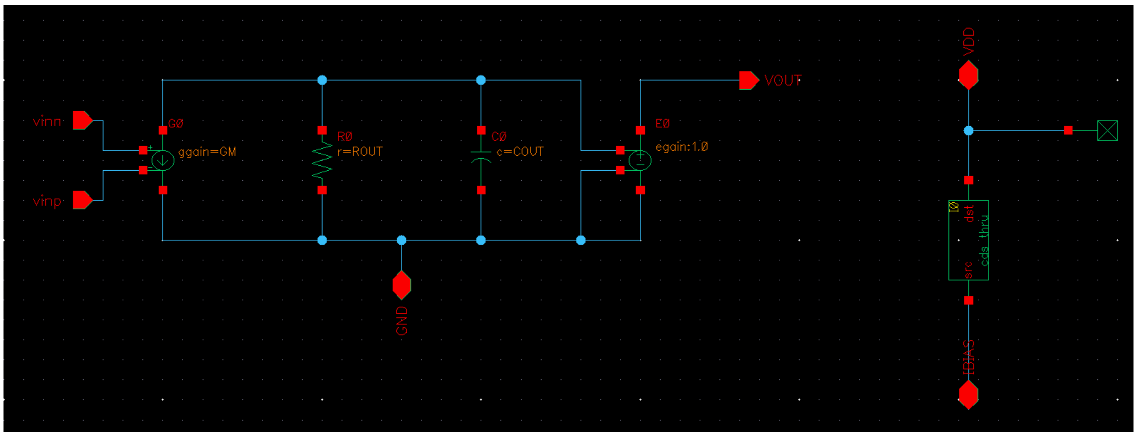
CMOS AIC design - ITI - lab 8

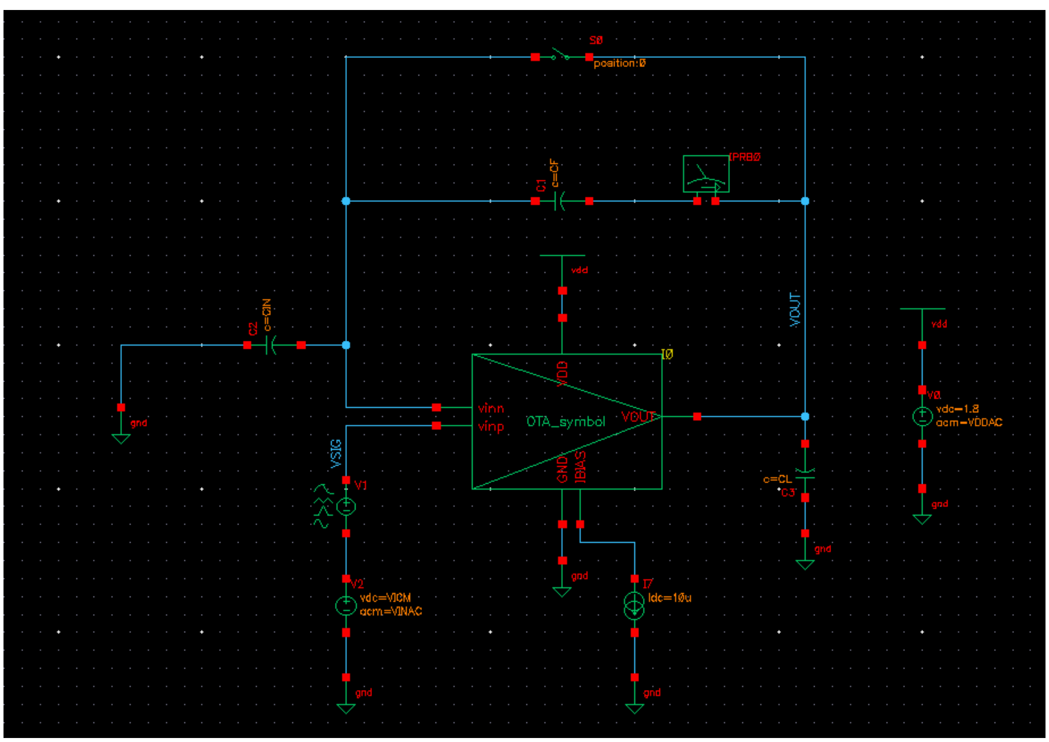
Part 1: Feedback With Behavioral OTA

- Create the behavioral model of an opamp as shown below.



