EE230: Lab 2
Zener Regulator &
BJT Series Regulator

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1 Overview of the experiment

1.1 Aim of the experiment

1. Creating and Simulating a model of a DC Power Supply with Zener Regulator, finding V_{out}, I_S, I_Z, I_L, and comparing simulation results with hand calculations.

2. Creating and Simulating a model of a DC Power Supply with BJT Series Regulator, finding the node voltages, and observing V_{out} with changes in R_1 and R_2.

1.2 Methods

The circuit diagrams for the Zener Regulator and the BJT Series Regulator were provided in the lab handout, using which I created and simulated them in NGSpice.

2 Design

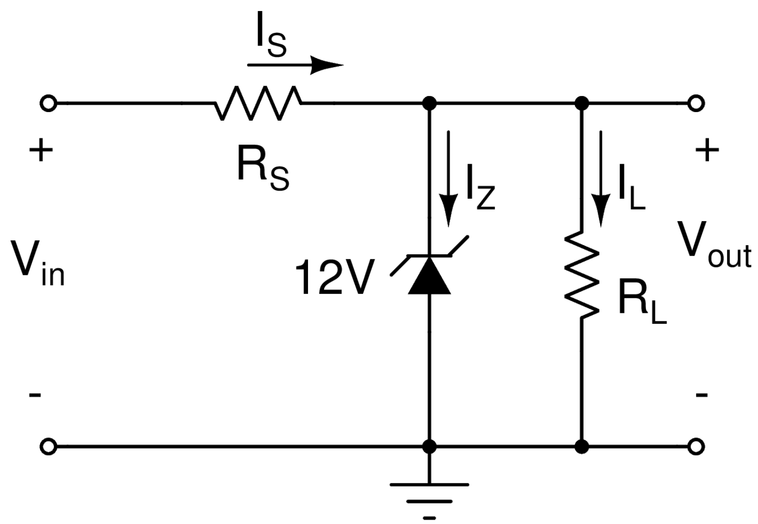


