University POLITEHNICA of Bucharest

Faculty of Electronics, Telecommunications and Information Technology

Project 1

Positive Voltage Regulator

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Group: 432F

Year: 2024-2025

1. Project requirements

It is required to design a positive linear voltage regulator with discrete components, with the following specifications: (N = 18)

- Supply voltage between 25÷28 [V];
- Programmable output voltage 20÷22[V];
- The output current through the load between 0÷52 [mA];
- Short circuit protection of the output terminals with foldback current limiting circuit.
- Overvoltage protection of the output terminals.
- $S = \left.\frac{\Delta V_i}{\Delta V_o}\right|_{RL} \geq 68$
- The output impedance of the regulator $R0 \leq 2\Omega$.

2. The block diagram of the circuit (1-2 pages)

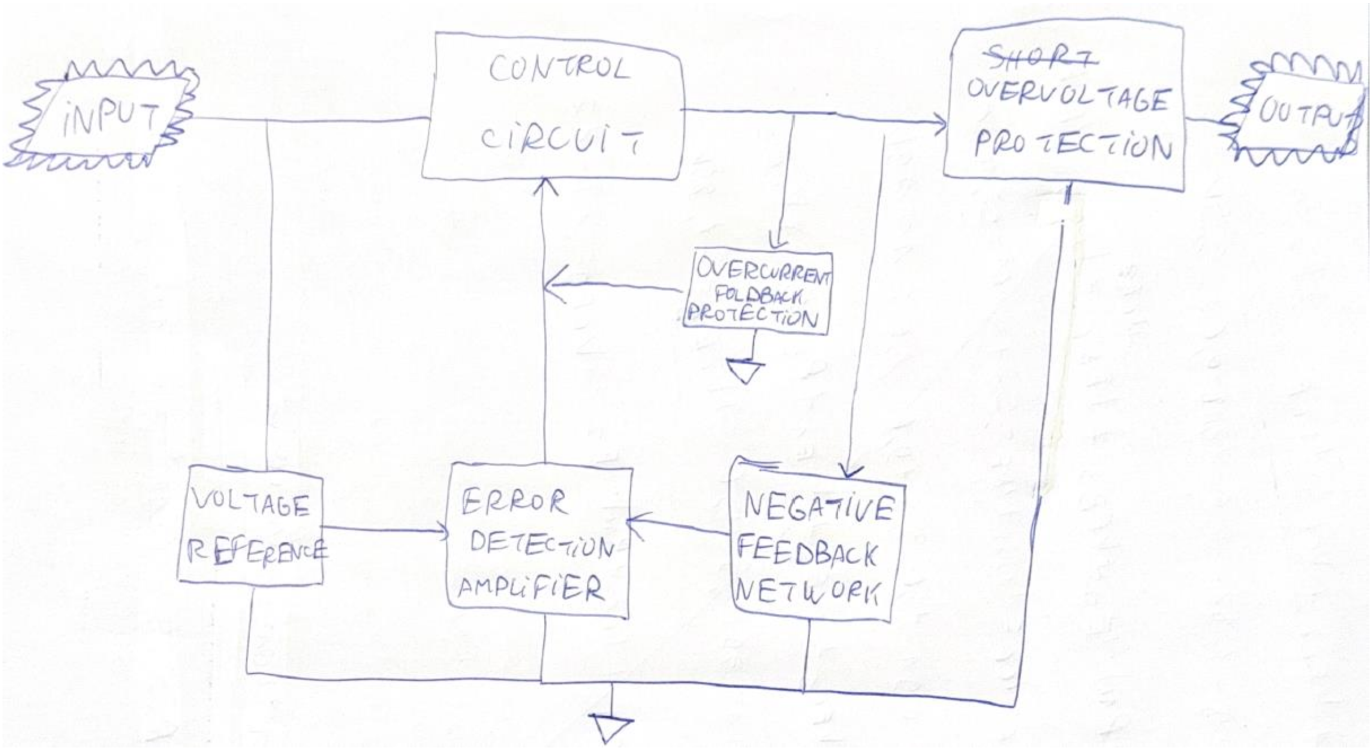


Fig.1. The block diagram

1. **Input (25V to 28V DC)**:

This is the DC voltage supply input, which varies between 25V and 28V. The circuit is designed to stabilize this input voltage to our fixed calculated output level.

2. **Reference Voltage**:

This block supplies a consistent reference voltage that assists in establishing the target output voltage. A Zener diode is commonly utilized in this context to ensure a steady voltage, regardless of input fluctuations. The reference voltage is crucial for the regulator to deliver a stable output.

3. **Error Detection Amplifier**:

This block assesses the actual output voltage against the reference voltage. If there is a deviation from the reference, it produces an error signal that indicates the difference. Typically, this block includes an operational amplifier or a comparator to supervise and identify any voltage differences between the output and the reference.

4. **Control Circuit**:

The control circuit analyzes the error signal and modifies the output by regulating a pass transistor or another control element, either increasing or decreasing the output voltage. It guarantees that the output stays within the designated range, even with variations in input voltage or load. In this instance, the control circuit adjusts the output to remain between 20V and 22V, depending on the input conditions.

5. **Overcurrent Foldback Protection**:

Foldback protection in my circuit design ensures reliable performance by reducing the current significantly during overloads or faults, like short circuits, while maintaining manageable power dissipation. This approach safeguards the series pass element and prevents overheating, enhancing the overall durability and safety of the system even under challenging operating conditions.

6. **Negative Feedback Circuit**:

The feedback circuit monitors the output voltage and relays it back to the error detection block. This feedback loop is essential for ongoing regulation, enabling error detection to evaluate the discrepancy between the output and the target level. The feedback loop promotes stability and ensures a quick response to changes in load or input voltage fluctuations.

7. **Overvoltage Protection:**

The protection block features current limiting to prevent overcurrent, overvoltage protection to safeguard against excessive voltage, and thermal protection to shut down the output in case of overheating. Furthermore, output capacitors are employed to filter out noise or ripple, ensuring a stable voltage for the load. This method enhances the circuit's reliability and longevity by maintaining consistent output even in demanding conditions, thereby protecting both the load and the internal control systems.

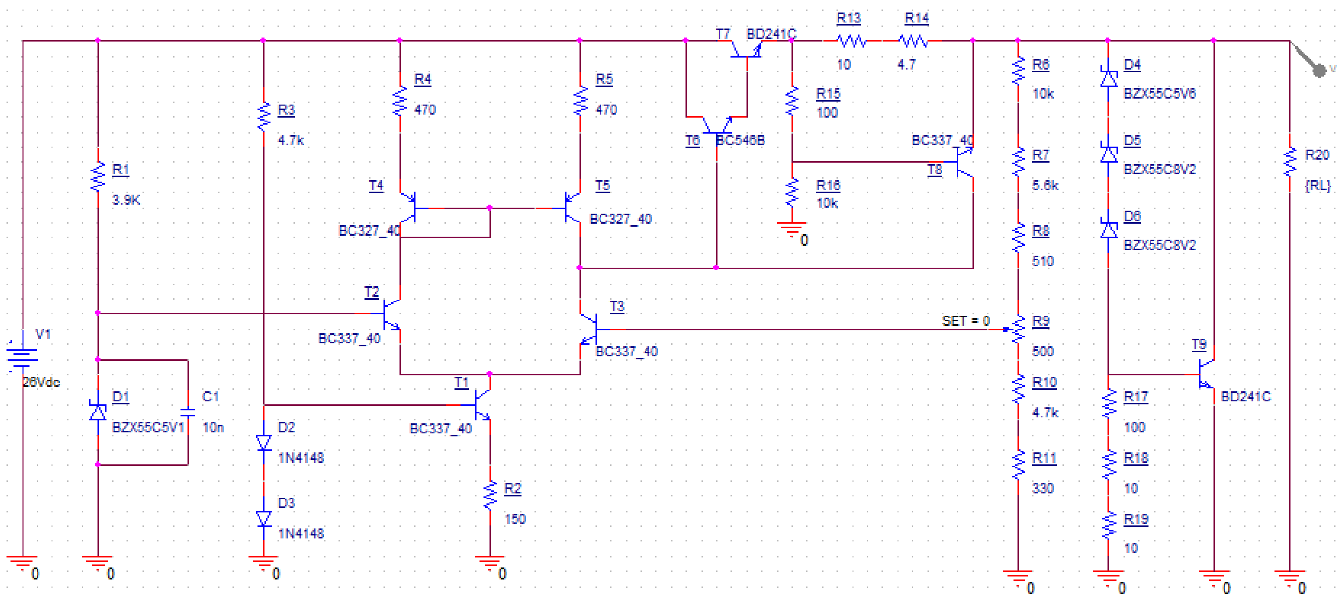
8. **Output (20V to 22V DC)**:

This represents the regulated output of the voltage regulator, which is expected to remain stable between 20V and 22V, as specified in the design. The regulator will uphold this output within the desired range, even with changes in input voltage or load current, accommodating a maximum current of 52 mA.

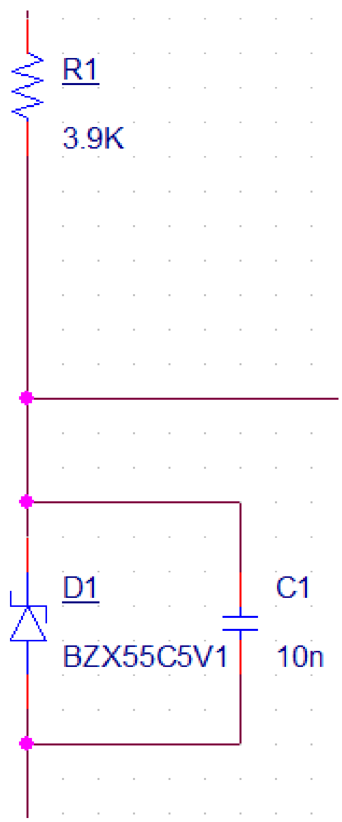
The block diagram illustrates the main stages and their functions in stabilizing the input voltage to achieve the required output voltage range in a programmable voltage regulator design. The operation relies on sustaining a feedback loop that continuously adjusts the output to align with the designated reference voltage.

3. **The detailed schematic diagram with detailed explanations related to operation, identification of each sub-block which was presented in the block diagram, and the calculations for each component (passive or active) that is part of that sub-block**

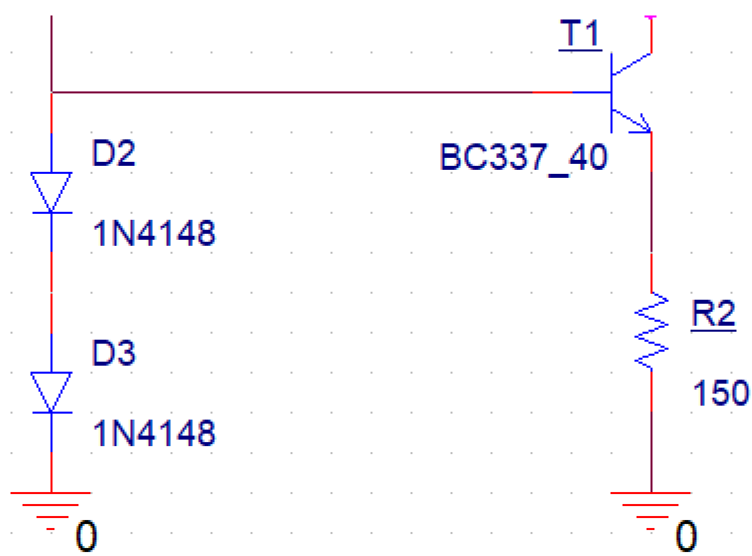
Circuit Diagram:



Voltage reference:

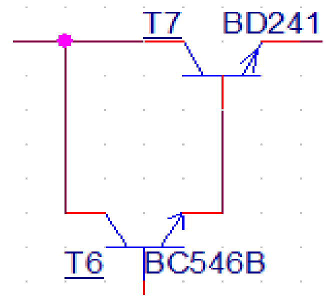


Current source:

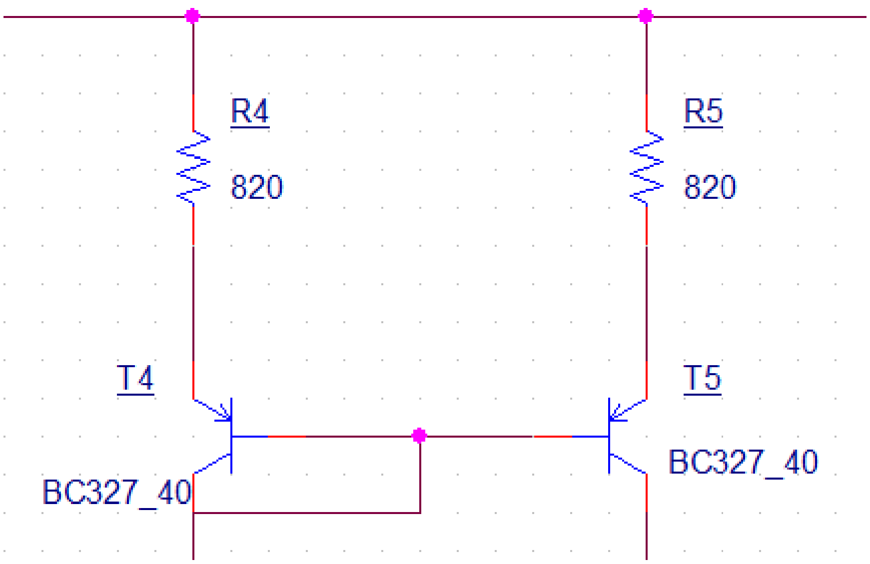


Diferential Amplifier:

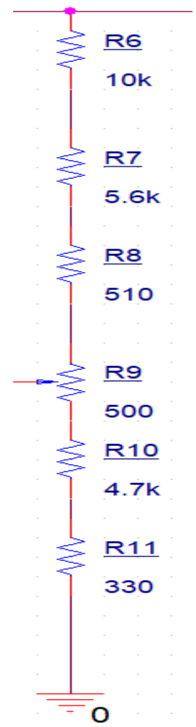
Series-pass element:



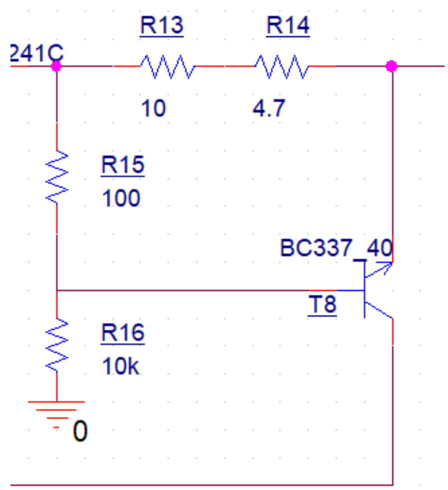
Current mirror and biasing transistors:



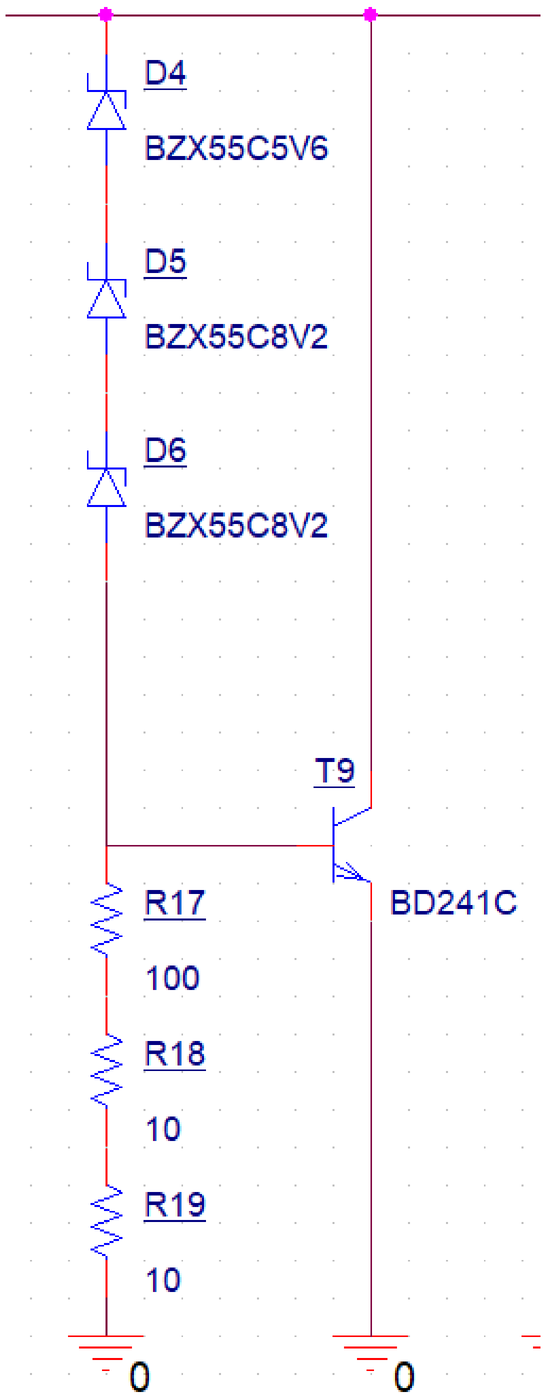
Negative feedback network:



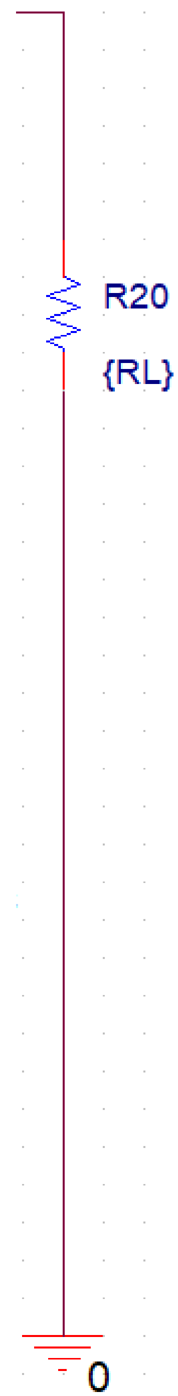
Short circuit protection with foldback:



Overvoltage protection:



Load resitance:



MANTA MĂDĂLIN-ȘTEFAN 432FA 08.11.2024

4) Calculations for each component

a) Voltage reference

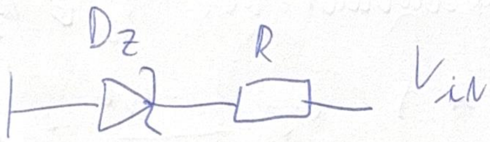
We need to have a reference voltage between

$(V_{i\,min} - V_{o\,MAX}) \div (V_{i\,min} - V_{o\,min}) \Rightarrow (25-22) \div (25-20) \Rightarrow$

$\Rightarrow V_{ref} \in [3,5] \Rightarrow$ I chose a Zenner Diode with a value of 5,1 V, ZPD5.1, but because I don't have this one in ORCAD I use BZX55C5V1.

~~We use~~ $V_{IN_{MIN}} \cancel{= \frac{V_{i\,min} + V_{i\,MAX}}{2} = \frac{25+28}{2} = \frac{53}{2} = 26,5V}$ for the calculus of the value.

To activate the diode, we need a minimum value of 5mA and now we should calculate the adjacent resistance:



$$R_1 = \frac{V_{IN_{MIN}} - V_Z}{I_{Z\,min}} = \frac{25-5,1}{5 \cdot 10^{-3}} = \frac{19,9 \cdot 10^3}{5} = 3,98 \cdot 10^3\,\Omega = 3980\,\Omega$$

I choose a single resistor with a value of 3.9 KΩ

$$\Rightarrow \boxed{R_1 = 3,9\,K\Omega}$$

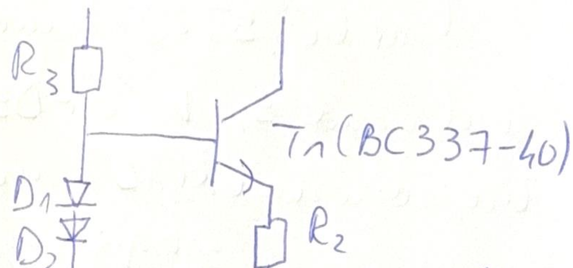
$$I_{Z\,MAX} = \frac{V_{in\,MAX} - V_Z}{R} = \frac{28-5,1}{3,9 \cdot 10^3} = 5,87\,mA > 5\,mA$$

$$i_{Z\,min} = \frac{V_{in\,min} - V_Z}{R} = \frac{25-5,1}{3,9\cdot 10^3} = 5,1\,mA > 5\,mA$$

$$P_{MAX} = I_{Z\,MAX}^2 \cdot R = 5,87^2 \cdot 10^{-6} \cdot 3,9\cdot 10^3 = 134\,mW <$$

$< 0,25W$, the max of the resistor

I also use a capacitor in parallel with the Zener Diode, to filter any noise and stabilize the diode. I chose a value of $\boxed{10nF}$ to be both fast and effective.



b) Current Source

I chose the diodes D_2, D_3 as 1N4148 from the data sheet. $V_D = V_{BE1} = 0,6V$

We choose the lower resistor as $R_2 = \frac{2V_D - V_{BE1}}{i_{E1}}$

To split an equal current over T_2 & T_3 of 2mA, I choose i_{E1} to be 4mA $\Rightarrow R_2 = \frac{1,2-0,6}{4\cdot 10^{-3}} = 150\,\Omega \Rightarrow$

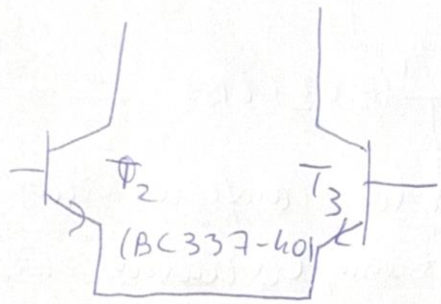
$\Rightarrow$ We pick the resistor with $\boxed{R_2 = 150\,\Omega}$ from the Annex.

$$R_3 = \frac{V_{in} - 2V_D}{I_d} = \frac{28-1,2}{6\cdot 10^{-3}} = 4,46\,k\Omega,$$ meaning a current of 6mA on the diode.

For the transistor, I pick T_1 as BC337-40 from the annex for an optimum balance.

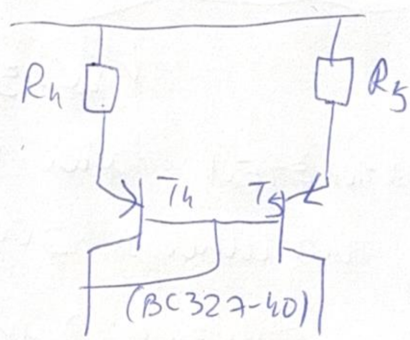
We use the ~~most app~~ closest value for $\boxed{R_3 = 4{,}7\,k\Omega}$

c) Differential Amplifier



I also use the BC 337-40 NPN transistor here for a great balance, having high gain and high collector capacity.

d) Current mirror + biasing transistors

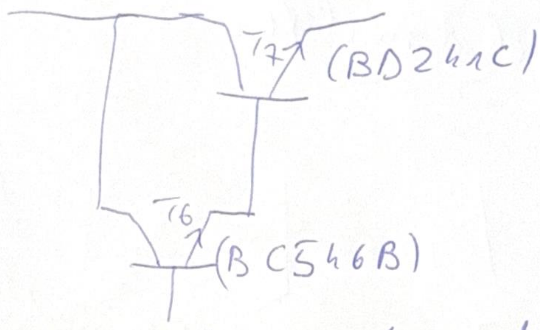


For correct transistor operation, we need a minimum value of 0,7 V a each biasing resistor; we choose 0,8 V.

$$R = \frac{0{,}8}{2\,mA}$$ (the current was split into 2 at b)) $\Rightarrow$

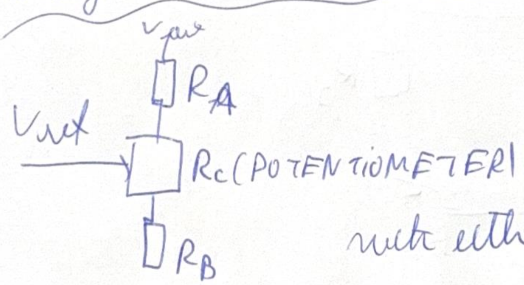
$\Rightarrow R \simeq 400\,\Omega \Rightarrow$ We pick $R_4 = R_5 = 470\,\Omega$

e) Series-pass element



I chose a Darlington configuration to have a very high current amplification and get an output impedance with a low value. For this amplification, I first use T6/BC546B as a low power transistor, and then T7/BD241C as a high-power one.

f) Negative feedback network



$V_{ref} = 5{,}1V$

After making calculus with either a 500 Ω or a 2kΩ potentiometer, I choose the 500 Ω one for best match.

$$\begin{cases} V_{REF} = \dfrac{R_B}{R_A + R_B + R_C} \cdot V_{out_{MAX}} \\[2ex] V_{REF} = \dfrac{R_B + R_C}{R_A + R_B + R_C} \cdot V_{out_{min}} \end{cases}$$

$$\begin{cases} R_A+R_B+R_C = \dfrac{R_B \cdot V_{MAX}}{V_{REF}} \\ R_A+R_B+R_C = \dfrac{(R_B+R_C)\cdot V_{MIN}}{V_{REF}} \end{cases}$$

$$\begin{cases} R_A+R_C = R_B\left(\dfrac{V_{MAX}}{V_{REF}}-1\right) \\ R_A = (R_B+R_C)\left(\dfrac{V_{min}}{V_{REF}}-1\right) \end{cases}$$

We calculate in $k\Omega$

$$\begin{cases} R_A+0{,}5 = R_B\left(\dfrac{22}{5{,}1}-1\right) \\ R_A = (R_B+0{,}5)\left(\dfrac{20}{5{,}1}-1\right) \end{cases} \Rightarrow \begin{cases} R_A+0{,}5 = R_B \cdot 3{,}31 \\ R_A = 2{,}92 R_B + 1{,}46 \end{cases} \ominus$$

$$0{,}5 = 0{,}39 R_B - 1{,}46$$

$$1{,}96 = 0{,}39 R_B \Rightarrow R_B = \frac{1{,}96}{0{,}39} = 5{,}02\ k\Omega$$

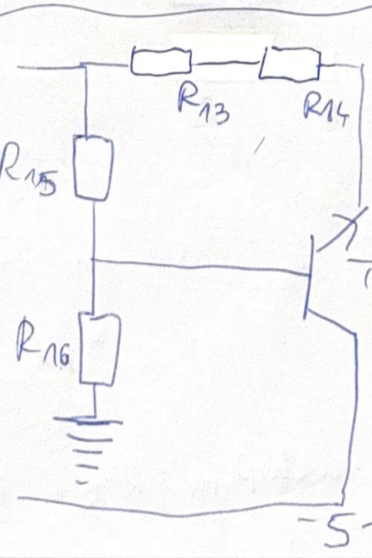
$$R_A = 3{,}31 \cdot 5{,}02 - 0{,}5 = 16{,}11\ k\Omega$$

So we choose $R_B = R_{10} + R_{11} = 4700 + 330 = 5{,}03\ k\Omega$?