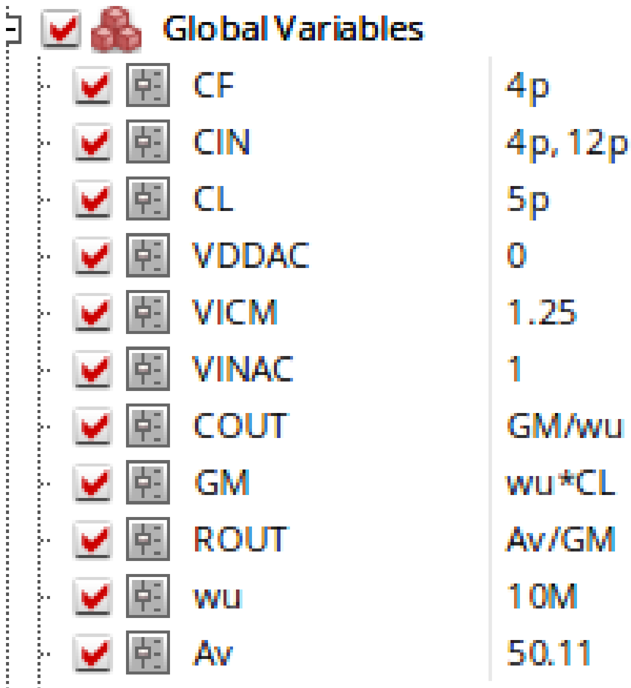
Required behavioral model

- Create a new testbench as shown below.



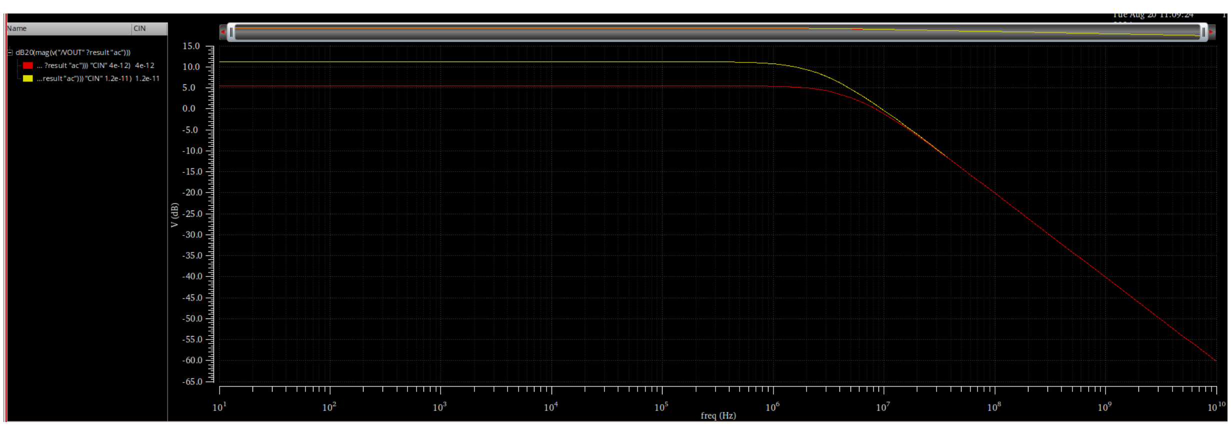
Required testbench

- Set the simulation parameters as below.



Required parameter setting

- Report the following:
  ➔ 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.



VOUT vs frequency @ CIN = 4p, 12p

Point	Test	Output	Nominal	Spec	Weight	Pass/Fail
Parameters: CIN=4p						
1	ITI_labs:OTA_tb:1	/VOUT				
1	ITI_labs:OTA_tb:1	Ao_dB	5.719			
1	ITI_labs:OTA_tb:1	Ao	1.932			
1	ITI_labs:OTA_tb:1	BW	5.171M			
1	ITI_labs:OTA_tb:1	UGF	10.01M			
Parameters: CIN=12p						
2	ITI_labs:OTA_tb:1	/VOUT				
2	ITI_labs:OTA_tb:1	Ao_dB	11.45			
2	ITI_labs:OTA_tb:1	Ao	3.736			
2	ITI_labs:OTA_tb:1	BW	2.677M			
2	ITI_labs:OTA_tb:1	UGF	10.02M			

Required calculations

☐ Compare the DC gain, BW, and GBW with hand analysis in a table.

$Quantity$	$Calculated$	$Simulated$
$DC\ gain$	$A_{v,4pF} = 1 + \frac{C_{in}}{C_f} = 2$ $A_{v,12pF} = 4$	$A_{v,4pF} = 1.932$ $A_{v,12pF} = 3.736$
BW	$BW_{4pF} = (1 + LG)\omega_{pOL}$ $= 5.2M$ $BW_{12pF} = 2.7M$	$BW_{4pF} = 5.171M$ $BW_{12pF} = 2.667M$
UGF	$UGF_{4pF} = \frac{G_m}{C_L} = 10M$ $UGF_{12pF} = 10M$	$UGF_{4pF} = 10.01M$ $UGF_{12pF} = 10.02M$