Fig. DC Power Supply with Zener Diode Regulator

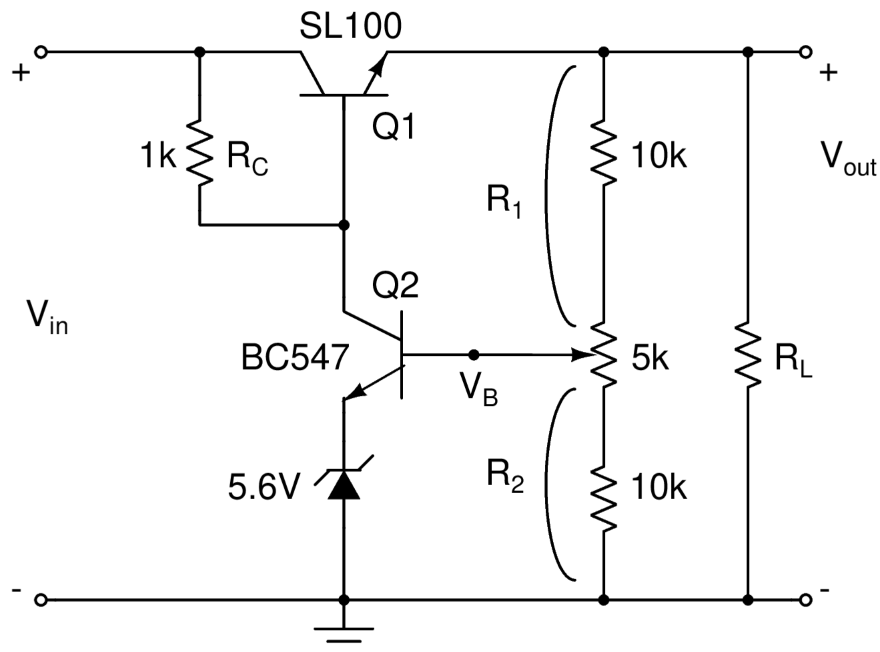


Fig. DC Power Supply with a BJT Series Regulator

3 Simulation results

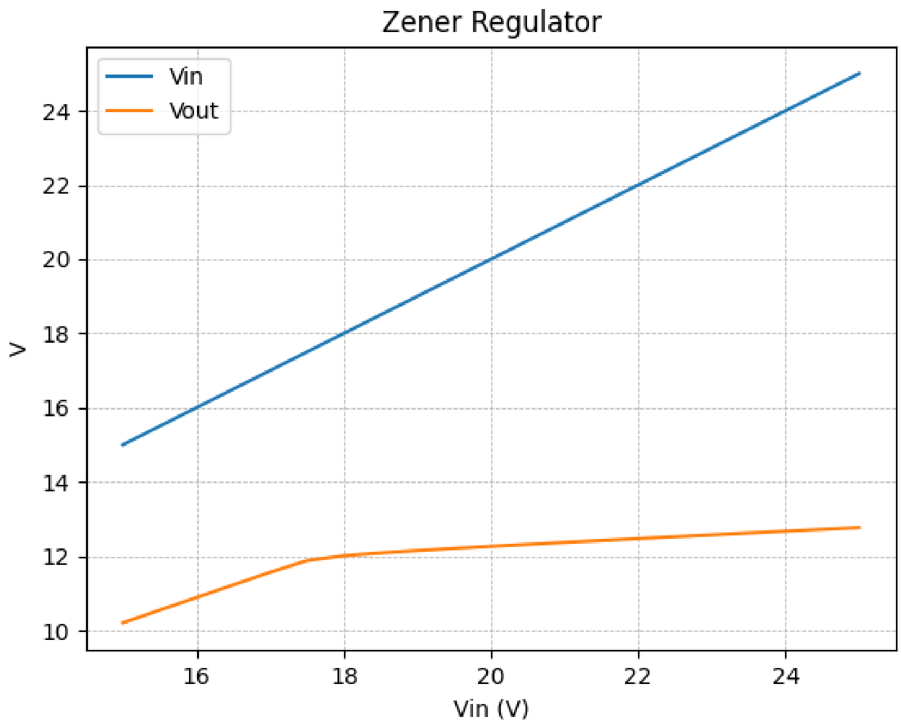
3.1 Zener Regulator

3.1.1 Code snippet

```
Zener Regulator
*Zener Subcircuit
.SUBCKT ZENER_12 1 2
D1 1 2 DF
DZ 3 1 DR
VZ 2 3 10.8
.MODEL DF D ( IS=27.5p RS=0.620 N=1.10 CJO=78.3p VJ=1.00
+ M=0.330 TT=50.1n)
.MODEL DR D ( IS=5.49f RS=50 N=1.77 )
.ENDS
Rs 1 dummys 470
Vdummys dummys 2 dc 0
xz dummyz 2 ZENER_12
Vdummyz dummyz 0 dc 0
Rl 2 dummyl 1k
Vdummyl dummyl 0 dc 0
Vin 1 0 dc 20
.op
*.dc Vin 15 25 0.5
.control
run
print v(2) i(Vdummys) i(Vdummyz) i(Vdummyl)
.endc
.end
```

