**ECE 342 Electronics I**

**Exam $\sqrt[3]{8}$** **Oct. 26, 2018**

**Name:** Spencer Goulette

- Make sure you write your name on all pages.
- Detailed descriptions of how you solved the problem will get you maximum partial credit if your final answer is wrong.
- You must provide the correct unit along with your answer in the answer areas. An answer without its unit will be considered incorrect.
- You may only use FE exam approved, so called dumb calculators.
- A table of commonly used constants, parameters and equations is being distributed with the exam.
- Unless noted otherwise, assume room temperature conditions, i.e. T = 300K

| Question | Grade | Out of |
|---|---|---|
| #1 | 16 | 20 |
| #2 | 20 | 20 |
| #3 | 15 | 15 |
| #4 | 18 | 18 |
| #5 | 15 | 15 |
| #6 | 12 | 12 |
| Total Grade | 96 | 100 |

**Choice of candy:** Left Twix

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1. **(20 points)** Each correct answer is worth +2 points. Indicate if the following statements are True or False:

__T__ A pn junction diode is a rectifying device.

__F__ A p-type semiconductor has very few holes compared to electrons.

__F__ The I-V characteristics of a pn junction diode are temperature independent.

F __T__ Arsenic (As) is a group V element. It is an acceptor-type dopant in Si, which is a group IV element.

__T__ A pn junction diode can be used to regulate voltage.

__T__ The resistivity of a semiconductor is related to the drift current.

__F__ The depletion region of a pn junction diode will shrink with increasing reverse bias.

F __T__ A pn junction diode can be used to amplify an AC signal.

__T__ The electronic properties of a semiconductor are temperature dependent.

__T__ Diffusion current in a semiconductor is due to a gradient in the carrier concentration.

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2. **Quick calculations (20 points).** Each of the questions below are quick calculations, usually requiring ***a single equation***.

   a. A Si diode conducts $I_F = 2$ mA when forward biased with $V_F = 0.7$ V. What is the forward bias voltage if the current decreases to $I_F = 1$ mA? $V_T = 26$ mV, and $\eta = 1$.

   $V_{F_{new}} = V_{F_{prev}} + 26m \ln\left(\frac{1mA}{2mA}\right)$

   **$V_F$ =** 0.682 V

   b. A pn junction diode with a built-in potential of $V_{bi} = 0.8$ V has a zero-bias capacitance of $C_{j0} = 2$ nF. What is its junction capacitance at a reverse bias voltage of 16 V?

   $C_j = \frac{C_{j0}}{\sqrt{1 + V_R/V_{bi}}} = \frac{2n}{\sqrt{1 + 16/0.8}}$

   **$C_j$ =** 436 pF

   c. What is the forward bias diffusion capacitance of a pn junction diode forward biased with $I_F = 10$ mA and a minority carrier lifetime $\tau = 260$ ns, operating at room temperature?

   $C_d = \frac{\tau_T}{V_T} I = \frac{260n}{26m} 10m =$

   0.0000001

   **$C_D$ =** 100 nF

   d. A $p^+n$ Si diode has $N_A = 2\text{x}10^{18}$ cm$^{-3}$ and $N_D = 5\text{x}10^{15}$ cm$^{-3}$. Calculate the built in potential, $V_{bi}$, at room temperature. $n_i = 10^{10}$ cm$^{-3}$, $V_T = 26$ mV

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

   **$V_{bi}$ =** 838 mV

   e. What is the conductivity of an n-type Si sample which is doped with $N_D = 5\text{x}10^{15}$ cm$^{-3}$? Take $\mu_n = 1200$ cm$^2$/Vs and $\mu_p = 450$ cm$^2$/Vs.

