ECE 310L: Microelectronic Circuits Lab

Lab 1: Voltage Divider and Measurement Basics

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Objectives

(1) Familiarize with lab equipment and basic electrical and electronic theory using a voltage divider and a Zener diode.
(2) Demonstrate the ability to apply the concepts of part tolerance and line/load regulation.

Background

Often in circuit design, a voltage is required that is less than the supply voltage found in the system. An example would be a situation in which the designer determines that 4.7 VDC is needed but the available system voltage is 8.0 VDC.

The simplest way to obtain this voltage is to use a voltage divider circuit as shown in Figure 1. However, in this case the output voltage is very sensitive to the load applied to the voltage divider, as well as to changes in the input voltage.

Another method to create a voltage that is less than the supply voltage is to use a Zener diode within the circuit. A Zener diode will act as voltage regulator. In reverse bias, as shown in Figure 2, a Zener diode will have a fairly constant voltage drop over a range of current. This characteristic of the Zener diode makes a circuit less sensitive to changes in input voltage and load currents. We will use a 1N5230B Zener diode in the lab. You can find the datasheet on the course Blackboard site.

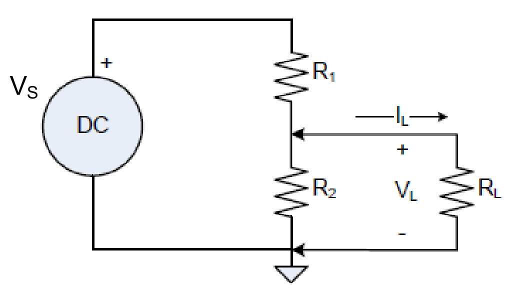

Figure 1
Voltage Divider with Load Resistor

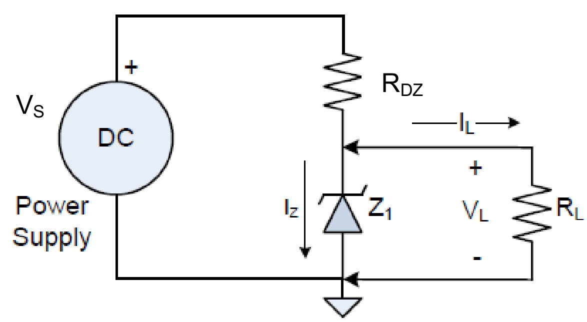

Figure 2
Zener Regulator with Load Resistor

A good power supply is characterized by its line regulation and load regulation.

Line Regulation

Line regulation is a measure of the ability of the power supply to maintain its output voltage given changes in the input line voltage. There are many reasons source voltage V_S will not be a perfect constant with time. For example, thermal noise and temperature drift can affect the source voltage. Coupling to 60 Hz signals (or digital clock signals) could also add fluctuation to V_S.

Line regulation is expressed as percent of change in the output voltage relative to the change in the input line voltage.

$$\%\ Line\ Regulation = \frac{\Delta V_L}{\Delta V_S}$$

Load Regulation

Load regulation is a measure of the ability of an output channel to remain constant given changes in the load. For constant-voltage source, variations in the load result in changes in the output current. This variation is expressed as a percentage of range per amp of output load and is synonymous with a series resistance. In constant voltage mode, the load regulation specification defines how close the series resistance of the output is to 0 ohms - the series resistance of an ideal voltage source.

$$\%\ Load\ Regulation = \frac{V_{min-load} - V_{max-load}}{V_{norm-load}}$$

Where:

$V_{max-load}$ is the voltage at maximum load. The maximum load is the one that draws the greatest current, i.e. the lowest specified load resistance (never short circuit);

$V_{min-load}$ is the voltage at minimum load. The minimum load is the one that draws the least current, i.e. the highest specified load resistance (possibly open circuit for some types of linear supplies, usually limited by pass transistor minimum bias levels);

$V_{norm-load}$ is the voltage at the typical specified load.

Load regulation is also expressed as the ratio of output voltage variation and output current variation, albeit less frequently.

$$Load\ Regulation = \frac{\Delta V_L}{\Delta I_L}$$

Under this definition, load regulation has a unit of Ohm. An ideal voltage source would have a load regulation of 0.

For this lab, express load regulation in <u>both</u> definitions.

Materials

- DC power supply, HP E3631A
- DMM, Agilent E3631A
- Protoboard
- Hookup Wires
- Assorted resistors
- Zener diode (part 1N5230B)

A diode is a two-terminal electronic component with asymmetric conductance; it has low (ideally zero) resistance to current in one direction, and high (ideally infinite) resistance in the other. A semiconductor diode, the most common type today, is a crystalline piece of semiconductor material with a p–n junction connected to two electrical terminals. In our labs, diodes are typically packaged in tiny glass cylinders with a connecting lead at each end. A stripe on the cylinder marks the diode's cathode, as shown in Fig. 3, making the opposite side the anode.

