Lecture 7 Zener Diodes

ECEL 301 ECE Laboratory I
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The Scenario

- You have done a preliminary design for a voltage regulator
  - nominal output 5.6 V - 1N4734 zener diode
  - nominal output 6.2 V - 1N4735 zener diode
- Your manager would like to know if your circuit can operate safely under the conditions he/she has in mind
- What are the minimum and maximum voltages that can be applied?
The Plan

- First we need to learn something about voltage regulators and the zener diode
- Next we'll look at circuit details
- Then we will show the calculations your manager requires

Voltage Regulator

The purpose of the regulator is to maintain a nearly constant output voltage across the load in spite of large variations at the source.
Simple Voltage Regulator

![Diagram of Simple Voltage Regulator]
What’s a Zener Diode?

A zener diode is one designed to have a controlled reverse bias breakdown.

If you keep the zener biased below the "knee", you can have major changes in current, but very small changes in voltage across the diode - it "regulates".
Simple Zener Model

$V_{Z0}$, with its positive terminal at top, slides the IV curve to the left. Resistor $r_Z$ gives the IV curve a positive slope.

$V = IR$

$I = \frac{1}{R} V$

slope $\frac{\Delta Y}{\Delta X} = \frac{1}{R}$

When $R$ is very small, the slope is large and the line is nearly vertical.
Zener IV Terminology

- The inverse of the IV slope at a given current is called the dynamic resistance.

Regulator Operating Limits

- The maximum power dissipation rating limits the current you can pass through a diode with a given $V_Z$. The source voltage that generates this current would be $V_{S_{\text{max}}}$.
- If the load is fixed, the source voltage that brings the operating point to the knee would be $V_{S_{\text{min}}}$.
Regulator Operating Limits

The white line indicates the safe operating region for a 1 watt zener diode. \( P_D = I_D \times V_D \)

Some 1N47 Series Zeners

<table>
<thead>
<tr>
<th>Device</th>
<th>Nominal Zener Voltage (VZ)</th>
<th>Test Current IZT (mA)</th>
<th>ZZT@IZT (Ω)</th>
<th>ZZK@IZK (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1N4740A</td>
<td>10</td>
<td>25</td>
<td>7</td>
<td>700</td>
</tr>
<tr>
<td>1N4741A</td>
<td>11</td>
<td>23</td>
<td>8</td>
<td>700</td>
</tr>
<tr>
<td>1N4742A</td>
<td>12</td>
<td>21</td>
<td>9</td>
<td>700</td>
</tr>
<tr>
<td>1N4743A</td>
<td>13</td>
<td>19</td>
<td>10</td>
<td>700</td>
</tr>
<tr>
<td>1N4744A</td>
<td>15</td>
<td>17</td>
<td>14</td>
<td>700</td>
</tr>
<tr>
<td>1N4745A</td>
<td>16</td>
<td>15.5</td>
<td>16</td>
<td>700</td>
</tr>
</tbody>
</table>

These diodes can dissipate 1 Watt and are available in a DO-41 glass, axially-leaded package.
Some 1N52 Series Zeners

<table>
<thead>
<tr>
<th>Device</th>
<th>Nominal Zener Voltage (VZ)</th>
<th>Test Current IZT (mA)</th>
<th>ZZT@IZT (Ω)</th>
<th>ZZK@IZK (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1N5240A</td>
<td>10</td>
<td>20</td>
<td>17</td>
<td>600</td>
</tr>
<tr>
<td>1N5241A</td>
<td>11</td>
<td>20</td>
<td>22</td>
<td>600</td>
</tr>
<tr>
<td>1N5242A</td>
<td>12</td>
<td>20</td>
<td>30</td>
<td>600</td>
</tr>
<tr>
<td>1N5243A</td>
<td>13</td>
<td>9.5</td>
<td>13</td>
<td>600</td>
</tr>
<tr>
<td>1N5244A</td>
<td>14</td>
<td>9</td>
<td>15</td>
<td>600</td>
</tr>
<tr>
<td>1N5245A</td>
<td>15</td>
<td>8.5</td>
<td>16</td>
<td>600</td>
</tr>
</tbody>
</table>

These diodes can dissipate 0.5 Watt and are available in a DO-35 glass, axially-leaded package.

