University POLITEHNICA of Bucharest

Faculty of Electronics, Telecommunications and Information Technology

Project 1:

Positive Voltage Regulator

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Group: 432F

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2024-2025

I.Introduction

1. Project requirements

A positive linear voltage regulator needs to be designed using discrete components, with the following specifications:

N=23

- **Supply voltage between 30÷33 [V];**
- **Programmable output voltage 25÷27[V];**
- **The output current through the load between 0÷42 [mA];**
- **Short circuit protection of the output terminals with foldback current limiting circuit.**
- **Overvoltage protection of the output terminals.**
- $S = \left.\frac{\Delta V_i}{\Delta V_o}\right|_{RL} \geq$ **57**
- **The output impedance of the regulator RO** $\leq$**3.3** Ω

2. General information

Voltage stabilizers are electronic circuits that deliver a constant (stabilized) DC voltage at the output (across the load resistance), even when there are changes in input voltage, load current, or temperature within certain limits. They are a key component within the power supply, positioned between the rectifier and the circuit's load. Voltage stabilizers can be classified into two primary categories:

- **Linear stabilizers;**
- **Switching stabilizers.**

APPLICATIONS OF VOLTAGE STABILIZER

- **In communication systems, they are essential for ensuring accurate signal transmission.**
- **They protect equipment from surges or sudden voltage fluctuations caused by events such as lightning or power supply interruptions.**
- **Avionics systems demand a stable and high-quality power supply to guarantee the safe and proper operation of aircraft.**
- **They provide consistent and accurate voltages to various components within computers, including the motherboard, processor, video card, and storage devices.**

3. REGULATORY ELEMENT

It refers to the electronic components used to keep voltage constant, such as:

- **Bipolar transistors**
- **Zener Diode**
- **Integrated circuits**

II.The Block Diagram

- **Operating principle**:

The block diagram of the electronic stabilizer is illustrated in the figure below.

