uA741

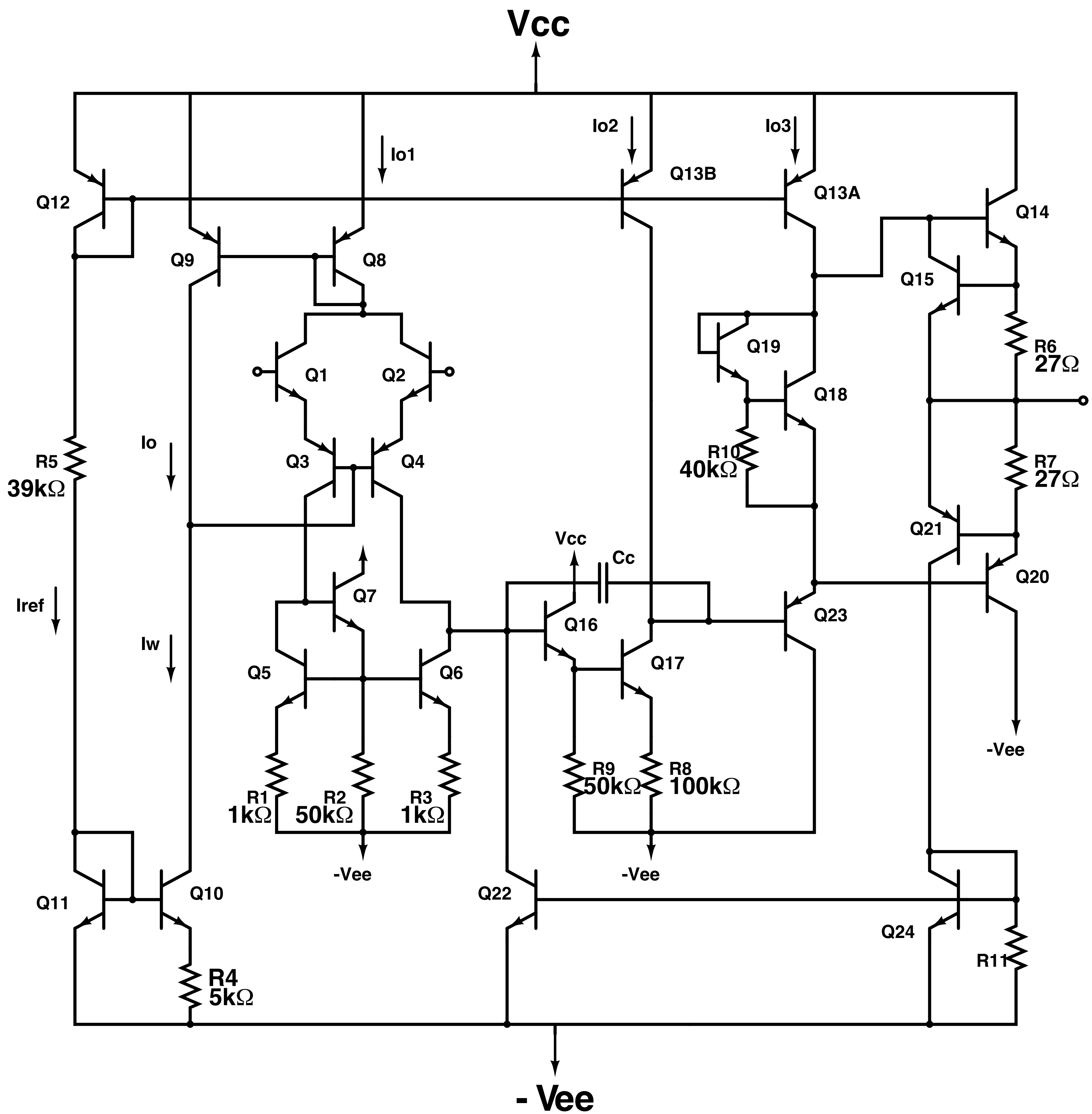
INEL4202 - Fall 2009

Device Parameters

