Student ID:______________________**Student Name:** ___________________________

EHB222E INTRODUCTION TO ELECTRONICS (11483-11359-11360-11443)

Midterm Exam 1 ✐ 30 October 2019 🕔 17.00-19.00

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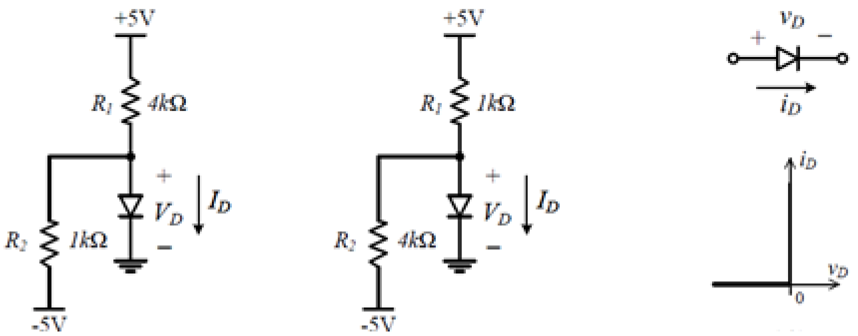
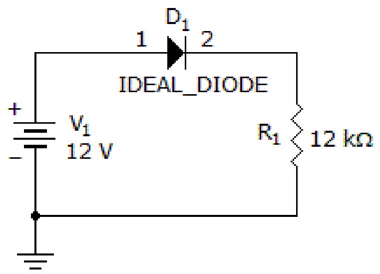
1. Assume you are to create a diode using n- and p-typed doped silicon with the following doping parameters: $N_D = 3\ 10^{17}$ /cm^3, and $N_A = 10^{14}$ /cm^3.
   a. Find the barrier voltage and saturation current for a junction area of 0,25 mm^2. (7 points)
   b. Calculate the specific conductivities of n- and p-type doped silicon. (6 points)
   c. Determine the depletion zone width in unbiased state, when the junction is reverse biased at 3,5 V and when it is forward biased at 0,35 V. (6 points)
   d. Calculate the junction capacitances for the cases in (c). (6 points)

   $L_n = 10\ \mu m$, $L_p = 5\ \mu m$, $\mu_n = 1500$ cm^2/Vs, $\mu_p = 500$ cm^2/Vs. $n_i = 1.5\ 10^{10}$ /cm^3, $q = 1.602\ 10^{-19}$ C,

   $\varepsilon_r = 12$, $\varepsilon_o = 8.85\ 10^{-12}$ F/m, $V_T = 25$ mV.

2. Assume the diodes are ideal as shown on the rightmost image below. Find V_D and I_D for both circuits. HINT: Assume the diode is forward (or reverse) biased and prove (or disprove) it. (25 points)

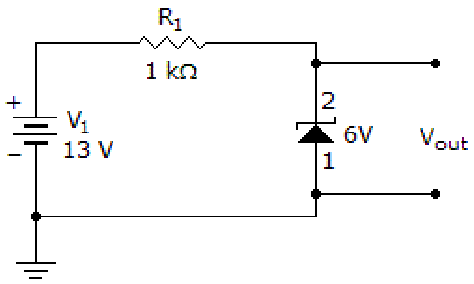




3. What is the current in the circuit shown on the left? (Diode is IDEAL, i.e., $V_D = 0$ V when forward biased) (5 points)

4. What is correct about the breakdown voltage of a Zener diode?
a) undefined b) has high slope c) is zero d) has zero slope
e) none of the above (5 points)

5. What is true about a Zener diode? (5 points)
a) non-linear device b) linear device
c) amplifier d) bipolar e) none of the above

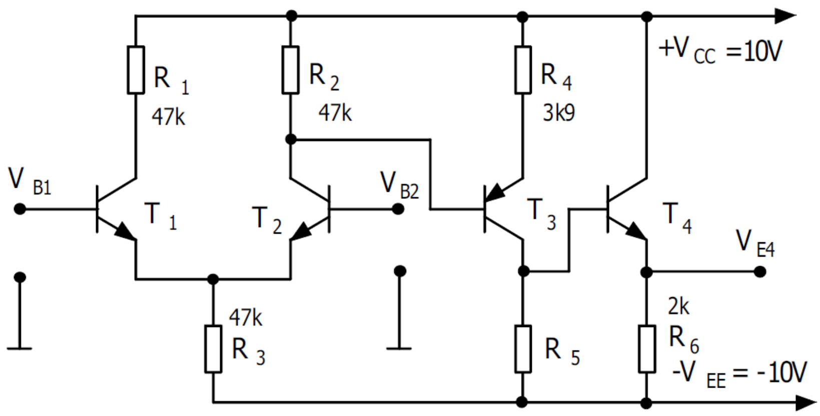


6. What is the Zener current in the circuit shown on the right? (5 points)

7. What is the current gain for BJT? ______________________ (5 points)

GOOD LUCK EVERYONE

8. For the circuit shown, transistors are identical. Their parameters are $V_A = \infty$, V_T = 25 mV, $|V_{BE}|$ = 0,6 V and $h_{FE} = \beta$ = 300. (25 points)
    a. Calculate R_5 for the input voltages of $V_{B1} = V_{B2}$ = 0V and output of V_{E4} = 0 V
    b. Determine DC collector currents and collector-emitter voltages (V_{CE}).



