INEL 4202 - Electronics II
Solutions to Exam 3 from Summer 2001
Prof. M. Toledo

The following 12 questions refer to the circuit sketched in the last page. In your analysis you can assume the $v_{BE} \approx 0.7V$ and that $\beta = 100$.

1. Find the approximate operating point (both i_C and v_{CE}) for Q_1 and Q_2. (10 pts)

   ANSWER:

   The constant current source splits equally between the Q_1 and Q_2, so the $i_{CQ} = 0.5mA$ for both transistors. Since the Q-point assume grounded inputs, $v_{E1} = v_{E2} = -0.7V$. Therefore, $V_{CE,1} = +6V - (-0.7V) = 6.7V$. For Q_2, $v_C = +6V - i_C R_C \approx 6V - 0.5mA \times 10k\Omega = 6V - 5V = 1V$ and $v_{CE,2} = 1.7V$.

2. Find the value of v_{OUT} when $v_1 = v_2 = 0$. (10 pts)

   ANSWER:

   The collector of Q_2 is connected to the base of Q_3, so that $v_{OUT} = v_{C,Q2} - 0.7V = 0.3V$.

3. Evaluate g_m for Q_1, Q_2 and Q_3. (10 pts)

   ANSWER:

$$g_{m,Q1} = g_{m,Q2} = \frac{i_{C,Q1}}{V_T} = \frac{0.5mA}{25mV} = 0.02A/V$$

   For Q_3, observe that $i_{C,Q3} \approx i_{E,Q3} = 6.3V/1k\Omega = 6.3mA$. Thus,

$$g_{m,Q3} = \frac{6.3mA}{25mV} = 0.252A/V$$

4. Find the value of R_{ref} that should be used in the constant current source. Assume equal areas for Q_4 and Q_5. (10 pts)

   ANSWER:

$$R_{ref} = \frac{0 - 0.7 - (-6V)}{1mA} = 5.3k\Omega$$

5. Find the differential gain $A_d = v_{OUT}/v_d$, where $v_d = v_1 - v_2$. (10 pts)

   ANSWER: Observe that Q_3 is in the common-collector configuration, so it's gain is abot 1. Thus

$$A_d = -\frac{1}{2} g_{m,Q1} R_{c2}$$

   where R_{c2} is the incremental resistance seen at the collector of Q_2, and is equal to $10k \mid\mid (r_{\pi 3} + (\beta + 1)) = 10k \mid\mid (\frac{100}{0.252A/V} + 101 \times 1k) = 10k \mid\mid 101.4k = 9.1k$. Thus

$$A_d = -0.5(0.02A/V)9100 = -91$$

6. Find the common-mode gain assuming that $V_A = 100V$ for transistor Q_4. (10 pts)

ANSWER:

$$A_{CM} \approx \frac{g_{m,Q1} R_c}{1 + 2g_{m,Q1} R_{TAIL}}$$

$$R_{TAIL} = v_A / i_{C,Q_4} = 100V/1mA = 100k\Omega$$

$$A_{CM} \approx \frac{0.02 \times 9.1k\Omega}{1 + 2 \times 0.02 \times 100k\Omega} = \frac{182}{4001} = 0.0455$$

7. Find the common-mode rejection ratio (CMMR) for the amplifier. (10 pts)

ANSWER:

$$CMRR = \mid \frac{A_d}{A_{CM}} \mid = \frac{91}{0.0455} \approx 2000$$

Or $66dB$.

