# *Microelectronic Devices and Circuits- EECS105*
## *Second Midterm Exam*

*Wednesday, April 16, 2003*

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*Your Name:* Official Solutions
*(last)* *(first)*

*Your Signature:* ______________________

1. *Print and sign your name on this page before you start.*
2. *You are allowed two, 8.5"x11" handwritten sheet. No books or notes!*
3. *A correct expression is worth 70% 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* | $\mu$=75 $\sigma$=16 | */100* |

MOS Device Data[1] (you may not have to use all of these...)

$\mu_n C_{ox} = 50\mu A/V^2$, $\mu_p C_{ox} = 25\mu A/V^2$, $V_{Tn} = -V_{Tp} = 1V$, Lmin = 2μm. $V_{BS} = 0$.
$\lambda_n = \lambda_p = 0.1V^{-1}$ when L = 1μm, and it is otherwise proportional to 1/L
$C_{ox} = 2.3fF/\mu m^2$, $C_{jn} = 0.1fF/\mu m^2$, $C_{jp} = 0.3fF/\mu m^2$, $C_{jswn} = 0.5fF/\mu m$,
$C_{jswp} = 0.35fF/\mu m$, $C_{ovn} = 0.5fF/\mu m$, $C_{ovp} = 0.5fF/\mu m$

BJT Device Data[1] (you may not have to use all of these...)

$\beta_f = \beta_o = 100$, $I_S = 10^{-17}A$, $V_{CE\,SAT} = 0.1V$, $V_A = 25V$, $\tau_F = 50ps$, $C_{je} = 15fF@V_{BE} = 0.7V$,
$C\mu = 10fF@V_{BC} = -2.0V$

[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?

| | | | | | | |
|---|---|---|---|---|---|---|
| Rin | 5-10 Ω | 100-1000 Ω | 10-20 kΩ | (100-300 kΩ) | (1-10 MΩ) | $r_\pi + \beta_o (r_o \| r_{oc} \| R_L)$ |
| Rout | 5-10 Ω | (100-1000 Ω) | (10-20 kΩ) | 100-300 kΩ | 1-10 MΩ | $1/g_m + \frac{R_s}{\beta_o}$ |

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
- [x] 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 transonductance drops in value
- [ ] The beta drops in value
- [x] The $r_o$ drops in value
- [ ] The Early voltage gets delayed

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

Base width modulation due to the CB depletion region making the base even shorter (decreases |VA|)

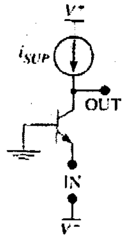
1.4 What happens when the channel of a MOSFET is very long? (choose one)

- [ ] The transconductance increases
- [ ] Velocity saturation kicks in
- [ ] The transistor gets too hot
- [x] The $r_o$ 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 λ)

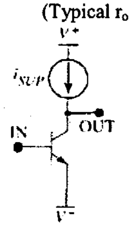
1.5 Why it is important to have a current supply with a huge (i.e. tens of MOhms) internal resistance when you design a current buffer utilizing a Common Base BJT? (Typical $r_o$ for a BJT is 100kOhms)




because a CB is meant to have a huge output resistance and you do not want the $r_{oc}$ to limit it!

$r_{oc} \,//\, [(1+g_m(r_\pi // R_S))r_o]$ HUGE

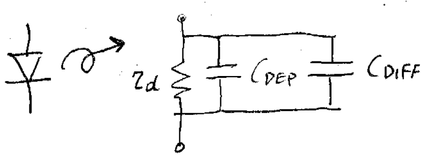
1.6 Why it is NOT so important to have a current supply with an internal resistance greater than ~1MOhm when you are designing a Common Emitter amplifier? (Typical $r_o$ for a BJT is 100kOhms)




Because $r_{oc}$ goes in parallel to $r_o$ and $r_o$ limits the $R_{out}$ value. A very large $r_{oc}$ will be wasted...