$R_A = R_6 + R_7 + R_8 = 10\ k\Omega + 5{,}6\ k\Omega + 510\ \Omega$

$R_C = R_9 = 500\ \Omega$

g) Short circuit protection with foldback



We need to have a voltage drop higher than 0,7V in order to make Q_3 conduct. (We use 0,75 V)

$$V_R = R \cdot i_{MAX} \Rightarrow R = \frac{V_R}{i_{MAX}} = \frac{0,75V}{52mA} \simeq 14,42\,\Omega$$

We use 2 resistors, $R_{13} + R_{14} = 10\,\Omega + 4,7\,\Omega = 14,7\,\Omega$

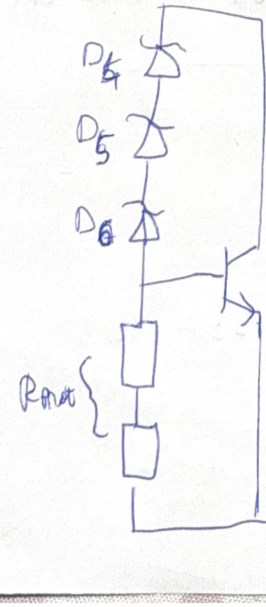
$$(R_{13}+R_{14}) = \frac{(V_{BE_8}+V_{out})\cdot\frac{R_{15}+R_{16}}{R_{16}} - V_{out}}{i_{MAX}} \Rightarrow$$

$$\Rightarrow 14,7 = \frac{20,6\cdot x - 20}{52\cdot 10^{-3}} \Rightarrow 20,6x - 20 = 0,764 \Rightarrow$$

$$\Rightarrow x = \frac{R_{15}+R_{16}}{R_{16}} \simeq 1,008 \Rightarrow R_{15} \text{ is approx } 0,2\% \cdot R_{16}$$

and we choose $R_{15} = 100\,\Omega$; $R_{16} = 10k\Omega$
380 Ω

h) Overvoltage protection



$$R_{protection} = \frac{V_{BE_9}}{I_Z} = \frac{0,6}{5\cdot 10^{-3}} = 120\,\Omega$$

We can use a resistor $R_{17} = 100\,\Omega$ from the annex in series with $R_{18} = R_{19} = 10\,\Omega$

We shouldn't get a voltage higher than 22V on our output, but the OVP will turn on at $V_Z + V_{BE}$ => We choose 3 Zenner Diodes

$$D_4 = 5,6V$$
$$D_5 = D_6 = 8,2V$$ } =>

$$\Rightarrow D_4 + D_5 + D_6 = 5,6 + 2 \cdot 8,2 = 5,6 + 16,4 = 22V$$

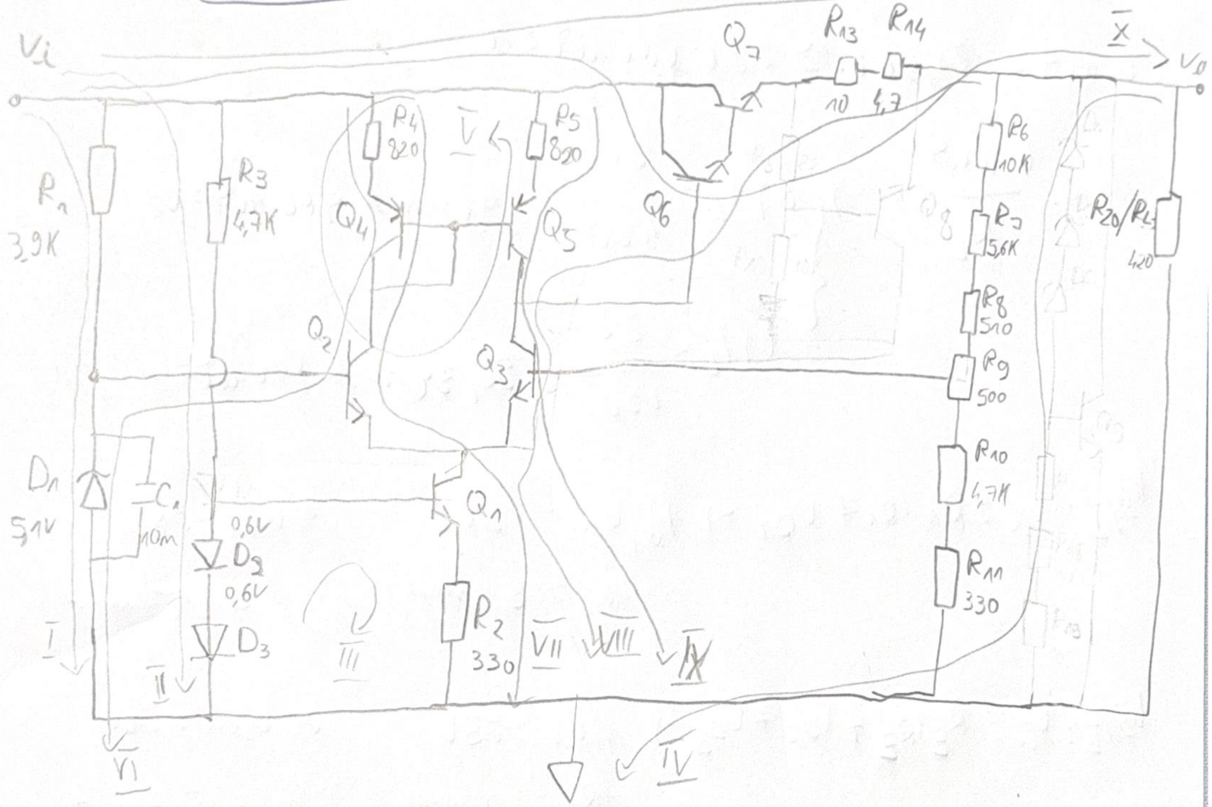
i) Load resistance

We use $R_L = \frac{V_{uMAX}}{i_{MAX}} = \frac{22V}{52mA} = 423\Omega$

=> We choose from the Annex $R_{20} + R_{21} + R_{22} = 220\Omega + 100\Omega + 100\Omega = 420\Omega$

- 7 -

DC bias



We don't take into calculus the OCP & OVP circuits for DC.

We have 2 cases:

1) $V_{in} = 25\,V$ 2) $V_{in} = 28\,V$

a|ret=0 a|ret=0

b|ret=1 b|ret=1

$$V_{out} = V_{ref} \cdot \frac{R_6 + R_7 + R_8 + R_{9\,up} + R_{10} + R_{11} + R_{1\,down}}{R_6 + R_7 + R_8 + R_{9\,down}}$$

$$a|ret = 0 \Rightarrow V_{out} = 5{,}1 \cdot \frac{10000 + 5600 + 510 + 0 + 4700 + 330 + 500}{4700 + 330 + 500} = 19{,}95\,V$$

$$b|ret = 1 \Rightarrow V_{out} = 5{,}1 \cdot \frac{10000 + 5600 + 510 + 500 + 4700 + 330 + 0}{4700 + 330 + 0} = 21{,}94\,V$$

$V_{out} = 19{,}95V \simeq 20\,V$ for ret=0

$V_{out} = 21{,}94V \simeq 22V$ for ret=1

$$i_L = \frac{V_{out}}{R_L} \Rightarrow \begin{cases} a)\ i_L = \dfrac{20}{420} = 47{,}61\,mA \text{ for ret}=0 \\ b)\ i_L = \dfrac{22}{420} = 52{,}38\,mA \text{ for ret}=1 \end{cases}$$

$KII/_{I}$: $V_i = R_1 i_{R_1} + V_{D1} \Rightarrow$ 1) $V_{in} = 25V$, $i_{R_1} = 5{,}1\,mA$ 2) $V_{in} = 28V$, $i_{R_1} = 5{,}87\,mA$

$KII/_{II}$: $V_i = R_3 i_{R_3} + V_{D2} + V_{D3} \Rightarrow$ 1) $V_{in} = 25V$, $i_{R_3} = 5{,}06\,mA$ 2) $V_{in} = 28V$, $i_{R_3} = 5{,}7\,mA$

$KII/_{III}$: $V_{BE_1} + R_2 i_{R_2} = V_{D2} + V_{D3} \Rightarrow R_2 i_{R_2} = V_{D2} + V_{D3} - V_{BE_1} =$

$= 0{,}6 + 0{,}6 - 0{,}6 = 0{,}6 \Rightarrow i_{R_2} = \dfrac{0{,}6}{R_2} = \dfrac{0{,}6}{330} = 1{,}81\,mA \Rightarrow$

$\Rightarrow i_{R_2} = \boxed{i_{C2} = i_{E_2} = 1{,}81\,mA}$

For Q_4 & Q_5 current mirror:

$$\begin{cases} \boxed{i_{C_4}} = i_{E_4} = \boxed{i_{C5}} = i_{E5} = i_{R_4} = i_{R_5} = \\ = i_{C_2} = i_{E_2} = \boxed{i_{C_3}} = i_{E_3} = 1{,}81\,mA \\ \Rightarrow \\ KI: i_{C_1} = i_{E_2} + i_{E_4} \end{cases}$$

$\Rightarrow \boxed{i_{C_1} = 3{,}62\,mA}$

$K_{II}/\underline{IV}$: $1)\ i_{NF} = \frac{V_{out}}{R_{TOTAL}} = \frac{20}{21630} = 0{,}92\ mA$

$2)\ i_{NF} = \frac{V_{out}}{R_{TOTAL}} = \frac{22}{21630} = 1{,}01\ mA$

$K_{II}/\underline{V}$: $\cancel{R_4 i_{E_4}} + V_{EC_4} + V_{BE_5} - \cancel{R_5 i_{E_2}} = 0 \Rightarrow \boxed{V_{CE_4} = V_{BE_2} = 0{,}6V}$

$K_{II}/\underline{VI}$: $V_i = R_4 i_{E_4} + V_{EC_4} + V_{CE_2} - V_{BE_2} + V_{D_1} \Rightarrow$

$\Rightarrow\ 1)\ \boxed{V_{CE_2} = 19{,}61V}$ $\quad 2)\ \boxed{V_{CE_2} = 22{,}61V}$

$V_{in} = 25V$ $\quad V_{in} = 28V$

$K_{II}/\underline{VII}$: $V_i = R_4 i_{E_4} + V_{EC_4} + V_{CE_2} + V_{CE_1} + R_2 i_{C_1} \Rightarrow$

$\Rightarrow 1)\ \boxed{V_{CE_1} = 2{,}76V}$ $\quad \boxed{V_{CE_1} = 2{,}76V}$

$V_{in} = 25V$ $\quad V_{in} = 28V$

$i_{E_7} = i_{C_7} = I_{QMAX} + i_{NF} <$ $52{,}92\ mA$ / $53{,}01\ mA$

$K_{II}/\underline{VIII}$: $V_o = (R_{13} + R_{14}) \cdot i_{E_7} + V_{EB_7} + V_{EB6} + V_{CE_3} + V_{CE_1} + R_2 i_{C_1} \Rightarrow$

$\Rightarrow\ 1)\ V_o = 20V$ $\quad 2)\ V_o = 22V$

$\boxed{V_{CE_3} = 19{,}88\ V}$ $\quad \boxed{V_{CE_3} = 21{,}87\ V}$

$K_{II}/\underline{IX}$: $V_i = R_5 \cdot i_{E_5} - V_{CE_5} + V_{CE_3} + V_{CE_1} + R_2 i_{E_2}$

1) $V_i = 25V$ $\boxed{V_{CE_5} = -0{,}6\,V}$

2) $V_i = 28V$ $\boxed{V_{CE_5} = -0{,}61V}$

$K_{II}/\underline{X}$: $V_i - V_o = V_{CE_6} + V_{BE_7} + (R_{13} + R_{14}) \cdot i_{E_7}$

