NATIONAL UNIVERSITY OF SINGAPORE

EXAMINATION FOR

(Semester I: 2013/2014)

EE2021 –DEVICES AND CIRCUITS

November/December 2013 - Time Allowed: 2.5 Hours

MATRIC. NO

SECTION A	Marks
Q.1	
Q.2	
Q.3	
Q.4	
Q.5	
Q.6	
Q.7	
Q.8	
SECTION A TOTAL	

SECTION B	Marks
Q.9	
Q.10	
Q.11	
SECTION B TOTAL	

TOTAL MARKS	

INSTRUCTIONS TO CANDIDATES:

1. This paper contains **SECTIONS A and B** and comprises **TWENTY SIX (26)** printed pages.
2. Section A contains **EIGHT (8)** short questions (Total marks of 60) and Section B contains **THREE (3)** longer questions (Total marks of 40).
3. Answer all questions. **<u>Write your answers on this examination paper</u>.**
4. The questions **DO NOT** carry equal marks.
5. This is a **CLOSED BOOK** examination.
6. Programmable calculators are allowed in this examination.
7. The following information can be used where applicable:

Electronic charge	q	=	1.602×10^{-19} C
Boltzmann constant	k	=	1.381×10^{-23} J K^{-1}
		=	8.618×10^{-5} eV K^{-1}
Thermal energy (T = 300 K)	kT	=	0.025 eV
Thermal voltage (T = 300 K)	V_T	=	0.025 V
Permittivity of free space	ε_0	=	8.854×10^{-14} F cm^{-1}

<u>For silicon at 300 K:</u>

Intrinsic carrier concentration	n_i	=	1.5×10^{10} cm^{-3}
Relative permittivity of silicon	ε_r (Si)	=	11.7
Relative permittivity of silicon dioxide	ε_r (SiO_2)	=	3.9

8. A set of formulas and tables is given in a **SEPARATE APPENDIX** for your reference.

Section A

Q.1 A piece of n-type silicon is uniformly doped with donor impurities. It is at thermal equilibrium at 300 K. The resistivity of the silicon is 0.031 Ω-cm. The electron and hole mobilities are, respectively, μ_n = 400 cm^2 V^{-1} s^{-1}, μ_p = 80 cm^2 V^{-1} s^{-1}.

(a) Calculate the dopant concentration N_D. Assume that all the dopants are ionized.

[2 marks]

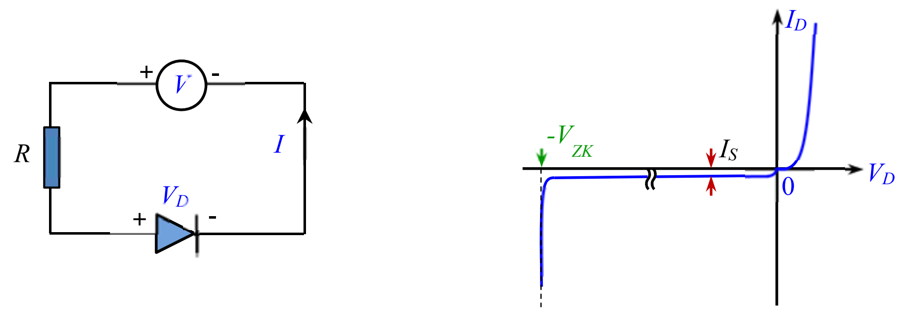
(b) The piece of silicon is to be made p-type by the addition of another impurity, and its resistivity changed to 0.156 Ω-cm. Assume that all the dopants are ionized, and that the mobilities of the electrons and holes remain unchanged, calculate the concentration of the impurity that has to be added.

[2 marks]

$(a)\quad N_D = 5.03\times 10^{17}\,\mathrm{cm}^{-3}$

$(b)\quad N_A = 1\times 10^{18}\,\mathrm{cm}^{-3}$

Q.2 Fig. Q2 (a) shows a simple circuit with a voltage source (V), resistor (R) and a diode and Fig. Q2 (b) shows the current-voltage ($I_D - V_D$) characteristic of the diode. In Fig. Q2(b), I_S is the reverse saturation current of the diode and V_{ZK} is the breakdown voltage of the diode. Polarity of the voltage source (V) and voltage across the diode (V_D) are positive as indicated in Fig. Q2 (a).



(a) (b)

Fig. Q2

(a) When the value of V is positive, state the equations needed to solve for the current (I) through the circuit and describe briefly how to solve the equations. Do not use circuit model to approximate the $I_D - V_D$ characteristic of the diode. (Note: You do not need to solve the equations.)

