2 stage CMOS op-amp design

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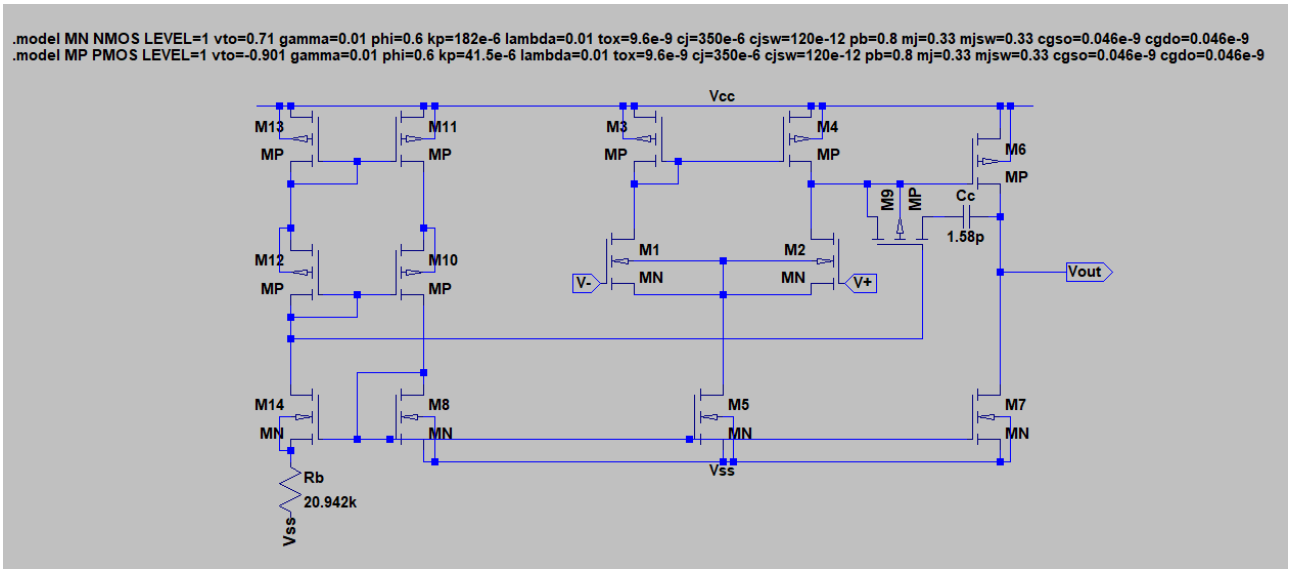
1. Schematic and Specifications



		W[µm]	L[µm]	S
	M1	1.71	1	1.71
V_{DD}/V_{SS} $2.5/-2.5V$	M2	1.71	1	1.71
Slew Rate $+5/-5\ {}^{V}/_{\mu s}$	M3	2.115	1	2.11
Load Capacitor $C_L = 5pF$	M4	2.115	1	2.11
max V_{in} *common mode* $= 2.1V$	M5	0.79	1	0.79
min V_{in} *common mode* $= -1.3V$	M6	84.32	4.786	17.6
max $V_{out} = 2.2V$	M7	3.3	1	3.3
min $V_{out} = -2.2V$	M8	0.79	1	0.79
Gain Bandwidth $=$ 5MHz	M9	4.23	1	4.23
Differential Gain $>$ 80dB	M10	4.23	1	4.23
Phase Margin $>$ 60°	M11	4.23	1	4.23
$\sqrt{S_n(f)} < 28\ {}^{nV}/_{\sqrt{Hz}}$	M12	4.23	1	4.23
	M13	4.23	1	4.23
	M14	3.17	1	3.17

2. Design procedure

Derivation of technological parameters:

$$C_{ox} = \frac{\varepsilon_0 \cdot \varepsilon_r}{t_{ox}} = \frac{8.85 \cdot 10^{-12} \cdot 3.9}{9.6 \cdot 10^{-9}} = 3.6 \cdot 10^{-3} \frac{F}{m^2}$$

$$\mu_n = \frac{KP_n}{C_{ox}} = \frac{182 \cdot 10^{-6}}{3.6 \cdot 10^{-3}} = 50.5 \cdot 10^{-3} \qquad \mu_p = \frac{KP_p}{C_{ox}} = \frac{41.5 \cdot 10^{-6}}{3.6 \cdot 10^{-3}} = 11.5 \cdot 10^{-3}$$

