Lab 4: Operational Amplifier

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Preparation

2) Find the numerical values for A_d, A_c, CMRR, and f_{3dB} for I_B=1mA and C_L=1nF. Show hand calculations.

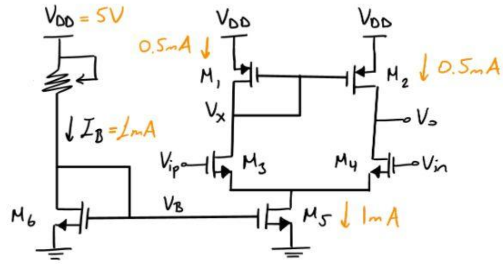
A_d = -65.1 V/V = 36.3 dB

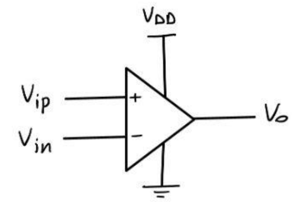
A_c = 4.31 mV/V = -47.3 dB

CMRR = A_d/A_c = 15103 V/V = 83.6 dB

f_{3dB}= 5.183 kHz

(See the hand calculations below.)





$$g_m = \sqrt{2\mu_n C_{ox}\left(\frac{W}{L}\right) I_{DS}}$$

NMOS $\mu_n C_{ox}\left(\frac{W}{L}\right) = 4.49\ mA/V^2$ $\quad g_{m4} = \sqrt{2\cdot(4.49\cdot 10^{-3})\,0.5\cdot 10^{-3}} = 0.00212 = 2.12\ mA/V$

PMOS $\mu_p C_{ox}\frac{W}{L} = -2.10\ mA/V^2$ $\quad g_{m2} = \sqrt{2\cdot(-2.10\cdot10^{-3})\cdot(-0.5)\cdot 10^{-3}} = 0.00145 = 1.45\ mA/V$

$$r_o = \frac{|V_A|}{I_{DS}} \qquad |V_A|_{NMOS} = 80\ V \qquad |V_A|_{PMOS} = 19\ V$$

$$r_{o2} = \frac{19\ V}{0.5mA} = 38\ k\Omega \qquad r_{o4} = \frac{80\ V}{0.5mA} = 160\ k\Omega \qquad r_{o5} = \frac{80V}{1mA} = 80\ k\Omega$$

$$A_d = -g_{m4}\left(r_{o4} \parallel r_{o2}\right) = -2.12\cdot 10^{-3}\left(160\cdot 10^3 \parallel 38\cdot 10^3\right) = -65.1\ V/V = \boxed{36.3\ dB}$$

$$A_c = -g_{m4} r_{o4} \frac{\frac{1}{g_{m2}}}{2g_{m4} r_{o4} r_{o5} + \frac{1}{g_{m2}}} \approx -\frac{1}{2g_{m2} r_{o5}}$$

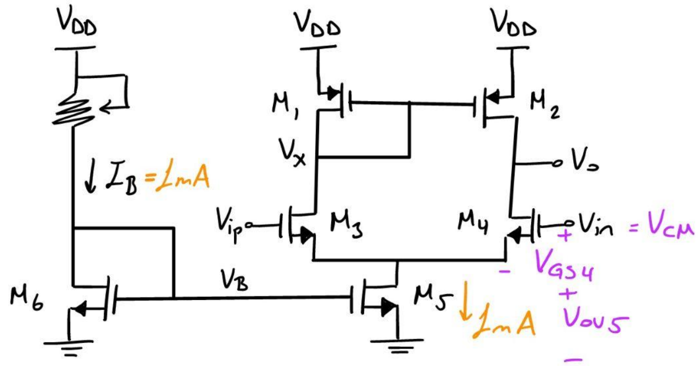
$$\approx -\frac{1}{2\cdot(1.45mA)80k\Omega} = 4.31\cdot 10^{-3}\ V/V = \boxed{-47.3\ dB}$$

$$\frac{A_d}{A_c} = 2g_{m2}g_{m4} r_{o5}\left(r_{o4} \parallel r_{o2}\right) = 2\left(1.45m\right)\left(2.12m\right)\cdot 80k\cdot\left(160k \parallel 38k\right) = 15103\ V/V = \boxed{83.6\ dB}$$

$$f_{3dB} = \frac{1}{2\pi(r_{o4}\parallel r_{o2})C_L} = \frac{1}{2\pi\left(160k \parallel 38k\right)1nF} = 5183\ Hz = \boxed{5.18\ kHz}$$

