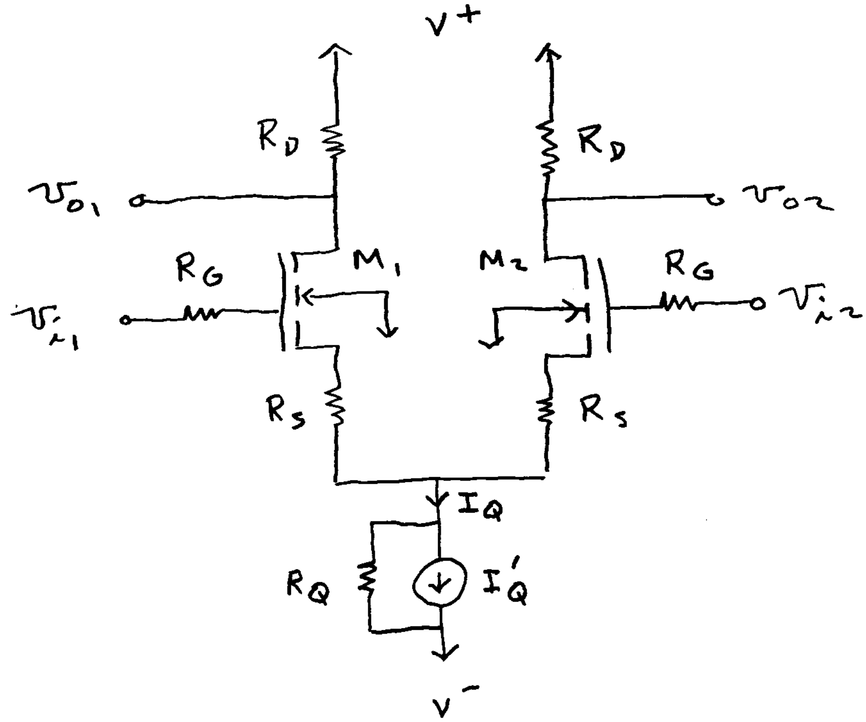
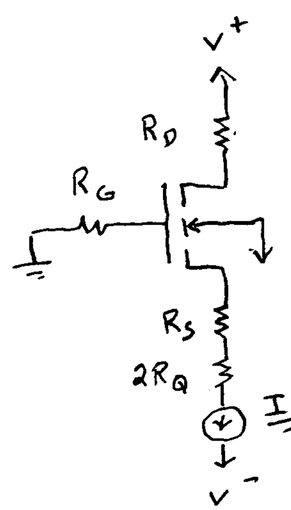
The MOSFET Diff Amp with Body Effect



For the dc analysis, set $v_{i1} = v_{i2} = 0$ and split the source tail supply into two parallel sources - $I_Q'/2$ in parallel with $2R_Q$. For identical devices, the equivalent circuit for either M_1 or M_2 is



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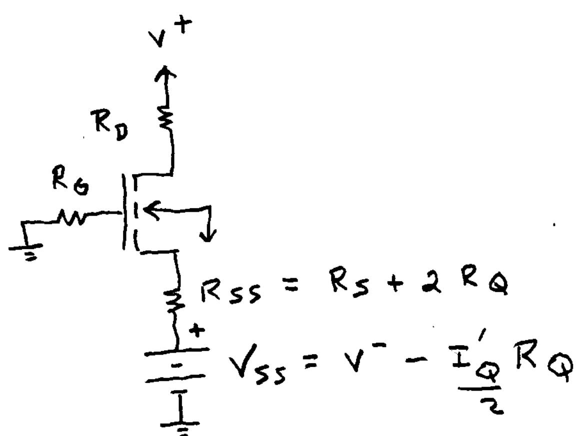
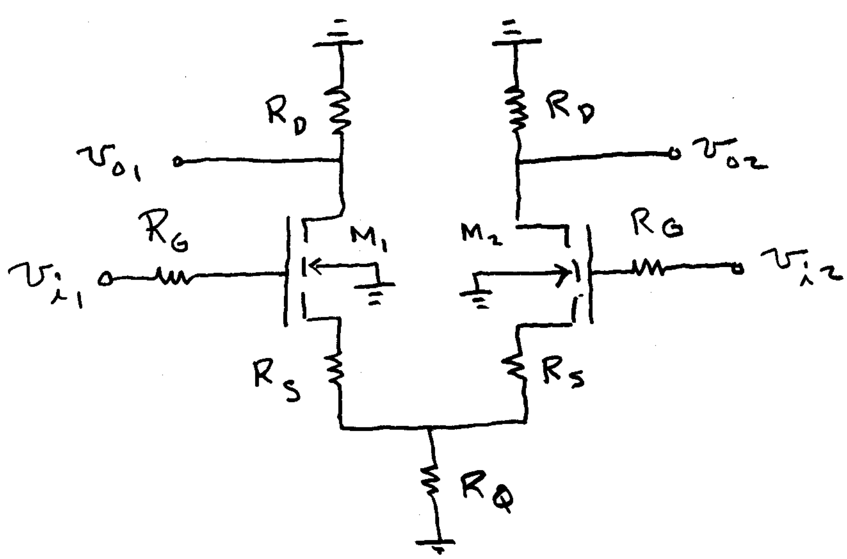


