Problem S.6. Op-amp compensation

Figure 1 shows an op-amp in the 0.35u CMOS process (a simulation of which has also been addressed in problem S.8). A Miller compensation capacitor Cc is connected between the high-impedance nodes 1 and 2.

Note that the op-amp is connected as a closed-loop unity-gain amplifier, with input Vp and output V(out). An ideal ac voltage source Vz is inserted between the output and the (−) input (node inm) to allow finding the loop gain as $T = -v(out)/v(inm)$.

(a) Use a dc sweep with Vp from 0 to 3.3 V, to find the range of input voltages $V_{p\text{min}} < V_p < V_{p\text{max}}$ where the closed-loop unity-gain amplifier operates properly, i.e. where $V(out)=V_p$. Turn in the values for $V_{p\text{min}}$ and $V_{p\text{max}}$.

(b) Use parametric ac sweep simulations to find the cross-over frequency and the phase margin for $Cc = 0.01 \text{ pF}, 0.1 \text{ pF}, 1 \text{ pF}, \text{ and } 10 \text{ pF}$. You do not need to turn in plots of the loop gain magnitude and phase responses. Just turn in a table showing the phase margin as a function of $Cc$.

(c) Find the minimum compensation capacitance $Cc = C_{c\text{min}}$ required to ensure stability of the closed-loop unity-gain amplifier in Fig.1.

(d) Find Cc so that the phase margin is 60°. What is the cross-over frequency $f_c$ in this case? Use this Cc in all subsequent simulations.

(e) Use Cc found in part (d). Describe your simulation setups, and turn in the appropriate simulation plots and the results you obtained for the following op-amp characteristics:
   a. Gain-bandwidth product, GBW
   b. Slew-rate limitations $SR^+$ and $SR^-$

(f) Use Cc found in part (d). Plot the closed-loop magnitude response $A_{CL} = v(out)/v_p$, and turn in the values of the maximum peaking in the closed-loop magnitude response, and the closed-loop -3dB bandwidth $BW_{CL}$. Plot a step transient response for the pulse input shown in Fig. 1, and determine the percentage overshoot and undershoot in the output voltage. Compare your simulation results to the expectations based on the values of GBW, cross-over frequency and phase margin.