UNIVERSITY OF CALIFORNIA AT BERKELEY
College of Engineering
Department of Electrical Engineering and Computer Sciences

EE105 Lab Experiments

Prelab 8: Multi-stage Amplifiers

Solutions

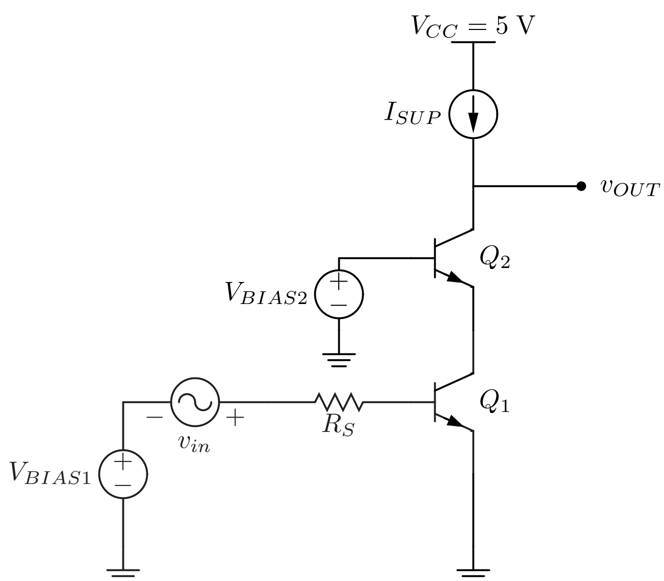

Figure 1: Cascode amplifier with ideal current source

1. The cascode in Figure 1 is biased by an ideal current source. Let $I_S = 1 \times 10^{-15}$ A, $V_A = 100$ V, $\beta = 200$, $I_{SUP} = 1$ mA, $T = 300$ K, $v_{OUT,DC} = 3.5$ V, and $V_{BIAS2} = 2$ V. Calculate V_{BIAS1} to match these biasing conditions.

$$0.001 \text{ A} = \left[1 \times 10^{-15} \cdot e^{\frac{2-V_{E2}}{0.026}} \cdot \left(1 + \frac{3.5 - V_{E2}}{100}\right)\right] \text{ A}$$

$$V_{E2} = 1.28216 \text{ V}$$

$$0.001 \text{ A} = \left[1 \times 10^{-15} \cdot e^{\frac{V_{BIAS1}}{0.026}} \cdot \left(1 + \frac{V_{BIAS1}}{100}\right)\right] \text{ A}$$

$$V_{BIAS1} = 0.718 \text{ V}$$

$$V_{BIAS1} = \boxed{0.718 \text{ V}}$$

2. What is the gain of this amplifier?

Using the small signal model, G_m can be found from i_{out},

$$i_{out} = g_{m1} \cdot v_{in} \cdot \left(\frac{r_{o1}}{r_{o1} + \frac{1}{g_{m2}} \parallel r_{o2}} \right)$$

But $\frac{1}{g_{m2}} << r_{o2}, r_{o1}$,

$$\begin{aligned} i_{out} &= g_{m1} v_{in} \\ G_m &= g_{m1} \\ A_v &= -G_m R_{out} = -g_{m1} \left[\left(1 + g_{m2} \left(r_{o1} \parallel r_{\pi 2}\right)\right) r_{o2} + r_{o1} \right] \end{aligned}$$

Using the fact that $g_{m1} \approx g_{m2}$ and $r_{o1} \approx r_{o2}$ to simplify, we have

$$A_v = -g_{m1} \left(g_{m1} \left(r_{o1} \parallel r_{\pi 2} \right) r_{o1} + r_{o1} \right)$$

Dropping the last r_{o1}, since $g_{m1} \left(r_{o1} \parallel r_{\pi 2} \right) r_{o1} >> r_{o1}$, we get

$$A_v \approx -g_{m1} r_{o1} g_{m1} \left(r_{o1} \parallel r_{\pi 2} \right)$$

$$\boxed{A_v = -731,200}$$

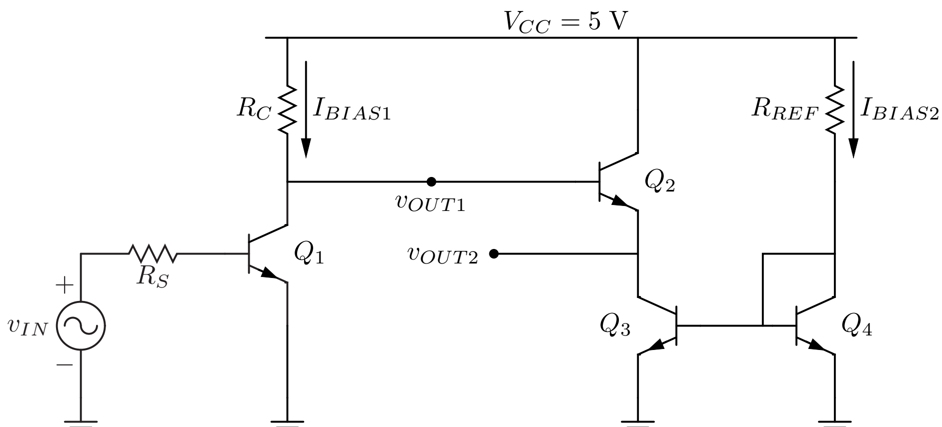

Figure 2: Multi-stage amplifier

3. Now construct a SPICE netlist for the multi-stage amplifier shown in Figure 2. Let $R_C = 10\,\text{k}\Omega$, $R_S = 51\,\text{k}\Omega$, and $R_{REF} = 200\,\Omega$. Bias transistor Q_1 with $V_{BE1} = 560$ mV. What is the small signal gain (A_{v1}) between v_{IN} and v_{OUT1}? What is the small signal gain (A_{v2}) between v_{OUT1} and v_{OUT2}? Using A_{v1} and A_{v2}, find the overall gain ($A_{v,tot}$) between v_{IN} and v_{OUT2}. Attach the SPICE netlist to the end of this prelab.

```
EE105 Lab 8 Prelab

vcc vcc gnd 5V

vin vin gnd 0.56
rs  vin vb1 51k

q1 vout1 vb1   gnd QN4401
rc vcc   vout1 10k

q2   vcc   vout1 vout2 QN4401
q3   vout2 vb3   gnd   QN4401
q4   vb3   vb3   gnd   QN4401
rref vcc   vb3   200

.model QN4401 NPN(Is=26.03f Xti=3 Eg=1.11 Vaf=90.7 Bf=4.292K Ne=1.244
+ Ise=26.03f Ikf=.2061 Xtb=1.5 Br=1.01 Nc=2 Isc=0 Ikr=0 Rc=.5
+ Cjc=11.01p Mjc=.3763 Vjc=.75 Fc=.5 Cje=24.07p Mje=.3641 Vje=.75
+ Tr=233.7n Tf=466.5p Itf=0 Vtf=0 Xtf=0 Rb=10)

.tf v(vout1) vin
* .tf v(vout2) vin
.op
.option post=2 nomod
.end
```

You can swap out the `.tf` statements to get v_{out1}/v_{in} and v_{out2}/v_{in}. From these, we can derive $v_{out2}/v_{out1} = \frac{v_{out2}/v_{in}}{v_{out1}/v_{in}}$.

$$\boxed{A_{v1} = -6.3173}$$

$$\boxed{A_{v2} = 0.9994}$$

$$\boxed{A_{v,tot} = -6.3133}$$