

Zener DC-to-DC Converter

Procedure

Some devices (for example, the ultrasonic sensor in your kit) are designed to work with a maximum voltage supply below the 9-volts that you have in your kit. This exercise will allow you to complete a design for a 9-volt-to-5-volt dc converter. The end result will be something that behaves much like a 5-volt battery although with a higher effective resistance than the original battery.

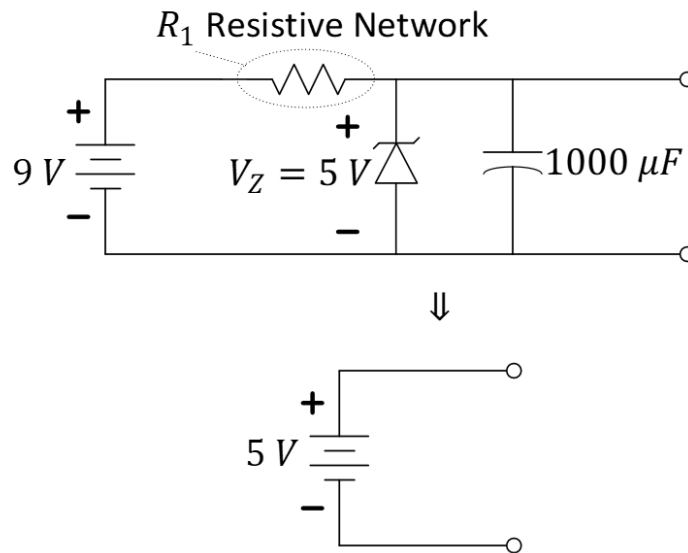


Figure 1: A 9VDC-to-5VDC Zener-regulator circuit (top schematic).

The Zener diode (https://en.wikipedia.org/wiki/Zener_diode) is a special diode that allows current to flow in **either** direction once a turn-on voltage has been reached in that polarity. While the forward-bias turn-on voltage is typical of the semiconductor material, the reverse-bias turn-on voltage (also called a “breakdown” voltage although it does not imply damage) can be designed to take on different turn-on voltage for different projects. The IV characteristic of a Zener diode is demonstrated in Figure 2.

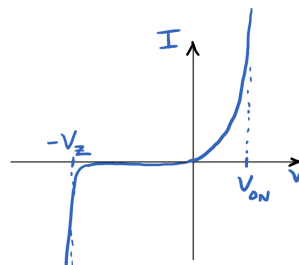


Figure 2: Current-voltage characteristic of a Zener diode with a breakdown voltage labeled “ V_Z ”.

The special diode in your kit (it will be separate with thicker wires than the “signal” diodes that you may have already used) is a Zener diode with a reverse-bias turn-on voltage near 5 volts. **For our analysis purposes**, you can imagine the Zener diode in Figure 1 to be a regular diode oriented in the downward direction with a (sharp) turn-on voltage of $V_Z \approx 5V$.

Silicon Power Zener Diodes

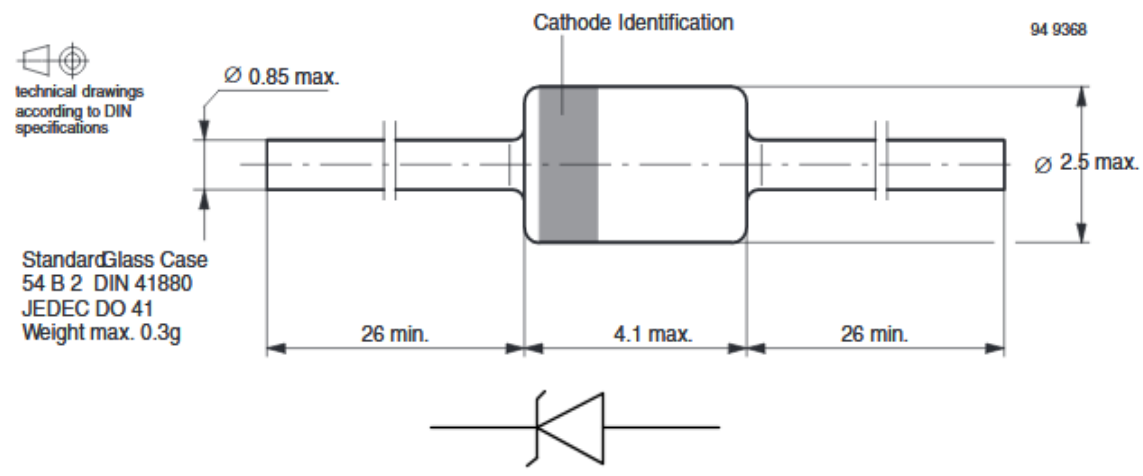
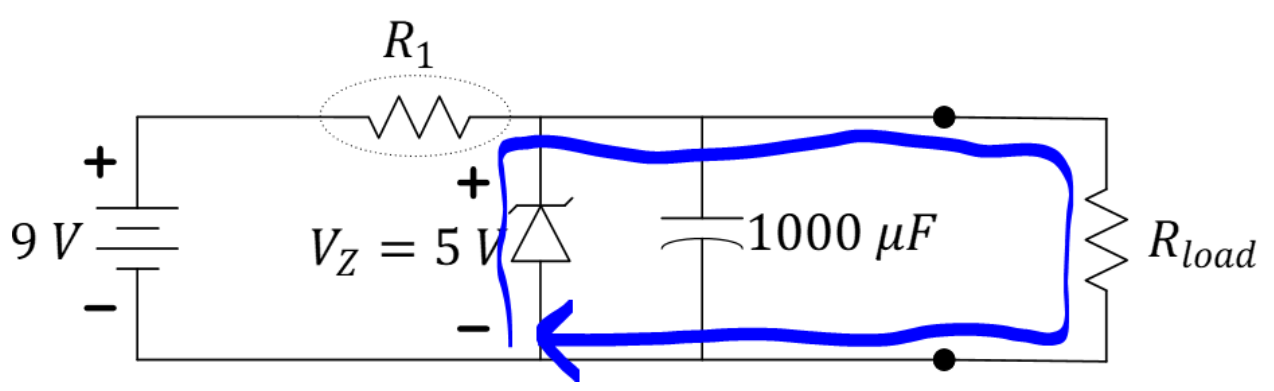


