Questions about Zener Diodes
Fall 2004
Question 3 - Zener Diodes (18 points)
Below is a circuit built with a zener diode and a picture of the characteristic curve of the diode.


Here are the input and output, when a 10 Volt, 1 K Hertz signal is applied at the input.

a) Write the letter of the appropriate region on the zener diode characteristic curve next to each of the five descriptions below. (5 points)

Forward Bias Region
Zener Region

Reverse Bias Region
Zener Voltage ( $-\mathrm{V}_{\mathrm{Z}}$ )

Saturation Current
b) Identify the following areas on the plot of the input and output. (5 points)

1. The input signal
2. The output signal
3. An area on the output signal where the diode is forward biased.
4. An area on the output signal where the saturation current runs through the diode.
5. An area on the output signal where the voltage across the diode is the zener voltage.
c) Using the output plot, estimate the zener voltage and the forward bias cutoff voltage of the diode. (4 points)

$$
\mathrm{V}_{\mathrm{Z}}
$$

Von
d) If $\mathrm{R}=5 \mathrm{~K}$, what is the current through the load resistor when the input voltage is -10 V ? (2 points)
d) If $\mathrm{R}=5 \mathrm{~K}$, what is the current through the load resistor when the input voltage is +10 V ? (2 points)

## Fall 2004 Solution <br> Question 3 - Zener Diodes (18 points)

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Here are the input and output, when a 10 Volt, 1 K Hertz signal is applied at the input.

a) Write the letter of the appropriate region on the zener diode characteristic curve next to each of the five descriptions below. (5 points)

| Forward Bias Region $B$ | Reverse Bias Region $A$ |
| :--- | :--- |
| Zener Region $E$ | Zener Voltage $\left(-\mathrm{V}_{\mathrm{Z}}\right) D$ |
| Saturation Current $C$ |  |

b) Identify the following areas on the plot of the input and output. (5 points)

1. The input signal
2. The output signal
3. An area on the output signal where the diode is forward biased.
4. An area on the output signal where the saturation current runs through the diode.
5. An area on the output signal where the voltage across the diode is the zener voltage.
c) Using the output plot, estimate the zener voltage and the forward bias cutoff voltage of the diode. (4 points)

$$
\begin{aligned}
& \mathrm{V}_{\mathrm{Z}}=4.7 \mathrm{~V} \text { (Vout is } 4.7 \text { volts less than Vin) } \\
& \text { Von }=0.7 \text { (Vout is } 0.7 \text { volts more than Vin) }
\end{aligned}
$$

A-d) If $\mathrm{R}=5 \mathrm{~K}$, what is the current through the load resistor when the input voltage is 10V? (2 points)
$I=(-10+0.7) / 5 K=-1.86 m A$

B-d) If $R=6 \mathrm{~K}$, what is the current through the load resistor when the input voltage is 10V? (2 points)
$I=(-10+0.7) / 6 K=-1.55 \mathrm{~mA}$

A-e) If $\mathrm{R}=5 \mathrm{~K}$, what is the current through the load resistor when the input voltage is +10 V ? (2 points)
$I=(10-4.7) / 5 K=1.06 m A$
$B-e)$ If $R=6 \mathrm{~K}$, what is the current through the load resistor when the input voltage is +10 V ? (2 points)
$I=(10-4.7) / 6 K=0.883 m A$

## Spring 2004

## 2. Zener Diodes/Circuit Functionality (25 points)

The relatively complex looking circuit below was designed to produce a constant DC voltage for the load shown.

a. Identify all of the functional blocks of this circuit by connecting the name with the letter for each circled section of the circuit. (7 points)

| Circle |  | Name |
| :---: | :---: | :---: |
| A |  | Voltage Follower |
| B |  | Zener Diode |
| C |  | Load Resistor |
| D |  | Voltage Source |
| E |  | Full Wave Rectifier |
| F |  | Transformer |
| G |  | Smoothing Capacitor |

b. The voltage observed at the input and output of the circuit appears as follows.


Is the transformer stepping up or stepping down the source voltage? How do you know? (3 points)
c. The following three circuits were built and analyzed.


