Simon Fraser University

Mechatronic Systems Engineering

Midterm Exam for ENSC 226: Electronic Circuits

Instructor: Behraad Bahreyni

23 February 2012

Time: 110 minutes

Name: Solutions

Student number: _______________

Question	Mark
1	/ 10
2	/ 15
3	/ 20
4	/ 15
5	/ 30
Total	/ 90

SAMPLE

USE PROPER MODELS FOR DEVICES BASED ON THE INFORMATION AVAILABLE TO YOU FOR THAT PARTICULAR PROBLEM. JUSTIFY ANY ASSUMPTION YOU MAKE.

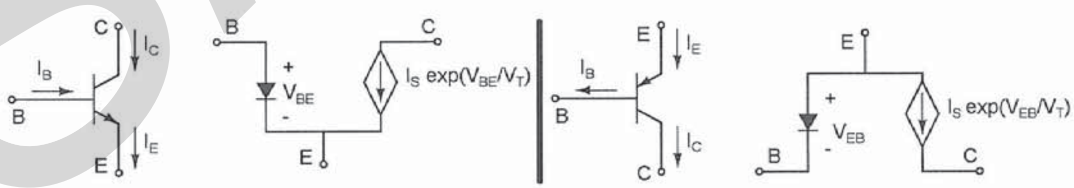
$$\alpha = \frac{\beta}{\beta+1} \qquad r_d = \frac{V_T}{I_D} \qquad V_T = 25mV$$

$$g_m = \frac{1}{r_m} = \frac{I_C}{V_T} \qquad r_\pi = \beta\, r_m = \frac{\beta}{g_m} \qquad r_o = \frac{V_A}{I_C}$$

Physical model of a diode: $I_D = I_s\left(e^{\frac{V_D}{V_T}} - 1\right)$

Ripple voltage in half wave rectifiers: $V_r = \frac{V_P - V_{D,on}}{f\, R_L C_L}$

	Active	**Saturation**	**Cut-off**
	BE forward biased BC reverse biased	BE forward biased BC forward biased	BE reverse biased BC reverse biased
npn	$V_{BE} \approx 0.7V$ $V_{BC} < 0$ $I_C = \beta\, I_B = \alpha\, I_E$ $I_C = I_S\, e^{\frac{V_{BE}}{V_T}}\left(1 + \frac{V_{CE}}{V_A}\right)$	$V_{BE} \approx 0.7V$ $V_{BC} \approx 0.5V$ $I_B > \frac{I_C}{\beta}$ $V_{CE} \approx 0.2V$	$V_{BE} < 0.7$ $V_{BC} < 0.7$ $I_B \approx I_C \approx I_E \approx 0$
pnp	$V_{EB} \approx 0.7V$ $V_{CB} < 0$ $I_C = \beta\, I_B = \alpha\, I_E$ $I_C = I_S\, e^{\frac{V_{EB}}{V_T}}\left(1 + \frac{V_{EC}}{V_A}\right)$	$V_{EB} \approx 0.7V$ $V_{CB} \approx 0.5V$ $I_B > \frac{I_C}{\beta}$ $V_{EC} \approx 0.2V$	$V_{EB} < 0.7$ $V_{CB} < 0.7$ $I_B \approx I_C \approx I_E \approx 0$



SAMPLE

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Question 1. [10 marks]

1.a. [6 marks] In Lab 2 you tested a transistor whose collector and emitter pins were switched in the circuit. Which transistor parameter was mostly affected by this?

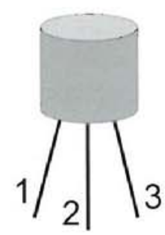
β

What was the conclusion from that experiment?

Do not use it in reverse active mode!

1.b. [4 marks] Assume that you are given a working BJT whose model number has been erased from its package. We want to use a multimeter similar to the one you used in the lab to determine the type (npn or pnp) and pins (base, collector, and emitter) of the transistor. Using the diode more on the multimeter, the following data is obtained:

Between pins 2&1: *0.5V*
Between pins 3&1: *0.7V*
Between pins 2&3: *OPEN*
Between pins 1&2: *OPEN*
Between pins 1&3: *OPEN*
Between pins 3&2: *OPEN*



where, for example, the measurement between pins 1&2 is taken by connecting the positive lead of the multimeter to pin 1 and its negative lead to pin 2. What are the type and pin arrangement of this transistor? Circle the correct answer.

