American University of Beirut

Department of Electrical and Computer Engineering

EECE 310 – Electronics
Quiz 1 – November 14, 2008
Closed Book – No Programmable Calculators

90 minutes

Penalty is 5 to 1

(1 to 4 wrong answers do not result in a penalty; 5 to 9 wrong answers cancel one correct answer; 10 to 14 wrong answers cancel two correct answers; and so on)

Name: _____ANSWERS_____________________________ **ID number:** _________________

Assume that V_T = 25 mV, n = 1.5 (unless otherwise specified.)

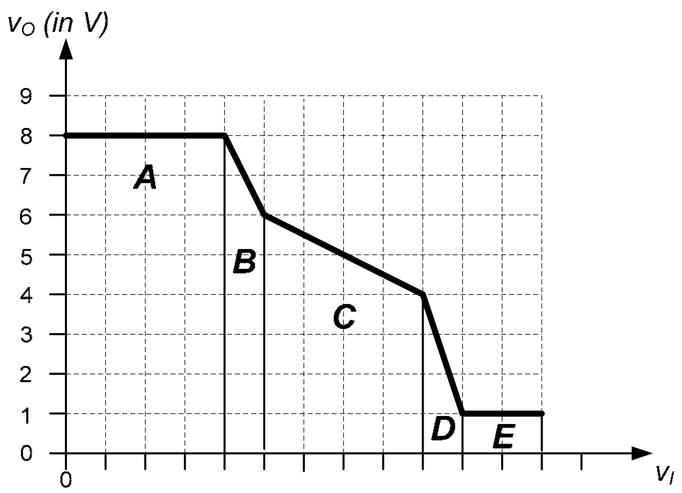
$$J_p = -qD_p \frac{dp}{dx} \qquad J_n = qD_n \frac{dn}{dx}$$

$$J_d = \left(qp\mu_p + qn\mu_n\right)E$$

$$\boldsymbol{I = J \times A}$$

$$V_0 = V_T \ln\left(\frac{N_A N_D}{n_i^2}\right)$$

Consider the amplifier transfer characteristics shown below. The horizontal (v_I) axis *division* is 0.2 V, while the vertical (v_O) axis division is 1 V. The different segments of the transfer characteristics are referred to as A, B, C, D, and E, as shown in the figure.



1. Where should the amplifier be biased for maximum gain? Determine the region of operation.
a) A b) B c) C d) D e) E

For maximum gain, we should look for the region with the largest slope (in absolute value). This region is D (slope is –3/0.2 = –15 V/V.)

2. The amplifier should be biased for maximum input peak-to-peak voltage that results in an *undistorted* output. What is this maximum input peak-to-peak voltage (in V)?
a) 0.8 b) 1.2 c) 1.6 d) 2.0 e) 0.4

The region with largest input range and that produces an output is C. The range of input is 4 divisions or 4×0.2 = 0.8 V.

3. Find the gain of the amplifier when it is biased at an operating point such that $V_{OQ} = 7$ V.
a) –5 b) –4 c) –10 d) –6.7 e) –20

The gain is the slope at the point where $V_{OQ} = 7$ V, which is –(2/0.2) = –10 V/V.

4. Find the maximum value of the output voltage (in V) when the input voltage is $v_I = 1 + 0.6\sin(\omega t)$ V.
a) 8 b) 7 c) 6 d) 5 e) 4

The output for such an input varies in regions A, B, and C. Therefore, its maximum value is 8 V (in region A.)

5. Find the average value of the output voltage (in V) when the input voltage is $v_I = 2 + 0.2\sin(\omega t)$ V.
a) 1.95 b) 2.35 c) 3.25 d) 5.15 e) 4.65

The output voltage in this case is 1 + half_wave_rectified(3 sin(ωt)). The average value of the output is therefore Ave(1 + half_wave_rectified(3 sin(ωt))) = Ave(1) + Ave(half_wave_rectified(3 sin(ωt))) =

$1 + 3/\pi = 1.95$ V.

