

ELEN 458 Lab 6

Active Filter Synthesis & Approximation: Designing an Simple Graphic Equalizer Filter

I Introduction

Equalizers are used in many different applications and the most commonly known one is in audio systems. The main purpose of the equalizer is to adjust the output sound to the desire of the user. The simplest type of equalizer to construct is the graphic equalizer. It takes simple band pass filters in parallel and then adds them together to generate a single output.

One currently popular form of spectrum modifier is the graphic equalizer. This often consists of a bank of slide potentiometers that emphasize or de-emphasize portions of the audio spectrum. The graphic equalizer is used to improve or match apparent room acoustics, to match instruments, to add special effects to an otherwise dull recording, to improve speech intelligibility on a noisy channel, and similar tasks.

Often the individual filter channels are made of Opamps or OTAs, low-Q, bandpass filters. These are usually placed inside the feedback loop of an operational amplifier as shown in Fig.1. This feedback provides a 'boost' or 'cut' operation where each slide control provides a flat response in the middle of its range and provides progressively more emphasis or de-emphasis as the limits of the slider are approached.

II Objective

The objective of the lab is to create an equalizer and reinforce all the techniques that have been taught based on the standard active filter configurations and using OTA as a flexible tuning amplifier.

III Component List

- Components necessary for lab will vary depending on your design.

IV Prelab

a) Using the FIESTA2 software, design two band pass filters. The box constraints are as follows:

- Band Pass Filter 1
 - Lower Stop Frequency : 100Hz
 - Lower Pass Frequency : 300Hz
 - Higher Pass Frequency : 700Hz
 - Higher Stop Frequency : 1.1kHz
 - Maximum Attenuation in the Pass Band : 3dB
 - Minimum Attenuation in the Stop Band : 20dB
- Band Pass Filter 2
 - Lower Stop Frequency : 1kHz
 - Lower Pass Frequency : 2.5kHz
 - Higher Pass Frequency : 5kHz
 - Higher Stop Frequency : 8kHz
 - Maximum Attenuation in the Pass Band : 3dB
 - Minimum Attenuation in the Stop Band : 20dB

b) Design both filters with Active-RC. The filter designed with Active-RC.

c) Perform the designs using the **Elliptical** approximation methods. Draw neat schematics for each filter synthesized, use the nearest standard component value for each component included on the schematic. For each filter, obtain a HSPICE (or SpectreS) input netlist file and be sure to use the LM13600 and LM741 macro models in the simulations. Be sure to turn in all FIESTA2 files (approximation data). When running FIESTA2, carefully observe all the different responses generated by the GRAPHICS output option for each approximation method (this will be important for the lab report) e.g. order, center frequency, ripple in the pass band / stop band, phase response, group delay response.

d) Simulate the filters using HSPICE (or SpectreS) and provide plots of magnitude and phase response for bandpass filter 1&2 (total 4 graphs).

e) After designing both filters, construct Fig 1. **Hint** : You may need to put an unity gain buffer before each input to the Bandpass filter. The variable resistor (10k pot) R1 and R2 can be modeled with two resistors connected in series as in Fig.1, e.g. with R1 represented by Rhi1 and the other is 10k-Rhi1. Varies Rhi1 in steps of 2k from 1k to 9k while keeping R2 fixed at Rhi2 = 1k. Provide AC magnitude

at V_o for the parametric sweep of R_{hi1} . The AC magnitude second plot would be varying R_{hi2} from 1k to 9k in steps of 2k. The plots would give a good understanding of working of an Equalizer as how we can boost the bass (low frequency components) or the treble (high frequency components).

- f) Develop the transfer function (symbolic and not numerical values) for bandpass filter. **Hint** : If you choose the same type of configurations for bandpass filter 1 and 2, and also within each bandpass filter, if you choose both stage 1 and 2 to be the same configuration, e.g. tow-thomas, you just need to provide single transfer function. Support your answers using block diagrams. As an example, the transfer function for the tow-thomas configuration as in Figure 2 is transfer function is formulated as in Equation (1). Please verify the equation.
- g) In the bandpass filter 2, provide programmability (tuning) of center frequency ω_o . From Equation (1) it can be noted that we can vary R_4 to achieve 'tunability' in ω_o (why ?). However, we may have to trade-off with Q variation. **Why** ? The tuning can be achieved by having an OTA which served as an 'floating resistor'[1] as in Fig.3. **Why** is it necessary to have a voltage divider scheme with R_{b1} and R_{b2} as in as in Fig.3 ? Through this voltage divider scheme, we are making impedance scaling and we must correspondingly scale the G_m of the OTA as well. Calculate the G_m needed for it to function as a resistor. Plot on the same scale, as a form of comparison, the frequency response of the with OTA acting as a floating resistor and in the case with the actual resistor R_4 . Calculate the biasing current I_{abc} required for the floating OTA. Simulate your response using LM13600 model file in HSPICE (or SpectreS). Keep both $R_{hi1}=R_{hi2}=1k$ ohms. By changing the I_{abc} , we could change both the pole and zero locations. Verify it with your transfer function. Observe that in your bandpass filter 2 configuration by providing plot for varying 3 I_{abc} values including the nominal value.
- h) Provide transient responses of overall filter with the OTA floating resistor with input signal at frequencies of 500Hz, 1.3kHz, 4kHz. Keep both $R_{hi1}=R_{hi2}=1k$ ohms.

