VOLTAGE REGULATOR

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Abstract:

A voltage regulator is an electronic device or circuit that maintains a constant output voltage regardless of changes in input voltage or load conditions. This report shows a circuit of such a voltage regulator (LDO).

Introduction:

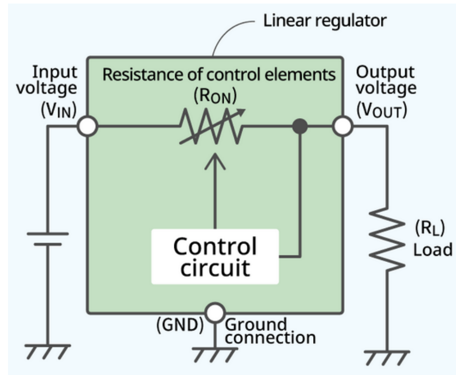
Voltage regulators can be classified based on the functionality as follows:

1) Load Regulation: Refers to the ability of a voltage regulator to maintain a constant output voltage when the load (the connected electrical device or circuit) changes.
2) Line Regulation: Refers to the ability of a voltage regulator to maintain a constant output voltage despite variations in the input voltage (line voltage).

In this report, we will be discussing our implementation of line regulator, that is, the output voltage is expected to remain constant despite the changes in the input voltage.

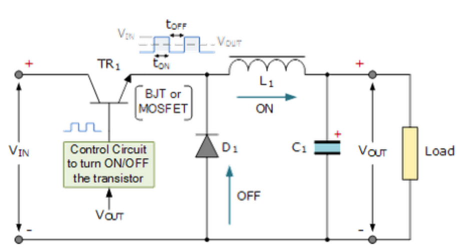
They can also be classified based on the type of operating principle:

1) Linear voltage regulator: These regulators use a variable resistor (like a transistor) to adjust the voltage and maintain a constant output. They operate by dissipating excess voltage as heat, which limits their efficiency, especially for large voltage differences between input and output.



Drawback: Inefficient for large voltage differences, as they dissipate excess energy as heat, leading to lower overall efficiency, especially in high-power applications.

2) Switching voltage regulator: These regulators operate by rapidly switching the input voltage on and off and then filtering it to obtain the desired output voltage. They are more efficient than linear regulators as they do not dissipate excess voltage as heat but instead control the output through high-frequency switching.

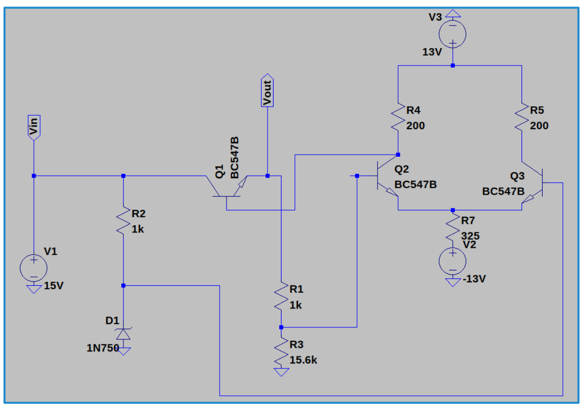


Drawback: More complex circuitry and control mechanisms compared to linear regulators, requiring additional components such as inductors and capacitors, which can increase cost and complexity.

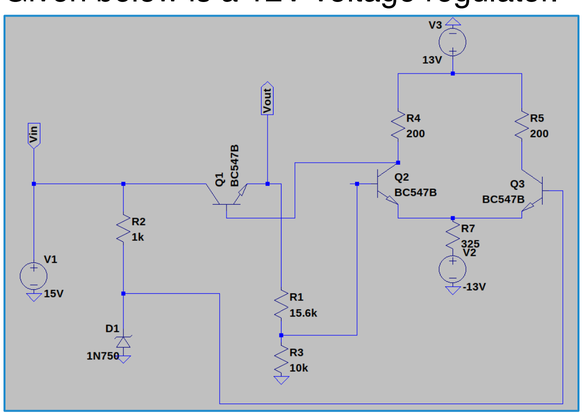
We have tried to replicate the functionality of LM317 which is a linear voltage regulator.

Circuit of Voltage Regulator:

Given below is a 5V voltage regulator.



Given below is a 12V voltage regulator.



