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STRUCTURE OF A MINIATURE MODULAR POWER SUPPLY

D.E. Lekhner, student, group NEB-251 (KuzSTU)
V.E. Chernoivanenko, student, group NEB-251 (KuzSTU)
Scientific - supervisor: I.V.Graborskaya , senior lecturer of the department of foreign languages 1T.F. Gorbachev Kuzbass State Technical University, Kemerovo

This article presents an overview of power supply block diagrams, examining the main and widely used isolated and non-isolated power supply topologies, their advantages and disadvantages. Based on the analysis, a block diagram for a miniature isolated power supply (up to 25 W) for automation systems is selected.

Despite the dominance of switching power supplies in modern electronics, interest in linear and hybrid topologies not only persists but is gaining renewed significance. This is driven, on one hand, by increasingly stringent requirements for power supply quality in fields such as high-precision instrumentation, medical equipment, and high-end audio systems, where the low noise levels of linear regulators remain unattainable for conventional switching solutions. On the other hand, the issues of energy efficiency and miniaturization are becoming increasingly critical. In response, hybrid architectures that combine the high efficiency of switching preregulators with the output signal purity of linear regulators have undergone active development. Consequently, the investigation and comparison of these topologies constitute an important task for selecting the optimal circuitry capable of achieving a balance between power quality, energy efficiency, and the size and weight parameters of modern devices.

The primary objective of this work is a comparative analysis of linear and hybrid power supply topologies, enabling the identification of the characteristic advantages of each and the determination of their respective areas of effective application.

Since electronic components require stabilized DC voltage, the power supply (PS) becomes a key component of any circuit. Its characteristics determine the fundamental parameters of the entire product: size, cost, efficiency, service life, and electromagnetic compatibility.

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Within the framework of this study, the primary method employed was the analysis of theoretical sources, including scientific publications, technical documentation, and specialized literature on the subject of linear and hybrid power supplies.

Linear (transformer) power supplies - characterized by a simple design, have two key drawbacks: low efficiency (≤50%) due to excess energy dissipation as heat in the stabilizer, and large dimensions and weight due to the use of a low-frequency transformer. Switched-mode power supplies are free of these problems. They operate on a different principle: they convert the input voltage (AC-DC or DC-DC) to high-frequency power, allowing the use of compact chokes or transformers. As a result, they offer high efficiency, small size, and weight.

Switched-mode power supplies can be divided into two types: those with galvanic isolation (using a pulse transformer or dual-winding choke) and those without galvanic isolation (using chokes). This paper focuses on selecting a switching power supply design for automation systems that require galvanic isolation of system components; therefore, only linear power supplies of the first type are discussed below.

Generalized structure of a linear power supply

Before discussing specific types of stabilizers, it's helpful to understand what a classic linear power supply consists of, especially if it operates from an AC line.

Here are its main functional blocks:

1. Power transformer: Steps down the line voltage (220V) to the required level and provides galvanic isolation from the line for safety.
2. Rectifier: Typically a diode bridge that converts AC voltage to pulsating DC.
3. Smoothing filter: A large capacitor (and sometimes a choke) that smooths out pulsations after the rectifier.
4. Stabilizer: This is the heart of the power supply, the key element determining the topology. It maintains a constant voltage across the load, regardless of fluctuations in the line voltage or changes in the load current.

Main Topologies (Types) of Stabilizers

Three main stabilization schemes are used in linear power supplies.

