adapt and compensate for reasonable imperfections in the audio feature extractor. This implies that while the filter bank should achieve the desired mel-spaced center frequencies and unity gain at these center frequencies, the exact attenuation achieved by a single filter at the center frequency of adjacent filters is not critical. The system designer believes that 10dB rejection should be sufficient for the application but has indicated that this specification may be flexible depending on practical implementation aspects.

2 Subcomponents:

The company plans to build the audio feature extractor on a printed circuit board with surface mount devices. Therefore, you are to implement your prototype filter bank using generic off-the-shelf LM741 operational amplifiers. A schematic for this operational amplifier is provided. In your Cadence directory, open your cds.lib file and at the following line to define the library that includes the LM741 operational amplifier.

DEFINE ELEN4215_TDickson /homes/user/stud/fall22/ad4034/ee4215/ELEN4215_TDickson

To use this amplifier, you will need to include the following model file when running Spectre simulations.

/homes/user/stud/fall22/ad4034/ee4215/models/LM741.scs

Be aware that the LM741 requires a positive and negative power supply. You will need to provide a +15V supply to VCC and -15V supply to VEE. These can be provided using dc voltage sources 'vdc' from analogLib in Cadence.

Your design should make use of standard surface mount resistor and capacitor values. Surface mount resistor values have 1% tolerance and follow standard EIA-96 markings as described here:

https://eepower.com/resistor-guide/resistor-standards-and-codes/resistor-smd-code/#

Surface mount capacitor values can be found from catalogs provided by common vendors. One such vendor is Kyocera. Please refer to page 8 of the following catalog for available surface mount capacitor values.

https://catalogs.kyocera-avx.com/SurfaceMount.pdf

3 Assessment:

3.1 A report will be submitted from each design group (maximum of 2 students per group, but you can work individually if you prefer – there will be no difference in assessment). ***Quality of the written report will be assessed, including clarity and organization.*** It is insufficient to show that your design works. You must describe the design procedure, and demonstrate to the instructor that you fully understand *why* your design works. The report should be no more than 10 pages, including figures. The IEEE template for transactions articles should be followed:

https://ieeeauthorcenter.ieee.org/create-your-ieee-article/use-authoring-tools-and-ieee-article-templates/ieee-article-templates/templates-for-transactions/

References to the textbook (Schaumann) or the instructor's lecture notes are not required. Any other books or scholarly articles that may have inspired your design should be properly cited.

3.2 You are free to include any information you feel relevant to describing your design into your report. Here are some recommendations of what could be included in a successful report:

- 3.2.1 Filter transfer functions – clearly derive the required filter transfer functions. MATLAB plots of the transfer function frequency response are encouraged to verify that the transfer functions meets the specifications.
- 3.2.2 Describe the procedure for implementing the transfer function.
- 3.2.3 Schematics – clearly show all filter and/or sub-section designs, including resistor/capacitor values and how they are determined.
- 3.2.4 Simulation Results – show relevant simulation results for your filter bank. Be sure to include adequate descriptions of any plots included.