From the MOSFET bias equation, we have

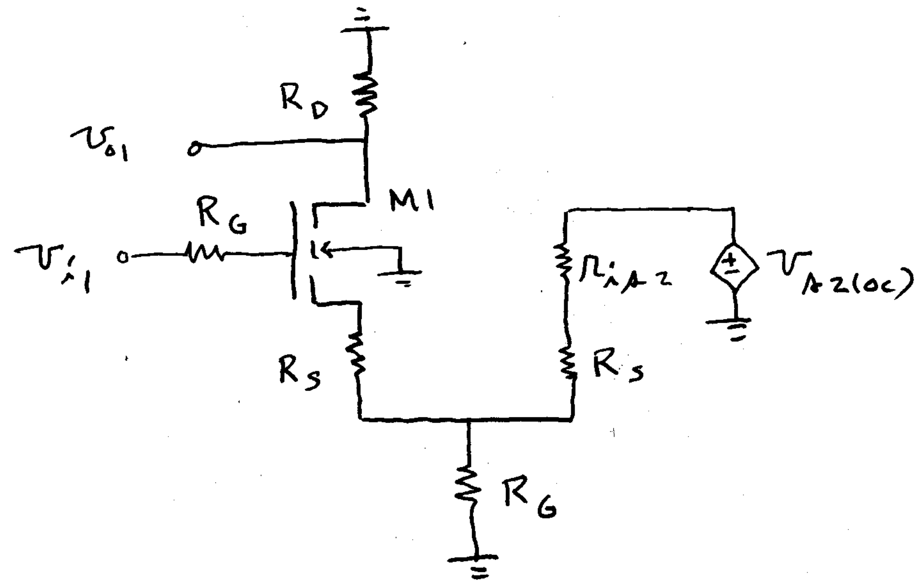
$$I_{D1} = I_{D2} = \frac{1}{4KR_{SS}}\left[\sqrt{1+4KV_1R_{SS}} - 1\right]^2$$

where $V_1 = V_{GG} - V_{SS} - V_{TO}$ and $V_{GG} = 0$

The ac signal circuit is obtained by setting $V^+ = V^- = 0$ and $I_Q' = 0$.



To solve for v_{o1}, replace M_2 with its Thévenin source circuit. The circuit becomes



