E6312: Problem Set 4

Miles Sherman

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1 Bullet Point 1

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2 Bullet Point 2

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To build the folded cascade OTA, I began by sizing transistors M0, M1, and M2 (see figure 1 for instance names). Because I want $160\mu A$ through transistor M9 and that transistor is sized with $W = 42\mu m$ and I want $320\mu A$ through transistor M2, I sized M2 at $84\mu A$. For the sake of convenience, I decided to use a $320\mu A$ current source so I sized transistors M0 and M1 at $84\mu A$ as well. In addition, because I will eventually put this circuit into feedback and I would like my output to be close to mid-rail, I set $V_{cm} = 800mV$ which is close to the ceiling of input voltage. This is an acceptable value because the small signal input will never be above 1V.

To bias V_{b1}, V_{b2}, and V_{b3} I utilized two branches of self-biasing current mirrors (see Figure 1). The first branch, which consists of one PMOS and four NMOS transistors, serves a number of purposes. The PFET (M21) mirrors current from M0 and cuts it in half (sized $42\mu A$). The four NMOS receive the $160\mu A$ of current and are sized as follows. M28 will have half the current of M14 and its gate voltage will bias V_{b1} so it must be half the width of M14, $10.5\mu m$. M29 will have the same current as M13 and its gate voltage will bias V_{b2} so it must be the same width as M13, $10.5\mu A$. M27 will also take the same width as M29 and M28. M20 will take one third of that width. Using a very similar methodology, I built the second self-biasing current mirror branch but this time mirroring the current with an NMOS and receiving the current with four PMOS transistors. M31 mirrors the current of $160\mu A$ so it is sized the same as M28. M44, M45, and M40 will all have the same current as M10 and the gate of M45 will bias V_{b3} so they are all sized the same as M10 at $42\mu A$. M4 is sized one third of that. As can be seen in Figure 2, the biasing is successful.

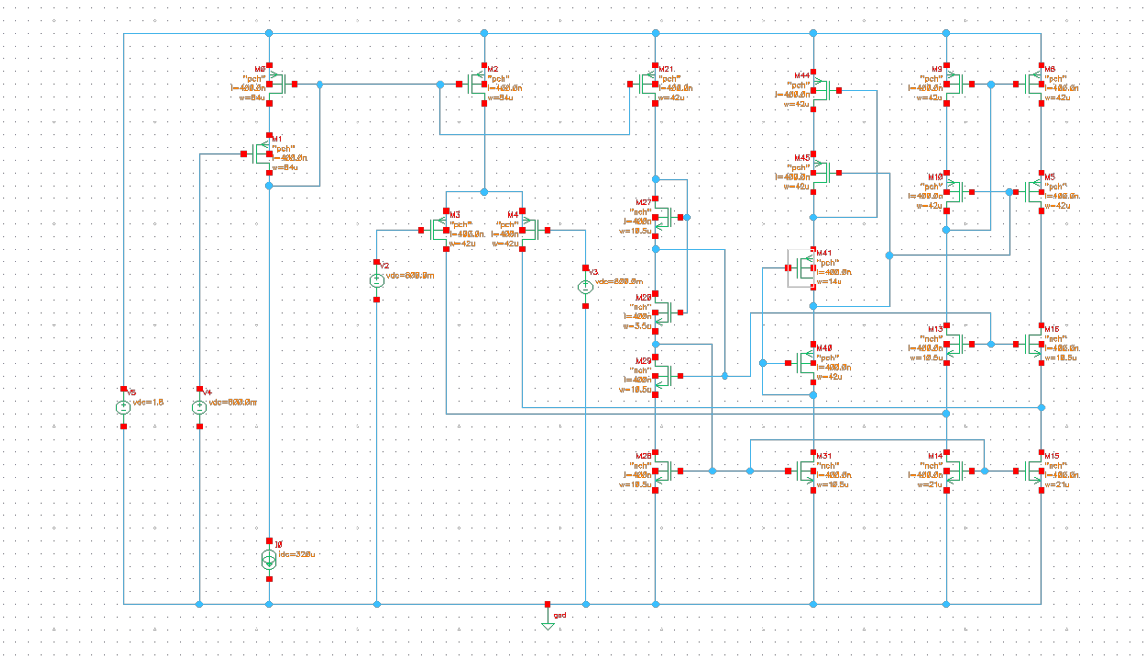

Figure 1: Schematic Diagram for the Folded Cascode OTA with Associated Biasing Circuitry