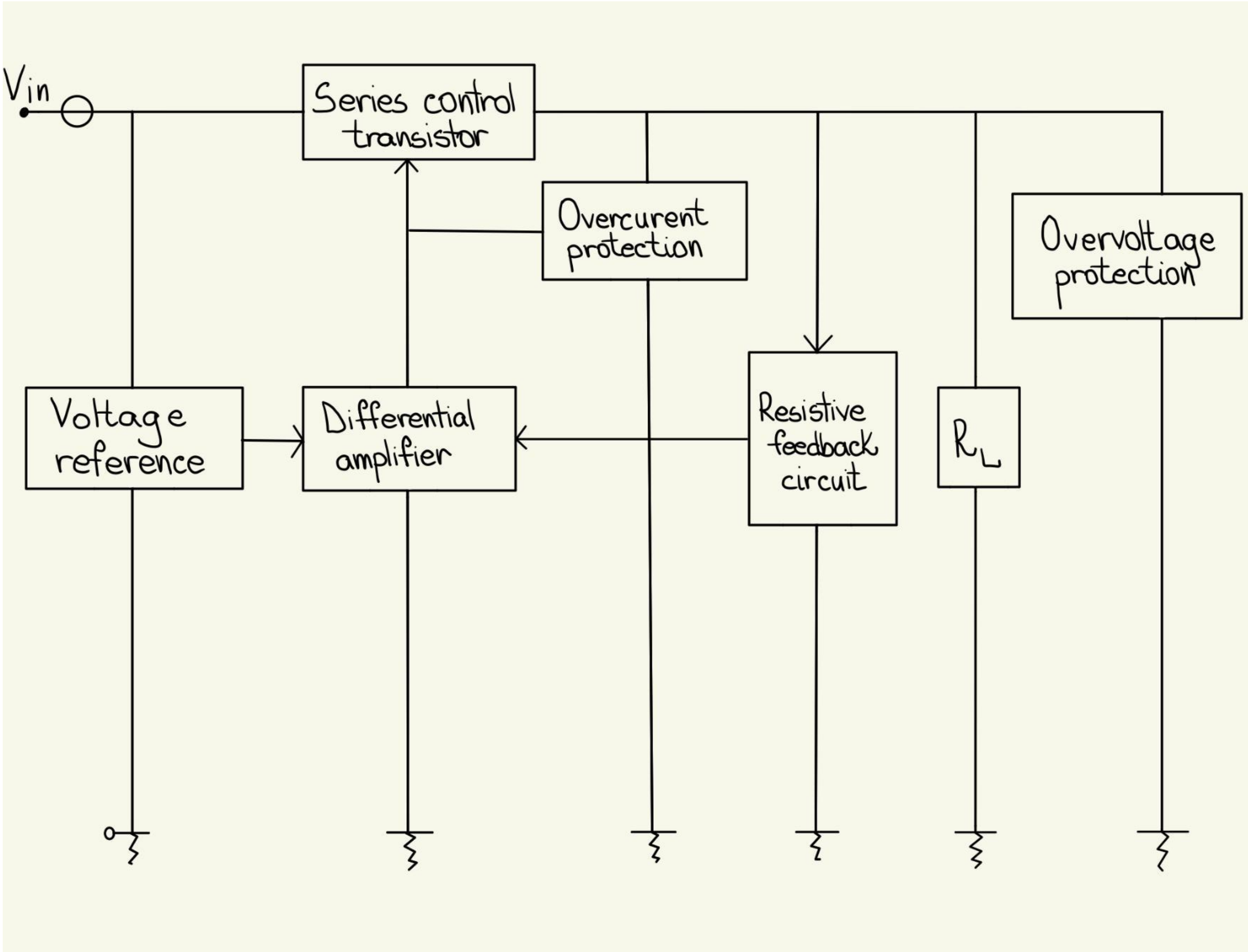


Fig 2.1

III.The detailed schematic diagram AND identification of each subblock

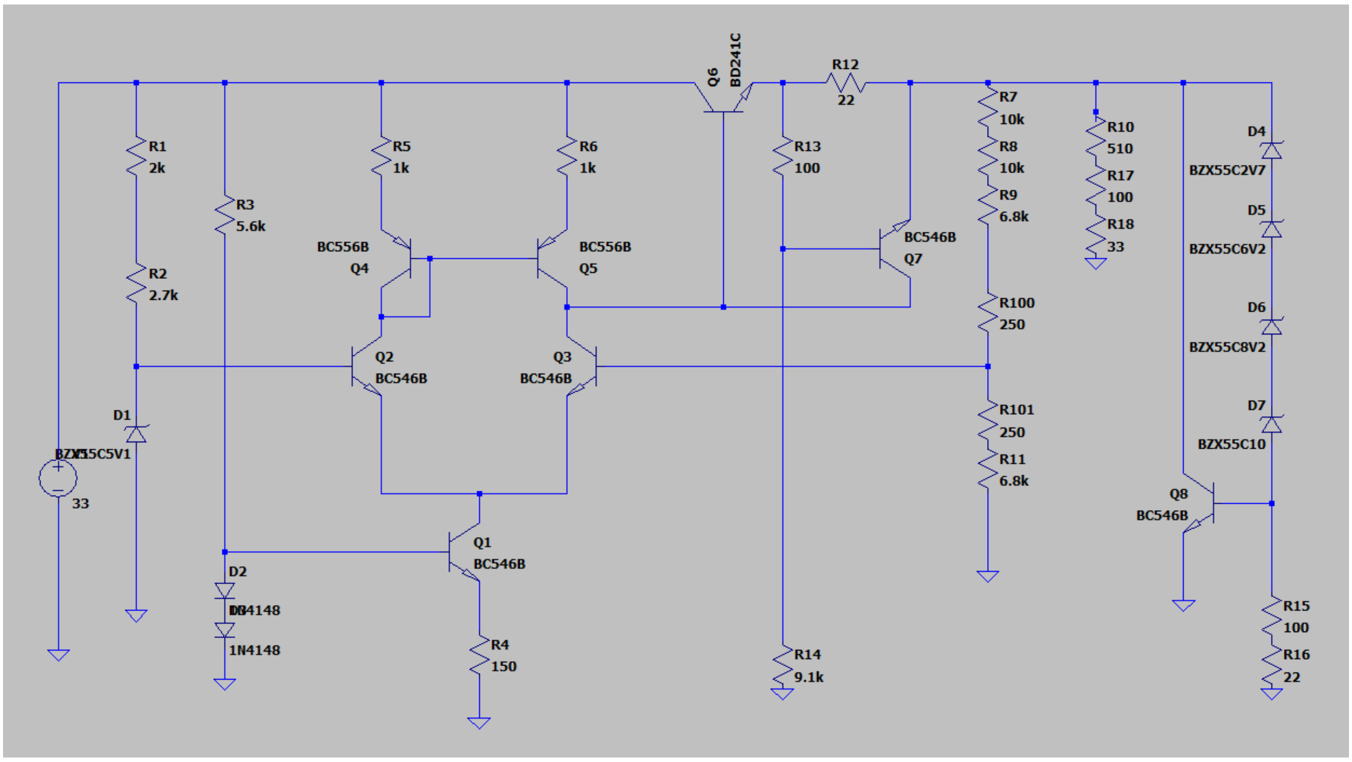


Fig 3.1

Reference Voltage:

D1: Zener diode (BZX55C5V1) — establishes a stable reference voltage.R1(2K), R2 (2.7K): Resistors used to set the current through the Zener diode.Functionality: The Zener diode operates in its reverse breakdown region to produce a stable reference voltage. The resistor R1 and R2 in series limits the current through the Zener, ensuring the Zener diode operates within its safe limits and further stabilizes the current and prevents excess fluctuations. This reference voltage is the baseline for all other blocks, ensuring consistent operation regardless of input voltage changes . Vin=33V,VZ=5.1V

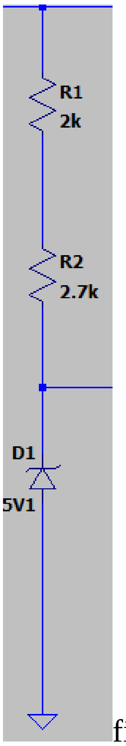
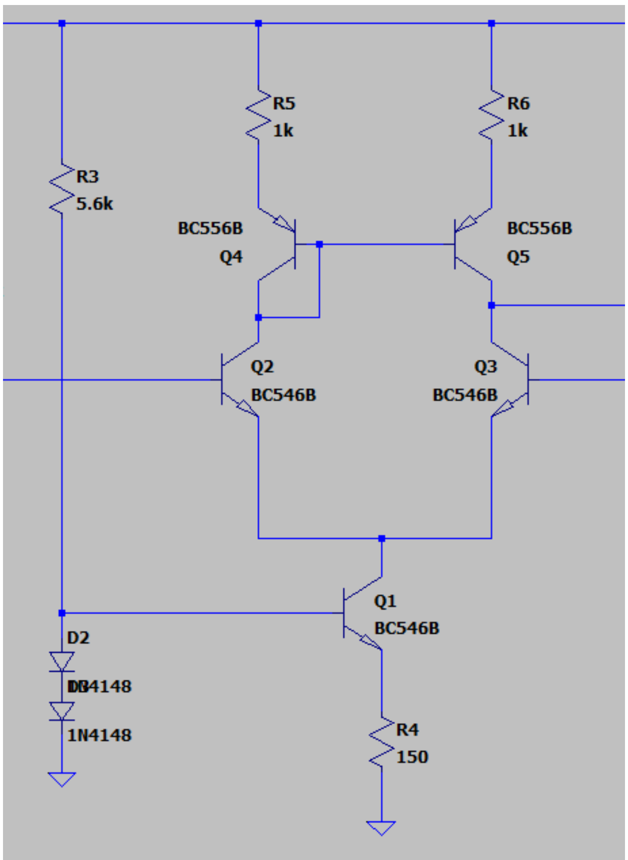


fig 3.2

Differential amplifier

Transistors Q2 and Q3(BC546B) form the differential pair that amplifies the difference between the two input signals. The current mirror, composed of transistors Q4 and Q5(BC556B), ensures balanced collector currents in the differential pair. Resistors R5 and R6(1K) set the operating point and provide biasing for the differential pair. The current source is formed by transistor Q1, resistor R4, and the two diodes, 1N4148, which help set a stable reference voltage for proper operation of the circuit. (fig3.3)



Series control transistor

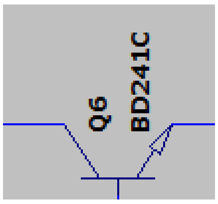


fig 3.4

Through this Transistor passes the Load Current.

Feedback Circuit:

The feedback circuit monitors the output voltage and relays it back to the differential amplifier block. This feedback loop is essential for continuous regulation, enabling the amplifier to assess the difference between the output and the desired level. The feedback loop provides stability and a quick response to changes in load or input voltage.

