University POLITEHNICA of Bucharest
Faculty of Electronics, Telecommunications and Information Technology

Project 1

Positive Voltage Regulator

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1.Project requirements

It is required to design a postive voltage regulator with the following parameters:

- Supply voltage between **15** and **18** [V];
- Programmable output voltage between **10** and **12** [V];
- The output current through the load between **0** and **72** [mA];
- Short circuit protection of the output terminals with foldback current limiting circuit.
- Overvoltage protection of the output terminals.
- $S = \left.\frac{\Delta V_i}{\Delta V_o}\right|_{RL} \geq 72$
- The output impedance of the regulator $R_O \leq$ 1 Ω.

The circuit will be practically implemented using the Through Hole Technology (THT) method.

N = 8

1. Block diagram of the circuit

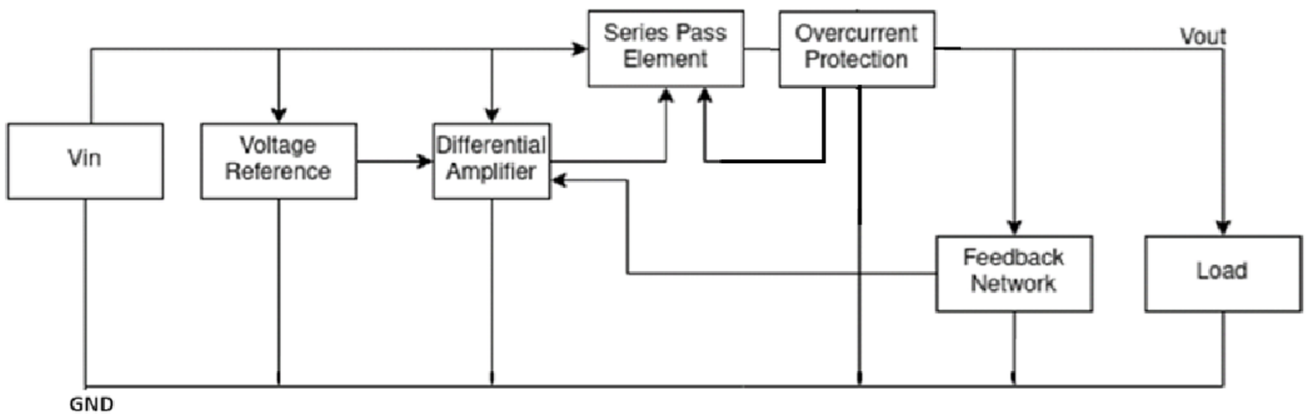


Figure1

Reference voltage – Represented by a Zener diode meant to stabilise the input voltage for the differential amplifier , independent of any other circuit or environment parameters such as changes in temperature, changes in power supply voltage, etc.

Differential / error amplifier – This block is made up of a non-inverting amplifier, which receives the reference voltage on the non-inverting input (+) and a part of the stabilized voltage on the inverting input (-) other from a feedback circuit linked to the output. It consists of four transistors, with two functioning as a current mirror. This configuration biases the series pass element, ensuring a steady output voltage.

Series pass element – element comprises a power transistor, which is biased to maintain a constant output voltage, irrespective of variations in the input voltage.

Overcurrent protection - employs a foldback current limiting design. It includes one transistor, two resistors for base biasing, and a current sensing resistor. This setup limits the series pass element's current when it exceeds the desired threshold.

Negative feedback circuit – controls the output voltage's value by receiving a portion of the output signal and sending it back into the differential amplifier. The feedback circuit consists of two resistors and a potentiometer arranged as a voltage divider. The potentiometer allows for the adjustment of the output voltage to the desired level. In doing so, we make it so that the output voltage will depend only on a set of passive components and the reference voltage.

Overvoltage Circuit - This part of the circuit consists of a simple Diode clamp and transistor circuit that limits the voltage during overload.

3.The detailed schematic diagram and blocks

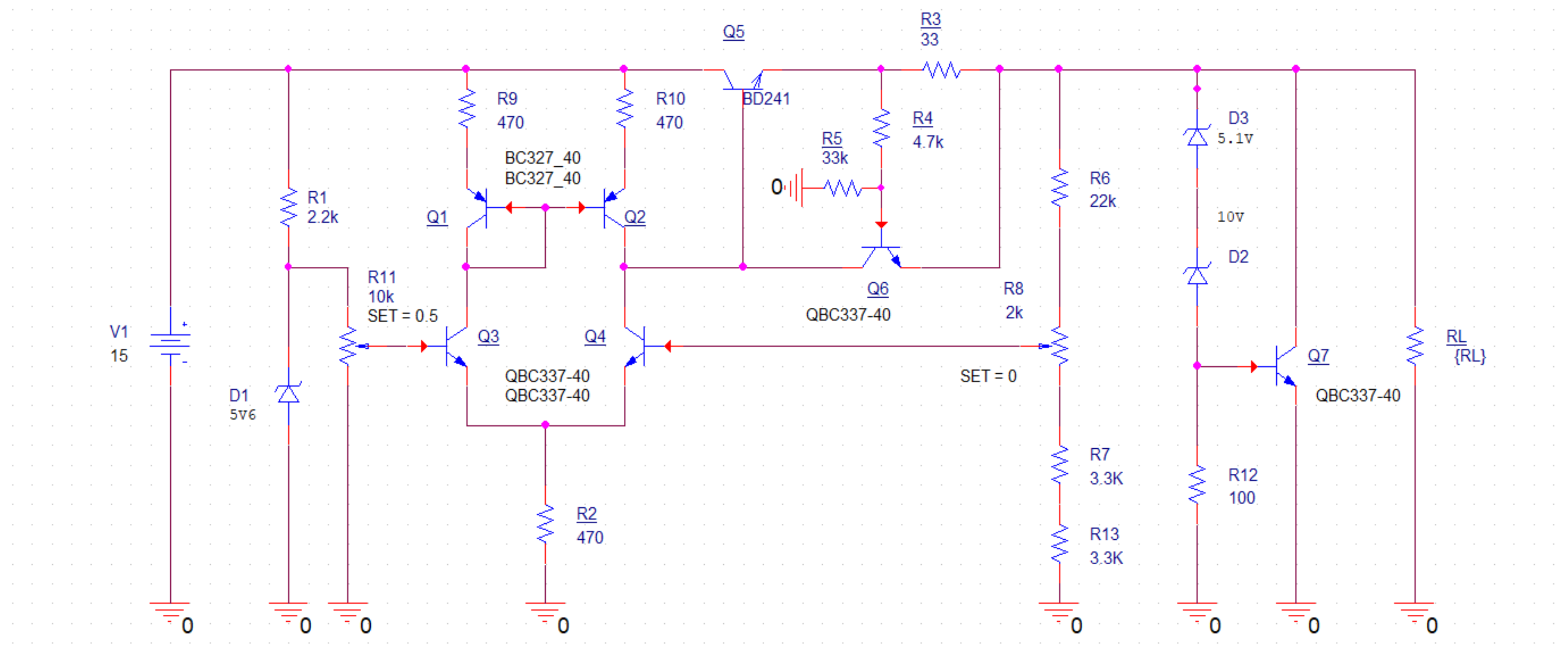


Figure2

Schematic with each block highlighted:

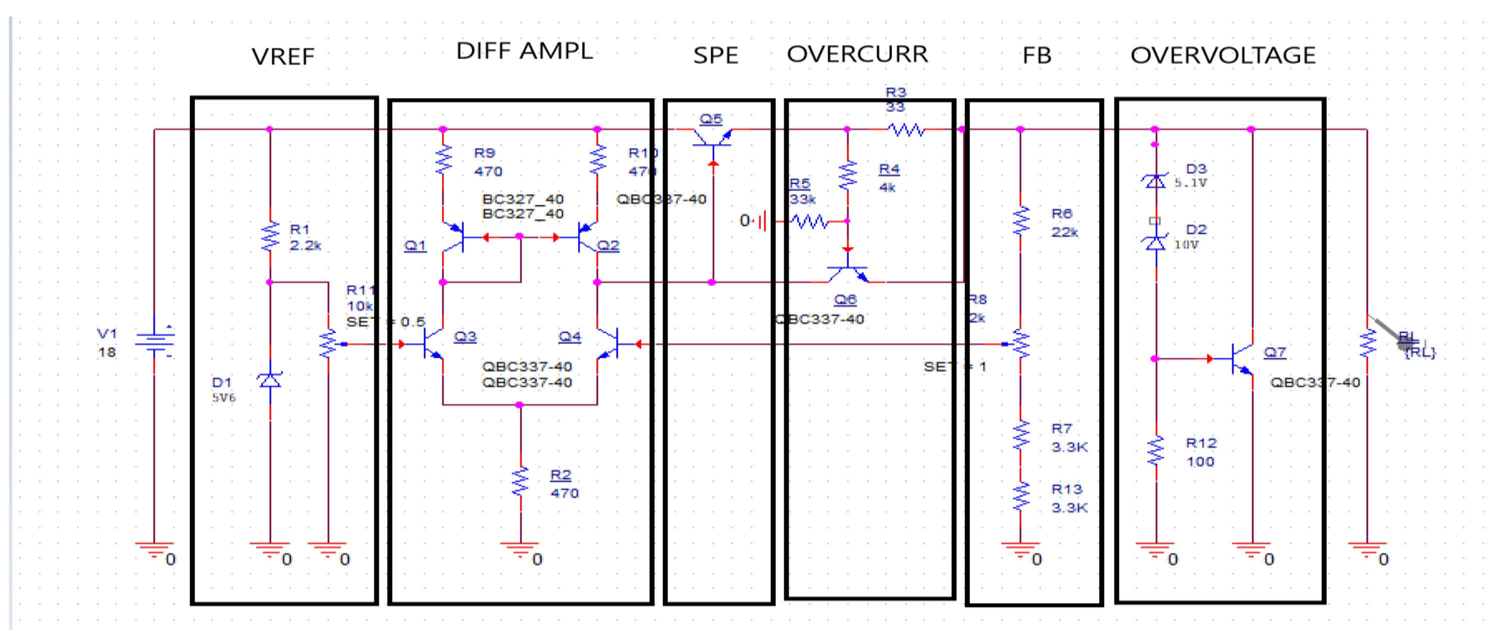


Figure3

Individual blocks explanation :

a) Voltage reference block

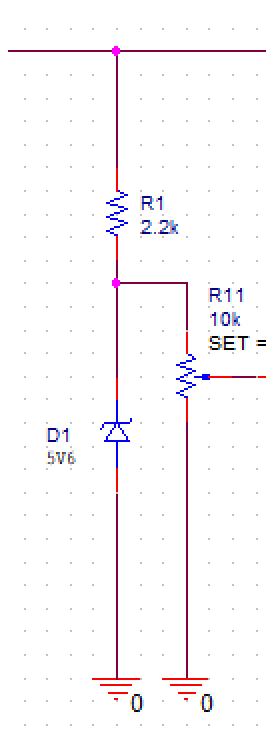
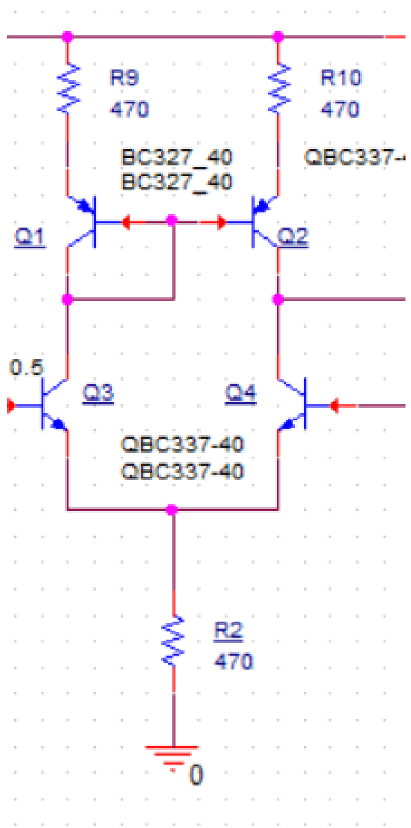


Figure4

- The section consists of a simple Zener diode (D1) and a current-limiting resistor (R1), producing a very stable DC voltage of approximately 2.7V. **For better stability**, a higher voltage Zener diode and a potentiometer R11 are used to get the necessary 2.7V.
- For reference voltage we choose 2.7V. But as low voltage zener diodes are not stable, we chose a higher voltage zener diode (5V6) and used a potentiometer as a voltage divider to reduce the 5,6V to 2,7V

b) Differential amplifier block



- It uses a current mirror, made up of transistors Q1 and Q2 (PNP)
- Its purpose is to ensure the symmetry of the differential amplifier, and as such the collector currents will be equal.
- Resistors R9 and R10 limit the current through the transistors.
- Transistors Q3 and Q4 form the positive input of the Differential amplifier, respectively the negative input and conduct the current through the Differential amplifier.

