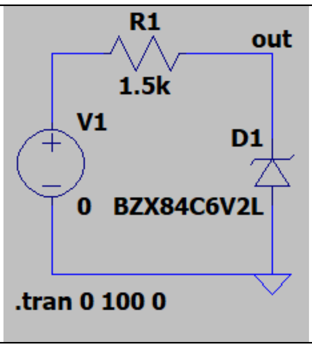
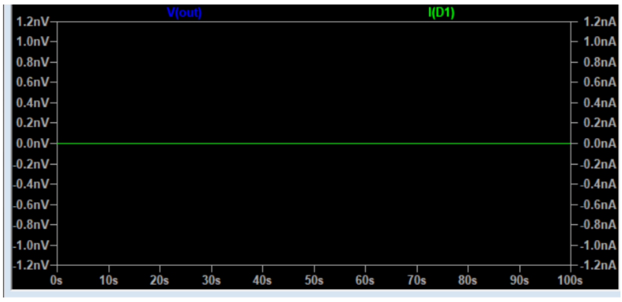
Analog Lab 3:
Voltage Regulator

Class: 電機系大二全英班
Group: 8
Member: 劉姵妤 B103015018
胡庭翊 B103015006

I. Lab 1: Characteristic of Zener Diode

1. Simulation:

<table>
<tr><td>E(V)</td><td>Simulation Circuit Design</td><td>Result of Simulation</td></tr>
<tr><td>0V</td><td>
</td><td>
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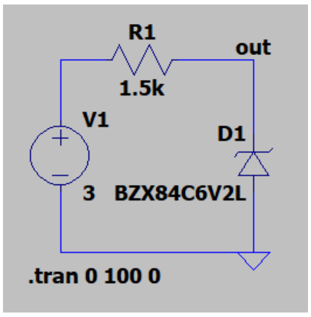
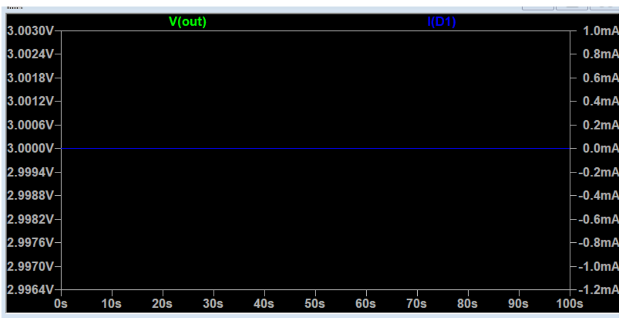
<tr><td>3V</td><td>
</td><td>
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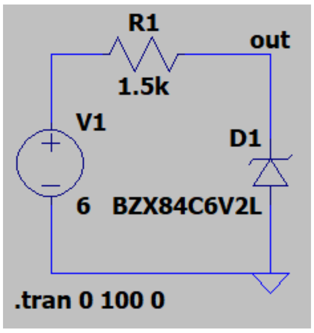
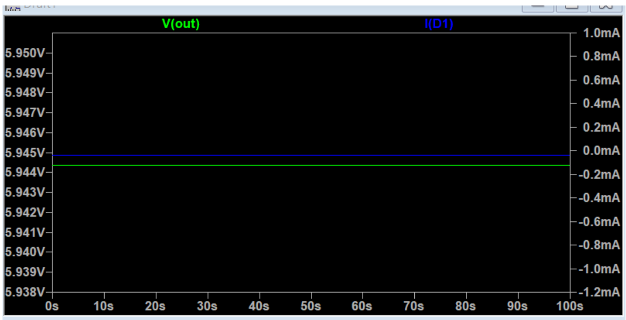
<tr><td>6V</td><td>
</td><td>
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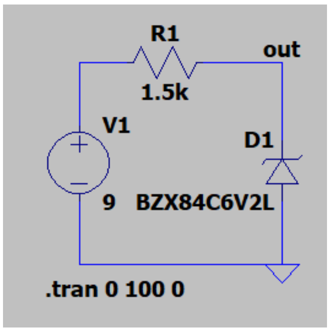
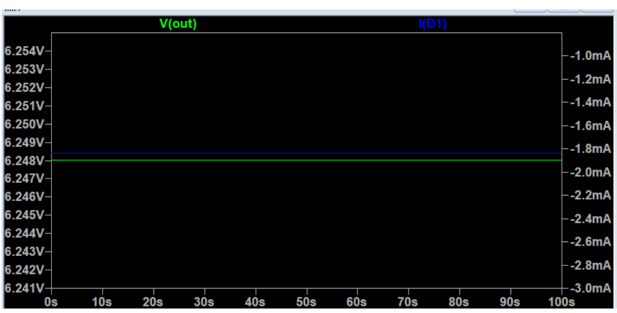
<tr><td>9V</td><td>
</td><td>
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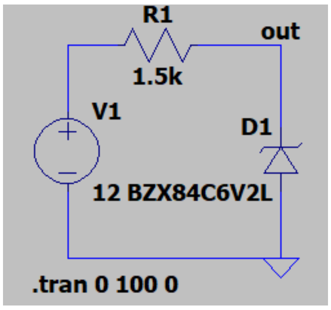
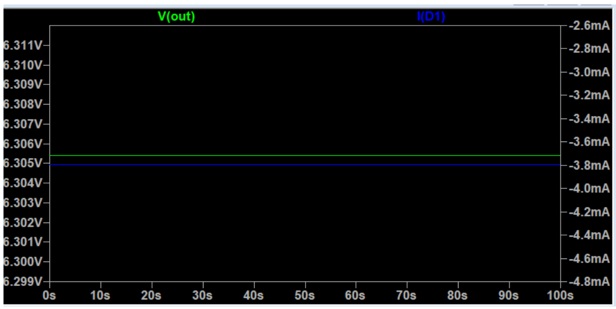
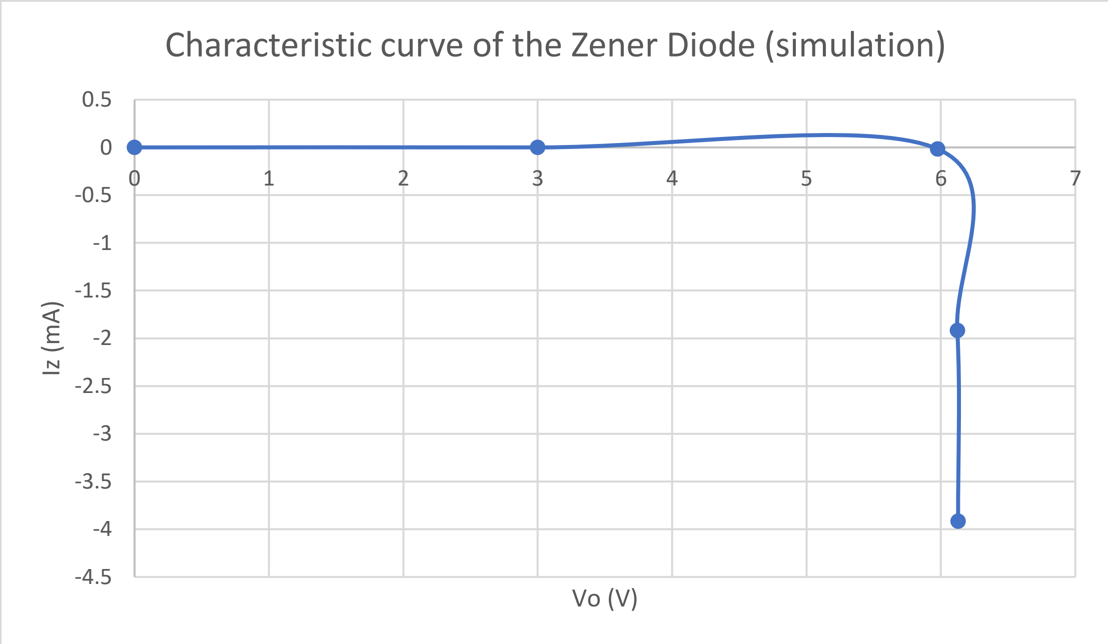
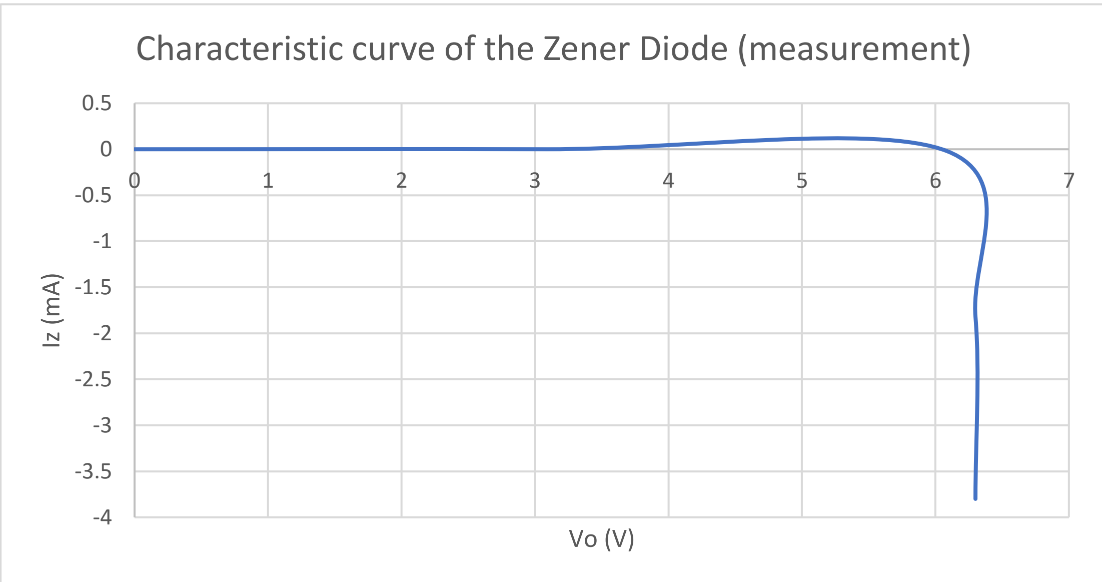
12V		