Which of the following traces shows the output voltage for each of these circuits?
(2 points each) [Total $=6$ points]

d. Using some of the components from the circuits in part c, design a circuit which uses a half wave rectifier to produce a constant DC voltage. (6 points)
e. Would this circuit be as effective at keeping the voltage level at a constant voltage as the circuit in b? Why or why not. (3 points)

## Spring 2004 solution

## 2. Zener Diodes/Circuit Functionality (25 points) (Answer for A and B)

The relatively complex looking circuit below was designed to produce a constant DC voltage for the load shown.

a. Identify all of the functional blocks of this circuit by connecting the name with the letter for each circled section of the circuit. (7 points)

| Circle |  | Name |
| :---: | :---: | :---: |
| A | $\boldsymbol{B}$ | Voltage Follower |
| B | $\boldsymbol{F}$ | Zener Diode |
| C | $\boldsymbol{G}$ | Load Resistor |
| D | $\boldsymbol{A}$ | Voltage Source |
| E | $\boldsymbol{D}$ | Full Wave Rectifier |
| F | $\boldsymbol{C}$ | Transformer |
| G | $\boldsymbol{E}$ | Smoothing Capacitor |

b. The voltage observed at the input and output of the circuit appears as follows.


Is the transformer stepping up or stepping down the source voltage? How do you know? (3 points)

It is stepping up. If it were stepping down, then the output would never reach the cutoff region of the zener diode and the output would not be regulated (a straight line). Stepping the voltage up brings it above Vz and then the diode holds it at exactly Vz.
c. The following three circuits were built and analyzed.


Which of the following traces shows the output voltage for each of these circuits? (2 points each) [Total=6 points]

d. Using some of the components from the circuits in part c , design a circuit which uses a half wave rectifier to produce a constant DC voltage. (6 points)


You could also use the 0.1uF capacitor for smoothing.
e. Would this circuit be as effective at keeping the voltage level at a constant voltage as the circuit in b? Why or why not. (3 points)

The output of the above circuit looks like:


You can see that it is not as smooth as the original signal. This is because the smoothing capacitor is not large enough to always keep the voltage above Vz.

If you use the smaller capacitor, the result is even poorer:


Since the half wave rectifier only rectifies half the signal, the capacitor is discharging longer for each cycle. This gives the signal more time to drop below the zener voltage. If the signal drops below this voltage, the zener diode will be off and Vout will be equal to Vin (a voltage less than Vz). The smoothing is not complete.

Fall 2003
Question 4 - Zener Diodes (20 points)


The circuit above is a zener diode voltage regulator. Assume the zener voltage of the diode is 4.7 volts and its forward bias voltage is 0.7 volts.

1) What does a voltage regulator do? (2 points)
2) What would the voltage at V 2 be when $\mathrm{V} 1=6 \mathrm{~V}$ if R 2 has the following values: (6 points)
i) 1 K ohms
ii) 10K ohms
iii) 100K ohms
3) What would the voltage at V 2 be when $\mathrm{V} 1=-6 \mathrm{~V}$ and if R 2 has the following values: (6 points)
i) 1 K ohms
ii) 10K ohms
iii) 100K ohms
4) Each of the following three plots was made with a different value for R2: 1 K ohms, 10 K ohms and 100 K ohms. Indicate which plot was made with which value for R2. (6 points)




## Fall 2003 Solution

Question 4 - Zener Diodes (20 points)


The circuit above is a zener diode voltage regulator. Assume the zener voltage of the diode is 4.7 volts and its forward bias voltage is 0.7 volts.

1) What does a voltage regulator do? (2 points)

A voltage regulator is a circuit which prevents the voltage from exceeding a set voltage limit.
(In this case, the positive limit is +4.7 V and the negative limit is -0.7 V .)
2) What would the voltage at V2 be when V1 $=6 \mathrm{~V}$ if R 2 has the following values:
(6 points)
i) 1 K ohms expected voltage $V 2=(1 \mathrm{~K} / 11 \mathrm{~K}) 6 \mathrm{~V}=0.54 \mathrm{~V}(0.54<4.7)$

$$
V 2=0.54 \mathrm{~V}
$$

ii) 10 K ohms expected voltage $V 2=(10 K / 20 K) 6 V=3 V(3<4.7)$

$$
V 2=3 V
$$

iii) 100 K ohms expected voltage $V 2=(100 \mathrm{~K} / 110 \mathrm{~K}) 6 \mathrm{~V}=5.45 \mathrm{~V}(5.45>4.7)$