$R_{out} = r_o // r_{oc}$

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



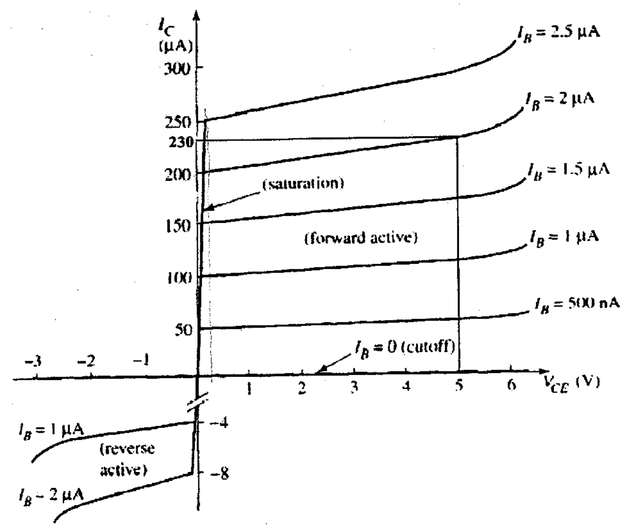

1.8 Provide a brief definition of the transition frequency $\omega_t$ of the BJT transistor.

the frequency at which a CE amp with shorted output has a current gain of -1.



**Problem 2 of 4: Answer each question briefly and clearly. (16 points)**

From the graph below, please estimate $\beta_F$ and $\beta_R$, as well as $r_o$. Also, estimate $g_m$ $r_\pi$ and $V_{CESAT\,min}$ when $I_B = 2\mu A$ at room temperature ($V_{th} = 0.025mV$. Do NOT use the default BJT values on the front page of this exam for this question. *Hint: in reverse active mode the role of the collector and emitter are reversed.* Mark the graph to clarify your method as needed.)

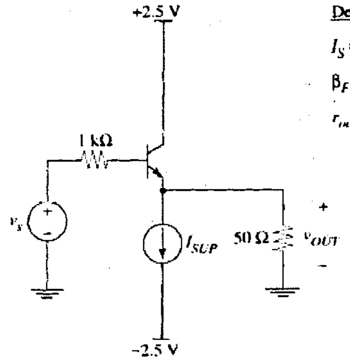



| | expression | value & units | Score |
|---|---|---|---|
| $\beta_F$ = | $I_C/I_B = 200\mu A/2\mu A$ | 100 | 2 |
| $\beta_R$ = | $I_E/I_B = (I_C - I_B)/I_B = \frac{8-2}{2}$ | 3 | 2 |
| $r_o$ = | $\frac{1}{slope} = \frac{1}{30\mu A/5V} = \frac{5V}{30\mu A} = \frac{5V}{3\cdot 10^{-5}A}$ | 167 KΩ | 3 |

Assuming $I_B = 2\mu A$:

| | expression | value & units | Score |
|---|---|---|---|
| $g_m$ = | $\frac{I_C}{V_{th}} = \frac{\beta_F \cdot I_B}{V_{th}} = \frac{200\mu A}{25mV} = \frac{2\cdot 10^{-4}}{25\cdot 10^{-2}} = 0.8\cdot 10^{-2}$ | 8mS | 3 |
| $r_\pi$ = | $\beta_F/g_m = 100/8\cdot 10^{-3}$ | 12.5KΩ | 3 |
| $V_{CE\,SATmin}$ = | ~0.2V (from the graph) | 0.2V | 3 |

**Problem 3 of 4: Answer each question briefly and clearly. (16 points)**




Device Data

$I_S = 10^{-17}$ A

$\beta_F = \beta_o = 100$

$r_o$ ---> ∞

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

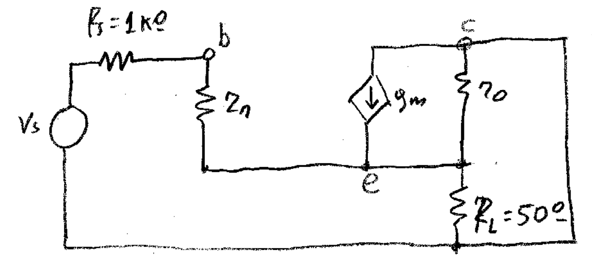
3.1 Calculate the output voltage swing, assuming that the $I_{SUP}$ needs a minimum of 0.5Volts across it in order to operate properly, and $V_{CE\,SATmin}$ is 0.1V.

