Voltage Regulator

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- Batteries are often shown on a schematic diagram as the source of DC voltage but usually the actual DC voltage source is a power supply.
- There are many types of power supply. Most are designed to convert high voltage AC mains electricity to a suitable low voltage supply for electronics circuits and other devices.
- A more reliable method of obtaining DC power is to transform, rectify, filter and regulate an AC line voltage.
- A power supply can by broken down into a series of blocks, each of which performs a particular function.



- Power supply: a group of circuits that convert the standard ac voltage (120 V, 60 Hz) provided by the wall outlet to constant dc voltage
- Transformer : a device that step up or step down the ac voltage provided by the wall outlet to a desired amplitude through the action of a magnetic field



- Rectifier: a diode circuits that converts the ac input voltage to a pulsating dc voltage
- The pulsating dc voltage is only suitable to be used as a battery charger, but not good enough to be used as a dc power supply in a radio, stereo system, computer and so on.



- There are two basic types of rectifier circuits:
 - Half-wave rectifier
 - Full-wave rectifier Center-tapped & Bridge full-wave rectifier
- In summary, a full-wave rectified signal has less ripple than a half-wave rectified signal and is thus better to apply to a filter.



- Filter: a circuit used to reduce the fluctuation in the rectified output voltage or ripple. This provides a steadier dc voltage.
- Regulator: a circuit used to produces a constant dc output voltage by reducing the ripple to negligible amount. One part of power supply.

Regulator - Zener diode regulator

- For low current power supplies a simple voltage regulator can be made with a resistor and a zener diode connected in reverse.
- Zener diodes are rated by their breakdown voltage V_z and maximum power P_z (typically 400mW or 1.3W)



Voltage Regulation

- Two basic categories of voltage regulation are:
 - line regulation
 - Ioad regulation
- The purpose of line regulation is to maintain a nearly constant output voltage when the input voltage varies.
- The purpose of load regulation is to maintain a nearly constant output voltage when the load varies

Line Regulation



output voltage of a regulator (within certain limits)

Line Regulation

• Line regulation can be defined as the percentage change in the output voltage for a given change in the input voltage.

Line regulation =
$$\left(\frac{\Delta V_{OUT}}{\Delta V_{IN}}\right) \times 100\%$$

Δ means "a change in"

• Line regulation can be calculated using the following formula:

$$Line \ regulation = \frac{\left(\Delta V_{OUT} \ / \ V_{OUT}\right) \times 100\%}{\Delta V_{IN}}$$



effect on the output voltage of a regulator (within certain limits)

• Load regulation can be defined as the percentage change in the output voltage from no-load (NL) to full-load (FL).

Load regulation =
$$\begin{pmatrix} V_{NL} - V_{FL} \\ V_{FL} \end{pmatrix} \times 100\%$$

- Where:
 - V_{NL} = the no-load output voltage
 - V_{FL} = the full-load output voltage

 Sometimes power supply manufacturers specify the equivalent output resistance (R_{out}) instead of its load regulation.



R_{FL} equal the smallest-rated load resistance, then V_{FL}:

$$V_{FL} = V_{NL} \left(\frac{R_{FL}}{R_{OUT} - R_{FL}} \right)$$

• Rearrange the equation:

$$\begin{split} V_{NL} &= V_{FL} \left(\frac{R_{OUT} - R_{FL}}{R_{FL}} \right) \\ Load regulation &= \frac{V_{FL} \left(\frac{R_{OUT} - R_{FL}}{R_{FL}} \right) - V_{FL}}{V_{FL}} \times 100\% \\ Load regulation &= \left(\frac{R_{OUT} - R_{FL}}{R_{FL}} - 1 \right) \times 100\% \\ Load regulation &= \left(\frac{R_{OUT}}{R_{FL}} \right) \times 100\% \end{split}$$

Example

1. The input of a certain regulator increases by 3.5 V. As a result, the output voltage increases by 0.042 V. The nominal output is 20 V. Determine the line regulation in both % and in %/V.

