وَمَا أُوتِيتُم مِّنَ الْعِلْمِ إِلَّا قَلِيلًا

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Analog IC Design
Lab 08
Negative Feedback

Intended Learning Objectives

In this lab you will:

- Create a behavioral model for an OTA.
- Investigate negative feedback properties.
- Design a non-inverting amplifier using a 5T OTA.
- Learn how to simulate different views of the same cell.

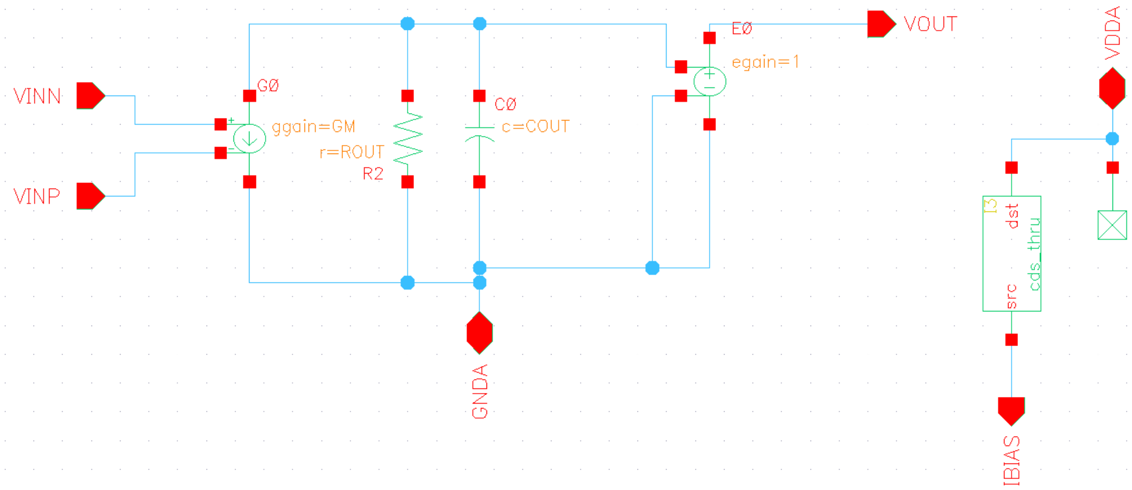
PART 1: Feedback with Behavioral OTA

Inside the 5T OTA cell we will create two schematic views. One is the transistor level schematic that you created in the previous lab, and the other is the behavioral schematic you will create in this lab.

➔ Cadence Hint: The hierarchy editor enables you to select which one you want to use for simulation as we will see later. This technique is very powerful, and is used extensively to simulate different views of the same cell (behavioral, schematic, post layout, etc.).