Purpose of Components:

D1: IN750 (Zener)

Used as a voltage reference, used in reverse bias at breakdown voltage of 4.7V.

R2: 1k (Resistor)

It limits the current flowing through the Zener diode, ensuring that it operates within its specified limits and does not experience excessive current, potentially leading to damage. We observe that if this value is increased, the resistor heats up less, the Zener breakdown voltage is achieved slower. Similarly, if a lower resistor is used, more current flows through it, excessively heating the resistor (and potentially damaging it, so it is required to choose based on the tradeoffs), the Zener breakdown voltage is achieved faster.

Q1: BC547B (npn resistor)

Used as a variable resistor (in active mode). When Vin increases, the resistance is supposed to increase (using comparator), thus controlling Vout from increasing.

R1 (1k) and R3 (15.6k) [for 5V regulator]

The ratio of these resistors will determine the output voltage as we will see further.

Q2 (BC547B–npn) and Q3 (BC547B–npn)

Used as part of analog comparator.

R4 (200 ohm), R5 (200 ohm) and R7 (375 ohm)

Used as part of analog comparator whose working, and calculations will be discussed.

Overall Working:
The base current of the BJT is controlled by the comparator. When the output voltage (Vout) rises above the desired setpoint, (reference voltage from the Zener diode) since when the input Vin rises since the BJT is initially ON (Vb = Vcc), the comparator sends a signal to decrease the base current of the BJT. This action increases the resistance of the BJT, reducing the current flowing through it and hence lowering the output voltage. The comparator continuously compares the output voltage (Vout) with the reference voltage from the Zener diode. If Vout deviates from the desired level, the comparator adjusts the BJT's resistance to bring Vout back to the setpoint. This feedback loop ensures that the output voltage remains stable and regulated, even if the input voltage or load conditions change. The Zener diode provides a reliable reference voltage for the comparator to compare against, facilitating precise voltage regulation.

By using the concept of virtual ground (high gain of the comparator), we get

$$V_z = \frac{R_3}{R_3 + R_1} V_{out}$$

$$\implies V_{out} = V_z \left(1 + \frac{R_1}{R_3}\right)$$

$$\textit{For 5V voltage regulator,}$$

$$\frac{R_1}{R_3} = \frac{V_{out}}{V_z} - 1$$

$$= \frac{5}{4.7} - 1$$

$$= 0.0638$$

$$\textit{Fixing } R_3 = 15.6k, \textit{ we get } R_1 \approx 1k$$

$$\textit{Similarly, for 12V regulator,}$$

$$\frac{R_1}{R_3} = \frac{V_{out}}{V_z} - 1$$

$$= \frac{12}{4.7} - 1$$

$$= 1.55$$

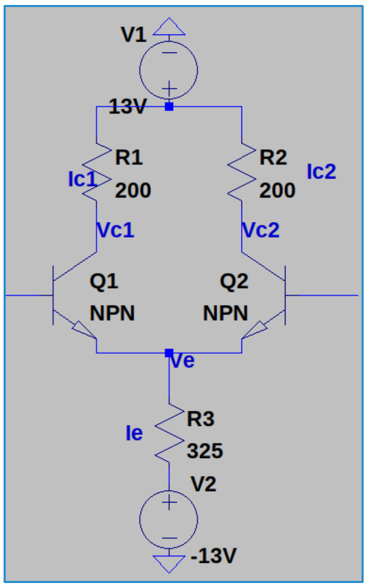
$$\textit{Fixing } R_3 = 10k, \textit{ we get } R_1 \approx 15.6k$$

Thus, by changing the ratio of these resistors and choosing the Zener diode, based on the requirements, we can easily modify the circuit for required regulated voltage.

Working of the Analog Comparator:
The analog comparator utilizes a differential amplifier setup. As the voltage at the base of the first transistor rises (due to an increase in output voltage), the collector current (Ic), which is directly related to the base-emitter voltage (Vbe), increases. Consequently, the voltage between Vcc and the collector (Vcc – Vc) rises, causing Vc to

drop. This Vc is connected to the base of another transistor, which lowers its emitter voltage (Vout) since the base-emitter voltage (Vbe) is typically around 0.7V. This reduction in Vout then decreases the base voltage of the first transistor, completing the feedback loop.

