ECE ECE145C (undergrad) and ECE218c (graduate)

Mid-Term Exam. Nov 13, 2003

Do not open exam until instructed to.

Open book

Use any and all reasonable approximations (5% accuracy is fine.), *AFTER STATING THEM.*

Name: ______________________
Problem 1, 50 points

You will be using the device model below:

\[ C_{be} = C_{be,depl} + g_m \tau_f \cdot C_{je} = 14 \text{ fF}, \]
\[ \beta = \infty, C_{cbi} = 2.2 \text{ fF}, C_{cb\text{,total}} = 4.3 \text{ fF}, \]
\[ R_{bb} = 21 \text{ Ohms}, R_{ex} = 4 \text{ Ohms}, \text{ and } \tau_f = 0.44 \text{ ps}. \]
This transistor model has 2.5 \text{ um}^2 emitter area.

The transistors have a \( V_{be} = 0.9 \) Volts when operating at 2.0 mA/\text{um}^2.

You will be working on the circuit below. Please note that because the exam is open-book, the circuit is by necessity somewhat unusual.

The circuit diagram is 100\% mirror-symmetric.
All transistors are 2.5 \text{ um}^2 emitter area.
\( I_1 = I_2 = I_3 = 5 \text{ mA}, R_L = 200 \text{ Ohms}, R_f = R_{\text{gen}} = 50 \text{ Ohms}. \) \text{Vindc} = 500 mV (e.g. the inputs are at -500 mVdc).
Part a, 5 points

DC bias.

Draw all DC node voltages and branch currents directly on the circuit diagram.
Part b, 15 points

Midband gains

Find the mid-band gain $V_{out}/V_{in} =$___________________

In order to receive partial credit, it is essential to show appropriate work and small-signal equivalent circuit diagrams.
Part c, 5 points
*device models*

Please enter the device parameter values below.

<table>
<thead>
<tr>
<th>transistor</th>
<th>Rbe</th>
<th>Rbb</th>
<th>Rex</th>
<th>Cbe</th>
<th>Ccbi</th>
<th>gm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1a</td>
<td></td>
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<tr>
<td>Q2a</td>
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<td></td>
</tr>
<tr>
<td>Q3a</td>
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</tbody>
</table>
Part d, 25 points

*high frequency analysis*

**Find the first-order time constants of the circuit:**

- First order time constant due to $C_{cbx}$ of $Q1a$ = ________________
- First order time constant due to $C_{cbi}$ of $Q1a$ = ________________
- First order time constant due to $C_{be}$ of $Q1a$ = ________________

- First order time constant due to $C_{cbx}$ of $Q2a$ = ________________
- First order time constant due to $C_{cbi}$ of $Q2a$ = ________________
- First order time constant due to $C_{be}$ of $Q2a$ = ________________

Total first order time constant = ________________

There are too many 2nd-order time constants to calculate them all; please find only one:

- Second order time constant due to $C_{be}$ of $Q1a$ and $C_{be}$ of $Q2a$ = ________________

Please show all your work clearly below
Problem 2, 50 points

You will be using the device model below:

\[ C_{be} = C_{be,depl} + g_m \tau_f. \]
\[ C_{je} = 14 \text{ fF, } \]
\[ \beta = \infty, \ C_{cibi} = 4.3 \text{ fF, } C_{cbx} = 0 \text{ fF, } R_{bb} = 0 \text{ Ohms, } R_{ex} = 0 \text{ Ohms, } \text{ and } \tau_f = 0.44 \text{ ps. } \]
This transistor model has 2.5 um^2 emitter area.

The transistors have a V_{be} = 0.9 Volts when operating at 2.0 mA/um^2.

You will be working on the circuit below. Please note that because the exam is open-book, the circuit is by necessity somewhat unusual. This problem most definitely requires thinking, rather than "plug and grind".

The circuit diagram is 100% mirror-symmetric.
All transistors are 2.5 um^2 emitter area
I1=I2=I3=5 mA, R_L=200 Ohms, R_f=R_{gen}=50 Ohms. \( V_{indc} = 500 \text{ mV (e.g. the inputs are at } -500 \text{ mVdc).} \)
Q1a/b and Q3a/b have zero base-emitter and base-collector capacitance
Part a, 5 points

DC bias.

Draw all DC node voltages and branch currents directly on the circuit diagram.
Part b, 5 points

Circuit representations

First draw a half-circuit equivalent circuit model of the amplifier, representing the transistors with transistor symbols. Then draw a second half-circuit equivalent circuit model of the amplifier, representing the transistors with hybrid pi models.
Part c, 15 points

*Midband gains (NOT EASY!)*

Using nodal analysis (or other methods you prefer), find the mid-band gain $V_{out}/V_{in}$. Please note that the feedback effect of $R_f$ has a major effect and cannot be ignored.
Part d, 5 points

device models

Please enter the device parameter values below.

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</table>
Part e, 20 points

high frequency analysis

Now find the first-order and second order time constants of the circuit. This is quite difficult, and will require clear understanding of the definitions of $R_{11}^0$, etc. Defining Cbe of Q2a as $C_1$ and Ccb of Q2a as $C_2$, Find $R_{11}^0$, $R_{22}^0$, $R_{22}^1$. Show all of your work clearly.