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Assignment/Lab Number:	Lab 2
Assignment/Lab Title:	Voltage Regulators

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ELE 404: Electronics I

Lab 2: Voltage Regulators

Introduction

In almost all electronic circuits, there is a need for one or more **voltage regulators**. These are circuits that offer an ideally constant voltage, either as a reference or as the power supply for another part of the circuit. This lab examines the three simplest types of **voltage regulator**, namely, a simple resistive voltage divider, a voltage regulator that capitalizes on the more-or-less constant and known on-state voltage drop of diodes, and a voltage regulator based on Zener diodes. This lab investigates the **load regulation** properties of the aforementioned three types of voltage regulator.

Pre-lab Assignment

P1. Consider the voltage divider of **Figure 1**, whose purpose is to produce an output voltage of $v_o = 6.2 V$ from a supply voltage of $V_{CC} = 10 V$. Assuming that $R_1 = 560 \Omega$ and $R_2 = 910 \Omega$, calculate the output voltage v_o for each of the load current values specified in **Table P1**. Then, based on the tabulated values, plot v_o versus i_L , and present the curve as **Graph P1**.

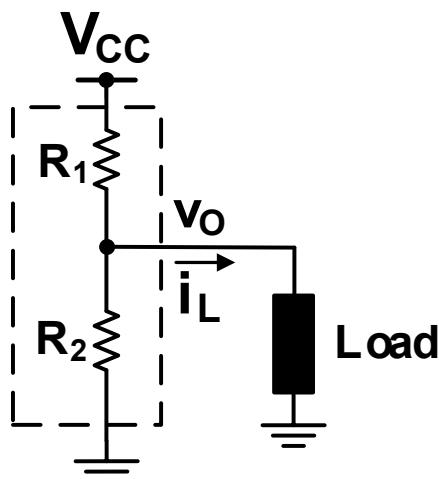
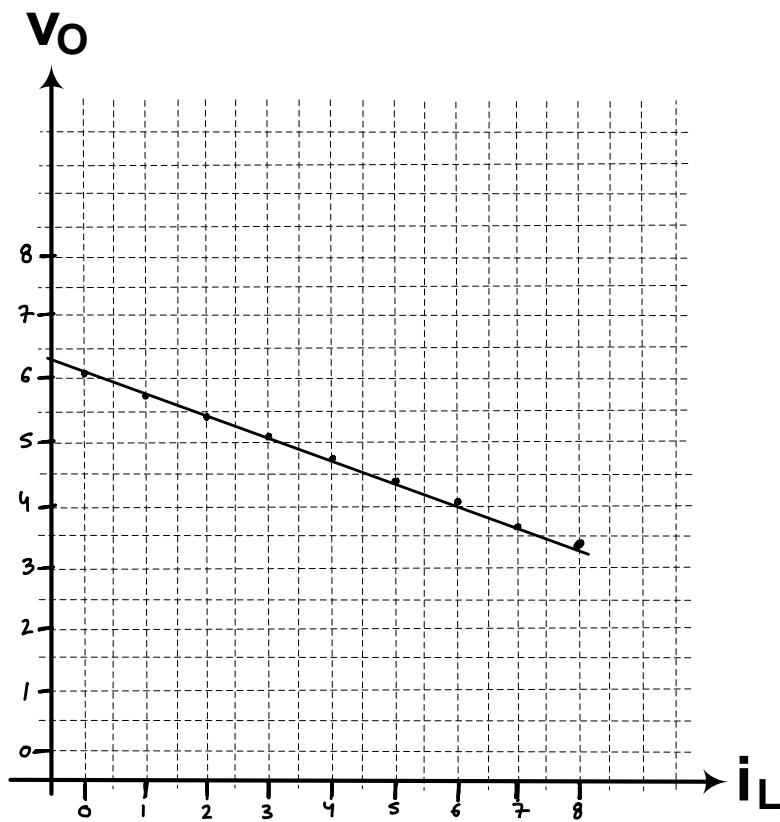


Figure 1. A resistive voltage divider supplying a load.

Table P1. Output voltage as a function of load current in the voltage divider of **Figure 1**.