Design of the Analog Comparator:



$$
\begin{gathered}
Let\ Ic\ =\ 26mA \\
WKT,\ V_{b2}\ =\ 4.7\ (zener\ breakdown\ voltage) \\
In\ this\ configuration,\ assuming\ active\ region,\ V_{be2} = 0.7V. \\
Thus,\ V_e = 4.7 - 0.7\ =\ 4V \\
Since,\ the\ configuration\ is\ symmetric\ (differential\ amplifier), \\
I_e\ =\ I_{c1}\ +\ I_{c2}\ =\ 2 * I_c\ =\ 52mA. \\
V_e - (-13)\ =\ I_e * R_3 \\
\implies R_3\ =\ \frac{17}{52m}\ =\ 327\,\Omega \\
Also,\ since\ Vout\ =\ 5V,\ V_{c2} = 5\ +\ 0.7 = 5.7V, \\
\implies 13\ -\ 5.7\ =\ I_{c1} * R_1 \\
\implies R_1\ =\ \frac{8}{26m}\ \approx\ 200\,\Omega
\end{gathered}
$$

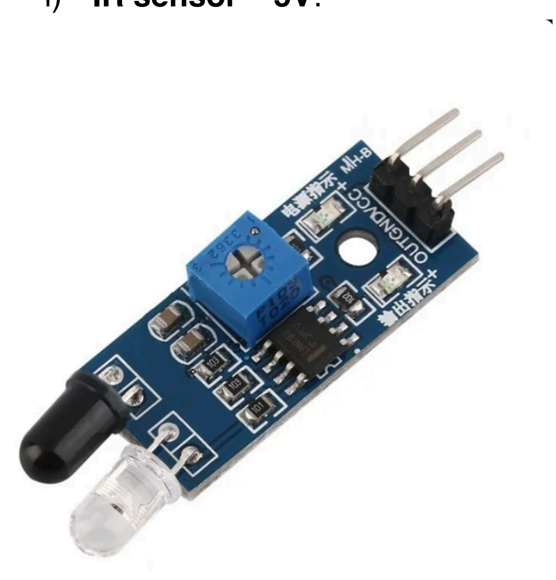
Thus, R1 and R2 = 200 ohm and R3 = 325 ohm.

Applications:

Voltage regulators are versatile components found in various technologies and industries. They ensure stable power delivery in smartphones, LED lighting systems, computers, medical equipment, automotive systems, telecommunication devices, industrial automation, renewable energy systems, audio amplifiers, and aviation electronics.

To demonstrate the working of the regulators, we have used two such applications.

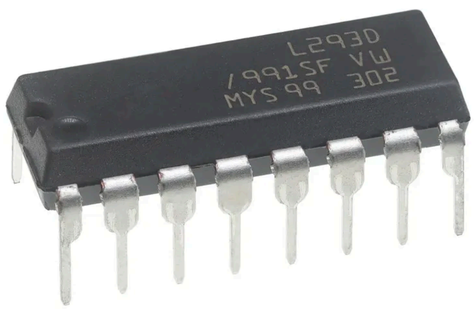
i) **IR sensor – 5V**:



The operating voltage for an IR sensor is between 3.3 V to 5V.

We used this as an application of 5V regulator to show that no matter the input ranges from 5 to 22 V, the sensor is not damaged due to the constant voltage output of 5V from the regulator.

ii) **Motor Driver IC (L293D).**



According to the Data sheet of L293D IC, the operating voltage for the motor driver IC is between 4.5 V to 36 V.

We are using 100 rpm Battery Operating Motors (BO). BO motors have been chosen for our application because as per our voltage limitations, we can supply a DC voltage between 0 to 22.8 Volts from the Voltage Supply. In this range, the BO motors were optimal as their operating voltage is between 3V to 12V.

We have used a 12V voltage regulator and varied voltage between 12V and 22.8V(Max). No matter what the applied voltage is, the motor driver IC should be able to drive the BO motor without getting it damaged.

This becomes a good application for our voltage regulator. However, there were some issues we faced to implement this at the circuit level.