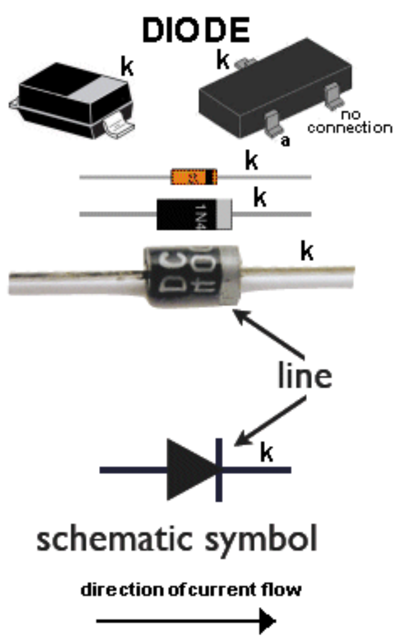

Figure 3. Marking of diodes in different packages

Pre-lab Assignments

Question 1. The voltage divider circuit, as show in Figure 1, produce an output voltage of 4.7 VDC, no load ($R_L = \infty$), with a supply voltage of 8 VDC. Select R_2 to be a 4.7 KΩ resistor, calculate the value of R_1.

Question 2. Read textbook Section 3.12 [1], write an expression to calculate line regulation for the circuit described in question (1).

Question 3. In practice, differential expression (such as dV_S) is approximated by the difference operation, for example, $dV_S \approx V_{Smax} - V_{Smin}$. V_{Smax} and V_{Smin} are source voltages that is 10% above and below nominal source voltage ($V_S = 8$ V), respectively. V_{Lmax} and V_{Lmin} are resulting load voltages with source voltage V_{Smax} and V_{Smin}, respectively. Calculate the line regulation for a load resistance of $R_L = 56$ KΩ.

Question 4. Derive an expression of power efficiency for the circuit in (1) using only the symbols R_1, R_2, and R_L. Calculate the power efficiency for a load resistance of 56 KΩ.

Question 5. The Zener regulator circuit, as shown in Figure 2, produce an output voltage of 4.7 VDC, no load ($R_L = \infty$), with a supply voltage of 8 VDC. Assuming I_Z = 25 mA, calculate the value of R_{DZ}.

Question 6. Calculate line regulation of the circuits in question 5 for a load resistance of 56 KΩ. Let V_{Smax} and V_{Lmax} be the source and load voltages when the input is 10% <u>above</u> the nominal source voltage (V_{S} = 8 V) and let V_{Smin} and V_{Lmin} be the source and load voltages when the input is 10% <u>below</u> the nominal source voltage.

Question 7. Derive an expression of power efficiency for the circuit in (1) using only the symbols V_S, V_L, R_{DZ}, and R_L. Calculate the power efficiency for a load resistance of 56 KΩ.

Question 8. Write an expression for load regulation.

Setup

Turn on power to the DC power supply and the DMM. Set the current limit on the power supply +25 V output to 100 mA.

Lab Assignments

Voltage Divider

1. For the voltage divider circuit designed in the **Prelab Assignment (1)**, measure the actual values of R_1 and R_2 using the multi-meter and verify they are with the 5% tolerance. Record the measurements in Table 1.
2. The experiment will use three load resistances: open circuit, 1.2 KΩ, and 56 KΩ. Use multi-meter and verify they are with the 5% tolerance. Record the measurements in Table 1.

Table 1: Measured Resistance

Expected Resistance	R_1 = 3.3 KΩ	R_2 = 4.7 KΩ	R_{L1} = 1.2 KΩ	R_{L2} = 56 KΩ
Measured Resistance	3.26 KΩ	4.64 KΩ	1.21 KΩ	55.9 KΩ

3. Build the voltage divider circuit on the protoboard and measure the 'no load' output voltage. There will be no load resistor, R_L, in this measurement. Record the measurements in Table 2.
4. Repeat the output voltage measurement with the supply voltage altered by +/-10%. This measurement will show the sensitivity to supply voltage changes. Record the measurements in Table 2.
5. Add a 56 KΩ resistor to the circuit as the load, R_L and repeat the voltage measurements with the original supply voltage, and altered by +/-10%. Record the measurements in Table 2.
6. Change the 56 KΩ resistor to a 1.2 KΩ resistor and repeat the measurements in steps 5. Record the measurements in Table 2.
7. Calculate the line regulation and power efficiency of the circuit under different load resistances. Record the values in Table 2.
8. Calculate the load regulation for the voltage divider circuit. Record the values in Table 2.

