Introduction

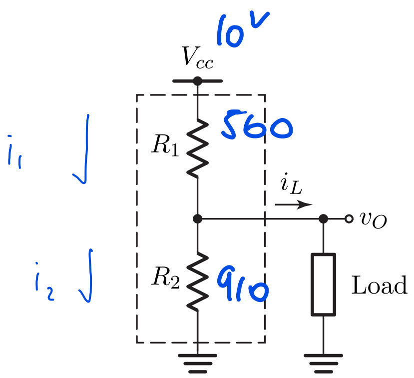
In almost all electronic circuits, there is a need for one or more **voltage regulators**. These are circuits that offer an ideally constant voltage, either as a reference or as the power supply for another part of the circuit. This lab examines the three simplest types of voltage regulator, namely, 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 $v_O = 6.2V$ from a supply voltage of $V_{cc} = 10V$. 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 1. Then, based on the tabulated values, plot v_O versus i_L, and present the curve as Graph P1.

$i_1 = i_L + i_2$

$V_o = 10 - 560 i$



$$\frac{V_{cc} - V_o}{R_1} = \frac{V_o}{R_2} + i_L$$

$$\frac{V_{cc}}{R_1} - i_L = \frac{V_o}{R_1} + \frac{V_o}{R_2}$$

$$\frac{V_{cc}}{R_1} - i_L = V_o\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

Figure 1: A resistive voltage divider supplying a load.

Table 1: 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
$v_O(V)$	6.19	5.84	5.497	5.15	4.80	4.457	4.11	3.764	3.142

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 the datasheet, the 1N4735 produces $v_Z = 6.2V$ at a current of $i_Z = 41mA$, and its series resistance is $r_Z = 2\Omega$, as long as its current is larger than $I_{ZK} = 1mA$. Assuming that $R_1 = 560\Omega$ and $V_{cc} = 10V$, calculate the output voltage v_O for each of the load current values specified in Table 2. Then, based on the tabulated values, plot v_O versus i_L, and present the curve as Graph P2.

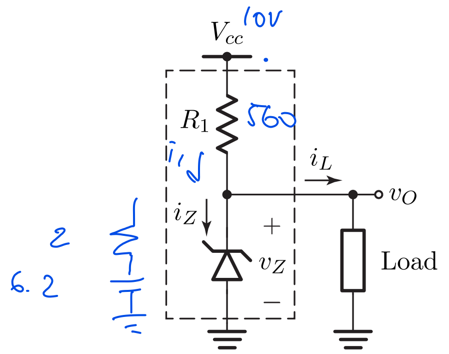


Figure 2: A Zener-diode-based voltage regulator.

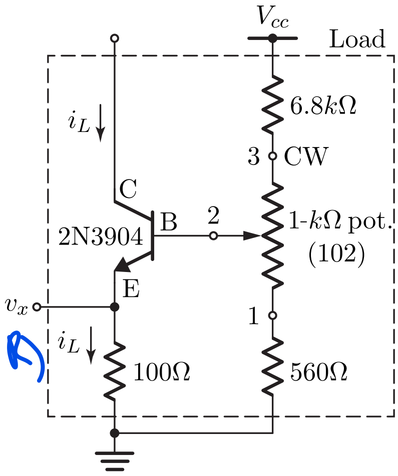
Table 2: Output voltage as a function of load current in the Zener-diode-based voltage regulator of Figure 2.

$i_L(mA)$	0	1	2	3	4	5	6	7	8
$v_O(V)$	6.132	6.130	6.128	6.126	6.124	6.122	6.120	6.118	6.116

Experiment and Results

E1. First, construct the circuit of Figure 3, which will serve as an 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 $6.8k\Omega$. Furthermore, the load is energized by a power supply, V_{cc}, as the figure shows, and is therefore classified as 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.



$i_L = \frac{vx\,(\text{over } R)}{R}$

Figure 3: Circuit of the ”load” for this lab.

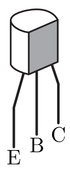


Figure 4: Terminals of transistor 2N3904.

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 kΩ. You can use a small flathead screwdriver or the corner of a credit card to turn the potentiometer’s wiper.

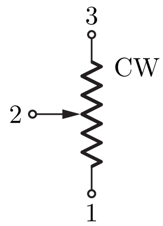


Figure 5: Schematic symbol of a potentiometer.

With the circuit of Figure 3 and $V_{cc} = 10V$, you can change the load current i_L from zero to at least $10mA$ by turning the potentiometer’s wiper. The value of i_L in mA will be ten times the value of the voltage v_x in volts (i.e., $i_L = 10v_x$). Measure v_x using 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 that you built in 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 $10V$. Then, turn the potentiometer to adjust the load current as desired (remember, you know the 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 3. Then, plot v_O versus i_L and present the curve as Graph E2.

$10 \cdot \frac{910}{560+910}$

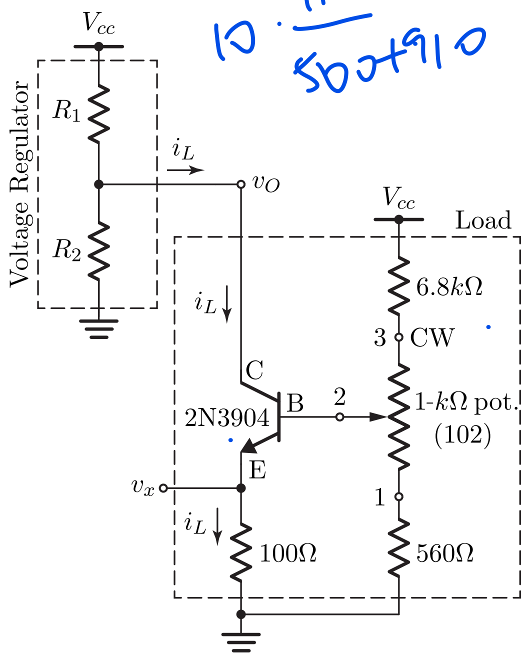


Figure 6: Voltage divider of Figure 1 supplying the adjustable load of Figure 3.