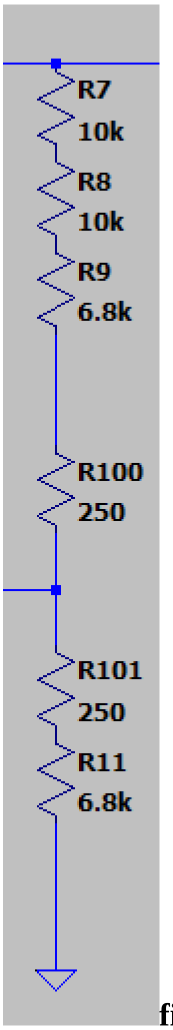
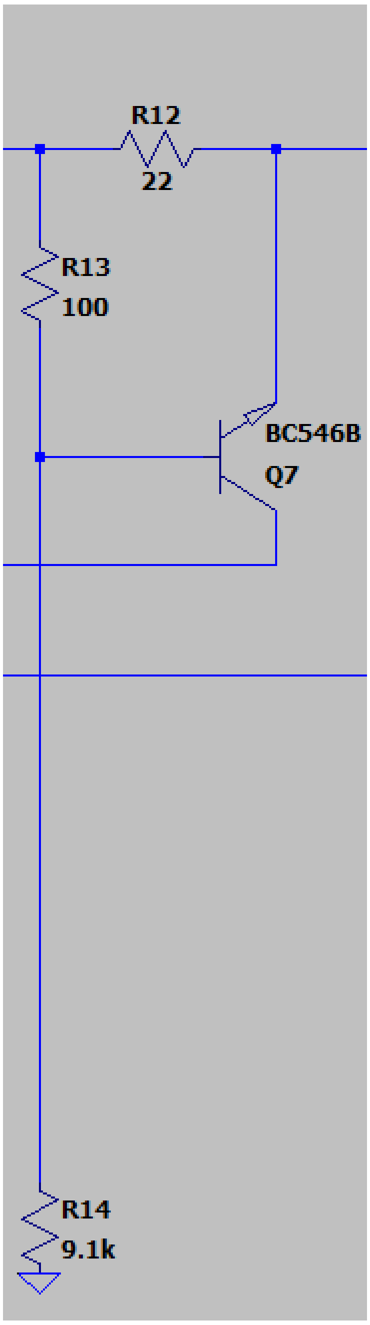
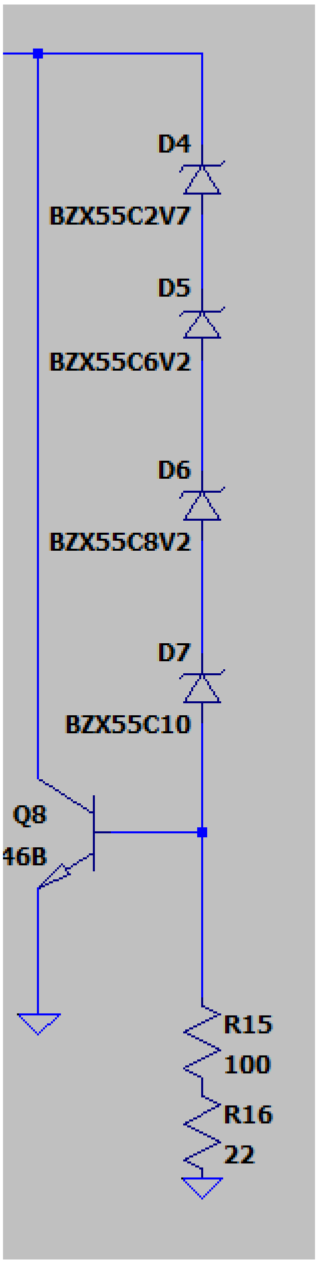


fig 3.5

Circuit Protection:



OCP(fig 3.6)



OVP (fig 3.7)

Resistor R12 sense the overcurrent and drive the NPN transistor Q7(BC546B) into conduction, effectively limiting the output current by turning off the series pass element. This ensures that the output voltage is restricted, preventing the current from exceeding a safe operating limit.

Diodes D4, D5, D6, and D7 monitor the output voltage. When the output voltage exceeds the maximum allowed value, the Zener diodes begin conducting current into the base of transistor Q8. This causes Q8 to enter conduction, creating a current path through resistors R15 and R16, which effectively clamps the output voltage and prevents it from rising further.

IV.CALCULATIONS FOR EACH COMPONENT

- Component calculation -

Voltage reference

$x1 = 23 \Rightarrow V_{ref} \in [3;5]$

The only zener diode that fits the scheme is BZX55C5V1 = 5,1V

The resistance on this branch has the formula:

$$R_1 = \frac{V_{in\,min} - V_Z}{5 \cdot 10^{-3}} = \frac{30 - 5,1}{5 \cdot 10^{-3}} = \frac{24,9 \cdot 10^3}{5} = 4,98\,k\Omega$$

minimum 5mA for the diode to be running. ($I_{Z\,min}$)

the closest resistance in the annex is $R_S = 4,7\,k\Omega$

I use two resistors of 2k, 2,7k;

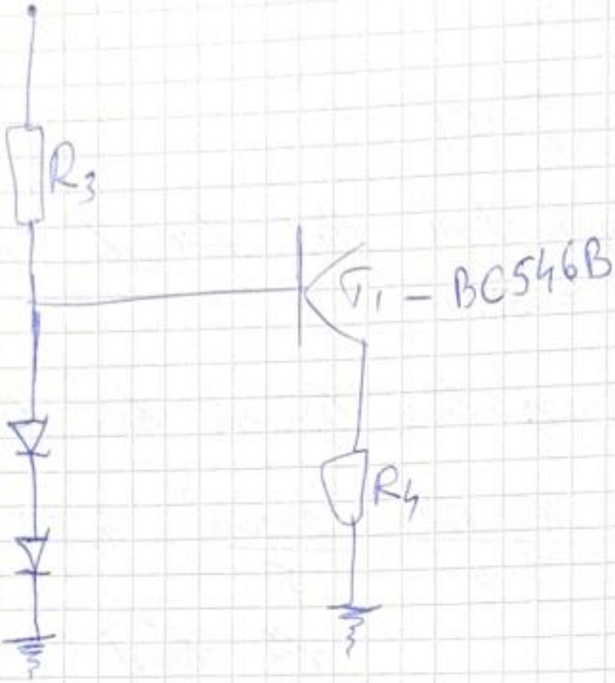
For a smoother transition, I will use two resistors, $R_1 = 3\,k\Omega$ and $R_2 = 1,70\,k\Omega$ $(R_1 + R_2 = R_S)$.

Now, we calculate

$$\begin{cases} I_{Z\,max} = \dfrac{V_{in\,max} - V_Z}{R_S} = \dfrac{33 - 5,1}{4700} = 5,69\,mA > 5mA \\[2ex] I_{Z\,min} = \dfrac{V_{in\,min} - V_Z}{R_S} = \dfrac{30 - 5,1}{4700} = 5,08 > 5mA \end{cases}$$

$$P_{max} = I_{Z\,max}^2 \cdot R_S = 5,69^2 \cdot 4,9 \cdot 10^{-3} = 158,6\,mW < 0,3\,W$$

Current source



Diodes D_2 and D_3 are 1N4148 from the ~~appendix~~ annex

R_4 should be equal to:

$$R_4 = \frac{2V_D - V_{BE_1}}{I_E} = \frac{0{,}6}{4\,mA} = 150\,\Omega$$ same as in the annex

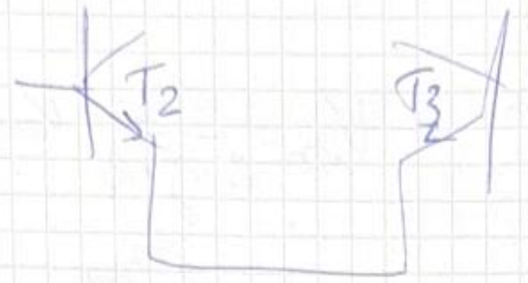
Because of T_2 and T_3, that both should have 2mA current => $I_E = 4\,mA$

$$R_3 = \frac{V_{IN\,min} - 2V_D}{I_d} = \frac{30 - 1{,}2}{5 \cdot 10^{-3}} = 5{,}76\,K\Omega$$

$R_3 = 5{,}6\,K\Omega$ (as in the annex)

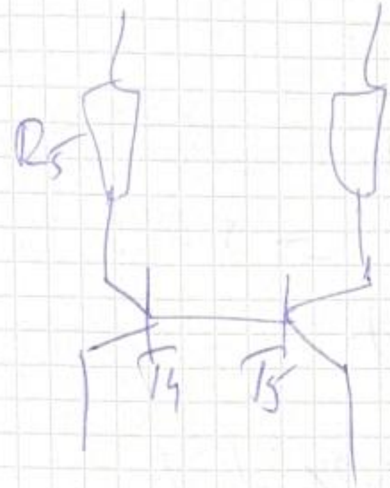
T_1 = ~~[illegible]~~

Differential amplifier



Both BC546B

Current mirror



– both BC556-B

min value for each resistor > 0,7V.