Calculation of the compensation capacitance C_c:

$$\Delta V_3 = \Delta V_4 = V_{DD} - V_{INCMAX} - |V_{TP}| + V_{TN} = 2.5 - 2.1 + 0.71 - 0.901 = 0.209V$$

$$C_c = \frac{16\,k\,T}{3(2\pi)GBS_n}\left[1 + \frac{SR}{(2\pi)GB\Delta V_3}\right] = \frac{4 \cdot 1.66 \cdot 10^{-20}}{3 \cdot 2\pi \cdot 5 \cdot 10^6 \cdot (28 \cdot 10^{-9})^2}\left[1 + \frac{5 \cdot 10^6}{2\pi \cdot 5 \cdot 10^6 \cdot 0.209}\right] = 1.58pF$$

Calculation of the current of M7 and M6:

$$I_{D7} = I_{D6} = SR(C_c + C_L) = 5 \cdot 10^6 \cdot (1.58 + 5) \cdot 10^{-12} = 32.9\mu A$$

Sizing M6:

$$\Delta V_6 = V_{DD} - V_{outmax} = 2.5 - 2.2 = 0.3V$$

$$L_6 = \sqrt{\frac{3}{2}\frac{\mu_p \Delta V_6 C_c}{(2\pi)GB(C_L + C_c)\tan PM}} = \sqrt{\frac{3}{2}\frac{11.5 \cdot 10^{-3} \cdot 0.3 \cdot 1.58 \cdot 10^{-12}}{2\pi \cdot 5 \cdot 10^6 \cdot 6.58 \cdot 10^{-12} \cdot 1.732}} = 4.774\mu m$$

$$W_6 = \frac{2I_{D6}L_6}{\beta_p' \Delta V_6} = \frac{2 \cdot 32.9 \cdot 10^{-6} \cdot 4.774 \cdot 10^{-6}}{41.5 \cdot 10^{-6} \cdot 0.3^2} = 84.1\mu m$$

$$S_6 = \frac{W_6}{L_6} = \frac{84.1}{4.774} = 17.61$$

Calculation of the currents flowing through M1, M2, M3, M4, M5:

$$I_{D5} = C_c SR = 1.58 \cdot 10^{-12} \cdot 5 \cdot 10^6 = 7.9\mu A$$

$$I_{D1} = I_{D2} = I_{D3} = I_{D4} = \frac{I_{D5}}{2} = 3.95\mu A$$

Sizing M1 and M2:

$$\Delta V_1 = \frac{SR}{2\pi GB} = \frac{5 \cdot 10^6}{2\pi \cdot 5 \cdot 10^6} = 0.16V$$

$$S_1 = \frac{2I_{D1}}{\beta_n' {\Delta V_1}^2} = \frac{2 \cdot 3.95 \cdot 10^{-6}}{182 \cdot 10^{-6} \cdot 0.16^2} = 1.7$$

$$S_2 = S_1 = 1.7$$

Sizing M5 and M8:

$$\Delta V_5 = V_{incmin} - V_{ss} - \Delta V_1 - V_{TN} = 2.5 - 1.3 - 0.16 - 0.71 = 0.33V$$

$$S_5 = \frac{2I_{D5}}{\beta_n' {\Delta V_5}^2} = \frac{2 \cdot 7.9 \cdot 10^{-6}}{182 \cdot 10^{-6} \cdot 0.33^2} = 0.8$$

$$S_8 = S_5 = 0.8 \qquad I_{D8} = I_{D5} = 7.9\mu A$$

Sizing M7, M3, M4:

$$S_7 = \frac{I_7}{I_5} S_5 = \frac{32.9}{7.9} 0.8 = 3.33$$

$$S_3 = S_4 = \frac{S_6 S_5}{2S_7} = 2.11$$

Form factor of M14 is set equal to four times S8:

$$S_{14} = 4S_8 = 3.2$$

Sizing M10, M11, M12, M13:

$$S_{13} = \frac{S_6 S_8}{S_7} = \frac{17.6 \cdot 0.8}{3.33} = 4.23$$

$$S_{10} = S_{11} = S_{12} = S_{13} = 4.23$$

$$I_{D11} = I_{D10} = I_{D8} = 7.9\mu A$$

$$I_{D12} = I_{D14} = I_{D13} = I_{D11} \frac{S_{13}}{S_{11}} = 7.9\mu A$$

Sizing M9 used as compensation resistor:

$$S_9 = \frac{C_c}{C_c + C_L} S_6 = \frac{1.58}{1.58+5} 17.6 = 4.23 \qquad I_{D9} = 0$$