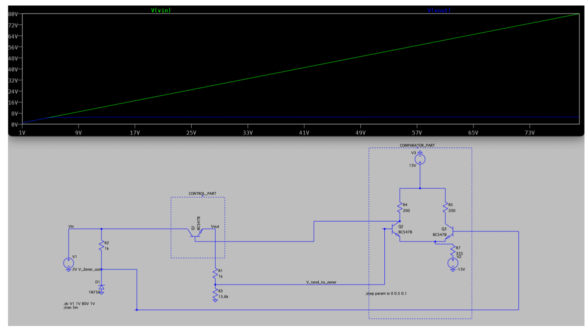
Every Voltage Regulator has a load capacity. If the load capacity is exceeded, i.e. the circuit is unable ((not enough power)) to drive the application circuit, the circuit does not work.

This will be discussed in more detail at the end of the report, while displaying the DSO outputs of the voltage regulators.

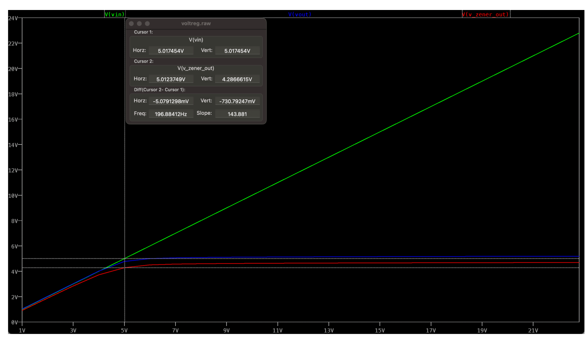
LT SPICE SIMULATION RESULTS

(i) 5V Regulator

Overall Picture



V_zener, Vinput and Vout vs Vinput



In our voltage regulator, we are using Zener diode to maintain a constant 4.7 volts across it. Because of using a resistor (R2) i.e. 1k ohm between the Zener and the input, some input voltage drops across the resistor. So, when Vin = 5V, V_Zener is not equal to 5V. Here, V_Zener ~ 4.28V. Since the zener diode voltage is not 5V when Vin is 5, the reference voltage set to the comparator is 4.28V, so the analog comparator tries to bring the base input to 4.28V. Hence,

the output Voltage (Vout) cannot reach 5V by the time input voltage reaches 5V.
So, now,
V_zener = 4.28V, we get Vout as ~4.78V.
From the voltage divider formula

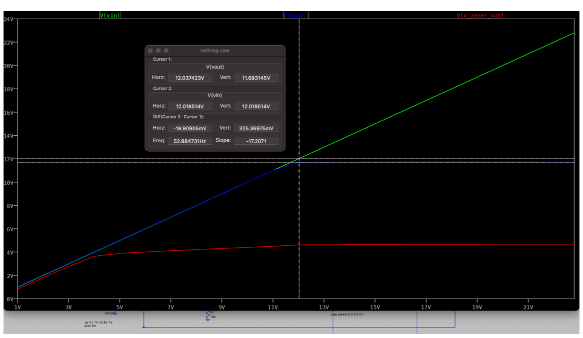
$$V_z = \frac{R_3}{R_3 + R_1} V_{out}$$

$$\implies V_{out} = V_z \left(1 + \frac{R_1}{R_3}\right)$$

Here, we calculate the error occurred due to the voltage regulator. Ideally, we expect the voltage regulator to give 5V, when the input applied is 5V, but it does not. Lower side Error of the voltage regulator is:
I error_lower_side I = 5 – 4.78 = 0. 22V

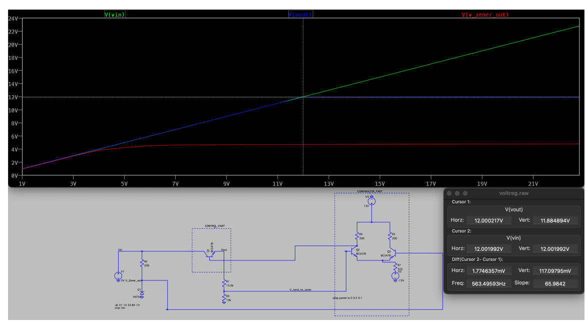
(ii) *12V Regulator*

V_zener , Vinput and Vout vs Vinput



Similarly, for a 12 V regulator, when Vin = 12V, Vout ~ 11.63 V
So, the lower side error for the 12 V regulator is
I error_lower_side I = 12 – 11.63 = 0.37V
The magnitude of the lower side error could be decreased by decreasing the value of R2(Resistor between input and Zener). But the actual application of votage regulator could not be satisfied. We generally use voltage regulators when we want the low output of our choice when high input is applied, which is the concept of hart limiter. When R2 is decreased, for high inputs, the current across the Zener branch increases than usual because of the R2 resistance. So, the current flowing through the control branch decreases, implying less drop across the controller branch. But as high input is applied, there should be a high drop across the controller branch to achieve the desired output-regulated voltage.
For example, let us take resistance R2 to be 200 ohms instead of 1 Kohm