$i_L [mA]$	0	1	2	3	4	5	6	7	8
$v_o [V]$	6.1904	5.843	5.497	5.150	4.803	4.457	4.110	3.763	3.417



Graph P1. Output voltage versus load current in the resistive voltage divider of Figure 1.

P2. Consider the circuit of **Figure 2**, which is the circuit of **Figure 1** in which R_2 is replaced by a **1N4735 6.2-V Zener diode**. According to its datasheet, **1N4735** produces $v_z = 6.2 V$ at a current of $i_z = 41 mA$, and its series resistance is $r_z = 2 \Omega$, as long as its current is larger than $I_{ZK} = 1 mA$. Assuming that $R_1 = 560 \Omega$ and $V_{CC} = 10 V$, calculate the output voltage v_o for each of the load current values specified in **Table P2**. Then, based on the tabulated values, plot v_o versus i_L and present the curve as **Graph P2**.

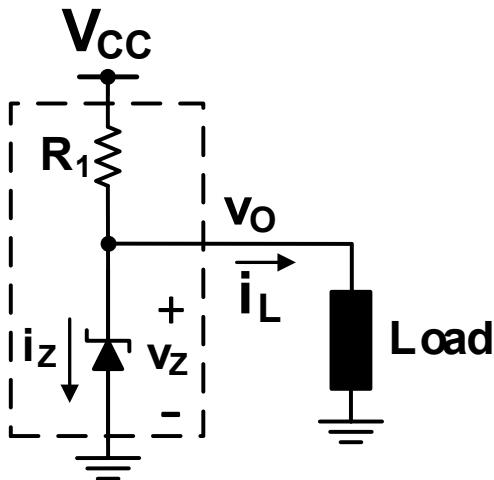
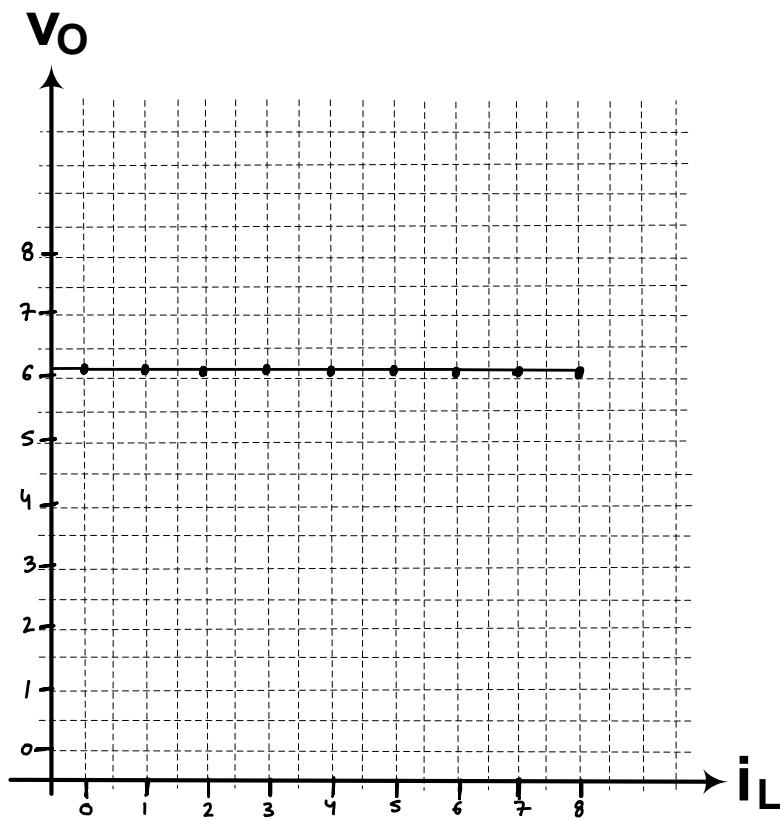


Figure 2. A Zener-diode-based voltage regulator.

Table P2. Output voltage as a function of load current in the Zener-diode-based voltage regulator of **Figure 2**.

$i_L [mA]$	0	1	2	3	4	5	6	7	8
$v_o [V]$	6.132	6.129	6.128	6.126	6.124	6.122	6.120	6.118	6.116



Graph P2. Output voltage versus load current in the Zener-diode-based voltage regulator of Figure 2.

