Georgia Institute of Technology

School of Electrical and Computer Engineering

ECE 4435 Op Amp Design Laboratory Fall 2003

Design Project 3

A Non-Linear Low-Pass Filter Having an Imbedded Clipper

Introduction.

When a sharp cutoff low-pass filter is preceded by a peak clipper, the complex filter poles can cause ringing in the filter output when the clipper is activated. This can cause signal peaks at the output of the filter to exceed the clipper threshold level at the filter input. A proposed method for eliminating this problem is to follow the clipper with a non-ringing Bessel filter and to precede the clipper with a filter such that when its transfer function is multiplied by the Bessel filter transfer function, the overall transfer function is that of the desired sharp cutoff low-pass filter. It follows that the signal peaks at the output of the non-linear filter can never exceed the clipper threshold level at the filter input. In addition, when the clipper is not activated, the signal will be low-pass filtered by the sharp cutoff filter. The object of this design project is to design such a filter with an imbedded clipper.

Circuit Specifications

1. The circuit will have a signal input with an input impedance of $10\,\mathrm{k}\Omega$ and a signal output with an output impedance of $100\,\Omega$. The dc offset at the output must be less than $50\,\mathrm{mV}$.
2. The circuit will contain an imbedded clipper that has symmetrical clipping thresholds of $\pm 5\,\mathrm{V}$. The clipper should have as "hard" a clipping characteristic as possible. A possible circuit for realizing this is to subtract the output of a center clipper from the signal and adjust the gain of the center clipper output to optimize the "hardness" of the clipping.
3. The clipper is to be followed by a unity-gain third-order Bessel low-pass filter that has a $1/\sqrt{2}$ cutoff frequency of $5\,\mathrm{kHz}$.
4. The clipper is to be preceded by a filter which has a transfer function such that when it is multiplied by the transfer function of the Bessel filter, the resulting transfer function will be a unity-gain $0.75\,\mathrm{dB}$ ripple third-order Chebyshev filter with a $1/\sqrt{2}$ cutoff frequency of $5\,\mathrm{kHz}$.
5. The circuit is to operate from $\pm 15\,\mathrm{V}$ power supplies.
6. The permissible error tolerance for the specifications is $\pm 5\%$.

Design Considerations.

An important criterion of your design will be the correlation you can achieve between your experimental laboratory results, SPICE computer simulations, and your theoretical calculations. In your preliminary design, you can consider all operational amplifiers to be ideal. Your final design circuit should be capable of being tuned to compensate for non-ideal characteristics occurring in op amps and other components. Keep in mind that you should be designing a circuit which can be mass produced and widely utilized. Therefore, it should be easily adjusted with off-the-shelf components.

Comparisons should be made among the response of an ideal noise-gate circuit, the theoretical circuit response as predicted by SPICE, and the experimental circuit response. In the lab, it will be relatively easy to measure a frequency response characteristic using the laboratory equipment. Comparing theoretical, experimental, and SPICE transfer characteristics will be essential in checking the quality of your design.

Power supplies of ±15 V and +5 V are available for your design.

Design Schedule

1. Submit for approval a preliminary "paper design" to your lab GTA for his review on or before class November 12, 2003. This paper design should show a possible block diagram with complete circuit diagrams of each block with all component values chosen. Also, provide design equations and explain the thought processes behind your preliminary design. This preliminary design does not have to be the final design you realize for this experiment, but it should help you begin to solidify the underlying concepts and specifications. Remember, the more information that you can provide for your lab GTA, the more direction he can give you and the more time he can save you in the laboratory. Your "paper design" should be complete enough so that you can begin to assemble and test your design in your laboratory period on November 13.

2. Utilize SPICE to theoretically verify your circuit design. Use the 741 or LF351 op-amp macromodels that are given on page 35 of the document located on the class web page at http://users.ece.gatech.edu/~mleach/ece4435/chap02.pdf. Obtain SPICE transfer characteristic plots for the output. Present this SPICE verification of your design to your lab GTA for his certification at your regular lab period on November 20.

3. Complete the laboratory evaluation of your design with a witness verification of proper design performance during lab on December 4.

4. Submit your complete report to your lab GTA before 6:00 p.m. on December 5.

Design Evaluation Criteria

1. Design approach, philosophy, and clarity of explanation. Follow suggestions given in the "Op Amp Design Lab Procedures and Instructions" sheet on the class web page.

2. Achievement of design specifications.

3. Documentation of design performance.

4. Design simplicity and economics. Evaluate the cost of your design according to the instructions on the "Op Amp Design Lab Procedures and Instructions" sheet.

5. Assume that your design is to be used in an application requiring large quantity production using off-the-shelf components.

6. Other Components: If you are considering using some special device or component, determine the cost and availability of a tested and guaranteed unit from a reliable vendor. With this information, your laboratory GTA will determine the equivalent cost units.

ECE 4435 Design Project Evaluation Criteria

Prelab Submitted on 11/12/03	5 points
Laboratory Attendance	10 points
Explanation of Design Approach & Insight Into Design	10 points
Block Diagram of Circuit	
Derivation of Gains and/or Transfer Functions	

Design of the Bessel Filter
Design of the clipper
Design of the Bessel to Chebyshev converter filter
Input Impedance Considerations
Output Impedance Considerations

Results & Presentation of SPICE Simulations — 5 points
“Signed Off” in Lab during the second lab period
SPICE Simulation of Final Overall Circuit
Presentation

Economics & Cost Analysis — 5 points
Justify Design Choices
Total Component Cost

Presentation of Experimental Results — 5 points
Complete Documentation of Results Verified in Lab
Comparison of Theoretical, SPICE, and Experimental Results (In Tabular Form with % Errors)
Explanation of Results
Explanation of Measurement Techniques
Experimental Results Obtained — 5 points
Gains
Clipping levels
$1/\sqrt{2}$ cutoff frequencies
Operation of the Bessel Filter
Operation of Bessel to Chebyshev converter filter
Input & Output Impedances
Output Offsets

Conclusions — 5 points
Sources of Error
Proposed Improvements to Circuit
General Comments on Whether Specifications are Reasonable
General Comments on Whether Measuring Techniques are Reasonable

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Evaluation Sheet for Design Project 3

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Name:____

__________ 05 Verification of Preliminary Design

__________ 10 Laboratory Attendance

__________ 05 Explanation of Design Approach

__________ 05 Demonstration of Insight into the Design

__________ 05 Results and Presentation of SPICE Simulations

__________ 05 Economics and Cost Analysis

__________ 05 Presentation of Experimental Results

__________ 05 Experimental Results Obtained

__________ 05 Conclusions

__________ 50 Total

Verification of Experimental Results

Parameter	Specification	Result	Witness
Midband Gain	unity		
Bessel Filter $1/\sqrt{2}$ Cutoff Frequency	$5\,\text{kHz}$		
Chebyshev Filter $1/\sqrt{2}$ Cutoff Frequency	$5\,\text{kHz}$		
dB Ripple for Chebyshev Filter	$0.75\,\text{dB}$		
Positive and Negative Clipping Levels	$5\,\text{V}$		
Absence of Ringing on Clipped Waveform	Yes/No		
Input Resistance	$10\,\text{k}\Omega$		
Output Resistance	$100\,\Omega$		

Witnessed by: ________________________ Date: ________________________