Figure5

c) Series Pass Element block

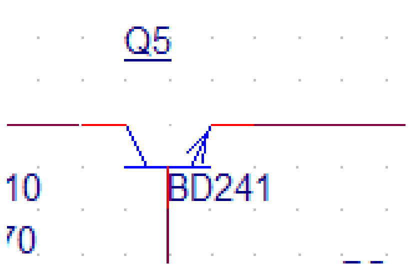
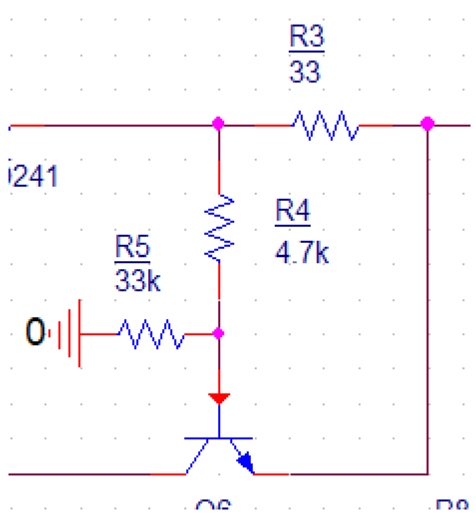


Figure5

- A power NPN transistor Q5, is used as a series pass element.
- This transistor is one of the crucial elements of the entire scheme, because it controls the behavior of the regulator through its collector-emitter voltage, which is approximately equal to the difference in the input and output potentials.

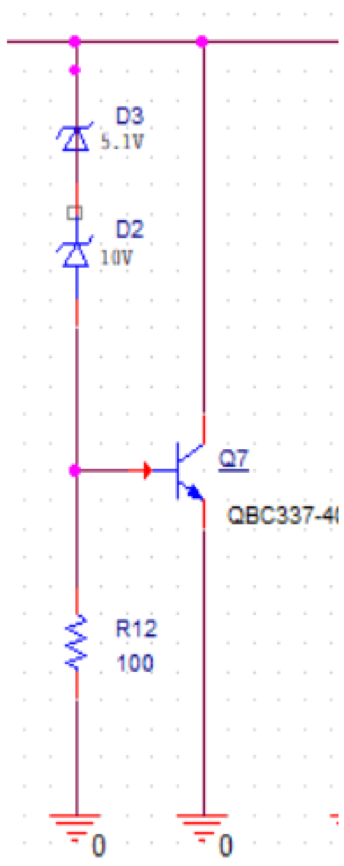
d) Over Current Protection Block



- Overcurrent protection is achieved through a foldback current limiting circuit. The resistor R3 functions as the current sensor, and resistors R4 and R5 provide biasing for the transistor Q6. This configuration effectively restricts the current through the series pass element when excessive current is detected.

Figure6

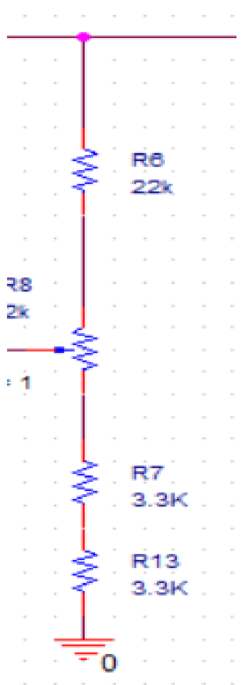
e) Over Voltage Protection Block



- This over-voltage protection block uses a 5.1V Zener diode (D3) 10V Zener diode D2 , and NPN transistor (Q7) to shunt excess voltage to ground. When the voltage exceeds 24V, D2+D3 conducts, activating Q7, which diverts excess current through resistor R12 to protect the load.

Figure7

f) Feedback circuit Block



- To feed a portion of the output voltage back to the differential amplifier, a resistor divider circuit is employed. The potentiometer R8 is used to set the desired output voltage, while resistors R6 and R7 (also R13) ensure the correct voltage division.

g)

Figure8

DC Calculations

I Load resistance

In order to compute the load resistance I will use the formula $RL = \frac{V_{out\,max}}{I_{L\,max}} \Rightarrow RL = \frac{12V}{72mA} = 166.6\Omega$

~~I choose a resistor of~~

$$RL = \frac{V_{out\,min}}{i_{L\,max}} = RL = \frac{10V}{72} = 138.8$$

II Voltage reference

I will assume the voltage reference needs to be close to this interval ($V_{in\,min} - V_{out\,max}$) and ($V_{in\,min} - V_{out\,min}$). So in my case Vref should be $[15-12, 15-10] \Rightarrow V_{ref} \in [3, 5]$.

I will choose a zener diode with a voltage of 5,6 V.

For reference voltage we choose 2.7 V, As low voltage diodes are not stable, we choose a higher voltage zener diode (5V6) and use a potentiometer as a voltage divider to reduce the 5,6 V to 2,7 V

We will denote $V_{in} = \frac{V_{in\,max} + V_{in\,min}}{2} = \frac{15+18}{2} = 16,5\ V$

In order to activate the zener diode, we need to have a minimum current $I_{Z\,min} = 5\,mA$ (from datasheet).

Since $V_{in} = V_Z + R_e I_{Z\,min}$

$$R_e = \frac{V_{in} - V_Z}{I_{Z\,min}} = \frac{16,5 - 5,6}{5}\ \frac{V}{mA} = 2,18\ k\Omega$$

1.

$\Rightarrow R_e = R_1$, which we choose to be $2.2\ k\Omega$

$$|i_{Z\,max}| = \frac{|V_{in\,max}| - |V_Z|}{R_1} = \frac{18 - 5,6}{2,2}\ \frac{V}{k\Omega} = 5,63\ mA$$

$$|i_{Z\,min}| = \frac{|V_{in\,min}| - |V_Z|}{R_1} = \frac{15 - 5,6}{2,2}\ \frac{V}{k\Omega} = 4,27\ mA$$

$$P_{max} = i_{Z\,max}^2 \cdot R = 10^2 \cdot 2,2 \cdot 10^{-3}$$

$$P_{max} =$$

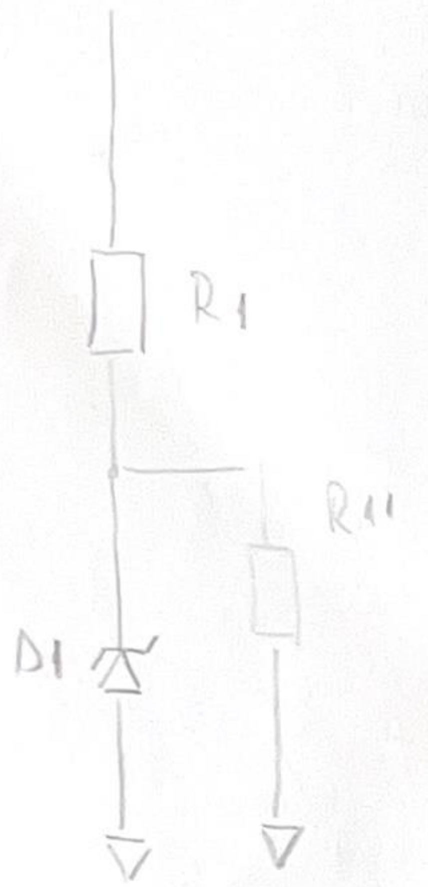
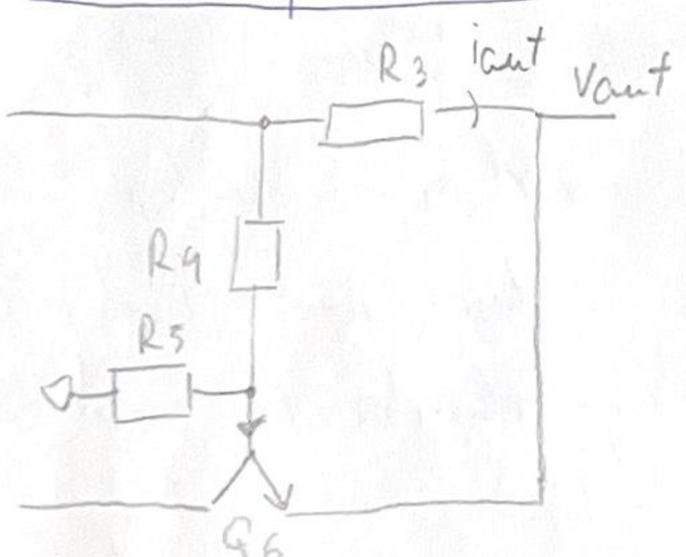


Figure 9

III Overcurrent protection block



We assume

$R_4 = 4.7\ k\Omega$

$R_5 = 33\ k\Omega$

$i_{out} = 72\ mA$

$V_{out} = 10\ V$

Figure 10

$$V_R = V_{out} \cdot \frac{R_4}{R_4 + R_F} = 12V \cdot \frac{4k\Omega}{4k\Omega + 33k\Omega} = 12V \cdot \frac{4}{37} \simeq 1.29\ V$$

$$R_3 = \frac{V_R + 0.7V}{72mA} = \frac{1,291\ V + 0,7V}{72\ mA} \simeq \cancel{24.79\ \Omega}\ 27.63\ \Omega$$

In this circuit, R_3 acts as a current to voltage converter. When the output current reaches 72mA, the voltage drop across R_3 exceeds 0.7V, which triggers transistor Q_6 to conduct. This conduction

2.

$\Rightarrow R_e = R_1$, which we choose to be 2.2 kΩ

$$|I_{Z\,max}| = \frac{|V_{in\,max}| - |V_Z|}{R_1} = \frac{18 - 5{,}6}{2{,}2}\ \frac{V}{k\Omega} = 5{,}63\ mA$$

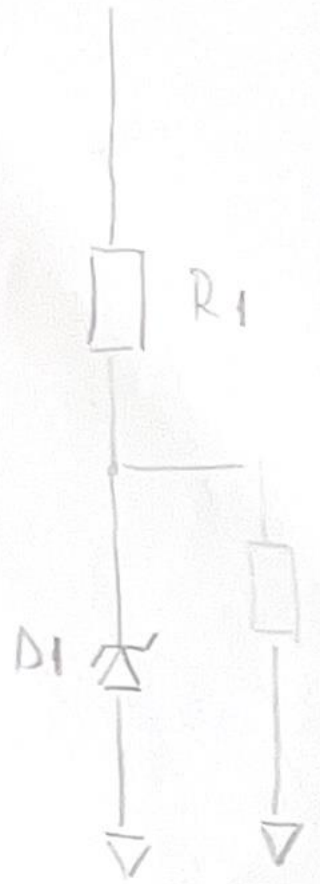


Figure 9

$$|i_{Z\,min}| = \frac{|V_{in\,min}| - |V_Z|}{R_1} = \frac{15 - 5{,}6}{2{,}2}\ \frac{V}{k\Omega} = 4{,}27\ mA$$

$$P_{max} = i_{Z\,max}^2 \cdot R = 10^2 \cdot 2{,}2 \cdot 10^{-3}$$

$P_{max} =$

III Overcurrent protection block

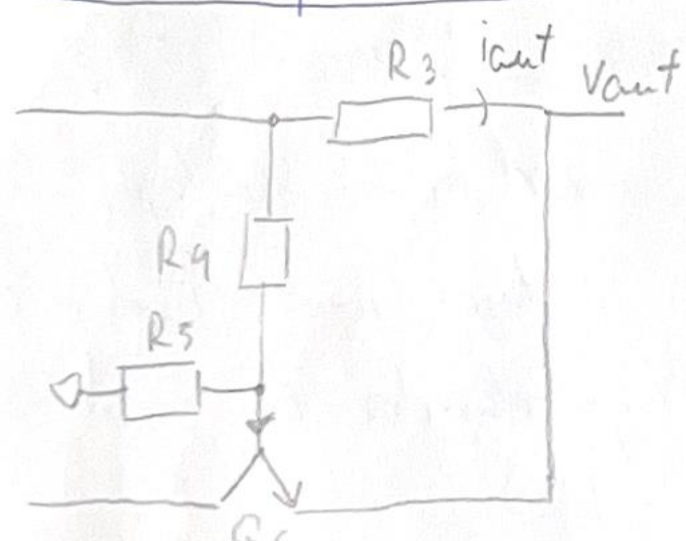


Figure 10

We assume

$R_4 = 4.7\ k\Omega$

$R_5 = 33\ k\Omega$

$i_{out} = 72\ mA$

$V_{out} = 10\ V$

$$V_R = V_{out} \cdot \frac{R_4}{R_4 + R_F} = 12V \cdot \frac{4k\Omega}{4k\Omega + 33k\Omega} = 12V \cdot \frac{4}{37} \simeq 1.29\ V$$

$$R_3 = \frac{V_R + 0.7V}{72mA} = \frac{1{,}291\ V + 0{,}7V}{72\ mA} \simeq \cancel{24.79\ \Omega}\ 27.63\ \Omega$$

In this circuit, R_3 acts as a current to voltage converter. When the output current reaches 72mA, the voltage drop across R_3 exceeds 0.7V, which triggers transistor Q_6 to conduct. This conduction

2.

cuts off the control voltage to the series regulator, wich consist of transistor Q5. When Q6 conducts, it removes the control voltage for Q5, cutting of power to protect the circuit from excessive current.