SOLUTIONS:

1. Using Einstein Equation , i.e., $D_{p/n} = V_T \cdot \mu_{p/n}$, we find D_p = 12,5 cm²/s and D_n = 37,5 cm²/s.

    a. $V_B = V_T \cdot \ln\left(\frac{N_A \cdot N_D}{n_i^2}\right)$=640 mV; $I_o = A \cdot q \cdot n_i^2 \cdot \left[\frac{D_p}{L_p N_D} + \frac{D_n}{L_n N_A}\right]$ = 33,8 pA

    b. $\sigma_p = q \cdot \left(\frac{n_i^2}{N_A}\mu_n + N_A\mu_p\right) \cong qN_A\mu_p$= 0,008 /(Ω cm)

    $\sigma_n = q \cdot \left(N_D\mu_n + \frac{n_i^2}{N_D}\mu_p\right) \cong qN_D\mu_n$ = 72,1 /(Ω cm)

    c. unbiased $w_{dep} = \sqrt{\frac{2 \cdot \varepsilon_o \cdot \varepsilon_r \cdot V_B}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right)}$ =2,91 µm

    with reverse bias at 3,5 V, $w_{dep} = \sqrt{\frac{2 \cdot \varepsilon_o \cdot \varepsilon_r \cdot (V_B + V_{bias})}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right)}$ = 7,41µm

    with forward bias at 0,35 V, $w_{dep} = \sqrt{\frac{2 \cdot \varepsilon_o \cdot \varepsilon_r \cdot (V_B - V_{bias})}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right)}$ = 1,96 µm

    Thus, $C = \varepsilon_o \cdot \varepsilon_r \cdot \frac{A}{w} = \begin{cases} 9{,}11\,pF, unbiased \\ 3{,}58\,pF, reverse @ 3{,}5V \\ 13{,}5\,pF, forward @ 0{,}35V \end{cases}$

2. First circuit: Assume the diode is forward biased with V_D = 0 V: $I_D = \frac{5V}{4k} + \frac{-5V}{1k} = \frac{-15V}{4k} < 0$. This case is impossible.

If I_D = 0 mA and V_D < 0 V then $I_D = \frac{5V-V_D}{4k} + \frac{-5V-V_D}{1k} = 0 \rightarrow V_D\left(\frac{-1}{4k} + \frac{-1}{1k}\right) = \frac{-5V}{4k} + \frac{5V}{1k} \rightarrow V_D = -3\ V$, and this is the case. The diode is reverse biased.

Second circuit: Assume the diode is forward biased with V_D = 0 V: $I_D = \frac{5V}{1k} + \frac{-5V}{4k} = \frac{15V}{4k} > 0$. This case is possible.
If I_D = 0 mA and V_D < 0 V then $I_D = \frac{5V-V_D}{1k} + \frac{-5V-V_D}{4k} = 0 \rightarrow V_D\left(\frac{-1}{1k} + \frac{-1}{4k}\right) = \frac{-5V}{1k} + \frac{5V}{4k} \rightarrow V_D = 3\ V$. This case is impossible. The diode is forward biased.

3. What is the current in the circuit shown on the left? $\boldsymbol{I_D = \frac{12V}{12k} = 1\ mA}$

4. What is correct about the breakdown voltage of a Zener diode? **b) has high slope**

5. What is true about a Zener diode? **a) non-linear device**

6. What is the Zener current in the circuit shown on the right? $\boldsymbol{I_Z = \frac{13V-6V}{1k} = 7\ mA}$

7. What is the current gain for BJT? $\boldsymbol{h_{FE} = {}^{I_C}/_{I_B} = \beta}$

8 V_{E4} = 0 V, thus we know emitter current for T_4

$$I_{C4} + I_{B4} = \frac{V_{E4} - (-V_{EE})}{R_6} = \frac{10}{2k} = 5mA$$

Since T_1 and T_2 are identical

$$I_{C1} = I_{C2} = \frac{V_{EE} - V_{BE1}}{2R_3} = \frac{10 - 0{,}6}{94k} = 0{,}1mA$$

From the loop R_2, R_4 and T_3

$$I_{C3} = -h_{FE3}\frac{R_2 I_{C2} + V_{BE3}}{R_2 + (h_{FE3}+1)R_4} \cong -1mA$$

We had found emitter current for T_4 earlier, thus

$$I_{C4} = -h_{FE4}\frac{R_5 I_{C3} + V_{BE4}}{R_5 + (h_{FE4}+1)R_6} = -300\frac{-R_5.1mA + 0{,}6}{R_5 + 301.2k} = 5mA$$

We thus find
R_5=10.8kΩ

$$V_{CE1} = V_{CC} + V_{BE1} - R_1 I_{C1} = 10 + 0{,}6 - 47.0{,}1 = 5{,}9V$$
$$V_{CE2} = V_{CC} + V_{BE1} - R_2 I_{C2} - R_2 I_{B3} = 6{,}06V$$
$$V_{CE3} = -(V_{CC} + V_{EE}) - R_5(I_{C3} + I_{B4}) - R_4(I_{C3} + I_{B3}) = -5{,}48V$$
$$V_{CE4} = V_{CC} = 10V$$