2. Measurement:

E (V)	0	3	6	9	12
Vo (V)	0	3.091	6.087	6.3	6.3
Iz (mA)	0	0	0.02	1.82	3.8

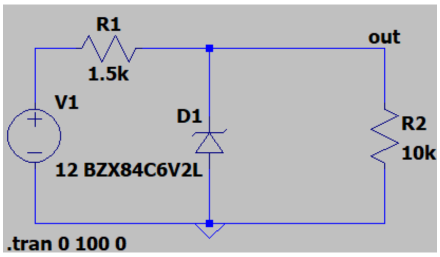
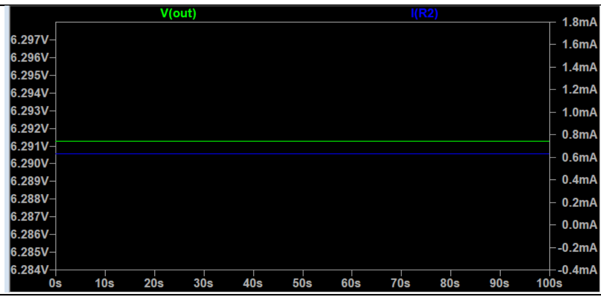
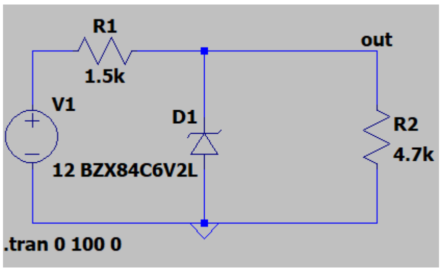
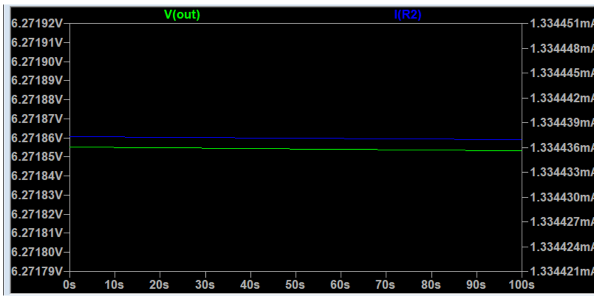
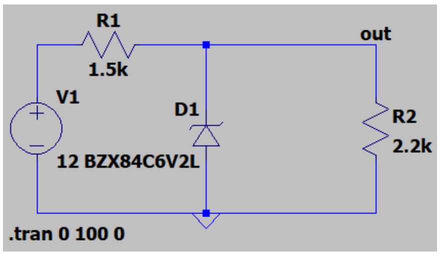
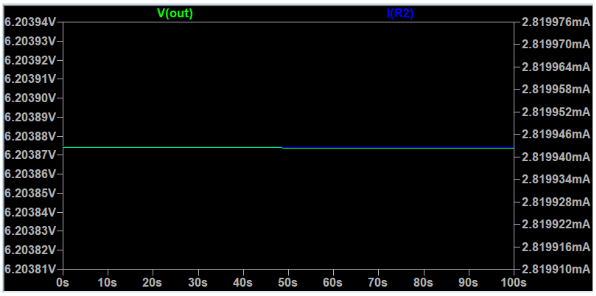


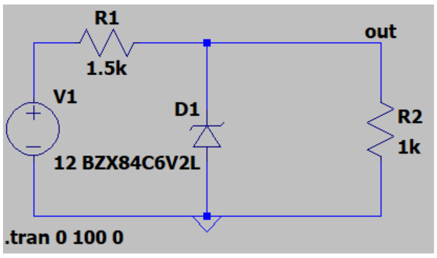
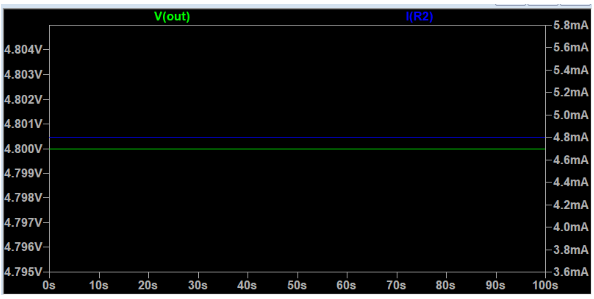
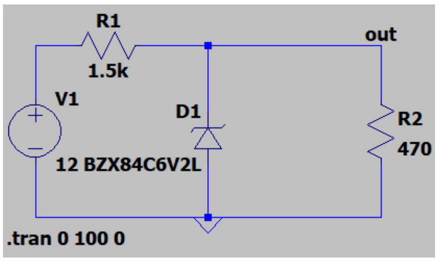
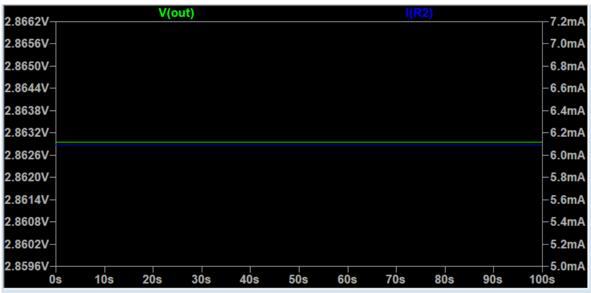
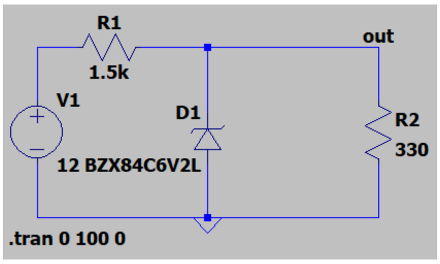
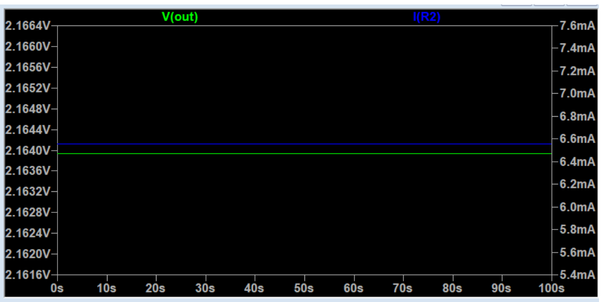
3. Analysis

With a voltage E source strong enough, when the load current changing, the output voltage stays still. In this process of experiment, the Zener diode is working at the negative bias with the voltage source bigger than the breakdown voltage of the diode. According to the result of experiment, when the voltage source provide a voltage smaller than 6.2V, which is the breakdown voltage of the Zener, the circuit works like open circuit. While the voltage larger than 6.2V, the circuit works like a simple circuit added a negative voltage source.

II. Lab2: Basic Voltage Regulator

1. Simulation:

R_L	Simulation Circuit Design	Result of Simulation
10kΩ		
4.7kΩ		
2.2kΩ		

1kΩ		
470Ω		
330Ω		

2. Measurement:

R_L (Ω)	10k	4.7k	2.2k	1k	470	330
V_o (V)	6.24	6.3	6.29	4.857	2.882	2.188
I_L (mA)	0.62	1.35	2.86	4.81	6.13	6.59

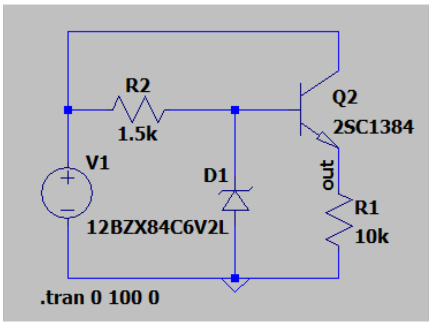
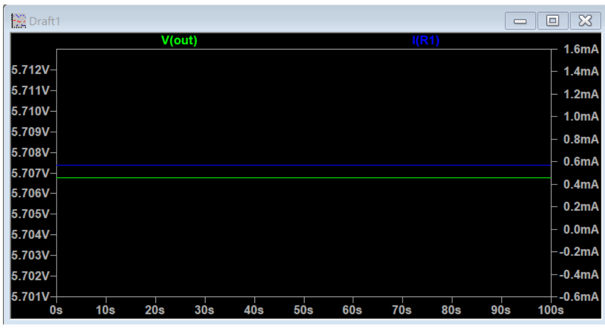
V_o is not consistent, when R_L become small enough, V_o decreases as well.