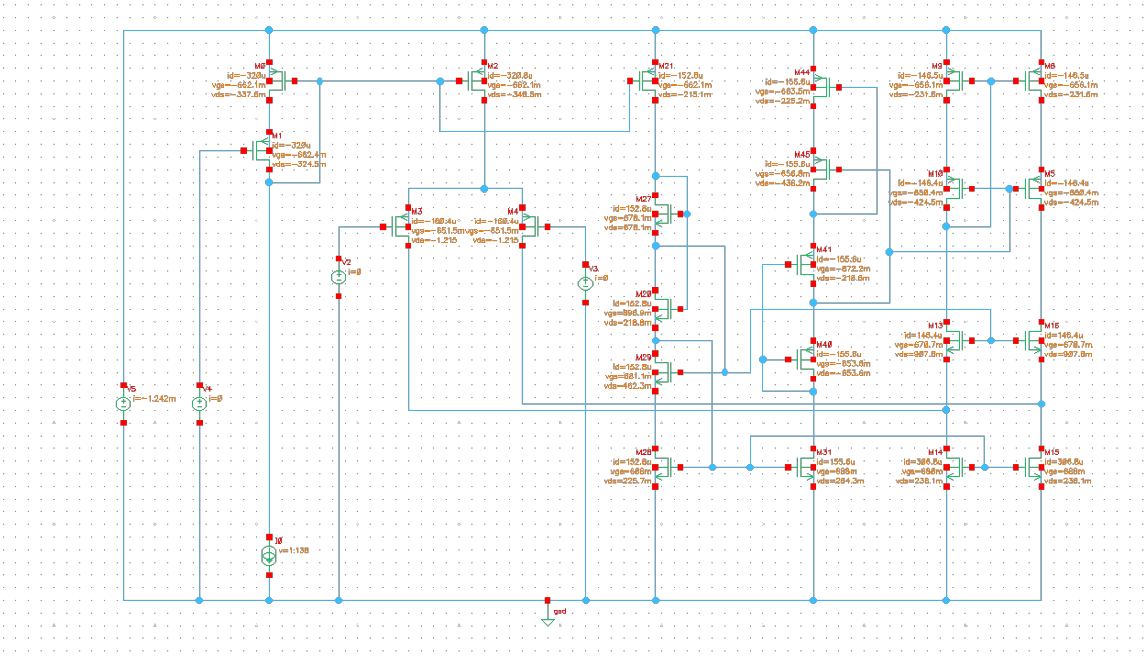

Figure 2: Schematic Diagram for the Folded Cascode OTA with Annotated DC Operating Point Values

3 Bullet Point 3

I performed a DC sweep of V_{out-OL} against V_{in-OTA} with the OTA in stand alone and the expected transfer function for a differential amplifier is attained (see Figure 3).