[3 marks]

(b) When the value of V is negative, but with a magnitude smaller than V_{ZK}, what is I equal to? What is the voltage across the diode (V_D)?

[2 marks]

(c) When the value of V is negative, but with a magnitude larger than V_{ZK}, What is the voltage across the diode (V_D)? What is I equal to?

[3 marks]

Q.3 The following statements refer to an npn bipolar junction transistor biased in the forward active mode. It is further given that the emitter doping concentration is much higher than the base doping concentration, which in turn is much higher than the collector doping concentration. For each statement, circle TRUE if the statement is correct and FALSE if the statement is wrong. **[10 marks]**
(**Marks will be deducted for each wrong answer you give. The minimum mark for this question is zero.**)

(a) The base-emitter junction voltage (V_{BE}) is positive and the base-collector junction voltage (V_{BC}) is negative.

TRUE/FALSE

(b) The depletion region of the base-emitter junction has positively charged ions in the emitter side and negatively charged ions in the base side.

TRUE/FALSE

(c) Since the emitter doping concentration is much higher than the base doping concentration, the injection of holes from the emitter into base is much higher than the electrons injected from the base into the emitter.

TRUE/FALSE

(d) If the width of the neutral base region is comparable to its minority carrier diffusion length, there is negligible recombination of carriers injected from the emitter with the majority carriers in the base in the neutral base region.

TRUE/FALSE

(e) If the width of the neutral base region is much shorter than its minority carrier diffusion length and that there is negligible Early effect, the collector current is relatively independent on the base-collector junction voltage (V_{BC}).

TRUE/FALSE

Q4. In the circuit shown in Fig. Q4, M_1 and M_2 are identical N-MOSFET devices whose parameters are $K_n = 2$ mA/V^2, $V_{THN} = 1$ V, and $\lambda_n = 0.01$ V^{-1}. Find the value of R_{REF} such that the DC drain current of M_1 is equal to 1.5 mA.

[4 marks]

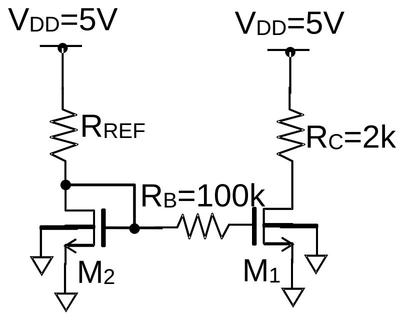


Fig. Q4

$$R_{REF} = 2.087k$$

Q5. For the amplifier circuit shown in Fig. Q5, the transistor Q_1 has the following parameter values: $I_S = 10^{-15}$ A, $\beta = 100$, $V_A = 100$ V. Using the formulae tables or otherwise, calculate the values of

(a) the parameters of the small signal model for this transistor,

[3 marks]

(b) the input resistance, R_{in},

[3 marks]

(c) the output resistance, R_{out},

[3 marks]

(d) the voltage gain, A_v (= v_{out}/v_S).

[3 marks]

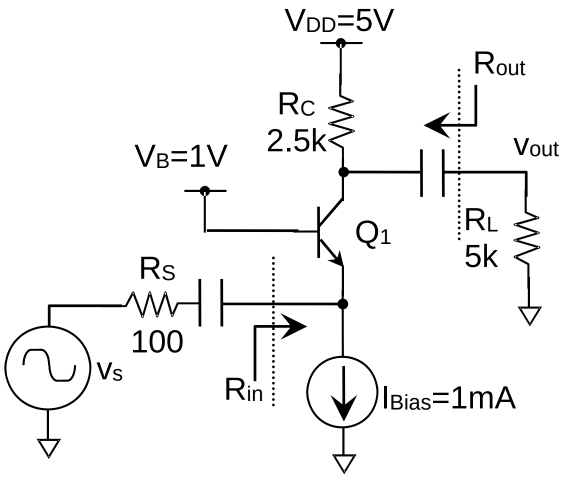


Fig. Q5

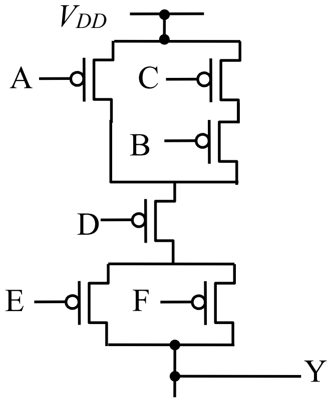
$$(a) g_m = 40mA/V, r_\pi = 2.5k, r_o = 100k$$

$$(b) R_{in} \approx 25\Omega$$

$$(c) R_{out} \approx 2.5k$$

$$(d) A_V \approx 13.34$$

Q.6 Derive the logic function that corresponds to the following PUN: **[4 marks]**