Bias resistor:

$$R_B = \frac{1}{\sqrt{2\mu_n C_{ox} S_8 C_c SR}} = \frac{1}{\sqrt{2 \cdot 50.5 \cdot 10^{-3} \cdot 3.6 \cdot 10^{-3} \cdot 0.8 \cdot 1.58 \cdot 10^{-12} \cdot 5 \cdot 10^{6}}}$$
$$= 20.492k\Omega$$

Power dissipated:

$$\mathrm{P} = (V_{DD} - V_{SS})(I_{D14} + I_{D8} + I_{D5} + I_{D7}) = 282.984\mu W$$

3. SPICE plots

Figure 1- Gain

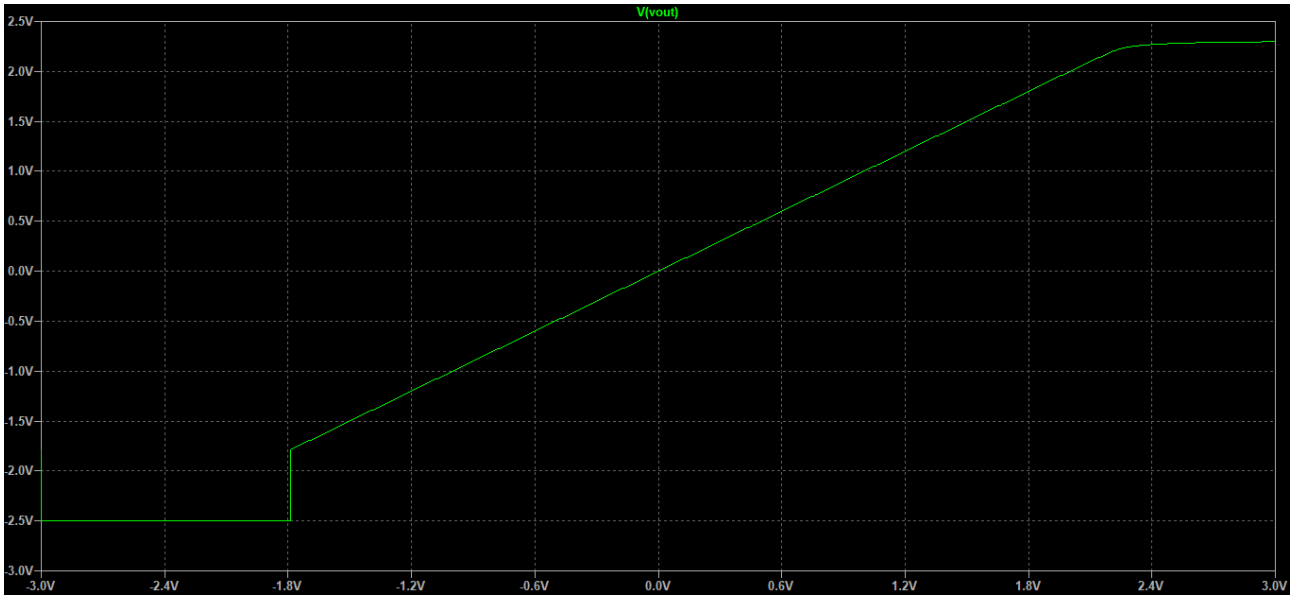