Table 2: Voltage Divider Circuit

<table>
<tr><td colspan="7">Voltage divider circuit</td></tr>
<tr><td rowspan="3">Load resistanc e</td><td colspan="3">Measured values</td><td colspan="3">Calculated values</td></tr>
<tr><td>Source tolerance</td><td>Sourc e voltag e</td><td>Load voltage</td><td>Line regulation</td><td>Load regulation</td><td>Power efficiency</td></tr>
<tr><td></td><td>V_S (V)</td><td>V_L (V)</td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">No load</td><td>+10%</td><td>8.8</td><td>5.168</td><td rowspan="3">58.8%</td><td rowspan="9">58.1%</td><td></td></tr>
<tr><td>Nominal</td><td>8</td><td>4.698</td><td></td></tr>
<tr><td>-10%</td><td>7.2</td><td>4.228</td><td></td></tr>
<tr><td rowspan="3">56 KΩ</td><td>+10%</td><td>8.8</td><td>4.997</td><td rowspan="3">56.9%</td><td></td></tr>
<tr><td>Nominal</td><td>8</td><td>4.543</td><td>18.38%</td></tr>
<tr><td>-10%</td><td>7.2</td><td>4.087</td><td></td></tr>
<tr><td rowspan="3">1.2 KΩ</td><td>+10%</td><td>8.8</td><td>1.999</td><td rowspan="3">22.7%</td><td></td></tr>
<tr><td>Nominal</td><td>8</td><td>1.818</td><td>4.43%</td></tr>
<tr><td>-10%</td><td>7.2</td><td>1.636</td><td></td></tr>
</table>

Zener diode circuit

1. For the Zener regulator circuit designed in the **pre-lab question (5)**, measure the actual values of R_{DZ} using the multi-meter and verify they are with the 5% tolerance. Record the measurements in Table 3.
2. The experiment will use three load resistances: open circuit, 1.2 KΩ, and 56 KΩ. Use multi-meter and verify they are with the 5% tolerance. Record the measurements in Table 3.

Table 3: Measured Resistance for Zener Regulator Circuit

Expected Resistance	R_{DZ} = 132 Ω	R_{L1} = 1.2 KΩ	R_{L2} = 56 KΩ
Measured Resistance	120 Ω	1.208 KΩ	55.902 KΩ

3. Build the Zener regulator circuit on the protoboard and measure the 'no load' output voltage. There will be no load resistor, R_L, in this measurement. Record the measurements in Table 4.
4. Repeat the output voltage measurement with the supply voltage altered by +/-10%. This measurement will show the sensitivity to supply voltage changes. Record the measurements in Table 4.
5. Add a 56 KΩ resistor to the circuit as the load, R_L and repeat the voltage measurements with the original supply voltage, and altered by +/-10%. Record the measurements in Table 4.
6. Change the 56 KΩ resistor to a 1.2 KΩ resistor and repeat the measurements in steps 5. Record the measurements in Table 4.
7. Calculate the line regulation and power efficiency of the circuit under different load resistances. Record the values in Table 4.
8. Calculate the load regulation for the voltage divider circuit. Record the values in Table 4.

Table 4: Zener Regulator Circuit

Zener regulator circuit						
Load resistance	Measured values			Calculated values		
	Source tolerance	Source voltage	Load voltage	Line regulation	Load regulation	Power efficiency
		V_S (V)	V_L (V)			
No load	+10%	8.8	4.877	4.87%	0.7%	
	Nominal	8	4.843			
	-10%	7.2	4.799			
56 KΩ	+10%	8.8	4.877	5.06%		
	Nominal	8	4.852			1.72%
	-10%	7.2	4.796			
1.2 KΩ	+10%	8.8	4.858	6.25%		
	Nominal	8	4.818			8.38%
	-10%	7.2	4.758			

Discussion

Answer the following questions regarding the two circuits:

(1) What does line regulation and load regulation represents physically?

Line Regulation - the stability of the output with respect to input variations

Load Regulation - the stability of the output with respect to load current variations

(2) Comparing the two circuits, what are the pros and cons? Discuss this under the context of line regulation, load regulation, and power efficiency.

The circuit utilizing the Zener diode was an excellent example of load regulation; however, it disappoints in the power efficiency department.

Usually you don't think of mismatched resistive load as being efficient, but in this case the number swing in favor of that circuit; conversely, the load and line regulation for this circuit leaves much to be desired.

(3) Neither of the two circuits is a very good power source. What are the limitations of both circuits in terms of how load resistance affects their operation? As semester progresses, you will be tasked to design a better circuit with the possible use of MOSFET or BJT.

Neither configuration would be ideal; and, even here, neither configuration wins overall – you would have to sacrifice regulated voltage for power efficiency and vice versa.

The Zener diode is a wasteful component in this configuration. Purely resitive circuits are too linear to be efficient – if we wanted to create a more efficient power supply we would need a combination of RLC components.

Comment and Conclusion

Provide a succinct review of the lab.

Using two different configurations attached to a controlled variable – the values of the restive load – we were able to see the difference in (albeit both were awful) load regulation vs power efficiency. We also get an introduction to how a diode functions in a physical circuit, sort-of.

Reference

1. Blalock T and Jaeger R, 2010 *Microelectronic Circuit Design*, 4th ed. (New York: McGraw-Hill)