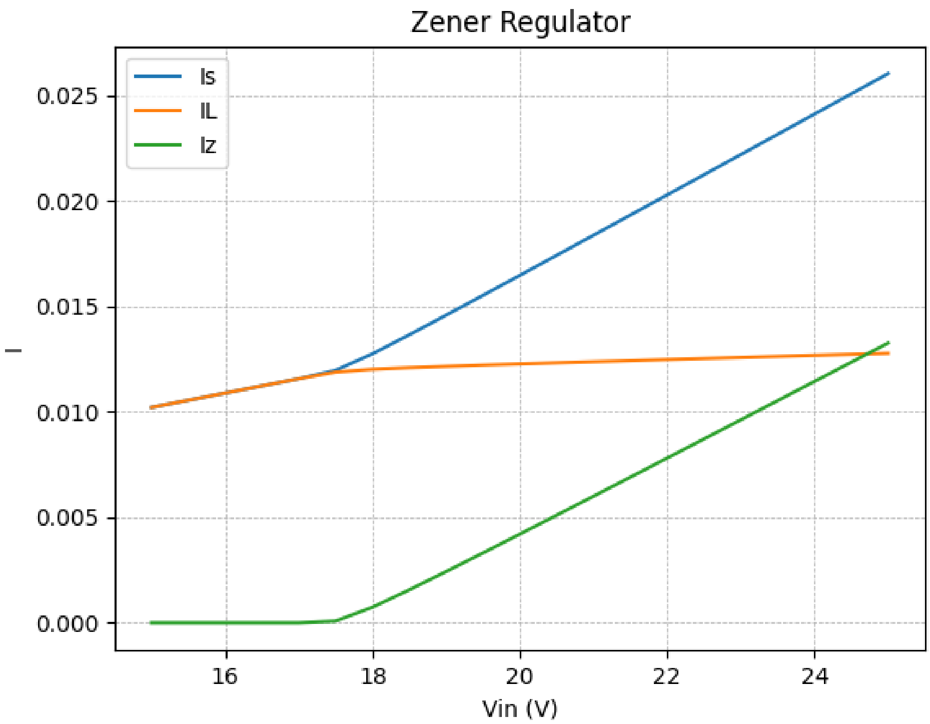
3.1.2 Simulation results

Given below is the plot for V_{out} waveform obtained from the DC analysis of the Zener Regulator:



We can observe in the graph above that for $Vin > 17.5V$, V_{out} is bound between $12 - 13V$. But for $V_{in} < 17.5V$, the Zener diode does not regulate the voltage very well around $12V$.

Given below is the plot for currents I_S, I_L and I_Z obtained from the DC analysis of the Zener Regulator:



We can observe in the graph above that for $V_{in} < 17.5V$, I_Z is approximately 0, which means that the Zener diode is not Reverse Breakdown and thus is not functioning as a Voltage Regulator.

3.2 BJT Series Regulator

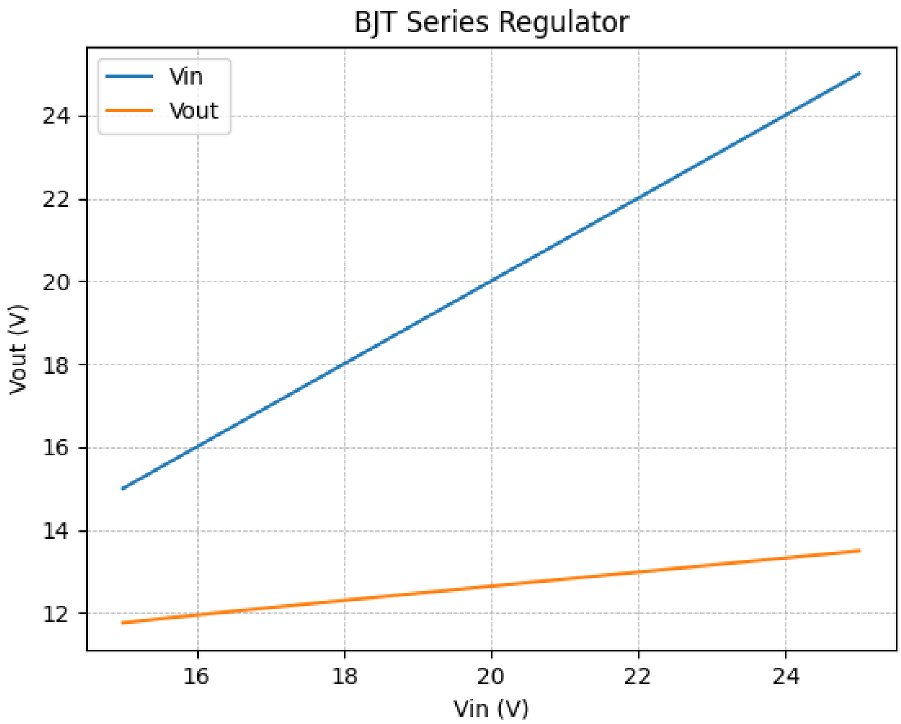
3.2.1 Code snippet

```
BJT Series Regulator
*Zener Subcircuit
.SUBCKT ZENER_12 1 2
D1 1 2 DF
DZ 3 1 DR
VZ 2 3 4.4
.MODEL DF D ( IS=27.5p RS=0.620 N=1.10 CJO=78.3p
+ VJ=1.00 M=0.330 TT=50.1n)
.MODEL DR D ( IS=5.49f RS=50 N=1.77 )
```

```
.ENDS
.model bc547a NPN IS=10f BF=200 ISE=10.3f IKF=50m
+ NE=1.3 BR=9.5 VAF=80 IKR=12m ISC=47p NC=2 VAR=10
+ RB=280 RE=1 RC=40 tr=0.3u tf=0.5n cje=12p vje=0.48
+ mje=0.5 cjc=6p vjc=0.7 mjc=0.33 kf=2f
.model SL100 NPN IS=100f BF=80 ISE=10.3f IKF=50m
+ NE=1.3 BR=9.5 VAF=80 IKR=12m ISC=47p NC=2 VAR=10
+ RB=100 RE=1 RC=10 tr=0.3u tf=0.5n cje=12p vje=0.48
+ mje=0.5 cjc=6p vjc=0.7 mjc=0.33 kf=2f
Rc 1 2 1k
Q1 1 2 3 SL100
Q2 2 4 5 bc547a
xz 0 5 ZENER_12
R1 3 4 10.2k
R2 4 0 14.8k
Rl 3 0 1k
Vin 1 0 dc 20
.op
*.dc Vin 15 25 0.5
.control
run
print v(1) v(2) v(3) v(4) v(5)
.endc
.end
```