3) Find the input common-mode voltage that maximizes the output swing. Show hand calculations.

V_{CM} = 1.85 V



$$V_{CM} = V_{ov5} + V_{GS4}$$

$$V_{ov5} = \sqrt{\frac{2 I_{DS}}{\mu_n C_{ox} \left(\frac{W}{L}\right)}} = \sqrt{\frac{2 \cdot 1mA}{4.49 mA/V^2}} = 0.667\ V = 667 mV$$

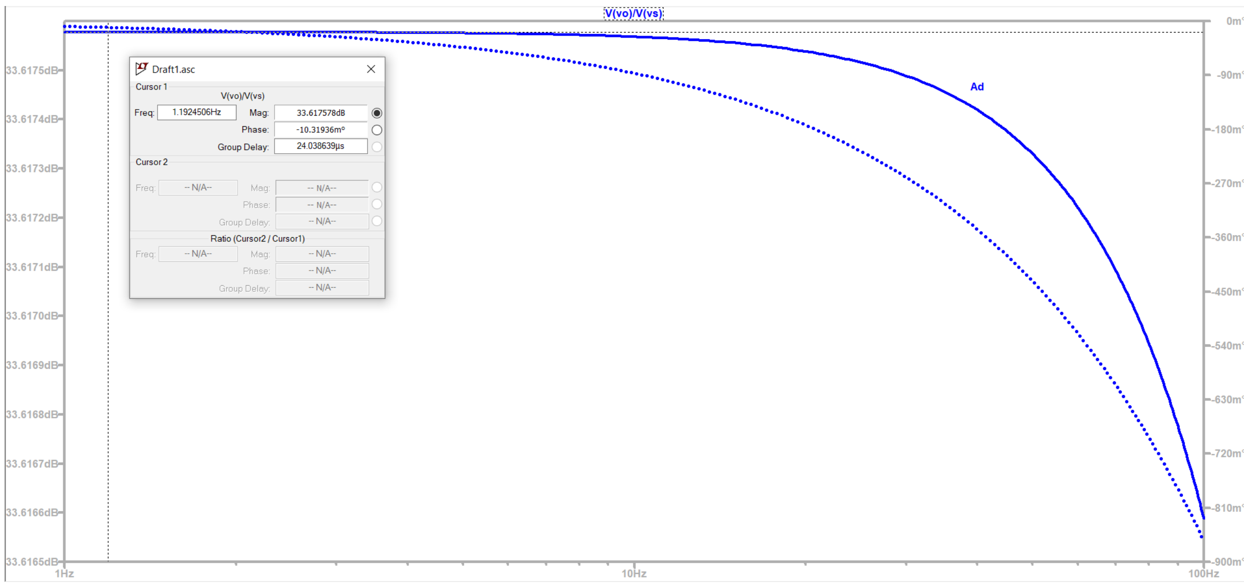
$$V_{GS4} = V_{ov_4} - V_{T_{NMOS}}$$

$$V_{ov_4} = \sqrt{\frac{2 \cdot 0.5 mA}{4.49 mA/V^2}} = 0.472\ V = 472 mV \qquad V_{T_{NMOS}} = 0.71\ V$$