(a) npn; pin 1: Base, pin 2: Emitter, pin 3: Collector

(b) npn; pin 1: Base, pin 2: Collector, pin 3: Emitter

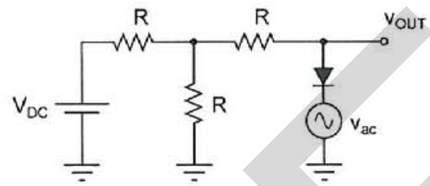
(c) pnp; pin 1: Base, pin 2: Emitter, pin 3: Collector

(d) pnp; pin 1: Base, pin 2: Collector, pin 3: Emitter

(e) None of the above

SAMPLE

Question 2. [15 marks]
Assume $I_S = 10^{-12}A$ for the diode in the circuit to the right. v_{ac} is a small-signal source and $v_{ac} = 0.01 \sin \omega t$. All resistors are the same with a value of $R = 500\Omega$ and $V_{DC} = +6V$.

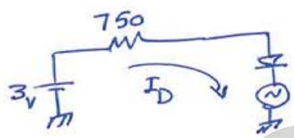


2.a. [9 marks] What is the DC voltage at the output node with an error of less than 0.005V?

V_{OUT} = 0.547 V

0.827

Thevinin circuit



KVL
KCL } 4
Thevenin

$R_{Th} = 500 + 500 \| 500 = 750\Omega$

$V_{Th} = \frac{500}{1000} \times 6 = 3V$

$$A = 3 - 750 I_D + V_D = 3 - 750 I_D - V_T \ln \frac{I_D}{I_S} = 3 - V_D - 750 I_S e^{V_D/V_T}$$

$V_D = 0.6\ V \rightarrow A = -17.46$

$V_D = 0.5 \rightarrow A = 2.136$

$V_D = 0.54 \rightarrow A = 0.65$

$V_D = 0.56 \rightarrow A = -1.571$

$V_D = 0.55 \rightarrow A = -0.238$

$V_D = 0.545 \rightarrow A = 0.253$

$V_D = 0.547 \rightarrow A = 0.068$

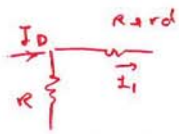
Fixed voltage → 0

Iteration wrong answer 3

Iteration Correct 5

$I_D = 3.18mA$

2.32mA



$I_1 (R + r_d) = (I_D - I_1) R$

$I_1 (2R + r_d) = I_D \cdot R \quad I_1 = \frac{I_D R}{}$

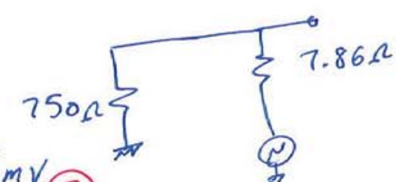
2.b. [6 marks] What is the amplitude of the small-signal output voltage at the output node?

v_{out} = 9.896×10^{-3} * sin ωt

$I_D \rightarrow 1$

$r_d = \frac{25}{3.18} = 7.86\Omega$ 2

10.78



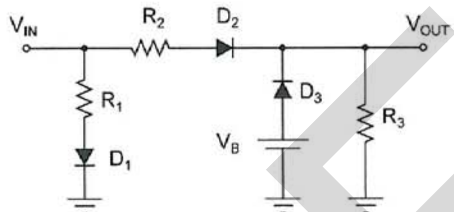
$v_{out} = \frac{750}{750 + 7.86} \times 0.01 = 9.896\ mV$ 3

9.88

~~2/6 A → 1 mark rd → 2 mark~~

SAMPLE

Question 3. [20 marks]



Using the constant voltage drop model for the diodes, draw the input-output voltage characteristic curve for $-10V < V_{IN} < +10V$ for the circuit shown.
Clearly mention the state of all diodes for any voltage range in your analysis and label all important information on your graph (next page).
Assume $V_D(on) = 0.7V$, $R_1 = R_2 = R_3 = 1k\Omega$, and $V_B = +3V$.

① $V_{in} \to -\infty$ D_1: off, D_2: off, D_3: on

$\to V_{out} = 3 - 0.7 = 2.3V$

4 regions
4 marks each
-1 wrong diode
-2 wrong Vout

A: D_1 turns on when $V_{in} > 0.7$
B: D_2 turns on when $V_{in} > 3V$

A happens first

② $V_{in} = 0.7 \to$ D_1: on, D_2: off D_3: on

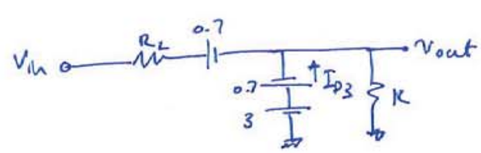
$V_{out} = 2.3V$ (Does not change)