$$
V 2=4.7 V
$$

3) What would the voltage at V 2 be when $\mathrm{V} 1=-6 \mathrm{~V}$ and if R 2 has the following values: (6 points)
i) 1 K ohms expected voltage $V 2=(1 \mathrm{~K} / 11 \mathrm{~K})-6 \mathrm{~V}=-0.54 \mathrm{~V}(-0.54>-0.7)$

$$
V 2=-0.54 V
$$

ii) 10 K ohms expected voltage $V 2=(10 \mathrm{~K} / 20 \mathrm{~K})-6 \mathrm{~V}=-3 \mathrm{~V} \quad(-3<-0.7)$

$$
V 2=-0.7 V
$$

iii) 100K ohms expected voltage $V 2=(100 \mathrm{~K} / 110 \mathrm{~K})-6 \mathrm{~V}=-5.45 \mathrm{~V}(-5.54<-0.7)$

$$
V 2=-0.7 V
$$

3) Each of the following three plots was made with a different value for R2: 1 K ohms, 10 K ohms and 100 K ohms. Indicate which plot was made with which value for R2. (6 points)

The plot below cuts off at 4.7 and -0.7 --> R2=100K


The plot below doesn't cut off at all --> R2=1K


The plot below cuts off at -0.7 , but not at +4.7 --> R2 $=10 \mathrm{~K}$


## Spring 2003

1. Zener Diode ( 20 pts)

a) Assuming that $\mathrm{R} 1=1 \mathrm{~K} \Omega, \mathrm{~V}_{\mathrm{z}}=5 \mathrm{v}, \mathrm{I}_{\mathrm{knee}}=1 \mathrm{~mA}$, find the maximum value of the amplitude of V2, so that the diode stays in the Zener region. (10 pts)
b) Choose an amplitude below the threshold for V2 and demonstrate that you are indeed in the zener region of the diode ( 2 pts ).
c) Choose an amplitude above the threshold for V2 and demonstrate that you are not in the zener region of the diode (2 pts).
d) Assuming that the amplitude of the input voltage, V2, is 3 volts, which graph would a plot of V2 vs. Vout look most like (8 points)?




Time


## Spring 2003 solution

## 2. Zener Diode ( $\mathbf{2 5} \mathbf{~ p t s ) ~}$


b) Assuming that $\mathrm{V} 1=10 \mathrm{v}, \mathrm{R} 1=1 \mathrm{~K} \Omega, \mathrm{~V}_{\mathrm{z}}=6 \mathrm{v}, \mathrm{I}_{\mathrm{knee}}=1 \mathrm{~mA}$, find the minimum value of R2, so that the diode stays in the Zener region. (10 pts)

$$
\begin{aligned}
& I_{D}=-I_{R 1}+I_{R 2}=-\frac{V 1-V_{z}}{R 1}+\frac{V_{z}}{R 2}<-I_{\text {knee }} \\
& -\frac{10 v-6 v}{1 K \Omega}+\frac{6 v}{R 2}<-1 m A \Rightarrow-4 m A+\frac{6 v}{R 2}<-1 m A \Rightarrow \frac{6 v}{R 2}<3 m A \\
& \Rightarrow R 2>\frac{6 v}{3 m A} \Rightarrow R 2_{\min }=2 K \Omega
\end{aligned}
$$

c) Assuming that $\mathrm{V} 1=10 \mathrm{v}, \mathrm{R} 2=100 \Omega, \mathrm{~V}_{\mathrm{z}}=6 \mathrm{v}, \mathrm{I}_{\text {knee }}=1 \mathrm{~mA}$, find the maximum value of R1, so that the diode stays in the Zener region. (10 pts)

$$
\begin{aligned}
& I_{D}=-I_{R 1}+I_{R 2}=-\frac{V 1-V_{z}}{R 1}+\frac{V_{z}}{R 2}<-I_{\text {knee }} \\
& -\frac{10 v-6 v}{R 1}+\frac{6 v}{100 \Omega}<-1 m A \Rightarrow-\frac{4 v}{R 1}+60 m A<-1 m A \Rightarrow 61 m A<\frac{4 v}{R 1} \\
& R 1<\frac{4 v}{61 m A} \Rightarrow R 1_{\max }=65.6 \Omega
\end{aligned}
$$