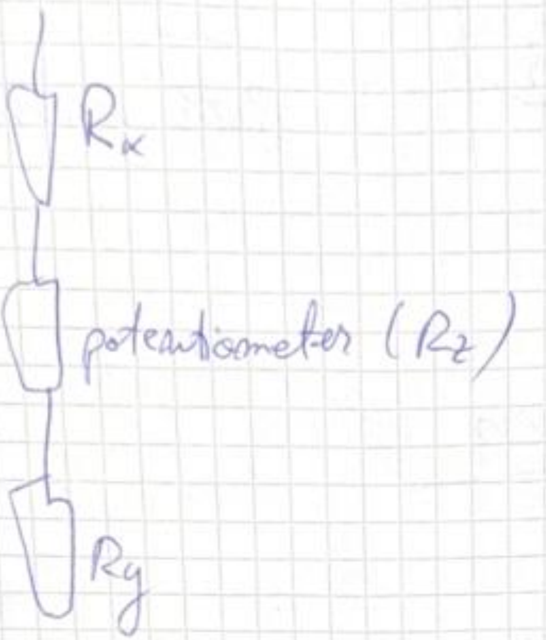
Let's say it is 1V

$R_{5,6} = \frac{1}{1} = 1k\Omega$

$R_5 = R_6 = 1k\Omega$ (annex)

Negative feedback

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



$$V_{REF} = \frac{R_y}{R_x + R_y + R_z} \cdot V_{out\,max}$$

$$V_{REF} = \frac{R_y + R_z}{R_x + R_y + R_z} \cdot V_{out\,min}$$

$$R_x + R_z = R_y \left(\frac{V_{omax}}{V_{REF}} - 1 \right) \Rightarrow$$

$$R_x = (R_y + R_z)\left(\frac{V_{out\,min}}{V_{REF}} - 1 \right)$$

$$\Rightarrow R_x + 0{,}5 = R_y \left(\frac{27}{5{,}1} - 1 \right)$$

$$R_x = (R_y + 0{,}5)\left(\frac{25}{5{,}1} - 1 \right) \quad \ominus \Rightarrow$$

$$\Rightarrow \cancel{R_x} \; 0{,}5 = 4{,}29 R_y - 3{,}9 R_y + 1{,}95$$

$$0{,}39 R_y = 2{,}45$$

$$R_y = 6{,}28\,k\Omega \simeq 6{,}8k$$

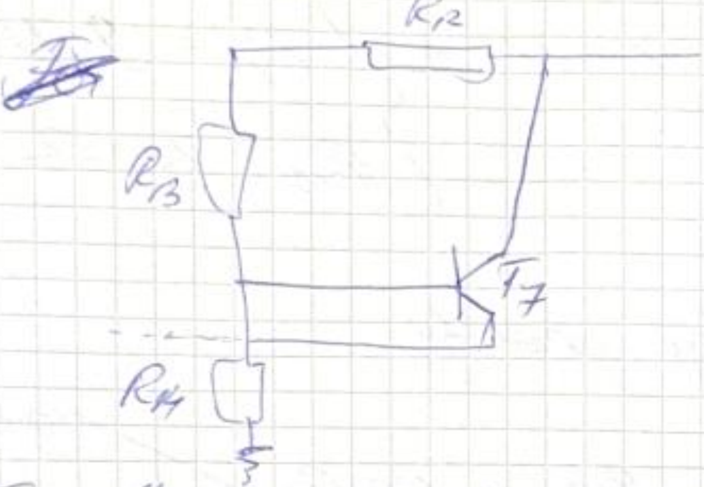
$$R_x = 6{,}78 \cdot 3{,}9 = 26{,}44\,k\Omega \simeq \cancel{\ldots}\; 10k, 10k, 6{,}8k$$

$$R_z = 0{,}5\,k\Omega = 510k$$

Series control transistor - max dissipation = 50W

I want to use a BD241C.

Overcurrent protection



For the transistor to conduct, we need voltage drop > 0,7V

$$V_R = R \cdot I_{max} \Rightarrow R = \frac{V_R}{I_{max}} = \frac{0,9}{42} = 21,43\ \Omega$$

We approximate to $R_{12} = 22k\Omega$ as in the annex

Now we should find the relationship between R_{13} and R_{14}, the next 2 resistances that have to be placed.

$$R_{12} = \frac{(V_{BE} + V_{out}) \cdot \frac{R_{13}+R_{14}}{R_{14}} - V_{out}}{I_{max}} \cong$$

$$21,43 = \frac{25,6 \cdot \frac{R_{13}+R_{14}}{R_{14}} - 25}{42 \cdot 10^{-3}} \Rightarrow$$

$$\frac{R_{13}+R_{14}}{R_{14}} \cdot 25,6 - 25 = 0,9$$

$$\Rightarrow \frac{R_{13}+R_{14}}{R_{14}} \cdot 25,6 = 25,9$$

$$\frac{R_{13}+R_{14}}{R_{14}} = 1,011 \Rightarrow \begin{cases} R_{14} = 9,1k \\ R_{13} = 100\,\Omega \end{cases}$$

Overvoltage protection.

$$R_L = \frac{V_{BE}}{I_Z} = \frac{0,6}{5\cdot 10^{-3}} = 120\,\Omega \; \begin{cases} 100\,\Omega \\ 22\,\Omega \end{cases} \text{from series}$$

Output voltage is maximum $27V \Rightarrow$

$$\Rightarrow D_4 + D_5 + D_6 + D_7 = 27V \quad \cancel{27V} \quad \begin{cases} D_4 = 2,7 \\ D_5 = 6,2 \\ D_6 = 8,2 \\ D_7 = 10 \end{cases}$$

I chose cause it's the closest combination.

Load resistance

I. $R_L = \frac{U_{out\,max}}{I_{max}} = \frac{27V}{42} = 642\,\Omega$.

We use $510 + 100 + 33\,\Omega$. from the annex.

