ECE 137A - notes set 10

multi-stage example - Audio amplifier

Q 9, 10: $\beta \geq 25$
others: $\beta \geq 100$
all: $V_a \geq 100V$

Q 9 & 11 are closely matched
Q 10 & 12 "" ""
Q 26 & 27 are roughly matched.
Small Signal analysis

Q9 and 10 are a push pull stage

analysis is inherently inaccurate:

- Strong positive output: Q9 on, Q10 off
- Strong negative output: Q10 on, Q9 off

- Small output: both on.

Over the signal swing, Ic varies greatly.
This causes Ic to vary, which changes the gain.

Approximately: Q9 on, Q10 off

\[ \frac{V_{b9}}{V_{b9}} = 8.2 / 9.2 = 0.89 \]

\[ V_{b9} = V_{b9} = \frac{9.2}{9.2 + 8.1} \geq \frac{9.2}{9.2 + 0.92} = 0.91 \text{ bias condition} \]

\[ R_{in} \geq 10 \left( \frac{9.2 + 10 + 0.92}{2} \right) = 24.7 \Omega \]
Q8: EF

Plate 8 = Plate 9 ≥ 250 ohm

\[ \text{R}_{\text{ef}} = \frac{2600 \text{ mV}}{30 \text{ mA}} = 0.9 \text{ ohm} \]

\[ \text{At 8} = \frac{250}{(250 + 0.9)} = 0.996 \]

\[ \text{Plate 8} \geq \text{ Vmin} \cdot (\text{R}_{\text{ef}} + \text{R}_{\text{reg}}) \]

\[ = 100 \cdot (250 \text{ ohm}) \]

\[ = 25 \text{mA} \]
Q3/Q4: degenerated differential pair

\[ \Rightarrow V_{04} = \frac{-R_{eg4}}{R_{14} + 275.5} \]

\[ \Rightarrow V_{04} = \frac{-2.3k\Omega}{2.3k\Omega + 275.5} \]

\[ \Rightarrow V_{04} = \frac{-2.1k\Omega}{2.3k\Omega} \]

\[ \Rightarrow V_{04} = \frac{-2.1k\Omega}{2.3k\Omega} \]

\[ R_{in4} = \sqrt{3 \min \cdot (275.5 + 124)} = 29k\Omega \]
$Q_{11Qz}$:

\[ V.G. \]

If CMRR is large, then differential gain is \( \approx \) single-ended gain.

\[ \text{Req} = \frac{2k\Omega}{2k\Omega} = 1.87k\Omega \]

Imp is large \( \rightarrow \) neglected.

\[ \frac{V_{t+}}{V_{t-}} = -\frac{\text{Req}}{R_{2z} + 640\Omega} \]

\[ \frac{V_{t+}}{V_{t-}} = \frac{1.87k\Omega}{26\Omega} = 2.81 \]

\[ \frac{V_{t+}}{V_{t-}} = 1.41 \]

\[ R_{1z} = \frac{\beta(640\Omega + 10\Omega)}{\mu} = 66.6k\Omega \]

\[ R_{1z, 1mp} = 66.6k\Omega / 10k\Omega = 6.7k\Omega \]

\[ AV, \text{ amplifier} = 1.41 \cdot (7.3) \cdot 0.996 \cdot 0.91 \cdot 0.89 = 8.27 \]
Signal swing limits

- many are possible - you must check cutoff & saturation of all devices.

- dominant here are:

  - cutoff of Q8
  - cutoff of Q4
  - Saturation of Q4
  - Saturation of Q7
  - Cutoff of Q3
Cutoff of Q8

(This is the same as base drive to Q10 being limited by I=7)

\[ (\beta +1) \cdot 30 \text{ mA} = 780 \text{ mA} \]

\[ 5 \ R_2 = 8 \ R_2 \quad 780 \text{ mA} \cdot 8 \ R_2 = 6.24 \text{ V} \]

negative swing limit = -6.24 V


Cutoff of Q4:

\[ \Delta I_{c4}, \text{max decrease} = 2mA \]

\[ \Rightarrow \Delta V_{c4} \uparrow \text{max} = 2 mA \cdot R_{2} \Rightarrow 4.2V \]

\[ \Delta V_{out} = \Delta V_{c4} \cdot R_{6} \cdot A_{v9} \cdot Q/4 = +3.38V \text{ (1)} \]

\[ 0.996 \quad 0.91 \]

Cutoff of Q3:

\[ \Delta I_{c3} = -\Delta I_{c4} \]

\[ \text{max decrease in } I_{c3} \text{ is } 2mA \]

\[ \Rightarrow \text{max increase in } I_{c4} \text{ is } 2mA \]

Same calculation as above, but opposite sign

\[ \Delta V_{out} = -3.38V \text{ (1)} \]
Saturation of Q4:

6:45:

\[ V_{CE4} = 4.7 + 1.4 = 6.1 \text{V} \]

\[ V_{CE5\text{cl}} = 0.5 \text{V} \]

\[ \Delta V_{CE\text{max}} = 5.6 \text{V} \] negative going.

Now \[ \Delta V_{CE} = \Delta V_{C} - \Delta V_{B} \]

and \[ \Delta V_{C} / \Delta V_{B} = -R_{225} / R_{65} = -2.1 \Omega / 275 \Omega \]

\[ = -7.6:1 \]

So \[ \Delta V_{CE4} = \Delta V_{CE} / 7.6 = 4.9 \text{V} \] negative going.

\[ \Delta V_{CE4} = \Delta V_{CE4} \cdot \Delta V_{S} \cdot \Delta V_{S} \cdot 8.14 = 4.44 \text{V} \] negative going.

4.9 0.996 0.91
Saturation of Q7

\[ V_{CE} = 5.0 \text{V} \]
\[ V_{CE_{min}} = V_{CE_{sat}} = 1.2 \text{V} \]
\[ \Delta V_{CE} = 4.5 \text{V} \text{ negative going} \]
\[ \Delta V_{out} = 4.5 \text{V} \times 0.91 \times 8/9 = 3.64 \text{V} \text{ negative going} \]

\[ V_{out} = 0.91 \]