0.1 Regulated Power Supply

In almost all electronic systems, a stable DC voltage is a fundamental requirement for proper operation. While batteries can provide a pure and ripple-free DC voltage, they are often impractical for continuous, long-term use due to their limited lifespan, replacement cost, and restricted current-delivering capabilities. Therefore, the vast majority of electronic devices rely on a dedicated power supply circuit that converts the alternating current (AC) power from the standard mains grid into a direct current (DC) voltage suitable for powering delicate electronic circuits such as microcontrollers, operational amplifiers, and digital logic gates.

However, a simple combination of a step-down transformer, a diode rectifier, and a basic capacitor filter circuit produces what is known as an *unregulated power supply*. The DC output voltage of an unregulated power supply is not perfectly constant; it exhibits significant fluctuations due to two primary external factors:

1. **Line Variations:** Changes in the input AC mains voltage directly and proportionally affect the DC output voltage. If the standard 230V AC mains voltage momentarily drops to 210V due to heavy grid loads, the secondary voltage of the transformer drops proportionately. This sequentially leads to a decreased peak DC output voltage from the rectifier and filter stages.

2. **Load Variations:** Changes in the load current drawn by the connected electronic circuit cause variations in the output voltage. All practical power supplies possess some internal resistance. As the load demands more current, the voltage drop across this internal resistance increases, causing the terminal output voltage available to the load to decrease.

Furthermore, the output of an unregulated supply containing just a basic filter capacitor will still contain a significant amount of ”ripple”—a small residual AC component riding on top of the DC voltage. For sensitive analog and digital circuits, this ripple can cause severe operational noise and errors. To overcome these issues, a specialized voltage regulating circuit is essential.

title=Regulated Power Supply

A regulated power supply is an electronic circuit that maintains a rigidly constant DC output voltage irrespective of fluctuations in the input AC mains voltage, variations in the load current demand, or changes in ambient temperature.

A complete regulated power supply system is typically composed of four main functional blocks connected in a cascade: a transformer, a rectifier, a smoothing filter, and a final voltage regulator stage.

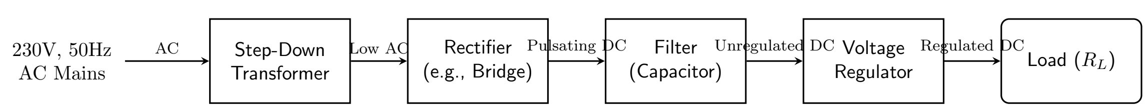

Figure 1: Block Diagram of a Regulated DC Power Supply showing signal conversion stages.

The **voltage regulator** block is the heart and final stage of this system. It continuously monitors the output voltage and automatically adjusts its internal parameters (using negative feedback mechanisms) to compensate for any changes. It essentially absorbs the excess input voltage and dissipates it as heat, ensuring that the voltage delivered to the load remains perfectly flat and constant.

The performance and quality of a voltage regulator are primarily evaluated using two critical metrics:

- **Line Regulation (Source Regulation):** A measure of the regulator's ability to maintain a constant output voltage when the unregulated input voltage varies. It is usually expressed as a percentage change in output voltage for a specified change in input voltage (e.g., 0.05%/V).
- **Load Regulation:** A measure of the regulator's ability to maintain a constant output voltage when the load current varies from zero (no-load condition) to its maximum rated value (full-load condition). It is computed as:

$$\% \text{ Load Regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\%$$

  where V_{NL} is the no-load voltage and V_{FL} is the full-load voltage.

Ideally, both line and load regulation percentages should be exactly zero, implying that the output voltage is entirely independent of external variables. In modern IC regulators, these values are extremely low, often less than 1%.

0.2 Three Terminal Fixed and Adjustable Voltage Regulator ICs: 78xx, 79xx, LM317

Historically, precise voltage regulators were built using discrete components, requiring careful selection of Zener diodes, error-amplifier transistors, and precision resistors. These discrete designs were bulky, complex to design, and prone to temperature drift. Today, monolithic integrated circuit (IC) voltage regulators have completely revolutionized power supply design. They are universally used due to their compact size, exceptional regulation performance, self-protection features, and extremely low cost. The most ubiquitous among these are the three-terminal voltage regulators.

As the name implies, these ICs require only three connections to function: Input, Output, and a Reference pin (either Ground for fixed types or an Adjust pin for variable types). They are internally highly complex, containing dozens of transistors to provide precise voltage references and high-current driving capabilities. Furthermore, they incorporate robust built-in protection mechanisms that make them virtually indestructible under normal fault conditions:

- **Thermal Shutdown:** The IC continuously monitors its internal junction temperature. If it exceeds a safe critical limit (usually around 150°C to 170°C), the regulator automatically shuts off its output current. It will remain off until it cools down, preventing catastrophic destruction due to overheating or inadequate heatsinking.
- **Short-Circuit Current Limiting:** The internal pass transistor is protected from excessive current. If the output is accidentally shorted directly to ground, the internal circuitry imme-

diately detects the surge and clamps the output current to a safe maximum value (typically around 1.5A to 2A), protecting both the regulator IC and the load from burning out.