$\cancel{510 + 100 + 33 =}$

II. $R_L = \frac{U_{out\,min}}{I_{max}} = \frac{25}{42} = 595\,\Omega$.

V. SPICE SIMULATIONS

a) ***FOR :*** DC SWEEP - POT 50%

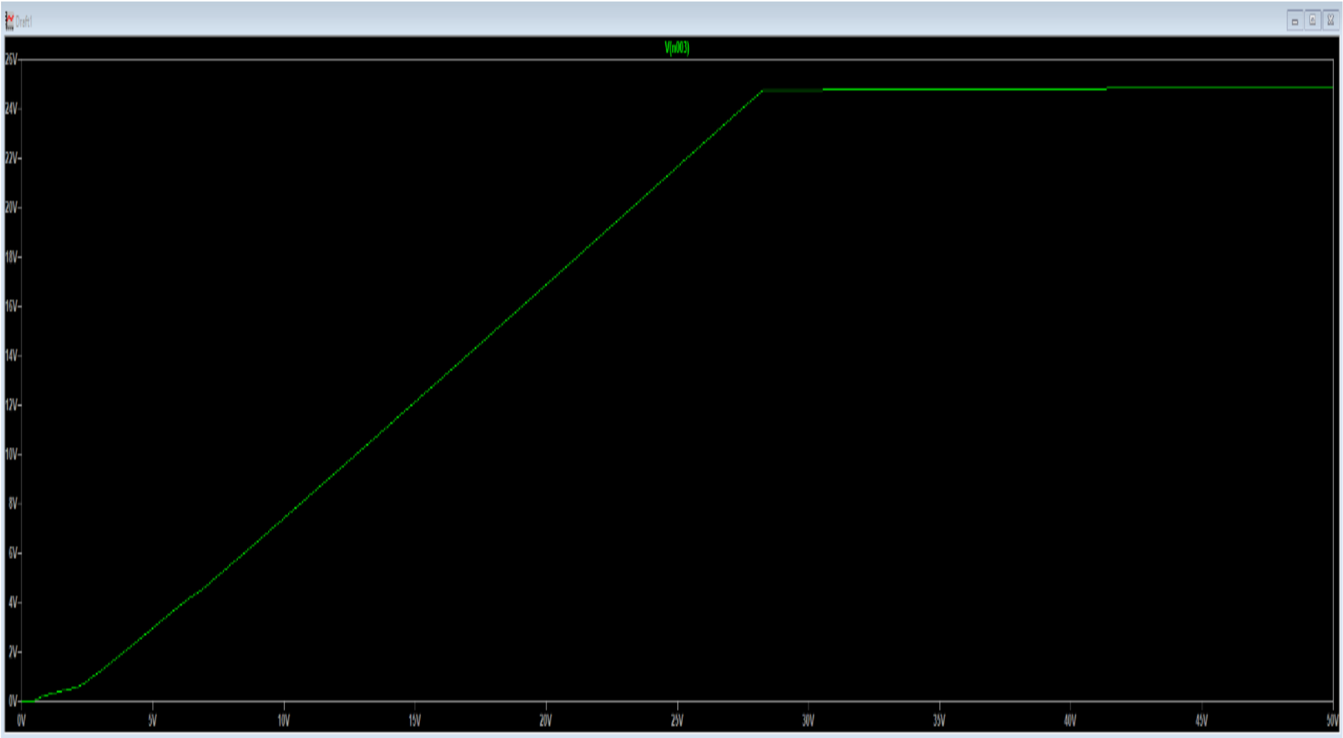


Fig 5.1

b) FOR: DC SWEEP SET 0 – POT HIGH

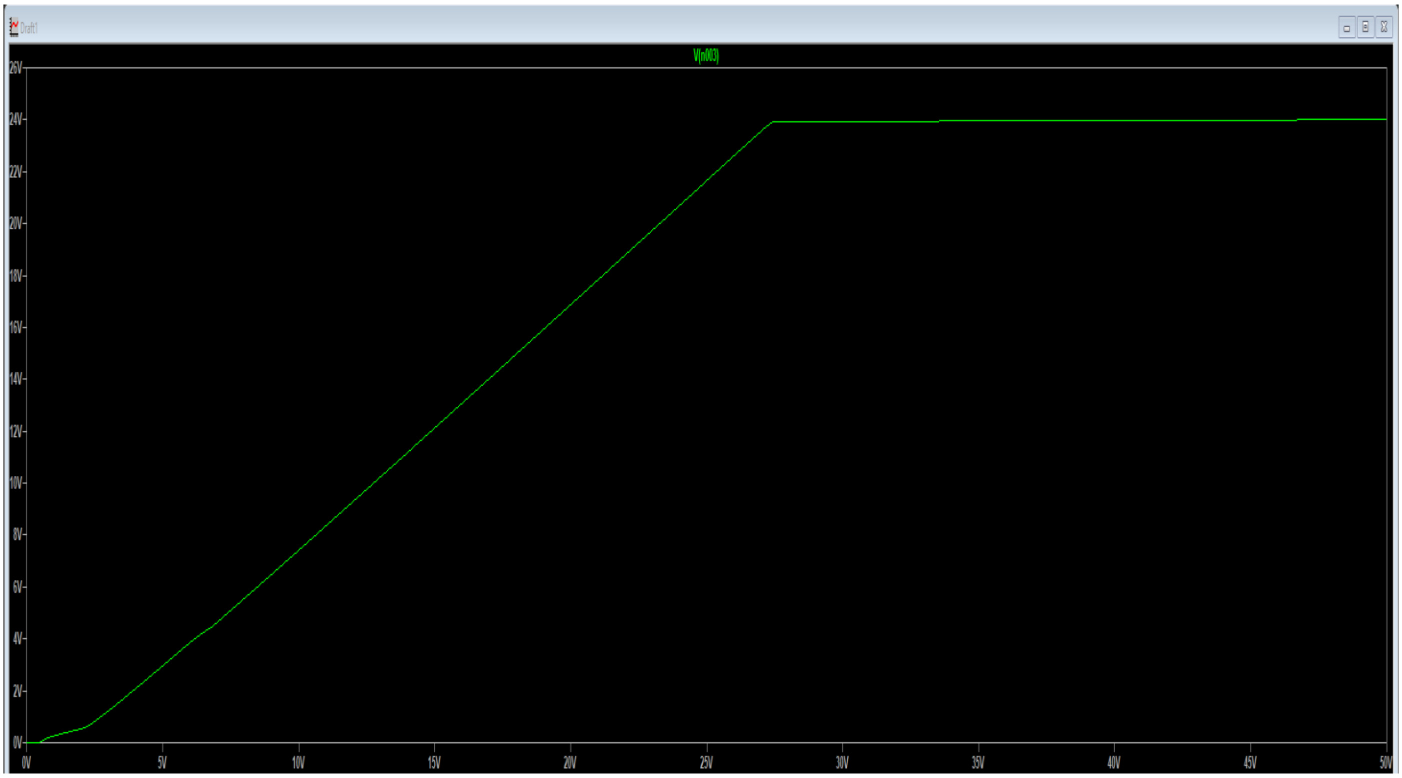


Fig 5.2