(Solution: 1.2%; 0.06%/V)

 If a 5 V power supply has an output resistance of 80 mΩ and a specific maximum output current of 1 A. Calculate the load regulation in % and %/mA. (Solution: 1.6%; 0.0016%/mA)

Types of Regulator

- Fundamental classes of voltage regulators are linear regulators and switching regulators.
- Two basic types of linear regulator are the series regulator and the shunt regulator.
- The series regulator is connected in series with the load and the shunt regulator is connected in parallel with the load.



Series Regulator Circuit

- Control element in series with load between input and output.
- Output sample circuit senses a change in output voltage.
- Error detector compares sample voltage with reference voltage → causes control element to compensate in order to maintain a constant output voltage.



Op-Amp Series Regulator



Op-Amp Series Regulator

- The resistor R₁ and R₂ sense a change in the output voltage and provide a feedback voltage.
- The error detector compares the feedback voltage with a Zener diode reference voltage.
- The resulting difference voltage causes the transistor Q₁ controls the conduction to compensate the variation of the output voltage.
- The output voltage will be maintained at a constant value

$$V_o = \left(1 + \frac{R_1}{R_2}\right) V_Z$$

of:

Transistor Series Regulator



- The transistor Q₁ is the series control element.
- Zener diode provides the reference voltage.

Transistor Series Regulator

• Since Q_1 is an npn transistor, V_0 is found as:

$$V_{BE} = V_Z - V_o$$

- the response of the pass-transistor to a change in load resistance as follows:
 - If load resistance increases, load voltage also increases.
 - Since the Zener voltage is constant, the increase in $V_{\rm o}$ causes $V_{\rm BE}$ to decrease.
 - The decrease in V_{BE} reduces conduction through the pass- transistor, so load current decreases.
 - This offsets the increase in load resistance, and a relatively constant load voltage is maintained

Example

Determine the output voltage for the regulator below.
 (Solution: 10.2 V)



Example

Calculate the output voltage and Zener current for R_L=1kΩ.
 (Solution: V_o=11.3 V; I_z≈36 mA)



Shunt Regulator Circuit

- The unregulated input voltage provides current to the load.
- Some of the current is pulled away by the control element.
- If the load voltage tries to change due to a change in the load resistance, the sampling circuit provides a feedback signal to a comparator.
- The resulting difference voltage then provides a control signal to vary the amount of the current shunted away from the load to maintain the regulated output voltage across the load.



Op-Amp Shunt Regulator



Op-Amp Shunt Regulator

- When the output voltage tries to decrease due to a change in input voltage or load current caused by a change in load resistance, the decrease is sensed by R₁ and R₂.
- A feedback voltage obtained from voltage divider R₁ and R₂ is applied to the op-amp's non-inverting input and compared to the Zener voltage to control the drive current to the transistor.
- The current through resistor R_s is thus controlled to drop a voltage across R_s so that the output voltage is maintained.

Transistor Shunt Regulator



- The control element is a transistor, in parallel with the load.
 While, the resistor, R_s, is in series with the load.
- The operation of the transistor shunt regulator is similar to that of the transistor series regulator, except that regulation is achieved by controlling the current through the parallel transistor

Transistor Shunt Regulator

- Resistor R_S drops the unregulated voltage depends on current supplied to load R_L.
- Voltage across the load is set by zener diode and transistor base-emitter voltage.
- If R_L decrease, a reduced drive current to base of Q1 → shunting less collector current.
- Load current, I_L is larger, maintaining the regulated voltage across load.



Transistor Shunt Regulator

- The output voltage to the load is: $V_o = V_L = V_Z + V_{BE}$
- voltage across the load is set by the Zener diode voltage and the transistor base-emitter voltage.
- If the load resistance decreases, the load current will be larger at a value of: $I_L = \frac{V_L}{r}$

The increase in load current causes the collector current shunted by the transistor is to be less:

$$V - V$$

• The current through R_S: $I_{S} = \frac{V_{i} - V_{L}}{R_{S}}$

Example

• Determine the regulated voltage, V_L and circuit currents. (Solution: V_L=8.9 V; I_L=89 mA; I_S=109 mA; I_C=20 mA)



- The switching regulator is a type of regulator circuit which its efficient transfer of power to the load is greater than series and shunt regulators because the transistor is not always conducting.
- The switching regulator passes voltage to the load in pulses, which then filtered to provide a smooth dc voltage.