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6. If the gain of a voltage amplifier is 100, and its clipping levels at the output are +/– 10 V, what should the *peak* value for an input sine voltage be (in V) in order to have the output voltage clipped at 35% of the *RMS* value of the input voltage?

a) 40.4 b) 47.14 c) 23.57 d) 17.68 e) 35.36

The output voltage is clipped at 10 V, which is 35% of the RMS value of the input voltage. For a sine wave, the RMS value is the 0.7071×peak value. Therefore (35/100)×0.7071 V_{I_peak} = 10, which gives V_{I_peak} = 40.4 V

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7. An amplifier is connected to +/– 5 V DC supplies from which it is drawing a current of 30 mA (from each of the two supplies). The amplifier supplies a load of 75 Ω with an 4 V peak sine wave while drawing a negligible current from a 0.8 V peak sine input signal. What is the efficiency of this amplifier?

a) 26.67% b)13.3% c) 8.89% d) 35.6% e) 21.3%

The power coming from the supplies is 5×30 + 5×30 = 300 mW. The output power in the load is $V^2_{O\_peak}/(2R) = 4^2/150$ = 106.7 mW. The efficiency is therefore 106.7/300 × 100% = 35.6%

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8. The hole concentration in a *p*-type silicon sample is described by:

$p(x) = 10^3 + 10^{16}\exp(-x/L_p)$ holes/cm³, where L_p = 1.6 μm and D_p = 10 cm²/sec.

What is the cross sectional area *A* of the sample (in μm²) if the diffusion current at $x = L_p/2$ is 100 μA?

a) 115.4 b) 271.8 c) 164.9 d) 139.6 e) 128.4

$$A = \frac{I}{J} = \frac{I}{-qD_p\frac{dp}{dx}} = \frac{I}{q\frac{D_p}{L_p}10^{16}e^{-x/L_p}} = \frac{IL_p e^{1/2}}{10^{16}qD_p} = \frac{10^{-4}\times 1.6\times 10^{-6}\times 1.649}{10^{16}\times 1.6\times 10^{-19}\times 10^{-3}}$$

$$= 164.9\times 10^{-6}\, m^2$$

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9. If the doping concentration of the *p* side in a PN junction is increased by 30%, find the incremental change (in mV) for the built-in potential barrier.

a) 4.56 b) 6.56 c) 8.41 d) 10.13 e) 2.38

$$V_{02} - V_{01} = V_T \ln\left(\frac{N_{A2}N_D}{n_i^2}\right) - V_T \ln\left(\frac{N_{A1}N_D}{n_i^2}\right) = V_T \ln\left(\frac{N_{A2}}{N_{A1}}\right) = 25\ln(1.3) = 6.56\, mV$$

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10. Which of the following statements is true?
a) Holes move in Silicon due to diffusion mechanism whereas free electrons move due to drift

mechanism

b) Drift is associated with the flow of holes from the region of high concentration to the region of low concentration

c) Drift is associated with random motion due to thermal agitation

d) Diffusion occurs when an electric field is applied across a semiconductor

e) Free electrons drift in the direction opposite to that of the applied electric field

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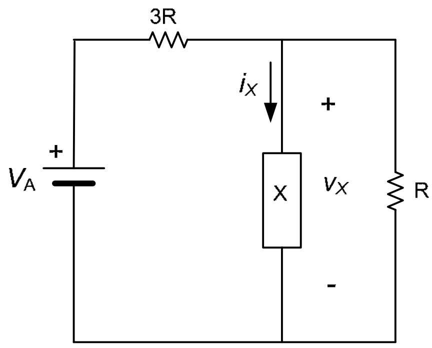
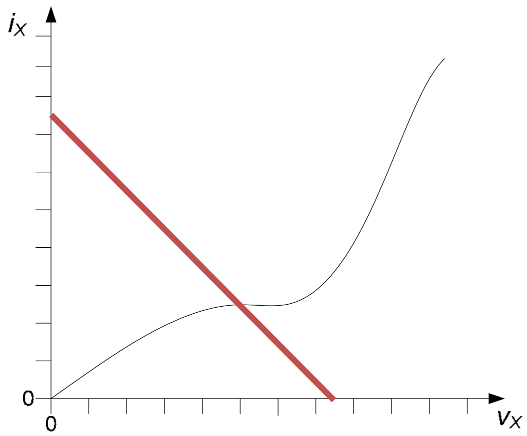
In the circuit shown below, device *X* has the characteristics shown in the i_x–v_x plot. The x-axis division is 0.3 V, and the y-axis division is 20 μA. Assume that V_A = 9 V and R = 20 KΩ.

Use the graphical method to plot the load line.





11. What is the x-axis intercept of the load line (in V)?

a) 4.5 b) 1.5 c) 2.25 d) 3 e) 3.75

The equation of the load line is the circuit equation: $\frac{V_A - v_X}{3R} = i_X + \frac{v_X}{R} \Rightarrow i_X = \frac{V_A - 4v_X}{3R}$.