3. Analysis

If the resistance of the load resistor is large enough to make the divided voltage across the load resistance larger than the breakdown voltage of the Zener diode, the voltage across the load resistor is fixed to the breakdown voltage of the Zener with the redundant current passing through the zener. Otherwise the zener acts like open, which doesn’t function as a voltage regulator.

III. Lab3: Simple Voltage Regulator

1. Simulation:

<table>
<tr><th>R_L (Ω)</th><th>Simulation circuit design</th><th>Simulation result</th></tr>
<tr><td>10k</td><td>
</td><td>
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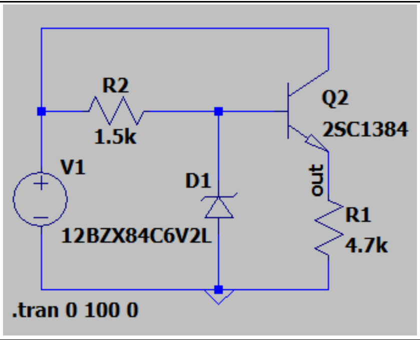
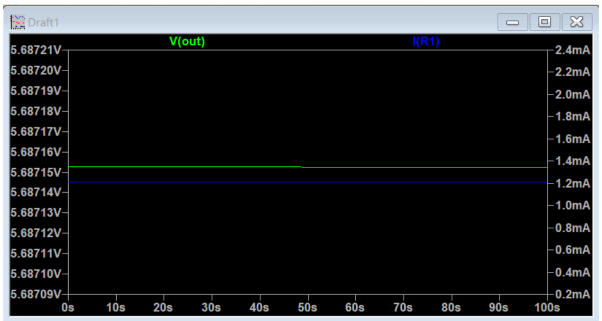
<tr><td>4.7k</td><td>
</td><td>
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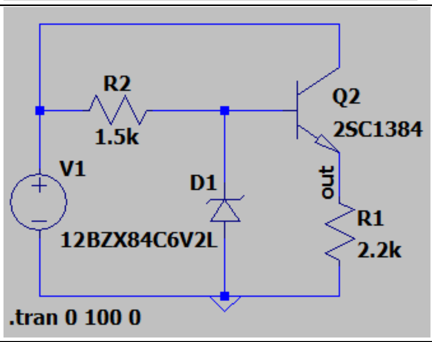
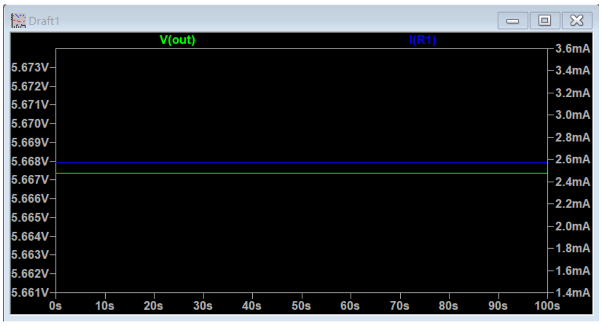
<tr><td>2.2k</td><td>
</td><td>
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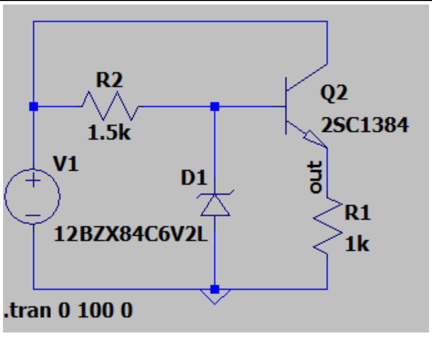
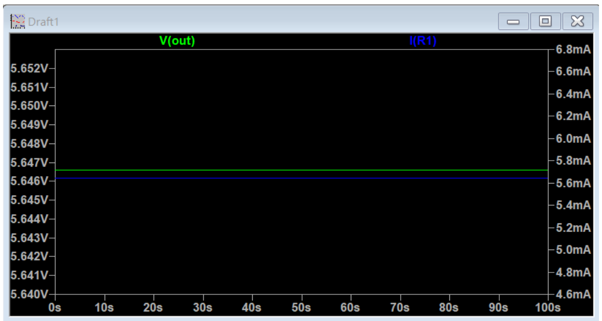
<tr><td>1k</td><td>
</td><td>
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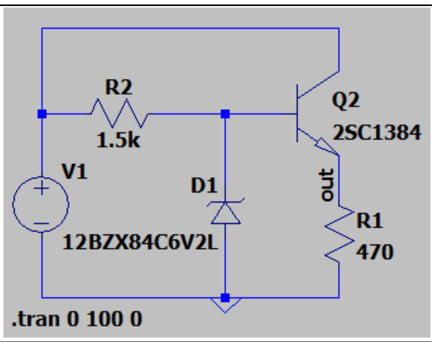
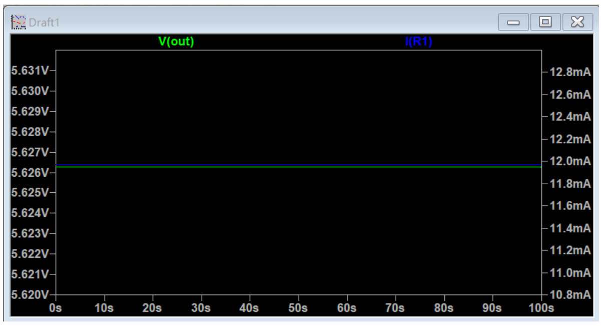
<tr><td>470</td><td>
</td><td>
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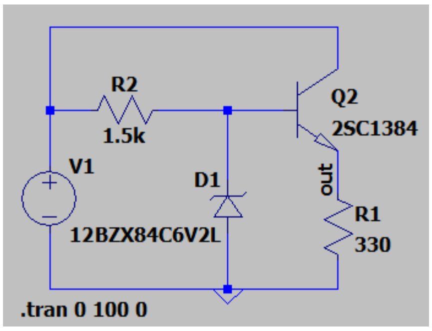
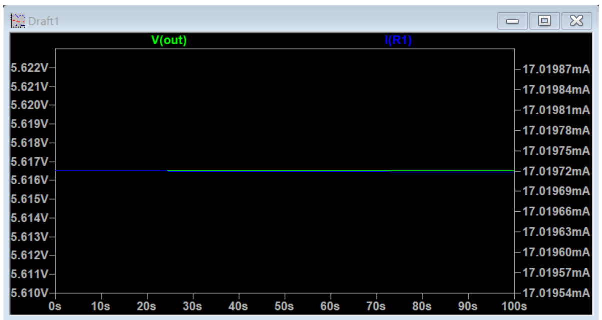
330		

2. Measurement:

R_L (Ω)	10k	4.7k	2.2k	1k	470	330
V_o (V)	5.380	5.720	5.697	5.630	5.658	5.427
I_L (mA)	0.56	1.22	2.59	5.58	11.81	16.55

V_o become consistent with given resistors.
Higher value of I_z is allowed to pass by with consistent V_o.

3. Analysis

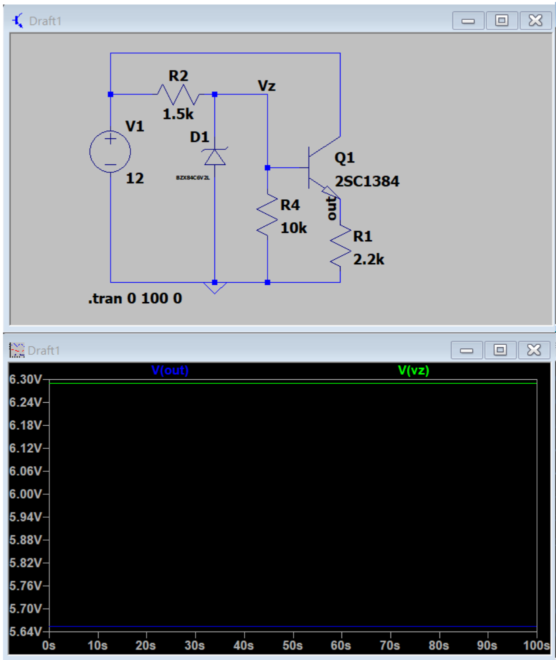
The transistor is added to the circuit to make the current bass through R2 is relatively much smaller than I_L which makes the Zener be able the reach the breakdown voltage to work as voltage regulator appropriately, in order to allow wider range of the resistance of the load resistor.