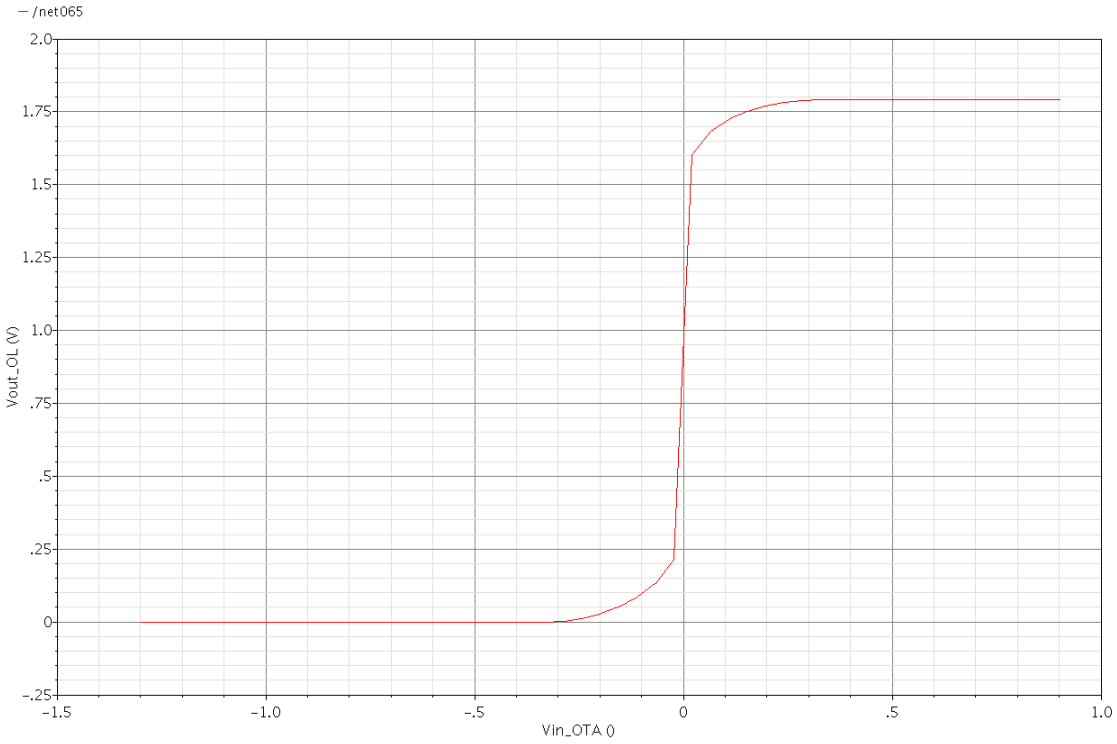

Figure 3: Voltage Transfer Characteristic for the Folded Cascode OTA in Stand Alone

4 Bullet Point 4

I applied a small-signal differential input as well as some DC feedback circuitry in order to simulate the open loop gain. Because the open loop gain does not consider small signal feedback, I wanted to build a circuit that would block all AC feedback. However, I wanted to use this feedback to bias V_{cm}. To do this I implemented an RC lowpass filter with a negligible cutoff voltage as can be seen in Figure 4. I performed an AC simulation of the open loop gain of the circuit (see Figure 5) and was able to attain $A(s) = 485.40\frac{V}{V} = 53.39dB$. Please note that since transistor M44 does not directly affect the biasing, I was able to reduce its size to $16\mu A$ and optimize my gain.

From the phase plot of my optimized open loop circuit (Figure **??**), I estimate that there are poles at $227kHz$ and $471MHz$ and a zero at 945MHz. I estimate the gain-bandwidth product (taken at -3dB from the maximum gain) to be $72.2MHz$.