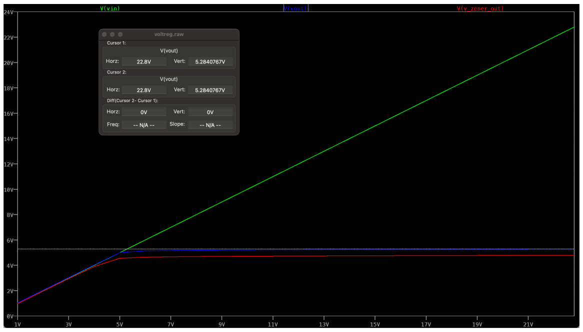
Overall Picture:



Here, we can see that when the input
Vin = 12V,
Vout = 11.88V
So, the lower side error
I error_lower_side I = 12 – 11.88V
= 0.12V < 0.22V
which is expected.
Now, let us calculate the upper side error for the 5V and 12 V regulator and compare with the upper side error of 12V regulator for a lower value of R2 as an example.

Since the maximum voltage that could be given from the voltage supply in the lab is ~23V. Let us analysis the upper side error when the input is ~ 23V

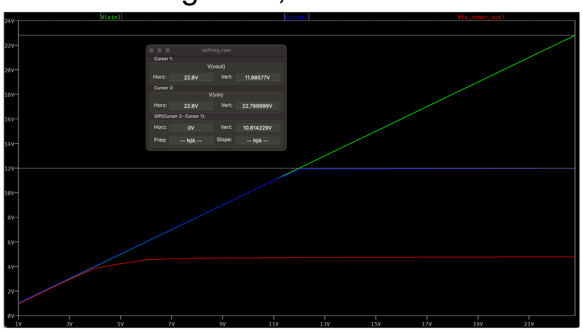
For a 5V Regulator,



When input is 22.8V, the upper side error is

I upper_side_error I = 5.28 - 5 = 0.28V

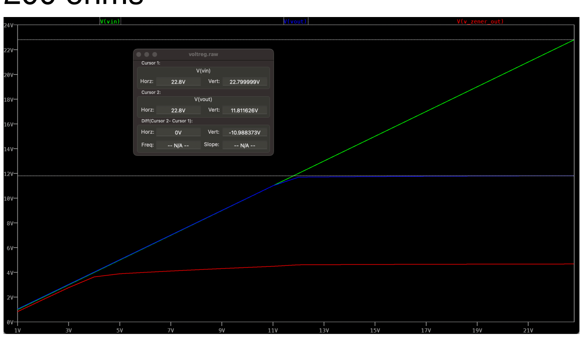
For a 12V regulator,



When input is 22.8V, the upper side error is

I upper_side_error I = 12 – 11.98577 = 0.01423

Now, taking the reistor value as R2 = 200 ohms



When input is 22.8V, the upper side error is

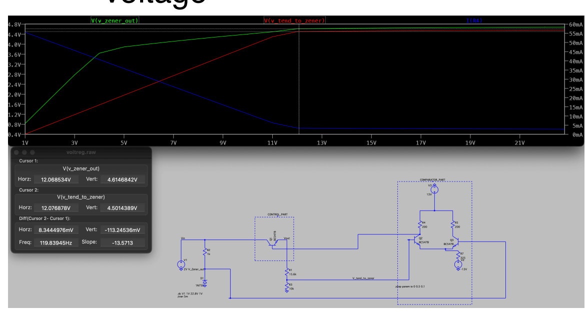
I upper_side_error I = 12 – 11.81 ~ 0.19

But for R2 = 1k ohm, error was 0.0143 << 0.19.

So, if we want to maintain the upper side error to be low, setting the Resistor value to be a little high is a good choice. But if we want the voltage regulator to work ideally at lower voltages, setting the resistor R2 to be a little low is a good choice.