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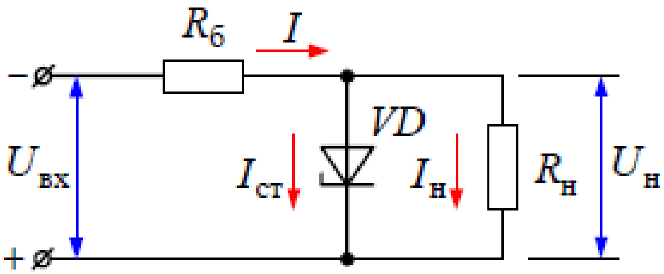
1. Parametric Stabilizer(Pictures 1):



Pictures 1 – Parametric Stabilizer

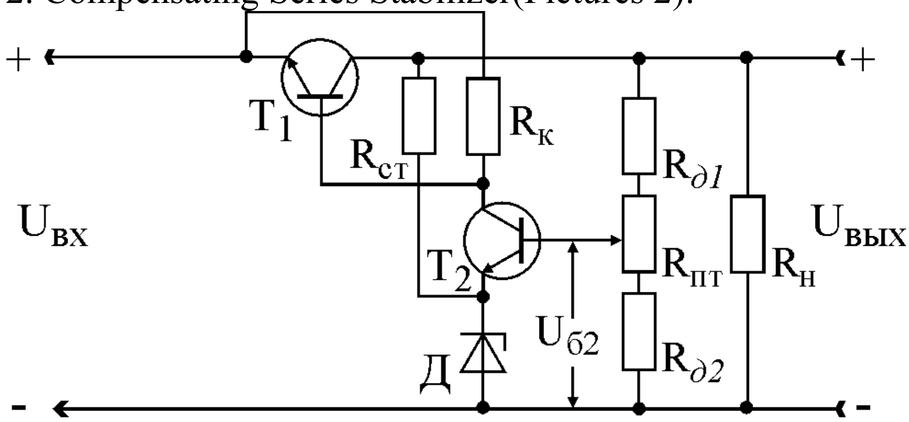
This is the simplest topology. It is based on the use of elements with a nonlinear volt-ampere characteristic—most often a zener diode.

Operating Principle: A ballast resistor absorbs excess voltage, and a zener diode connected in parallel with the load maintains a constant voltage by changing its internal resistance.

Features:

1. Very simple and inexpensive circuit.
2. Low efficiency.
3. Low output power and poor regulation.
4. Used primarily as a reference voltage source in more complex circuits or to power low-current components.

2. Compensating Series Stabilizer(Pictures 2):



Pictures 2 – Compensating Series Stabilizer

This is the most common topology for medium- and high-power linear power supplies. It is the one most often referred to when referring to a "linear stabilizer." This group also includes popular microcircuits such as the LM78xx and LM317.

Operating principle: The regulating element (transistor) is connected in series with the load. The control circuit compares the output voltage with a precise reference voltage and, if there is a difference, adjusts the resistance of this transistor. Think of it as an automatically adjustable resistor that "dampens" excess voltage.

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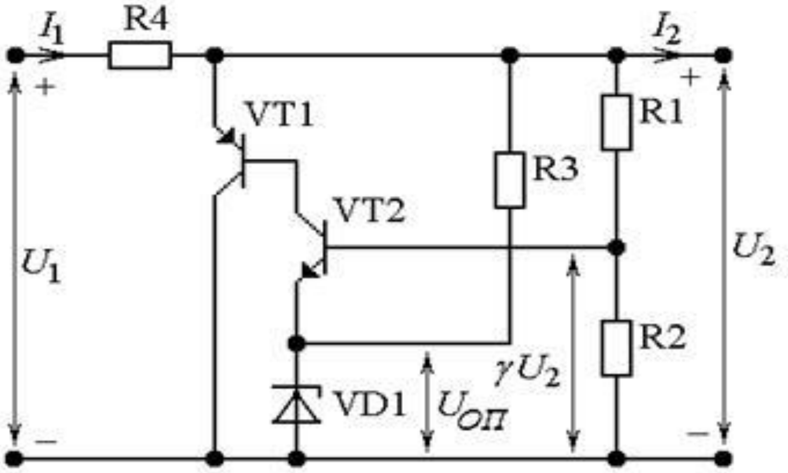
Features:
1. High output voltage accuracy and stability.
2. Low output impedance.
3. Low output noise (the main advantage over switching power supplies).
4. The greater the difference between the input and output voltage, the lower the efficiency (excess power is simply dissipated as heat in the transistor).