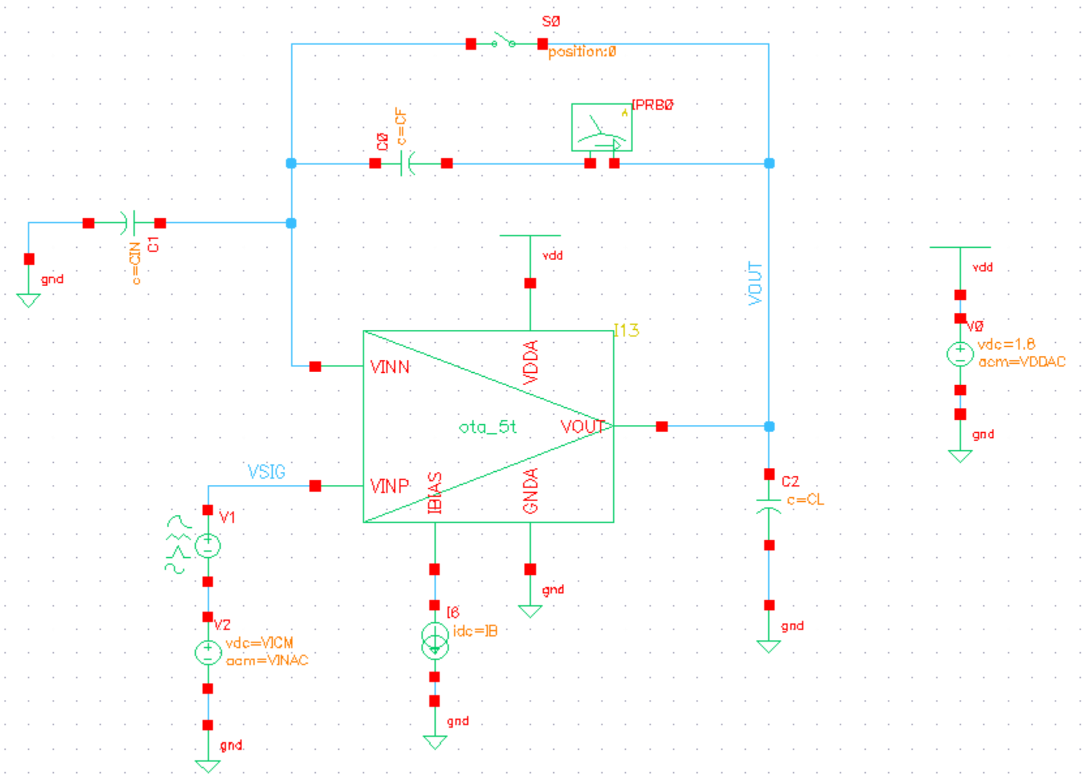
- In the project manager, create a new schematic **inside the same cell of the 5T OTA** that you designed in the previous lab.
- Choose “schematic” as the view type and “schematic_behav” as the view name .
- Create the behavioral model of an opamp as shown below. Use vccs and vcvs from analogLib.
- The behavioral model below consists of two stages: the first stage is an OTA with a single pole, and the second stage is an ideal buffer. The ideal buffer prevents any loading from the feedback network on the OTA.
- Note that we must add additional dummy pins (IBIAS and VDDA) to match the pins in the symbol and schematic views of the OTA (the two schematic views must be “pin-accurate”).

➔ Cadence Hint: Use “cds_thru” from “basic” library to connect ports/nets that have different names. It is simply a short-circuit (i.e., a jumper wire).



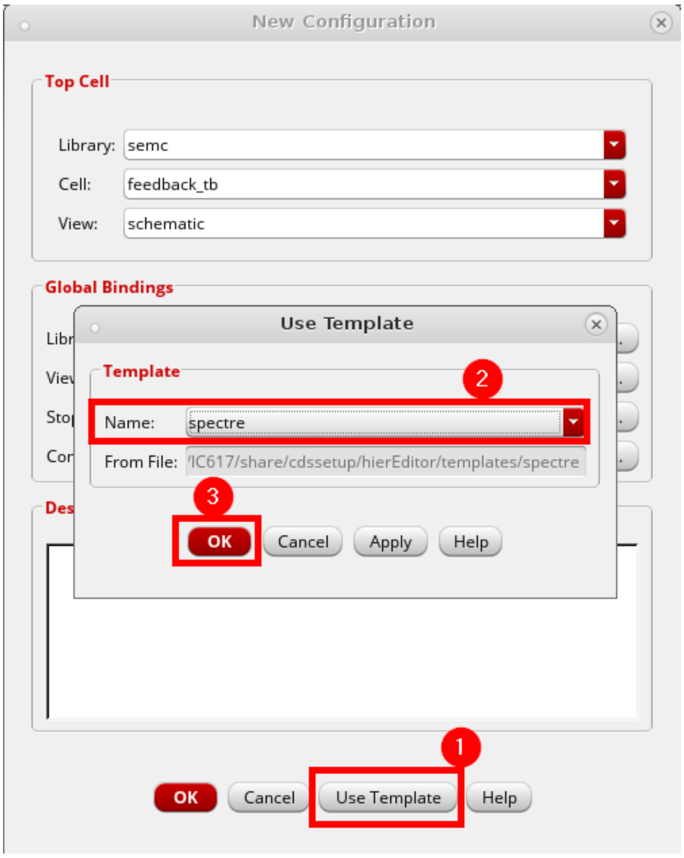
Create a new test bench as shown below.