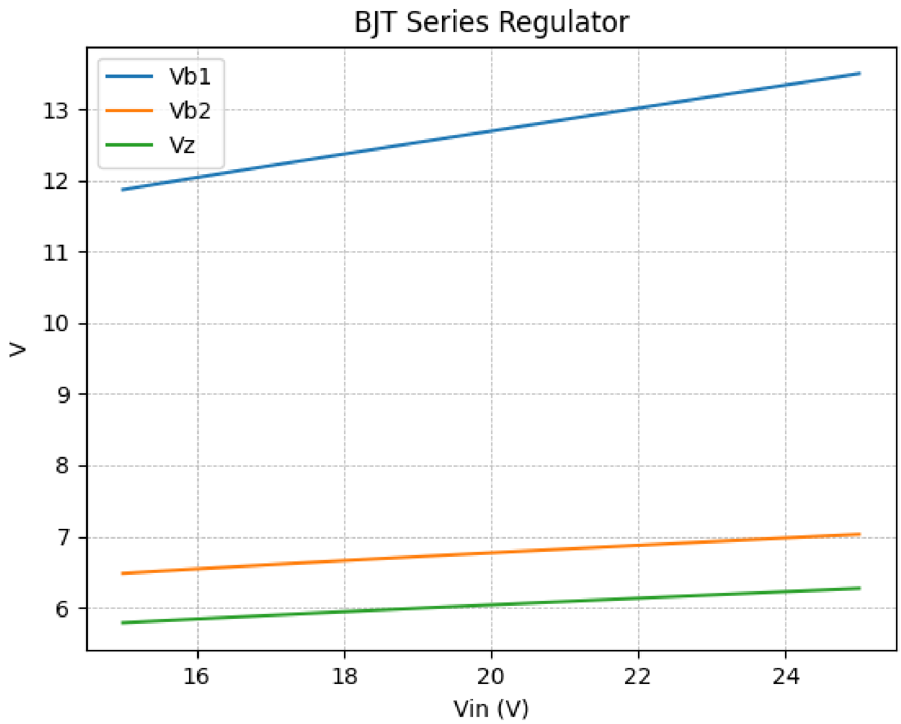
3.2.2 Simulation results

Given below is the plot for the V_{out} waveform obtained from the DC analysis of the BJT Series Regulator:



We can observe that V_{out} is bound between $12-14V$ and even for $Vin < 17V$, V_{out} is close to $12V$, which means it still regulates unlike the Zener Regulator.