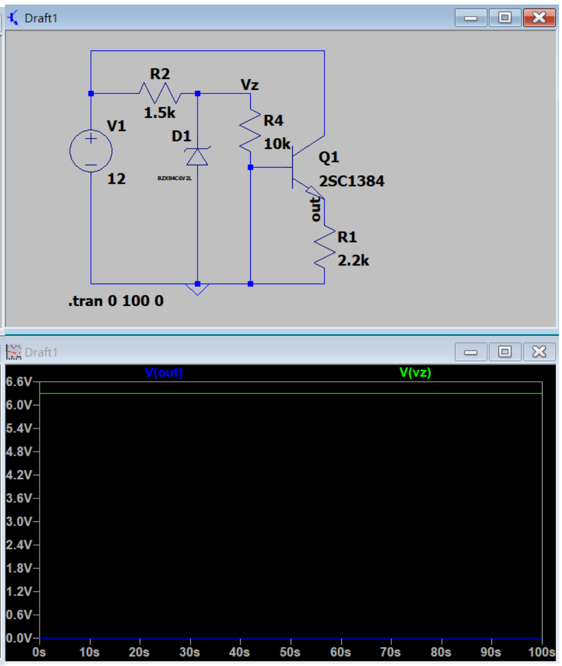
IV. Simple adjustable voltage regulator (1)

1. Simulaton:

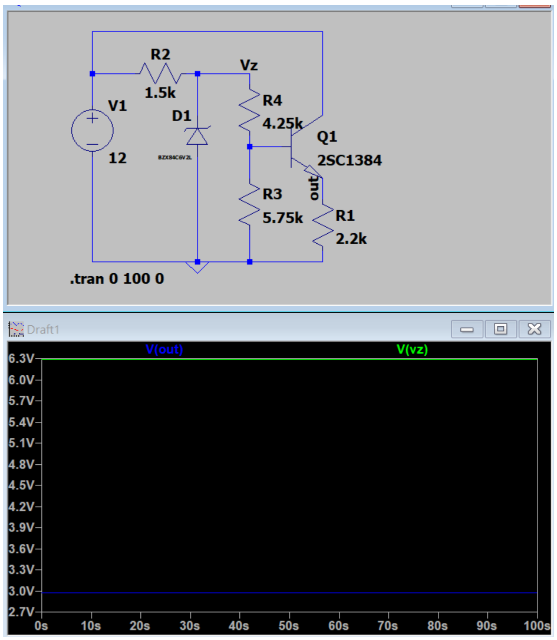
i. Simulation result:

1. $V_{o(max)}$= 5.65V, $V_{o(min)}$=0V, V_z= 6.29V



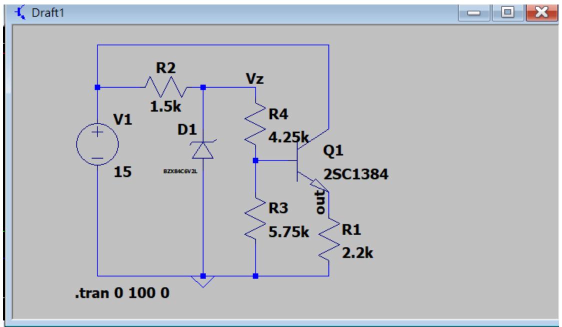


2. Adjust the variable resistor VR to make V_o=3V



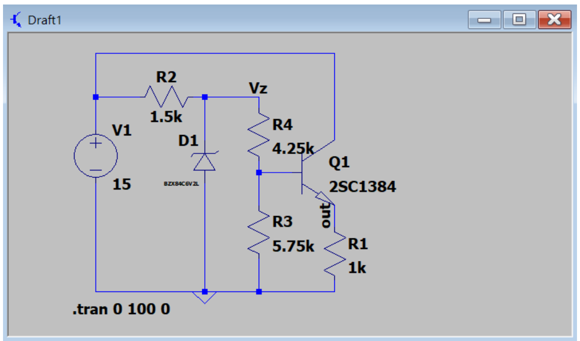
V_o=3V

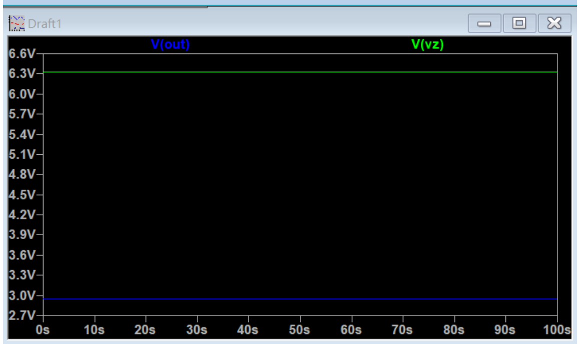
3. increase the value of voltage source form 12V to 15V



V_o=3V

4. change R_1 with a 1kΩ resistor





V_o=3V

⇨ with the simulation result above, it shows that the output voltage V_o keep consistent while the voltage source or R_1 is changed with different value.

2. Measurement:

i. Theorem result:

1. $V_{o(max)}$= 5.61V, $V_{o(min)}$=0V

ii. Measurement result:

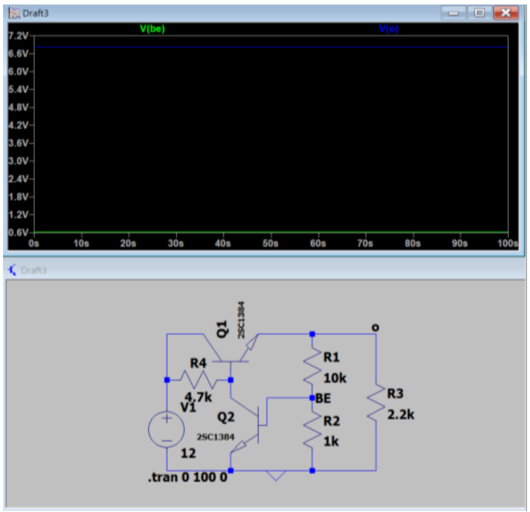
1. $V_{o(max)}$= 5.703V, $V_{o(min)}$=0V, V_z= 6.31V
2. Increase voltage outlet: V_o=3.015V
3. Change R_L by 1kΩ: V_o=2.980V

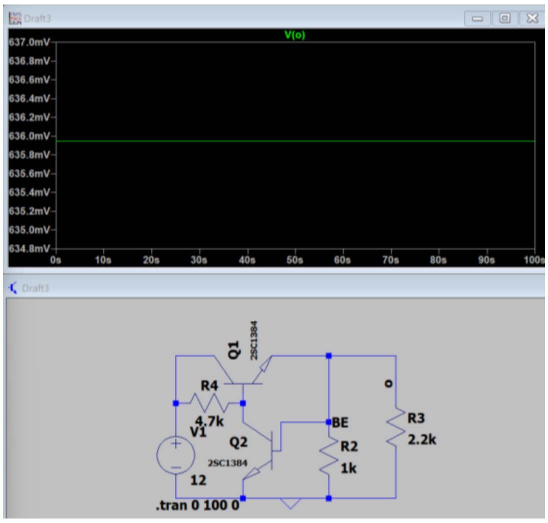
⇨ with the measurement result above, it shows that the output voltage V_o is approximately consistent while the voltage source or R_1 is changed with different value.

V. Simple adjustable voltage regulator (2)

1. Simulation:

i. V_{BE}=0.61V, $V_{o(max)}$=6.82V, $V_{o(min)}$=0.636V





2. Measurement:

i. Theorem result

1. $V_{o(max)}$=0.595V, $V_{o(min)}$=6.523V

ii. Measurement result

1. V_{BE}=0.593V, $V_{o(max)}$=6.68V, $V_{o(min)}$=0.559V

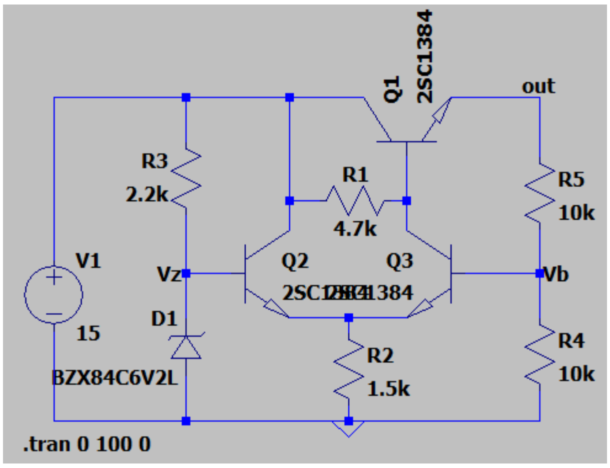
3. Analysis

Adjustable simple voltage regulator circuit differs from the simple voltage regulator by adding a variable resistor parallel to the load resistor. Adjusting the variable resistor to increase or decrease the total resistor, with the Zener work at the breakdown voltage to make the voltage across the load resistor fixed, to know that $V_o=V_{BE}*(\frac{R2}{R1}+1)$.