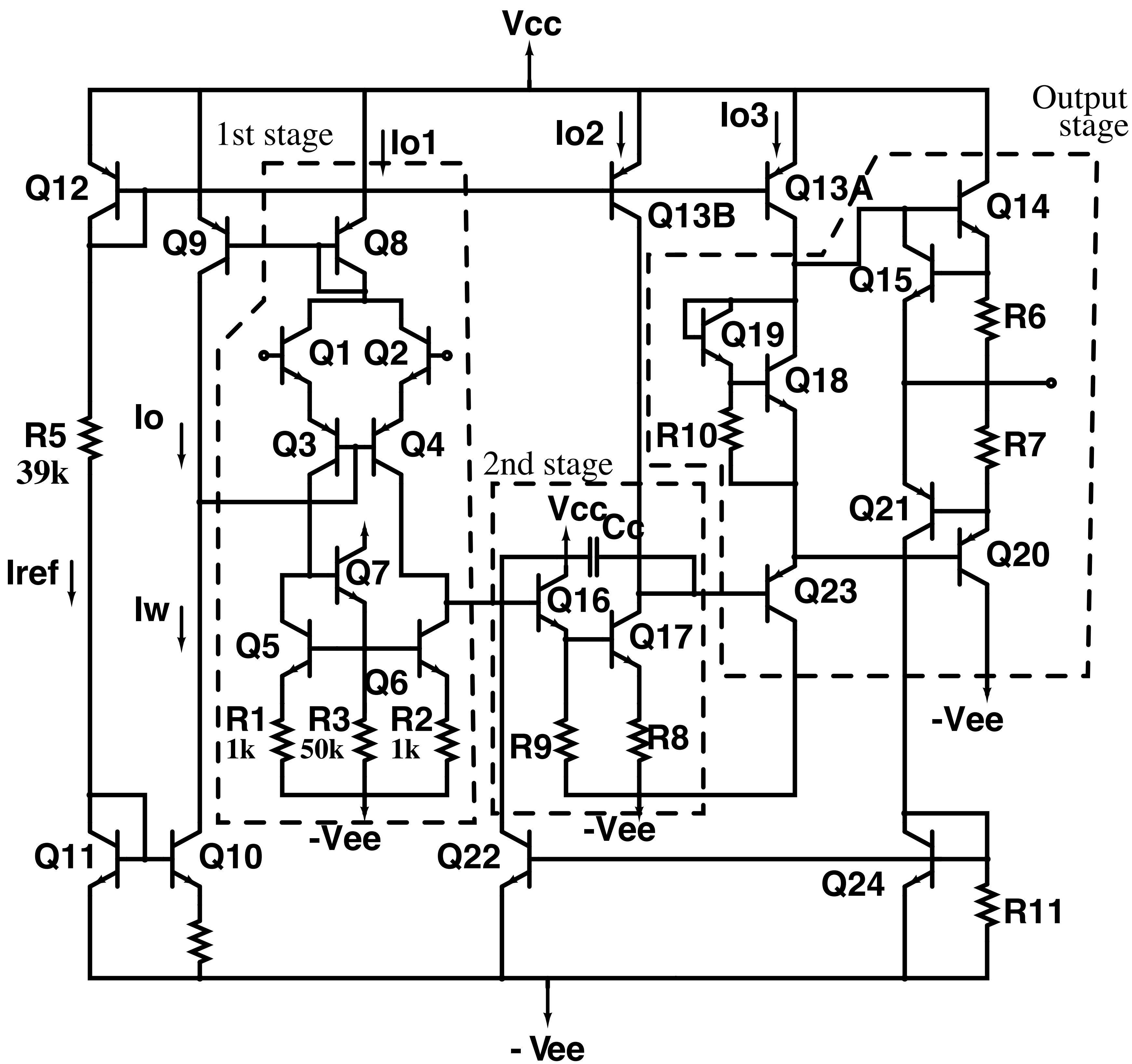
Parameter	npn	pnp
I_S	10^{-14}A	10^{-14}A
β	200	50
V_A	125	50

