Semiconductor Technology from A to Z

Analog & Mixed-Signal Design

Voltage Regulators: LDOs and Switching Regulators

The Low-Dropout Regulator (LDO)

A low-dropout regulator (LDO) is a linear voltage regulator that controls the output voltage through a series pass transistor, whose control voltage is generated by an error amplifier comparing a reference voltage with a fraction of the output voltage taken from a resistive divider. The term low-dropout refers to the minimum voltage difference between input and output at which the pass transistor is just barely kept out of saturation and regulation breaks down; modern LDOs achieve dropout voltages of only 100 to 300 mV at load currents of several hundred milliamperes.

Because the pass transistor operates as a controllable resistor, the power dissipated in the regulator always equals the product of the voltage difference and the load current, regardless of the ratio of input to output voltage. The efficiency of an LDO therefore roughly equals the ratio V_{out}/V_{in} – converting from 3.3 V to 1.8 V, for example, gives a theoretical efficiency of only about 55 %. This purely linear operation makes LDOs particularly low-noise and fast in regulation, but inefficient at larger voltage differences.

Switching Regulators Using the Buck Converter as an Example

A switching regulator, by contrast, generates the output voltage not by continuously dissipating power in a series transistor but by periodically turning a power switch on and off at typical switching frequencies of 300 kHz to several megahertz, with its duty cycle controlled by a feedback loop. In the widely used buck converter, the switch charges an energy-storage inductor from the input voltage during the on-time; during the off-time, a freewheeling diode or a synchronous rectifier keeps current flowing through the inductor, so that the output capacitor sees a smoothed output voltage that, on average, is lower than the input voltage.

Because the switching transistor ideally passes through only two states – fully on or fully off – almost no power is dissipated in the switching element itself, allowing switching regulators to reach efficiencies of 85 to over 95 %, well above linear regulators, especially at large voltage differences between input and output.

Comparison and Typical Combination of Both Principles

The high efficiency of switching regulators comes at the cost of periodic switching noise (ripple) on the output voltage, typically a few tens of millivolts, and electromagnetic emission from the fast switching edges, while LDOs deliver a very clean, nearly noise-free output voltage with residual ripple in the microvolt to low-millivolt range, but dissipate power that grows linearly with the voltage difference. Switching regulators also require external components such as an inductor and an output capacitor, whereas an LDO can often be fully integrated on the chip.

In practice, both principles are frequently combined: a switching regulator efficiently steps the input voltage down to an intermediate voltage only slightly, often just 200 to 500 mV, above the required output voltage, and a downstream LDO then smooths out the remaining switching noise, providing a low-noise supply for sensitive analog circuit blocks such as PLLs or data converters.