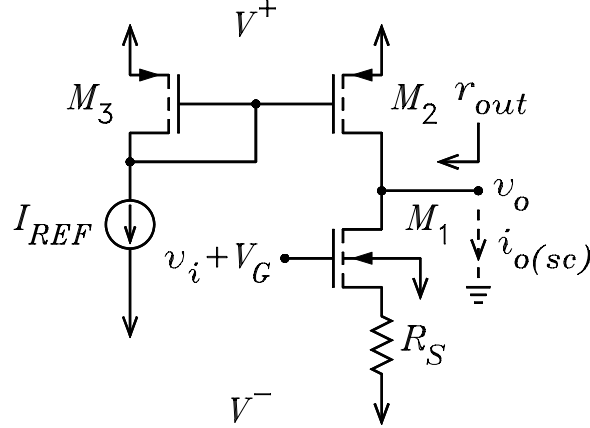


ECE3050 – Assignment 14

1. The figure shows a CS amplifier with a current-mirror active load.



- (a) If the r_0 approximations are used, show that the small-signal short-circuit output current is given by

$$i_{o(sc)} = -\frac{v_i}{1 + \chi_1} \frac{1}{r'_{s1} + R_S} = \frac{g_{m1}}{1 + g_{m1}(1 + \chi_1)R_S} v_i$$

- (b) Show that the small-signal output resistance is given by

$$r_{out} = r_{id1} \parallel r_{o2} = \left[r_{o1} \left(1 + \frac{R_S}{r'_{s1}} \right) + R_S \right] \parallel r_{o2}$$

- (c) Show that the small-signal open-circuit voltage is given by

$$v_{o(oc)} = i_{o(sc)} r_{out} = -\frac{g_{m1}}{1 + g_{m1}(1 + \chi_1)R_S} \left[r_{o1} \left(1 + \frac{R_S}{r'_{s1}} \right) + R_S \right] \parallel r_{o2} \times v_i$$

2. For the CS amplifier of Problem 1, each MOSFET has the parameters $K_0 = 0.002 \text{ A/V}^2$, $V_{TO} = 1.4 \text{ V}$, $\lambda = 0.02 \text{ V}^{-1}$, $\gamma = 1.5 \text{ V}^{1/2}$, and $\varphi = 0.6 \text{ V}$. It is given that $V^+ = 10 \text{ V}$, $V^- = -10 \text{ V}$, $I_{ref} = 1 \text{ mA}$, $R_S = 200 \Omega$.

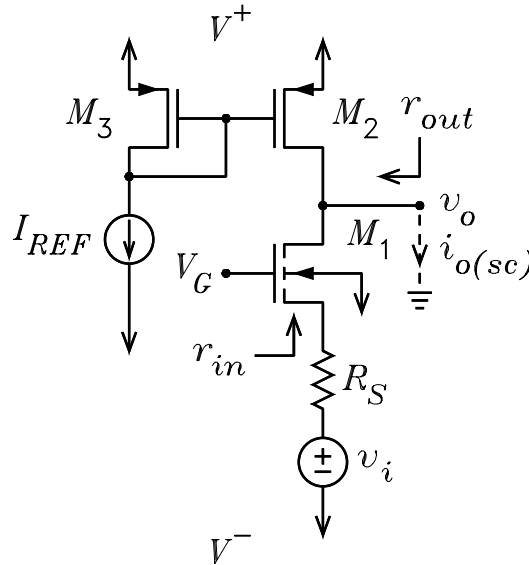
- (a) Use the equation $I_D = K_0(1 + \lambda V_{SD})(V_{SG} - V_{TO})^2$ to show that $V_{SG3} = 2.09 \text{ V}$. Note that $V_{SD3} = V_{SG3}$.
- (b) Use the equation $I_D = K_0(1 + \lambda V_{SD})(V_{SG} - V_{TO})^2$ to show that $I_{D2} = 1.15 \text{ mA}$. Note that $V_{SG2} = V_{SG3}$.
- (c) Show that $V_{DS1} = 9.77 \text{ V}$ and $V_{BS1} = -0.23 \text{ V}$. Note that the current through R_S is equal to I_{D2} .
- (d) Use the equation $\chi = 0.5\gamma/\sqrt{\varphi - V_{BS}}$ to show that $\chi_1 = 0.823$.
- (e) Use the equation $K = K_0(1 + \lambda V_{DS})$ to show that $K_1 = 4.78 \times 10^{-3} \text{ A/V}^2$.
- (f) Use the equations $g_m = 2\sqrt{KI_D}$ and $r_0 = (V_{DS} + 1/\lambda)/I_D$ to show that $g_{m1} = 3.32 \times 10^{-3} \text{ S}$ and $r_{o1} = 51.9 \text{ k}\Omega$.
- (g) Use the equation $r_0 = (V_{SD} + 1/\lambda)/I_D$ to show that $r_{o2} = 52.1 \text{ k}\Omega$.

(h) Show that the small-signal short-circuit output current is

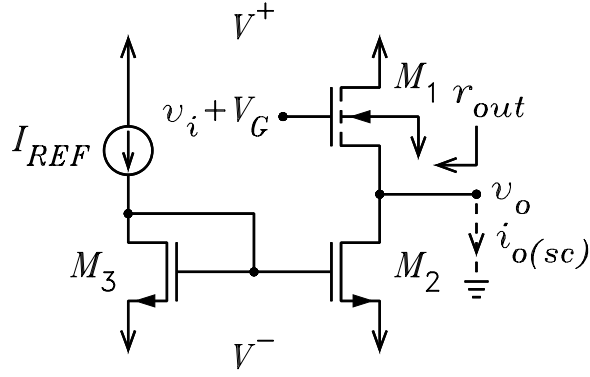
$$i_{o(sc)} = -\frac{v_i}{1 + \chi_1} \frac{1}{r'_{s1} + R_S} = 1.50 \times 10^{-3} v_i$$

Assume $r_{o1} = \infty$ and use the simplified T model.