Table 3: 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]
$v_O(V)$									

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 E2 with the new circuit. Complete Table 4, then plot v_O versus i_L, and present the curve as Graph E3.

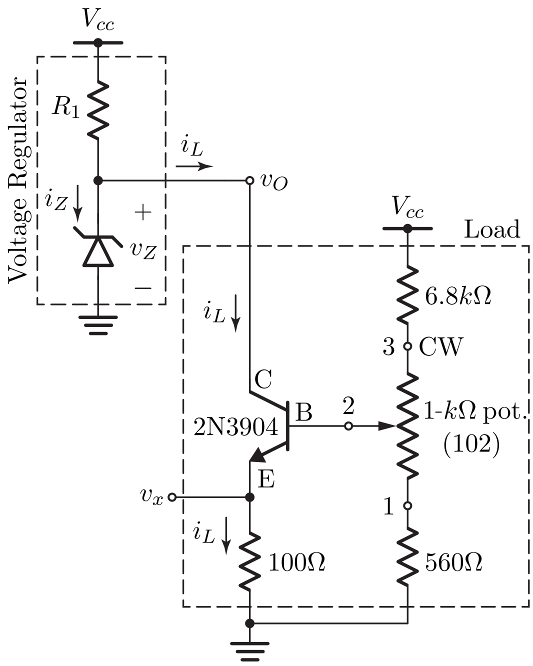


Figure 7: A Zener-diode-based voltage regulator supplying the adjustable load of Figure 3.

Table 4: 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]
$v_O(V)$									

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 $6.3V$. Assuming that the forward voltage drop of each diode is approximately $0.7V$, you should need more or less 9 diodes. Therefore, with the load not connected, insert as many diodes in series as you need to get the closest (no-load) output voltage of $6.3V$. Then, connect the load and repeat experiment E2 with the new circuit. Complete Table 5, plot v_O versus i_L, and present the curve as Graph E4.

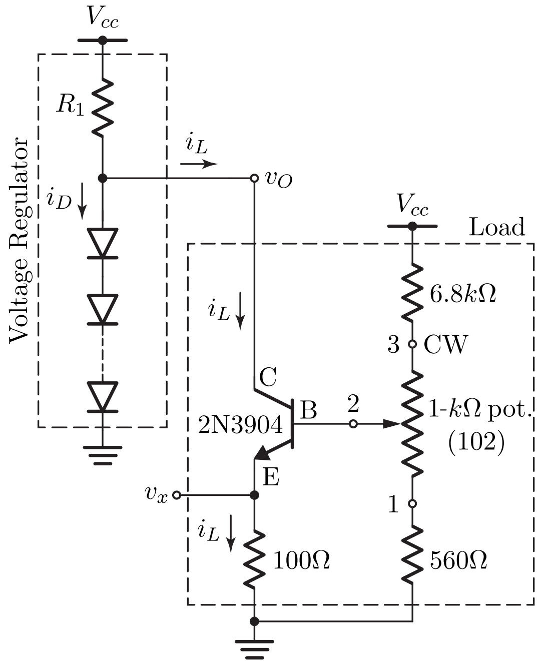


Figure 8: A diode-based voltage regulator supplying the adjustable load of Figure 3.

Table 5: 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]
$v_O(V)$									

Conclusion

C1. Based on the results of 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 1, and complete Table 6. Based on Table 6, 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 voltage is insignificant.

Table 6: 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 1)**									
$R_L(k\Omega)$									

C2. For the voltage divider of Figure 1, compare the calculated output voltages (Table 1) and the measured output voltages (Table 3), correspondingly, and calculate the percent error as:

$$e_{\%} = \frac{\text{theoretical value} - \text{measured value}}{\text{measured value}} \times 100$$

Complete Table 7 and comment on the acceptability of, and reasons for, the errors.

Table 7: Percent error between the calculated and measured v_O of the voltage divider of Figure 1.

$i_L(mA)$	0	1	2	3	4	5	6	7	8
$v_O(V)$ **(Table 1)**									
$v_O(V)$ **(Table 3)**									
$e_{\%}$									

C3. For the Zener-diode-based voltage regulator of Figure 2, compare the calculated output voltages (Table 2) and measured output voltages (Table 4), correspondingly, and calculate the percent error. Complete Table 8 and comment on the acceptability of, and reasons for, the errors.

Table 8: Percent error between the calculated and measured output voltages of the Zener-diode-based regulator of Figure 2.

$i_L(mA)$	0	1	2	3	4	5	6	7	8
$v_O(V)$ **(Table 2)**									
$v_O(V)$ **(Table 4)**									
$e_{\%}$									

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

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

TA Copy of Results

Table 9: 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]
$v_O(V)$									

Table 10: 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]
$v_O(V)$									

Table 11: 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]
$v_O(V)$									

Student Name	Pre-lab (/20)	Set-up (/10)	Data Collection (/10)	Participation (/5)