③ D_2 turns on when ~~Vin~~ $V_{in} = 3V$ ~~turns off D3~~

$V_{in} > 3V \to$ D_1: on, D_2: on, ~~D3: off~~ D_3: on

~~$V_{out} = (V_{in} - 0.7) \times \frac{R_3}{R_3+R_2}$~~ $V_{out} = 2.3V$

$$I_{D3} = \frac{V_{out}}{R_3} + \frac{V_{out} - (V_{in} - 0.7)}{R_2}$$



$I_{D3} = 0 \to V_{in} = 2.3 + (2.3 + 0.7) = 5.3V$

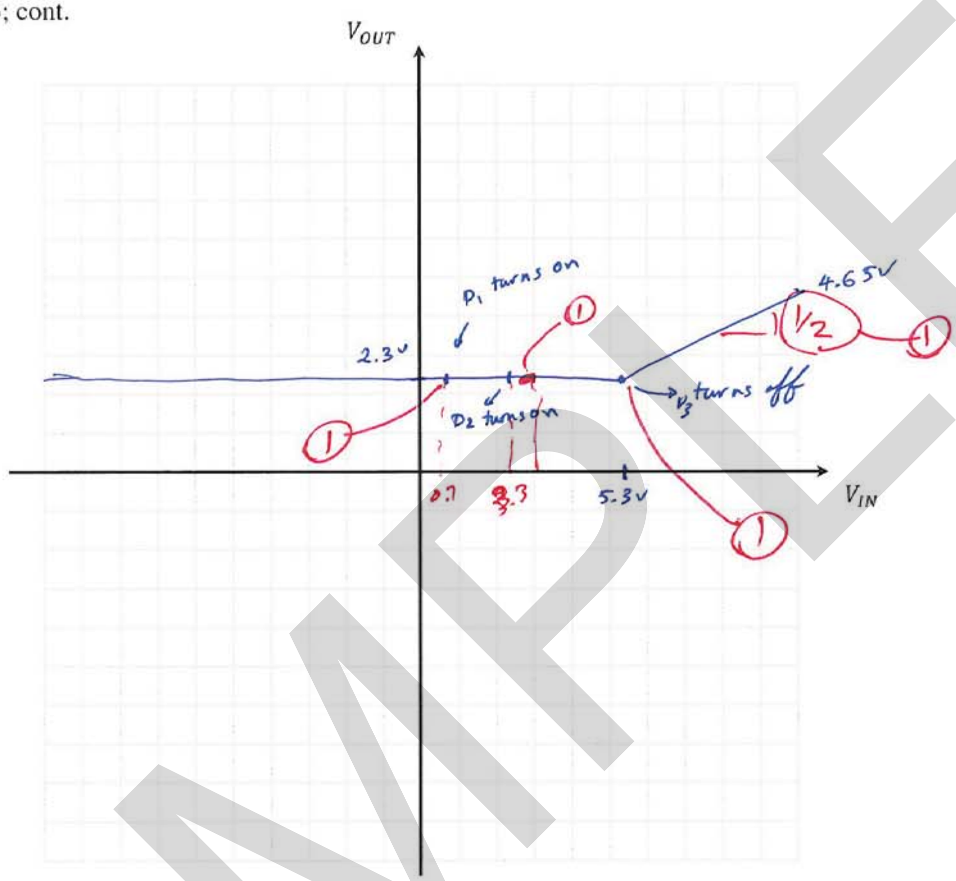
④ $V_{IN} > 5.3 \to$ D_1: on, D_2: on, D_3: off

$$V_{out} = (V_{in} - 0.7) \times \frac{R}{2R} = \frac{V_{in}}{2} - 0.35$$

$V_{in} = 10V \to V_{out} = 4.65V$

SAMPLE

Question 3; cont.



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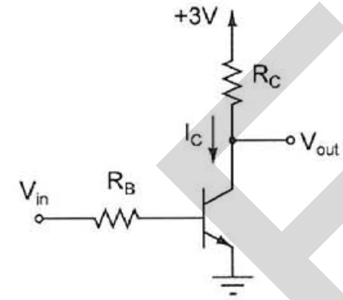
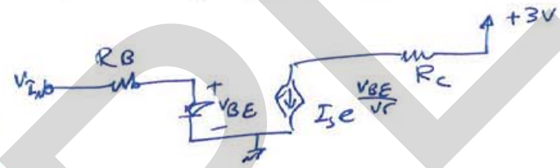
Question 4. [15 marks]

Consider the circuit shown to the right where $R_C = 2k\Omega$ and $R_B = 13k\Omega$. The transistor parameters are $V_{BE}(on) = 0.7V$, $V_{CE}(sat) = 0.2V$, $\beta = 100$, and $V_A = \infty$.
Justify any assumptions you make.



4.a. What is the operating region of the transistor if $V_{in} = 0V$? What is the collector current, I_C?