The x-axis intercept is therefore at $V_A - 4v_X = 0 \Rightarrow v_X = \frac{V_A}{4} = \frac{9}{4} = 2.25\ V$.

Note that this is also equal to $V_{TH} = V_{OC} = V_A R/(R+3R) = V_A/4$.

12. What is the slope of the load line (in μA/V)?

a) 133.3 b) 66.7 c) 44.4 d) 33.3 e) 26.7

The slope of the load line in absolute value is $\frac{4}{3R} = \frac{4}{60K} = 66.7\ \mu A/V$. Note that this is also equal to $1/R_{TH}$, with $R_{TH} = R//3R = 3R/4$.

13. What is the bias point voltage (V_X) of the device (in V)?

a) 0.88 b) 1.35 c) 1.88 d) 3.36 e) 2.5

The x-axis intercept is 2.25 V, which is 2.25/0.3 = 7.5 divisions.

The y-axis intercept is $\frac{V_A}{3R} = \frac{9}{60K} = 150\mu A$, which corresponds to 7.5 divisions.

The plot shows the load line. The bias point is at (4.5 to 5) *x*-axis divisions, or around 1.35 V (closest answer.)

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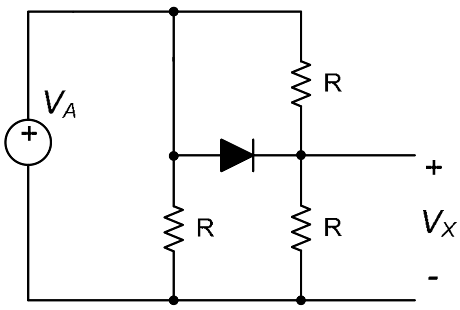
14. The diode in the circuit shown below is biased at a DC current of 10 mA. Find the change in the voltage V_X when the source V_A changes by an amount v_a, not exceeding a few milliVolts. Assume $R = 10\ \Omega$.

a) $0.9\ v_a$ b) $0.558\ v_a$ c) $0.7\ v_a$ d) $0.786\ v_a$ e) $0.863\ v_a$



We should note first that the lower-left resistor is in parallel with the source V_A and has no effect on the currents in the diode or the other two resistors. The diode is connected across (in parallel with) the upper-right resistor. Using small signal analysis, and the voltage divider formula, the voltage v_x becomes: $v_x = v_a \frac{R}{R+R//r_d} = v_a \frac{R+r_d}{R+2r_d}$. The value of r_d is given by: $r_d = \frac{nV_T}{I_D} = \frac{1.5\times25}{10} = 3.75\ \Omega$.

Therefore $v_x = v_a \frac{13.75}{17.5} = 0.786 v_a$.

15. In Problem 14, what is the *change* in diode current (in µA) when v_a is 5 mV.

a) 400 b) 200 c) 285.7 d) 363.6 e) 58.8

The small-signal current in the diode is $i_d = \frac{v_d}{r_d} = \frac{v_a - v_x}{r_d} = \frac{1-0.786}{3.75} 5m = 285.7\ \mu A$

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16. A forward-biased diode is conducting a current of 1 mA at a diode voltage of 0.6 V. An increase in the diode voltage by 0.2 V results in an increase in the diode current by a factor of 400. Find the value of *n* for this diode.

a) 1.158 b) 1.477 c) 1.335 d) 1.853 e) 1.657

At large forward currents, we can write: $V_{D2} - V_{D1} = nV_T \ln(I_{D2}/I_{D1})$.

Therefore $n = (V_{D2} - V_{D1})/ (V_T \ln(I_{D2}/I_{D1})) = 200/25\ln(400) = 1.335$.

17. The same diode of Problem 16 is now connected in series with a 27 MΩ resistor and a 5 V battery, such that the diode is *reverse biased*. Find the voltage across the 27 MΩ resistor (in mV).

a) 27×10^{-3} b) 0.422 c) 64 d) 13.8 e) 2.37

The diode is reverse biased, with a reverse bias of a few Volts. We can therefore safely assume that the current in the diode is equal to $-I_S$. The value of I_S is calculated from the given of Problem 16:

$I_D = 1m = I_S\left(\exp\left(\frac{0.6}{1.335\times25m}\right)-1\right) \Rightarrow I_S = 15.6\ pA$.The drop across the resistor is RI_S = 0.422 mV.

