Physics 116A Fall 2000: Exam 2

11/22/2000

Closed book and notes except for two 8.5 × 11 in^2 sheets of paper. Show reasoning for full credit. There are 4 problems and 100 points.

1. A bar of silicon has a length of 1 cm and a cross-sectional area of 1 mm^2. At 300 K, Si has 5×10^{28} atoms/m^3 and an intrinsic carrier concentration of 1.5×10^{16} m^{-3}. The free electron and hole mobilities are 0.13 m^2/Vs and 0.05 m^2/Vs, respectively. The bar is doped with one part per 10^8 of an acceptor impurity.

   (a) A voltage of 10 V is applied across the ends of the bar, producing a uniform electric field in the bar of 1000 V/m. Find the current due to holes in the resulting p-type semiconductor bar, assuming the mobilities of the charge carriers are not changed appreciably by the doping. (The magnitude of the electron's electric charge is 1.6×10^{-19} C.)

   (b) Find the concentration of free electrons in the doped material. Do the electrons contribute appreciably to the current?

2. The figure below represents an NPN BJT biased in the active region. The biasing circuitry is not shown.

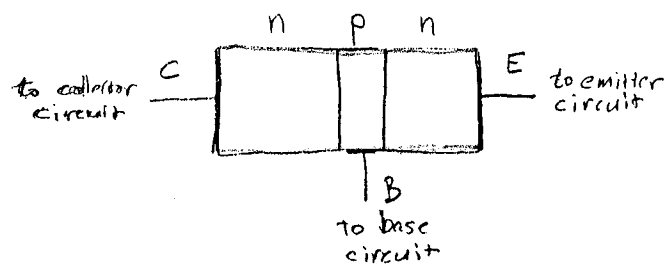
   (a) On the figure, indicate the locations of any depletion regions.

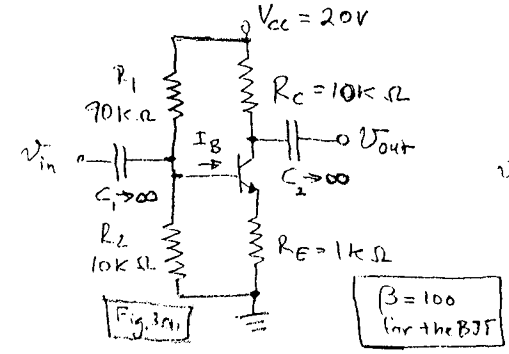
   (b) On the figure, show any forward-biased pn junctions.

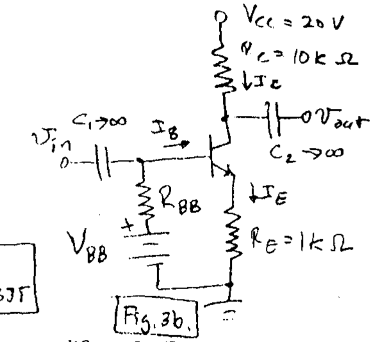
   (c) On the figure, show any reverse-biased pn junctions.

   (d) Which type of charge carrier is primarily responsible for the current through the BC junction? Is the current there primarily due to drift or to diffusion?

   (e) Explain why substantial current flows through a reverse-biased pn junction in the active-region BJT.







3. Fig. 3a above represents a common emitter amplifier. In Fig. 3b, the base bias resistor chain (R_1, R_2 and V_{CC}) has been replaced with its Thévenin equivalent (V_{BB} and R_{BB}) for Q point calculations. Assume the BJT is in the active region. For the BJT, $\beta = 100$, both for large signals and small signals.

   (a) Estimate V_{BE} at the Q point.

   (b) Find V_{BB}, R_{BB} and use Fig. 3b to calculate I_{BQ}, the base current at the Q point.

   (c) Find I_{EQ}, I_{CQ} and V_{CQ}.

   (d) Find r_e and estimate the voltage gain, $A_v = v_{out}/v_{in}$ for the amplifier (you don't need to derive the formulas).