c) FOR : DC SWEEP SET 1 – POT LOW

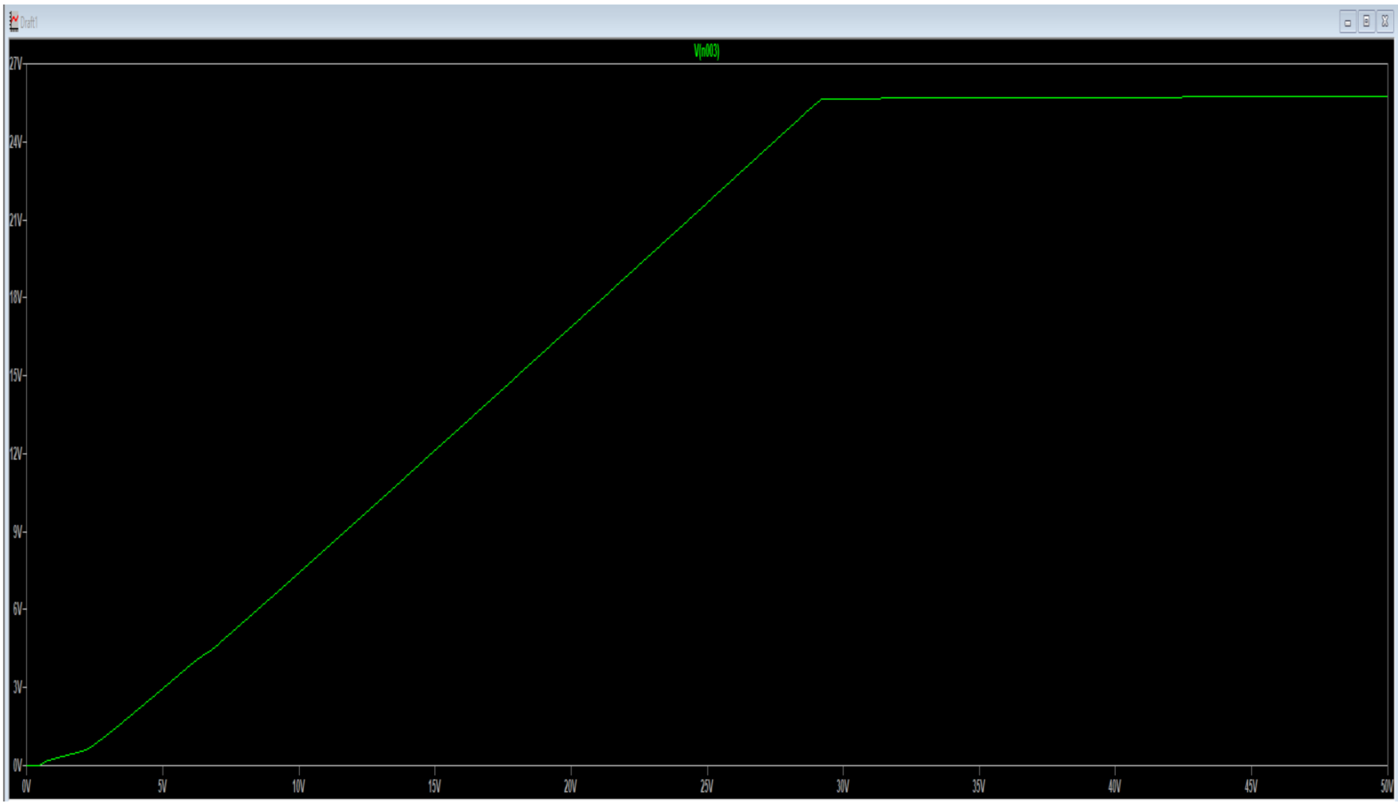


Fig 5.3

Overcurrent Protection

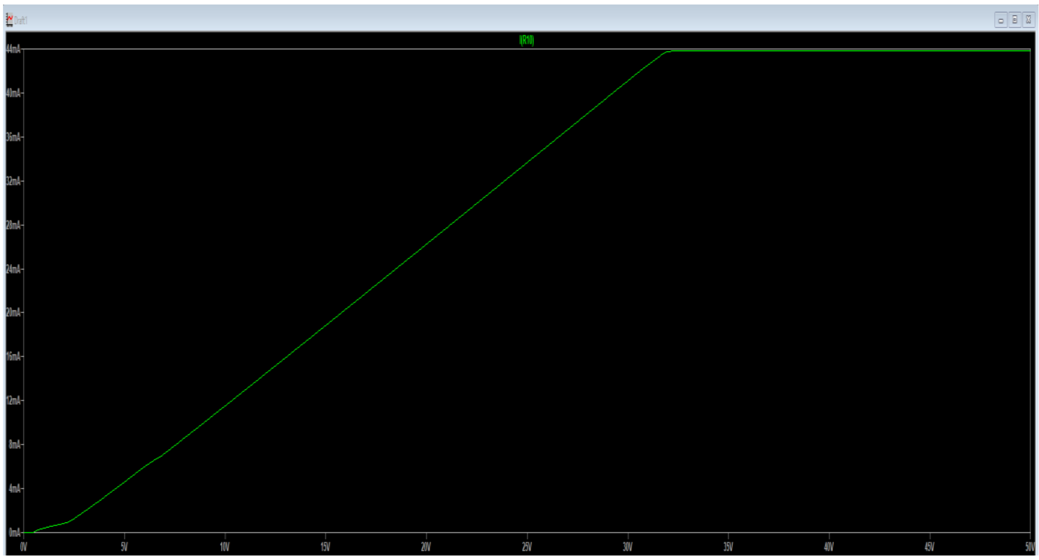


Fig 5.4

The circuit successfully enforces a current limit below 42 mA, which is a safety feature to protect components from overcurrent conditions.