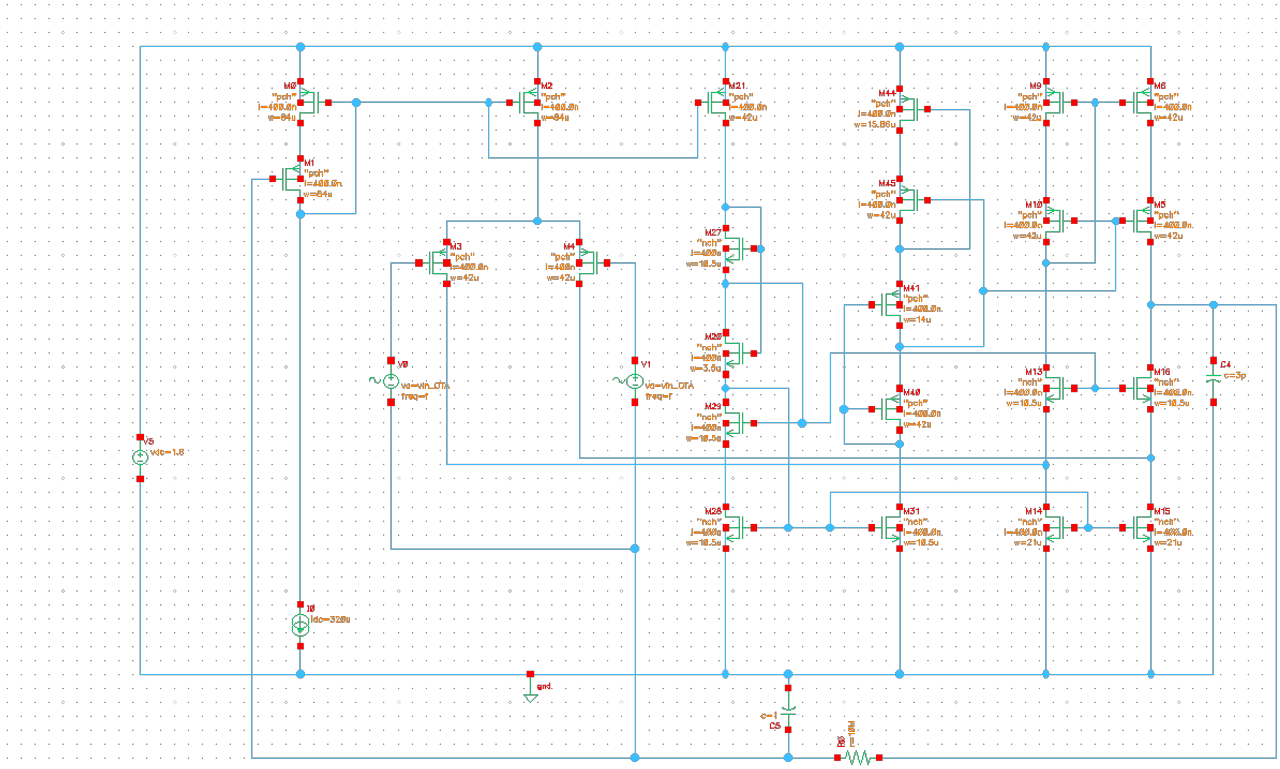

Figure 4: Schematic Diagram for the Folded Cascode OTA for Open Loop Gain Simulation