Given below is the plot for the node voltages V_Z, V_{B_1} and V_{B_2} obtained from the DC analysis of the BJT Series Regulator:



4 Experimental results

4.1 Zener Regulator

Performing Thevenin Analysis for the given Zener Regulator circuit:

$$V_{th} = \frac{V_{in}R_Z + V_Z R_S}{R_S + R_Z} \tag{1}$$

$$R_{th} = R_S || R_Z \tag{2}$$

where V_{in} is the input voltage applied, $V_Z = 12V$ is the Zener voltage, $R_Z = 125\Omega$ is the Zener region diode resistance, $R_S = 470\Omega$.

4.1.1 Case (i)

Results of the Voltage and Current readings for the Zener Regulator at $V_{in} = 20V$ are as follows:

	Theoretical	Simulation
$V_{out}(V)$	1.226269e+01	1.245000e+01
$I_Z(A)$	4.199669e-03	3.600000e-03
$I_S(A)$	1.646236e-02	1.605000e-02
$I_L(A)$	1.226269e-02	1.245000e-02

We can observe that the Theoretical and Simulation readings are reasonably close to each other.

4.1.2 Case (ii)

Results of the Voltage and Current readings obtained from DC analysis of the Zener Regulator are as follows:

Sr. No.	$V_{in}(V)$	$V_{out}(V)$	$I_Z(A)$	$I_S(A)$	$I_L(A)$
1	1.500000e+01	1.020408e+01	3.710268e-11	1.020408e-02	1.020408e-02
2	1.550000e+01	1.054422e+01	3.778295e-11	1.054422e-02	1.054422e-02
3	1.600000e+01	1.088435e+01	3.849787e-11	1.088435e-02	1.088435e-02
4	1.650000e+01	1.122449e+01	9.754691e-11	1.122449e-02	1.122449e-02
5	1.700000e+01	1.156459e+01	9.838411e-08	1.156469e-02	1.156459e-02
6	1.750000e+01	1.187787e+01	8.409802e-05	1.196197e-02	1.187787e-02
7	1.800000e+01	1.200973e+01	7.355326e-04	1.274526e-02	1.200973e-02
8	1.850000e+01	1.208601e+01	1.560762e-03	1.364678e-02	1.208601e-02
9	1.900000e+01	1.214904e+01	2.427471e-03	1.457651e-02	1.214904e-02
10	1.950000e+01	1.220753e+01	3.308364e-03	1.551589e-02	1.220753e-02
11	2.000000e+01	1.226282e+01	4.199255e-03	1.646208e-02	1.226282e-02
12	2.050000e+01	1.231638e+01	5.095567e-03	1.741195e-02	1.231638e-02
13	2.100000e+01	1.236880e+01	5.995462e-03	1.836426e-02	1.236880e-02
14	2.150000e+01	1.242034e+01	6.898083e-03	1.931842e-02	1.242034e-02
15	2.200000e+01	1.247121e+01	7.802798e-03	2.027401e-02	1.247121e-02
16	2.250000e+01	1.252156e+01	8.709161e-03	2.123072e-02	1.252156e-02
17	2.300000e+01	1.257148e+01	9.616852e-03	2.218833e-02	1.257148e-02
18	2.350000e+01	1.262105e+01	1.052564e-02	2.314669e-02	1.262105e-02
19	2.400000e+01	1.267033e+01	1.143534e-02	2.410567e-02	1.267033e-02
20	2.450000e+01	1.271937e+01	1.234582e-02	2.506518e-02	1.271937e-02
21	2.500000e+01	1.276818e+01	1.325696e-02	2.602514e-02	1.276818e-02

For the Zener diode to function properly as a Voltage Regulator, the Voltage across it must be at least $12V$. For the limiting case when the Zener diode just stops regulating, we can simply open circuit the Zener and find the voltage across it.