Voutmax = limited by BJT staying in FAM
Voutmin : limited by Isup staying functional

| Expression | Value |
|---|---|
| $V_{OUTmax}$ = $V^+ - V_{CESATmin}$ = 2.5-0.1 | 2.4V |
| $V_{OUTmin}$ = $V^- + V_{supmin}$ = -2.5 +0.5 | -2.0V |

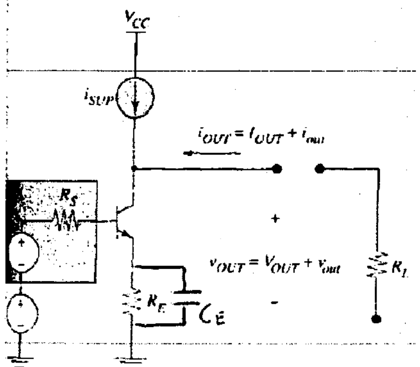


3.2 Draw the equivalent small signal circuit of the common collector amplifier shown on the preceding page.



**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 capacitor $C_E$ connected across that resistor.




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

| $G_m$ | $R_{in}$ | $R_{out}$ |
|---|---|---|
| $\frac{g_m}{(1+g_m R_E)}$ | $r_\pi(1+g_m R_E)$ | $r_o[1+g_m R_E] \parallel r_{oc}$ |

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

All I have to do is to replace $R_E$ with $Z_E = R_E \parallel Z_{CE}$ where $Z_{CE} = \frac{1}{j\omega C_E}$. So $Z_E = \frac{R_E/j\omega C_E}{R_E + \frac{1}{j\omega C_E}} = \frac{R_E}{1+j\omega R_E C_E}$

expression

| | |
|---|---|
| $G_m = \frac{g_m}{1+g_m Z_E} = \frac{g_m(1+j\omega R_E C_E)}{1+j\omega R_E C_E + g_m R_E}$ | |
| $R_{in} = r_\pi(1+g_m Z_E) = r_\pi\left(1+\frac{g_m R_E}{1+j\omega R_E C_E}\right)$ | |
| $R_{out} = r_o(1+g_m Z_E) \parallel r_{oc} = r_o\left(1+\frac{g_m R_E}{1+j\omega R_E C_E}\right) \parallel r_{oc}$ | |

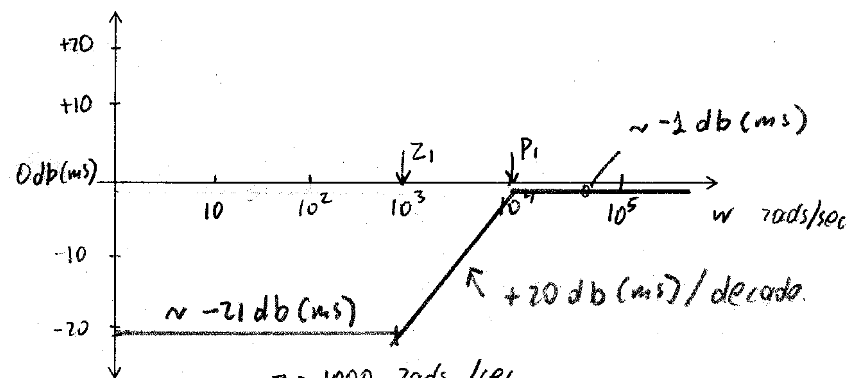


4.2 Given the following values: $R_E$ = 10kOhms, $g_m$ = 0.9mS, and $C_E$ = 100nF, write the expression $G_m(\omega)$, restate it to show its pole(s) and zero(es) and plot it on a Bode Plot, whose vertical axis is in units of $20\log_{10}(|Gm|/mS)$. (These units are actually db-mS with reference of 1mS,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

$$G_m = \frac{g_m}{1+g_m\left(R_E \parallel \frac{1}{j\omega C_E}\right)} = \frac{g_m(1+j\omega R_E C_E)}{1+j\omega R_E C_E + g_m R_E} = \frac{g_m}{1+g_m R_E}\left[\frac{1+j\omega R_E C_E}{1+j\omega \frac{R_E C_E}{1+g_m R_E}}\right]$$

$$Z_1 = \frac{1}{R_E C_E} \qquad P_1 = \frac{1+g_m R_E}{R_E C_E}$$

| Expression | Value |
|---|---|
| $G_m(\omega) = \frac{g_m}{1+g_m R_E}\left[\frac{1+j\omega R_E C_E}{1+j\omega R_E C_E/[1+g_m R_E]}\right]$ | |
| $G_m$ when $\omega$ very low = $\frac{g_m}{1+g_m R_E}$ | 0.09mS ~(-21dbmS) |
| $G_m$ when $\omega$ very high = $g_m$ | 0.9mS ~(-1dbmS) |




$Z_1$ = 1000 rads/sec

$P_1$ = 10,000 rads/sec