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:

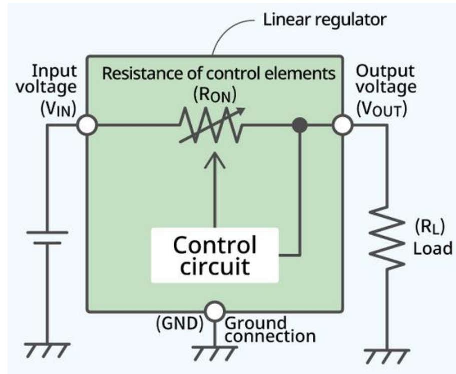
Voltage regulators can be classified based on the functionality as follows:

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.

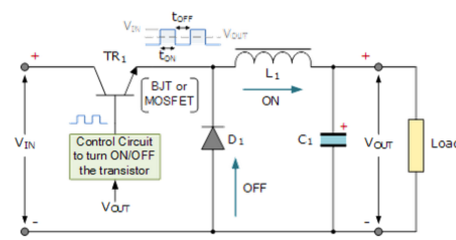
They can also be classified based on the type of operating principle:

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.

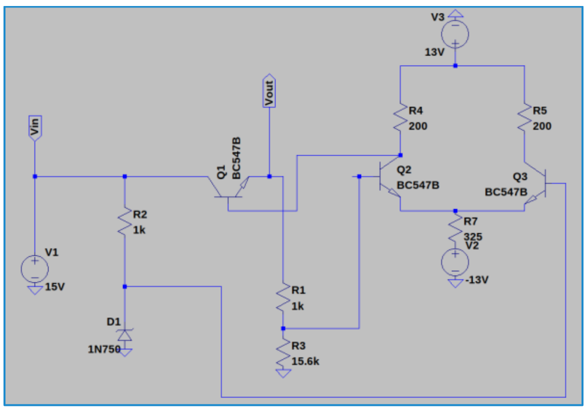


Drawback: More complex circuitry and control mechanisms compared to linear regulators, requiring additional components such as inductors and capacitors, which can increase cost and complexity.

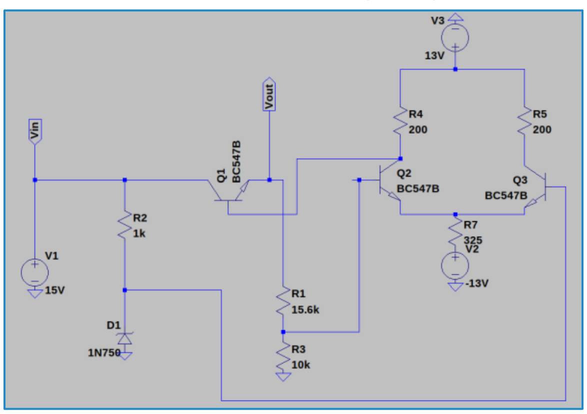
We have tried to replicate the functionality of LM317 which is a linear voltage regulator.

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

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

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

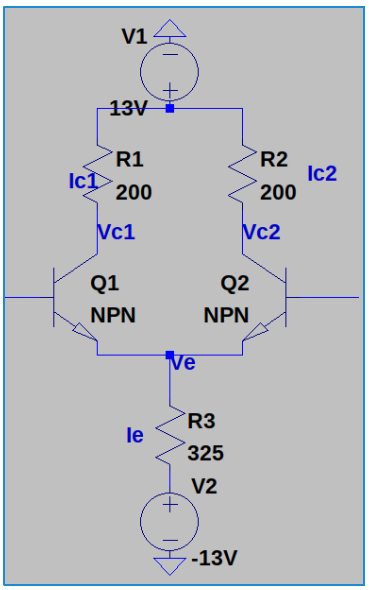
$$\begin{aligned}
&\textit{For } 5V \textit{ voltage regulator,} \\
&\frac{R_1}{R_3} = \frac{V_{out}}{V_z} - 1 \\
&= \frac{5}{4.7} - 1 \\
&= 0.0638 \\
&\textit{Fixing } R_3 = 15.6k, \textit{ we get } R_1 \approx 1k \\
&\textit{Similarly, for } 12V \textit{ regulator,} \\
&\frac{R_1}{R_3} = \frac{V_{out}}{V_z} - 1 \\
&= \frac{12}{4.7} - 1 \\
&= 1.55 \\
&\textit{Fixing } R_3 = 10k, \textit{ we get } R_1 \approx 15.6k
\end{aligned}$$

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:



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

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:

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)