d) If $\mathrm{V} 1=10 \mathrm{v}, \mathrm{R} 1=50 \Omega, \mathrm{R} 2=1 \mathrm{~K} \Omega, \mathrm{~V}_{\mathrm{z}}=6 \mathrm{v}$, and the diode is in the Zener region, how much current is drawn from the source? ( 5 pts )

$$
I_{V 1}=I_{R 1}=\frac{V 1-V_{z}}{R 1}=\frac{10 v-6 v}{50 \Omega}=80 \mathrm{~mA}
$$

Fall 2002
3. Zener Diodes (20 points)


Figure 2: Zener Diode Circuit
In Figure 2, the voltage V1 is sinusoidal with frequency 2 kHz with an amplitude of 15 volts. The Zener diode has a Zener voltage of 5 V and the non-Zener diodes have a threshold voltage of 0.6 V .
a) Draw the V1 and $\mathrm{V}_{\text {out }}$. Clearly label the Zener region. (12 points)

a) What description best fits this circuit? (Circle one) (8 points)
i) Inverter and half-wave rectifier.
ii) Voltage regulator with full-wave rectifier.
iii) Voltage regulator with half-wave rectifier.
iv) Integrator and voltage regulator.

Fall 2002 Solution
(none available)

## Spring 2002 <br> 3) Zener Diodes (20 pts)


a) Which Plot matches this circuit diagram (7pt)


B)


Below are 3 graphs that match 3 values for R4. Choose which goes with 50 ohms, 5000 ohms and 50000 ohms. (6pt)


C) What is the main difference between standard diode, and a zener diode?? (7pt)

## Spring 2002 solution <br> 3) Zener Diodes ( 20 pts)

a) Which Plot matches this circuit diagram (7pt)

This question was particularly difficult and should not have appeared on the test.
At +10 V make a loop equation:
Both diodes are above threshold, so D2 (forward bias) cuts off at the 0.6 V and
D3(reverse bias) at the zener voltage (about 4.7V)
$+10 V=0.6+4.7+V(R 3)$
$V(R 3)=4.7 \mathrm{~V}$
At 0 make a loop equation:
Both diodes are off, so D2 is open and D3 is open. R3 is attached to ground. $V(R 3)=0 V$

At -10V make a loop equation:
Both diodes are above threshold (but the current is running in reverse), so
D2 cuts off at -4.7 V and D3 cuts off at -0.6 volts.
$-10 V=-4.7+-0.6+V(R 3)$
$V(R 3)=-4.7 V$
At 10 volts, the voltage should be +4.7 , at 0 V it should be 0 , at -10 V it should be -4.7 . Only the fist plot satisfies these criteria.
B) The zener diode will turn into a short at +4.7 when the voltage is positive and -0.6 when the voltage is negative.

Note that in general, the voltage at R4 can be found using the voltage divider rule:

$$
\begin{aligned}
& V(R 4)=V 1 *(R 4) /(R 4+R 6) \\
& \text { At } 50 \text { ohms, } V(R 4)=V 1 * 50 / 1050=0.05 V 1 \\
& \text { At } 5000 \text { ohms, } V(R 4)=V 1 * 5000 / 6000=0.83 V 1 \\
& \text { At } 50000 \text { ohms, } V(R 4)=V 1 * 50000 / 51000=0.98 \text { V1 }
\end{aligned}
$$

At 50 ohms, the theoretical maximum voltage across the diode is $0.05 * 10 \mathrm{~V}=0.5 \mathrm{~V}$. This never exceeds the 0.6 V or 4.7 V thresholds, so the diode is off. The output is determined only by the voltage divider. This is the second graph (50 ohms). At 5000 ohms, the theoretical maximum voltage across the diode is $0.83 * 10 \mathrm{~V}=8.3 \mathrm{~V}$. This exceeds the 0.6 V (negative) and 4.7 V (positive) voltages across both diodes. Therefore, the first graph which cuts off at -0.6 and +4.7 is correct. ( 5000 ohms) At 50000 ohms, the theoretical maximum voltage across the diode is $0.98 * 10 \mathrm{~V}=9.8 \mathrm{~V}$. This exceeds the 0.6 V (negative) and 4.7 V (positive) voltages across both diodes. Therefore, the first graph which cuts off at -0.6 and +4.7 is correct. ( 50000 ohms)