Figure 2- Input Common Mode Range Test

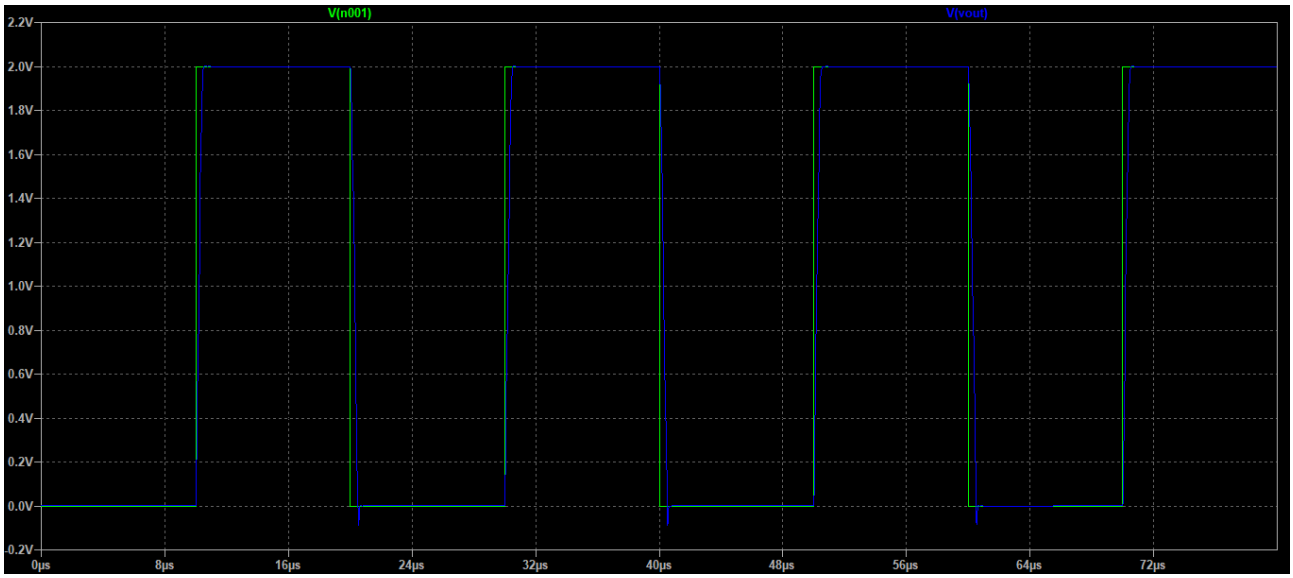


Figure 3- Slew Rate Test

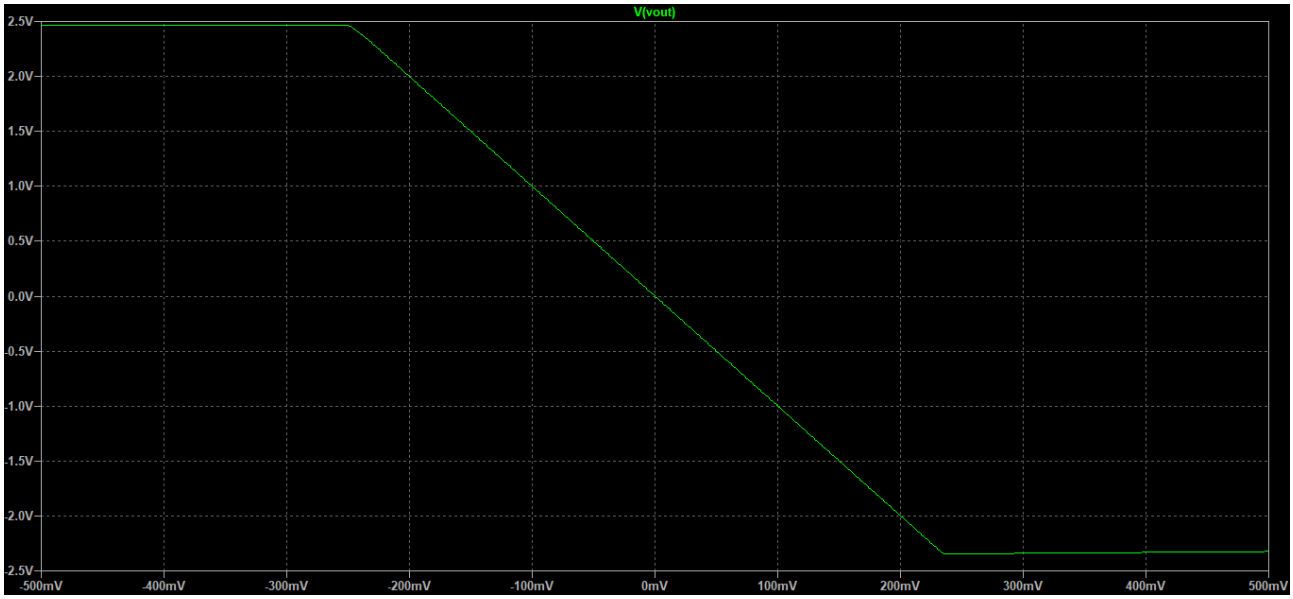


Figure 4 - Output Swing Test

4. Conclusion

	Specification	Achieved
Differential Gain	>80dB	106.8dB
Output Swing	±2.2V	max 2.4V, min -2.4V
Phase Margin	>60°	62°
Gain Bandwidth	5MHz	4.347MHz
Slew Rate	±5V/µs	±5V/µs
Input comm. mode range	max +2.1V, min -1.3V	max +2.15V, min -1.75V