8. Find the output resistance of the amplifier. (10 pts)

ANSWER:

$$R_{out} = R_E \mid\mid \frac{r_\pi + R_B}{\beta + 1}$$

In this case, $R_B \approx 10k\Omega$ and $r_\pi = r_{\pi,Q3} \approx 400\Omega$. Thus

$$R_{out} = 1k \mid\mid \frac{400 + 10k}{101} = 93\Omega$$

9. Find the input resistance of the amplifier, as seen by a differential signal. (10 pts)

$$r_d = 2r_{\pi,Q1} = 2\frac{100}{0.02A/V} = 10k\Omega$$

10. Find the input resistance of the amplifier, as seen by a common-mode signal. (10 pts)

ANSWER:

$$r_{CM} = r_{\pi,Q1} + (\beta + 1)2R_{TAIL} = 5k + 101 \times 100k \approx 10M\Omega$$

11. Find the amplifier's gain if a differential signal is applied between v_1 and v_2 using a source with a thevenin resistance of $5k\Omega$, and a 100Ω load is connected to the output terminal. (10 pts)

ANSWER:

We will have loading at the input and output. The gain will be

$$A_v = A_d \frac{r_d}{r_d + R_{TH}} \frac{R_L}{R_L + R_{out}}$$

$$A_v = -91 \times \frac{10k}{10k + 5k} \times \frac{100}{100 + 93} = -31.4$$

12. Redesign the current mirror to use a Widlar current source. Find the common-mode gain and CMRR when your Widlar source is used. Draw a schematic diagram of the circuit. (15 pts)

ANSWER:

For the Widlar source,

$$V_T ln(I_{ref}/i_O) = i_o R_M$$

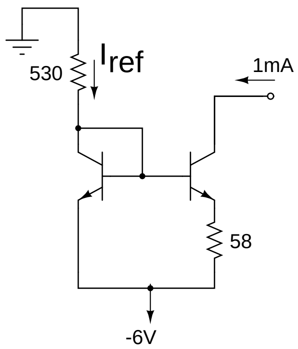
For our circuit, $i_o = 1mA$. Choose $I_{ref} = 10mA$ and then