Zener Diode Packages

- **DO-35**
  - 0.5 Watt
  - Dim in mm

- **DO-41**
  - 1.0 Watt
  - Dim in mm
Finding $V_{S_{\text{MAX}}}$

- To find $V_{S_{\text{MAX}}}$ we will assume the worst case - your load has failed or has been disconnected, so all current passes through the diode.
- Draw the new circuit using the zener model.

\[ -V_S + I \times R_S + V_{Z_0} + I \times r_Z = 0 \quad (1) \]

\[ P_{\text{MAX}} = I \times V_Z \quad (2) \]
Finding $V_{S_{\text{MAX}}}$

From (1)  
$$V_S = I(RS + r_Z) + V_{Z0} \quad (3)$$

Put (2) into (3)  
$$V_{S_{\text{MAX}}} = \frac{P_{\text{MAX}}}{V_{Z0}} (RS + r_Z) + V_{Z0} \quad (4)$$

assuming $V_Z \approx V_{Z0}$

Choose a zener: 1N5240

$V_Z = 10 \text{ V} \quad I_{ZT} = 20 \text{ mA} \quad r_{ZT} = 17 \text{ } \Omega$

$P_{\text{MAX}} = 0.5 \text{ W} \quad I_{ZK} = 0.25 \text{ mA} \quad r_{ZK} = 600 \text{ } \Omega$

Finding $V_{S_{\text{MAX}}}$

Use the test condition to find $V_{Z0}$

Use the test condition to find $V_{Z0}$

$$V_{Z0} = V_{ZT} - I_{ZT} \times r_{ZT} \quad (5)$$

$$V_{Z0} = 10 \text{ V} + 20 \text{ mA} \times 17 \text{ } \Omega$$

$$V_{Z0} = 9.66 \text{ V}$$
Finding $V_{SMAX}$

Put $V_{Z0}$ into (4)

$$V_{SMAX} = \frac{0.5 \text{W}}{9.66 \text{V}} (100\Omega + 17\Omega) + 9.66 \text{V}$$

$$V_{SMAX} = 15.72 \text{V}$$

You can use PSpice to verify this solution.

Finding $V_{SMIN}$

- Assume $RS=100\Omega$ and $RL=1000\Omega$
- What is the smallest voltage $VS$ I can apply and keep the zener regulating?
- The operating point is now near the “knee”
Finding \( V_{S_{MIN}} \)

Current from source (assuming \( V_{Z0} \approx V_{ZK} \))

\[
I(RS) = \frac{V_{S_{MIN}} - V_{Z0}}{RS} \quad (6)
\]

Current and voltage at load

\[
\begin{align*}
I(RL) &= I(RS) - I_{ZK} \quad (7) \\
V(RL) &= I(RL) \times RL \quad (8) \\
V(RL) &= V_{ZK} \approx V_{Z0} \quad (9)
\end{align*}
\]

From (6)

\[
V_{S_{MIN}} = I(RS) \times RS + V_{Z0} \quad (10)
\]

Put (7), (8), (9) into (10)

\[
V_{S_{MIN}} = \left( \frac{V_{ZK}}{RL} + I_{ZK} \right) \times RS + V_{Z0}
\]

\[
V_{S_{MIN}} = \left( \frac{9.66V}{1k\Omega} + 0.25mA \right) \times 100\Omega + 9.66V
\]

\[
V_{S_{MIN}} = 10.65 \text{ V}
\]
Lab Procedure

- Measure the full IV curve for your zener - forward and reverse bias - using IV Sweep 1.1 LabVIEW VI
  - $-20\,\text{V} \leq \text{Vin} \leq +10\,\text{V}$
  - Capture data to file
  - Plot the results

LabVIEW Measurement
### LabVIEW Measurement

![IV Curve Graph](image)

- Trace starts here
- Switch leads on Pwr Supply
- Trace ends here

-20V ≤ Vin ≤ +10 V sweep

### Lab Procedure

- Use MATLAB and the measured reverse bias IV data to find the dynamic resistance of your diode
  - You can base your code on the textbook example 5.5, and modify as necessary
  - Your results should show the dynamic resistance both below the knee and through the transition into the region above the knee.
The Algorithm in Example 5.5

The dynamic resistance associated with point i+1 is calculated from neighboring points i and i+2
Dynamic R Calculation Results

Lab Procedure

- Match your $V_Z$ and $r_{ZT}$ results with those on a manufacturer’s data sheet
- Using your results, calculate $V_{S\text{MIN}}$ and $V_{S\text{MAX}}$
- Confirm your voltage limits using PSpice
PSpice shows 10.8V, or 1.3% from 10.66V calculated.
Confirming $V_{S\text{MAX}}$

Lower plot: find intersection of IV and max power curve
Upper curve: find VS at the same current

Deliverables

- Put the following deliverables into our standard lab report format, in the proper places
  - IV curve of your zener diode as measured using LabVIEW. You can plot the data any way you like. Put the graph in the body of the report.
  - MATLAB m-file that will read LabVIEW data, as captured, and calculate the dynamic resistance. In addition to putting this in your report, submit this m-file through WebCT. Insert the dynamic resistance graph into the report.
Deliverables

- Put the following deliverables into our standard lab report format, in the proper places
  - Comparison of your dynamic resistance with a commercial datasheet. Cite your source.
  - Results of the calculations of the $V_{S_{\text{MIN}}}$ and $V_{S_{\text{MAX}}}$ voltage limits. Put sample calculations in the appendix.
  - Verification of the $V_{S_{\text{MIN}}}$ and $V_{S_{\text{MAX}}}$ voltage limits from PSpice.