For any voltage Regulator, Behavior of the current in the left branch of the comparator, as the input varies. We are going to divide it into two sections.

(i) Before the resistor divider output (V_tend_to_zener as in ltspice simulation) at emitter of the control transistor, reaches Zener breakdown voltage
(ii) Before the resistor divider output at emitter of the control transistor, reaches Zener breakdown voltage



As we can observe, as the input voltage increases and before the Zener reaches its threshold voltage, the current through the comparator branch gradually decreases. This is because as current decreases, the collector voltage Vc =

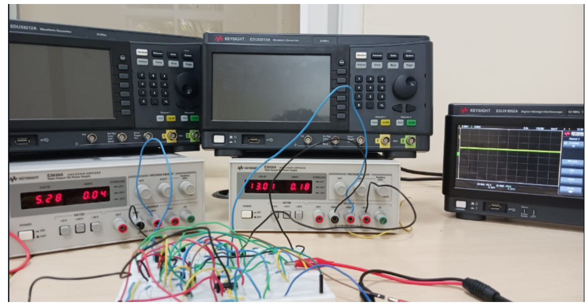
Vcc – Ic * R4 increases. As Vc increases, the output Vout increases, as Vout ~ Vc + 0.7 V, as the transistor remains on. We also think in another way. As the base voltage increases, the collector current increases and more drops occur across the transistor, if a transistor is considered a resistor at low voltages (linear mode).

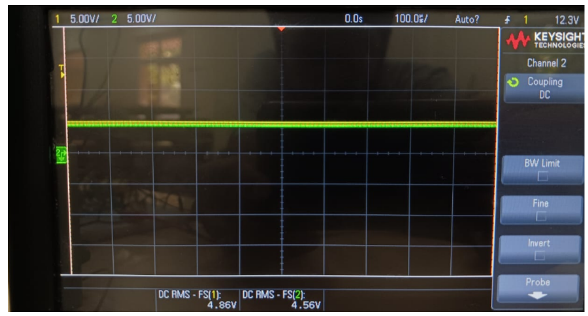
Now, after the Zener attains its breakdown voltage, the current remains unchanged. Because the comparator tries to maintain the output voltage at its desired regulated voltage, the collector current does not change.

The point regarding how the comparator regulates the output voltage Vout to its desired regulated voltage has been discussed earlier in the section "WORKING OF THE COMPARATOR".

Hardware Results:
Without load:

Input = 5.28V





Green Output = 4.56V (5V regulator)

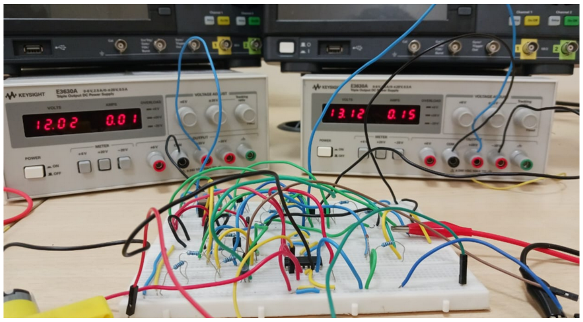
Let us calculate the lower side error for 5V regulator, when the input applied is 5V.

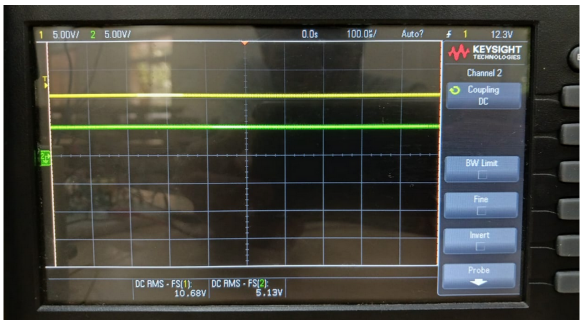
| error_lower_side | = 5 – 4.56 = 0.44 (whereas in simulation, error was 0.22 V).

The reason for a higher error may be because of the change of resistance values when it comes to hardware. Another reason can be because of the Zener diodes. Ideal Zener diodes try to maintain the output voltage to their breakdown voltage as the input voltage is increased. But in reality, the IV characteristics of the Zener diode is not a vertical line at its breakdown voltage for it to ideally regulate voltage up to ~4.7V.