$$R_M = \frac{25mV}{1mA} ln(10) = 58\Omega$$

To get a reference current of 10mA,

$$R_{ref} = \frac{0 - 0.7 - (-6V)}{10mA} = 530\Omega$$

The circuit diagram of the current source is



To find the common-mode gain, use the formula used in problem 6,

$$A_{CM} \approx \frac{g_{m,Q1} R_c}{1 + 2g_{m,Q1} R_{TAIL}}$$

$$R_{TAIL} = r_{o,Q4}(1 + g_{m,Q4} R_M)$$

$$r_o = v_A / i_{C,Q_4} = 100V/1mA = 100k\Omega$$

$$g_{m,Q4} = \frac{1mA}{25mV} = 0.04$$

$$R_{TAIL} = 100k(1 + .04 \times 58) = 330k\Omega$$

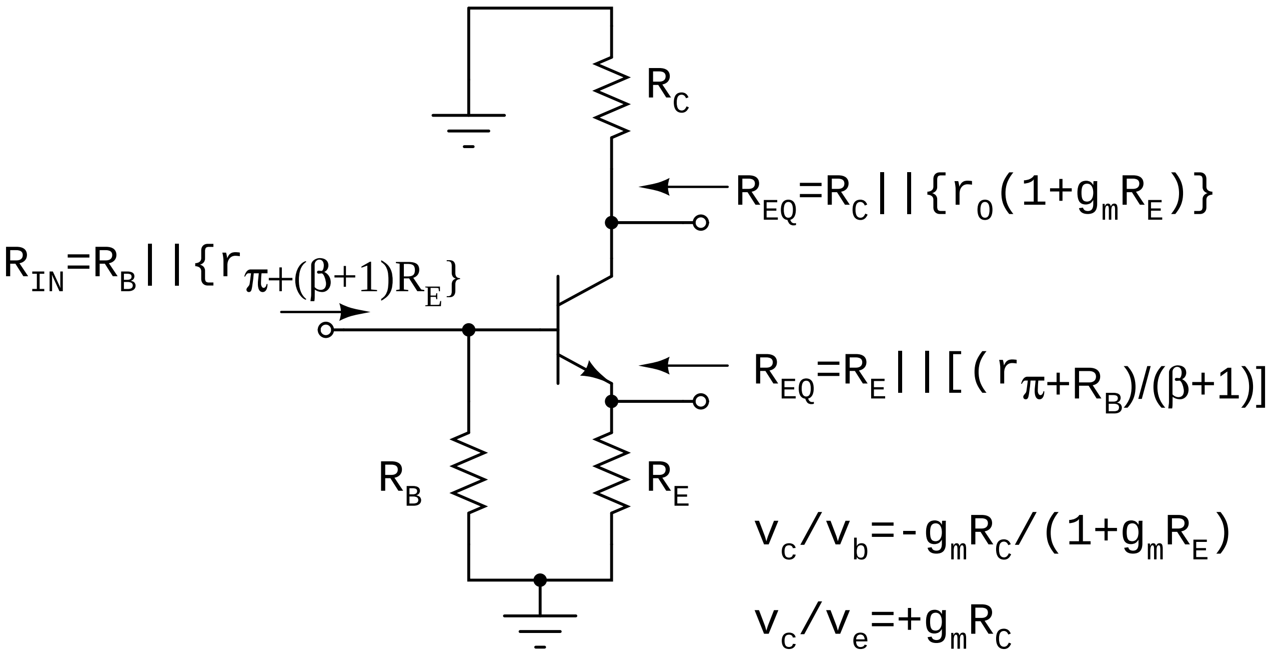
and finally,

$$A_{CM} \approx \frac{.02 \times 9.1k}{1 + 2 \times 0.02 \times 330k} = 0.014$$

and

$$CMRR = \mid \frac{A_d}{A_{CM}} \mid = \frac{91}{0.014} \approx 6606$$

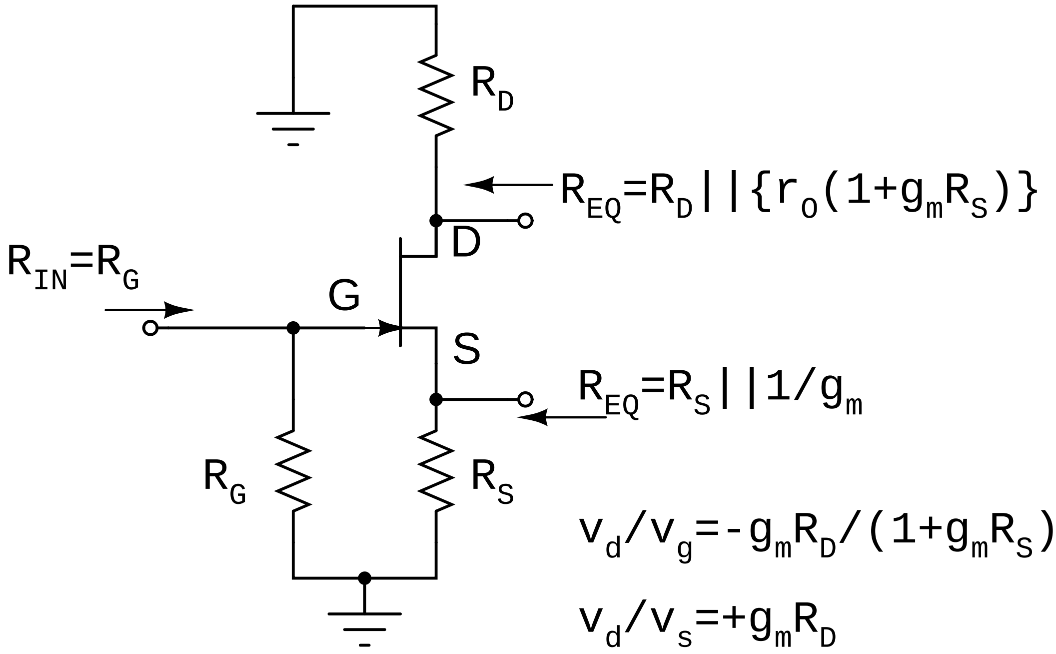
Or $76dB$.