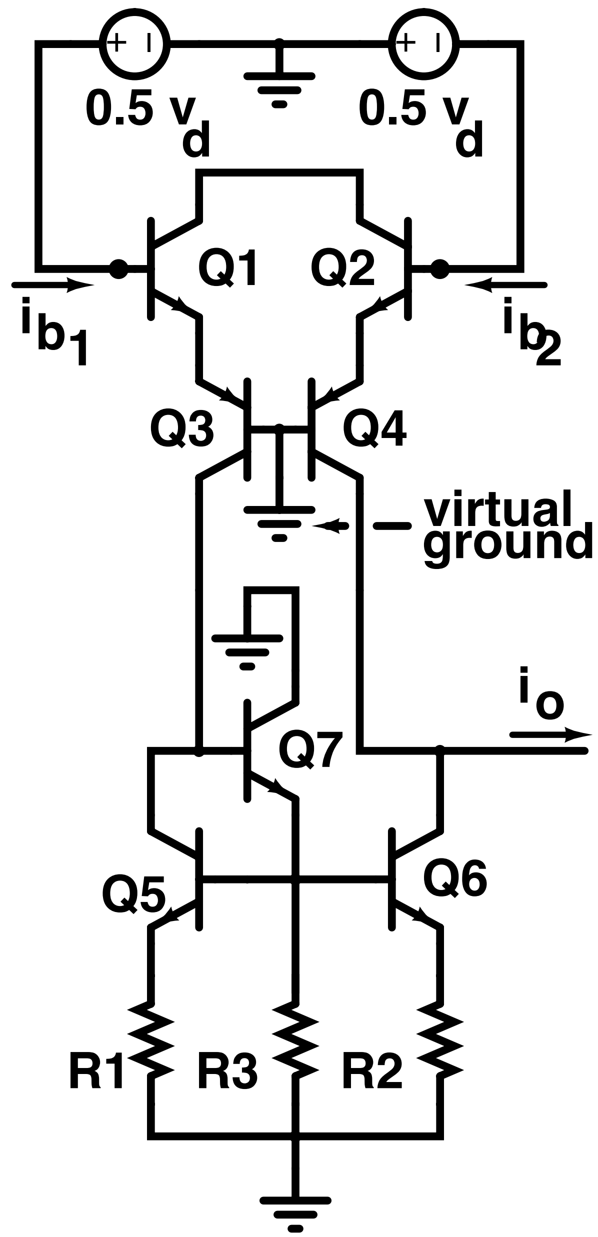
For Q_{13A} and Q_{13B} assume I_S equal to 0.25×10^{-14}A and 0.75×10^{-14}A, respectively.

The area of power transistors Q_{14} and Q_{20} is assumed to be three times that of regular transistors.

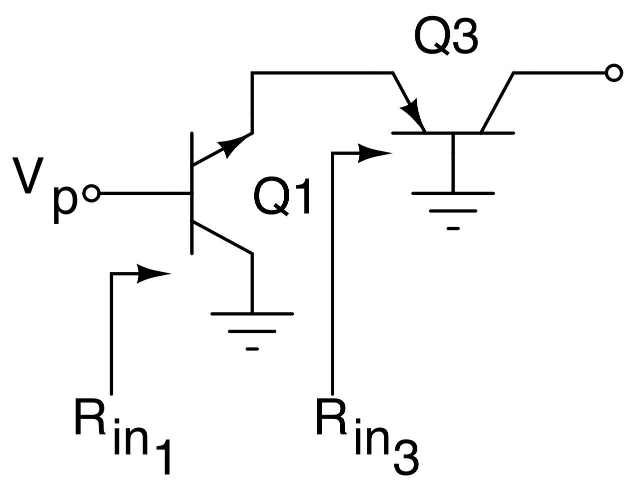


Vcc
Io1
Io2
Io3
Q12
Q13B
Q13A
Q14
Q9
Q8
Q15
Q1
Q2
Q19
R6
27Ω
Q18
Q3
Q4
R10
40kΩ
R7
27Ω
R5
39kΩ
Io
Q21
Q7
Vcc
Cc
Q20
Iref
Q16
Q23
Iw
Q5
Q6
Q17
-Vee
R9
50kΩ
R8
100kΩ
R1
1kΩ
R2
50kΩ
R3
1kΩ
-Vee
-Vee
Q11
Q10
Q22
Q24
R11
R4
5kΩ
- Vee


Vcc
Io1
Io2
Io3
1st stage
Output stage
Q12
Q9
Q8
Q13B
Q13A
Q14
Q15
Q1
Q2
Q19
R6
Q18
Q3
Q4
R10
R5
39k
Io
2nd stage
R7
Q21
Vcc
Cc
Q20
Iref
Q7
Q16
Q23
Iw
Q5
Q17
Q6
R1
1k
R3
50k
R2
1k
R9
R8
-Vee
-Vee
-Vee
Q11
Q10
Q22
Q24
R11
- Vee