Overvoltage protection

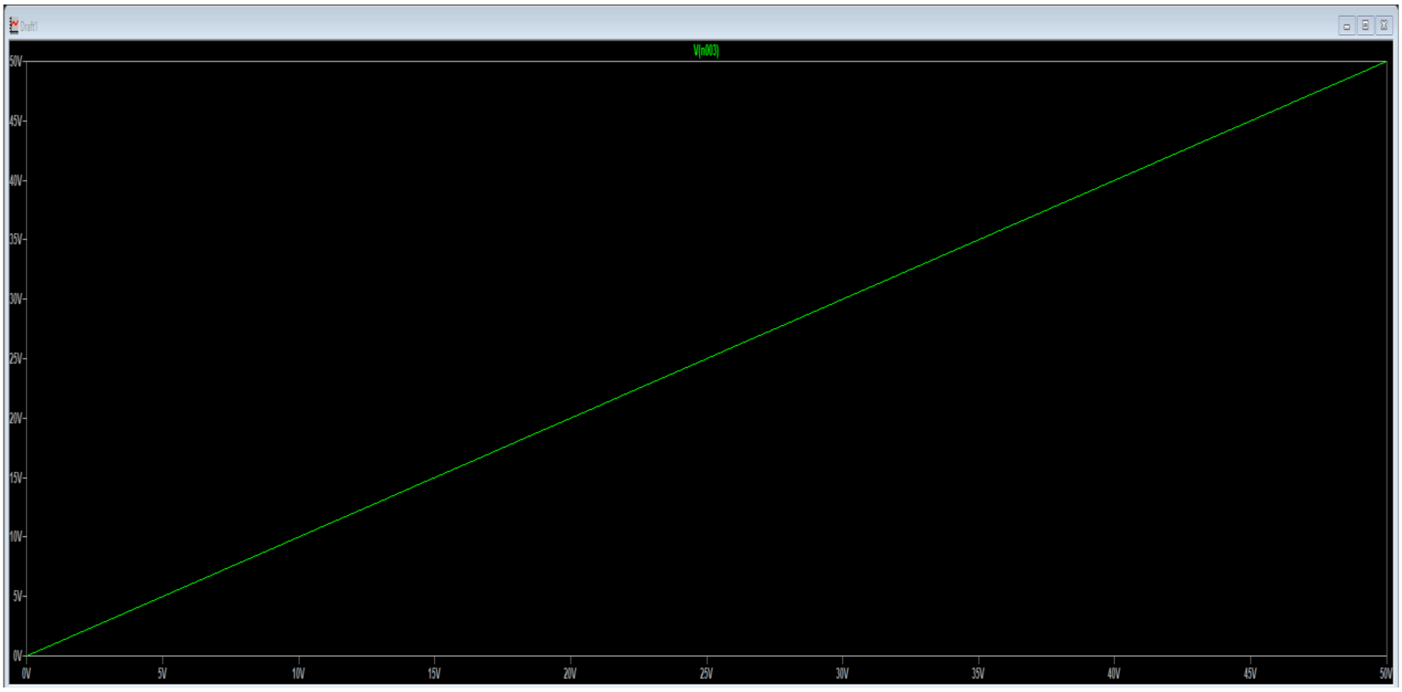


Fig 5.5

With the feedback divider shorted, the voltage regulation would fail, leading to a potential rise in output voltage.

If the overvoltage protection is working as intended, it should prevent the voltage from exceeding a certain threshold by activating a clamping or shutdown mechanism.

The current plot indirectly indicates that the circuit maintains control, as the current limit remains within bounds, meaning the overvoltage circuit has likely prevented catastrophic failure.