   (e) Draw a simple small-signal AC model for the circuit in Fig. 3a, representing the BJT as a controlled current source and a resistor.

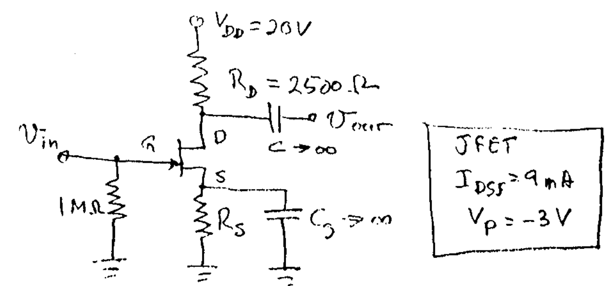
   (f) Use the small signal model just obtained to derive an expression for the effective resistance looking into the transistor base, $R_b \equiv v_b/i_b$. (Hint: find an expression for v_b in terms of i_b, r_e, R_E and β.) Evaluate R_b for the values given.

4. Consider the JFET common source amplifier below. For the JFET, $V_p = -3$ V and $I_{DSS} = 9$ mA. Assume "active region" operation.

   (a) We want $V_{GSQ} = -1$ V. Find I_{DQ} and the proper value of R_S to achieve this.

   (b) Find V_{DQ}, V_{SQ} and verify that the JFET is indeed in the active region.

   (c) Find g_m and estimate $A_v \equiv v_{out}/v_{in}$. (You do not need to derive the formulas for these quantities).



116A Exam 2 11/22/00 Solutions

1.(a) $I_p = \int_A \vec{J}_p \cdot d\vec{A} = J_p A = p q \mu_p E A$ (for holes only as requested)

$$p = 5\times 28\ m^{-3} \times 10^{-8} = 5\times 10^{20}\ m^{-3}$$

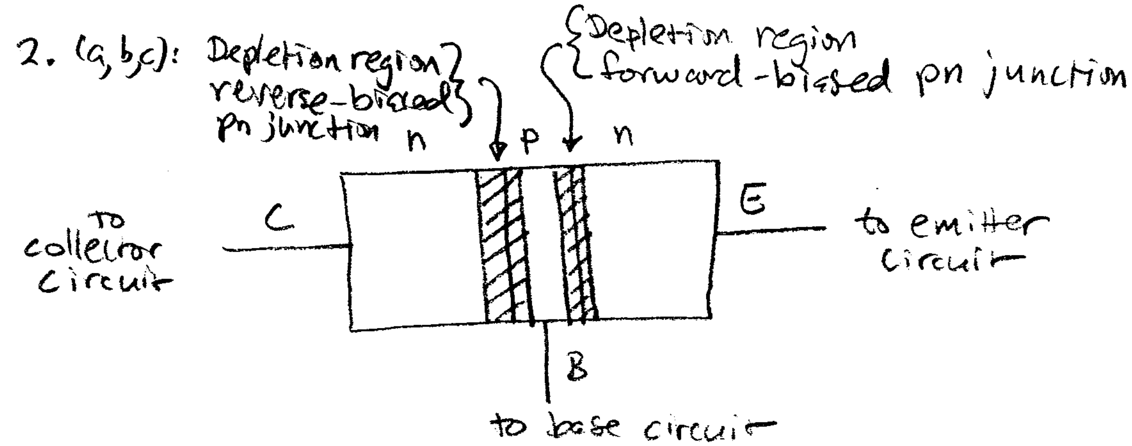
$$I = 5\times 10^{20}\ m^{-3} \times 1.6\times 10^{-19} C \times 0.05\ m^2/Vs \times 1000\ V/m \times 10^{-6} m^2$$

$= \underline{4.0\ mA}$.

(b) $np = n_i^2 \Rightarrow n = \frac{n_i^2}{p} = \frac{(1.5\times 10^{16}\ m^{-3})^2}{5\times 10^{20} m^{-3}} = 4.5\times 10^{11}\ m^{-3}$

$n \ll p$ so the current due to electrons is negligible.