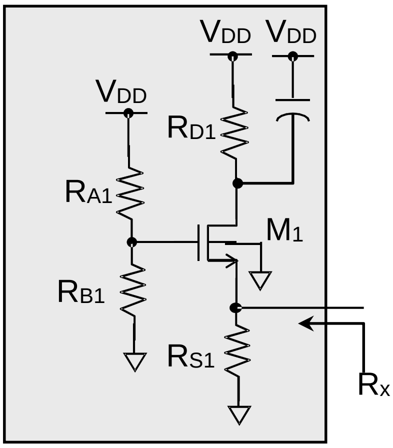
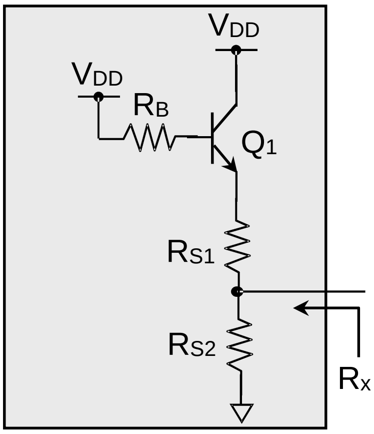
Y=____

Draw the corresponding PDN. **[4 marks]**

$$Y = \left(\overline{A} + \overline{B} \cdot \overline{C}\right) \cdot \overline{D} \cdot \left(\overline{E} + \overline{F}\right)$$

Q.7 Assume that the AC small signal parameters of the BJT are $g_{m,Q1}$, $r_{\pi,Q1}$, $r_{o,Q1}$, and the AC small signal parameters of the MOSFET are $g_{m,M1}$, $g_{mb,M1}$, $r_{i,M1}$, $r_{o,M1}$. Write down the expression for the small signal AC equivalent resistance (R_x) of the following configurations:

[6 marks]

 **[3 marks]**	
 **[3 marks]**	

Q.8 The following statements refer to silicon MOSFETs.

For each of the statements below, circle TRUE is if the statement is correct, and FALSE if the statement is wrong. **[8 marks]**
(**Marks will be deducted for each wrong answer you give. The minimum mark for this question is zero.**)

(a) The body of the pMOSFET is p-type.

TRUE/FALSE

(b) When a MOSFET is operating in the linear region, the channel extends from the source to the drain without pinch-off.

TRUE/FALSE

(c) Body effect occurs in the MOSFET when the drain and the body of the MOSFET are not connected together.

TRUE/FALSE

(d) An nMOSFET is operating in the saturation region when $V_{DS} \geq (V_{GS} - V_{TH})$ and $V_{GS} > V_{TH}$.

TRUE/FALSE

END OF SECTION A

Section B

Q.9 Consider a uniformly doped silicon pn junction at $T = 300$ K with doping concentrations of N_A and N_D, respectively for the p-doped side and n-doped side. The junction capacitance at zero bias is C_{j0} and at 10 V reverse bias is C_{j10}. The ratio of the two junction capacitances is

$$\frac{C_{j0}}{C_{j10}} = 3.78 \ .$$

It is also given that the width of the depletion region of the pn junction in the p-doped side, x_p, at 10 V reverse bias is 0.2 times the total depletion region width, W_{dep}.

(a) Determine the built-in voltage of the pn junction, V_o.

[3 marks]

(b) Show that the doping concentration of the p-doped side and n-doped side are $N_A \cong 1.02\times10^{17}$ cm^{-3} and $N_D \cong 2.55\times10^{16}$ cm^{-3}, respectively.

[4 marks]

(c) Calculate the minority carrier concentrations at the edges of the depletion region at a forward bias of 0.7 V.