Stability Factors

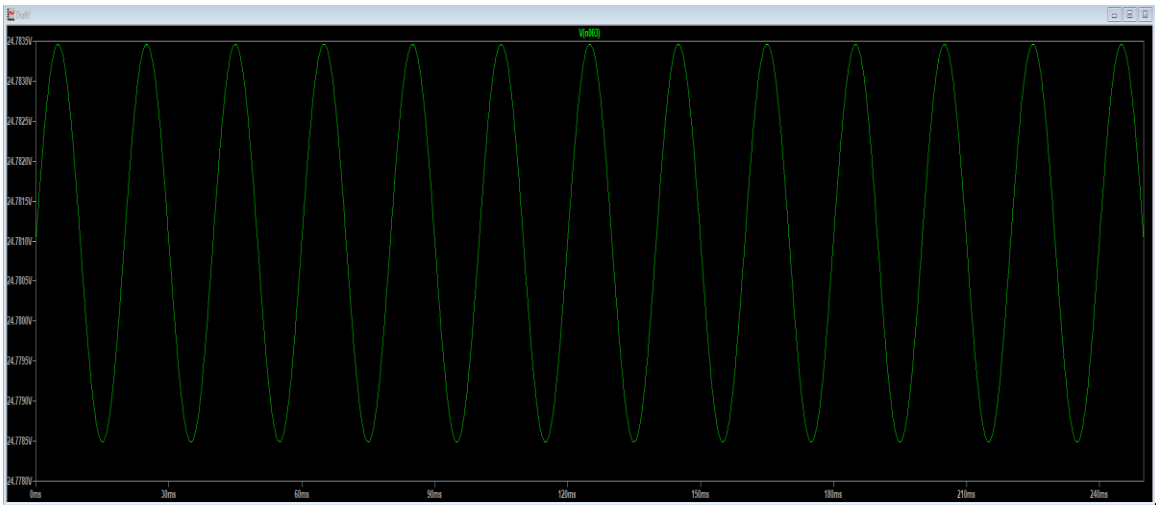


Fig 5.6

S=222.22, pot low, Vin = 33V

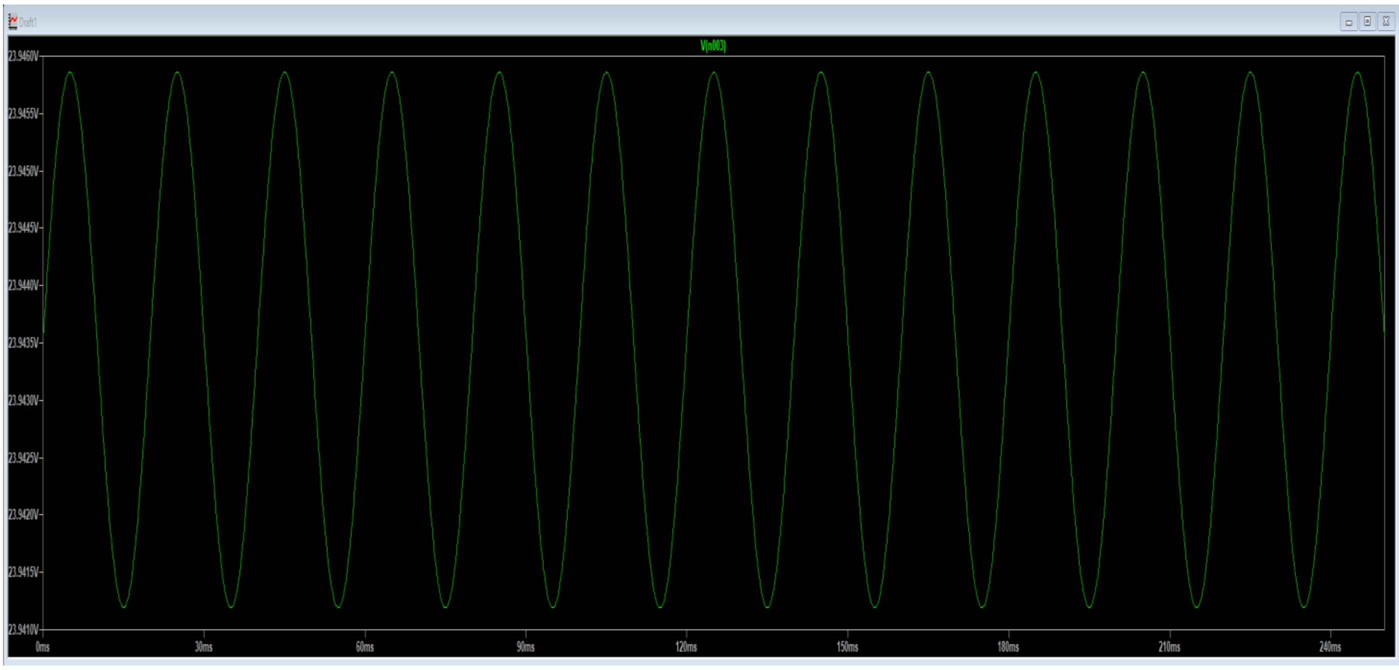


Fig 5.7

S=183.8,pot low, Vin = 30V

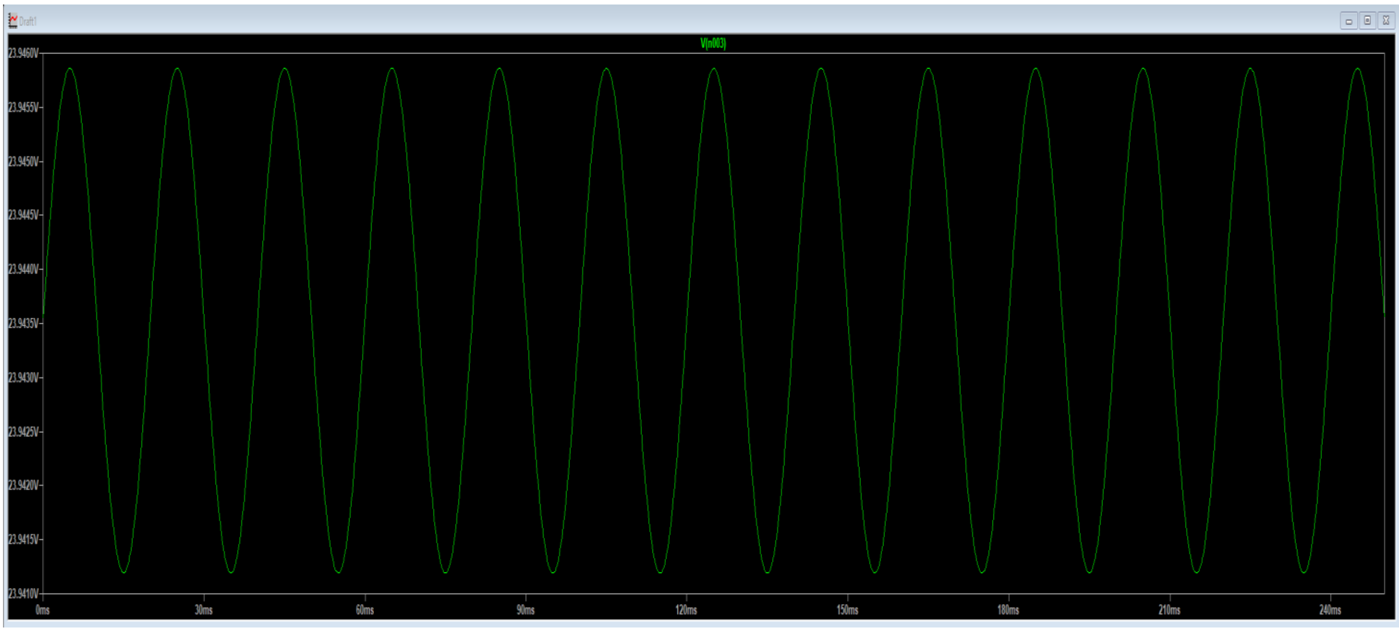


Fig 5.8

S = 147.7 , pot high, Vin = 30V

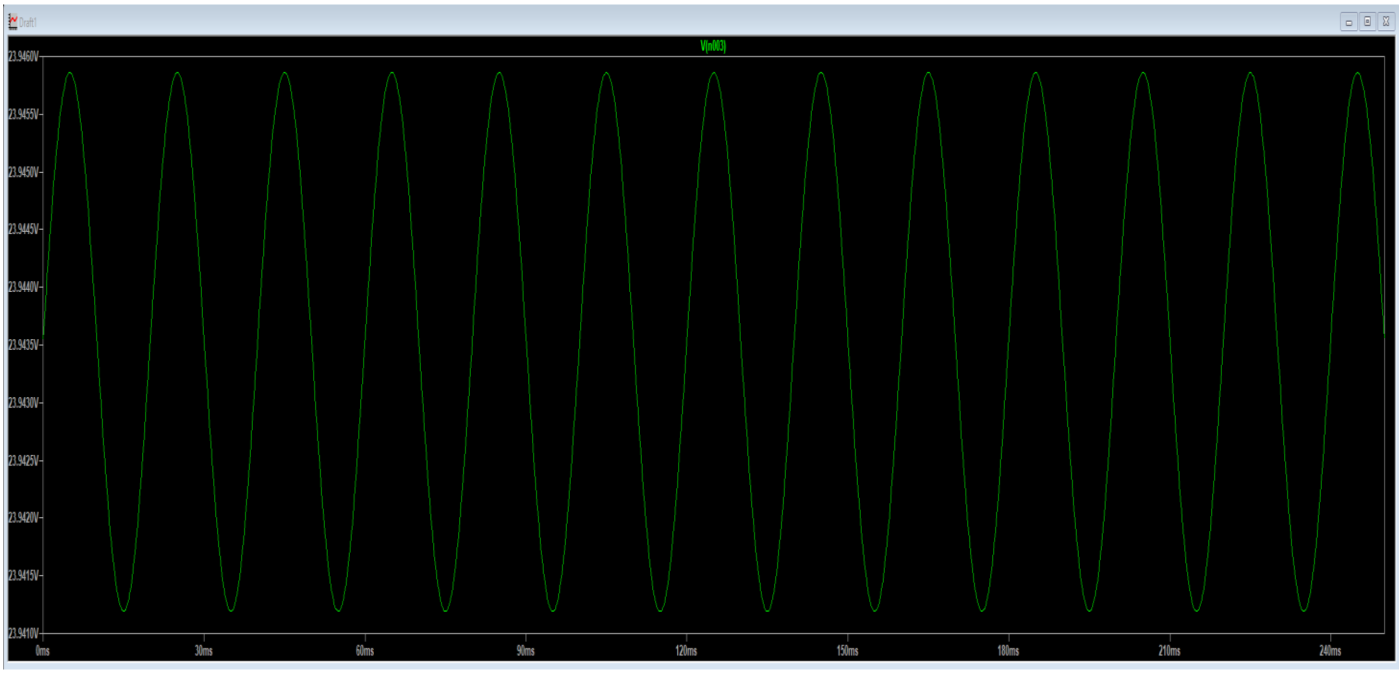


Fig 5.9

S = 193.4 , pot high , Vin = 33V

VI.COMMENTS:

This project was both challenging and rewarding, allowing me to deepen my knowledge of voltage regulation circuits and protective mechanisms. I contributed to the design, simulation, and analysis of a voltage regulator with overcurrent and overvoltage protection, focusing on integrating theoretical concepts with practical applications through calculations, component selection, and LTSpice simulations.

Key challenges included ensuring the seamless interaction of circuit blocks and achieving a stable output voltage. Designing the current source for biasing the differential amplifier, selecting precise resistor values, and configuring Zener diodes for the voltage reference block required careful attention to detail. Implementing overcurrent and overvoltage protection, including a foldback mechanism, added complexity and required extensive troubleshooting.

Simulating the circuit in LTSpice was particularly demanding, as I was using the software extensively for the first time. Despite the steep learning curve, I successfully modeled the circuit under various conditions, validated its performance, and adjusted the design accordingly.

My contributions included:

- **Designing the voltage reference, differential amplifier, and feedback network.**
- **Calculating and selecting components for reliability and safe operation.**
- **Integrating and verifying overcurrent and overvoltage protection mechanisms.**
- **Simulating and analyzing circuit performance under load and fault conditions.**

VII.Bibliography

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

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5.Tutorials for LTSpice circuit simulation and analysis.

IX.Mounting Map