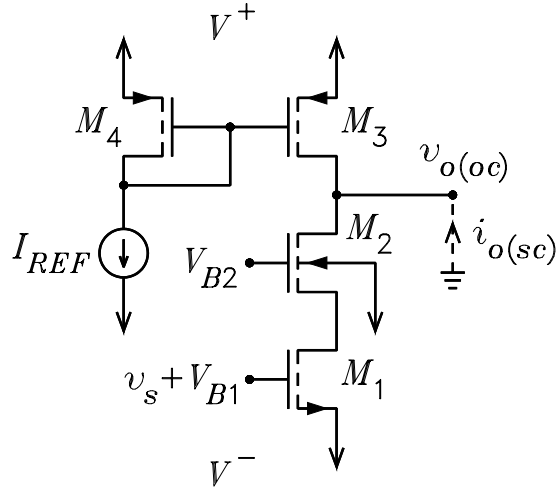
- (i) Show that the small-signal output resistance and open-circuit output voltage are $r_{out} = r_{id1} \parallel r_{o2} = 35.8 \text{ k}\Omega$ and $v_{o(oc)} = i_{o(sc)} \times r_{out} = -53.8 v_i$.
- (j) If a load resistor $R_L = 10 \text{ k}\Omega$ is connected from output to ground, show that the output voltage changes by the factor $R_L / (r_{out} + R_L) = 0.218$ (or by -13.2 dB) and the new voltage gain is $v_o / v_i = -11.7$.
- (k) If $R_S = 0$, show that $v_{o(oc)}$ increases to the value $v_{o(oc)} = -86.28 v_i$. Show that the gain increases by 4.10 dB .
3. The figure shows a CG amplifier with a current-mirror active load. The voltage V_G is a dc bias voltage. Each MOSFET has the parameters $g_m = 2.5 \times 10^{-3} \text{ S}$, $r_o = 40 \text{ k}\Omega$, and $\chi = 0.5$. It is given that $R_S = 200 \Omega$. It can be assumed that the dc value of the output voltage is zero.



- (a) Solve for the Norton short-circuit output current. Assume $r_{o1} = \infty$ and use the simplified T model. Answer: $i_{o(sc)} = v_i / (r'_{s1} + R_S) = 2.14 \times 10^{-3} v_i$.
- (b) Solve for the Thévenin equivalent circuit seen looking into the v_o node, i.e. solve for r_{out} and $v_{o(oc)}$. Answers: $r_{out} = r_{id1} \parallel r_{o2} = 25.5 \text{ k}\Omega$ and $v_{o(oc)} = i_{o(sc)} \times r_{out} = 54.6 v_i$.
- (c) By what factor does v_o change if a load resistor $R_L = 10 \text{ k}\Omega$ is connected from output to ground? What is the new voltage gain? Answer: $R_L / (r_{out} + R_L) = 0.282$ or by -11 dB and $v_o / v_i = 15.4$.
- (d) Show that the input resistance is $r_{in} = r'_{s1} = 267 \Omega$.
4. The figure shows a CD amplifier with a current-mirror active load. The voltage V_G is a dc bias voltage. Each MOSFET has the parameters $g_m = 2.5 \times 10^{-3} \text{ S}$, $r_o = 40 \text{ k}\Omega$, and $\chi = 0.5$.



- (a) Solve for the Norton short-circuit output current. Use the simplified T model. Answer: $i_{o(sc)} = v_i/r_{s1} = g_{m1}v_i = 2.5 \times 10^{-3}v_i$. Note that the body effect cancels when $v_o = 0$.
- (b) Solve for the Thévenin equivalent circuit seen looking into the v_o node, i.e. solve for r_{out} and $v_{o(oc)}$. Answers: $r_{out} = r'_{s1} \parallel r_{01} \parallel r_{02} = 263 \Omega$ and $v_{o(oc)} = i_{o(sc)} \times r_{out} = 0.658v_i$.
- (c) By what factor does v_o change if a load resistor $R_L = 10 \text{ k}\Omega$ is connected from output to ground? What is the new voltage gain? Answers: $R_L/(r_{out} + R_L) = 0.974$ or by -0.226 dB and $v_o/v_i = 0.641$.
5. The figure shows a cascode amplifier. M_1 is operated as a CS amplifier with a small-signal voltage v_s and a dc bias voltage V_{B1} applied to its gate. M_2 is operated as a CG amplifier with a dc bias voltage V_{B2} applied to its gate. M_3 and M_4 form a current mirror with an input dc current I_{REF} . For each MOSFET, it is given that $g_m = 0.005 \text{ S}$, $g_{mb} = 0.0025 \text{ S}$, and $r_0 = 50 \text{ k}\Omega$.



- (a) To simplify the solution for $i_{o(sc)}$, assume $r_{01} = r_{02} = \infty$. Show that $i_{o(sc)}/v_s = i'_{d2} = i'_{d1} = 0.005 \text{ S}$.
- (b) With $r_{01} = r_{02} = 50 \text{ k}\Omega$, show that the output resistance is
- $$r_{out} = r_{03} \parallel [r_{02} (1 + r_{01}/r'_{s2}) + r_{02}] = 49.87 \text{ k}\Omega$$
- (c) Show that $v_{o(oc)}/v_s = - [i_{o(sc)}/v_s] \times r_{out} \parallel r_{03} = -249.3$.