IV Differential amplifier

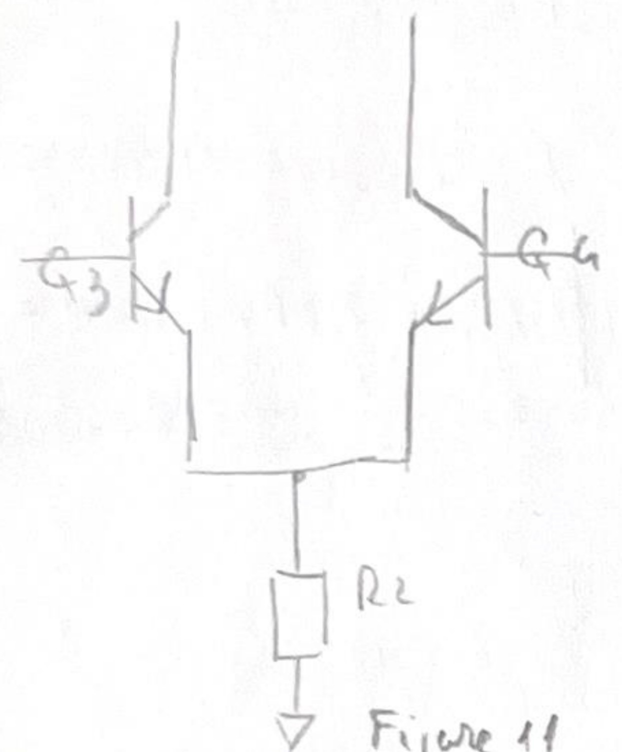


Figure 11

NPN transistor will be chosen

Q3, Q4 BC 337

For an average current of a few mA, a 470 ohm resistor is used (R2)

$$P_{max} = R \cdot i^2 = 470 \cdot 0{,}002^2 = \sim 2mW < 125mW$$

V Current mirror

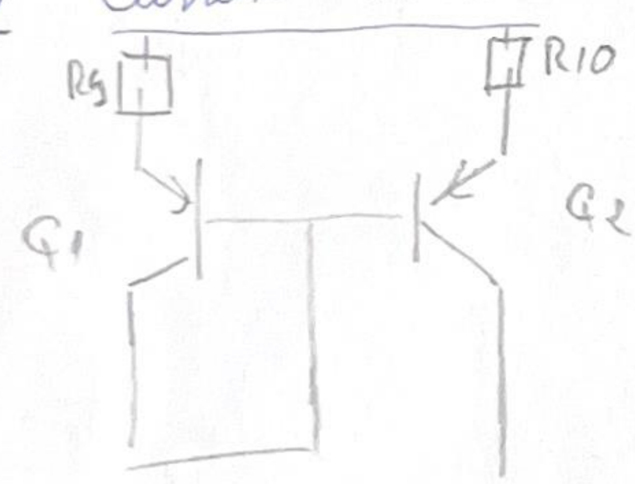


Figure 12

PNP transistor will be chosen

Q1, Q2 BC 327_40

We need 2 biasing resistors. We will chose them such that there is a small voltage drop on them. We will choose 2 identical resistors of 470Ω

VI Resistance feedback current

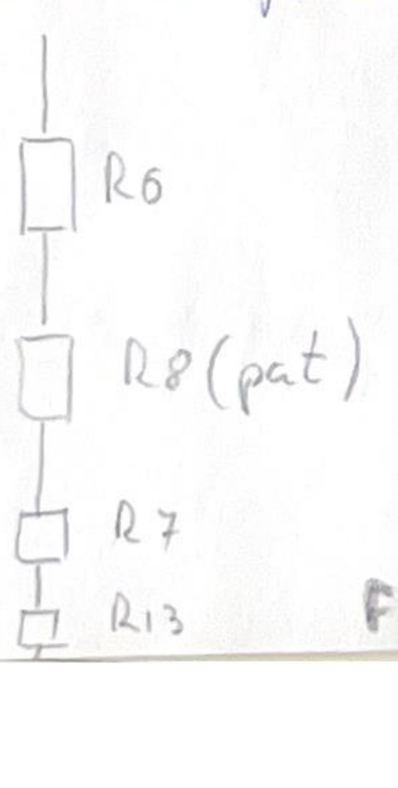


Figure 13

The resistances and potentiometer values should be chosed so the output voltages lies in the interval [10, 12] V

3.

$R_{pat} = R_8 = 2k$

$VREF = 2.7V$

The currents are very small (μA range)

$$\begin{cases} VREF = \dfrac{R_7}{R_6+R_7+R_{pat}} \cdot V_{out\,max} \iff 2.7 = \dfrac{R_7}{R_6+R_7+2000} \cdot 12 \\ VREF = \dfrac{R_7+R_{pat}}{R_6+R_7+R_{pat}} \cdot V_{out\,min} \iff 2.7 = \dfrac{R_7+2000}{R_6+R_7+2000} \cdot 10 \end{cases} \Rightarrow$$

$$\begin{cases} R_6+R_7+R_{pat} = \dfrac{R_7 \cdot V_{out\,max}}{VREF} \\ R_6+R_7+R_{pat} = \dfrac{(R_7+R_{pat}) \cdot V_{out\,min}}{VREF} \end{cases}$$

$$\begin{cases} 2.7R_6 + 2.7R_7 + 5400 = 12R_7 \\ 2{,}7R_6 + 2{,}7R_7 + 5400 = 10R_7 + 20000 \end{cases}$$

$$\begin{cases} R_6 + R_{pat} = R_7\left(\dfrac{V_{out\,max}}{VREF} - 1\right) \\ R_6 = (R_7+R_{pat})\left(\dfrac{V_{out\,max}}{VREF} - 1\right) \end{cases}$$

$$\cancel{\begin{cases} R_6+5 = R_7\left(\dfrac{12}{2{,}7} - 1\right) = \\ R_6 = (R_7+5)\left(\dfrac{10}{2{,}7} - 1\right) = \end{cases}}$$

$\Rightarrow 2.7R_6 + 5400 = 9.3R_7$

$2.7R_6 - 7{,}3R_7 = 14600$ ⊖

$5400 - 7{,}3R_7 = 9{,}3R_7 - 14600$

$20000 = 2R_7 \Rightarrow \boxed{R_7 = 10\,k\Omega}$

$\Rightarrow 2.7R_6 - 7{,}3 \cdot 10 \cdot 10^3 = 146\cancel{00}$

$2{,}7R_6 = 87600$

$\boxed{R_6 = 32{,}44\,k\Omega} \simeq 33\,k\Omega$

4.

$$\frac{R6}{R7} = \frac{33\,k\Omega}{10\,k\Omega} = 3{,}3$$

We use 1,5 as coefficient for the series conection of resistors ~~R7~~ R7 and R13 to obtain 6,6 kΩ, and for R6 to obtain 22 kΩ.

So we choose $R7 = 3.3\,k\Omega$

$R13 = 3.3\,k\Omega$

$R6 = 22\,k\Omega$

VII Overvoltage protection

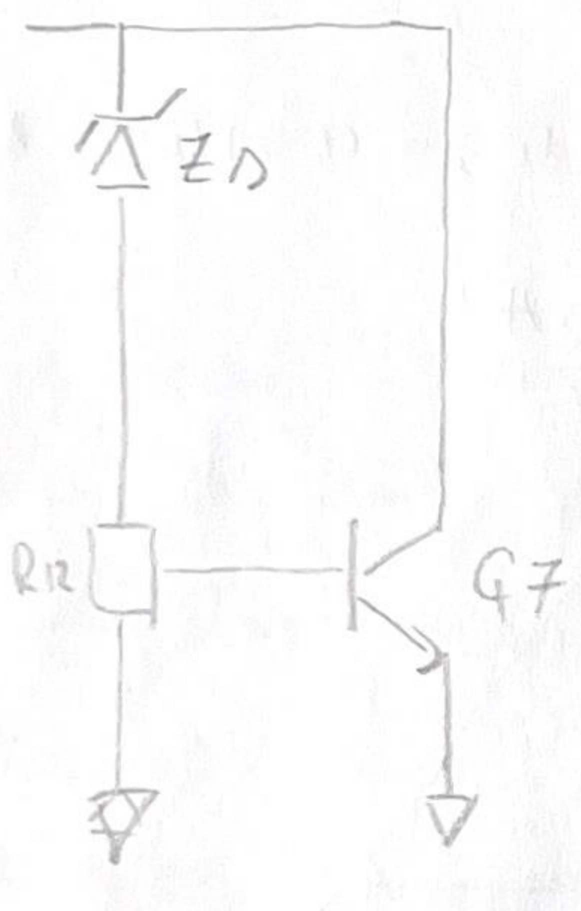


FIGURE 14

Zs series of zener diodes D2 and D3

$V_{out\,max} = 12\,V$

$V_Z = 5{,}1\,V + 10\,V = 15{,}1\,V$

$i_{R12} = i_Z = 5\,mA$

$R12 = \frac{V_{BB6}}{i_Z} = \frac{0{,}6\,V}{5 \cdot 10^{-3}} = 120\,\Omega$

We choose $R12 = 100\,\Omega$ with high tolerance

The overvoltage protection clamps at $V_{BB6} + V_{Zs} = 15{,}6\,V$.

VIII Series pass Element block

FIGURE 14

We will choose a high power transistor BC817_25

$P_{G5} = (V_{in\,max} - V_{out\,max}) \cdot I_L = (18-12) \cdot 72$

$= 6 \cdot 72 = 432\,mW$

5.