1) $\boxed{V_{CE_6} = 3{,}62\,V}$ $V_i = 25V;\ V_o = 20V$

2) $\boxed{V_{CE_6} = 4{,}62\,V}$ $V_i = 28;\ V_o = 22V$

$K_{II}/\underline{XI}$: $V_i - V_o = V_{CE_7} + (R_{13} + R_{14}) \cdot i_{E_7}$

1) $\boxed{V_{CE_7} = 4{,}22\,V}$ $V_i = 25V;\ V_o = 20V$

2) $\boxed{V_{CE_7} = 5{,}22\,V}$ $V_i = 28V;\ V_o = 22V$

$$i_{C_6} = i_{E_6} = i_{B_7} = \frac{1}{\beta_F + 1} \cdot i_{E_7} = 0{,}01 \cdot i_{E_7} \Rightarrow$$

$\Rightarrow$ 1) $V_{out} = 20V$ $\boxed{i_{E_6} = 0{,}529\,mA}$

2) $V_{out} = 22V$ $\boxed{i_{E_6} = 0{,}53\,mA}$

We obtain the results: 1) $V_{in} = 25V$ $\Rightarrow$

	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	
i_C	3,621	1,81	1,81	1,81	1,81	0,539	52,92	[mA]
V_{CE}	2,76	19,61	19,88	0,6	-0,6	3,62	4,22	[V]

2) $V_{in} = 28V \Rightarrow$

	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	
I_C	3,62	1,81	1,81	1,81	1,81	0,53	53,01	[mA]
V_{CE}	2,76	22,61	21,87	0,6	-0,6	4,62	5,22	[V]

Power computations:

$P_{R1} = i_{R1}^2 \cdot R_1 = 134,4 mW$

$P_{R2} = i_{R2}^2 \cdot R_2 = 1,9 mW$

$P_{R3} = i_{R3}^2 \cdot R_3 = 152,2 mW$

$P_{R4} = P_{R5} = 1,47 mW$

$P_{R6} = 10,41 mW$

$P_{R7} = 5,83 mW$

$P_{R8} = 531 \mu W$

$P_{R9} = 520,6 \mu W$

$P_{R10} = 4,83 mW$

$P_{R11} = 339,7 \mu W$

$P_{R13} = 29,78 mW$

$P_{R14} = 14 mW$

$P_{R15} = 1,1 mW$

$P_{R15} = 1,1 mW$

$P_{R16} = 50 mW$

$P_{R17} = 1086 \mu W$

$P_{R18} = P_{R19} = 10,86 \mu W$

$P_{R20} = 1,15 W$

$P_{D1} = V_{D1} \cdot I_{Z1MAX} = 29,93 mW$

$P_{D2} = P_{D3} = 3,55 mW$

$P_{D5} = P_{D6} = 8,51 W$

$P_{D4} = 5,81 mW$

$P_{Q1} = V_{EC1} \cdot i_{C1} = 13,79 mW$

$P_{Q2} = 39,18 mW$

$P_{Q3} = 39,18 mW$

$P_{Q4} = 5,43 mW$

$P_{Q5} = 5,43 mW$

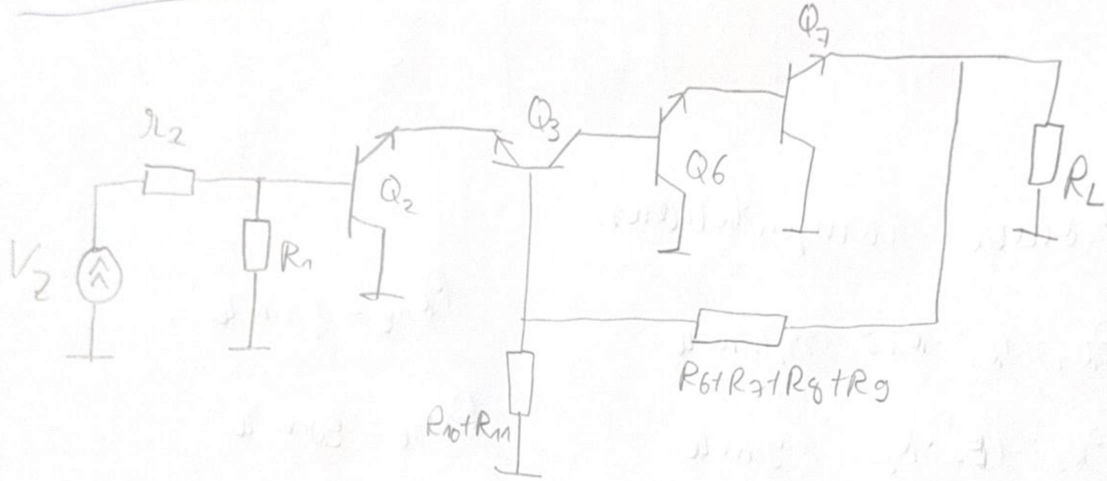
$P_{Q6} = 2,59 mW$

$P_{Q7} = 289,7 mW$

$P_{Q8} = 196,2 mW$

$P_{Q9} = 265,2 mW$

AC computation



$$g_{m2} = \frac{i_{C2}}{V_{Th}} = \frac{1{,}81 \cdot 10^{-3}}{25 \cdot 10^{-3}} = 72{,}4\,mS$$

$$g_{m3} = \frac{i_{C3}}{V_{Th}} = \frac{1{,}81 \cdot 10^{-3}}{25 \cdot 10^{-3}} = 72{,}4\,mS$$

$$g_{m6} = \frac{i_{C6}}{V_{Th}} = \frac{0{,}53 \cdot 10^{-3}}{25 \cdot 10^{-3}} = 21{,}2\,mS$$

$$g_{m7} = \frac{i_{C7}}{V_{Th}} = \frac{5{,}3 \cdot 10^{-3}}{25 \cdot 10^{-3}} = 212\,mS$$

$$r_{CE_2} = \frac{V_A}{g_{m2}} = \frac{100}{72{,}4 \cdot 10^{-3}} = 1{,}38\,k\Omega$$

$$r_{CE_3} = \frac{V_A}{g_{m3}} = \frac{100}{72{,}4 \cdot 10^{-3}} = 1{,}38\,k\Omega$$

$$r_{CE_6} = \frac{V_A}{g_{m6}} = \frac{100}{21{,}2 \cdot 10^{-3}} = 4{,}71\,k\Omega$$

$$r_{CE_7} = \frac{V_A}{g_{m7}} = \frac{100}{212 \cdot 10^{-3}} = 0{,}47\,k\Omega$$

$r_Z = 30\,\Omega$ (DATASHEET)

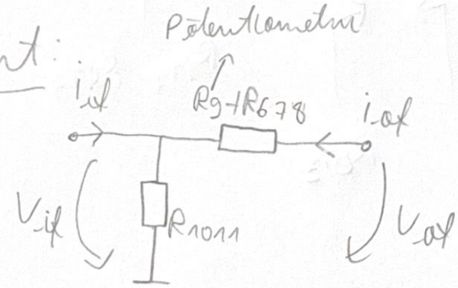
$$r_{be_2} = \frac{B_{F2}}{g_{m2}} = \frac{250}{72{,}4\cdot 10^{-3}} = 3{,}45\,k\Omega$$

$$r_{be_3} = \frac{B_{F3}}{g_{m3}} = \frac{250}{72{,}4\cdot 10^{-3}} = 3{,}45\,k\Omega$$

$$r_{be_6} = \frac{B_{F6}}{g_{m6}} = \frac{110}{21{,}2\cdot 10^{-3}} = 5{,}18\,k\Omega$$

$$r_{be_7} = \frac{B_{F7}}{g_{m7}} = \frac{25}{212\cdot 10^{-3}} = 117{,}92\,\Omega$$

Series-Shunt:



SET=0 (R_9=500)

$$k_V = \left.\frac{V_{if}}{V_{of}}\right|_{i_{if}=0} = \frac{R_{1011}}{R_{1011}+R_{678}+R_9} = \frac{5030}{21640} = 0{,}232$$

$$r_{if} = \left.\frac{V_{if}}{i_{if}}\right|_{V_{of}} = R_{1011}\,||\,(R_9+R_{678}) = 3{,}86\,k\Omega$$

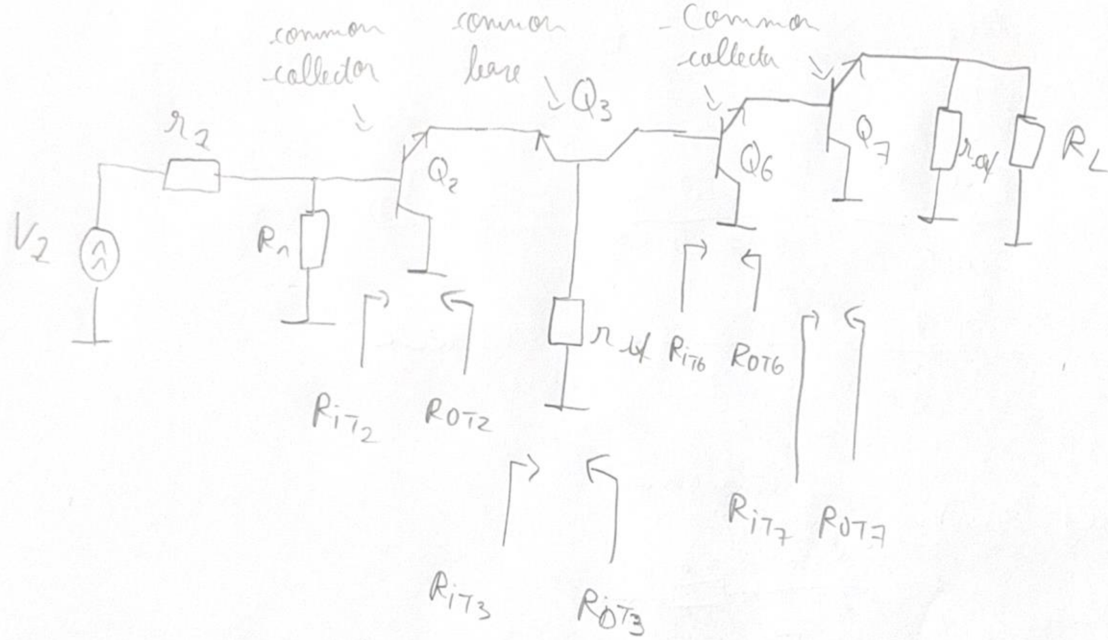
SET=1 ($P_1=0$)

$$k_V = \left.\frac{V_{if}}{V_{of}}\right|_{i_{if}=0} = \frac{R_{1011}}{R_{1011}+R_{678}+R_9} = \frac{5030}{21140} = 0{,}237$$

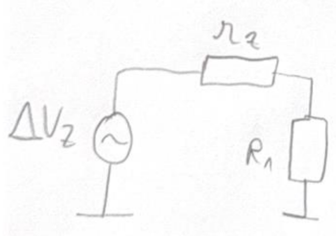
$$r_{if} = \left.\frac{V_{if}}{i_{if}}\right|_{V_{of}} = R_{1011}\,||\,(R_9+R_{678}) = 3{,}83\,k\Omega$$

$$r_{of} = \frac{v_{of}}{i_{of}}\Big|_{v_{sf}=0} = R_{1011} + R_{9} + R_{678} = 21{,}64\,k\Omega$$

$$r_{of} = \frac{v_{of}}{i_{of}}\Big|_{v_{sf}=0} = R_{1011} + R_{9} + R_{678} = 21{,}14\,k\Omega$$



Thevenin:



$$\Delta V_2' = \Delta V_2 \cdot \frac{R_1}{r_2 + R_1} = 5{,}1 \cdot \frac{3900}{30 + 3900} = 5{,}06\,V$$

$$r_2' = r_2 \,||\, R_1 = 29{,}77\,\Omega$$

$$R_{IT_2} = r_{be_2} + (1 + \beta_2)\, r_{CE_2} = 3{,}45 \cdot 10^3 + 251 \cdot 1{,}38 \cdot 10^3 = 349{,}83\,k\Omega$$

$$R_{OT_2} = \frac{r_{CE_2} + r_2'}{1 + \beta_2} \,||\, r_{CE_2} = \frac{3{,}45 \cdot 10^3 + 30}{1 + 251} \,||\, 3{,}45 \cdot 10^3 = 13{,}75\,\Omega$$

$$R_{iT_3} = (r_{be_3} + r_{ef}) \frac{1}{1+\beta_{F_3}} = (3{,}45 \cdot 10^3 + 3{,}86 \cdot 10^3) \frac{1}{1+250} = 29{,}12\,\Omega$$

$$R_{OT_3} = \infty$$

$$R_{iT_6} = r_{be6} + (1+\beta_{F6})\, r_{CE6} = 3{,}18 \cdot 10^3 + (1+110) \cdot 4{,}71 \cdot 10^3 = 527{,}99\,k\Omega$$

$$R_{OT_6} = \frac{r_{CE6}}{1+\beta_{F6}} \,||\, r_{CE6} = \frac{4{,}71 \cdot 10^3}{1+110} \,||\, 4{,}71 \cdot 10^3 = 42{,}05\,\Omega$$