2. (a,b,c):



(d) electrons are main charge carriers. The $\vec{E}$ field points to the right in the BC junction and the negatively charged electrons are moving to the left in response to this field. This is drift current.

(e) The electrons responsible for the current originate in the emitter. They are injected into the thin base by the forward-biased BE junction and diffuse across into the reverse biased BC junction, where they drift into the collector. Since the base is thin, most electrons enter the collector.

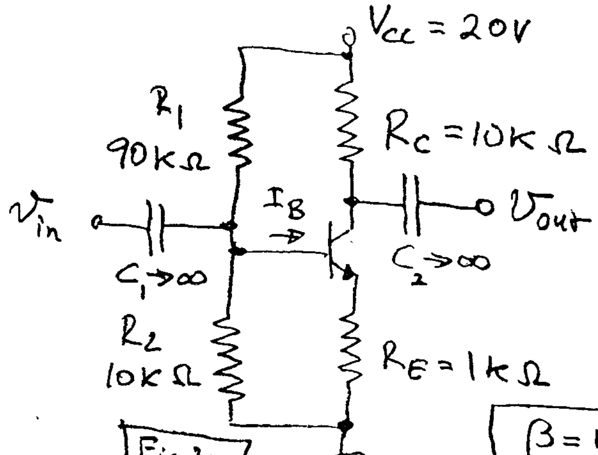


Fig. 3a.

$\beta = 100$ for the BJT

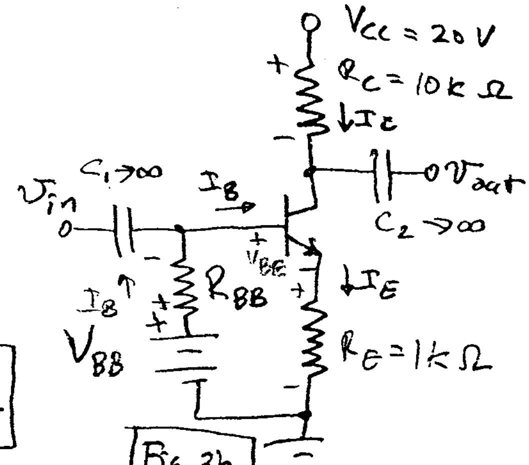


Fig. 3b.

3, (a) $V_{BEQ} = 0.7V$

(b) $V_{BB} = 20V \dfrac{10k\Omega}{10k\Omega + 90k\Omega} = \underline{2.0V}$, $R_{BB} = R_1 \| R_2 = \dfrac{10k \times 90k\Omega}{10k + 90k}$
$= \underline{9.0k\Omega}$

Use KVL: $V_{BB} - I_{B_Q} R_{BB} - V_{BE_Q} - I_{E_Q} R_E = 0$

$2.0V - I_{B_Q}(9k\Omega) - 0.7V - (\beta+1) I_{B_Q}(1k\Omega) = 0$

$I_{BQ} = \dfrac{1.3V}{9k\Omega + 101 \times 1k\Omega} = \underline{11.8\mu A}$

(c) $I_{EQ} = (\beta+1) I_{BQ} = 101 \times 11.8\mu A = \underline{1.2\ mA}$ $(1.19mA)$

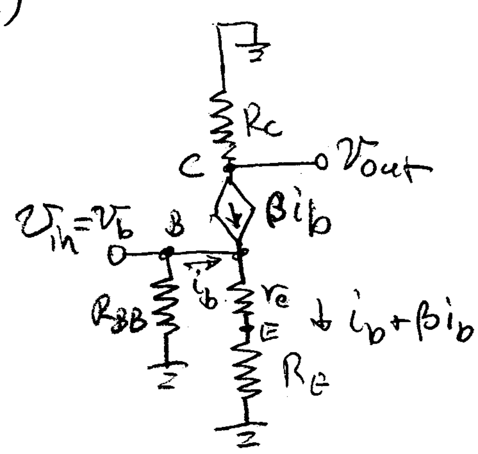
$I_{CQ} = \dfrac{\beta}{\beta+1} I_{EQ} = 1.18\ mA \simeq \underline{1.2\ mA}$.