VI. Voltage Regulator Circuit using Differential Amplifier Circuit:

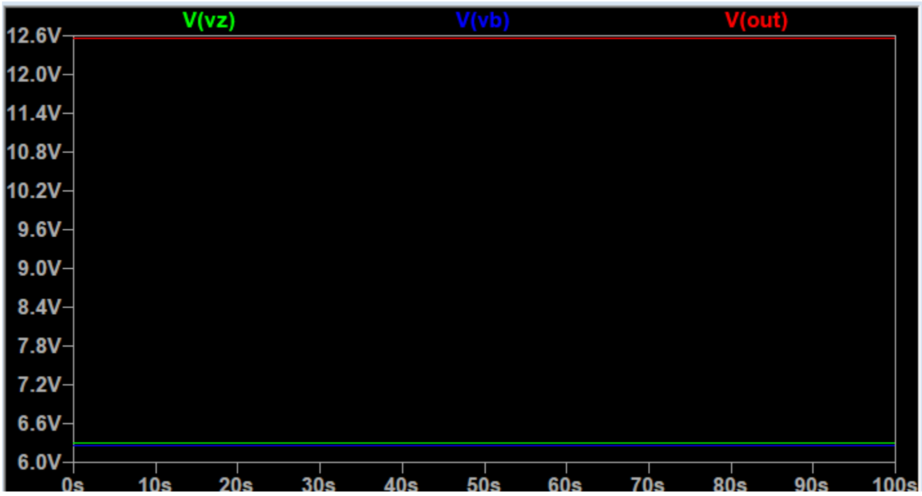
1. Simulation:

i. Circuit design:



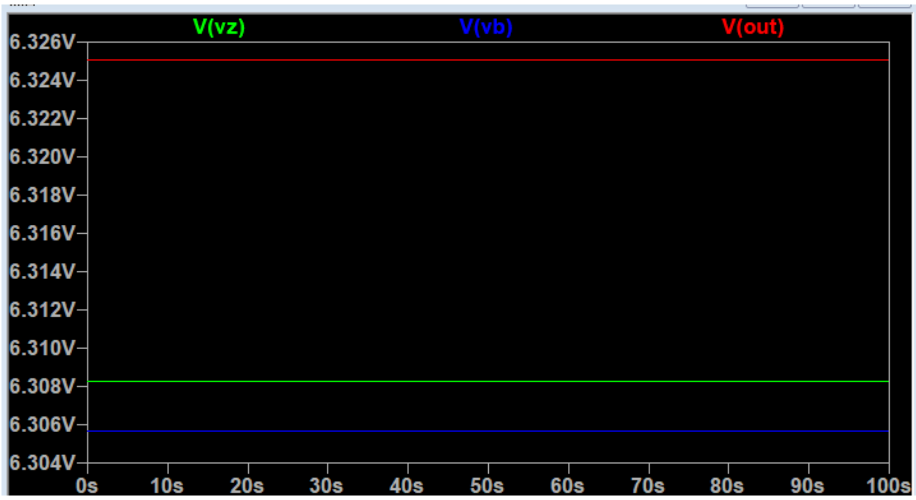
ii. Simulation result:

1. With the variable resistor in maximum value:



$V_{o(max)}$= 12.6V, $V_z \fallingdotseq V_b$=6.3V

2. With the variable resistor in minimum value:



$V_{o(min)}$=6.32V, V_z≒V_b=6.3V

2. Measurement:
   i. Theorem result:
      1. $V_{o(max)}$= 12.64V, $V_{o(min)}$=6.32V, V_z= 6.32V, V_b=6.32V
   ii. Measurement result:
      1. $V_{o(max)}$= 12.93V, $V_{o(min)}$=6.3V, V_z= 6.32V, V_b=6.14V
         ⇨ Approximately same as the result of simulation and theorem prediction.

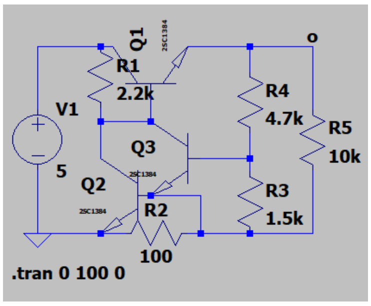
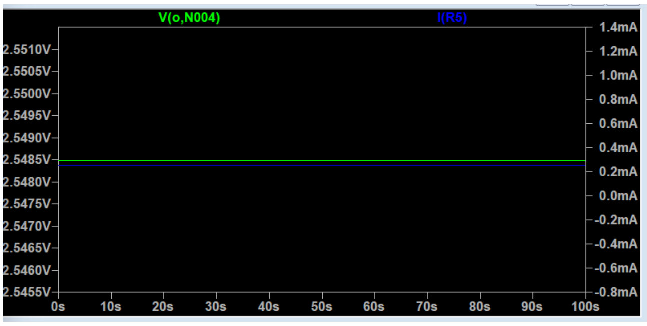
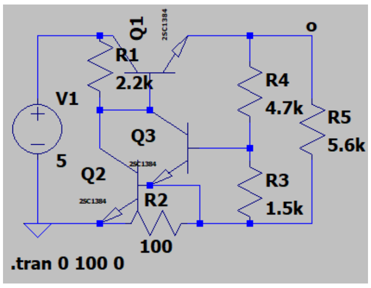
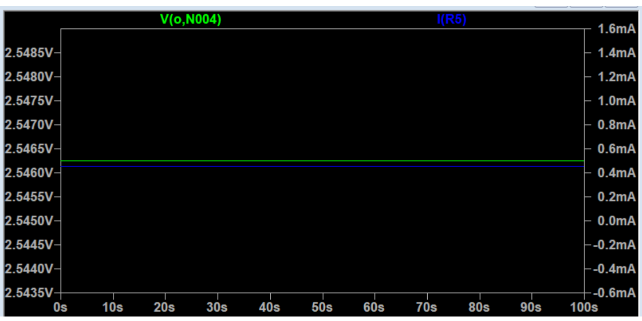
3. Analysis

While $V_E=V_Z-V_{BE1}$, $V_B=V_E+V_{BE2}=V_Z-V_{BE1}+V_{BE2}$ and having the transistors identical, $V_{BE1}=V_{BE2}$ would lead to $V_B=V_Z$. V_B can also be written as

$V_B=V_o*\frac{R1}{R1+R2}$ => $V_o=V_Z*(\frac{R2}{R1}+1)$

VII. Voltage Regulator Circuit with Current Limiting Protection:

1. Simulation:

R5(Ω)	Simulation circuit design	Simulation result
10k		
5.6k		

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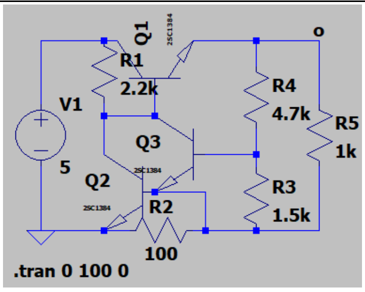
<tr><td>1k</td><td>
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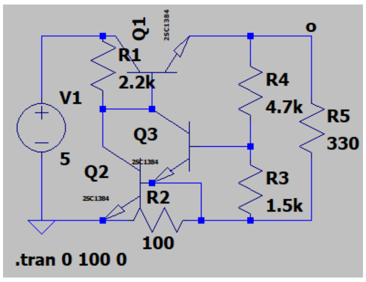
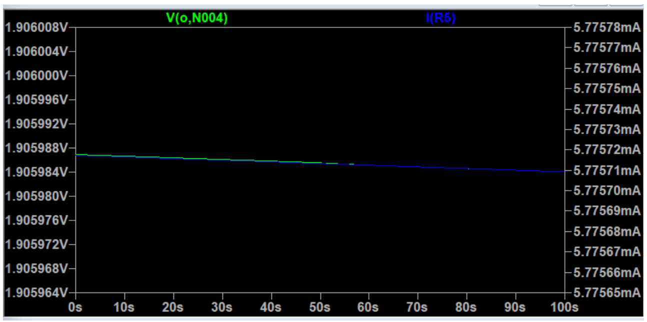
<tr><td>330</td><td>
</td><td>
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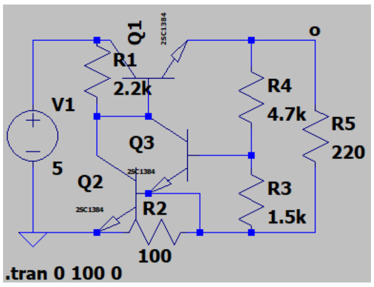
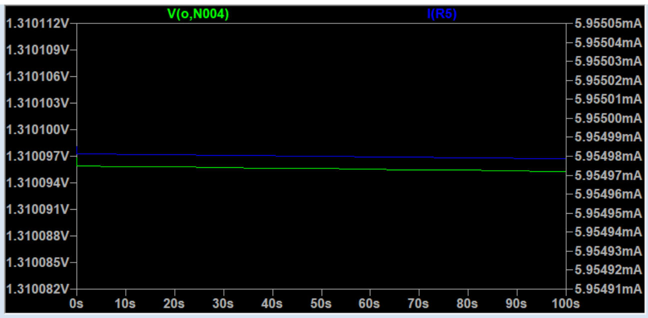
<tr><td>220</td><td>
</td><td>
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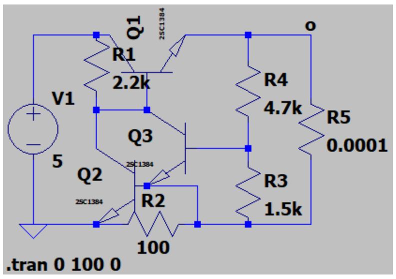
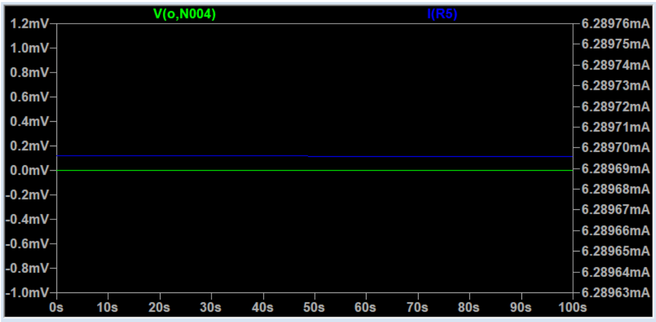
<tr><td>0</td><td>
</td><td>
</td></tr>
</table>