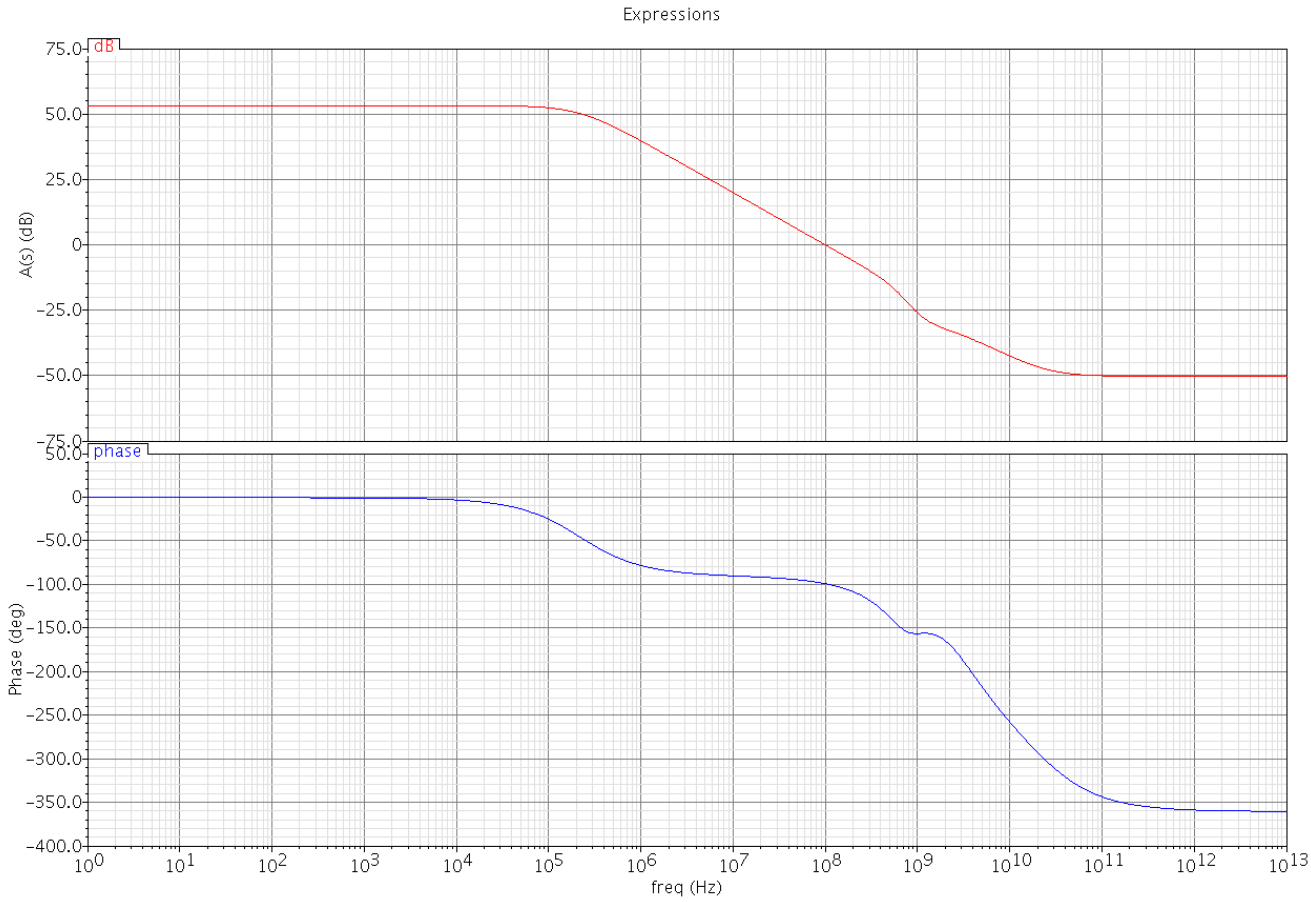

Figure 5: Bode Plot of the Open Loop Gain of the OTA

5 Bullet Point 5

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6 Bullet Point 6

I placed my OTA in AC feedback as shown in Figure 6 with $V_{cm} = 0.8V$. As can be seen, there is a significant reduction in gain which is expected and my bandwidth is increased (see Figure 7). The closed loop gain of $2.26V/V = 7.08dB$ can be used along with the below equation to find the feedback factor of $\beta = 0.44A/V$.

$$A_{closed-loop} = \frac{A_{open-loop}}{1 + \beta A_{open-loop}} \tag{1}$$

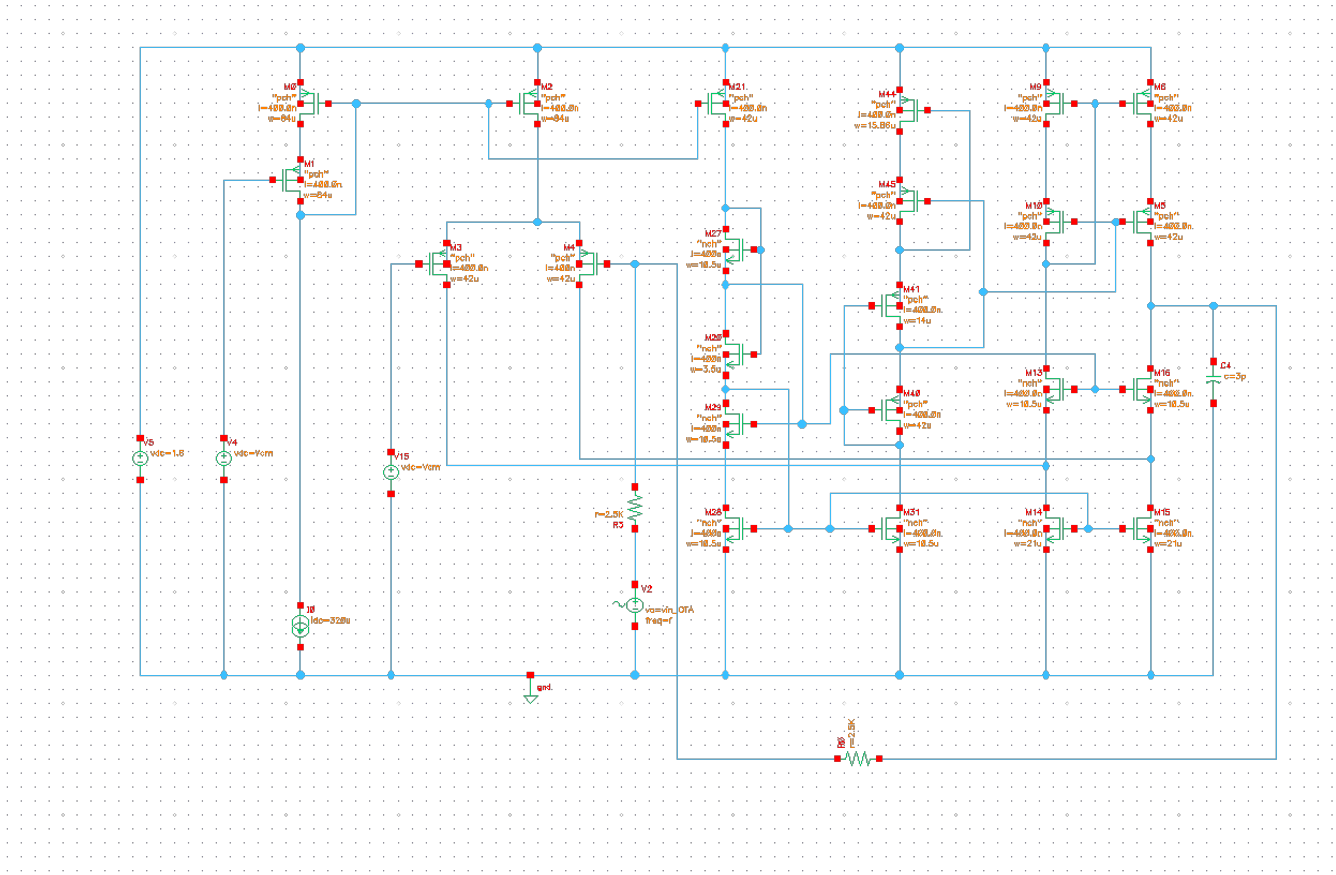

Figure 6: Schematic Diagram for the Folded Cascode OTA for Closed Loop Gain Simulation

