Ramesh Harjani EE5333: Analog Integrated Circuit Design Fall 2016

Project

***Why the project**: According to various academic studies, learning retention rates are 2% of what is seen, 20% of what is read, and 80% of what is actually done, three days after learning occurs[1].*

PROJECT PROPOSAL DUE:	Tuesday, September 27th
INTERIM PROJECT REPORT DUE:	Thursday, November 3rd
FINAL PROJECT REPORT DUE:	Tuesday, December 13th, 5 pm

There will be no extensions for the final project reports. Note, this is the last class of the semester not the last day of classes. If you are going to be out of town you can hand in your reports early. Late reports will not be accepted.

Sequence of steps while working on the project:

a) *Select a project.* All along the quarter students are expected to work on a project of significant size. You are expected to work on a single project. As these projects make up a significant proportion of your final grade, students are advised to start thinking of topics for their final project immediately. All students have to design an opamp as their first project. You will have to complete circuit design and layout, i.e., everything that is necessary to get your design fabricated at an IC foundry. You are expected to have completed your opamp design, including layout by the time the interim project report is due. The best place to start looking for ideas to design opamps is our book (chap 11) and the reference book. Additionally, you can use the list below or select one of your own. Remember you will be given more credit for innovation. In general the power supply voltages for CMOS is rapidly decreasing and low power is always import. So, circuits that use low power and low supply voltages will be given highest credit.

Opamp Design Ideas

- Ultra low power operational amplifier with high slew rate capability. Design a opamp that consumes low power under normal conditions but can provide large current into the load when slewing. Hint: this has to be an adaptive circuit. Static power in the nanoampere region
- A fixed gain (maybe 10) instrumentation amplifier. Gain must be very predictable. Instrumentation amplifier requires high input impedance, large input voltage swing, low noise, etc.
- Ultra low noise amplifier. Input referred noise 3μV rms. Lateral bipolar input transistors may be called for.
- Ultra low-noise lower frequency CMOS operational amplifier (Chopper stabilized, correlated double sampled or continuous time auto-zero)
- Ultra high frequency CMOS single-stage CMOS amplifier. Think about bandwidths of 3-10GHz and gains in the regions of 40-60dB.
- Class AB folded-cascode amplifier with large gain and bandwidth (100dB gain & 1GHz BW)
- Many more …

[1] http://www.csom.umn.edu. Carlson Ventures Enterprise Mission statement.

The second part of you project will be to use your opamp in a more complete design. This is the more difficult part. Everyone in class will design a second-order switched capacitor filter that uses their opamp as part of the circuit (chap 13). Once again, remember that low power and low voltage designs will be given greatest credit. **Everyone (UNITE students included) needs to discuss their projects with me before the due date.** Telephone discussions are not effective. So, please see me during office hours. If you are unsure of what the various projects mean, please, feel free to discuss it with me. Please restrict yourself to my office hours. I do not expect you to have a complete idea as to what you want to build. However, I want you to start thinking at this time and I want you to choose a general direction NOW. You can provide me with more complete details for the second part of the project during the interim project report. Mathematica, Mathcad, Mathlab are most usefully for this part of the project.

b) *Choose specs for the project.* For example, if you are going to be working on a low-power operational amplifier, choose the value of the bias current goal that you want to design for. Since performance specifications are correlated, you need to select the complete set of specifications, not just the most important ones. It is important that you take a first stab at these values. Without these goals you will not know what you want to design. To do so you need to look at past examples (papers and books). By September 27th please complete a short report of what you plan to do and the performance specifications that you plan to meet. Also include in your report where/how you think your circuit or tool will be used. Along with this report include particulars of the most important references (pages from books and papers) that you have looked at. This project proposal needs to be typed. Handwritten work will not be acceptable. Be a little aggressive about the specifications that you select. It is possible that you may not be able to meet these specifications in the final design. If you do not do so include an explanation in your final report. Performance specifications for the opamp you want to include are:

*Voltage gain
*Unity gain bandwidth
*Slew-rate
*Commercial temperature range (0-70C)
*Capacitance (you will be driving switched capacitor circuits during the 2nd half)
*Phase margin
*Supply voltage (0-1.25, +0.625 -0.625) Do not go above 1.25V total. For your simulations make sure you simulate your design for -+10% variation
*Output common-mode voltage (+/-)
*Optimization criteria (what you want to minimize, i.e., power, area, noise, etc)
*Power
* Input common-mode voltage (+/-)