DC BIAS

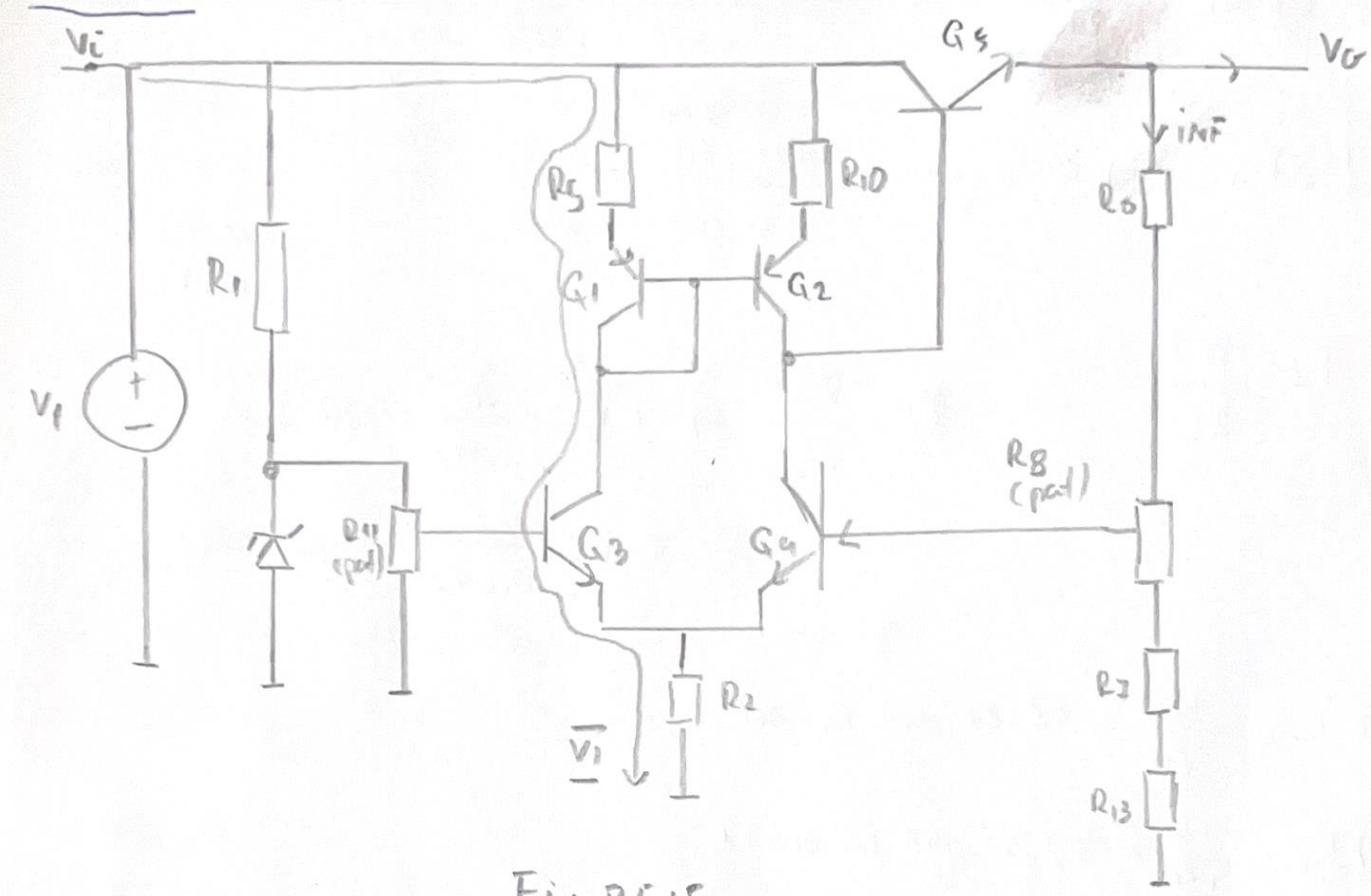


FiguRE 15

For Dc scheme, the overcurrent protection and overvoltage protection can be excluded, they don't influence the output voltage

We will have 2 cases

1. $V_{IN} = 15\ V$
   a) set = 0
   b) set = 1
2. $V_{IN} = 18\ V$
   a) set = 0
   b) set = 1

$$V_{out} = V_{ref} \cdot \frac{R6 + R8(up) + R7 + R13 + R8(down)}{R7 + R13 + R8(down)}$$

$V_{ref} = 2{,}7$ in both cases because the current supply on D1 are close 5mA

6

$$\Rightarrow \left| \begin{array}{l} a)\ set=0 \Rightarrow V_{out} = 2.7 \cdot \dfrac{22000 + 0 + 3300 + 3300 + \overset{2\cdot 10^3}{\cancel{500}}}{3300 + 3300 + \underset{2\cdot 10^3}{\cancel{500}}} = \cancel{2.7\cdot 4{,}09} = \cancel{11.066} \quad 9{,}6 \\ b)\ set=1 \Rightarrow V_{out} = 2.7\ \dfrac{22000 + \overset{2\cdot 10^3}{\cancel{500}} + 3300 + 3300 + 0}{3300 + 3300} = \cancel{2.7\cdot 4.405} = \cancel{11.90} = 12.518 \end{array} \right.$$

$$I_L = \frac{V_{out}}{R_L}$$

$$R_L = \frac{V_{out}}{i_{out}} \rightarrow 1.\ R_L = \frac{10}{0.072} = 138.8\ \Omega$$

$$2.\ R_L = \frac{12}{0.072} = 166.6\ \Omega$$

$$a)\ I_L = \frac{10}{170} = 58.82\ mA \text{ for } set=0$$

$$b)\ I_L = \frac{12}{170} = 70.58\ mA \text{ for } set=1$$

KII/I

$$V_i = R_1 \cdot i_{R1} + V_{D1} \Rightarrow 1.\ V_{IN} = \cancel{10V}\ 15\ V$$

$$i_{R1} = \frac{15 - 5{,}6}{2{,}2\cdot 10^3} = 4{,}272\ mA$$

$$2.\ V_{IN} = 18\ V$$

$$i_{R1} = \frac{18 - 5{,}6}{2{,}2\cdot 10^3} = 5{,}636\ mA$$

KII/II

$$V_i = R_1 \cdot i_{R1} + R_{11} \cdot i_{R11} \Rightarrow 1.\ V_{IN} = 15\ V$$

$$i_{R11} = \frac{15 - 2{,}2\cdot 10^3 \cdot 4{,}272\cdot 10^{-3}}{10\cdot 10^3} = 0{,}56\ mA$$

$$2.\ V_{IN} = 18\ V$$

$$i_{R11} = \frac{18 - 2{,}2\cdot 10^3 \cdot 5{,}636\cdot 10^{-3}}{10\cdot 10^3} = 0{,}56\ mA$$

7

K2/VI

$\cancel{V_{IN} = R_5 \cdot i_{E1} + V_{EC1} + V_{CB3} - R_{11}(up) \cdot i_{R11} + V_{D1}}$

~~1. $V_{IN} = 15V$~~

~~V_C~~

$V_{IN} = R_5 \cdot i_{E1} + V_{EC1} + V_{CE3} + i_{R2} \cdot R_2$

1. $V_{IN} = 15V$

$\Rightarrow V_{CE3} = V_{IN} - R_5 \cdot i_{E1} - V_{EC1} - i_{R2} \cdot R_2$

$V_{CE3} = 15 - 470 \cdot 2 \cdot 10^{-3} - 0{,}7 - 470 \cdot 4 \cdot 10^{-3}$

$= 11{,}48$

2. $V_{IN} = 18V$

$V_{CE3} = 18 - 470 \cdot 2 \cdot 10^{-3} - 0{,}7 - 470 \cdot 4 \cdot 10^{-3}$

$= 14{,}48$

K2/VII

$V_O = V_{EB5} + V_{CE4} + i_{R2} \cdot R_2$

1. $V_O = 10V$

$\cancel{10} = V_{CE4} = V_O - V_{EB5} - i_{R2} R_2$

$= 10 + 0{,}7 - 2 \cdot 10^{-3} \cdot 470$

$= 9{,}76$

2. $V_O = 12V$

$V_{CE4} = 12 + 0{,}7 - 2 \cdot 10^{-3} \cdot 470$

$= 11{,}76$

~~$i_{E5} = i_{C5} = i_O + i_{NF}$~~

$i_{E5} = i_{C5} = i_O + i_{NF}$

1. $i_O = 0mA$

$= \cancel{i_{E5}}\ i_{C5} = 0{,}39mA$

2. $i_O = 72mA$

$i_{C5} = 72{,}39mA$

8

$K_2/\overline{III}$.

$V_{R2} = V_E(Q3)$

$V_E = V_B - V_{BE} = 2,7 - 0,7 = 2V$

$\Rightarrow V_{R2} = 2$

$i_{R2} = \frac{V_{R2}}{R_2} = \frac{2}{470} = 0,0042\,A \simeq 4\,mA$

Current mirror: Q_1, Q_2

$i_{C1} = i_{E1} = i_{C2} = i_{E2}$

$i_{R9} = i_{E1}$

$i_{R10} = i_{E2}$

$i_{C1} = i_{C3}$

$i_{C3} = i_{E3}$

$i_{C2} = i_{C4}$

$i_{C4} = i_{E4}$

$\Rightarrow$ KI $\quad i_{R2} = i_{E3} + i_{E4}$

$\Rightarrow i_{C3} = i_{C4} = \frac{i_{R2}}{2} = 2\,mA$

$\Rightarrow i_{C1} = i_{C2} = i_{R9} = i_{R10} = 2\,mA$

$K_2/\overline{IV}$

$V_O = (R_6 + R_8 + R_7 + R_{13}) \cdot i_{NF} \Rightarrow$ 1. $V_O = 10\,V$

$i_{NF} = \frac{10}{R_6 + R_8 + R_7 + R_{13}} = \frac{10}{30,6 \cdot 10^3} = 0,32\,mA$

2. $V_O = 12\,V$

$i_{NF} = \frac{12}{30,6 \cdot 10^3} = 0,39\,mA$

$K_2/\overline{V}$

$R_9 \cdot i_{E1} + V_{EC1} + V_{BE2} - R_{10} \cdot i_{E2} = 0$

$R_9 = R_{10}$

$i_{E1} = i_{E2}$

$\Rightarrow V_{CE1} = -V_{BE} = -0,7\,V$

5

$\overline{VIII}$

$V_{iN} = R_{10} \cdot i_{E2} + V_{EC2} + V_{CE4} + i_{R2} R_2$

1. $V_{iN} = 15\,V$

$-V_{EC2} = R_{10} \cdot i_{E2} + \cancel{V_{EC2}}\ V_{CE4} + i_{R2} R_2 - V_{iN}$

$\cancel{V_{EC}}$

$V_{CE2} = 470 \cdot 2 \cdot 10^{-3} + 0{,}76 + 2 \cdot 10^{-3} \cdot 470 - 15$

$V_{CE2} = -3{,}36$

2. $V_{iN} = 18\,V$

$VCE2 = 470 \cdot 2 \cdot 10^{-3} + 1{,}76 + 2 \cdot 10^{-3} \cdot 470 - 18$

$= -4{,}36$

$\overline{IX}$ ~~V_{iN}~~

$V_{iN} = V_0 = VCE5$

1. $V_{iN} = 15\,V$
$V_0 = 10\,V$ $\Rightarrow VCE5 = 5\,V$

2. $V_{iN} = 18\,V$
$V_0 = 12\,V$ $\Rightarrow VCE5 = 6\,V$

10

Power computation

$P_{R1} = i_{R1}^2 \cdot R_1 = (5,636)^2 \cdot 2,2 = 69,88\,mW$

$P_{R2} = i_{R2}^2 \cdot R_2 = 4^2 \cdot 0,470 = 7,52\,mW$

$P_{R3} = 5.932\,mW$

$P_{R4} = 526,5\,\mu W$

$P_{R5} = 4,343\,mW$

$P_{R6} = 3,978\,mW$

$P_{R7} = 583.4\,\mu W$

$P_{R8} = 583.4\,\mu W$

$P_{R9} = 2.666\,mW$

$P_{R10} = 2.665\,mW$

$P_{R11} = 3.112\,mW$

$P_{R12} = 150.8\,pW$

$P_{D1} = V_{D1} \cdot i_{Z1max} = 5,6 \cdot 5 \cdot 10^{-3} = 28\,mW$

$P_{D2} = 5.384\,\mu W$

$P_{D3} = 10.56\,\mu W$

$P_{Q1} = \cancel{V_{EC}}\ \cancel{V_{CE1} \cdot I_{C1}} = V_{EC1} \cdot I_{C1} = 0,7 \cdot 2 \cdot 10^{-3} = 1,4\,mW$

$P_{Q2} = 6,845\,mW$

$P_{Q3} = 33.53\,mW$

$P_{Q4} = 26.02\,mW$

$P_{Q5} = 62.30\,mW$

11.

Knee/short- circuit current computation

$V_{out} = 12\,V$

$R_3 = \cancel{33\,\Omega}\ 27.63\,\Omega$

$R_4 = 4\,K$

$R_5 = 33\,K$

$V_R = 1.08\,V$

$$i_{knee} = \frac{V_R + 0.7}{R_3} = \frac{1.25 + 0{,}7}{33} = \cancel{0.0535\,A} = \cancel{53.9\,mA}$$

$$0.0603 = 60.3\,mA$$

$$i_{SC} = \frac{V_{IN} - 0{,}7}{R_{1|2}}$$

$1.\ V_{IN} = \cancel{20}\ 15\,V \Rightarrow i_{SC} = \frac{15 - 0{,}7}{33} = 0{,}43\,A$

$2\ V_{IN} = 18\,V \Rightarrow i_{SC} = \frac{18 - 0{,}7}{33} = 0{,}524\,A$

$$i_{knee} = \frac{1.25 + 0{,}7}{27{,}63} = 0.072\,mA = 72\,mA$$

$$i_{SC} = \frac{V_{IN} - 0{,}7}{R_3} \Rightarrow$$

$1.\ V_{IN} = 15\,V \Rightarrow i_{SC} = \frac{15 - 0{,}7}{27{,}63} = 0{,}51\,A$

$2\ V_{IN} = 18\,V \Rightarrow i_{SC} = \frac{18 - 0{,}7}{27{,}63} = 0{,}62\,A$

12.

