1. Print and sign your name on this page before you start.
2. You are allowed two, 8.5"x11" handwritten sheets. No books or notes.
3. A correct expression is worth 75% of the credit. The calculation gets you the rest.
4. You have until 4/25/03 to bring any grading issues to Prof. Spanos' attention.

Problem 1 [48]
Problem 2 [16]
Problem 3 [16]
Problem 4 [20]
TOTAL [75] σ=16 [100]

MOS Device Data1 (you may not have to use all of these...)
μ/Cox = 50μA/V², μ/Cox = 25μA/V², V Th = -V th = 1V, Lmin = 2μm, V BS = 0,
L = L when L = 1μm, and it is otherwise proportional to 1/L
Cox = 2.2fF/μm², C p = 6fF/μm², C p = 0.3fF/μm², C p = 0.5fF/μm²,
C p = 0.35fF/μm, C p = 0.5fF/μm, C p = 0.5fF/μm

BJT Device Data1 (you may not have to use all of these...)
β = β = 100, β = 10¹⁷A, V CE SAT = 0.1V, V A = 25V, τ r = 50ps, C p = 15fF/V BS = 0.7V,
C A = 10fF/V BS = 2.0V

1 Except as indicated on the particular problem...

Problem 1 of 4: Answer each question briefly and clearly. (6 pts each, 48 total)

1.1 What are the typical values of R in, R out for a decent CC voltage buffer?

R in 5-10 Ω 100-1000 Ω 10-20 kΩ
R out 5-10 Ω 100-1000 Ω 10-20 kΩ

1.2 Why is it important to make the base of a BJT as short as possible? (choose one)
- So that the transistor occupies less space
- So that there are no ohmic losses in the base
- So that almost all injected minority carriers make it across
- So that holes and electrons stay uniformly distributed

1.3 What happens when the base of a BJT is very short? (choose one)
- The transconductance drops in value
- The beta drops in value
- The τ r drops in value
- The Early voltage gets delayed

Provide a brief explanation of the mechanism responsible for the above:

Box width modulation due to the CB depletion region making the base even shorter (decreases |V t|)

1.4 What happens when the channel of a MOSFET is very long? (choose one)
- The transconductance increases
- Velocity saturation kicks in
- The transistor gets too hot
- The τ r increases in value

Provide a brief explanation of the mechanism responsible for the above:

Channel length modulation is less of a problem for long transistors (decreases )
1.5 Why it is important to have a current supply with a huge (i.e. tens of MOhms) internal resistance when you design a current buffer utilizing a Common Base BJT? (Typical \( r_c \) for a BJT is 100kOhms)

\[ \text{because } r_c \text{ is meant to have a huge output resistance and you do not want the } 70 \text{ to limit it!} \]

\[ r_o = \left( 1 + \frac{r_o}{(r_o||r_c)} \right) \]

1.6 Why it is NOT so important to have a current supply with an internal resistance greater than ~1MOhm when you are designing a Common Emitter amplifier? (Typical \( r_e \) for a BJT is 100kOhms)

\[ \text{Because } r_e \text{ goes in parallel to } r_o \text{ and } r_o \text{ limits the base value. A very large } r_e \text{ will be wasted...} \]

\[ r_o = \frac{r_o}{r_e} \]

1.7 Draw the small signal model of the forward biased diode. Name all distinct capacitive components.

1.8 Provide a brief definition of the transition frequency \( \omega_c \) of the BJT transistor.

the frequency at which a CE amp with stored output has a current gain of \(-1\).
Problem 3 of 4: Answer each question briefly and clearly. (16 points)

Device Data
- \( I_s = 10^{-11} \text{A} \)
- \( \beta_f = \beta_r = 100 \)

You are given the above Common Collector amplifier, with an ideal current supply source, and with values as shown above. Please do the following:

3.1 Calculate the output voltage swing, assuming that the \( I_{s,up} \) needs a minimum of 0.5Volts across it in order to operate properly, and \( V_{CE,ESAT} \) is 0.1V.

\[
\begin{align*}
\text{\( V_{OUT,\text{MAX}} \)} & \text{: Limited by } I_{s,up} \text{ staying in SAT} \\
\text{\( V_{OUT,\text{MIN}} \)} & \text{: Limited by } I_{s,up} \text{ staying in saturation}
\end{align*}
\]

<table>
<thead>
<tr>
<th>Expression</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{OUT,\text{MAX}} = V^+ - V_{CE,\text{ESAT,MIN}} = 2.5 - 0.1 )</td>
<td>2.4V</td>
</tr>
<tr>
<td>( V_{OUT,\text{MIN}} = V^- + V_{s,\text{MIN}} = -2.5 + 0.5 )</td>
<td>-2.0V</td>
</tr>
</tbody>
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3.2 Draw the equivalent small signal circuit of the common collector amplifier shown on the preceding page.
Problem 4 of 4: Answer each question briefly and clearly. (20 points)
You are given a common emitter amplifier with $R_E$ (degeneration emitter resistor), and an extra capacitance $C_E$ connected across that resistor.

Recall that without the capacitance $C_E$, the formulae for this amplifier are:

$$G_m = \frac{g_m}{1 + g_m R_E}$$
$$R_m = \frac{1}{g_m R_E}$$
$$T_{o} = \frac{1 + g_m R_E}{1 + g_m R_E}$$

4.1 Write expressions for $R_m$, $R_{out}$, and $G_m$ as a function of $\omega$ when $C_E$ is present (neglect all the transistor small signal capacitances).

All we have to do is to replace $R_E$ with $Z_E$:

$$Z_E = \frac{1}{j \omega C_E}$$

Expression | Value
--- | ---
$G_m = \frac{g_m}{1 + g_m Z_E}$ | $0.9 \text{mS} \text{ @ } (-21 \text{dB})$
$R_m = \frac{1}{g_m Z_E}$ | $0.9 \text{mS} \text{ @ } (-24 \text{dB})$
$R_{out} = \frac{70 (1 + g_m Z_E)}{1 + j \omega C_E}$ | $1000 \text{ rods / sec}$

4.2 Given the following values: $R_E = 10k\Omega$, $g_m = 0.9 \text{mS}$, and $C_E = 100 \text{mF}$, write the expression $G_m(\omega)$, restate it to show its pole(s) and zero(e) and plot it on a Bode Plot, whose vertical axis is in units of $20 \log_{10}(\text{mS})$. (These units are actually dBm with reference of 1mS, i.e. a value of 1mS will show as 0db, 10mS will show as 20db, etc.)

$$G_m = \frac{g_m}{1 + g_m (R_E + j \omega C_E)}$$

Expression | Value
--- | ---
$G_m(\omega) = \frac{g_m}{1 + g_m (R_E + j \omega C_E)}$ | $0.9 \text{mS} \text{ @ } (-21 \text{dB})$

$G_m$ when $\omega$ very low = $\frac{9g_m}{1 + 9g_m R_E}$ | $0.9 \text{mS} \text{ @ } (-24 \text{dB})$

$G_m$ when $\omega$ very high = $9g_m$ | $0.9 \text{mS} \text{ @ } (-24 \text{dB})$

Plot of $G_m(\omega)$ and $P_m$ with $Z_l$:

- $Z_l = 1 + j \omega C_E$
- $P_m = \frac{1 - g_m R_E}{R_E}$