Operating region: Cut-off $I_C =$ 0 mA



$V_{in} = 0 \rightarrow V_{BE} = 0 \rightarrow$ BE diode is off 2

$V_{BC} < 0 \rightarrow$ BC is off 2

$\rightarrow$ Transistor is in cut-off region 1

$\rightarrow I_C = 0$ 2

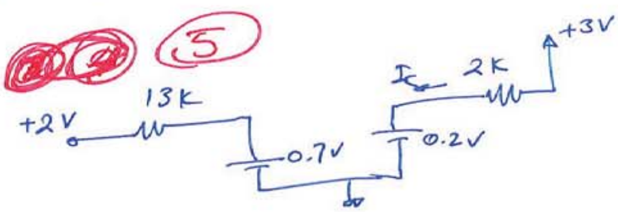
4.b. What is the operating region of the transistor if $V_{in} = +2V$? What is I_C in this case?

Operating region: Saturation $I_C =$ 1.4 mA

$I_B = \frac{2 - 0.7}{13K} = 100\mu A \rightarrow I_C = 10mA$ assumming in active

$\rightarrow V_C = 3 - 10m \times 2k = -17V \rightarrow$ X

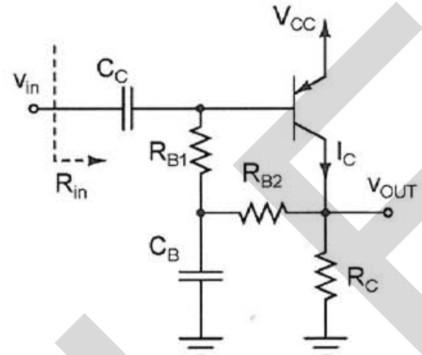
$\rightarrow$ Transistor is in saturation 5



$I_C = \frac{3 - 0.2}{2k} = 1.4mA$ 3

SAMPLE

Question 5. [30 marks]



Consider the circuit shown to the right where the transistor is operating in its active region. Both capacitors can be considered as open-circuits for the DC analysis and as short-circuits for the AC analysis.

Parameters for the pnp transistor are: $\beta = 100$, $V_A = \infty$, $V_{EB}(on) = 0.7V$.

Assume: $V_{CC} = +3V$, $R_C = 2k\Omega$ and $R_{B1} = R_{B2} = 20k\Omega$.

5.a. [8 marks] Calculate the collector current of the transistor.

$I_C =$ 0.95 mA

$V_{CC} = V_{EB} + I_B(R_{B1} + R_{B2}) + (I_B + I_C) R_C$ 5

$\rightarrow I_B = \dfrac{3 - 0.7}{20k + 20k + 101 \times 2k} = 9.5\mu A \rightarrow I_C = 0.95mA$ 3

5.b. [2 marks] What is the DC collector voltage of the transistor?

$V_{OUT} =$ 1.92 V

$V_C = 0.95m \times \frac{101}{100} \times 2k = 1.92V$ 2

if $V_C = I_C R_C \rightarrow$ 1

SAMPLE

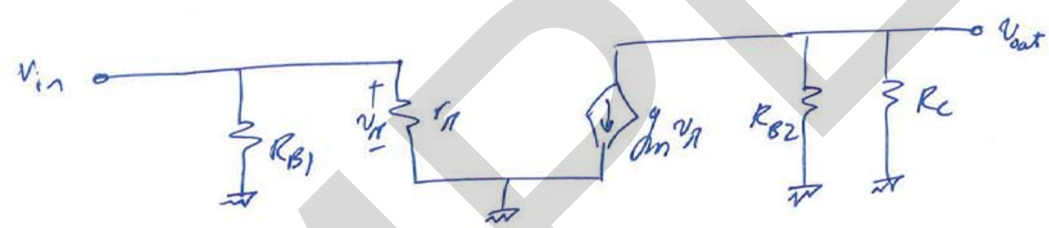
5.c. [2 marks] Calculate the small signal parameters g_m and r_π.

$g_m =$ 38 mS $\qquad r_\pi =$ 2.631 kΩ

$g_m = \frac{0.95}{25} = 38\ mS$ 1

$r_\pi = \frac{100}{38\ mS} = 2.631\ k\Omega$ 1

5.d. [4 marks] Draw the small signal equivalent of the circuit.



Missing Connection −1

Missing v_π polarity −1 Missing $g_m v_\pi$ direction −1

5.e. [6 marks] What is the voltage gain of the circuit?

$A_v = \frac{v_{out}}{v_{in}} =$ −69.16 V/V

2 2

$v_{out} = -g_m (R_C || R_{B2}) v_\pi \quad , v_\pi = v_{in}$

$\rightarrow A_v = -g_m (R_C || R_{B2})$

$R_C || R_{B2} = 1.82\ k\Omega$

$\longrightarrow A_v = -69.16\ V/V$ 2

SAMPLE

5.f. [8 marks] What is the input resistance of the circuit (R_{in} on the graph)?

R_{in} = 2.325 kΩ

$R_{in} = r_\pi \| R_{B1}$ 6

$= 2.325\,k\Omega$ 2

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