   $\sigma = q(N_D \mu_n)$

   **$\sigma$ =** 0.96 $1/\Omega$cm

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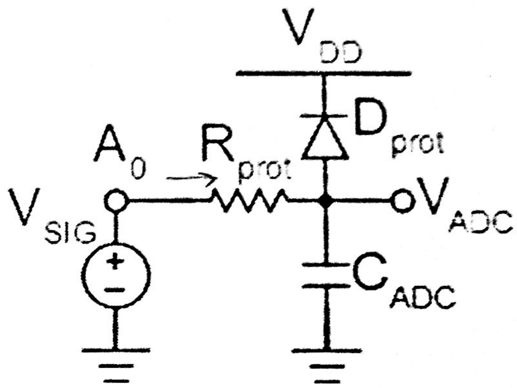
3. **(15 points)** The input protection diode $D_{prot}$ in the circuit below is used to limit the voltage at node ADC, representing the analog-to-digital converter of a microcontroller. The diode has $I_S$ = 1 nA and an ideality factor of $\eta$ = 1.3. The input protection resistor is $R_{prot}$ = 10 kΩ. An external voltage source of $V_{SIG}$ = 7 V is connected to the input pin A0 of the microcontroller. Calculate the voltage at node ADC, $V_{ADC}$. The supply voltage is $V_{DD}$ = 5 V.




$I_{max} = \frac{7-5}{10k\Omega} = 200\,\mu A$

$V_{D_{prot}} = V_T \eta \ln\left(\frac{I}{I_S}+1\right)$

$V_{D_{prot}} = 26m \cdot 1.3 \ln\left(\frac{200\mu}{1n}+1\right)$

$V_{D_{prot}} = 0.4125\ V$

$I_{guess} = \frac{7-5-0.4125}{10k\Omega} = 159\,\mu A$

$V_{D_{prot}} = 26m \cdot 1.3 \ln\left(\frac{159\mu}{1n}+1\right)$

$V_{D_{prot}} = 0.405\ V$

doing another iteration just to check

$I_{max} = \frac{7-5-0.405}{10k\Omega} = 159.5\,\mu A$

so $V_{D_{prot}}$ is 405 mV

$\boxed{V_{ADC} = 5 + 405\,mV = 5.405\ V}$ ✓

$V_{ADC}$ 5.405 V

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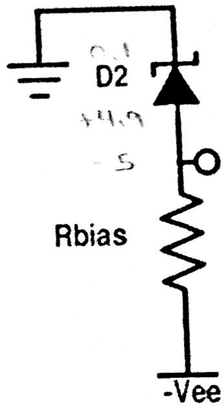
4. **(18 points)** The voltage reference circuit below uses a Zener diode which conducts a current of $I_Z = 1$ mA when biased with $V_Z = 5$ V, and has an equivalent resistance of $r_z = 100\ \Omega$. The supply voltage is $-V_{cc} = -12$ V.

**a)** Calculate the equivalent voltage source $V_{z0}$ of the Zener diode.

**b)** Calculate the required value of the bias resistor $R_{bias}$ such that $V_{out} = -5.0$ V.

**c)** Draw the equivalent circuit. Calculate $V_{out}$ if the circuit is connected to a -15 V supply instead of a -12 V supply.




a.

$V_{z0} = V_z - I_z r_z$

$V_{z0} = 5V - 1m \cdot 100$

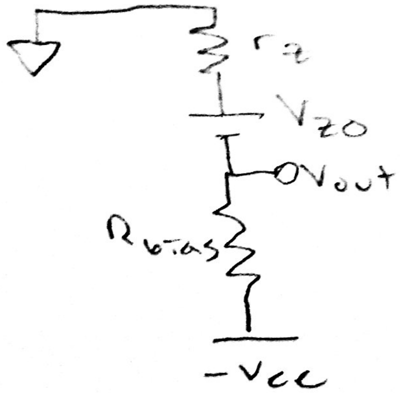
$\boxed{V_{z0} = 4.9V}$

b. $I_D = \frac{-4.9-(-5)}{100} = 1mA$

$R_{bias} = \frac{-5-(-12)}{1m}$

$\boxed{R_{bias} = 7K\Omega}$

c.