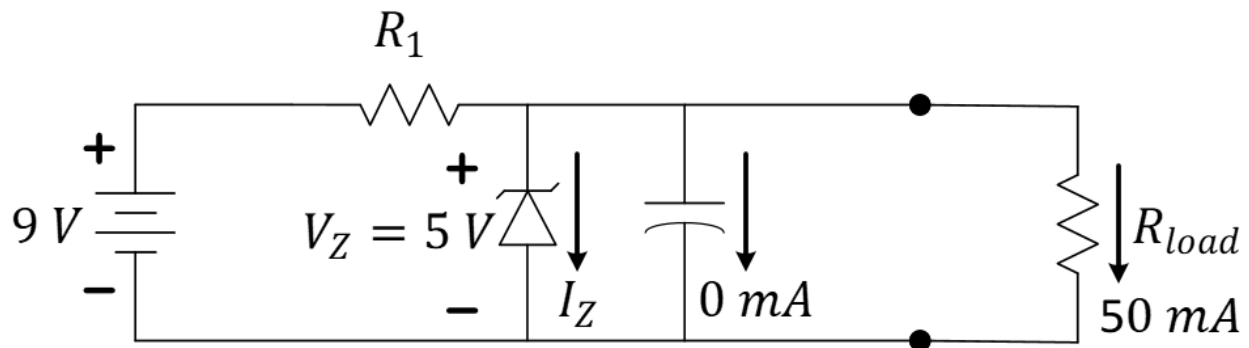
Figure 3: Select details from the Zener datasheet to aid with orientation in your circuit.

Before you build, as a design engineer, you will need to perform some analysis to verify both safety and function. Consider these facts and answer the following questions.

Question 1: We want to use this new 5-volt supply to operate both the ultrasonic (US) sensor which draws about 15 mA as well as a Schmitt-trigger oscillator which draws up to 35 mA. Using Kirchhoff's Voltage Law on the loop below, what is a good value to represent the resistive load, R_{load} , to represent both the current draw of the oscillator and the current draw of the US sensor? $R_{load} = \underline{\hspace{2cm}}$? Explain.



Question 2: You know that a charged capacitor draws no current. Determine the range of values appropriate for R_1 to provide 50 mA to the load. **Hint:** You need to use Kirchhoff's Current Law to find the range of R_1 that guarantees $I_Z \geq 0\text{ mA}$ while the Zener diode operates at the breakdown voltage, $V_Z = 5\text{ V}$. Show your work.



Question 3: Now, we must consider an engineering tradeoff. Choosing R_1 small will provide a 5-volt source with a smaller effective resistance and, therefore, capable of providing more current to the load if using this for other applications. However, a small R_1 will also mean *more power dissipated* by R_1 even when the load is drawing little current or disconnected entirely! Consider the resistor values in your kit and design a resistive network for R_1 that meets these goals:

- The effective resistance of your network, R_1 , is *near* the largest value in the range, but does not exceed the range so that 50 mA may be drawn by the load.
- Each resistor used in the resistive network for R_1 dissipates less than 0.2 W (our resistors are rated for 0.25 W , so we are being a little conservative here).
- The resistors come from the limited values available in your kit, the contents of which may be found at <https://ece.illinois.edu/academics/ugrad/lab-kits/ece110>.

Explain your reasoning as you show your work.

Question 4: Sketch the schematic of Figure 1 explicitly showing your resistor network for R_1 .

Question 5: How would you redesign your resistive network if you needed it to be capable of delivering more current, say 100 mA , to the load? Explain.

Question 6: How does power efficiency change between the optimized design to deliver 50 mA and the design to deliver 100 mA ? Explain using the definition of efficiency and a clear explanation of useful and wasted power in each design.

You may now build the circuit according to your design.

Question 7: Use your 9-volt battery and a voltmeter (or oscilloscope) to validate your design. Submit a video demonstrating the 9-volt input and 5-volt output with two different resistive loads, $1\text{ k}\Omega$ and $0.5\text{ k}\Omega$.

Learning Objectives

- Ability to map a circuit design onto the breadboard in a functional and clean manner.
- Demonstrate the ability to use an oscilloscope to monitor voltage.
- Design by considering both safety and function of a device.
- Ability to troubleshoot problems that occur during a build.