- Note that the direction of the bias current source (source/sink) will depend on the type of your input pair.
- This test bench is a simple non-inverting amplifier. The ideal gain is $= 1 + C_{IN}/C_F$.
- Since we use capacitive feedback, we need to set the DC voltage at VINN, otherwise it will be floating. We do this by the switch S0. Set S0 to be closed in DC and IC. We may also do this by using a large feedback resistance.
- Do not create an adexl view now.

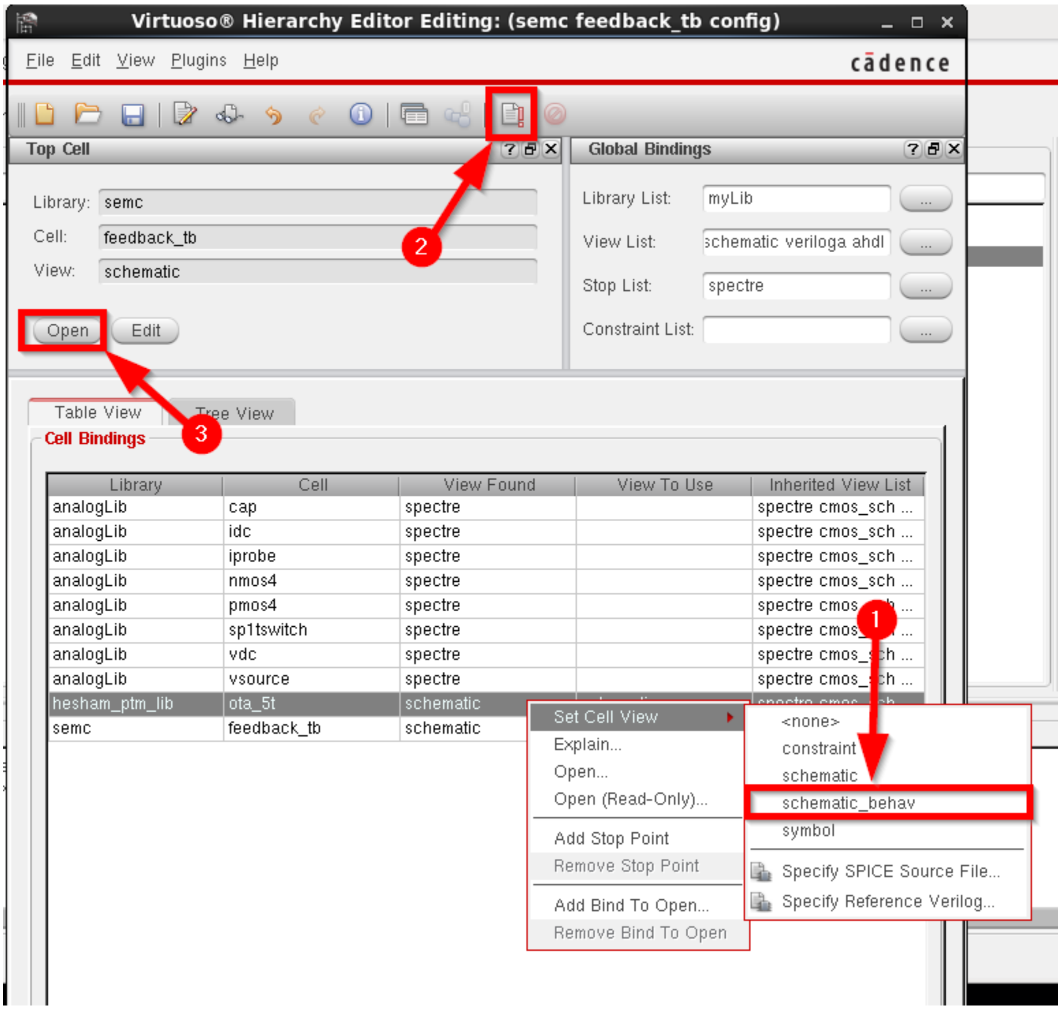


- Close the window of the test bench schematic. Create a new view for the same test bench cell you have just created. Choose “config” as the view type.