Yellow Output = 4.86V (12V regulator)

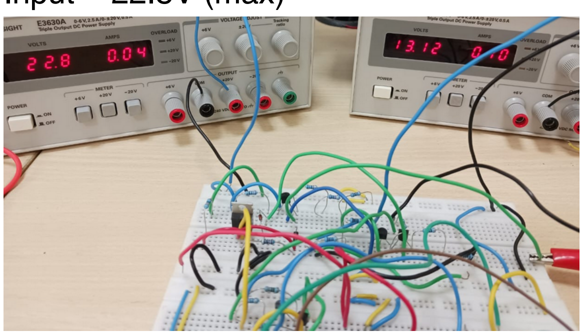
Input = 12V

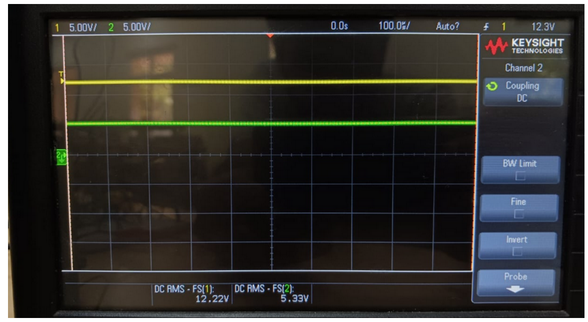




Green Output = 5.13V (5V regulator)
Yellow Output = 10.68V (12V regulator)
Let us calculate the lower side error for 12V regulator, when the input applied is 12V.
I error_lower_side I = 12 – 10.68 = 1.32V
The similar reason applies for the increase in the lower side error for the 12 when compared to that of the LT spice simulation.

Input = 22.8V (max)

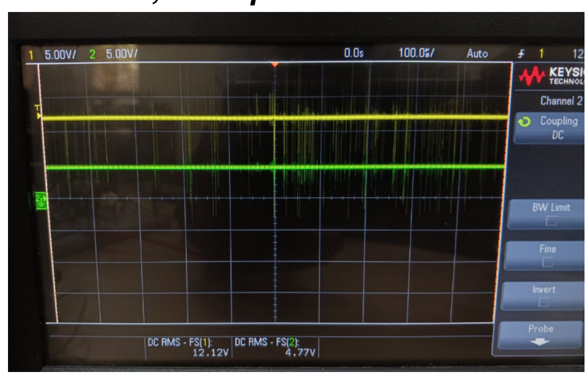




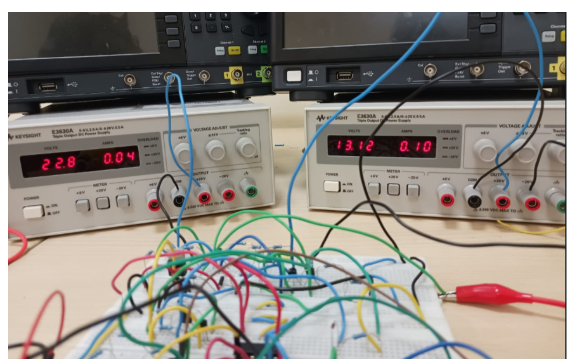
Now, calculating the upper side error for the 5 and 12 V regulators.
For 5V regulator
I error_upper_side I = 5.33 - 5 ~ 0.33