3. Compensating parallel regulator (shunt)(Pictures 3):



Pictures 3 – Compensating parallel regulator (shunt)

A less common topology in which the regulating element is connected in parallel with the load.

Operating principle: The transistor (or zener diode) shunts the load, diverting some of the current. To maintain a stable voltage across the load, the total current (load current + current through the regulator) always flows through the ballast resistor.

Features:
1. Very simple implementation of short-circuit protection.
2. Extremely low efficiency, especially at low load currents, since the stabilizer draws full current continuously.
3. Typically used in highly specialized applications, such as "splitting" voltage and creating a bipolar source from a unipolar one.

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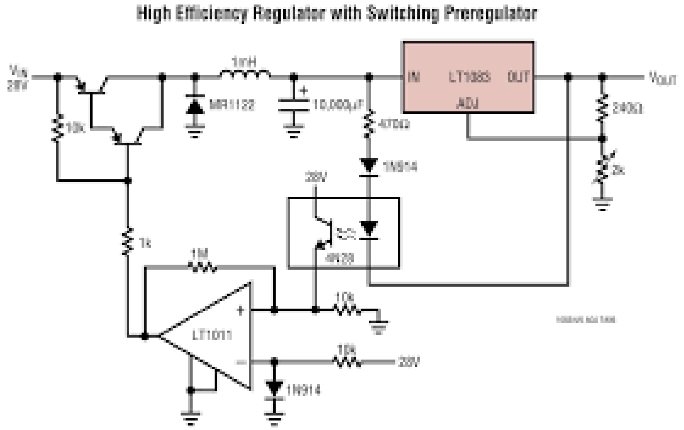
Basic Hybrid Power Supply Topologies

1. Series Hybrid: Switching Preregulator + Linear Regulator(Pictures 4):



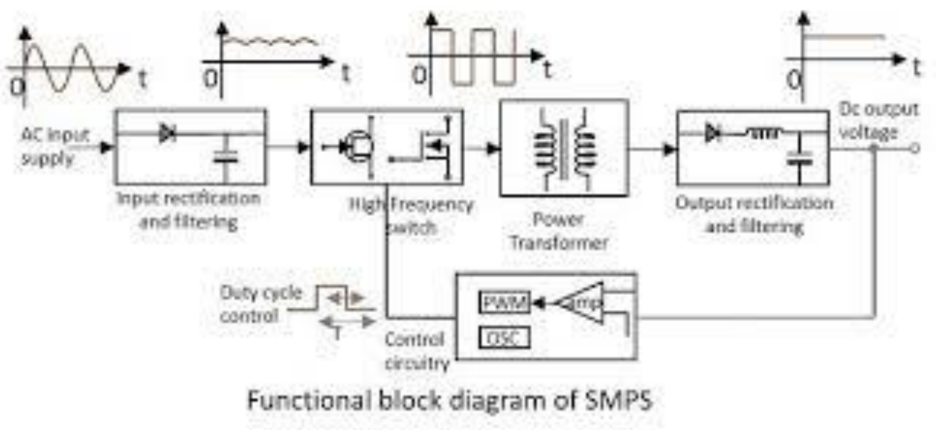
Pictures 4 – Series Hybrid: Switching Preregulator + Linear Regulator

This is the most common and commercially successful topology. It is used in modern laboratory power supplies, such as the GW Instek PLR7 series.

Operating principle: The input line voltage first enters a high-frequency switching converter. Its job is to roughly but effectively step down the voltage to a level just slightly higher than the required output voltage. This "rough" voltage is then fed to an output linear regulator (usually a series type), which trims the remaining ripple and noise, ensuring a clean and stable output voltage.

Rationale for circuit complexity: The linear regulator operates with minimal voltage drop across itself. This allows it to dissipate little heat, meaning the overall efficiency of the power supply is high (like switching circuits), while the output voltage is very clean, with low ripple (like linear circuits).