Experiments and Results

E1. First, construct the circuit of **Figure 3**, which will serve as your adjustable “*load*” in the subsequent steps of this lab. As **Figure 3** illustrates, the “*load*” consists of a “**transistor**”, a “**potentiometer**”, and three resistors ($100\ \Omega$, $560\ \Omega$, and $6.8\ k\Omega$). Further, the load must be energized by a power supply, V_{CC} , as the figure shows and, therefore, it is an **active load**.

The first new device in the load is a **Bipolar Junction Transistor (BJT)**. BJTs will be extensively discussed later on in the course. However, for the purpose of this lab, all you need to know is that a BJT is a three-terminal device whose terminals are called the “**Base**” (denoted by “*B*”), the “**Collector**” (denoted by “*C*”) and the “**Emitter**” (denoted by “*E*”). In this lab, you need BJT **2N3904** from your lab kit. **Figure 4** enables you to identify the terminals of 2N3904.

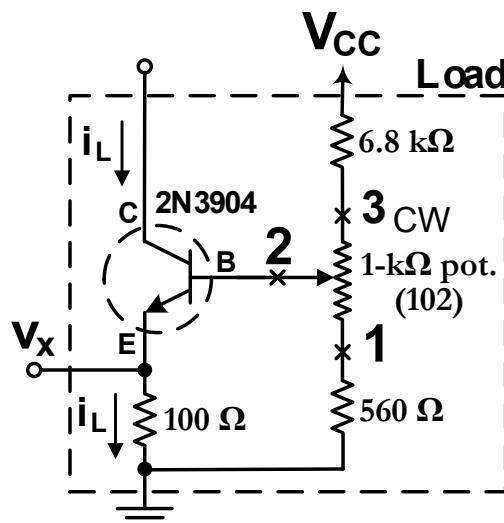


Figure 3. Circuit of the “*load*” for this lab.

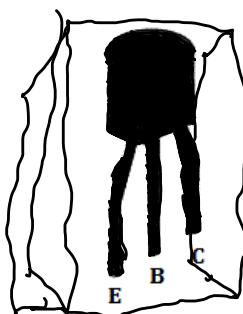


Figure 4. Terminals of transistor 2N3904.

The other device in the load that is new to you is the “**potentiometer**”. A **potentiometer** or, in short, a **pot**, is a three-terminal device that makes it possible to vary or fine-tune a resistance while the circuit is powered. It can also be used as a variable voltage divider, as is the case in this lab. The most tangible application example of a potentiometer is the volume-adjustment knob of an audio amplifier.

Figure 5 shows the schematic symbol of a potentiometer. As the figure illustrates, in a potentiometer there is a fixed resistance between two of the terminals, commonly marked as terminals “1” and “3”, whereas the third terminal, marked as terminal “2”, shows a variable resistance relative to the two other terminals. Thus, terminal “2” moves towards terminal “3”, and, therefore, the resistance between terminals “1” and “2” increases, as the potentiometer’s wiper or screw is turned clockwise (the marking “**CW**” next to terminal “3” indicates this). Conversely, the resistance between terminals “1” and “2” decreases as the wiper is turned counter-clockwise. This automatically varies the resistance between terminals “2” and “3”. At any rate, the resistance between each pair of terminals satisfy the relationship $R_{13} = R_{12} + R_{23}$. That is, as the wiper is turned clockwise and R_{12} increases, resistance R_{23} diminishes and vice versa.

A potentiometer is characterized by its fixed resistance, that is, the resistance between terminals “1” and “3”, as well as by the number of times its wiper or screw must be turned to make the resistance between terminal “1” and “2” rise from about zero to its maximum. For example, in this lab **you use a $1-k\Omega$ single-turn potentiometer**. Therefore, a) there is a resistance of about $1 k\Omega$ between its terminals “1” and “3”, and b) it takes one turn of the wiper for the resistance between terminals “1” and “2” to go from zero (i.e., a short circuit) to about $1 k\Omega$. You can use a small flathead screwdriver or the corner of a credit card to turn the potentiometer’s wiper.

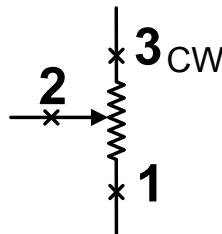


Figure 5. Schematic symbol of a potentiometer.