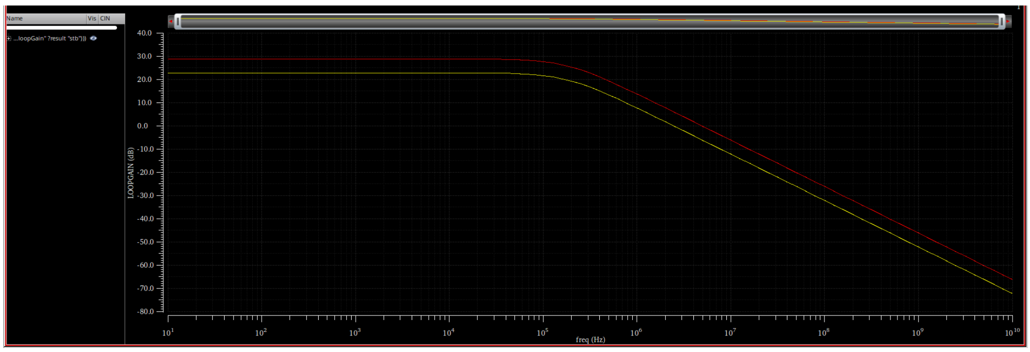
☐ Comment on the difference between the results for the two values of CIN.

- Changing C_{in} causes the CL gain to change, as indicated in the CL gain equation in the first row of the table.

➔ 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.



LG vs frequency

Point	Test	Output	Nominal	Spec	Weight	Pass/Fail
Parameters: CIN=4p						
1	ITI_labs:OTA_tb:1	UGF	4.998M			
1	ITI_labs:OTA_tb:1	LGo	28.26			
1	ITI_labs:OTA_tb:1	LGo_dB	29.02			
Parameters: CIN=12p						
2	ITI_labs:OTA_tb:1	UGF	2.496M			
2	ITI_labs:OTA_tb:1	LGo	14.13			
2	ITI_labs:OTA_tb:1	LGo_dB	23			

Required calculations

☐ Compare DC LG and GBW with hand analysis in a table.

$Quantity$	$Calculated$	$Simulated$
$DC\ LG$	$LG_{4pF} = \beta A_{OL} = 25$ $LG_{12pF} = 12.5$	$LG_{4pF} = 28.26$ $LG_{12pF} = 14.13$
GBW	$GBW_{4pF} = LG \times \omega_{pOL}$ $= 5M$	$GBW_{4pF} = 4.998M$

	$GBW_{12pF} = 2.5M$	$GBW_{12pF} = 2.496M$

☐ Comment on the differences between the results for the two values of CIN.

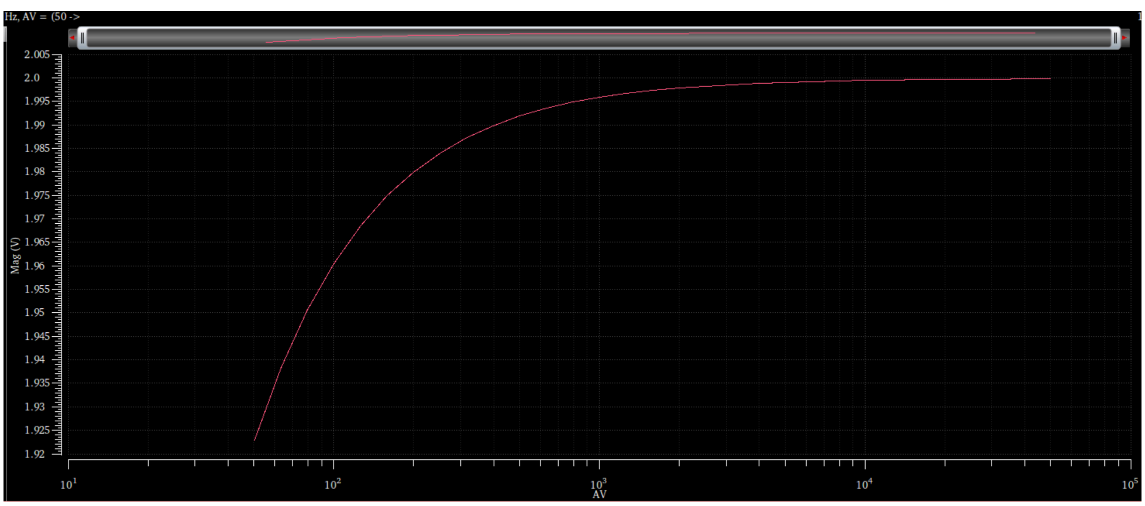
- Changing C_{in} from $4pF$ to $12pF$ halves β, thus quantities directly proportional to $C_{in} = 4pF$ is half of those related to $C_{in} = 12pF$.

➔ Gain Desensitization:

☐ Set CIN = 4pF (no sweep, ideal gain of 2).