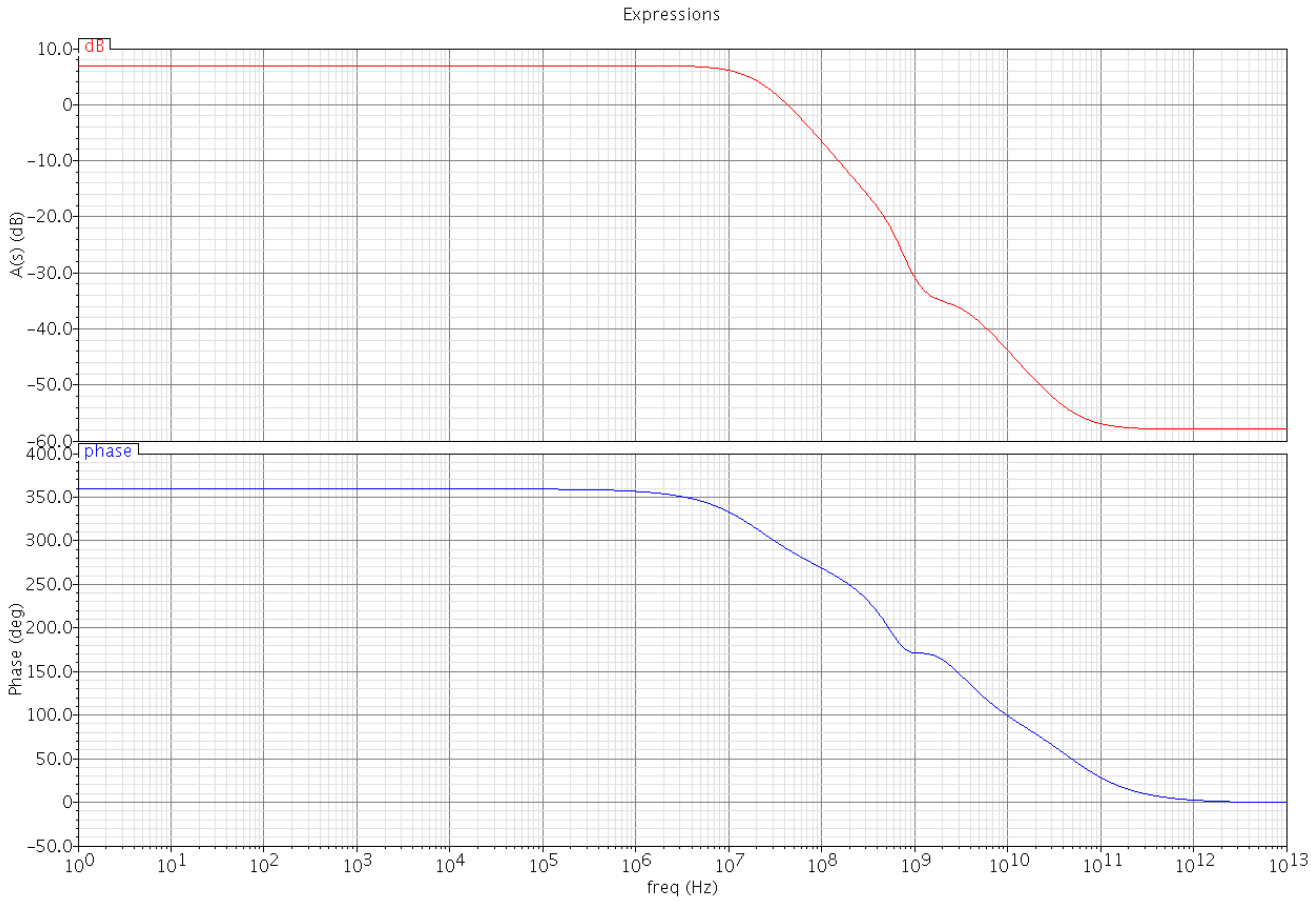

Figure 7: Bode Plot of the Closed Loop Gain of the OTA

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