$$V_Z = V_{in}(\frac{R_L}{R_S + R_L}) \tag{3}$$

For $V_Z > 12V$, we get $V_{in} > 17.64V$

Sr. No.	$Vin(V)$	$I_Z(A)$
1	1.500000e+01	3.710268e-11
2	1.550000e+01	3.778295e-11
3	1.600000e+01	3.849787e-11
4	1.650000e+01	9.754691e-11
5	1.700000e+01	9.838411e-08
6	1.750000e+01	8.409802e-05
7	1.800000e+01	7.355326e-04

We can observe that for $V_{in} < 17.64V$, I_Z is negligible and thus Zener does not act as a Voltage Regulator.

4.1.3 Case (iii)

$$V_Z = V_{in}(\frac{R_L}{R_S + R_L}) \tag{4}$$

For $V_Z > 12V$, we get $R_L > 705\Omega$

Sr. No.	$R_L(\Omega)$	$V_{out}(V)$
1	500	1.030928e+01
2	600	1.121495e+01
3	705	1.193305e+01
4	800	1.209606e+01
5	900	1.219168e+01

We can observe that for $R_L < 705\Omega$, V_{out} is not regulated at $12V$.

4.2 BJT Series Regulator

4.2.1 Case (i)

Given below are the Voltage readings at the 5 nodes, obtained using Operational analysis:

$V_{in}(V)$	2.000000e+01
$V_{B_1}(V)$	1.449511e+01
$V_{out}(V)$	1.378716e+01
$V_{B_2}(V)$	6.645576e+00
$V_Z(V)$	5.929149e+00

4.2.2 Case (ii)

Given below are the readings for V_{out} obtained by varying R_1 and R_2:

Sr. No.	$R_1(k\Omega)$	$R_2(k\Omega)$	$V_{out}(V)$
1	10.2	14.8	1.199875e+01
2	11.5	13.5	1.295299e+01
3	12.5	12.5	1.378716e+01
4	13.5	11.5	1.473014e+01
5	14.5	10.5	1.580584e+01

Using the results obtained above, we get $R_1 = 10.2k\Omega$ and $R_2 = 14.8k\Omega$ in order to obtain $V_{out} = 12V$ at $V_{in} = 20V$.

4.2.3 Case (iii)

Given below are the readings for V_{out} obtained separately from Zener and BJT Voltage Regulators:

Sr. No.	V_{in}	BJT	Zener
1	1.500000e+01	1.117649e+01	1.020408e+01
2	1.550000e+01	1.126299e+01	1.054422e+01
3	1.600000e+01	1.134652e+01	1.088435e+01
4	1.650000e+01	1.142977e+01	1.122449e+01
5	1.700000e+01	1.151228e+01	1.156459e+01
6	1.750000e+01	1.159418e+01	1.187787e+01
7	1.800000e+01	1.167563e+01	1.200973e+01
8	1.850000e+01	1.175673e+01	1.208601e+01
9	1.900000e+01	1.183757e+01	1.214904e+01
10	1.950000e+01	1.191823e+01	1.220753e+01
11	2.000000e+01	1.199875e+01	1.226282e+01
12	2.050000e+01	1.207920e+01	1.231638e+01
13	2.100000e+01	1.215960e+01	1.236880e+01
14	2.150000e+01	1.224000e+01	1.242034e+01
15	2.200000e+01	1.232042e+01	1.247121e+01
16	2.250000e+01	1.240090e+01	1.252156e+01
17	2.300000e+01	1.248144e+01	1.257148e+01
18	2.350000e+01	1.256207e+01	1.262105e+01
19	2.400000e+01	1.264281e+01	1.267033e+01
20	2.450000e+01	1.272367e+01	1.271937e+01
21	2.500000e+01	1.280466e+01	1.276818e+01

We can observe that the Zener circuit is a better Voltage Regulator than the BJT one as its V_{out} values are closer to the required $12V$. But unlike the Zener circuit, BJT does not require a minimum V_{in} to function as a Voltage Regulator.