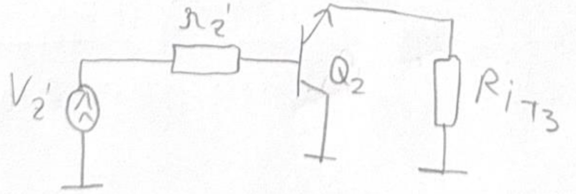
$$R_{iT_7} = r_{be7} + (1+\beta_{F7})(r_{CE7} \,||\, r_{of} \,||\, R_L) =$$

$$R_{OT_7} = \frac{r_{CE7}}{1+\beta_{F7}} \,||\, r_{CE7} = \frac{0{,}47 \cdot 10^3}{1+25} \,||\, 0{,}47 \cdot 10^3 = 17{,}44\,\Omega$$

$$\rightarrow 117{,}92 + (1+25)(0{,}47 \cdot 10^3 \,||\, 121{,}64 \cdot 10^3 \,||\, 420) =$$

$$= 117{,}92 + 26 \cdot 219{,}54 = 5{,}82\,k\Omega$$

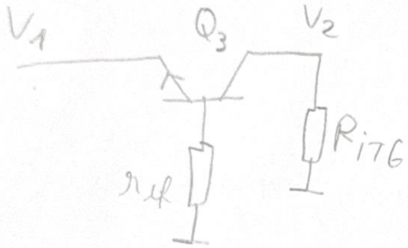
(1) Common Collector:



$$a_{v_1} = \frac{(1+\beta_{F_2})(R_{iT_3} \,||\, r_{CE_2})}{r_{be_2} + (1+\beta_{F_2})(R_{iT_3} \,||\, r_{CE_2})}$$

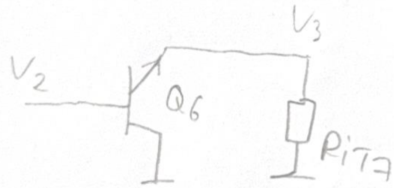
$$a_{v_1} = \frac{(1+250)\left(\frac{29{,}12 \cdot 1{,}38 \cdot 10^3}{29{,}12 + 1{,}38 \cdot 10^3}\right)}{3{,}45 \cdot 10^3 + (1+250)\left(\frac{29{,}12 \cdot 1{,}38 \cdot 10^3}{29{,}12 + 1{,}38 \cdot 10^3}\right)} = 0{,}674$$

2. Common base:



$$a_{V_2} = g_{m3} \cdot R_{i76} = 72{,}4 \cdot \cancel{10^{-3}} \cdot 527{,}99 \cdot \cancel{10^{3}} = 38226{,}47$$

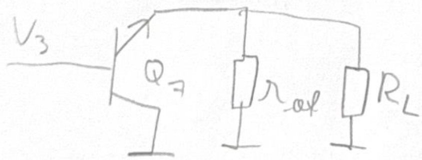
3. Common collector:



$$a_{V_3} = \frac{(1+\beta_{F6})(R_{i77} \| r_{CE6})}{r_{be6} + (1+\beta_{F6})(R_{i77} \| r_{CE6})} =$$

$$= \frac{(1+110)\left(\frac{5{,}82 \cdot 10^3 \cdot 4{,}71 \cdot 10^3}{5{,}82 \cdot 10^3 + 4{,}71 \cdot 10^3}\right)}{5{,}18 \cdot 10^3 + (1+110) \cdot \left(\frac{5{,}82 \cdot 10^3 \cdot 4{,}71 \cdot 10^3}{5{,}82 \cdot 10^3 + 4{,}71 \cdot 10^3}\right)} = 0{,}982$$

4. Common collector



$$a_{V_4} = \frac{(1+\beta_{F7})(r_{CE7} \| r_{of} \| R_L)}{r_{be7} + (1+\beta_{F7})(r_{CE7} \| r_{of} \| R_L)} =$$

$$= \frac{(1+25)(470 \| 21{,}64 \cdot 10^3 \| 420)}{117{,}92 + (1+25)(470 \| 21{,}64 \cdot 10^3 \| 420)} = \frac{26 \cdot 219{,}54}{117{,}92 + 26 \cdot 219{,}54} =$$

$$= 0{,}979$$

$$a_V = a_{V_1} \cdot a_{V_2} \cdot a_{V_3} \cdot a_{V_4} = 0{,}674 \cdot 38226{,}47 \cdot 0{,}982 \cdot 0{,}979 =$$

$$= 24769{,}55$$

$T = k_v \cdot a_v = 0,232 \cdot 24769,55 = 5746,53 \Rightarrow$

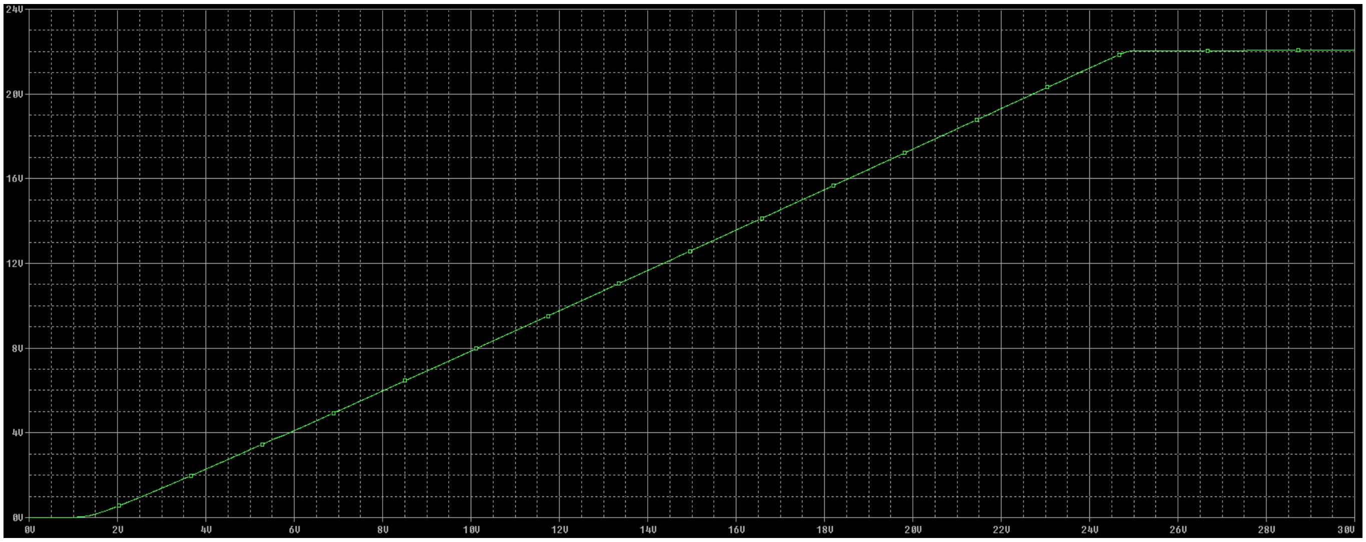
$$\Rightarrow A_v = \frac{a_v}{1+T} = \frac{24769,55}{5747,53} = 4,30$$

4. SPICE simulations of the designed circuit

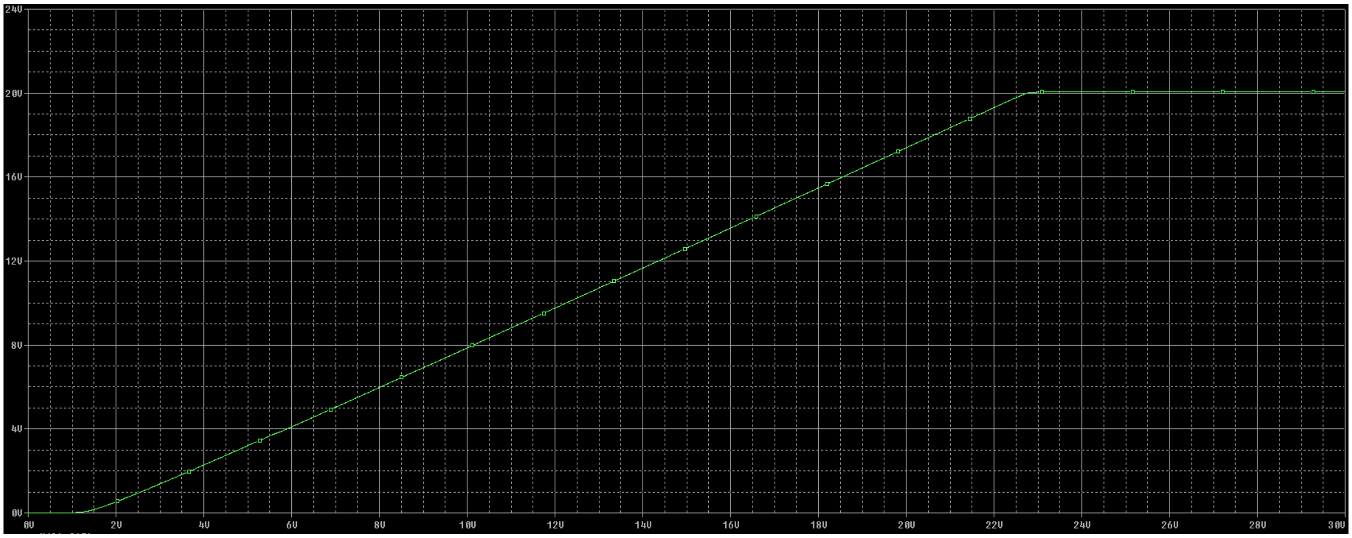
DC Sweep

To examine how the output voltage responds to variations in input voltage and potentiometer adjustments, I conducted simulations under different scenarios. When the potentiometer is set to its extreme positions (0 or 1), the results show that the output voltage stays constant at the defined minimum and maximum values.