2. Measurement:

R_L (Ω)	10k	5.6k	1k	330	220	0
I_L (mA)	0.311	0.542	2.4	5.57	5.75	4.02
V_o (V)	2.441	2.442	2.425	1.849	1.261	0

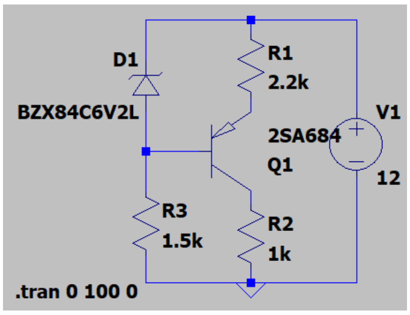
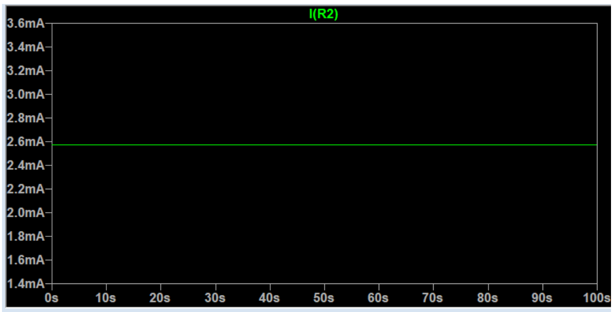
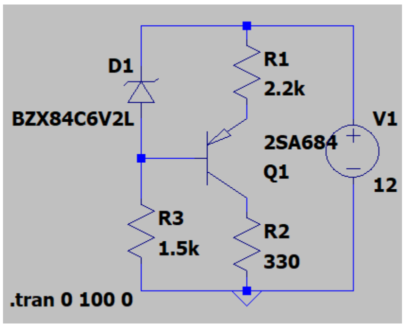
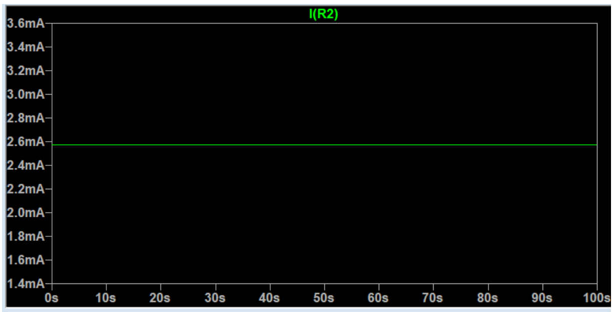
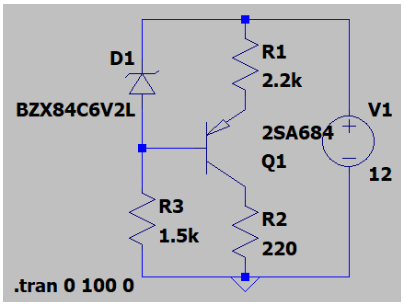
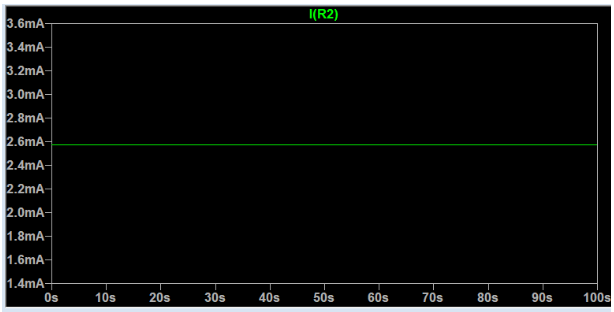
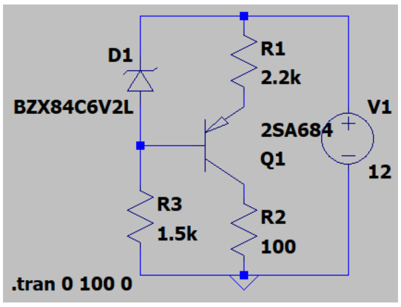
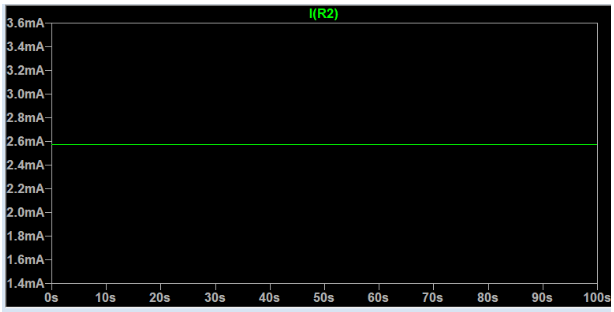
When resistor R_L smaller than 1kΩ, voltage across R_L starts decreasing.

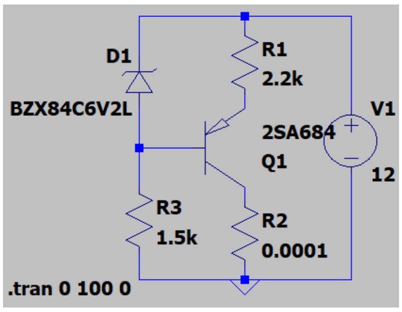
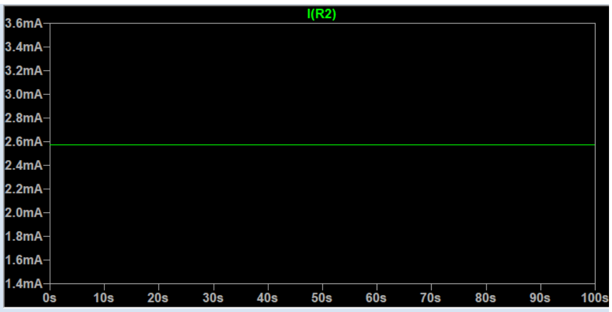
3. Analysis

Adding a additional transistor TR_3 and resistor R_S to prevent the transistors being burned out. The additional transistor is used to distribute the redundant current passing through the R_1 to make the current flowing through load resistor smaller, which is able to fix the voltage across load.