With the circuit of Figure 3 and $V_{CC} = 10 V$, **you can change the load current i_L from zero to at least 10 mA , by turning the potentiometer’s wiper clockwise**. The value of i_L in mA will be ten times the value of voltage v_x in volts (i.e., $i_L = 10v_x$). Measure v_x by your multimeter set in the DC voltage measurement mode as you turn the wiper.

E2. Construct the voltage-dividing circuit of **Figure 1** (with $R_1 = 560 \Omega$ and $R_2 = 910 \Omega$), and connect it to the adjustable “load” you built in **Step E1**, as shown in **Figure 6**. Turn both the potentiometer of the load and the voltage-control knob of the power supply all the way down counter-clockwise. Turn on the power supply and adjust V_{CC} to 10 V. Then, turn the potentiometer to adjust the load current as desired (remember, you know the current by measuring v_x and multiplying it by 10). Measure and record v_o for each of the load current values specified in **Table E2**. Then plot v_o versus i_L and present the curve as **Graph E2**.

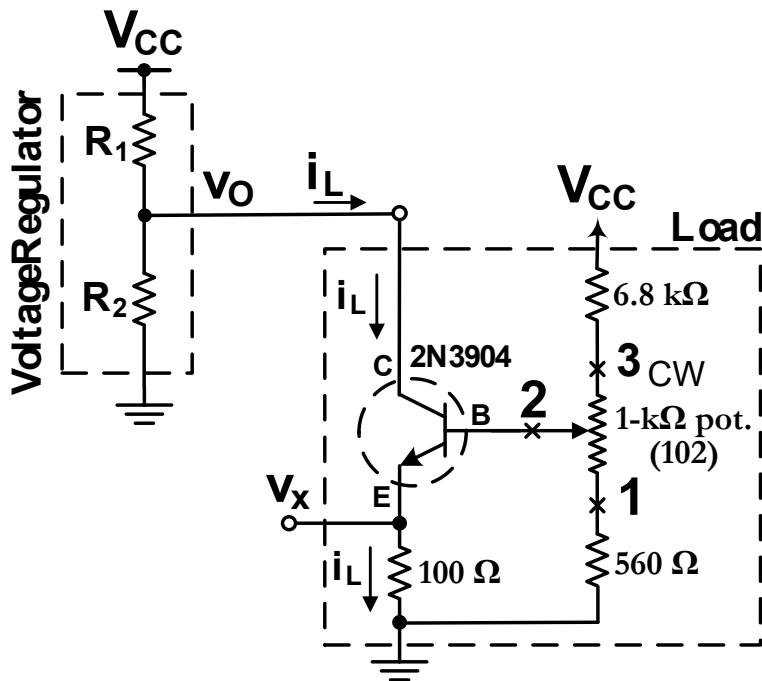


Figure 6. Voltage divider of Figure 1 supplying the adjustable load of Figure 3.

Table E2. Output voltage as a function of load current in the circuit of **Figure 6**.

$i_L [mA]$ ($v_x [V]$)	0 (0)	1 (0.1)	2 (0.2)	3 (0.3)	4 (0.4)	5 (0.5)	6 (0.6)	7 (0.7)	8 (0.8)
$v_o [V]$	6.24	5.96	5.63	5.27	4.91	4.59	4.20	3.89	3.50

E3. Turn off the power supply, and replace R_2 with a 1N4735, 6.2-V Zener diode, as shown in **Figure 7**. Then repeat experiment E2 with the new circuit. Complete **Table E3**, then plot v_o versus i_L and present the curve as **Graph E3**.