AC computation

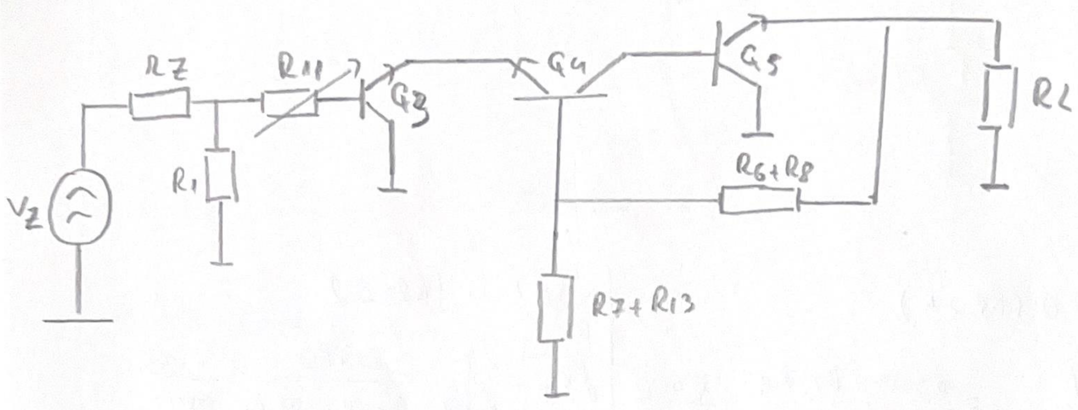


FIGURE 16

1. $V_{IN} = 15\,V$

$g_{m3} = 40 \cdot 2mA = 80\,mA/V$

$g_{m4} = 40 \cdot 2mA = 80\,mA/V$

$g_{m5} = 40 \cdot 72mA = 2{,}88\,A/V$

$r_{CE3} = \frac{V_{A3}}{g_{m3}} = \frac{100}{80} = 1{,}25\,k\Omega$

$r_{CE4} = 1{,}25\,k\Omega$

$r_{CE5} = \frac{100}{2{,}88} = 34.7\,\Omega$

$r_Z = 10\,\Omega$ (DATASHEET)

$r_{be3} = \frac{BF3}{g_{m3}} = \frac{250}{80} = 3.125\,k\Omega$

$r_{be4} = \frac{BF4}{g_{m4}} = \frac{250}{80} = 3.125\,k\Omega$

$r_{be5} = \frac{BF5}{g_{m5}} = \frac{25}{2.88} = 8.68\,\Omega$

2. $V_{IN} = 18\,V$

$g_{m3} = 40 \cdot 2mA = 80\,mA/V$

$g_{m4} = 40 \cdot 2mA = 80\,mA/V$

$g_{m5} = 40 \cdot 72\,mA = 2{,}88\,A/V$

$r_{CE3} = \frac{V_{A3}}{g_{m3}} = 1{,}25\,k\Omega$

$r_{CE4} = 1{,}25\,k\Omega$

$r_{CE5} = 34.7\,\Omega$

$r_Z = 10\,\Omega$ (DATASHEET)

$r_{be3} = \frac{BF3}{g_{m3}} = \frac{250}{80} = 3.125\,k\Omega$

$r_{be4} = 3.125\,k\Omega$

$r_{be5} = 8.68\,\Omega$

13.

SERIES - Schunt

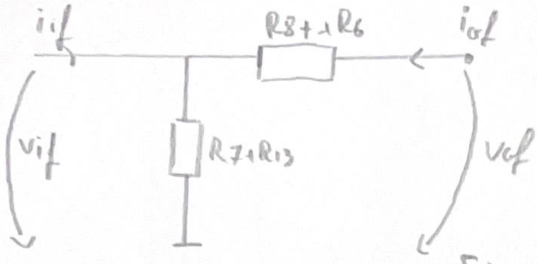


FigURE 17

SET = 0 (R8 = 2k)

$$fv = \frac{vif}{vof}\Big|_{iif=0} = \frac{\cancel{6600}\ R7+R13}{R7+R13+R6+R8} = \frac{6600}{30600}$$

$fv = 0.21$

$$rif = \frac{vif}{iif}\Big|_{vof=0} = (R7+R13)\,||\,(R8+R6) = 5.17 K\Omega$$

$$rof = \frac{vof}{iof}\Big|_{vif=0} = R7+R13+R8+R6 = 30{,}6\ K\Omega$$

SET = 1 (R8 = 0)

$$fv = \frac{vif}{vof}\Big|_{iif=0} = \frac{R7+R13}{R7+R13+R6+R8} = \frac{6600}{\cancel{301}\ 28600}$$

$fv = 0.23$

$$rif = \frac{vif}{iif}\Big|_{vof=0} = (R7+R13)\,||\,(R8+R6) = 5.07 K\Omega$$

$$rof = \frac{vof}{iof}\Big|_{vof=0} = R7+R13+R6 = 28{,}6\ K\Omega$$

Open loop gain

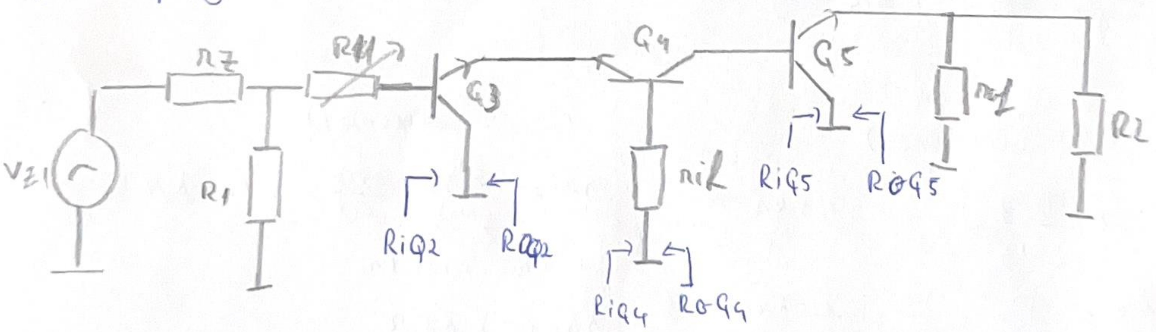


FiguRE 18

14.

Therenin

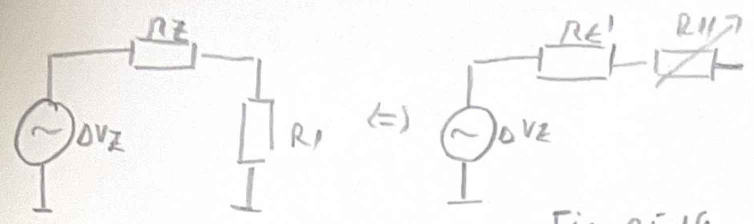


FIGURE 19

$\Delta V_Z' = \Delta V_Z \cdot \frac{R1}{V_Z + R1} = \frac{5.6}{2} \cdot \frac{2200}{2200+10} \sim 2.7$

$r_Z' = r_Z \parallel R1 = 10\,\Omega$

$R_{iT3} = r_{be3} + (1+\beta_3)\,r_{CE3} = 3.125 \cdot 10^3 + (1+250) \cdot 1{,}25 \cdot 10^3 = 316 \cdot 10^3$

$R_{oT3} = \frac{r_{CE3} + r_Z'}{1+\beta_3} \parallel r_{CE3} = \frac{1{,}25 \cdot 10^3 + 10}{1+250} \parallel r_{CE} = \frac{5{,}01 \cdot 1{,}25 \cdot 10^3}{5{,}01 + 1{,}25 \cdot 10^3} = 4{,}99$

$R_{iT4} = (r_{be4} + r_{if}) \cdot \frac{1}{1+\beta_4} = (3.125 \cdot 10^3 + 5{,}17 \cdot 10^3) \cdot \frac{1}{1+250} = 33{,}04$

$R_{oT4} = \infty$

$R_{iT5} = r_{be5} + (1+\beta_5)(r_{CE5} \parallel r_{cf} \parallel R_L) = 8.68 + (1+25)\left(\frac{34{,}66 \cdot 166}{34{,}66+166}\right)$

$= 754{,}18$

$R_{OT5} = \frac{r_{CE5}}{1+\beta_5} \parallel r_{CE5}$

$\frac{34.7}{1+25} = 1.33$

$\frac{1.33 \cdot 34{,}7}{1{,}33 + 34{,}7} = 1{,}28$

15.

1. Common collector

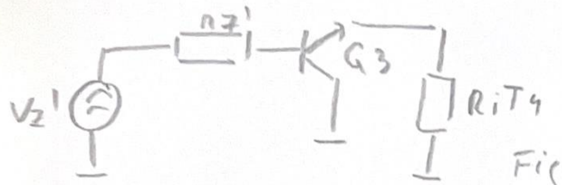


FIGURE 20

$$A_{V_1} = \frac{(1+\beta_3)(R_{iT4} \parallel r_{CE3})}{r_{Be3} + (1+\beta_3)(R_{iT4} \parallel r_{CE3})} = \frac{(1+250)\left(\frac{33{,}04 \cdot 1{,}25 \cdot 10^3}{33{,}04 + 1{,}25 \cdot 10^3}\right)}{3{,}125 \cdot 10^3 + (1+250)\left(\frac{33{,}04 \cdot 1{,}25 \cdot 10^3}{33{,}04 + 1{,}25 \cdot 10^3}\right)}$$

$$= 0{,}72$$

2. Common BASE

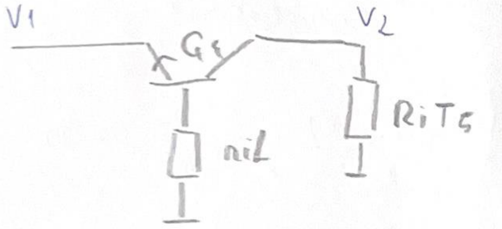


FIGURE 21

$$A_{V_2} = g_{m4}\,(R_{iT5}) = 80 \cdot 10^{-3} \cdot 745{,}18 = 59{,}6144$$

3. Common collector

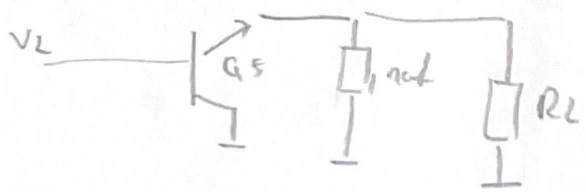


FIGURE 22

$$A_{V_4} = \frac{(1+\beta_5)(r_{CE5} \parallel r_{ref} \parallel R_L)}{r_{be5} + (1+\beta_5)(r_{CE5} \parallel r_{ref} \parallel R_L)}$$

$$A_{V_4} = \frac{(1+25)\left(\frac{1}{34.7} + \frac{1}{30{,}6 \cdot 10^3} + \frac{1}{166}\right)}{\cancel{325}\ 8.68 + (1+25)\left(\frac{1}{34.7} + \frac{1}{30{,}6 \cdot 10^3} + \frac{1}{166}\right)}$$

$$= 0{,}09$$

16.

$Av = Av_1 \cdot Av_2 \cdot Av_3$

$= 0{,}72 \cdot 59{,}6144 \cdot 0{,}09 = 3{,}86$

$T = f v \cdot av = 0.21 \cdot 3{,}86 = 0{,}8106$

$Av = \dfrac{aV}{1+T} = \dfrac{3{,}86}{1+0{,}8100} = 2{,}13$

17.