- The switching regulator is more efficient than the linear series or shunt type.
- This type regulator is ideal for high current applications since less power is dissipated.
- Voltage regulation in a switching regulator is achieved by the on and off action limiting the amount of current flow based on the varying line and load conditions.
- With switching regulators 90% efficiencies can be achieved.

Step-Down Configuration

- With the step-down (output is less than the input) configuration the control element Q₁ is pulsed on and off at variable rate based on the load current.
- The pulsations are filtered out by the LC filter.



Step-up configuration

- The difference is in the placement of the inductor and the fact that Q₁ is shunt configured.
- During the time when Q₁ is off the V_L adds to V_C stepping the voltage up by some amount.



Voltage-inverter configuration

- output voltage is of opposite polarity of the input.
- This is achieved by V_L forward-biasing reverse-biased diode during the off times producing current and charging the capacitor for voltage production during the off times.
- With switching regulators 90% efficiencies can be achieved.



IC Voltage Regulators

- Regulation circuits in integrated circuit form are widely used.
- Their operation is no different but they are treated as a single device with associated components.
- These are generally three terminal devices that provide a positive or negative output.
- Some types have variable voltage outputs.
- A typical 7800 series voltage regulator is used for positive voltages.
- The 7900 series are negative voltage regulators.
- These voltage regulators when used with heatsinks can safely produce current values of 1A and greater.
- The capacitors act as line filtration.

IC Voltage Regulators

- Several types of both linear (series and shunt) and switching regulators are available in integrated circuit (IC) form.
- Single IC regulators contain the circuitry for:
 - (1) reference source
 - (2) comparator amplifier
 - (3) control device
 - (4) overload protection
- Generally, the linear regulators are three-terminal devices that provides either positive or negative output voltages that can be either fixed or adjustable.

 The fixed voltage regulator has an unregulated dc input voltage V_i applied to one input terminal, a regulated output dc voltage V_o from a second terminal, and the third terminal connected to ground.

Fixed-Positive Voltage Regulator

The series 78XX regulators are the three-terminal devices
 that provide a fixed positive output voltage.
 Pin 1. Input



- An unregulated input voltage V_i is filtered by a capacitor C₁ and connected to the IC's IN terminal.
- The IC's OUT terminal provides a regulated +12
 V, which is filtered by capacitor C₂.
- The third IC terminal is connected to ground (GND)



Positive-Voltage Regulators in the 78XX Series

IC Part	Output Voltage (V)	Minimum V _i (V)
7805	+5	+7.3
7806	+6	+8.3
7808	+8	+10.5
7810	+10	+12.5
7812	+12	+14.5
7815	+15	+17.7
7818	+18	+21.0
7824	+24	+27.1

Fixed-Negative Voltage Regulator

- The series 79XX regulators are the three-terminal IC regulators that provide a fixed negative output voltage.
- This series has the same features and characteristics as the series 78XX regulators except the pin numbers are different.



Negative-Voltage Regulators in the 79XX Series

IC Part	Output Voltage (V)	Minimum V _i (V)
7905	-5	-7.3
7906	-6	-8.4
7908	-8	-10.5
7909	-9	-11.5
7912	-12	-14.6
7915	-15	-17.7
7918	-18	-20.8
7924	-24	-27.1

Adjustable-Voltage Regulator

- Voltage regulators are also available in circuit configurations that allow to set the output voltage to a desired regulated value.
- The LM317 is an example of an adjustable-voltage regulator, can be operated over the range of voltage from 1.2 to 37 V.



Summary

- Voltage regulators keep a constant dc output despite input voltage or load changes.
- The two basic categories of voltage regulators are linear and switching.
- The two types of linear voltage regulators are series and shunt.
- The three types of switching are step-up, stepdown, and inverting.

Summary

- Switching regulators are more efficient than linear making them ideal for low voltage high current applications.
- IC regulators are available with fixed positive or negative output voltages or variable negative or positive output voltages.
- Both linear and switching type regulators are available in IC form.
- Current capacity of a voltage regulator can be increased with an external pass transistor.