$v_c/v_b=-g_mR_C/(1+g_mR_E)$

$v_c/v_e=+g_mR_C$

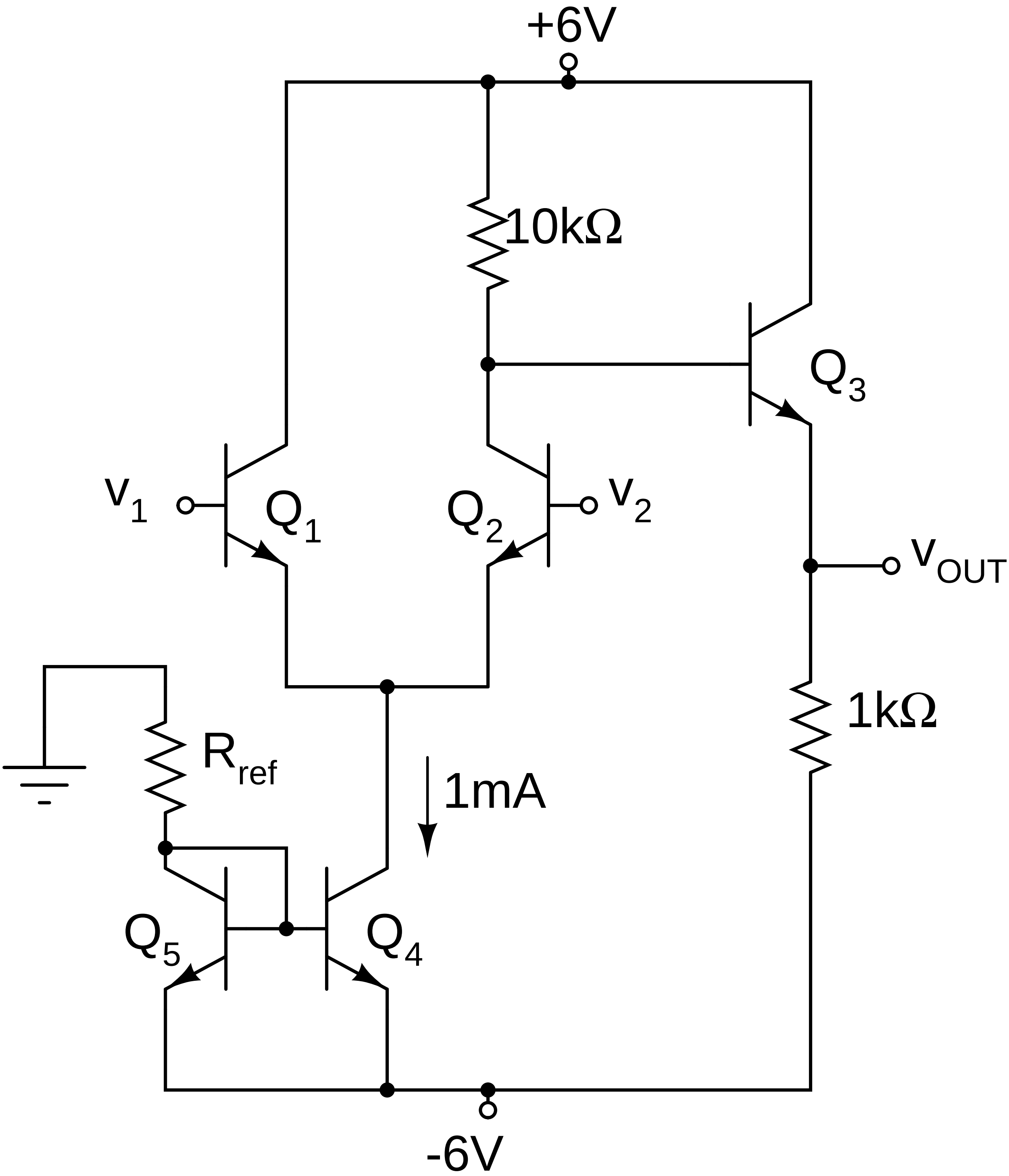
$v_e/v_b=1$



$v_d/v_g=-g_mR_D/(1+g_mR_S)$

$v_d/v_s=+g_mR_D$

$v_s/v_g=1$



+6V
10kΩ
Q3
v1
Q1
Q2
v2
vOUT
1kΩ
Rref
1mA
Q5
Q4
-6V