Note that if R4 was about 500 ohms, $V(R 4)=10 * 500 / 1500=3.33 \mathrm{~V}$. This is like the third graph where the -0.6 cuts off, but the 4.7 does not.
C) What is the main difference between standard diode, and a zener diode?? (7pt)

A standard diode has a reverse bias threshold which is very large. It is designed to only work in one direction (the forward bias) at a threshold of about 0.6. A zener diode is designed to work in the reverse bias direction and has a cutoff threshold which is much lower and known. Zener diodes are rated in terms of the voltage at which they cutoff in the reverse bias.

## Fall 2001 Solution

EI TEST 3A Fall 2001
Name
Sect
Please show all work on all questions for full credit, some explanation of your answer is required.
3. Voltage Regulator (20 points)

A zener diode is used to in the circuit below to produce the fallowing output.

a. Circle an area on the plot where the zener diode is functioning in the forward bias region. (3 points)
b. Circle an area on the plot where the zener diode is functioning in the zener region.
(3 paints)
c. What is the approximate value of the zener voltage (V) of the diode? ( 5 points)
$v_{z}=4.5$
d. Assuming the value of the resistor R 2 is 20 k , what is the current through the resistor, R2, when the diode is functioning in the zenger region? ( 6 points)

$$
I_{2}=\frac{V_{2}}{L_{2}}-\frac{V_{2}}{V_{2}}=\frac{4_{1} 5_{4}}{20 v_{2}}=21.5 \mu \mathrm{H}
$$

e. Why is this circuit called a voltage regulator? (3 points)

Since, whens ives stope is in Caner regt in, thea
output is constant.

Fall 2000

## 3. Zener Diode Voltage Regulation

Two zener diodes are used to regulate the voltage across the load resistor R2 in the circuit below. Two different values for R2 are tried ( 100 and $10 \mathrm{k} \Omega$ ), producing the two plots which follow. Identify which plot goes with which resistance value. Explain your answer.




Fall 2000

## 3. Zener Diode Voltage Regulation

Two zener diodes are used to regulate the voltage across the load resistor R2 in the circuit below. Two different values for R2 are tried ( 100 and $10 \mathrm{k} \Omega$ ), producing the two plots which follow. Identify which plot goes with which resistance value. Explain your answer.




## Fall 2000

## 3. Zener Diode Voltage Regulation

Two zener diodes are used to regulate the voltage across the load resistor R2 in the circuit below. Two different values for R2 are tried ( 100 and $10 \mathrm{k} \Omega$ ), producing the two plots which follow. Identify which plot goes with which resistance value. Explain your answer.


These two Zener diodes are pointing towards ground. This means that they will each turn on in the forward bias direction at about 0.7 and in the reverse bias direction at about $-V z(-4.7 V)$. Since there are two, we expect the voltage of the limiter to cut off when the voltage at A tries to go above $(2 * 0.7)=1.4 \mathrm{~V}$ and when the voltage at A tries to go below $-(2 * V z)=-(2 * 4.7)=-9.4 V$.

Now we need to figure out the voltage at A for the two different resistor values. When $R 2=100$ ohms, $V A=(V 2)(100) /(100+1 \mathrm{~K})=0.09 \mathrm{~V} 2$. The amplitude of $V 2$ is 20 V . Therefore, the voltage at A for this resistor (without the diodes) would range between (-$20)(0.09)=-1.8 \mathrm{~V}$ and $(20)(0.09)=1.8 \mathrm{~V}$. With the diodes, we should expect the output to cut off a little in the positive direction (at 1.4V), but not at all in the negative direction. This is plot $B$. When $R 2=10 K, V A=V 2(10 K) /(10 K+1 k)=0.9 V 2$. The amplitude of $V 2$ is 20 V . Therefore, the voltage at $A$ for this resistor (without the diodes) would range between $(-20)(0.9)=-18 \mathrm{~V}$ and $(20)(0.9)=18 \mathrm{~V}$. With the diodes, we should expect the output to cut off at 1.V4 in the positive direction and at -9.4 volts in the negative direction. This is plot $A$.