0.5 v
d
0.5 v
d
Q1
Q2
i
b
1
i
b
2
Q3
Q4
virtual
ground
i
o
Q7
Q5
Q6
R1
R3
R2

- INPUT RESISTANCE

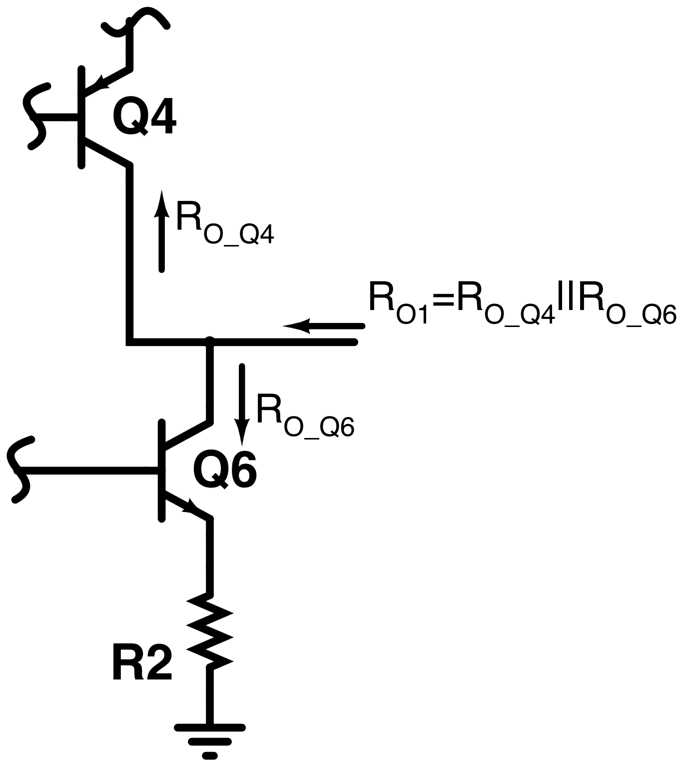


$$R_{in1} = r_{\pi 1} + (\beta_N + 1) R_{in3} = r_{\pi 1} + (\beta_N + 1)\frac{V_T}{I_{e2}} \approx 2 r_{\pi 1}$$

For differential signals: $R_{in} = 4 r_{\pi 1}$.

• OUTPUT RESISTANCE

$$R_{O1} = R_{O-Q4}\,||\,R_{O-Q6}$$



For Q6:

$$R_{O-Q6} = r_{O6}(1 + g_{m6}R_2)$$

For Q4:

$$R_{O-Q4} = r_{O4}(1 + g_{m4}R_{eQ4})$$

where R_{eQ4} is the small signal equivalent resistance at the emitter of Q4. Thus

$$R_{eQ4} = r_{e2}$$

and

$$R_{O-Q4} = r_{O4}(1 + g_{m4} r_{e2})$$

Using $I_{C4} = I_{C6} = 9.5\mu A$, we get the following values:

Quantity	Value
$g_{m4} = g_{m6}$	$\frac{I_{C4}}{V_T} = \frac{9.5\mu A}{25mV} = 0.38mA/V$
r_{e2}	$\frac{V_T}{I_{e2}} \approx \frac{25mV}{9.5\mu A} = 2.63k\Omega$
r_{O4}	$\frac{V_{A_{pnp}}}{I_{C4}} = \frac{50V}{9.5\mu A} = 5.26M\Omega$
r_{O6}	$\frac{V_{A_{npn}}}{I_{C6}} = \frac{125V}{9.5\mu A} = 13.16M\Omega$
R_{O-Q4}	$5.26M\Omega\left(1 + 0.38\frac{mA}{V} \times 2.63k\Omega\right) = 10.5M\Omega$
R_{O-Q6}	$13.16M\Omega\left(1 + 0.38\frac{mA}{V} \times 1k\Omega\right) = 18.16M\Omega$
R_{O1}	$10.5M\Omega \| 18.16M\Omega = 6.65M\Omega$