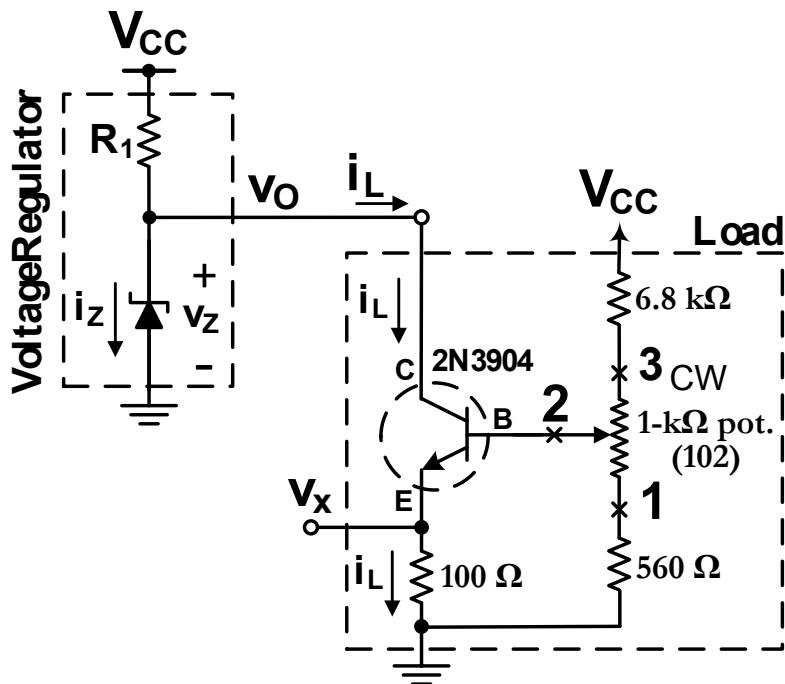


Figure 7. A Zener-diode-based voltage regulator supplying the adjustable load of Figure 3.

Table E3. Output voltage as a function of load current in the circuit of **Figure 7**.

$i_L [mA]$ ($v_x [V]$)	0 (0)	1 (0.1)	2 (0.2)	3 (0.3)	4 (0.4)	5 (0.5)	6 (0.6)	7 (0.7)	8 (0.8)
$v_o [V]$	6.290	6.180	6.184	6.174	6.163	6.157	6.148	6.027	5.990

E4. Turn off the power supply, and replace R_2 with a string of series-connected **1N4148** diodes, as shown in **Figure 8**, to achieve an output voltage of about 6.3 V. Assuming a forward voltage drop of about 0.7 V for each diode, this should take more or less 9 diodes. Therefore, with the load not yet connected, insert as many diodes in series as you need to get closest to the desired (no-load) output voltage of 6.3 V. Then, connect the load and repeat experiment **E2** with the new circuit. Complete **Table E4**, plot v_o versus i_L , and present the curve as **Graph E4**.

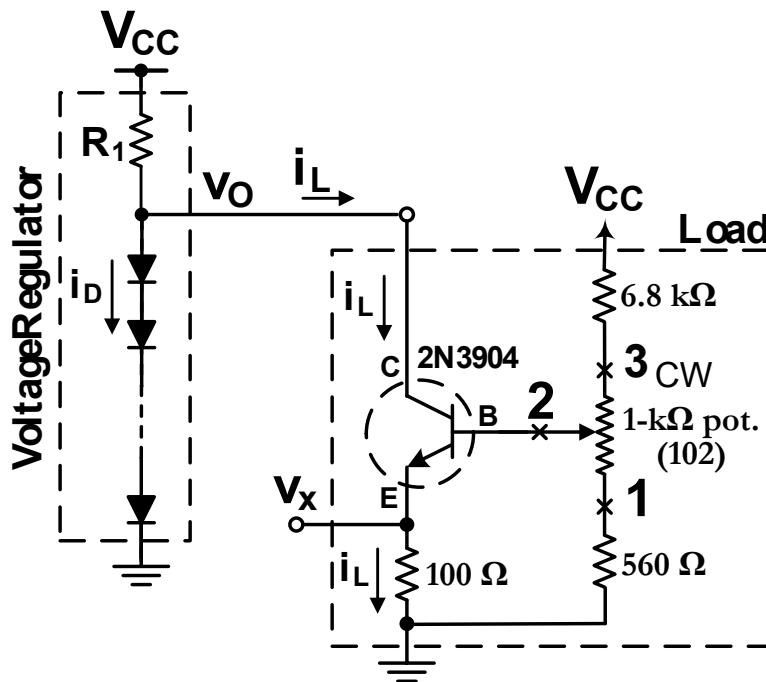


Figure 8. A diode-based voltage regulator supplying the adjustable load of Figure 3.