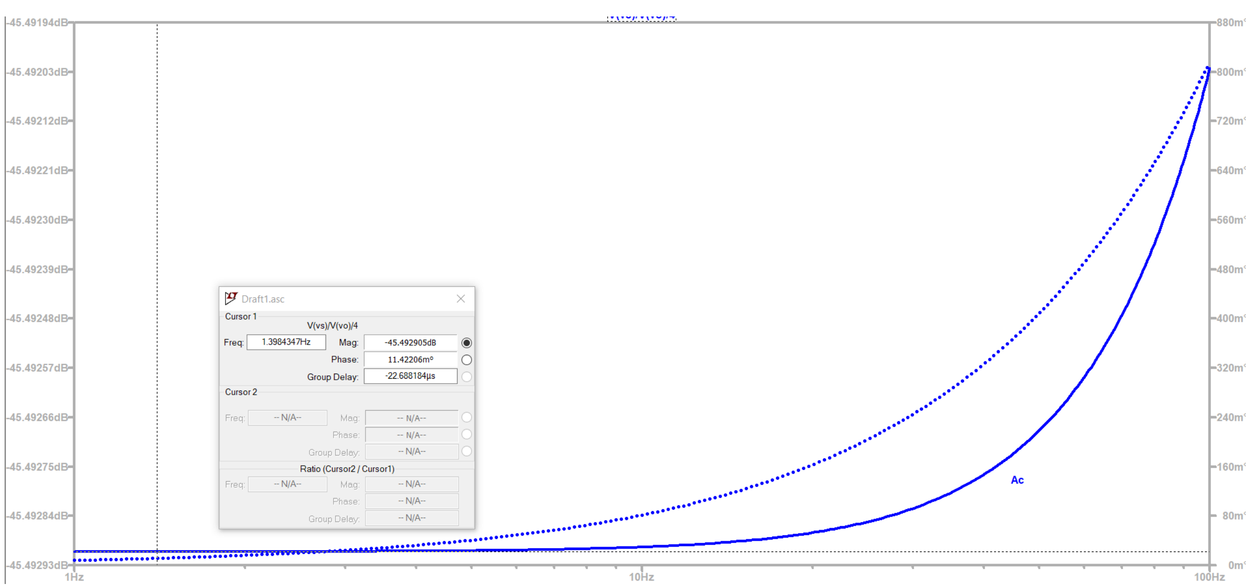
$$V_{GS_4} = 0.472\ V + 0.71\ V = 1.182\ V$$

$$V_{CM} = 667 mV + 1.182\ V = 1.849\ V \simeq \boxed{1.85\ V}$$

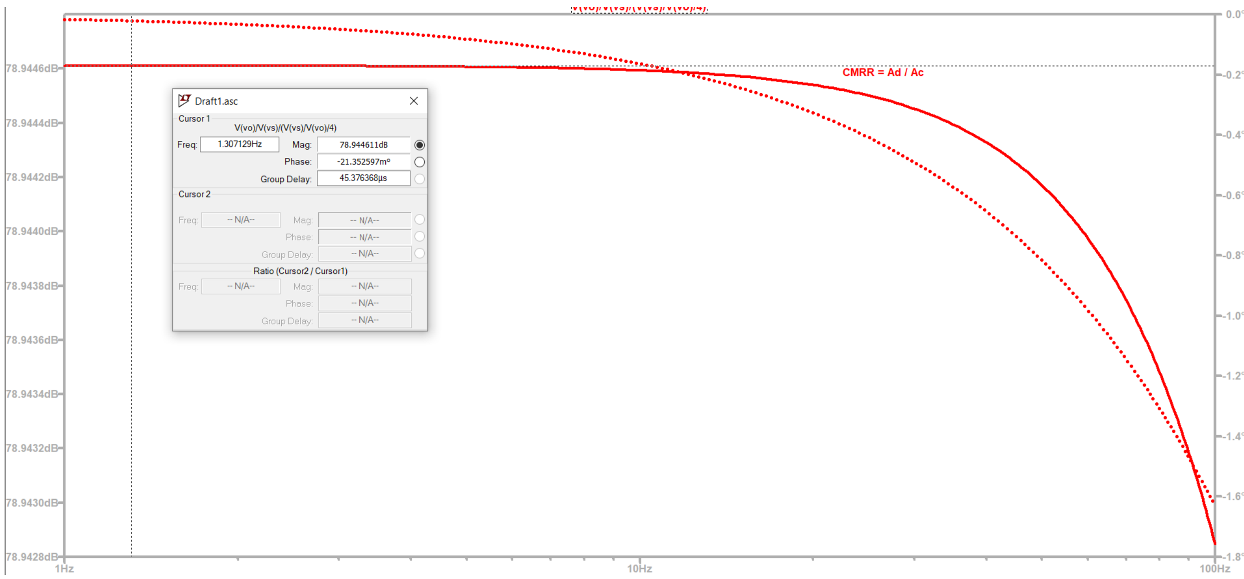
5) Run AC simulations to show Ad, Ac and CMRR at low frequencies. Also run a DC simulation to show the output swing with a differential input with the common-mode voltage found in 3. Label and comment on the plots to clearly show the results.