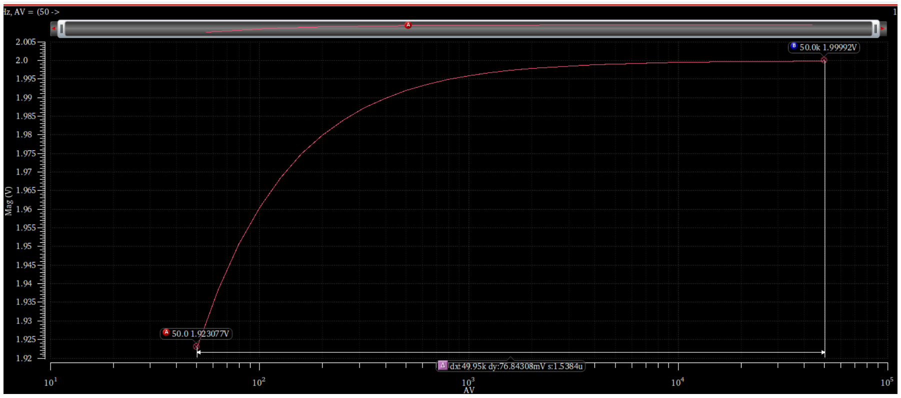
Set AC simulation to sweep design variable (Av = open loop gain of the behavioral OTA) = 50:50000, logarithmic, 10 points/decade. Set the AC simulation frequency at 10 Hz (single frequency point).

Plot closed loop DC gain (magnitude at 10Hz, not dB) vs Av.



DC CL gain 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.



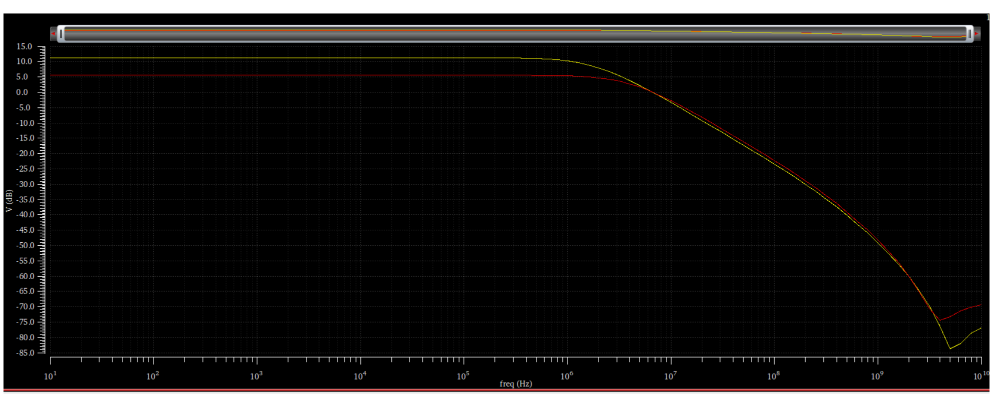
AB cursor added to the plot

$$\%\Delta A_{CL} = \frac{76.84m}{1.932} \times 100\% = 3.98\%$$

- The percent change in CL gain is very small, which is one of the goals of putting amplifiers in feedback loops and indicates a very robust amplifier design.

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:
    - ➔ Closed loop gain vs frequency.
    - ☐ Repeat what you did in Part 1 (Closed loop gain vs frequency).



VOUT vs frequency

Point	Test	Output	Nominal	Spec	Weight	Pass/Fail
Parameters: CIN=4p						
1	ITI_labs:OTA_tb:1	Ao_dB	5.746			
1	ITI_labs:OTA_tb:1	Ao	1.938			
1	ITI_labs:OTA_tb:1	BW	4.165M			
1	ITI_labs:OTA_tb:1	GBW	8.091M			
Parameters: CIN=12p						
2	ITI_labs:OTA_tb:1	Ao_dB	11.49			
2	ITI_labs:OTA_tb:1	Ao	3.754			
2	ITI_labs:OTA_tb:1	BW	1.878M			
2	ITI_labs:OTA_tb:1	GBW	7.067M			

Required calculations

☐ Compare between the results you obtained here and the results in Part 1 in a table.

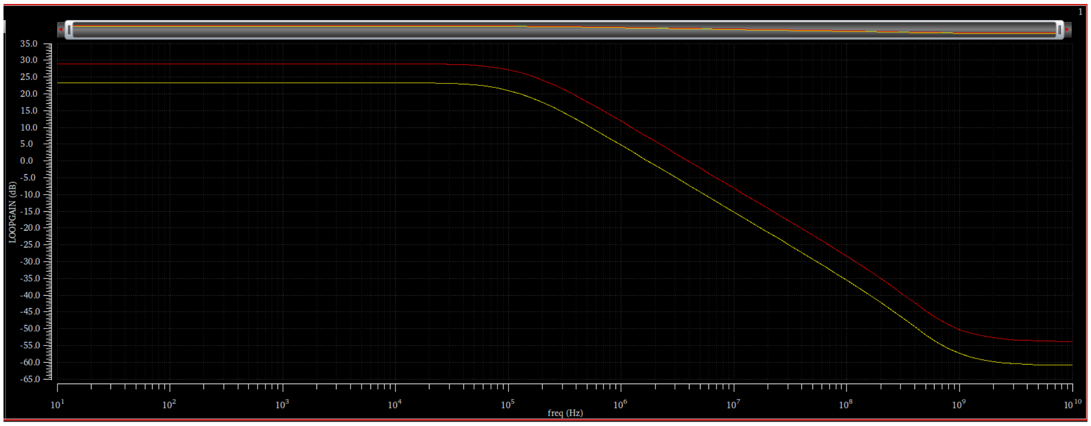
$Quantity$	$Part\ 1$	$Part\ 2$
$DC\ gain$	$A_{v,\ 4pF} = 5.719dB$ $A_{v,\ 12pF} = 11.45dB$	$A_{v,4pF} = 5.764dB$ $A_{v,12pF} = 11.49dB$
BW	$BW_{4pF} = 5.171M$ $BW_{12pF} = 2.677M$	$BW_{4pF} = 4.165M$ $BW_{12pF} = 1.878M$
GBW	$GBW_{4pF} = 10.01M$ $GBW_{12pF} = 10.02M$	$GBW_{4pF} = 8.091M$ $GBW_{12pF} = 7.067M$