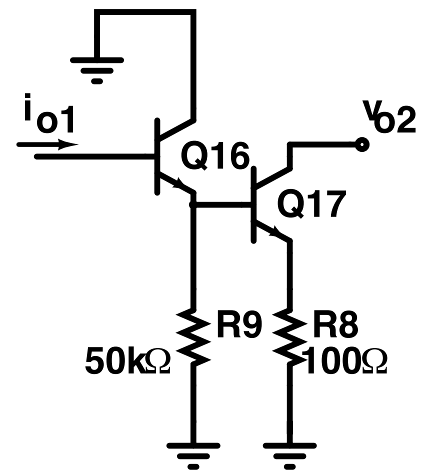
- TRANSCONDUCTANCE

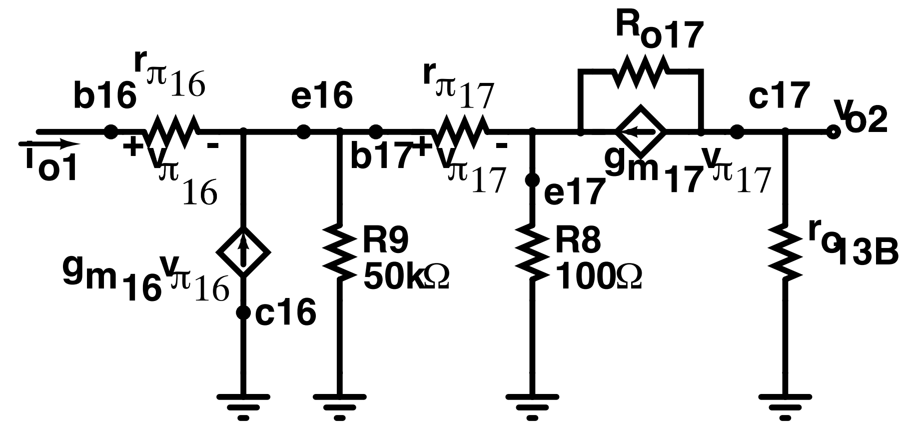
$$G_{M1} = \frac{i_{O1}}{v_d}$$

Use $i_{O1} = -i_{C6} - i_{C4} = -2i_{e1}$ and $i_{e1} = (\beta+1)\frac{v_d/2}{2r_\pi} = v_d \times \frac{1}{4r_{e1}}$.
Thus

$$G_{M1} = -\frac{1}{2r_{e1}} = -\frac{1}{2}g_{m1} = -\frac{1}{2}\frac{9.5\mu A}{25mV} = -0.19\frac{mA}{V}$$

Second Stage





- INPUT RESISTANCE

$$R_{in2} = r_{\pi 16} + (\beta_{npn} + 1) \times (R9 \,||\, (r_{\pi 17} + (\beta_{npn} + 1) R_8))$$

Using $I_{C16} = 16.2\mu A$ and $I_{C17} = 550\mu A$, we get $r_{\pi 16} = 200\frac{25mV}{16.2\mu A} = 308.6k\Omega$ and $r_{\pi 17} = 200\frac{25mV}{550\mu A} = 9.09k\Omega$. Thus we get

$$R_{in2} = 308.6k\Omega + 201\,(50k\Omega \,||\, (9.09k\Omega + 201 \times 100\Omega)) = 4M\Omega$$

- TRANSRESISTANCE

$$R_{M2} = \frac{v_{O2}}{i_{O1}} = \frac{v_{O2}}{v_{b16}/R_{in2}} = R_{in2} \times \frac{v_{O2}}{v_{b16}}$$

The output voltage at the collector of Q_{17} depends on the collector resistance. Let this resistance be R_{c17}. Then

$$R_{c17} = r_{o17}(1 + g_{m17}R_8) \,||\, r_{o13B}$$

From $I_{C17} = I_{C13B} = 550\mu A$, $r_{o17} = \frac{V_{Anpn}}{I_{C17}} = \frac{125V}{550\mu A} = 227k\Omega$ and $r_{o13B} = \frac{50V}{550\mu A} = 90.9k\Omega$. Thus

$$R_{c17} = 90.9k\Omega \,||\, 227k\Omega \times \left(1 + \frac{550\mu A}{25mV}100\Omega\right) = 80.8k\Omega$$

Using this value, we get

$$
\begin{aligned}
R_{M2} &= R_{in2} \times \frac{R_{e16}}{r_{e16} + R_{e16}} \times \frac{-g_{m17} R_{c17}}{1 + g_{m17} R_8} \\
&= 4M\Omega \times \frac{18.43k\Omega}{18.43k\Omega + \frac{25mV}{16.2\mu A}} \times \frac{-\frac{550\mu A}{25mV} 80.8k\Omega}{1 + \frac{550\mu A}{25mV} 100\Omega} \\
&= 4M\Omega \times 0.92 \times -556 = -2044M\Omega
\end{aligned}
$$

Notice that this can be expressed as a transconductance

$$
G_{M2} = \frac{i_{O2}}{v_{i1}} = \frac{-v_{O2} \div R_{c17}}{i_{i1} \times R_{i2}} = \frac{R_{M2}}{R_{i2} \times R_{c17}} = \frac{-2044M\Omega}{4M\Omega \times 80.8k\Omega} = 6.3\frac{mA}{V}
$$

Compare this result with the textbook's of $G_{M2} = 6.5mA/V$ (see page 829).

- OUTPUT RESISTANCE

$$R_{o2} = R_{c17} = 76.9k\Omega$$

<u>Voltage Gain of Stages One and Two</u>

The gain $A_v = \frac{v_{o2}}{v_d}$can be found from:

$$\frac{v_{o2}}{v_d} = \frac{i_{o1}}{v_d} \times \frac{R_{o1}}{R_{o1} + R_{i2}} \times \frac{v_{o2}}{i_{i2}}$$

Noticing that $i_{o1} = i_{i2}$ and using our previous results,

$$A_v = \frac{v_{o2}}{v_d} = -0.19\frac{mA}{V} \times \frac{6.65M\Omega}{6.65M\Omega + 4M\Omega} \times -2044M\Omega = 2.42 \times 10^5$$