$\Delta V_{out} = \frac{rd}{rd+R_1} \Delta V_{supply}$

$\Delta V_{out} = \frac{100}{100+7k}(-3)$

$-0.0422$

$V_{out} = -5 + -0.0422$

$\boxed{V_{out} = -5.042V}$

(a) $V_{z0}$ 4.9 V

(b) $R_{bias}$ 7K $\Omega$

(c) $V_{out}$ -5.042 V

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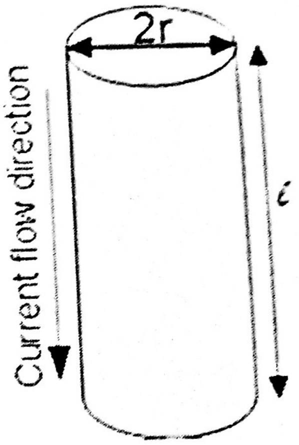
**5. (15 points)** An n-type Si cylindrical sample is doped with $N_D = 2\text{x}10^{16}$ $\text{cm}^{-3}$. It has a diameter of $2r = 1$ mm, and is $\ell = 10$ mm long. Use the following values: $n_i(300K) = 10^{10}$ $\text{cm}^{-3}$, $\mu_n = 1100$ $\text{cm}^2/\text{Vs}$, and $\mu_p = 420$ $\text{cm}^2/\text{Vs}$. Unit charge is $q = 1.6\text{x}10^{-19}$ C.

**a)** What is the conductivity of this sample, from the top surface to the bottom surface?

**b)** A 1 V bias voltage is applied between the top and bottom surfaces. Calculate the current flowing through the sample.

1 cm

0.05




a. $N_D >> N_A$

$\sigma = q(N_D \mu_n)$

$\sigma = 1.6 \cdot 10^{-19} \cdot 2 \cdot 10^{16} \cdot 1100$

$\boxed{\sigma = 3.52 \ \frac{1}{\Omega \text{cm}}}$

b. $R = \frac{1}{\sigma} \frac{L}{A}$

$R = \frac{1}{3.52} \frac{1}{\pi (0.05)^2}$

$R = 36.2 \Omega$

$\boxed{I = \frac{1}{36.2\Omega} = 27.6\text{mA}}$

**(a)** $\sigma$ $3.52 \ \frac{1}{\Omega\text{cm}}$

**(b) I** $27.6\text{mA}$

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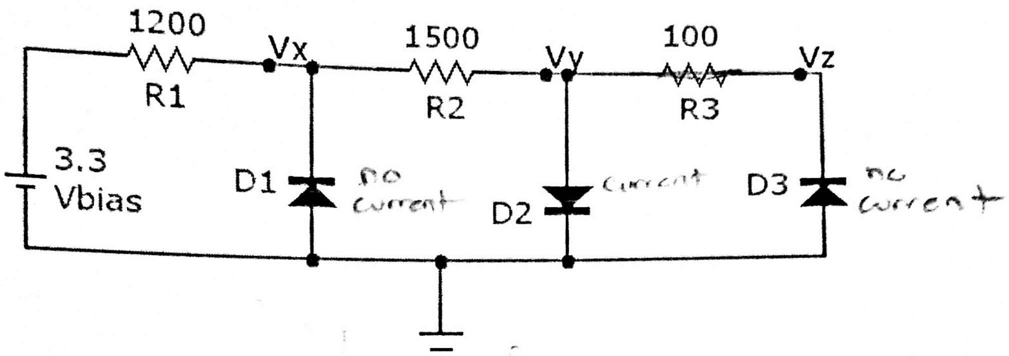
6. **(10 points)** Three identical diodes are used in the circuit in the figure. The only known fact about the diodes is that $I_D = 1$ mA at $V_D = 0.6$V. Calculate the three node voltages, $V_x$, $V_y$, $V_z$ if $V_{bias} = 3.3$V. ***Explain your reasoning.***




$V_y = V_z$ cause no current throug 100Ω resistor.

Assume $V_D = 0.6$ V
and current $I_D = 1$ mA,

so $3.3 = I_D \cdot 1200 + I_D \cdot 1500 + V_D$ KV

$3.3 = 1.2V + 1.5V + 0.6V$

$3.3 = 3.3$

$\boxed{V_y = V_z = 0.6V}$ since diode volt.

$V_x = 1.5V + 0.6V$

$\boxed{V_x = 2.1V}$

$V_x$ 2.1 V

$V_y$ 0.6 V

$V_z$ 0.6 V