☐ You will notice that the bandwidth, and consequently the GBW are much smaller than Part 1. Why? Comment.

- In part 1, there was a buffer present, preventing C_F (when decomposed using Miller theorem) from loading the o/p node. In part 2, it was not the case, there was not any sort of loading-block circuitry.

➔ Loop gain vs frequency.

☐ Repeat what you did in Part 1 (Loop gain vs frequency).



LG vs frequency

Point	Test	Output	Nominal	Spec	Weight	Pass/Fail
Parameters: CIN=4p						
1	ITI_labs:OTA_tb:1	UGF	3.992M			
1	ITI_labs:OTA_tb:1	LGo	28.71			
1	ITI_labs:OTA_tb:1	LGo_dB	29.16			
Parameters: CIN=12p						
2	ITI_labs:OTA_tb:1	UGF	1.774M			
2	ITI_labs:OTA_tb:1	LGo	15.06			
2	ITI_labs:OTA_tb:1	LGo_dB	23.56			

Required calculations

☐ Compare between the results you obtained here and the results in Part 1 in a table.

$Quantity$	$Part\ 1$	$Part\ 2$
$DC\ LG$	$LG_{4pF} = 29.02dB$ $LG_{12pF} = 23dB$	$LG_{4pF} = 29.16dB$ $LG_{12pF} = 23.56dB$
GBW	$GBW_{4pF} = 4.998M$ $GBW_{12pF} = 2.496M$	$GBW_{4pF} = 3.992M$ $GBW_{12pF} = 1.774M$

☐ You will notice that the unity gain frequency is much smaller than Part 1. Why? Comment.

- In part 1, there was a buffer present, preventing C_F (when decomposed using Miller theorem) from loading the o/p node. In part 2, this is not the case, there was not any sort of loading-block circuitry.

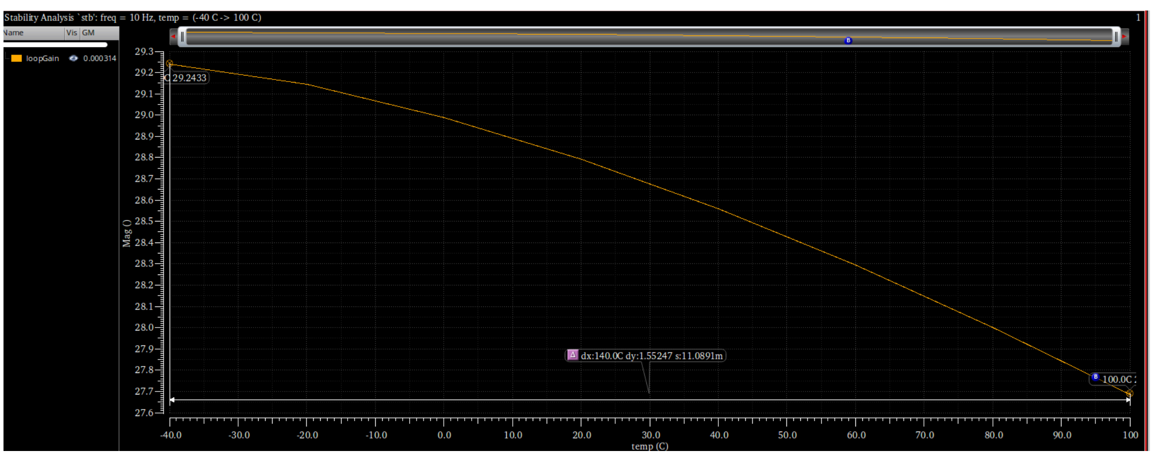
➔ Gain Desensitization.

☐ Set CIN = 4pF (no sweep, ideal gain of 2).