VIII. Constant Current Circuit:

1. Simulation:

R_2 (Ω)	Simulation circuit design	Simulation result
1k		
330		
220		
100		

0		

2. Measurement:

R_L (Ω)	1k	330	220	100	0
I_L (mA)	2.56	2.56	2.57	2.54	2.57

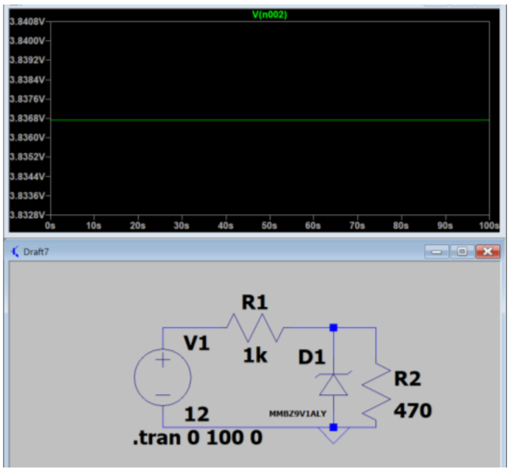
I_L is independent to R_L

3. Analysis

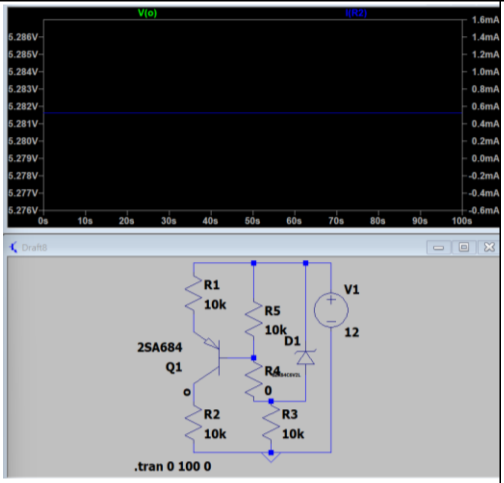
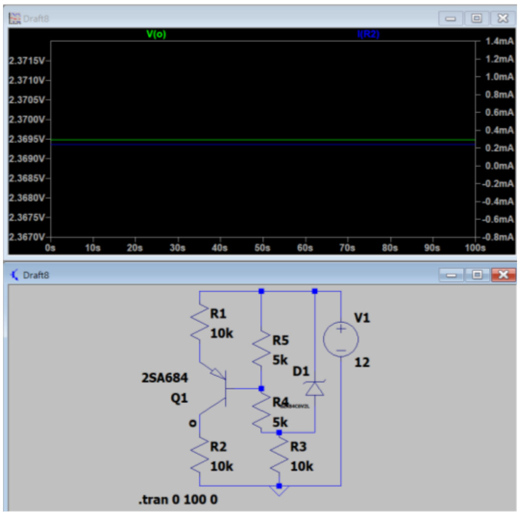
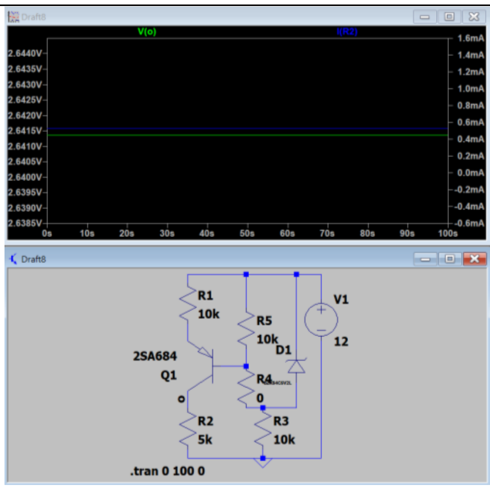
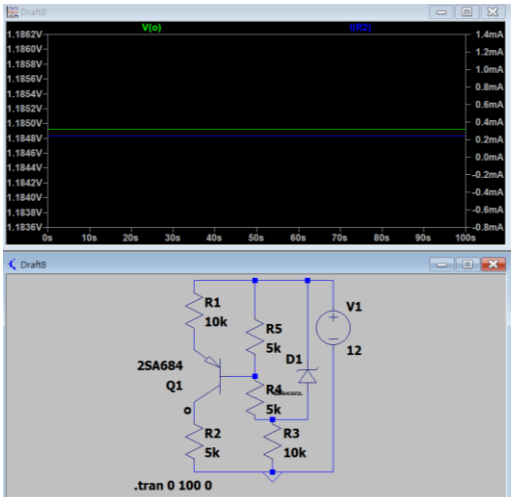
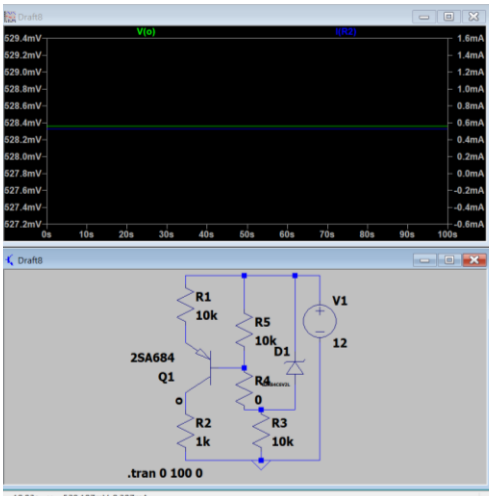
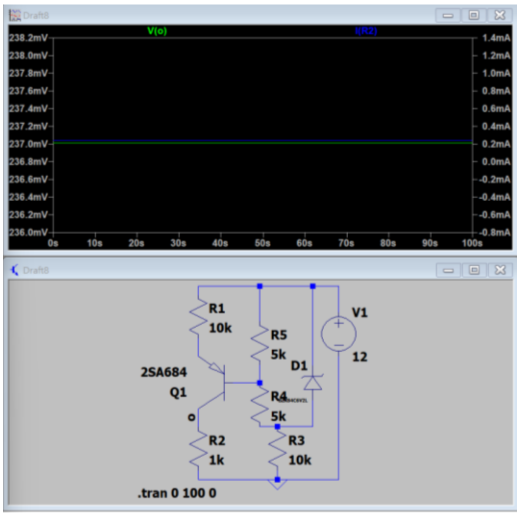
Having the characteristic of the zener diode, the Zener is able to fix the voltage across itself is the working region. While the voltage across R_1 is a constant (V_E=V_Z-V_{BE} with V_Z and V_{BE} being a constant), I_E=V_E/R_1=$\frac{\beta+1}{\beta}$*I_C, leading to the load current I_C keep constant with different load resistant R_L.

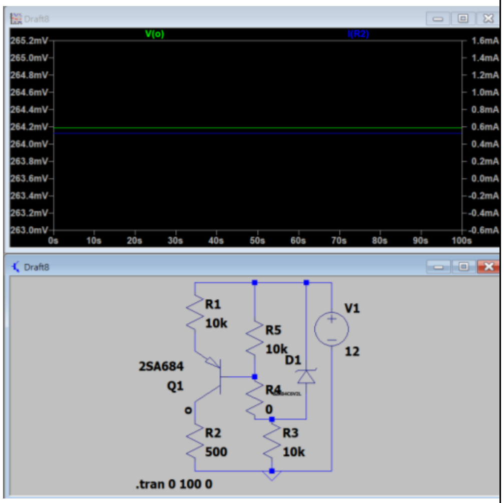
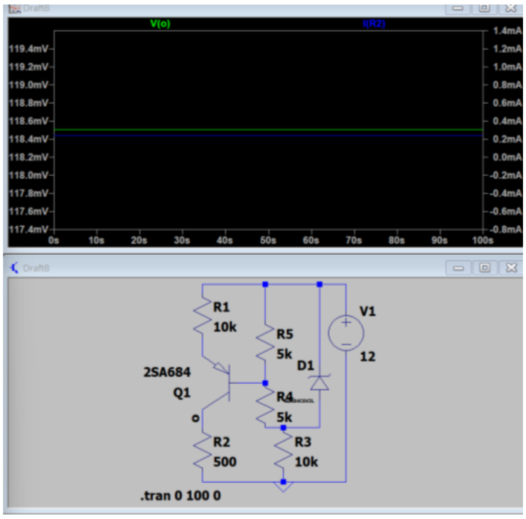
IX. Exercise

1. Problem 1
   i. The Zener diode can work appropriately with given parameter.
   ii. V_o=3.8368V



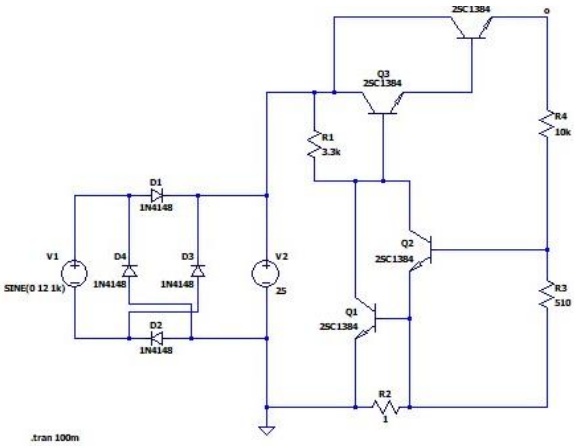
2. Problem 2
   i. Figure 19.23 is a constant current circuit, according to the analysis by simulation.
   ii. The variable resistor VR is used to adjust the value of the load current.