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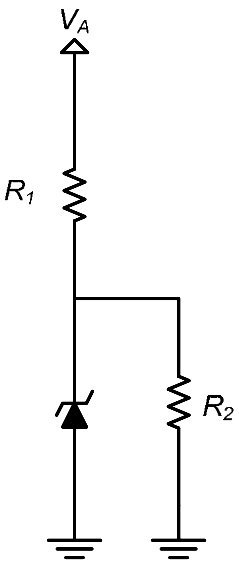
18. A Zener diode is connected as shown in the circuit below. Find the power dissipation in the Zener diode (in mW). Assume that V_A = 10 V, R_1 = 220 Ω, R_2 = 330 Ω, V_{Z0} = 5.4, r_Z = 10 Ω, I_{ZK} = 2 mA, and I_{ZMAX} = 200 mA.

a) 32.7 b) 23.0 c) 59.9 d) 52.9 e) 43.9



The Zener voltage is given by $V_Z = \left(\frac{V_A}{R_1}+\frac{V_{Z0}}{r_Z}\right)(R_1//R_2//r_Z)$ = 5.442 V. The Zener current is I_Z = $(V_Z - V_{Z0})/r_Z$ = 4.23 mA (between I_{ZK} and I_{ZMAX}). The power dissipation in the Zener is I_ZV_Z = 23 mW.

19. Find the voltage (in V) across the Zener when R_2 = 120 Ω.

a) 3.5 b) 4.5 c) 4.3 d) 4.7 e) 5.5

The Zener voltage in this case is given by $V_Z = \left(\frac{V_A}{R_1}+\frac{V_{Z0}}{r_Z}\right)(R_1//R_2//r_Z)$ = 5.19 V. This however is smaller than V_{Z0}. Therefore, the Zener is not in the breakdown region: it is not conducting any (sizeable) current. The Zener is OFF and the voltage across the Zener is given by the voltage divider formula: $V_Z = V_A R_2 / (R_1 + R_2)$ = 3.5 V.

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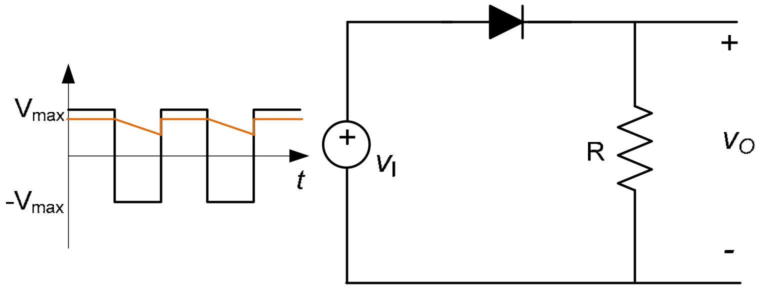
20. The input to a half-wave rectifier is a square wave with zero average, a peak value of 7 V, and frequency of 100 Hz. The diode drops 0.7 V when conducting. The load is a 3 KΩ resistor. Find the average value of the load current (in the resistor; in mA).

a) 1.55 b) 0.88 c) 1.05 d) 1.22 e) 1.38



The load current is a half-wave-rectified square wave (positive parts only), with a pulse (or peak) level of (7 – 0.7) / 3K = 2.1 mA. The average value of such a square wave is one half the pulse level or 2.1/2 = 1.05 mA.

21. A 330 μF capacitor is now connected in parallel with the load, in the circuit of Problem 20. Find the value of the resulting ripple voltage (in mV).

a) 20.3 b) 15.5 c) 40 d) 31.7 e) 25.8

The diode discharges during half the cycle (see figure above):

$V_{RIPPLE} = V_{O\_PEAK} - V_{O\_PEAK} \exp(-(\boldsymbol{T/2}) / (RC)) =$

$(7 - 0.7) \times (1 - \exp(-1/(2\times100\times3000\times330\times10^{-6}))) = 31.7$ mV

22. Find the PIV (in V) of the diode in the circuit of Problem 21.

a) 19.3 b) 11.3 c) 13.3 d) 15.3 e) 17.3

The most negative voltage on the diode occurs when the input switches from $+V_{max}$ to $-V_{max}$. The absolute value of the diode voltage in this case is $2V_{max} - V_D = 14 - 0.7 = 13.3$ V.