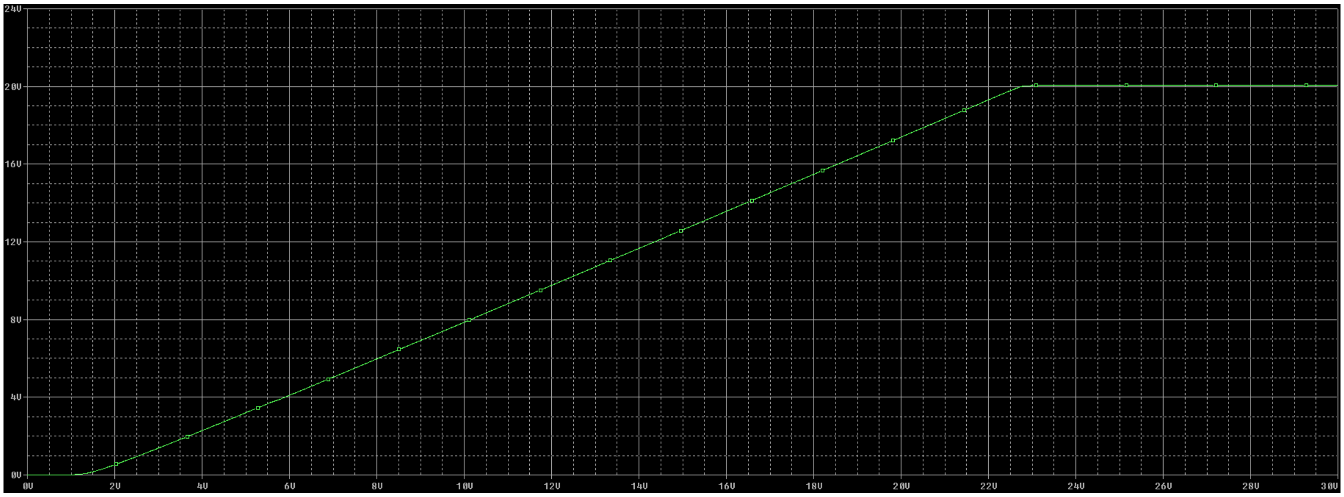
1.Vin = 25V, SET = 0 results Vout = 22V



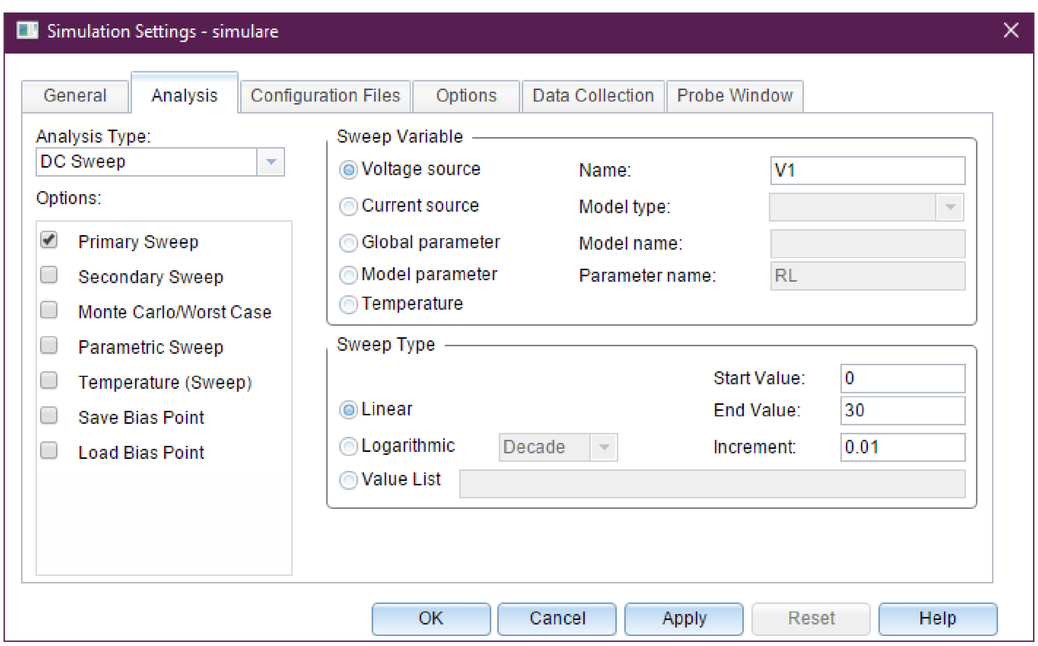
2.Vin = 25V, SET = 1 results Vout = 20V



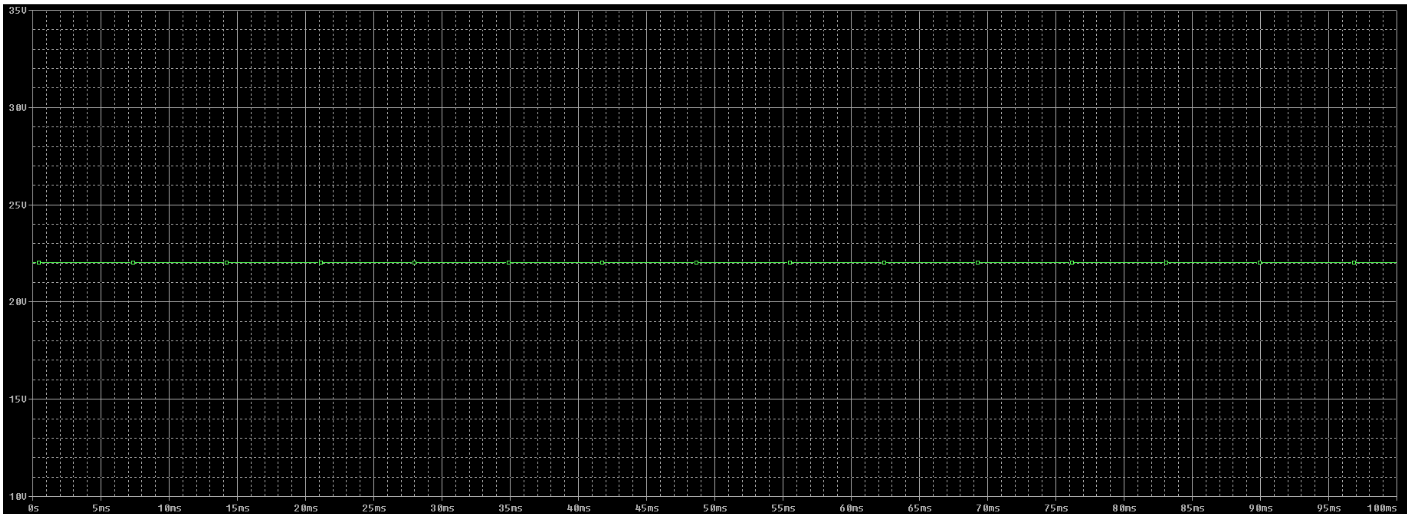
3.Vin = 28V, SET = 1 results Vout = 20V



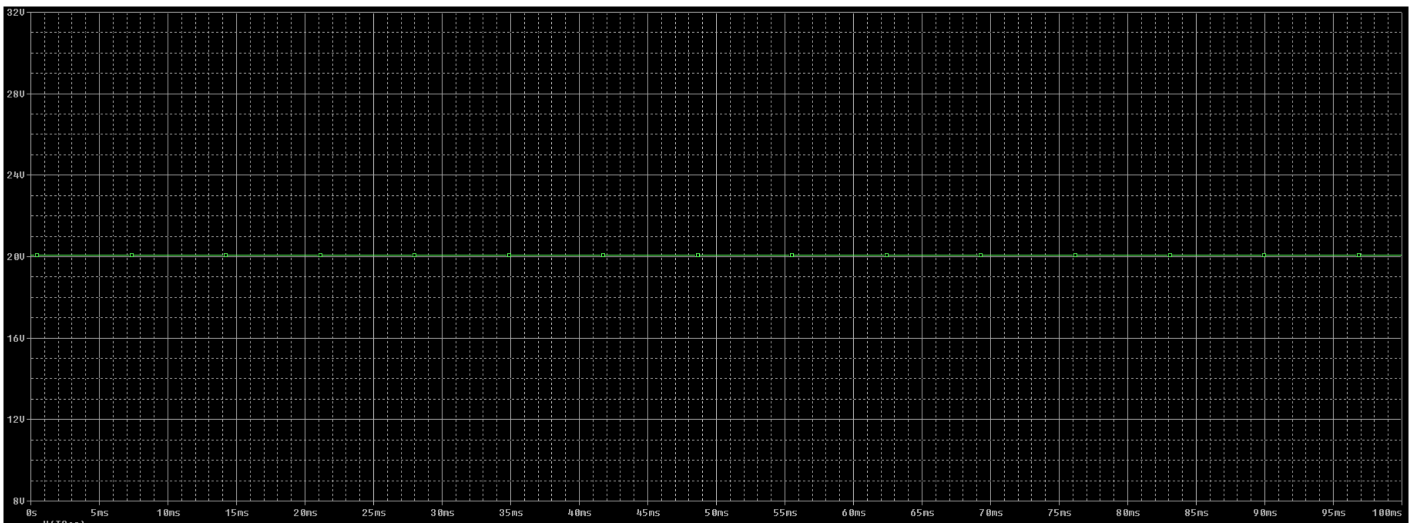
4.Vin = 28V, SET = 0 results Vout = 22V

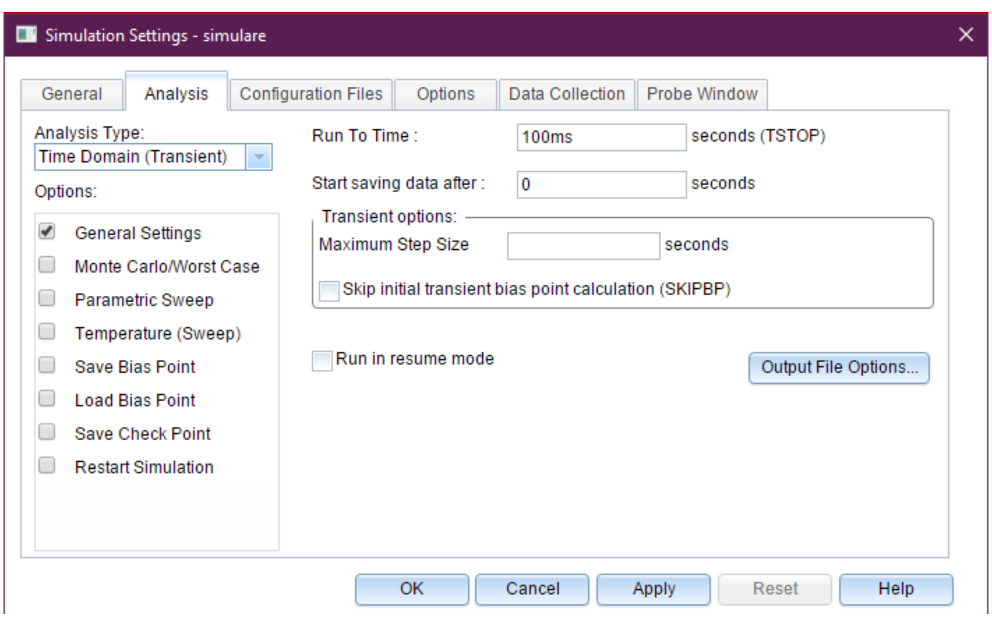


Output Voltage Level with the Potentiometer SET 0



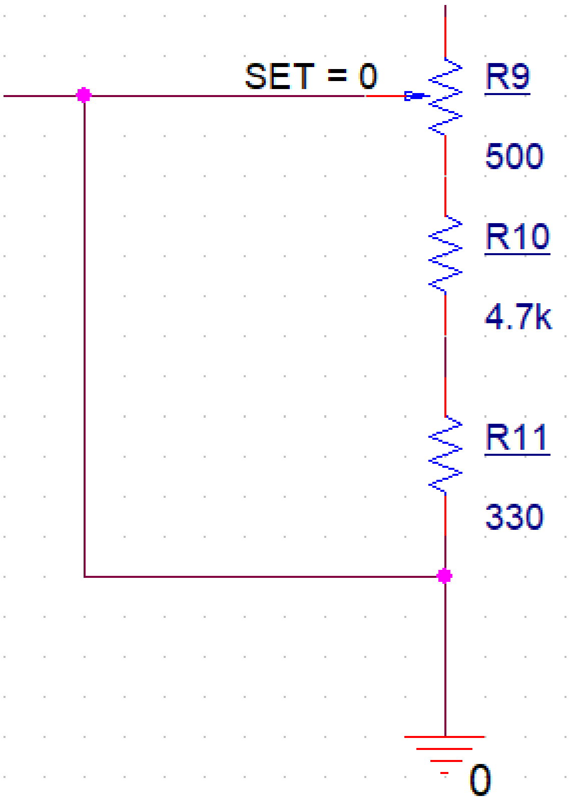
Output Voltage Level with the Potentiometer SET 1

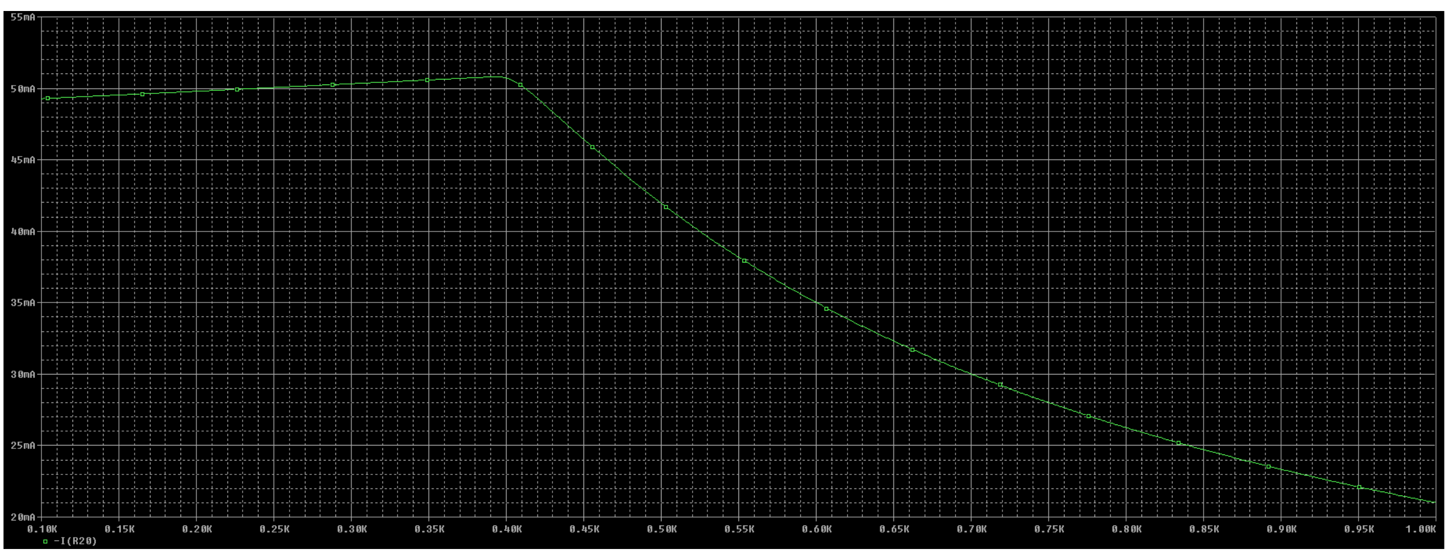




Overcurrent Protection Simulation

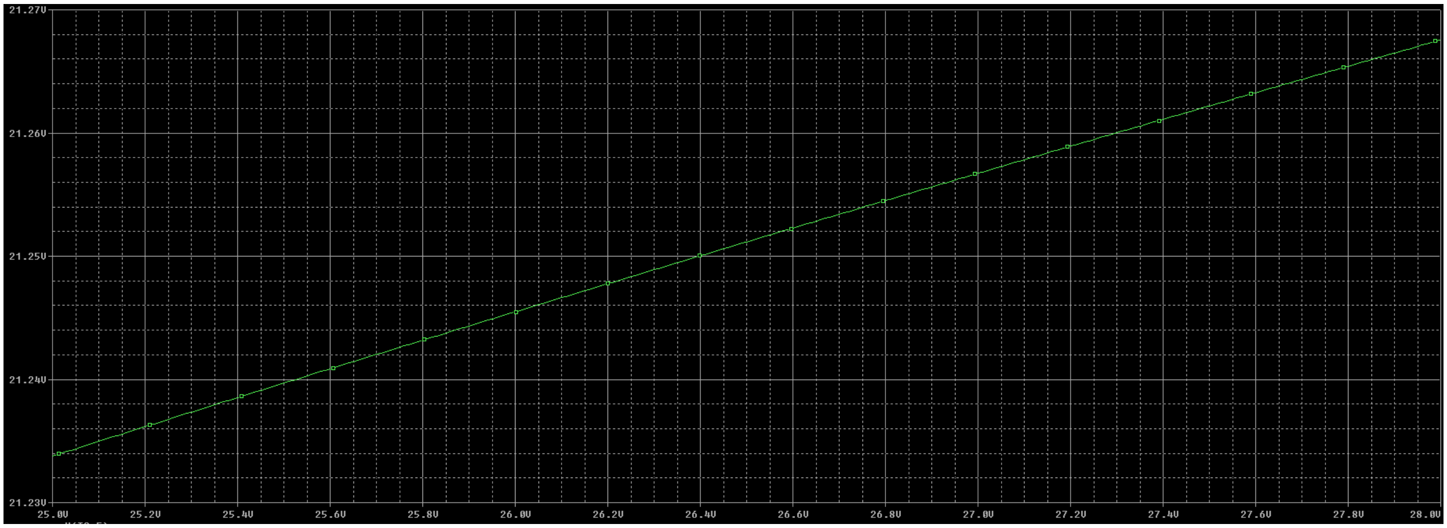
For testing short circuit we add a shunt:



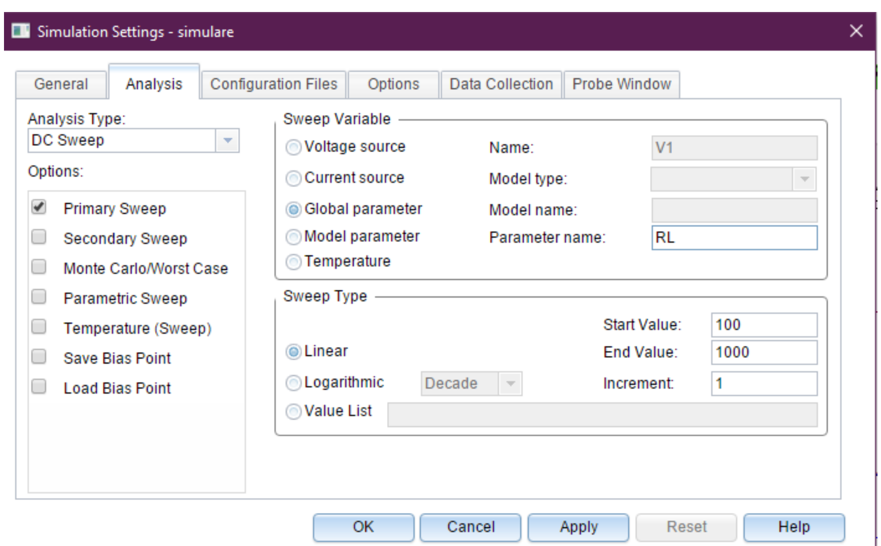


We see that it will never get past our designated value so it is an optiumum protection. We then take out the short circuit.

Overvoltage Protection Simulation

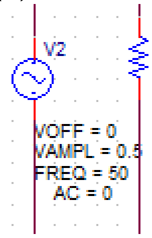


Simmulation of Load Resistance



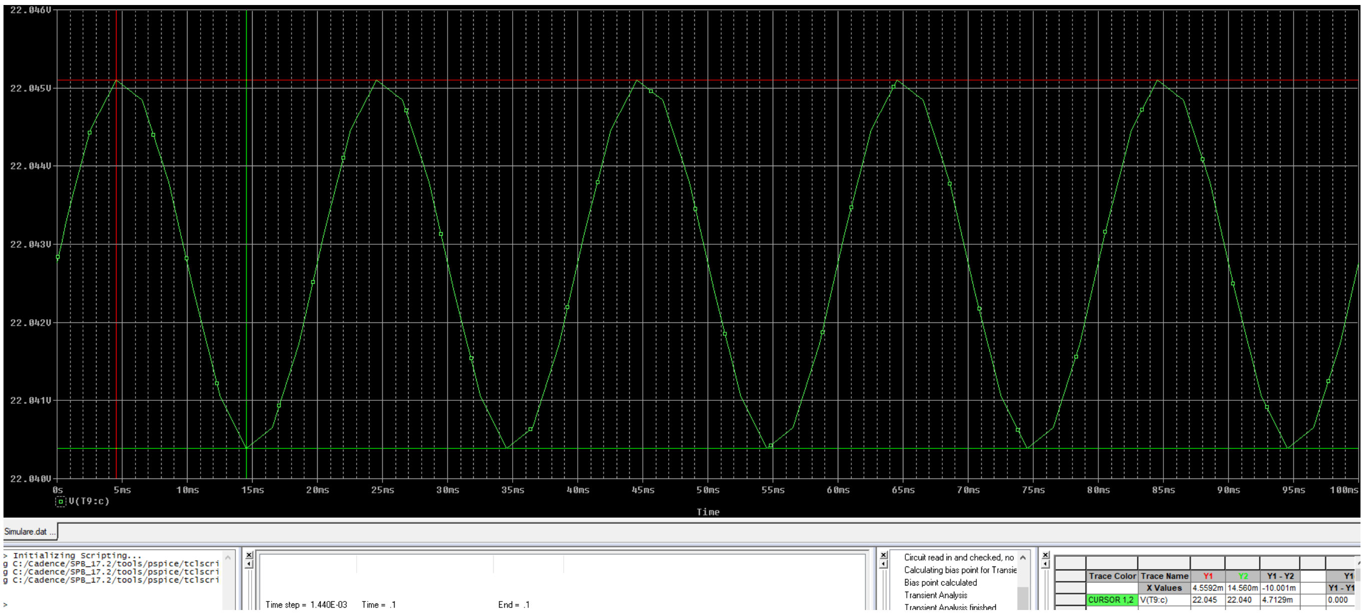
Stabilization factor(S)

To simulate the stabilization factor (S), I connected a sinusoidal voltage source (VOFF = 0, VAMPL = 0.5,

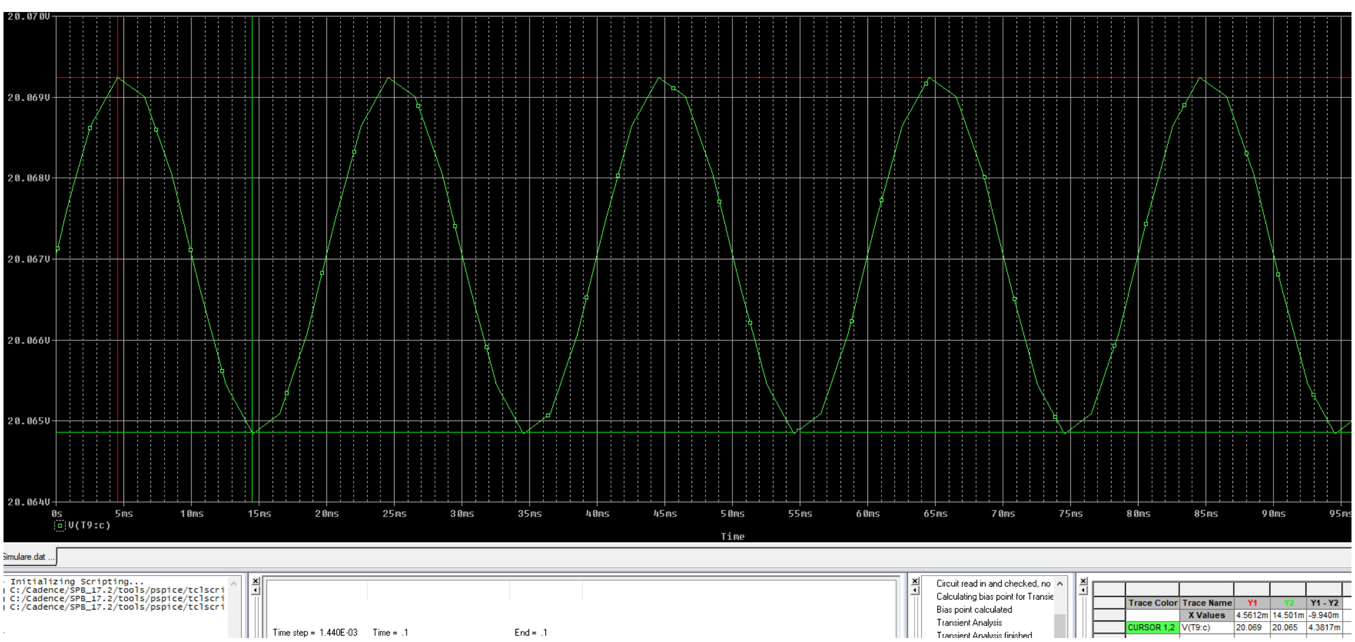


FREQ = 50, AC = 0) on top of V1:

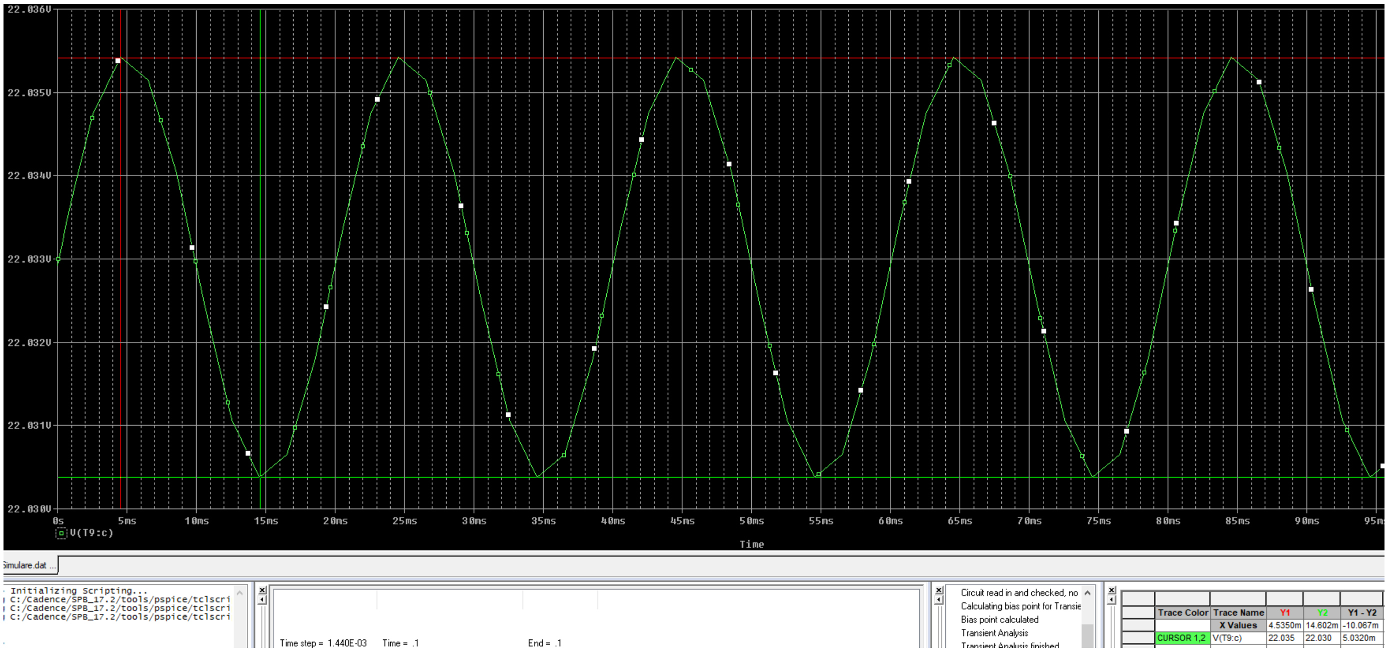
1) Vin = 28V, SET = 0 results S = 1/4.7129m = 212.18 > 68