Table E4. Output voltage as a function of load current in the circuit of **Figure 8**.

$i_L [mA]$ ($v_x [V]$)	0 (0)	1 (0.1)	2 (0.2)	3 (0.3)	4 (0.4)	5 (0.5)	6 (0.6)	7 (0.7)	8 (0.8)
$v_o [V]$	6.393	6.302	6.217	6.127	6.016	5.889	5.722	5.512	5.270

Conclusions and Remarks

C1. Based on the results of **Step P1**, and using the relationship $R_L = v_o/i_L$, calculate the (fictitious) load resistance that corresponds to each of the currents specified in **Table P1**, and complete **Table C1**. Based on **Table C1**, then, explain the relationship that R_L should have with the output resistance (i.e., the Thevenin resistance) of the voltage divider such that the deviation of the output voltage from the no-load output voltage is insignificant.

Table C1. Equivalent load resistance for the voltage divider of **Figure 1**.

$i_L [mA]$	0	1	2	3	4	5	6	7	8
$v_o [V]$ (Table P1)									
$R_L [k\Omega]$	∞								

C2. For the voltage divider of **Figure 1**, compare the calculated output voltages (**Table P1**) and measured output voltages (**Table E2**), correspondingly, and calculate the **percent error** as

$$e\% = \frac{\text{calculated value} - \text{measured value}}{\text{measured value}} \times 100.$$

Complete **Table C2** and comment on the acceptability of and reasons for the errors.

Table C2. Percent error between the calculated and measured output voltages of the voltage divider of **Figure 1**.

$i_L [mA]$	0	1	2	3	4	5	6	7	8
$v_o [V]$ (Table P1)									
$v_o [V]$ (Table E2)									
$e\%$									

C3. For the Zener-diode-based voltage regulator of **Figure 2**, compare the calculated output voltages (**Table P2**) and measured output voltages (**Table E3**), correspondingly, and calculate the **percent error**. Complete **Table C3** and comment on the acceptability of and reasons for the errors.

Table C3. Percent error between the calculated and measured output voltages of the voltage divider of **Figure 1**.

$i_L [mA]$	0	1	2	3	4	5	6	7	8
$v_o [V]$ (Table P2)									
$v_o [V]$ (Table E3)									
$e\%$									

C4. Plot the v_o - i_L curves of **Graph E2**, **Graph E3**, and **Graph E4** on one frame, as **Graph C4**. Based on **Graph C4**, comment on the capability of each type of voltage regulator (i.e., voltage divider, diode-based, and Zener-diode-based) in maintaining its output voltage as the load current rises.

C5. Aside from their voltage regulation performance, how are the Zener-diode-based voltage regulator of **Figure 7** and the diode-based voltage regulator of **Figure 8** compared?

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Table E2. Output voltage as a function of load current in the circuit of **Figure 6.**

$i_L [mA]$ ($v_x [V]$)	0 (0)	1 (0.1)	2 (0.2)	3 (0.3)	4 (0.4)	5 (0.5)	6 (0.6)	7 (0.7)	8 (0.8)
$v_o [V]$	6.24	5.96	5.63	5.27	4.91	4.59	4.20	3.89	3.50

Table E3. Output voltage as a function of load current in the circuit of **Figure 7.**

$i_L [mA]$ ($v_x [V]$)	0 (0)	1 (0.1)	2 (0.2)	3 (0.3)	4 (0.4)	5 (0.5)	6 (0.6)	7 (0.7)	8 (0.8)
$v_o [V]$	6.290	6.180	6.184	6.174	6.163	6.157	6.148	6.027	5.490

Table E4. Output voltage as a function of load current in the circuit of **Figure 8.**

$i_L [mA]$ ($v_x [V]$)	0 (0)	1 (0.1)	2 (0.2)	3 (0.3)	4 (0.4)	5 (0.5)	6 (0.6)	7 (0.7)	8 (0.8)
$v_o [V]$	6.393	6.302	6.217	6.127	6.016	5.889	5.722	5.512	5.270

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	Partner's Name	Set-Up (out of 10)	Data Collection (out of 10)	Participation (out of 5)
1	Hamza Malik	✓	✓	✓
2	Ryan Taine	✓	✓	✓