$V_{CQ} = V_{cc} - R_C \times I_{CQ} = 20V - 10k\Omega \times 1.2mA = \underline{8V}$. $(8.2V)$

(d) $r_e = \dfrac{26\ mA \cdot \Omega}{I_{EQ}} = \dfrac{26\Omega}{1.2} = 21.8\Omega \simeq \underline{22\Omega}$

$A_v \simeq -R_C/(r_e + R_E) = -10k\Omega/(1022\Omega) = \underline{-9.8}$

(e)



(f) $v_b = (i_b + \beta i_b)(r_e + R_E)$
$= (\beta+1)(r_e + R_E) i_b$

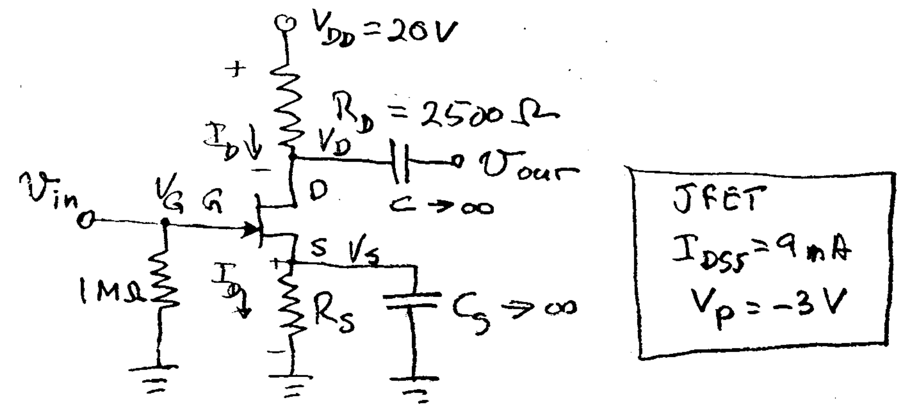
$R_b \equiv v_b / i_b = (\beta+1)(r_e + R_E)$

$R_b = 101(1022\Omega) = \underline{103k\Omega}$

4. (a)

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2 \quad \text{and } V_{GS_Q} = \underline{-1V}.$$

$$I_{DQ} = 9mA\left(1 - \frac{-1V}{-3V}\right)^2 = 9mA\left(\frac{4}{9}\right) = \underline{4mA}.$$



Note $I_{D_Q} = I_{S_Q} = 4mA$.

$$V_{GS_Q} = V_{G_Q} - V_{S_Q} = 0V - I_D R_S = -1V$$

$$R_S = \frac{1V}{4mA} = \underline{250\,\Omega}.$$

(b) $V_{DQ} = 20V - I_D R_D = 20V - 4mA \times 2500\,\Omega = \underline{10V}.$

$V_{SQ} = I_D R_S = 4mA \times 250\,\Omega = \underline{1V}.$

$V_{DS_Q} = V_{DQ} - V_{SQ} = 10 - 1 = \underline{9V}.$

For active region, $V_P < V_{GS} < 0\,V$ (ok) and

$V_{DS} > V_{GS} - V_P$

$9V > -1V + 3V = 2V$ (ok)

∴ active.

(c) Since R_S is bypassed by $C_S \to \infty$, $A_v \simeq -g_m R_D$.

$$g_m = -\frac{2}{V_P}\sqrt{I_D I_{DSS}} = -\frac{2}{-3}\sqrt{4mA \times 9mA} = 4 \times 10^{-3}\,℧$$

$A_v = -4 \times 10^{-3}\,℧ \times 2500\,\Omega = \underline{-10}$