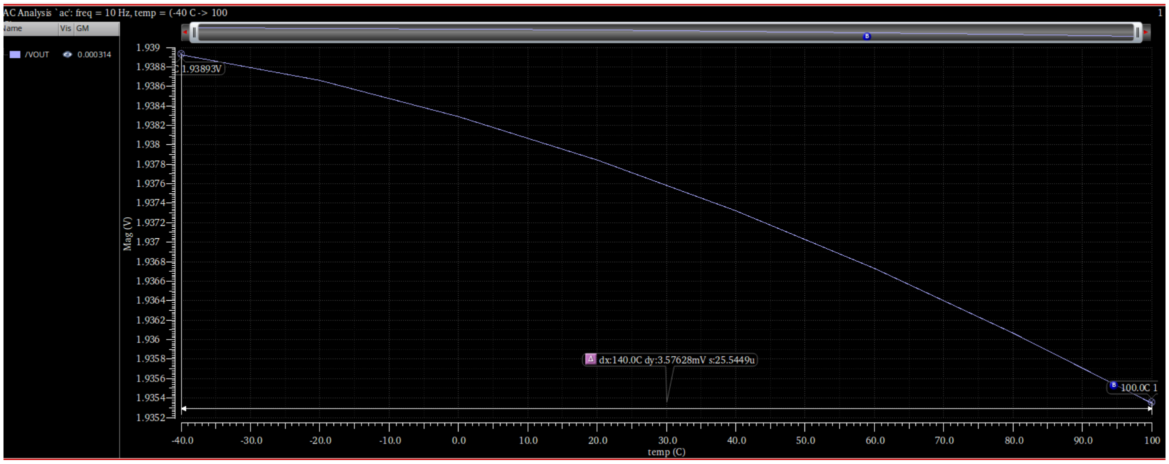
Sweep the temperature from the parameters window. Set temperature = -40:20:100.

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.



LG vs temp.



CL gain vs temp.

$$\%\Delta LG = \frac{1.55}{28.26} \times 100\% = 5.48\%$$

$$\%\Delta A_{CL} = \frac{3.58m}{1.932} \times 100\% = 0.19\%$$

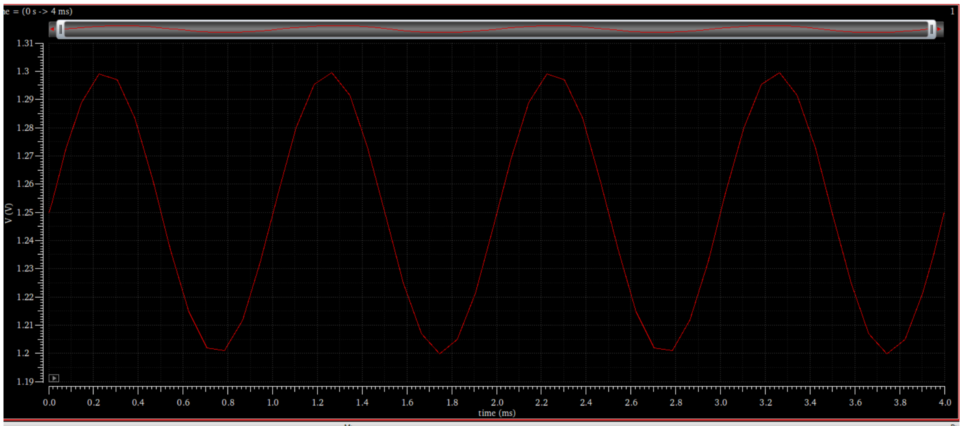
- The change CL gain relative to the large change in temperature is negligible. This number emphasizes the fact that electronic systems put in feedback loops are robust against PVT variations.

➔ Transient analysis.

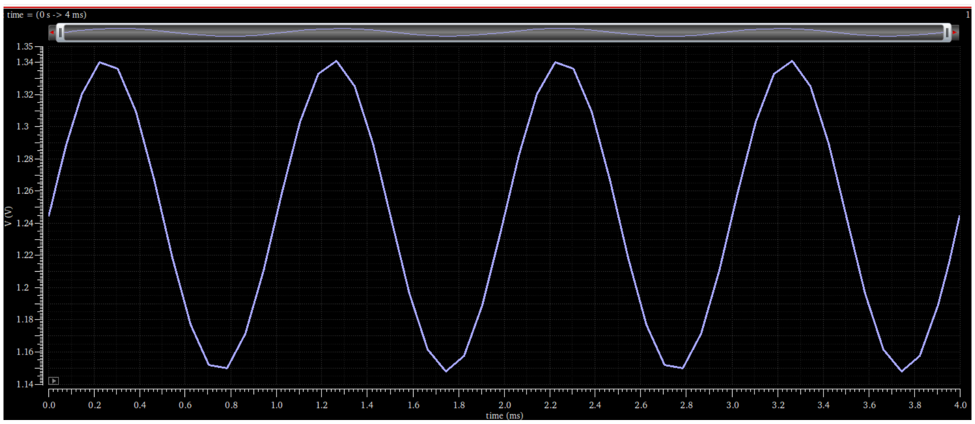
☐ Set CIN = 4pF (no sweep, ideal gain of 2).

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.