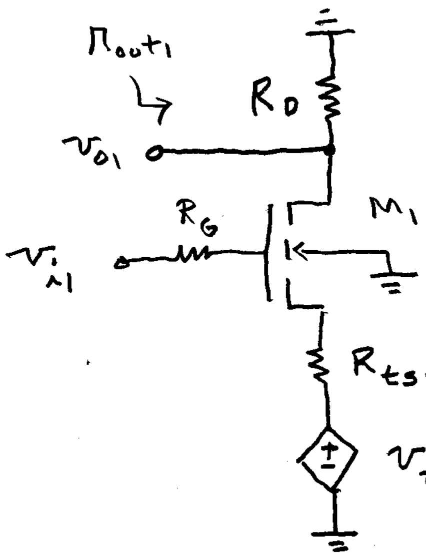
where

$$v_{A2(oc)} = \frac{v_{i2}}{1+\chi_2} \quad \frac{r_{o2}}{r'_{A2} + r_{o2}}$$

$$r_{iA2} = r'_{A2} \frac{r_{o2} + R_D}{r'_{A2} + r_{o2}}$$

$$r'_{A2} = r'_{A1} = \frac{r_s}{1+\chi} = \frac{1}{g_m (1+\chi)}$$

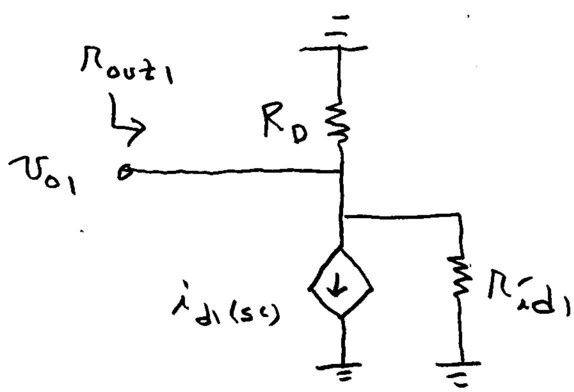
Next, replace the circuit looking out of the source of M_1 with a Thévenin equivalent circuit. The circuit becomes



$$R_{ts1} = R_S + R_Q \| (R_S + r_{is2})$$

$$v_{th1} = v_{s2(oc)} \frac{R_Q}{R_Q + R_S + r_{is2}}$$

To solve for v_{o1} and r_{out1}, replace M_1 with its Norton drain circuit. The circuit becomes



$$r_{out1} = r_{id1} \| R_D$$

$$v_{o1} = -i_{d1(sc)} \, r_{id1} \| R_D$$

where

$$r_{id1} = r_{01}\left(1 + \frac{R_{ts1}}{r_{s1}'}\right) + R_{ts1}$$

$$i_{d1(sc)} = G_{mg1} v_{i1} - G_{ms1} v_{ts1}$$

$$G_{mg1} = \frac{1}{1+\chi_1} \frac{1}{r_{s1}' + R_{ts1} \| r_{01}} \frac{r_{01}}{r_{01} + R_{ts1}}$$

$$G_{ms1} = \frac{1}{R_{ts1} + r_{s1}' \| r_0}$$

Combining terms, we obtain for v_{o1}

$$v_{o1} = -\left[G_{mg1} v_{i1} - G_{ms1} \frac{v_{i2}}{1+\chi_2} \frac{r_{02}}{r_{s2}' + r_{02}} \frac{R_Q}{R_Q + R_S + r_{is2}}\right]$$

$$\times\ r_{id1} \| R_D$$

To obtain r_{out2} and v_{o2}, interchange the 1's and the 2's in all subscripts.

But $$G_{ms2} \frac{1}{1+\chi_2} \frac{r_{02}}{r_{s2}' + r_{02}} = G_{mg2}$$

Thus the solution for v_{o1} can be simplified to

$$v_{o1} = -\left[G_{mg1} v_{i1} - G_{mg2} v_{i2} \frac{R_Q}{R_Q + R_S + r_{iA2}}\right]$$

$$\times \; r_{id1} \parallel R_D$$

Thus for identical devices biased at the same voltages and currents, we can write

$$v_{o1} = -G_{mg}\left[v_{i1} - v_{i2} \frac{R_Q}{R_Q + R_S + r_{is2}}\right] r_{id} \parallel R_D$$

If R_Q is sufficiently large, it can be replaced with ∞ (open circuit) in the formulas. In this case

$$v_{o1} = -v_{o2} = -G_{mg}\left[v_{i1} - v_{i2}\right] r_{id} \parallel R_D$$

In this case, the common-mode gain is zero and CMRR $= \infty$.

The above solution should be intuitively obvious because the small signal ac drain current in M_2 must be the negative of the small signal ac drain current in M_1.