Simulations in SPICE

DC bias point simulation

Normal load (RL=1000 ohms)

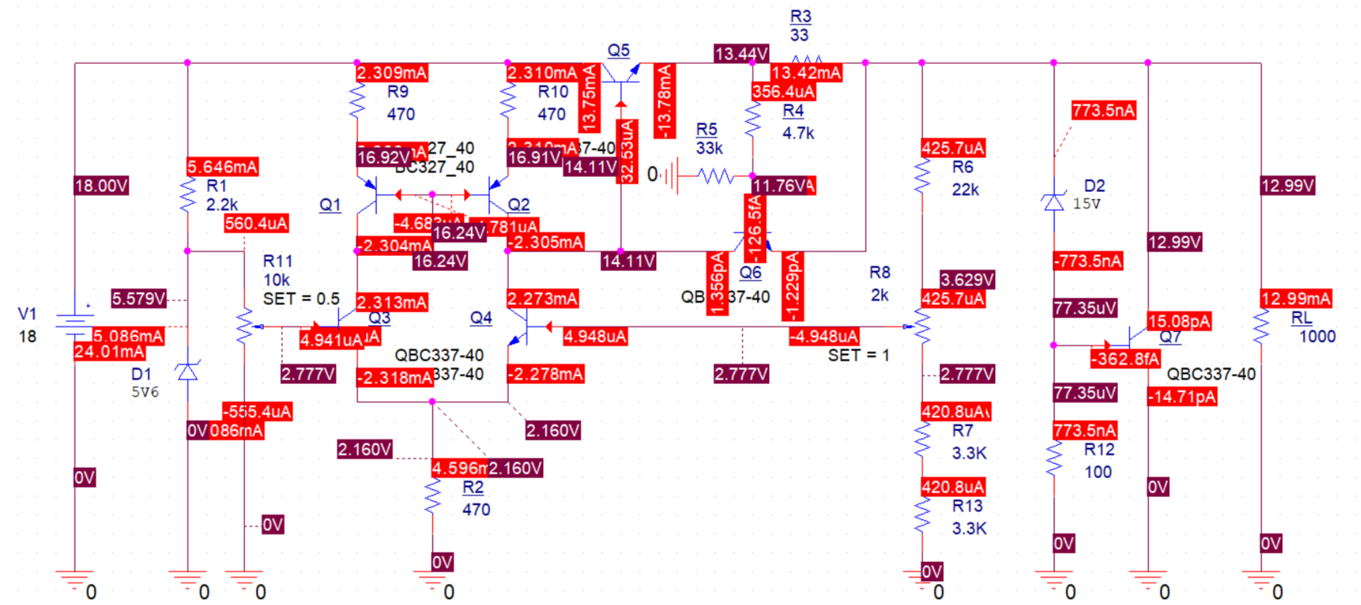


Figure23

Short circuited load (RL=1 ohm)

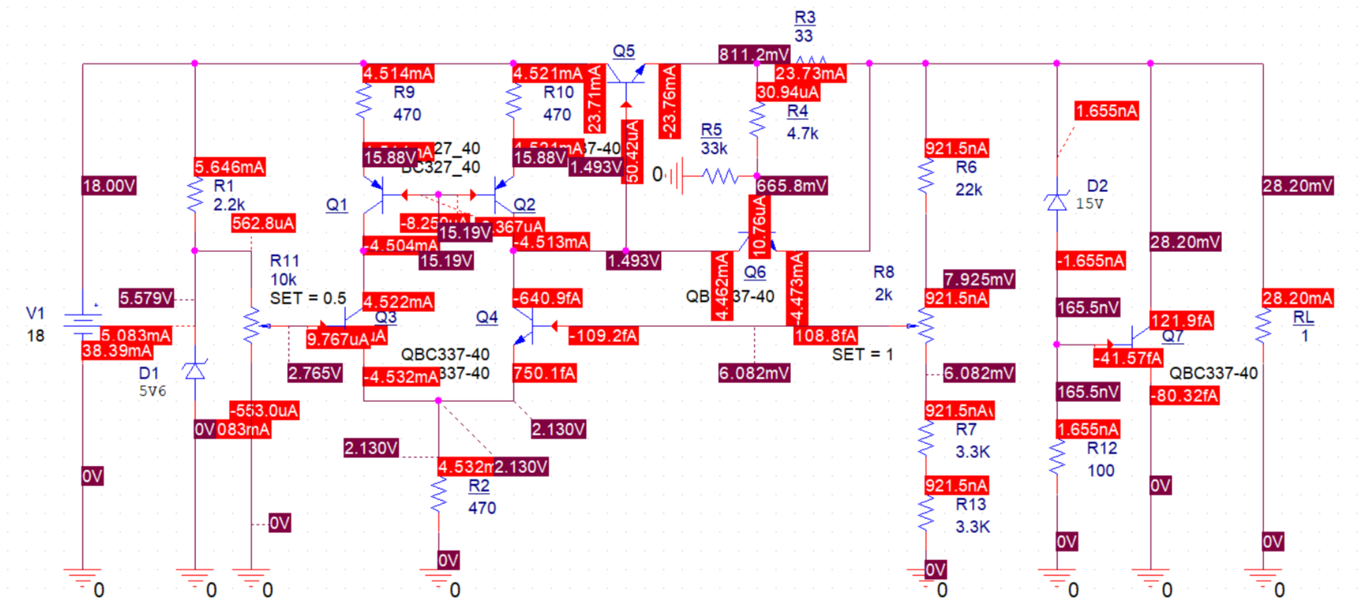


Figure24

The voltages measured throughout the circuit are as expected, indicating proper operation.

The current levels are also within normal limits, with the highest current flowing through the load RL.

The power dissipations are within normal ranges, typically in the milliwatt (mW) range, ensuring that no component is overheating.

DC Input voltage sweep
For potentiometer at its low point:

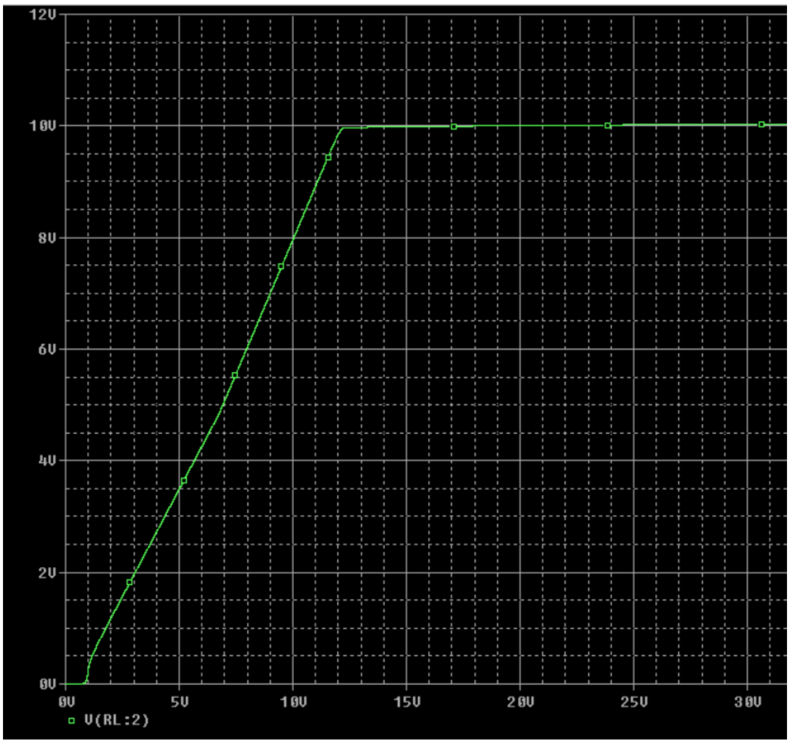


Figure25

For potentiometer at its high point:

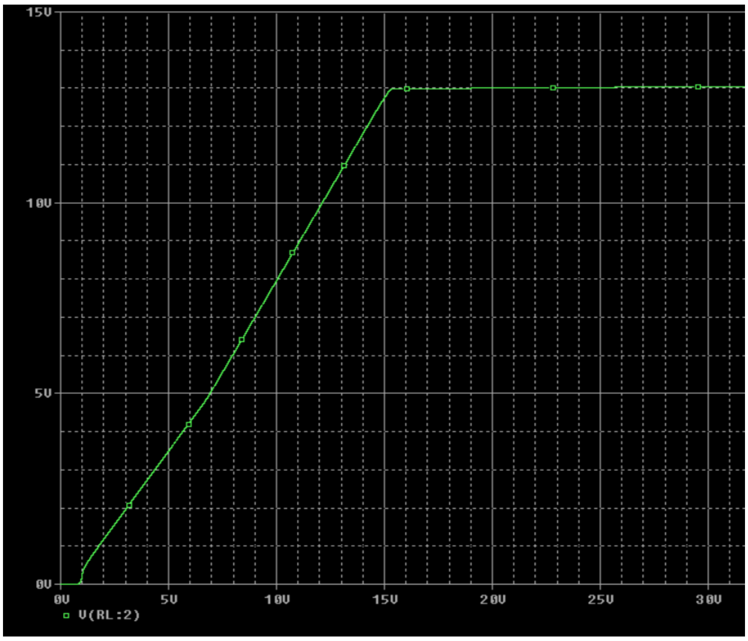


Figure26

The graphics clearly demonstrate that the circuit functions as intended, producing output **voltages of 10 and 12,** respectively. Additionally, it is evident how the voltage regulator circuit effectively regulates the variable input voltage.

<u>OBSERVING THE OPERATION OF THE OVERCURRENT PROTECTION CIRCUIT</u>

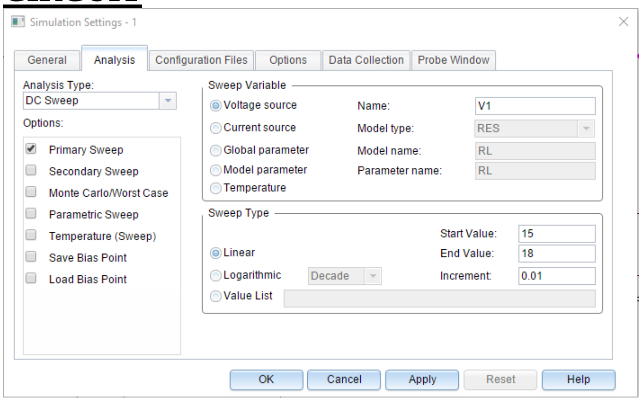


Figure27

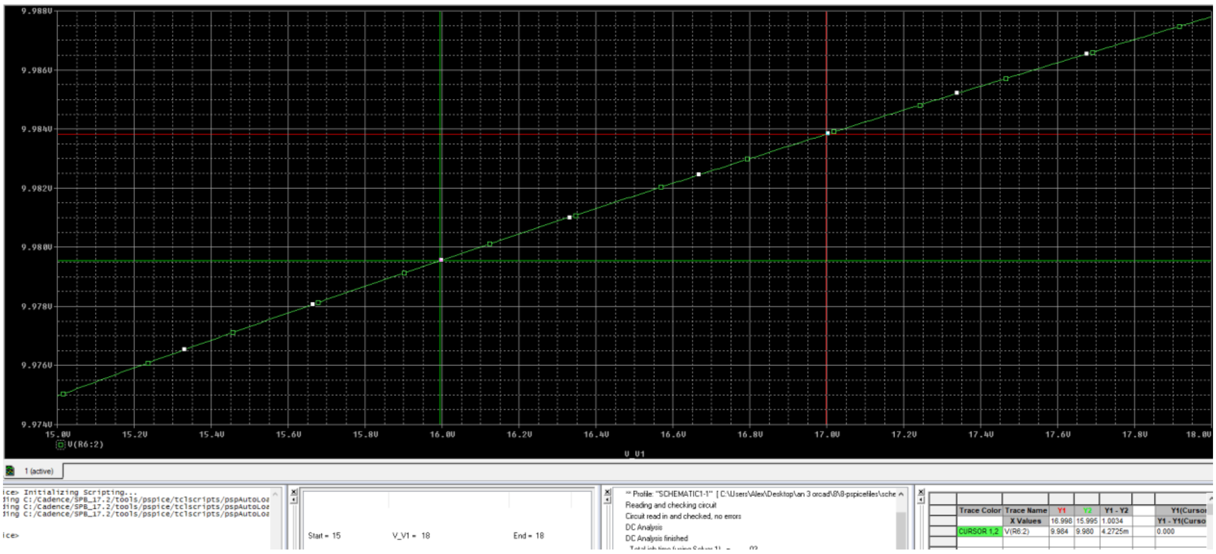


Figure28

<u>STABILIZATION FACTOR (S)</u>

To calculate S I used a sinusoidal voltage source (VOFF = 0, VAMPL = 0.5, FREQ = 50, AC = 0)