- **Safe-Operating-Area (SOA) Protection:** This ensures that the internal pass transistor operates within safe limits of voltage and current simultaneously, preventing secondary breakdown.

0.2.1 Fixed Positive Voltage Regulators: The 78xx Series

The 78xx series is a universally popular family of fixed *positive* voltage regulators. In the naming convention, the "78" designates it as a positive regulator, while the "xx" denotes the specific fixed output voltage it is manufactured to provide. Common members of this family include:

- **7805:** Provides a perfectly regulated +5V output (standard for digital TTL logic and microcontrollers).
- **7809:** Provides a regulated +9V output.
- **7812:** Provides a regulated +12V output.
- **7824:** Provides a regulated +24V output (common in industrial control systems).

These regulators can typically supply up to 1.5A of load current if properly cooled. The standard and most common package for these ICs is the TO-220 package, which features a metal backing tab with a hole, specifically designed for easy mounting to an aluminum heatsink.

When viewing a TO-220 packaged 78xx IC from the front (with the part number text facing you and the three pins pointing downwards), the pins are strictly defined from left to right as follows:

1. **Pin 1 (Input):** This pin receives the unregulated positive DC voltage from the filter capacitor.
2. **Pin 2 (Ground):** This pin is connected to the common ground of the circuit. It serves as the reference point. The metal mounting tab is also internally connected to this pin.
3. **Pin 3 (Output):** This pin delivers the regulated, stable positive DC voltage to the load.

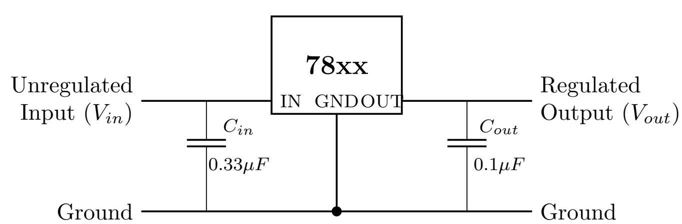

Figure 2: Typical application circuit for a 78xx series positive voltage regulator, illustrating necessary bypass capacitors.

In a practical circuit diagram as shown above, two small ceramic or tantalum bypass capacitors are highly recommended and should be soldered physically close to the IC pins.

- **Input Capacitor (C_{in}):** Usually a 0.33μF capacitor, it is strictly required if the regulator is located more than a few inches away from the main power supply smoothing filter capacitor. It neutralizes lead inductance and prevents the internal high-gain amplifier of the regulator from breaking into high-frequency self-oscillation.
- **Output Capacitor (C_{out}):** Usually a 0.1μF capacitor, it greatly improves the transient response of the regulator. This helps the regulator maintain its output voltage perfectly stable even when the load current demands exhibit sudden, sharp spikes (such as when a microcontroller switches states or a relay is activated).

title=Dropout Voltage and Power Dissipation

For a linear regulator like the 78xx series to function correctly, the unregulated input voltage (V_{in}) must always be greater than the desired regulated output voltage (V_{out}) by a specified minimum margin. This critical minimum voltage difference is called the **dropout voltage**. For the 78xx series, the dropout voltage is typically between 2V and 2.5V. For example, to guarantee a steady +5V from a 7805 regulator, the input voltage must never dip below +7.3V, even during the lowest dips of the input ripple. If V_{in} falls below this threshold, the regulator "drops out" of regulation, causing the output voltage to fall and ripple to heavily leak through to the load.
Furthermore, linear regulators operate by dropping excess voltage across their internal transistors. This dropped voltage is converted entirely into heat. The power dissipated by the regulator is calculated as:

$$P_d = (V_{in} - V_{out}) \times I_{load}$$

If the power dissipation exceeds 1W, a suitably sized heatsink must be attached to the metal tab to prevent the IC from triggering its thermal shutdown.

0.2.2 Fixed Negative Voltage Regulators: The 79xx Series

The 79xx series operates identically in principle to the 78xx series but is specifically designed to regulate *negative* voltages relative to ground. Negative voltage supplies are frequently required in analog systems, particularly those employing operational amplifiers (op-amps) which often require symmetrical dual-polarity or split-supply circuits (e.g., $\pm$12V or $\pm$15V to amplify both positive and negative AC signals symmetrically). The naming convention mirrors the positive series:

- **7905:** Provides a fixed -5V output.
- **7912:** Provides a fixed -12V output.
- **7915:** Provides a fixed -15V output.

It is absolutely critical to emphasize that the pinout configuration for the 79xx series in a standard TO-220 package is **fundamentally different** from the 78xx series. This is a common and costly pitfall for students and hobbyists. When viewing a 79xx IC from the front, the pins are assigned as follows:

1. **Pin 1 (Ground):** Connected to the common ground of the circuit.

2. **Pin 2 (Input):** Connected to the unregulated negative DC voltage source.

3. **Pin 3 (Output):** Delivers the regulated negative DC voltage to the load.