[3 marks]

(a) $V_o = 0.752$ V

(b)

(c) At the edge of the depletion region in the p-doped side:

$$n_p(-x_p) = 3.19 \times 10^{15}\ cm$$

At the edge of the depletion region in the n-doped side:

$$p_n(x_n) = 1.28 \times 10^{16}\ cm$$

Q.10

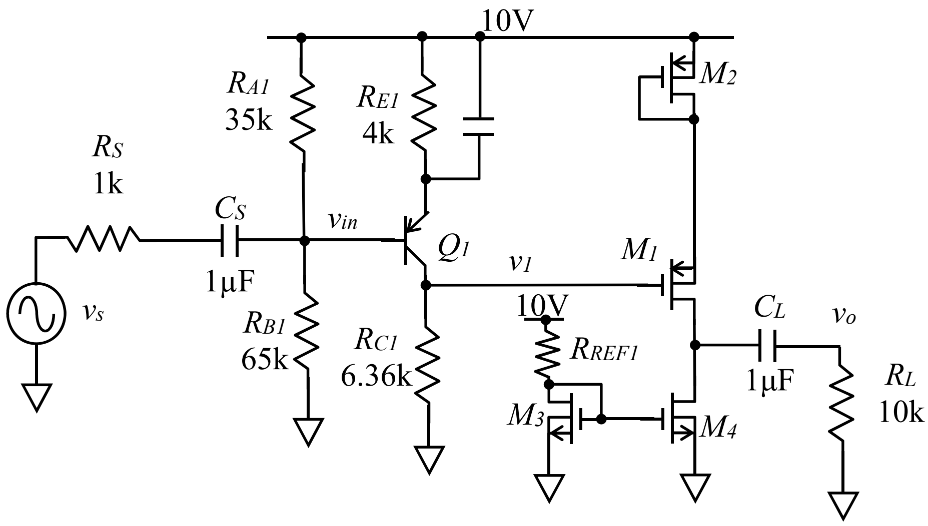


Fig. Q10

In the two-stage amplifier circuit shown in Fig. Q10, assume that the pnp BJT, the NMOS and the PMOS have the following device parameters:

- $V_A = 100$ V and $\beta = 100$ for the BJT, Q_1;
- $K_n = 2\text{m A/V}^2$, $V_{THN} = 1$ V, $\lambda_n = 0.001$ and no body effect for the MOSFETs, M_3 and M_4.
- $K_p = 2\text{m A/V}^2$, $V_{THP} = -1$ V, $\lambda_p = 0.001$ and no body effect for the MOSFET, M_1 and M_2.

(a) Identify the configuration of each stage of the multi-stage amplifier.

[2 marks]

(b) Estimate the collector current for Q1 and its corresponding small signal parameter, i.e. g_{m_Q1}, r_{π_Q1}, r_{o_Q1}.

[5 marks]

(c) Design R_{REF1} such that M_1, M_3, M_4 and M_2 each has a drain current of 3 mA.

[3 marks]

(d) Estimate the small signal parameters of M_1, i.e. g_{m_M1}, and r_{o_M1} assuming the value of the drain current in (c).

[2 marks]

(e) Estimate the overall gain, i.e., v_o/v_s.

[5 marks]

(f) M_2 can be replaced with an NMOS transistor. Show part of the new circuit including only M_1, M_2 and V_{DD} but with M_2 replaced using NMOS transistor. Comment on the effect on the overall gain with reasoning.

[3 marks]

(a) Identify the configuration of each stage of the multi-stage amplifier.

CE-CS with degeneration

(b) Estimate the collector current for Q1 and its corresponding small signal parameter, i.e. g_{m_Q1}, r_{π_Q1}, r_{o_Q1}.

$$I_C \approx 0.7mA$$

$$g_{m,Q1} = 28mA/V, r_{\pi,Q1} = 3.57k, r_{o,Q1} = 143k$$

(c) Design R_{REF1} such that M_1, M_3, M_4 and M_2 each has a drain current of 3mA.

$$R_{REF1} = 2.59k$$

(d) Estimate the small signal parameters of M_1, i.e. g_{m_M1}, and r_{o_M1} assuming the value of the drain current in (c).

$$g_{m,M1} = 4.9mA/V$$
$$r_{o,M1} = 333k$$

(e) Estimate the overall gain, i.e., v_o/v_s.

$$A_V = 3175$$

(f) M_2 can be replaced with an NMOS transistor. Show part of the new circuit including only M_1, M_2 and V_{DD} but with M_2 replaced using NMOS transistor. Comment on the effect on the overall gain with reasoning.

Q.11 You are given the following trigonometry identity:

$$\cos A \cos B = \frac{\cos(A-B)}{2} + \frac{\cos(A+B)}{2}$$

(a) Expand cos(ωt)×cos(100ωt) using the identity shown above.

[2 marks]

(b) Given an input of cos(ωt)×$\cos^2$(100ωt), express the input in terms of the sum of cosine terms. Explain how you would extract cos(ωt) term from this given input, i.e. the output only contains the cos(ωt) term and nothing else.

[5 marks]

(c) Draw an opamp circuit that can perform the task in (a).

[3 marks]

END OF PAPER