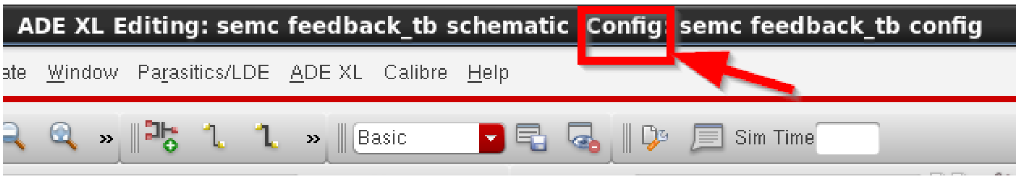
- The config view opens in “Hierarchy Editor”. Click “Use Template”. Choose “spectre” template from the dropdown list.



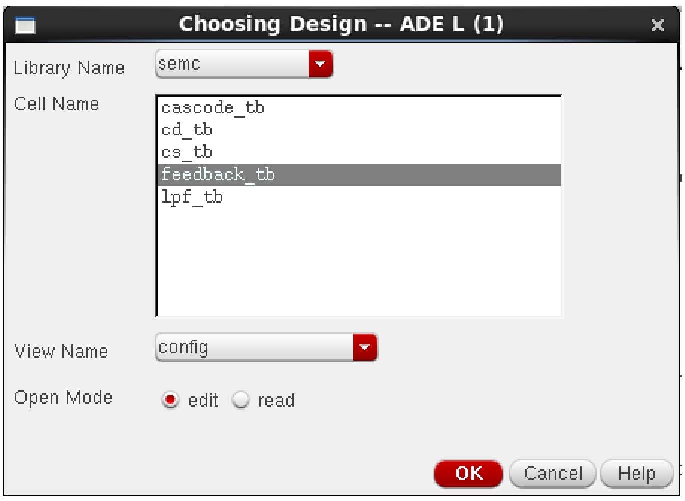
- The 5T OTA cell has two schematic views. One is the transistor level schematic in the previous lab, and the other is the behavioral schematic you created in this lab. The hierarchy editor enables you to select which one you want to use for simulation. This technique is very powerful, and is used extensively to simulate different views of the same cell (behavioral, schematic, post layout, etc.).
- From hierarchy editor, (1) choose the behavioral view of the 5T OTA, (2) update the heirarchy, and (3) open the schematic from inside the Hierarchy Editor as shown below.
- **Note that every time you open your design, you must open the config view first. Do NOT open the schematic view directly from adexl.**



- In the schematic view, make sure that the word "config" is shown in the title bar as shown below.



- Create a new adexl view. Make sure that the design to be simulated by adexl is the config view as shown below.



- Set the simulation parameters as below. Note that we set the DC gain and unity gain frequency (GBW) similar to those of the 5T OTA designed in the previous lab.

Description	Variable	Value
Feedback capacitance	CF	4p
Input capacitance	CIN	4p, 12p
Load capacitance	CL	as in Lab 07
Transconductance of behavioral model	GM	as in Lab 07
DC gain of behavioral model	Av	as in Lab 07
UGF of behavioral model	wu[1]	as in Lab 07
Output cap of behavioral model	COUT	GM/wu
Output res of behavioral model	ROUT	Av/GM
AC stimulus magnitude	VINAC	1
Transient stimulus peak	VP	50m
Transient stimulus frequency	FIN	1k
Bias current	IB	as in Lab 07
CM input voltage	VICM	At the middle of the CMIR

Report the following:

1) Closed loop gain vs frequency.
   - Run AC simulation (10Hz:10Gz, logarithmic, 10 points/decade).
   - Plot Vout in dB for the two values of CIN (4pF and 12pF). Indicate the DC gain, the bandwidth, and the unity gain frequency in the plot.

➔ Cadence Hint: Use the following expressions in adexl.

expr	ymax(dB20(VF("/VOUT")))
expr	ymax(mag(VF("/VOUT")))
expr	bandwidth(VF("/VOUT") 3 "low")
expr	gainBwProd(VF("/VOUT"))

   - Compare the DC gain, BW, and GBW with hand analysis in a table.
   - Comment on the difference between the results for the two values of CIN.

2) Loop gain vs frequency.
   - Run STB simulation (10Hz:10Gz, logarithmic, 10 points/decade). Note that you need to break the loop by a 0V dc voltage source at the OTA output.
   - Plot loop gain in dB for the two values of CIN. Annotate the DC loop gain, the dominant pole, and the unity gain frequency in the plot.