For a 12V regulator,
Ierror_upper_side I = 12.22 - 12 ~ 0.22

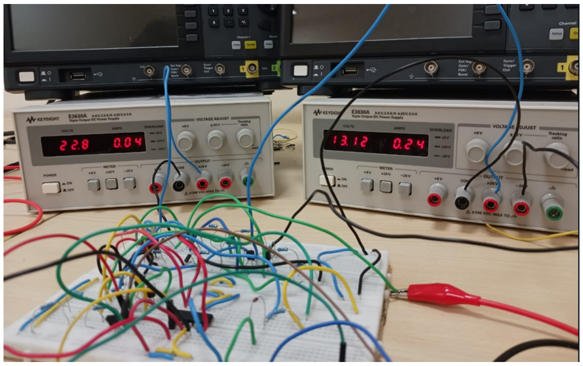
With load, for input = 22.8V



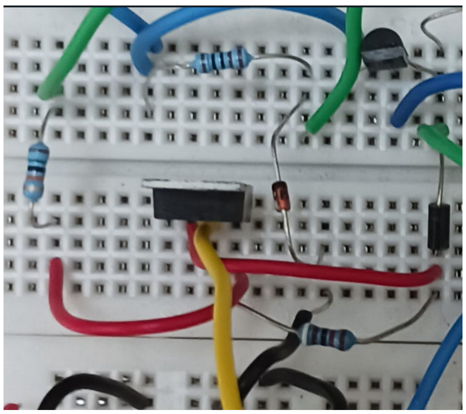
Current Analysis:
Before the loads are connected, current drawn is 0.1A



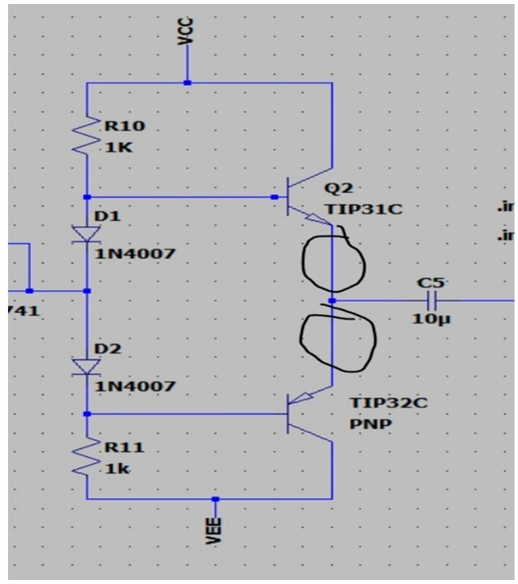
After the loads are connected, current drawn is 0.24A.



Since, the current from the output of the voltage regulator was not sufficient to drive the 12V load, a power amplifier was used as shown below:



In our audio power amplifier project, we have used a power amplifier which had amplifier the current to drive the speaker.



Over there, we have used to diode configuration for the sinusoidal input (+ half and - half). Here, since the input is +ve, only the lower half of the circuit is enough. The same has been implemented in the circuit level.

The input is given at the base and the output is taken at the emitter, so the power amplifier follows a common collector configuration.

At the emitter, we connected a resistor to the ground so that the emitter current is adjusted according to the required power to drive the L293D circuit.

As we increase the resistance at the emitter, the load current increases because the output impedance gets lowered which helps in driving more current to the load. The current amplifier does not amplify the input dc voltage given. So, it behaves similar to the BUFFER but just amplifies the current.

POWER CALCULATION

(i) Before load applied at the output
Current drawn: 0.10 Amp
Voltage supplied: 13V
Power supplied ~ I * V = 0.10 * 13 = 1.3W

(ii) After load applied at the output
Current drawn: 0.24 Amp
Voltage Supplied: 13V
Power supplied ~ I * V = 0.24 * 13 = 3.12V
We have ignored the power supplied because of the input voltage due to less current drawn through the control circuit as compared to that of the Comparator Circuit.
Demo

Conclusion:

In conclusion, this project aimed to design and implement a linear voltage regulator circuit capable of maintaining a constant output voltage despite fluctuations in input voltage and load conditions. Through the integration of components such as a BJT, analog comparator, and Zener diode, two voltage regulators were constructed to provide stable outputs of 5V and 12V.

Simulation results provided insights into the performance of the voltage regulators, indicating both lower and upper side errors under varying input conditions. Hardware testing further validated the functionality of the regulators, albeit with some discrepancies attributed to component variations and non-ideal characteristics.

Applications of the voltage regulators were demonstrated through practical implementations, showcasing their utility in powering devices such as IR sensors and motor driver ICs. However, challenges arose when driving higher loads, necessitating the use of additional amplification circuits to meet power requirements effectively.

Overall, this project sheds light on the complexities involved in designing and implementing voltage regulator circuits, highlighting the importance of careful component selection, circuit optimization, and thorough testing for achieving desired performance and reliability in real-world applications.

Some disadvantages of our Voltage regulator.

1) Less Load Capacity
2) Lower and upper side errors, when 5V, 12V and max Voltage (22.8V) is applied.