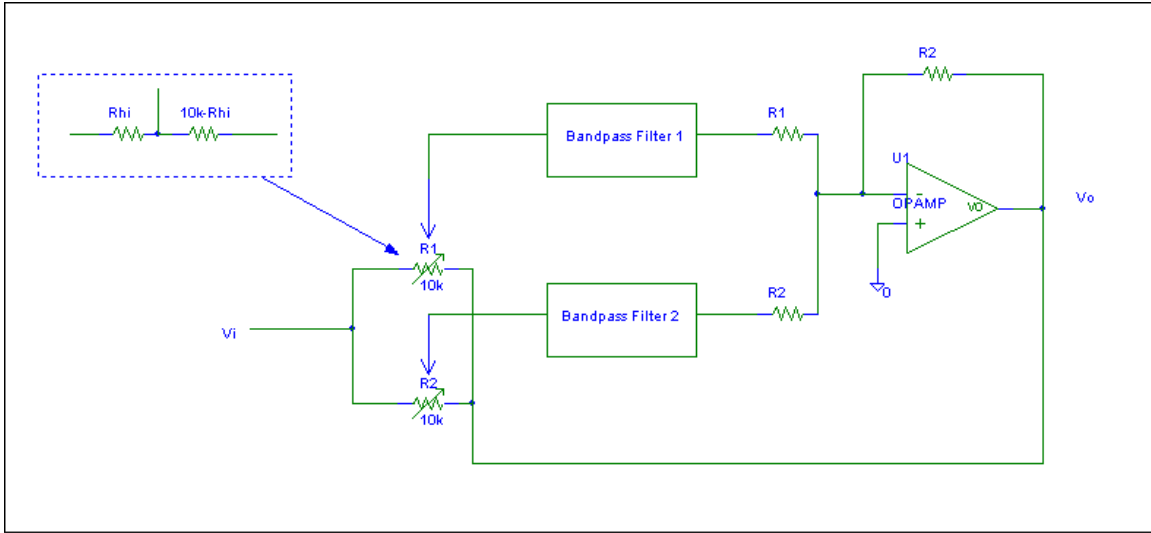


Figure 1. Graphic Equalizer uses multiple active filters within a single feedback loop

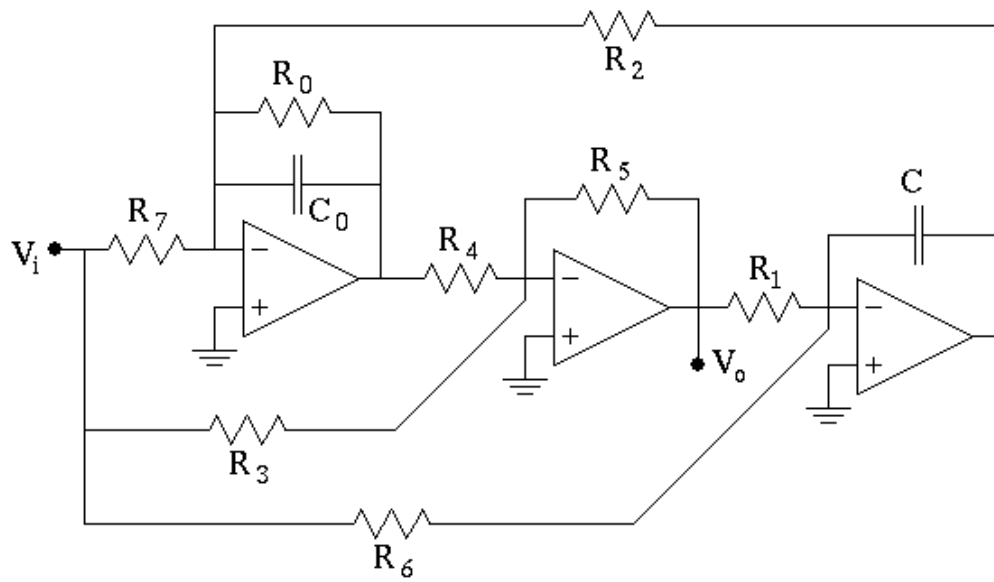


Fig.2 tow-thomas configuration

$$H(s) = \frac{V_o}{V_i} = \frac{-\frac{R5}{R3} \left(s^2 + \frac{R3}{R6CR2CoR4} \right)}{s^2 + \frac{s}{RoCo} + \frac{R5}{R4R1R2CCo}} \quad Eq(1)$$