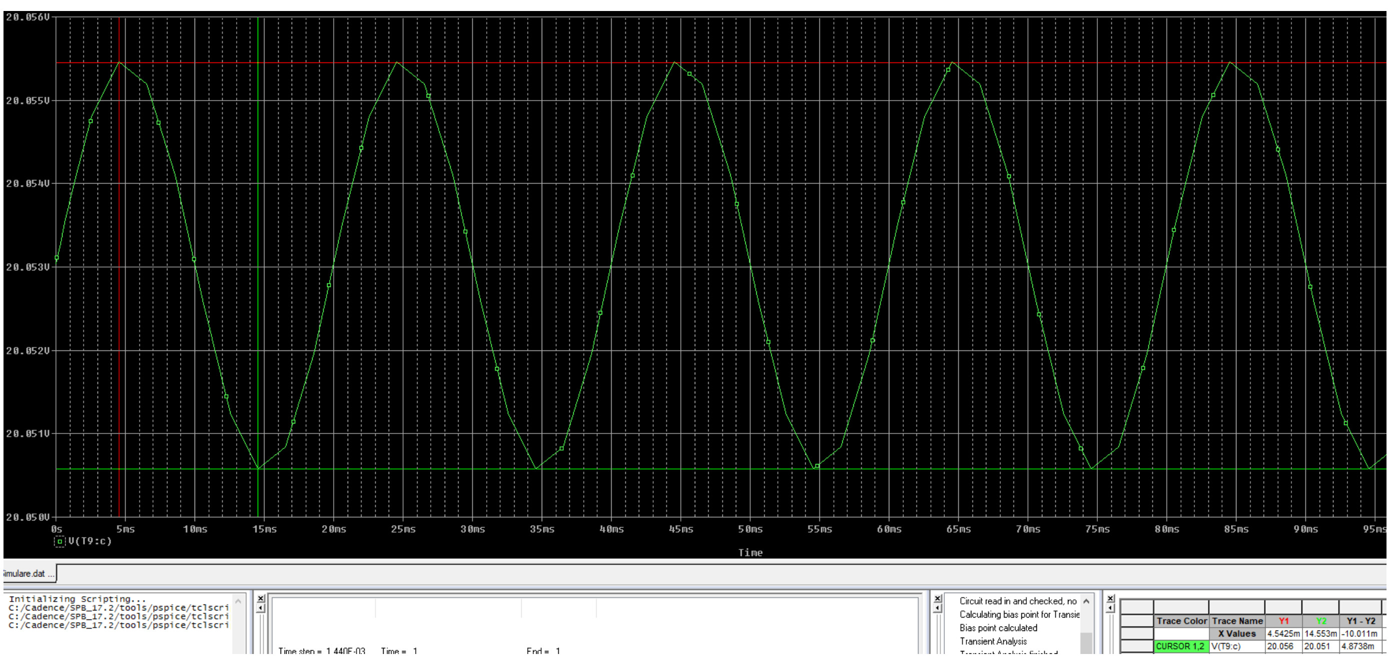
2) Vin = 28V, SET = 1 results S = 1/4.3817m = 228.22 > 68



3) Vin = 25V, SET = 0 results S = 1/5.0320m = 192.87 > 68



4) Vin = 25V, SET = 1 results S = 1/4.8738m = 205.17 > 68



5. Comments/Conclusions

Working on this project has been an incredible journey that has profoundly shaped my skills and perspective as an electronics engineer. Designing this circuit from scratch, tackling challenges like manual calculations, fine-tuning components, and simulating its behavior, has been both educational and rewarding. My role in ensuring robust protections against short circuits and overvoltage has underscored how critical these features are for creating safe, reliable systems—an insight I'll carry into future projects. This experience has also ignited a passion for practical design, inspiring me to explore innovative DIY solutions that could enhance everyday life. It's been a fulfilling process that has deepened my appreciation for how engineering transforms concepts into impactful real-world applications.

6. References/Bibliography

CF1/4W-3K9 [1] https://www.tme.eu/ro/details/cf1_4w-3k9/rezistente-tht/sr-passives/

CF1/4W-4K7 [2] https://www.tme.eu/ro/details/cf1_4w-4k7/rezistente-tht/sr-passives/

CE-10/16SP [3] https://www.tme.eu/ro/details/cck-10n/condensatoare-ceramice/sr-passives/

1N4148-TAP [4] https://www.tme.eu/ro/details/1n4148-tap/diode-universale-tht/vishay/

CF1/4W-820R [5] https://www.tme.eu/ro/details/cf1_4w-820r/rezistente-tht/sr-passives/

BC327-40 [6] https://www.tme.eu/ro/details/bc327-40-dio/tranzistori-tht-pnp/diotec-semiconductor/bc327-40/

BC337-40 [7] https://www.tme.eu/ro/details/bc337-40-dio/tranzistori-tht-npn/diotec-semiconductor/bc337-40/

CF1/4W-330R [8] https://www.tme.eu/ro/details/cf1_4w-330r/rezistente-carbon-tht-14w/sr-passives/

BD241C [9] https://www.tme.eu/ro/details/bd241c/tranzistori-tht-npn/stmicroelectronics/

CF1/4W-22R [10] https://www.tme.eu/ro/details/cf1_4w-22r/rezistente-tht/sr-passives/

CF1/4W-10K [11] https://www.tme.eu/ro/details/cf1_4w-10k/rezistente-tht/sr-passives/

CFR0W4J0100A50 [12] https://www.tme.eu/ro/details/1_4w10r/rezistente-tht/royalohm/cfr0w4j0100a50/

CF1/4W-4R7 [13] https://www.tme.eu/ro/details/cf1_4w-4r7/rezistente-tht/sr-passives/

ZPD5.1 [14] https://www.tme.eu/ro/details/zpd5.1-dio/diode-zener-tht/diotec-semiconductor/zpd5-1/

ZPD5.6 [15] https://www.tme.eu/ro/details/zpd5.6-dio/diode-zener-tht/diotec-semiconductor/zpd5-6/

ZPD8.2 [16] https://www.tme.eu/ro/details/zpd8.2-dio/diode-zener-tht/diotec-semiconductor/zpd82/

CF1/4W-5K6 [17] https://www.tme.eu/ro/details/cf1_4w-5k6/rezistente-tht/sr-passives/

CF1/4W-510R [18] https://www.tme.eu/ro/details/cf1_4w-510r/rezistente-tht/sr-passives/

PT15LV-500R [19] https://www.tme.eu/ro/details/pt15lv-500r/trimere-tht-cu-o-singura-tura/piher/pt15lv02501a2020s/

CF1/4W-100R [20] https://www.tme.eu/ro/details/cf1_4w-100r/rezistente-tht/sr-passives/

CF1/4W-220R [21] https://www.tme.eu/ro/details/cf1_4w-220r/rezistente-tht/sr-passives/

BC546BBK [22] https://www.tme.eu/ro/details/bc546bbk-dio/tranzistori-tht-npn/diotec-semiconductor/bc546bbk/

37 in parts in total without the source. - https://wiki.dcae.pub.ro/images/a/a0/Annex_1_THT_2024_2025.pdf

23. https://www.sciencedirect.com/topics/engineering/foldback-current-limiting

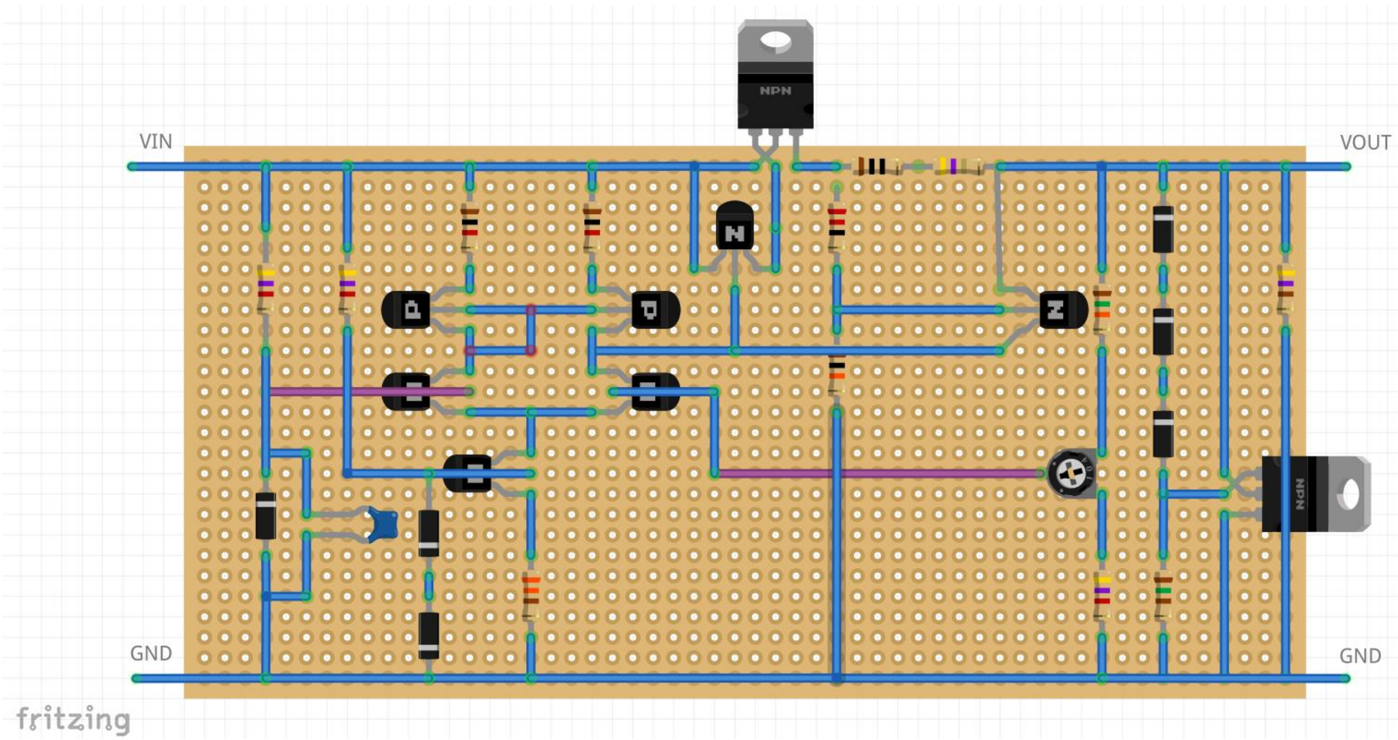
24. https://www.codrey.com/learn/foldback-current-limiting-little-secrets/

25. https://www.tme.eu/en/katalog/darlington-transistors_112834/

26. Analog Devices, "Basic Linear Design Seminar": https://www.analog.com/media/en/training-seminars/design-handbooks/BasicLinear-Design/Chapter9.pdf

27. Laurențiu Teodorescu, "Linear Voltage Regulator – functional description": https://wiki.dcae.pub.ro/images/7/79/Linear_regulator.pdf

7. Mounting map



8. Bill of Materials (BOM)

Nr. Crt.	Nume	Catalog	Cod distrib	Nume prod	Prod	Clasă	Qty min	Descriere	Distribuitor
1/4	4.7	(LINK)	CF1/4W-4R7	CF1/4W-4R7	SR PASSIVES	rezistor	1	Rezistor: de carbon; THT; 4,7Ω; 0,25W; ±5%; Ø2,3x6mm; Term: axial	TME România
2/5	10	(LINK)	1/4W10R	CFR0W4J0100A50	ROYAL OHM	rezistor	3	Rezistor: de carbon; THT; 10Ω; 0,25W; ±5%; Ø2,5x6,8mm; Term: axial	TME România
3/6	22	(LINK)	CF1/4W-22R	CF1/4W-22R	SR PASSIVES	rezistor	1	Rezistor: de carbon; THT; 22Ω; 0,25W; ±5%; Ø2,3x6mm; Term: axial	TME România
4/11	100	(LINK)	CF1/4W-100R	CF1/4W-100R	SR PASSIVES	rezistor	3	Rezistor: de carbon; THT; 100Ω; 0,25W; ±5%; Ø2,3x6mm; Term: axial	TME România
5/16	510	(LINK)	CF1/4W-510R	CF1/4W-510R	SR PASSIVES	rezistor	1	Rezistor: de carbon; THT; 510Ω; 0,25W; ±5%; Ø2,3x6mm; Term: axia	TME România
6/18	820	(LINK)	CF1/4W-820R	CF1/4W-820R	SR PASSIVES	rezistor	2	Rezistor: de carbon; THT; 820Ω; 0,25W; ±5%; Ø2,3x6mm; Term: axia	TME România
7/27	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
8/33	10k	(LINK)	CF1/4W-10K	CF1/4W-10K	SR PASSIVES	rezistor	2	Rezistor: de carbon; THT; 10kΩ; 0,25W; ±5%; Ø2,3x6mm; Term: axial	TME România
9/50	500ohm	(LINK)	CA6V-500	CA6V 500	ACP	potențiometru	1	Potenţiometru: de montare; singură tură,orizontal; 500Ω; 100mW	TME România
10/80	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
11/81	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
12/84	8.2V	(LINK)	ZPD8.2-DIO	ZPD8.2	DIOTEC SEMICONDUCTOR	diodă Zener	2	Diodă: Zener; 0,5W; 8,2V; Ambalaj: Ammo Pack; DO35	TME România
13/87	NPN	(LINK)	BC546BBK-DIO	BC546BBK	DIOTEC SEMICONDUCTOR	tranzistor bipolar	1	Tranzistor: NPN; bipolar; 65V; 100mA; 500mW; TO92	TME România
14/91	NPN	(LINK)	BC337-40-DIO	BC337-40	DIOTEC SEMICONDUCTOR	tranzistor bipolar	4	Tranzistor: NPN; bipolar; 45V; 800mA; 625mW; TO92	TME România
15/93	PNP	(LINK)	BC327-40-DIO	BC327-40	DIOTEC SEMICONDUCTOR	tranzistor bipolar	2	Tranzistor: PNP; bipolar; 45V; 800mA; 625mW; TO92	TME România