➔ Cadence Hint: Use the following expressions in adexl.

expr	unityGainFreq(mag(getData("loopGain" ?result "stb")))
expr	ymax(mag(getData("loopGain" ?result "stb")))
expr	ymax(dB20(getData("loopGain" ?result "stb")))

   - Compare DC LG and GBW with hand analysis in a table.
   - Comment on the differences between the results for the two values of CIN.

3) Gain Desensitization. Study the variation of closed loop gain with the variation of open loop gain. **This is the most important property of negative feedback.**
   - Set CIN = 4pF (no sweep, ideal gain of 2).

[1] Note that $\omega_u = 2\pi f_u = 2\pi \times GBW$.

- Set AC simulation to sweep design variable (Av = open loop gain of the behavioral OTA) = 50:50000, logarithmic, 10 points/decade. Set the AC simulation frequency at 10 Hz (single frequency point).
- Plot closed loop DC gain (magnitude at 10Hz, not dB) vs Av.
- Calculate the percent change in closed loop gain (magnitude, not dB). Note that open loop gain (Av) changes by three orders of magnitude (60 dB). Comment.

PART 2: Feedback with Real 5T OTA

Using the same procedure explained in Part 1, choose the transistor level schematic of the OTA (the 5T OTA that you designed in the previous lab).

Report the following:

1. Closed loop gain vs frequency.
   - Repeat what you did in Part 1 (Closed loop gain vs frequency).
   - Compare between the results you obtained here and the results in Part 1 in a table.
   - You will notice that the bandwidth, and consequently the GBW are much smaller than Part 1. Why? Comment.
2. Loop gain vs frequency.
   - Repeat what you did in Part 1 (Loop gain vs frequency).
   - Compare between the results you obtained here and the results in Part 1 in a table.
   - You will notice that the unity gain frequency is much smaller than Part 1. Why? Comment.
3. Gain Desensitization. Study the variation of closed loop gain and open loop gain with temperature. Note that if the feedback factor is constant, the change in the open loop gain is itself the change in the loop gain.
   - Set CIN = 4pF (no sweep, ideal gain of 2).
   - Sweep the temperature from the parameters window. Set temperature = -40:20:100.
   - Keep both AC and STB simulations enabled.
   - Compare the percent change in the DC loop gain (from STB) and the DC closed loop gain (from AC) across temperature extremes. Do NOT use dB when calculating percent change. Comment.
4. Transient analysis.
   - Set CIN = 4pF (no sweep, ideal gain of 2).
   - Set the transient source to sine wave with frequency FIN = 1kHz and amplitude VP = 50mV, where FIN and VP are two variables defined in the parameters window.
   - Run transient analysis. Set the simulation time to be {4/FIN} and the time step to be {0.01/FIN} (note that you must use the two braces). This will run for four complete periods, regardless of the input frequency.
   - Plot the input signal, the output signal, and the differential input signal of the OTA (VP – VN).
   - Calculate the peak-to-peak voltage of the previous three signals. What is the relation between the output and (VP – VN)? Comment.
     Hint: The relation between the output and the differential input is the open loop gain.
   - Repeat the transient analysis with FIN exactly equal to the closed loop bandwidth. Plot the input signal, the output signal, and the differential input signal of the OTA (VP – VN).
   - Calculate the peak-to-peak voltage of the previous three signals. What is the relation between the output and the input signal? What is the relation between the output and (VP – VN)? Compare between this case and the case of 1kHz input.
     Hint: The open-loop and closed-loop asymptotes coincide at this high frequency.

Lab Summary

- In Part 1 you learned:
  - How to simulate a different view for the same cell.
  - How to generate a behavioral model of a 5T OTA.
  - How to simulate a non-inverting amplifier with capacitive feedback using an ideal amplifier.
  - How the closed-loop gain of the non-inverting amplifier is insensitive to the open-loop gain of the 5T OTA because of the negative feedback effect.
- In Part 2 you learned:
  - How to simulate a non-inverting amplifier with capacitive feedback using a real amplifier.
  - How to compare the behavior of a non-inverting amplifier when using an ideal amplifier to a real one.
  - How the closed-loop and open-loop gains of a non-inverting amplifier change with frequency.

Acknowledgements

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