2. Parallel Hybrid: Pulse-Powered Current Source with a Linear Shunt(Pictures 5):



Pictures 5 – Parallel Hybrid: Pulse-Powered Current Source with a Linear Shunt

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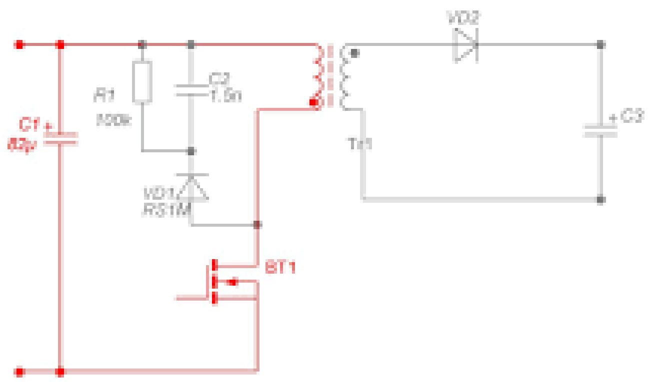
This is a more exotic and complex topology, which has been discussed on specialized forums for creating "ideal" laboratory power supplies.

Operating principle: The primary power comes from a pulse-power source operating as a current generator. A powerful linear regulator (shunt) is connected in parallel to the load, acting as a "valve," diverting excess current. The control system is designed so that the linear portion instantly responds to load changes, ensuring excellent dynamics, while the pulse-power portion "adapts" to them, maintaining overall high efficiency.

Rationale for circuit complexity: This design theoretically allows for a power source with fantastic characteristics: for example, 5 kW, while also being able to accurately handle currents in the microampere range, which is important when emulating chemical power sources (batteries). However, due to the complexity and cost of implementation, it has not achieved widespread use.

3. "DIY" Hybrid: Linear IC in Switching Mode(Pictures 6):



Pictures 6 – "DIY" Hybrid: Linear IC in Switching Mode

There are also amateur circuits that use a standard linear regulator IC (like the popular LM7805) in a switching mode rather than a linear mode.

Operating principle: The IC is used not as a pass-through element, but as a control element (PWM controller) for a high-power external transistor operating in switching mode. An inductor and a diode are added, and the circuit turns into a step-down switching converter. Interestingly, at low currents, the load can be powered directly through the IC (linear mode), and as the current increases, the circuit automatically switches to a more efficient switching mode.

Rationale for circuit complexity: This is an ingenious way to create a simple and inexpensive switching regulator with good characteristics using readily available components.

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General conclusion: Currently, a purely linear topology is obsolete due to its low efficiency and large size. However, it has an undeniable and very important advantage: complete isolation of the circuits from each other.

Therefore, efforts are currently underway to combine both linear and pulsed conversion.

Comparing the types is difficult, as each circuit is designed to solve specific problems. However, a pulsed current source with a linear shunt can be distinguished as more versatile, as it is most often used in new power supplies.

The comparative analysis of linear and hybrid power supply topologies reveals that each possesses characteristic advantages that define their respective areas of effective application. Linear power supplies, based on the series-pass compensation regulator, provide minimal output noise and ripple levels, rendering them indispensable for precision analog equipment, measurement instrumentation, and high-end audio systems. However, their limitations include low efficiency (particularly under significant input-output voltage differentials) and substantial size and weight parameters, which result from the use of low-frequency transformers and large heat sinks.

Hybrid power supplies implemented using the switching preregulator with linear output regulator architecture achieve high efficiency (up to 85–95%) while maintaining low output noise levels. This is accomplished by maintaining a minimal voltage drop across the linear regulating element. Such a solution provides an optimal compromise between energy efficiency, compactness, and output voltage quality, making it particularly valuable for modern laboratory power supplies, portable equipment, and devices incorporating both digital and analog components.

When absolute output signal purity and circuit simplicity are the primary priorities, the linear topology represents the superior choice. Conversely, when the combination of high energy efficiency, compactness, and acceptable noise levels is required, preference should be given to the hybrid topology, which currently constitutes the most balanced solution for a wide range of applications.

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