Ad = 33.6 dB

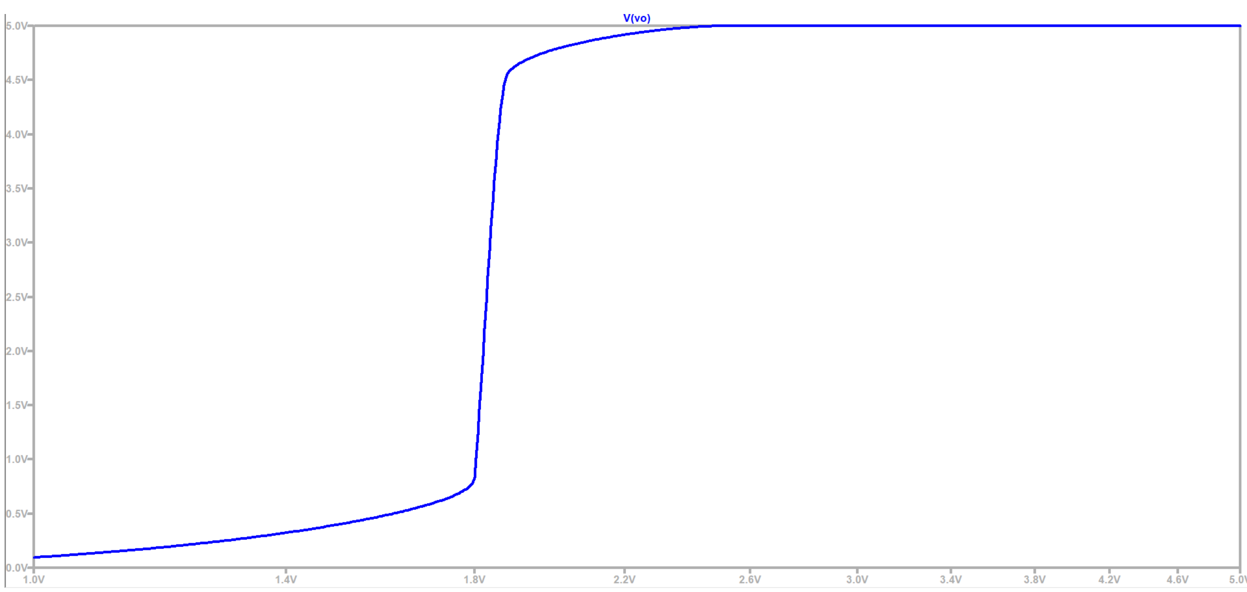


Ac = -44.5 dB



CMRR: 78.9 dB

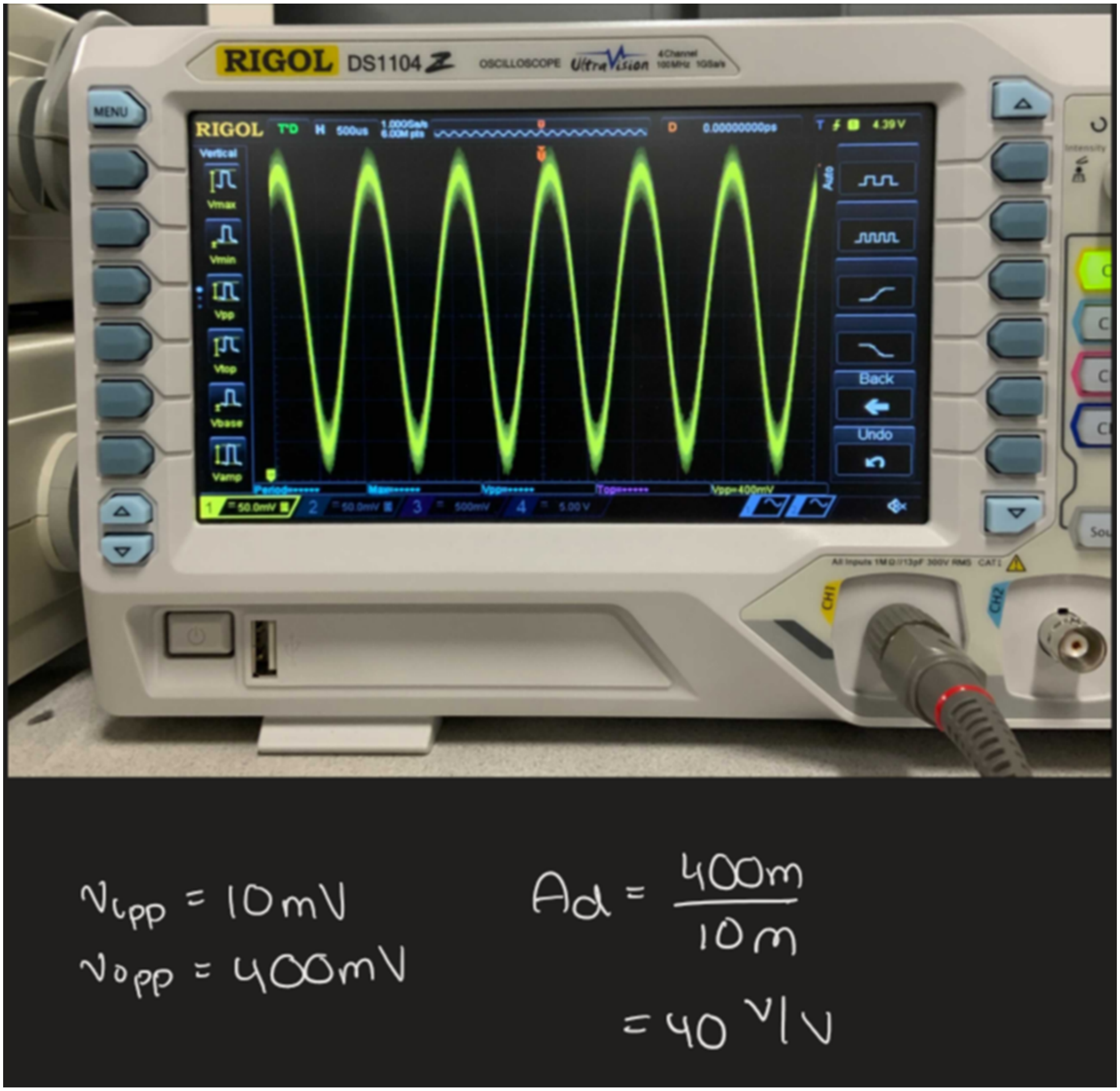
Output swing with a differential input with Acm = 1.85dB



Lab

2. Experiment

4) Connect one of the opamp inputs to a signal generator via a large capacitor as shown in Figure 3(b) and find the differential gain (A_d) of the opamp.



Final answer: 40 V/V = 32 dB

Final answer: 40V/V – less than theoretical value due to losses in the cct (wire resistance, potentiometer, leads for the input/output signals)