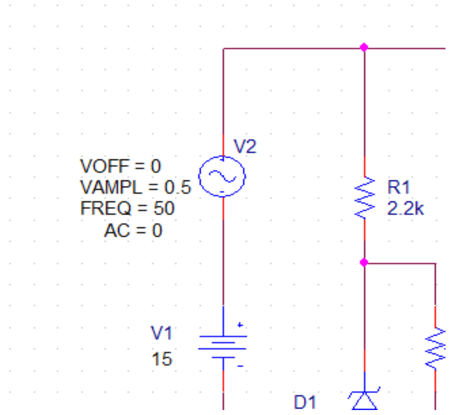


Figure29

1.Vin=15,set=0

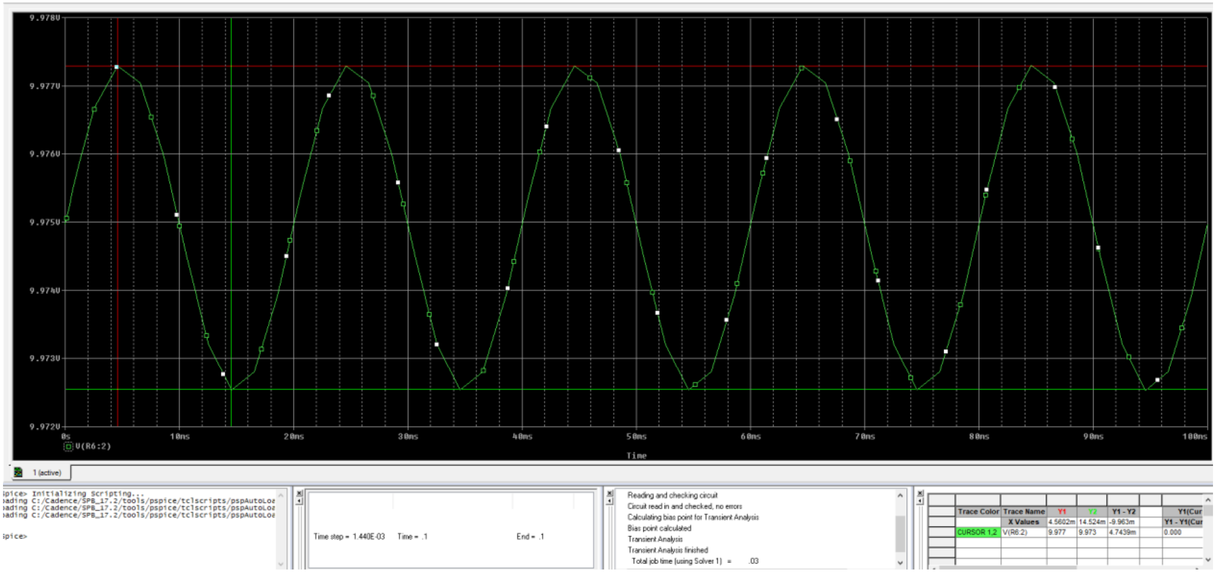


Figure30

***S* = 1/ 9.977− 9.973= 250> 72**

2.Vin=15,set=1

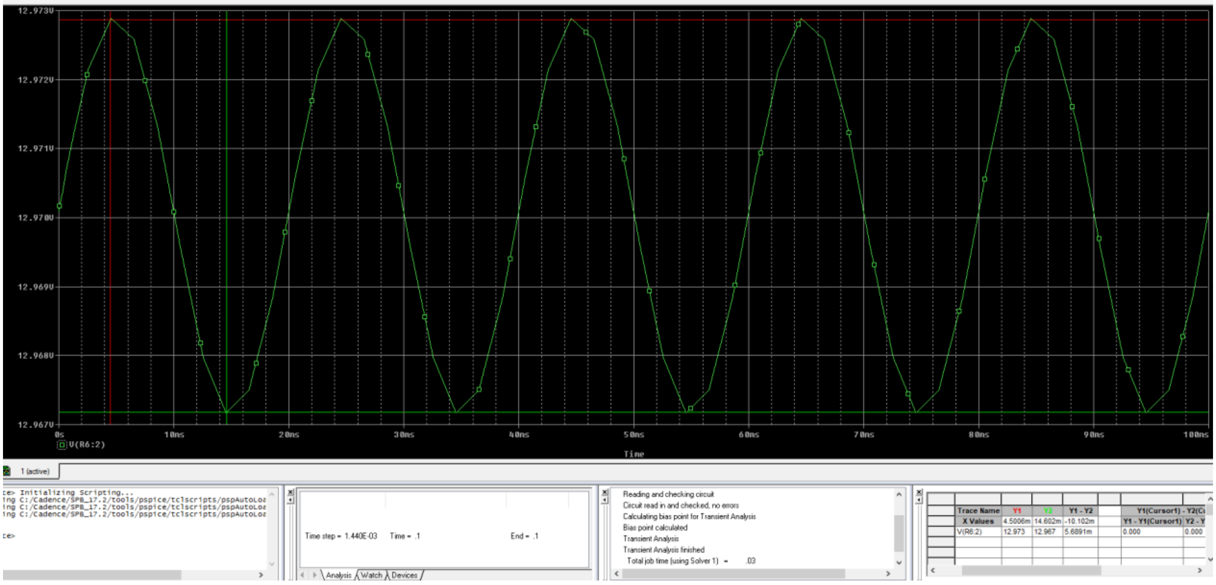


Figure31

$S = 1/\ 12.973 - 12.967 = 166.6 > 72$

3.Vin=18,set=0

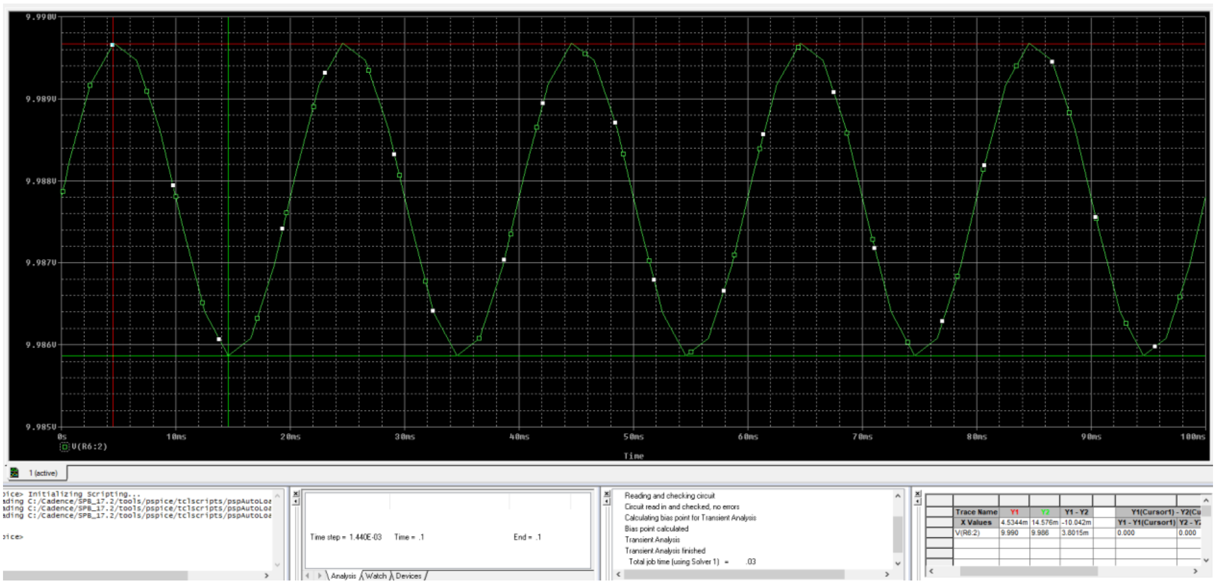


Figure32

$S = 1/\ 9.990 - 9.986 = 250 > 72$

4.Vin=18,set=1

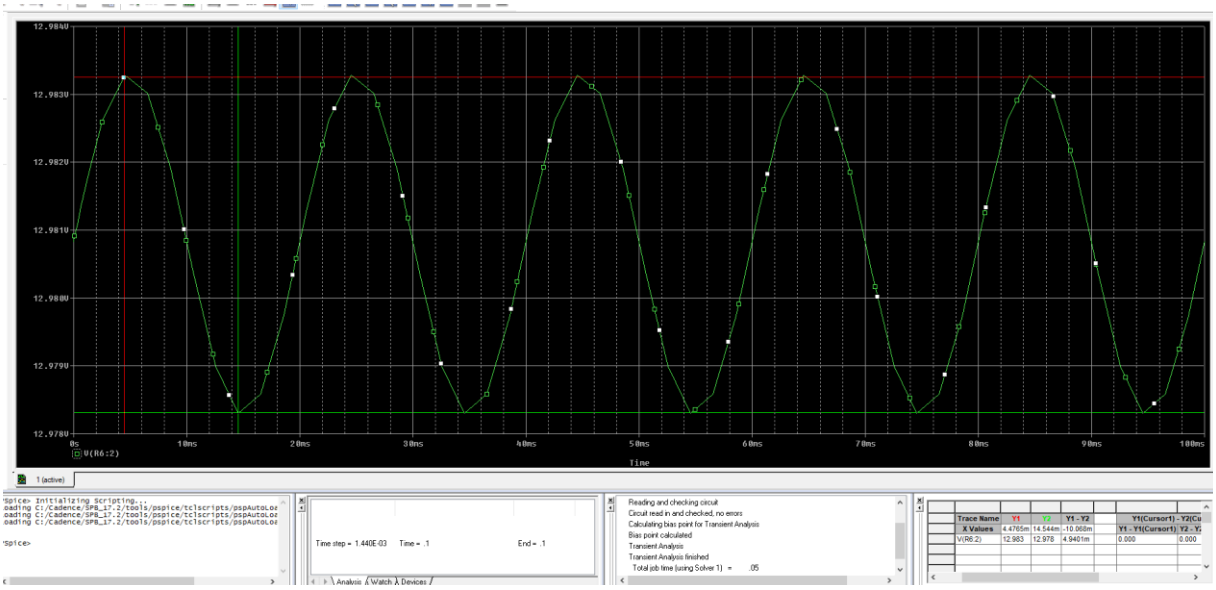


Figure33

$\boldsymbol{S = 1/\ 12.983 - 12.978 = 200 > 72}$

<u>THE SYMMULATION OF THE LOAD RESISTANCE</u>

for both the voltage and the current

Figure34

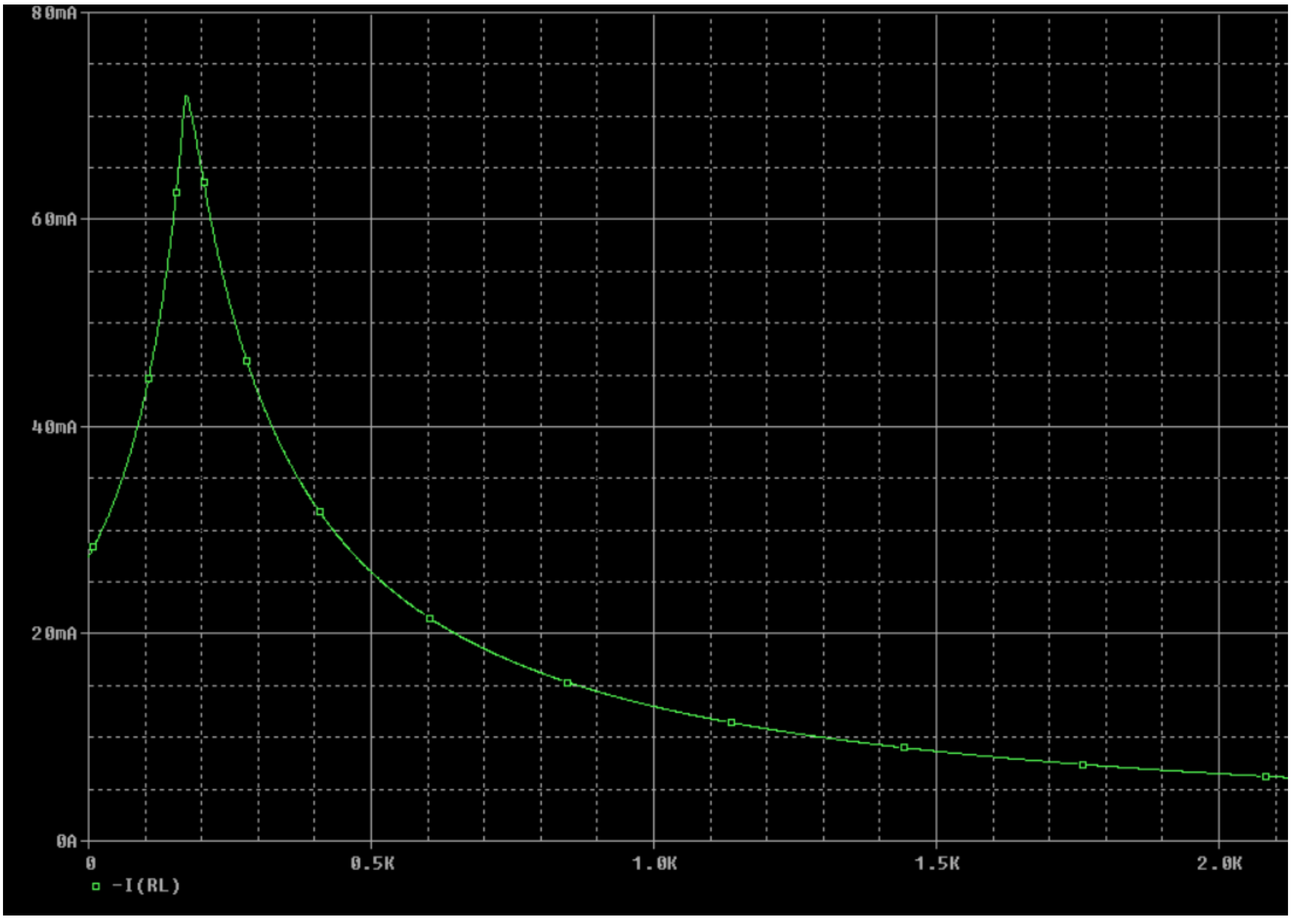


Figure35

The graph shows that a **maximum of 72mA (as required)** is delivered to the load, effectively protecting the circuit from overcurrent situations, such as a short circuit.