Additionally, in the 79xx series, the metal heatsink tab is internally connected to the *Input* pin (Pin 2), not Ground. If a 79xx regulator is mounted on the same grounded metal heatsink as a 78xx regulator without an insulating mica pad, it will cause a direct short circuit of the unregulated negative supply to ground. Mistaking the pinout of a 79xx regulator for a 78xx regulator will subject the internal components to reverse polarity, which will almost instantly destroy the IC.

0.2.3 Adjustable Voltage Regulator IC: LM317

While fixed voltage regulators are highly convenient, robust, and economical for standard logic voltages, many applications demand non-standard voltages or continuously variable voltages (such as in an adjustable laboratory bench power supply). The **LM317** is a legendary, highly versatile three-terminal *adjustable* positive voltage regulator capable of supplying over 1.5A of load current over a wide output voltage range, smoothly adjustable from 1.25V up to 37V.

Unlike the fixed 78xx/79xx regulators, the LM317 does not have a dedicated "Ground" pin. It is designed to be a "floating" regulator. Its three terminals are:

1. **Adjust (ADJ):** This pin is used to set the desired output voltage by connecting to the center point of an external resistor divider network.

2. **Output (V_{out}):** Provides the regulated adjustable positive voltage.

3. **Input (V_{in}):** Receives the unregulated input DC voltage.

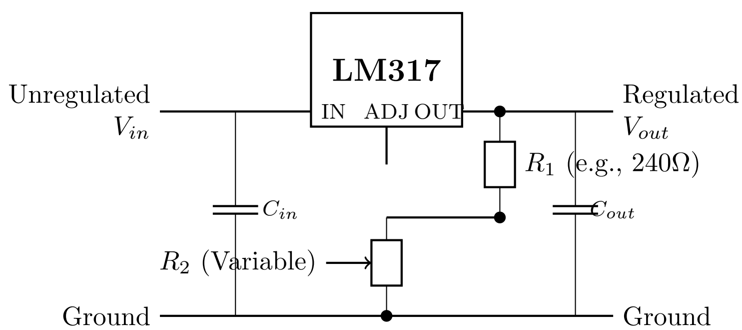

Figure 3: Typical application circuit for the LM317 adjustable voltage regulator, highlighting the R_1 and R_2 voltage divider network.

The operating principle of the LM317 relies entirely on maintaining a constant, precisely defined reference voltage of **1.25V** between its Output and Adjust pins. By connecting a fixed programming resistor (R_1, commonly chosen as 240Ω or 330Ω according to the datasheet) between the Output and Adjust pins, a constant current is forcibly established through R_1.

This exact same constant current then flows downward through the variable resistor potentiometer (R_2) connected from the Adjust pin to ground. A tiny, internal adjustment pin current (I_{adj}, typically around 50μA to 100μA) also flows out of the Adjust pin and joins the path through R_2.

The total output voltage referenced to ground is simply the sum of the voltage across R_1 (which is held rigidly at 1.25V) and the voltage drop across R_2. The mathematical formula defining the final output voltage is:

$$V_{out} = 1.25\text{V} \times \left(1 + \frac{R_2}{R_1}\right) + I_{adj}R_2 \tag{1}$$

Because the adjustment pin current I_{adj} is deliberately designed to be very small and remarkably constant over varying loads and temperatures, the term $I_{adj}R_2$ introduces only a minimal offset error. Therefore, for most practical applications, this term is ignored, and the simplified output voltage is considered to be dictated strictly by the ratio of the two resistors R_1 and R_2.

title=Calculating LM317 Resistors for a Variable Supply

Suppose we want to design a variable bench power supply using an LM317 to provide an output voltage that can be continuously adjusted up to exactly 12V. The fixed programming resistor R_1 is chosen as 240Ω. What maximum resistance value of the potentiometer R_2 is required to achieve this?

Using the simplified formula (ignoring the minimal I_{adj} error for simplicity):

$$\begin{aligned}
V_{out} &\approx 1.25 \times \left(1 + \frac{R_2}{R_1}\right) \\
12\text{V} &= 1.25 \times \left(1 + \frac{R_2}{240}\right) \\
\frac{12}{1.25} &= 1 + \frac{R_2}{240} \\
9.6 &= 1 + \frac{R_2}{240} \\
8.6 &= \frac{R_2}{240} \\
R_2 &= 8.6 \times 240 = 2064\Omega
\end{aligned}$$

Therefore, choosing a standard 2.2 kΩ linear potentiometer for R_2 will allow the output voltage to be smoothly dialed from its absolute minimum of 1.25V (which occurs when the potentiometer is turned all the way down, making $R_2 = 0\Omega$) up to slightly over 12V.

Just like the fixed series regulators, the LM317 includes comprehensive internal protections such as thermal overload protection and short-circuit current limiting, making it nearly blowout-proof. It is important to note that the LM317 also has a dropout voltage specification, meaning the unregulated input voltage must always be approximately 3V higher than the maximum desired output voltage to guarantee steady regulation under heavy load conditions.