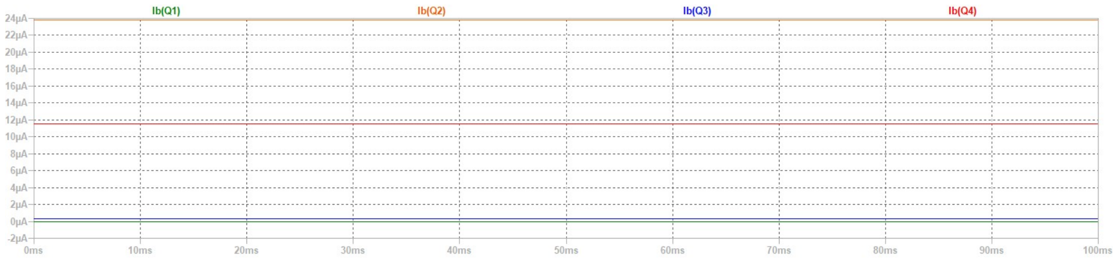
R_2 (Ω)	Vo(V) (10k/0)	V_0(V) (5k/5k)	I_L (mA) (10k/0)	I_L (mA) (5k/5k)	Simulation (VR=10k/0)	Simulation (VR=5k/5k)
10k	5.28	2.37	0.5	0.25		
5k	2.64	1.18	0.5	0.25		
1k	0.53	0.24	0.5	0.25		

500	0.26	0.12	0.5	0.25		

3. Problem 3

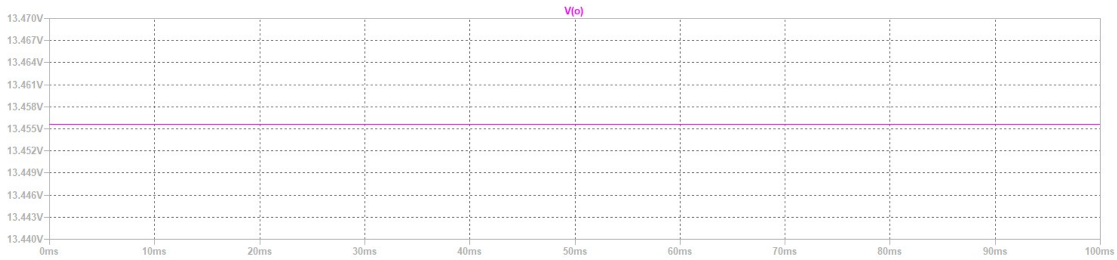
   i. Circuit design

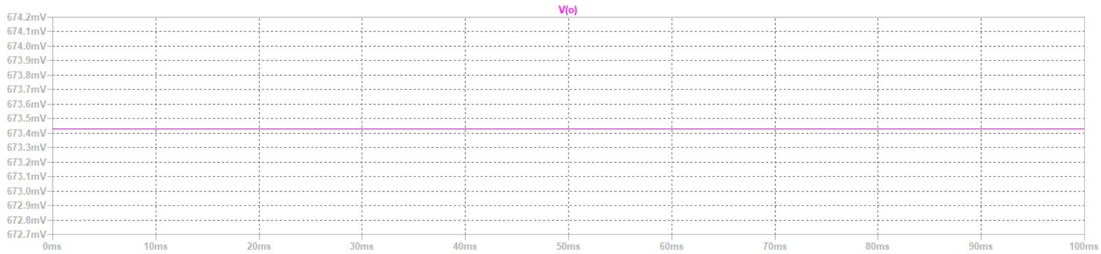


ii. 

According to the result of simulation, the current pass through the TR_3 transistor would be the highest one among the others. Hence, the heat sink should be added on the TR_3 transistor.

iii.

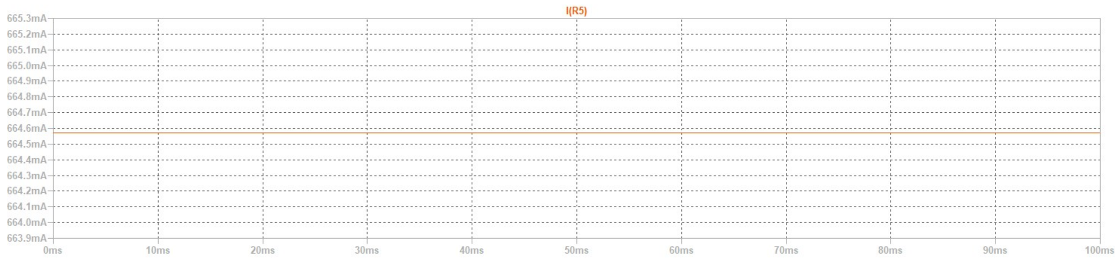




$V_{o(max)}$=13.456V, $V_{o(min)}$=0.673V

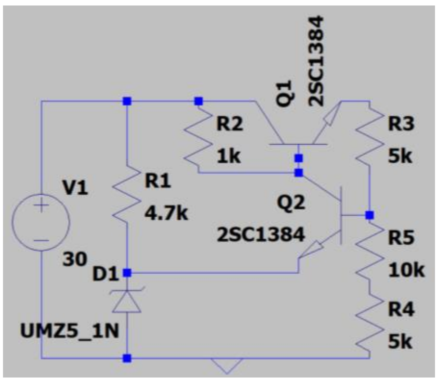
iv. The circuit is with current limiting protection. When the output terminal shorted, the current pass by is still low.

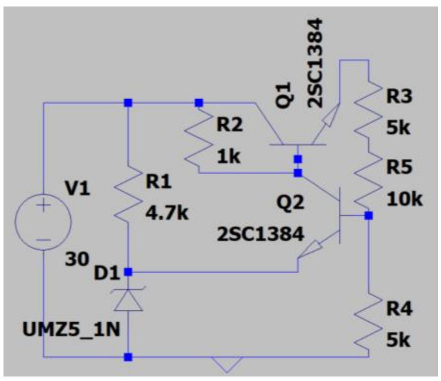
v. If the output port is accidentally short-circuited, 0.6646A current would pass through the wire.

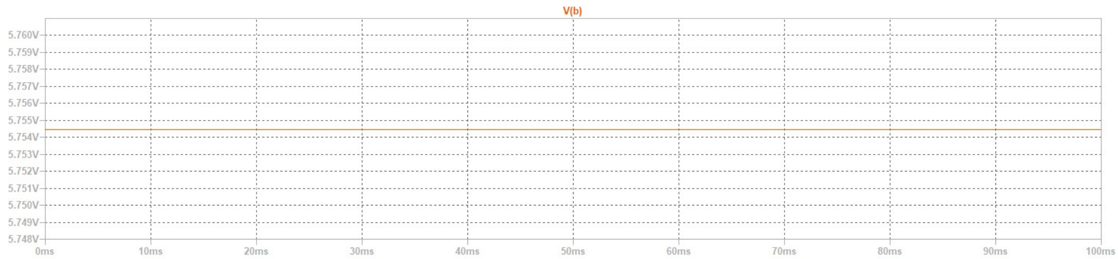


4. Problem 4

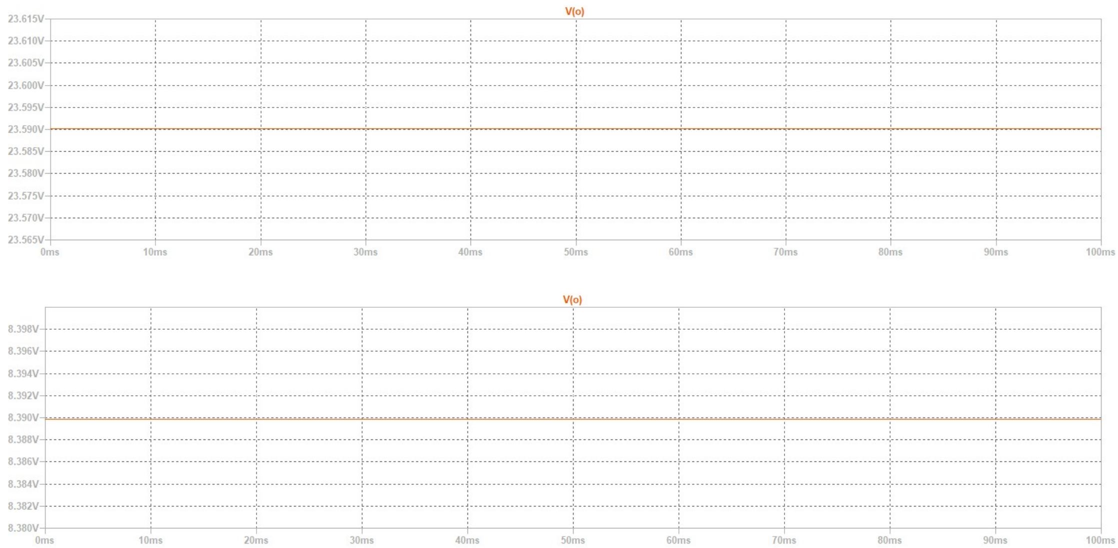
i. Circuit design





ii. 

V_B=5.7545V

iii. 

$V_{o(max)}$=23.59V

$V_{o(min)}$=8.39V

X. Observation & Discussion

In the voltage regulator circuit, the zener diode is connected in parallel with the load resistor. When the input voltage varies, the zener diode regulates the voltage across the load resistor by maintaining a constant voltage drop. The resistor in series with the zener diode limits the current flowing through the circuit and prevents the zener diode from burning out.

The variable resistor in the voltage regulator circuit allows us to adjust the input voltage and observe the behavior of the zener diode at different voltages. At low input voltages, the zener diode is not conducting, and the output voltage is equal to the input voltage minus the voltage drop across the series resistor. As we increase the input voltage, the zener diode starts to conduct, and the output voltage remains constant at the zener voltage. Beyond the breakdown voltage, the zener diode maintains a constant voltage drop, and the output voltage remains constant.

The voltage regulator with a zener diode is a simple yet effective circuit that can maintain a constant voltage across a load resistor. By exploiting the unique characteristics of the zener diode, we can build a voltage regulator that is immune to variations in the input voltage and the load current. Through this experiment, we gained a better understanding of the behavior of zener diodes and how they can be used to regulate voltage.