The output resistance can be calculated from the graph of the load resistance variation:

Protections simulation

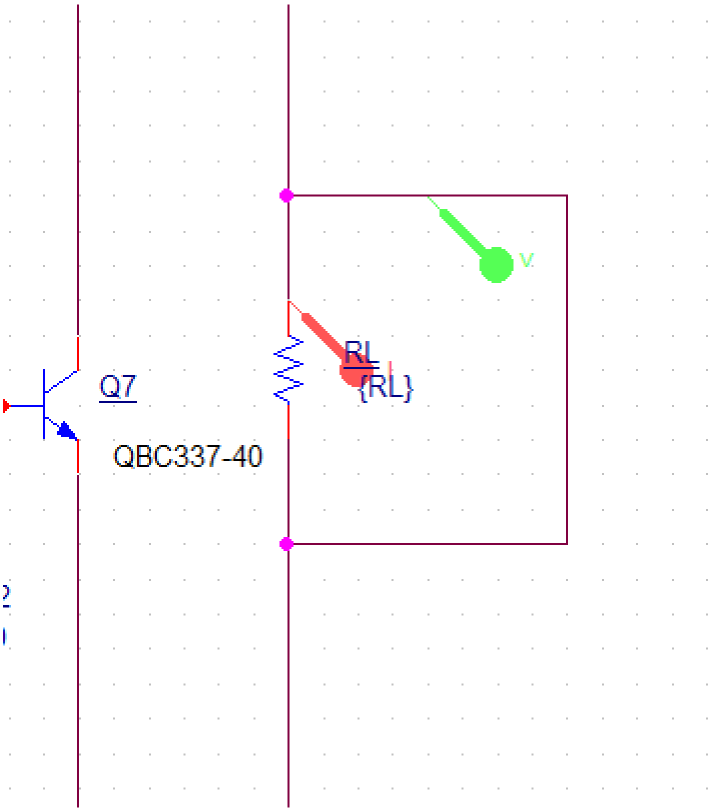


Figure36

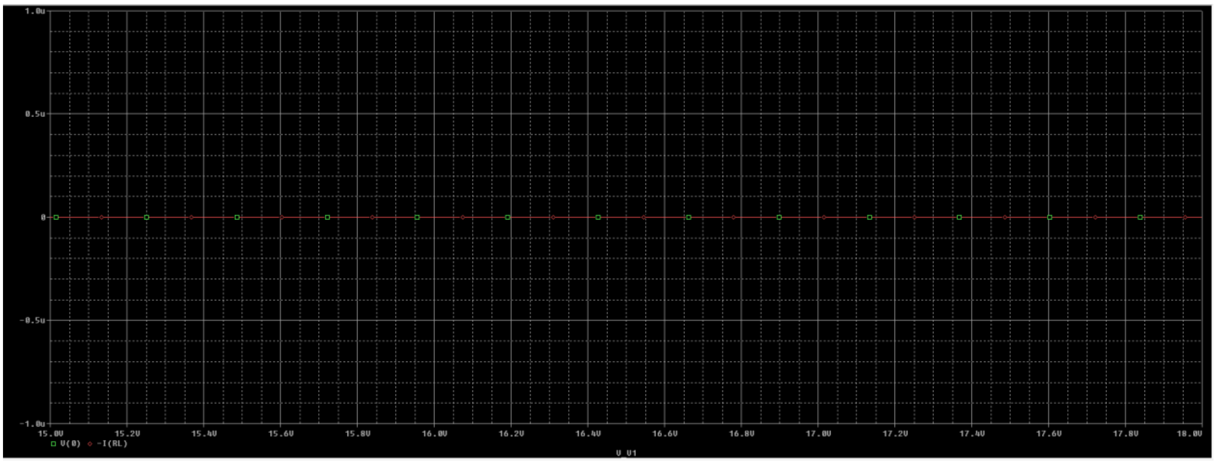


Figure37

Comments/Conclusions

A voltage regulator is an essential circuit used for stabilizing variable DC input voltages. Through this project, I gained a deeper understanding of its operation, the underlying principles, and the fundamental theory. Additionally, I learned valuable skills in circuit design, from efficiently using simulation software to conceptualizing circuits at a component level.

This experience has not only enhanced my technical knowledge but also sparked a greater interest in exploring more complex and unconventional circuit designs.

Mounting map:

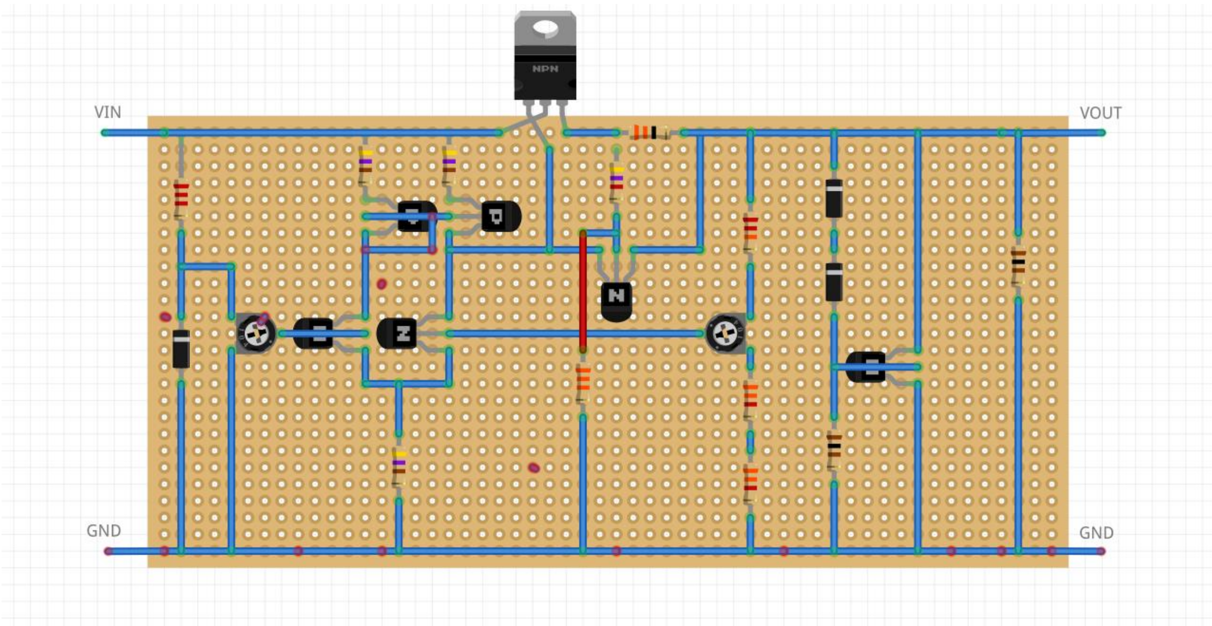


Figure38

Bill of materials:

Nr. Crt.	Nume	Catalog	Cod distrib	Nume prod	Prod	Clasă	Qty min	Descriere	Distribuitor
1	33	(LINK)	CF1/4W-33R	CF1/4W-33R	SR PASSIVES	rezistor	1	Rezistor: de carbon; THT; 33Ω; 0,25W; ±5%;	TME România

								Ø2,3x6mm; Term: axial	
2	100	(LINK)	CF1/4W-100R	CF1/4W-100R	SR PASSIVES	rezistor	1	Rezistor: de carbon; THT; 100Ω; 0,25W; ±5%; Ø2,3x6mm; Term: axial	TME România
3	470	(LINK)	CF1/4W-470R	CF1/4W-470R	SR PASSIVES	rezistor	3	Rezistor: de carbon; THT; 470Ω; 0,25W; ±5%; Ø2,3x6mm; Term: axial	TME România
4	1k	(LINK)	CF1/4W-1K	CF1/4W-1K	SR PASSIVES	rezistor	1	Rezistor: de carbon; THT; 1kΩ; 0,25W; ±5%; Ø2,3x6mm; Term: axial	TME România
5	2.2k	(LINK)	CF1/4W-2K2	CF1/4W-2K2	SR PASSIVES	rezistor	1	Rezistor: de carbon; THT; 2,2kΩ; 0,25W; ±5%; Ø2,3x6mm; Term: axial	TME România
6	3.3k	(LINK)	CF1/4W-3K3	CF1/4W-3K3	SR PASSIVES	rezistor	2	Rezistor: de carbon; THT; 3,3kΩ; 0,25W; ±5%; Ø2,3x6mm; Term: axial	TME România
7	3.9k	(LINK)	CF1/4W-3K9	CF1/4W-3K9	SR PASSIVES	rezistor	1	Rezistor: de carbon; THT; 3,9kΩ; 0,25W; ±5%; Ø2,3x6mm; Term: axial	TME România
8	22k	(LINK)	CF1/4W-22K	CF1/4W-22K	SR PASSIVES	rezistor	1	Rezistor: de carbon; THT; 22kΩ; 0,25W; ±5%; Ø2,3x6mm; Term: axial	TME România
9	47k	(LINK)	CF1/4W-47K	CF1/4W-47K	SR PASSIVES	rezistor	1	Rezistor: de carbon; THT; 47kΩ; 0,25W; ±5%; Ø2,3x6mm; Term: axial	TME România
10	2k	(LINK)	T75R-2K	T75R-2K	SR PASSIVES	potențiometru	1	Potenţiometru: de montare; singură tură, orizontal; 2kΩ; 250mW	TME România
11	10k	(LINK)	CA9V-10K	CA9V 10K	ACP	potențiometru	1	Potenţiometru: de montare; singură tură,orizontal; 10kΩ; 0,15W	TME România
12	5.1V	(LINK)	ZPD5.1-DIO	ZPD5.1	DIOTEC SEMICONDUCTOR	diodă Zener	1	Diodă: Zener; 0,5W; 5,1V; Ambalaj: Ammo Pack; DO35	TME România
13	5.6V	(LINK)	ZPD5.6-DIO	ZPD5.6	DIOTEC SEMICONDUCTOR	diodă Zener	1	Diodă: Zener; 0,5W; 5,6V; Ambalaj: Ammo Pack; DO35	TME România
14	10V	(LINK)	ZPD10-DIO	ZPD10	DIOTEC SEMICONDUCTOR	diodă Zener	1	Diodă: Zener; 0,5W; 10V; Ambalaj: Ammo Pack; DO35	TME România
15	NPN	(LINK)	BC337-40-DIO	BC337-40	DIOTEC SEMICONDUCTOR	tranzistor bipolar	4	Tranzistor: NPN; bipolar; 45V; 800mA; 625mW; TO92	TME România
16	PNP	(LINK)	BC327-40-DIO	BC327-40	DIOTEC SEMICONDUCTOR	tranzistor bipolar	2	Tranzistor: PNP; bipolar; 45V; 800mA; 625mW; TO92	TME România

17	NPN	(LINK)	BD241C	BD241C	ST MICROELECTRONICS	tranzistor bipolar	1	Tranzistor: NPN; bipolar; 100V; 3A; 40W; TO220	TME România

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https://www.tme.eu/ro/details/cf1_4w-10k/rezistente-tht/sr-passives/