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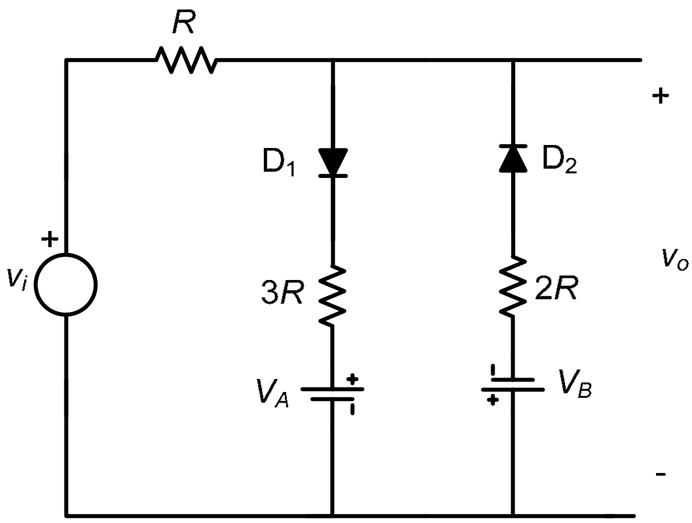
In the circuit shown below, assume $V_A = 5$ V, $V_B = 15$ V, and $R = 1$ KΩ. The diodes are *ideal*.



23. Find the value of the input voltage (in V) at which diode D_1 starts to conduct.

a) 6 b) 4 c) 3 d) 2 e) 5

D_1 starts to conduct when V_i becomes equal to $V_A = 5$ V.

24. Find the peak-to-peak variation in the output voltage (in V) when the input voltage is $v_I = -20 + 1.5\sin(\omega t)$ V.

a) 2 b) 1.6 c) 2.4 d) 1.2 e) 0.8

The input voltage varies between –20 – 1.5 = –21.5 V to –20 + 1.5 = –18.5 V. For this range of voltages, diode D_2 is ON, while diode D_1 is OFF. The current in D_2 is $I_{D2} = (-V_i - V_B) / (R + 2R)$.
The output voltage is $-V_B - 2R \times I_{D2} = -V_B + 2(V_i + V_B)/3$
Since V_B is a DC voltage, the time-varying component in the output voltage has a peak-to-peak value equal to $2V_{i\_peak\text{-}to\text{-}peak} / 3 = 2\times2\times1.5/3 = 2$ V.

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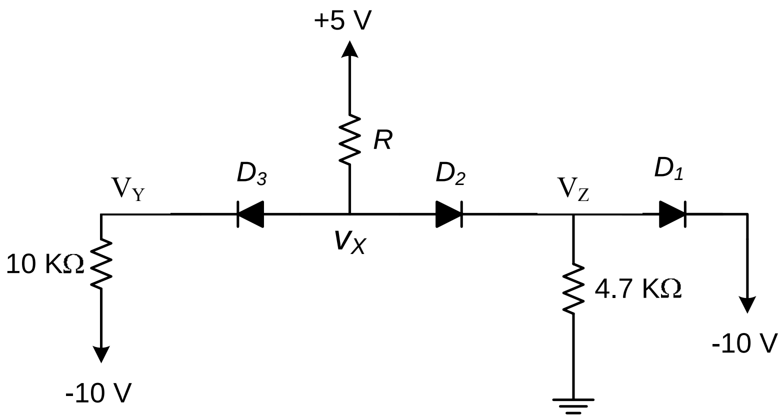
25. In the circuit shown below, the diodes are modeled by a constant voltage drop of 0.7 V when conducting. Find the current in D_1 (in mA) when R = 1.2 KΩ.

a) 3.9 b) 13.2 c) 9.5 d) 6.9 e) 4.8



Assume all three diodes are ON. The voltage V_Z will be –10 + 0.7 = –9.3V. The current in the 4.7K resistor is therefore 9.3/4.7K = 1.98 mA (flowing up).
The voltage V_X will be –9.3 + 0.7 = –8.6V.
The current in the R resistor will be (5 + 8.6) / R = 13.8/1.2 = 11.33 mA.
The voltage V_Y will be V_X – 0.7 = –9.3 V.
The current in the 10K resistor is (–9.3 + 10)/10 = 0.07 mA (flowing down.)
Therefore, the current in D_3 is 0.07 mA > 0 ,
the current in D_2 is $I_R - I_{D3}$ = 11.33 – 0.07 = 11.26 mA > 0 ,
and the current in D_1 is $I_{D2} + I_{4.7}$ = 11.26 + 1.98 = 13.2 mA > 0 .

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