Project proposal: A short (2 pages) proposal describing what you want to do in the project. I want to see a list of references, ideas, circuit concepts, etc. Make this in the format of a IEEE conference paper. I will not read anything longer than 4 pages. I do not wish to see reams of simulations etc. **5 points**

c) *Complete the first part of your project.* Please, take the time to analyze your circuit. Perform hand calculations and confirm using circuit simulation. It is not sufficient to choose device parameter values out of the blue and show through circuit simulation that the circuit meets specifications. If questioned you need to be able to defend your choices. You need to understand how the circuit works. This is the most important part of the project spend time on it. The project is equally, if not more, important than the examinations. Analog circuit design cannot be learned by just taking a test. You have to do it to learn it. The difficulty of the project should be about as much or more than a final examination. I expect a complete design, simulations to confirm your design, layout, simulations after layout. Make sure you understand the impact of temperature variations, power supply variations and fabrication process variations on your design. You are likely to fail multiple times within the project to meet your specifications. If you failing you are on the right path. If you do not fail at all your specs are too loose. All of your designs will be judged on a figure of merit for opamps developed by Prof. Willy M.C. Sansen in his book (Analog Design Essentials, 2007 –available online in our library). FOM=GBW(Hz)*Cload(pF)/Isupply (mA). A value of 1500 MHz-pF/mA is quite good.

d) *Write your interim project report.* The interim project report needs to be neat and typed. Hand written reports will not be accepted. Please, check your spelling and grammar as well. Even the best project if not presented well will loose its glamour. Interim Project report: 4 pages, 2 column IEEE conference format. This should include tables summarizing your results. References. If your project report is longer and not in the correct format you will receive a zero. **10points**

e) *Complete your final project:* Same as before but now you have to use your opamp in a complete system. Again, hand crafted equations, completed design, simulation results, layout, and simulations after layout.

f) *Write your final project report.* As with the interim project report do a good job at writing. Include everything you did on your opamp (i.e., interim project report) in this final report. Final Project report: 6 pages, 10 point font, double column IEEE conference format. **20 points**

<u>References</u>

Good sources in general:

- IEEE Journal of Solid-State Circuits (particularly December issues)
- IEEE Transactions on Circuits and System
- Electronic Letters
- Our book & reference book

Go to http://ieeexplore.ieee.org/ for journal and conference paper access. You need to be on campus or use a VPN client to have access to all the articles. You can obtain the VPN software from http://www.oit.umn.edu/utools/

1) **Opamps:**

a. Analog MOS Integrated Circuits for signal processing, Roubik Gregorian and Gabor C. Temes, John Wiley & Sons, 1986, Chapter 4

b. CMOS Analog Circuit Design, Phillip E. Allen and Douglas R. Holberg, Holt, Rinehart and Winston, 1986, Chapters 6-9

c. An Integrated NMOS Operational Amplifier with Internal Compensation, IEEE Journal of Solid-State Circuits, December 1976

2) **SC-Circuits**:

   a. Analog MOS Integrated Circuits for signal processing, Roubik Gregorian and Gabor C. Temes, John Wiley & Sons, 1986, (one of the best books for switched-capacitor circuits)

   b. An integrated CMOS switched-capacitor bandpass filter based on N-path and frequency-sampling principles, D.C. Von Grungen, R.P. Sigg, J. Schmid, G. S. Moschytz, and H. Melchior, JSSC 1983

   c. Principles of Operation and Analysis of Switched-Capacitor Circuits, Yannis Tsividis, Proceedings of IEEE, vol. 71, pp 926-940, August 1983

   d. MOS Switched-Capacitor Filters, Robert W. Brodersen, Paul R. Gray and David A. Hodges, Proceedings of the IEEE, vol. 67, pp 61-75, January 1979

   e. Technological Design Considerations for Monolithic MOS Switched-Capacitor Filtering Systems, David J. Allstot and William C. Black,
   Proceedings of IEEE, vol. 71, August 1983

   f. State-of-the-Art and Future Prospects of Analogue Signal Processing -A Tutorial, Gabor C. Temes, Lawrence E. Larson and Kenneth W. Martin,
   IEEE International Symposium on Circuits and Systems, 1988

3) **Sigma delta converters**:

   a. Delta-Sigma Modulators: Modeling, Design and Applications,George I. Bourdopoulos et al., Imperial College Press, 2003

   b. Oversampling Delta-Sigma Data Converters; Theory, Design, and Simulation, James Candy and Gabor C. Temes, Wiley-IEEE Press 1991

   c. Understanding delta-sigma data converters, Richard Schreier and Gabor C. Temes, Wiley-IEEE Press, 2004

   d. Delta-Sigma Data Converters: Theory, Design, and Simulation, Steven R. Norsworthy, Richard Schreier and Gabor C. Temes, Wiley-IEEE Press, 1996

   e. Go on to http://scholar.google.com/ to search for a number of good online resources on sigma-delta converters. (Hint: start with "sigma delta converters" as your search words)