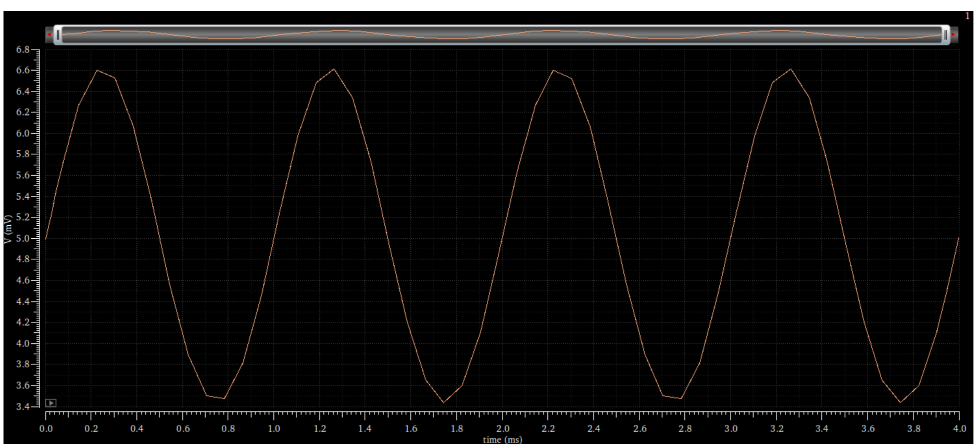
Run transient analysis. Set the simulation time to be {4/FIN} and the time step to be {0.01/FIN} (note that you must use the two braces). This will run for four complete periods, regardless of the input frequency.
Plot the input signal, the output signal, and the differential input signal of the OTA (VP – VN).



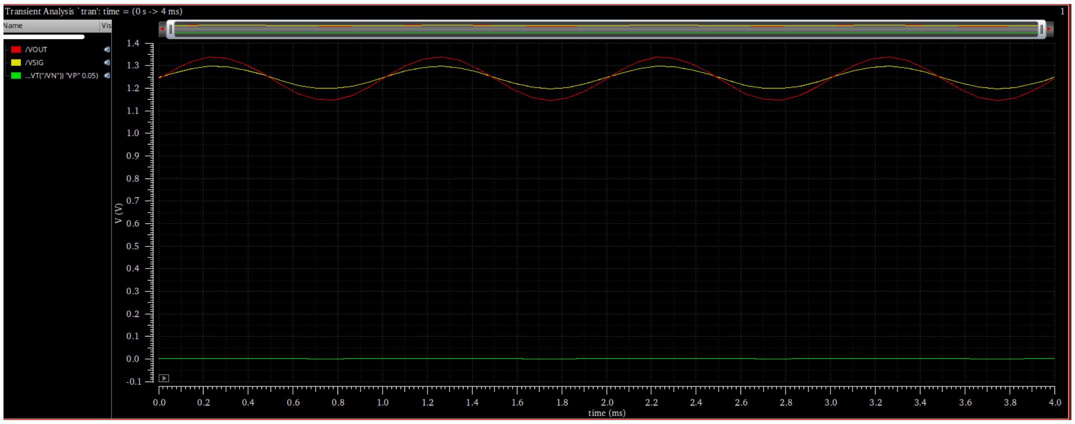
i/p signal



o/p signal



Diff i/p



All required signal appended on the same plot

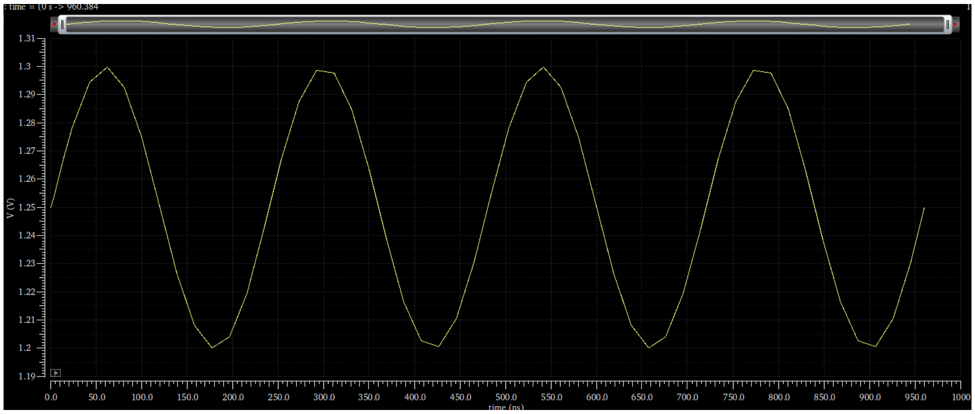
☐ Calculate the peak-to-peak voltage of the previous three signals. What is the relation between the output and (VP – VN)? Comment.