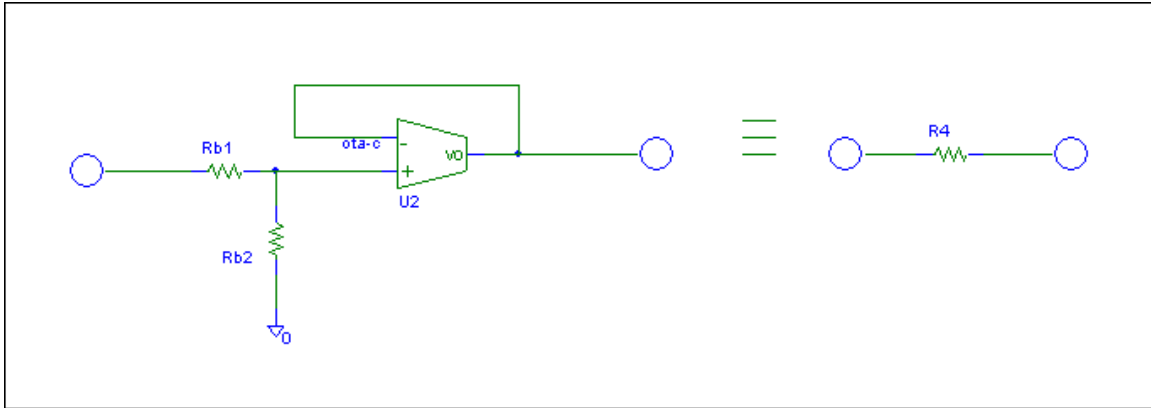
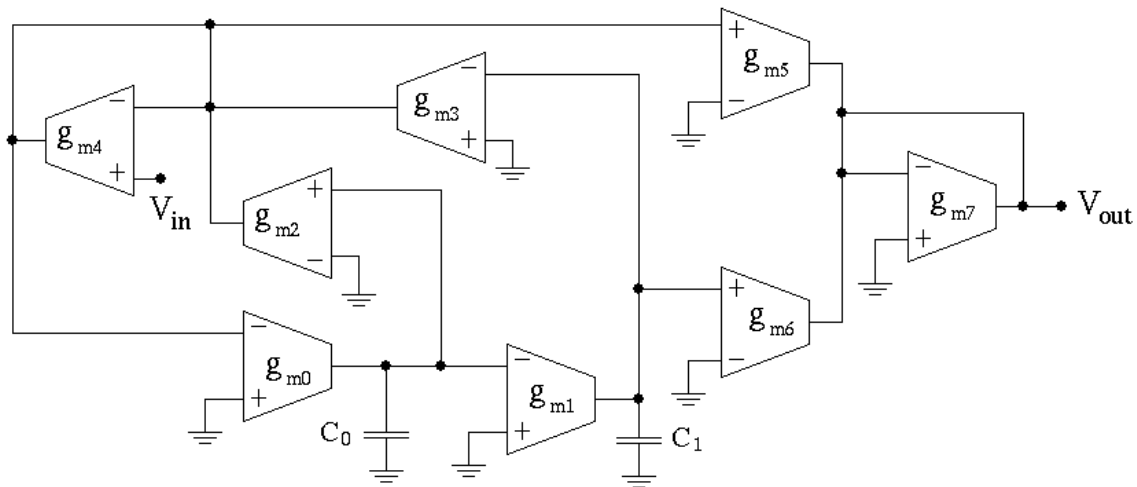


Fig. 3 Floating Resistor with OTA

(extra Credit : 3 points each items) :

- (i) Repeat (a)-(d) based on Chebyshev configuration.
- (ii) Construct Elliptical configuration based on OTA configurations. It will consist of two cascaded stages of second order filter system. In each second order systems, it further will consist of two identical stages in cascade, one of which is as shown in Fig.4. Reduce the number of OTAs from eight to NOT MORE than six.
- (iii) By tuning G_{m1} as in Fig.3, we could change the center frequency ω_0 . However, we would vary Q of that stage. Define a way to maintain the Q while having the complete filter with programmability (tuning ω_0). Also, provide a way to vary ω_0 while maintaining the Q factor.

*In each item, support your answer with HSPICE / SPECTRES simulation results using commercial LM13600 or LM741 model file.



V Lab Procedure

- Build and test figure 1 using the **Elliptical** approximations (be sure that the TA verifies your circuit for proper operation).
- Provide plots and record of the Magnitude and Phase response for each bandpass filter 1&2 in the lab report at the 3 important frequencies i.e $f_{3db,upper}$, f_{3db} , lower f_o .
- Provide plots and record the magnitude and phase response at important frequencies of overall response at frequencies 100Hz, 300Hz, 700Hz, 1kHz, 2.5kHz and 5kHz, 8kHz..
- Also, in the report compare and contrast the approximation methods listed above.
- What are the advantages and disadvantages of each method? Be sure to base your analysis on the following factors (besides others): order, center frequency, ripple in the pass band / stop band, phase response, group delay response, time domain response.

VI Reference

[1] T.Deliyannis, T.Sun, and J.K.Fidler, "Continuous-Time Active Filter Design", CRC Pres, Boca Raton, Chapter 8, section 8.6, 1999.