$Quantity$	$i/p\ signal$	$o/p\ signal$	$diff.\ i/p$
V_{P2P}	$99.78mV$	$193.3mV$	$3.177mV$

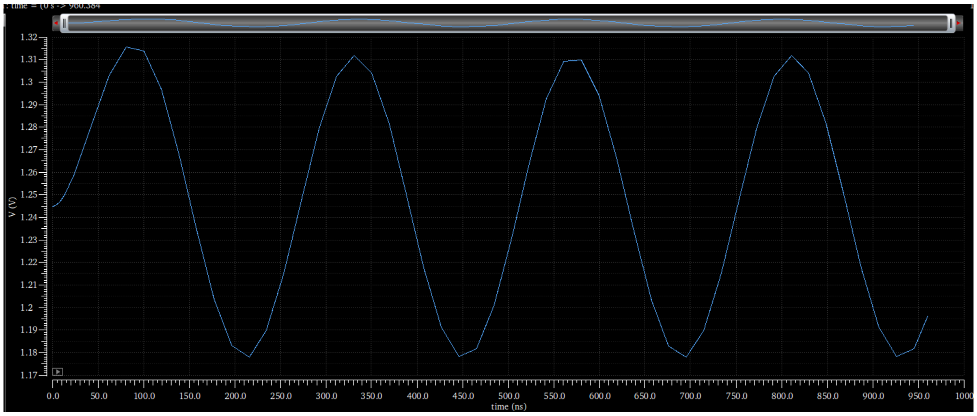
Values calculated in Cadence Calculator

- $o/p\ sig >> diff.\ i/p.$
- As the circuit is put in a feedback loop, the dif. i/p tends to be very small. It represents, from feedback control systems POV, the error signal, which any closed loop system tries to minimize as much as possible.

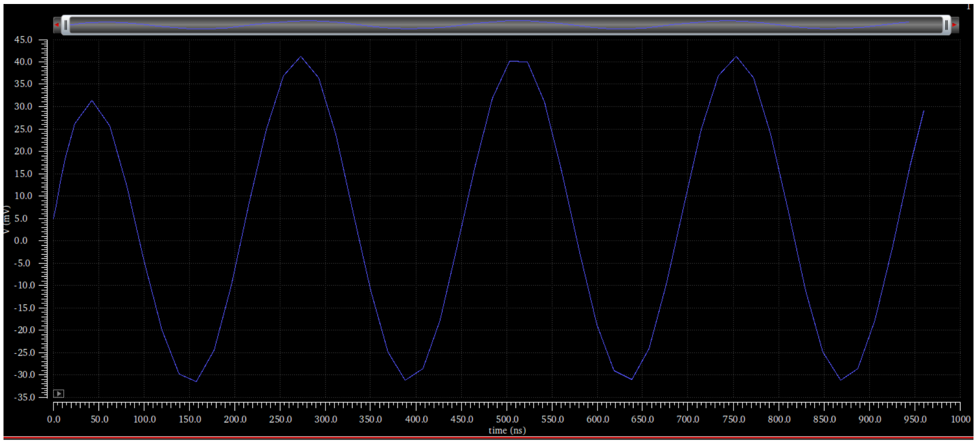
☐ Repeat the transient analysis with FIN exactly equal to the closed loop bandwidth. Plot the input signal, the output signal, and the differential input signal of the OTA (VP – VN).



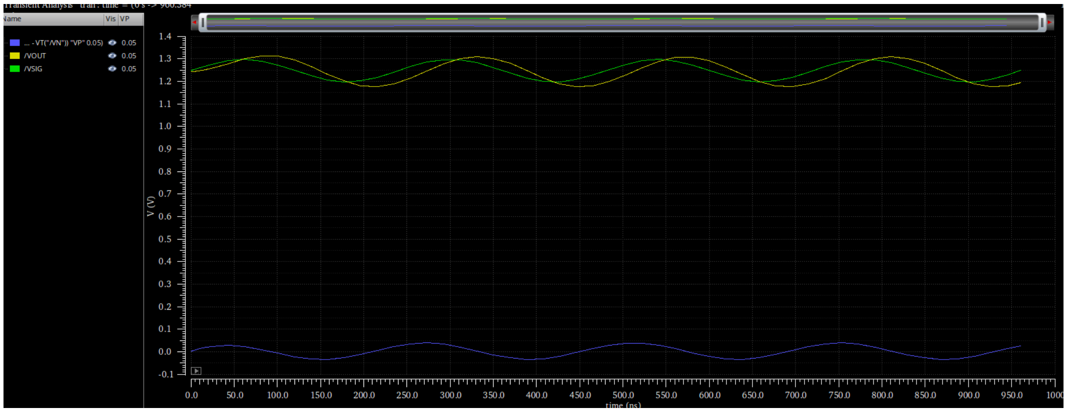
i/p signal



o/p signal



Diff. i/p



All required signal appended on the same plot

- [ ] 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.

$Quantity$	$i/p\ signal$	$o/p\ signal$	$diff.\ i/p$
V_{P2P}	$99.78mV$	$137.8mV$	$72.77mV$

Values calculated in Cadence Calculator

- $o/p\ sig\ >\ i/p\ sig.$
- $o/p\ sig\ >\ diff.\ i/p.$
- P2P voltage in this case is less than those of the 1kHz case.
- Operating at the dominant pole frequency means that 3dB are subtracted from the DC gain. When comparing the CL gain obtained from this analysis and that obtained from the previous one, in other words, $20\ Log(\frac{137.8}{193.3}) = -\ 2.93dB\ \approx -\ 3dB$. The same thing applies to the LG.