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LINEAR REGULATORS (LDO)

A linear regulator drops a higher voltage to a fixed lower one by burning the difference as heat. Dropout, the dissipation that sets a thermal limit, and when an LDO is right.

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A linear regulator, or LDO, turns a higher voltage into a fixed lower one by acting as a smart, self-adjusting resistor. It is simple and quiet, but the voltage it drops leaves as heat, and that heat sets a hard limit on how much it can do. This is the design-depth version of the Fundamentals power and heat lesson.

HOW AN LDO HOLDS ITS OUTPUT

An LDO watches its own output and continuously adjusts a pass transistor to hold that output at a fixed voltage, no matter how the input wanders or the load shifts. The `3.3 V` AP2112K on an L1.01 board does exactly this, taking a `5 V` USB input down to a steady `3.3 V`.

DROPOUT: THE MINIMUM YOU MUST GIVE IT

An LDO needs the input to sit at least a little above the output to keep regulating. That minimum gap is the dropout voltage. The AP2112K needs about `250 mV` of headroom at full load (Diodes AP2112). Give it less and the output falls out of regulation and follows the input down. Low-dropout means that gap is small, which is what lets a `3.3 V` LDO run from a `3.7 V` cell.

DISSIPATION: WHERE THE HEAT COMES FROM

An LDO passes the full load current while dropping the voltage difference across itself, so it burns that difference times the current as heat, every second. Drop `1.7 V` at `200 mA` and the regulator sheds `0.34 W`. Raise either the drop or the current and it runs hotter.

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

CALCULATOR · LDO HEADROOM + DISSIPATION CALCULATOR (LINEAR REGULATOR)

Check a linear regulator's headroom against its dropout and find the power it dissipates as heat, from Vin, Vout, dropout, and load current.

Interactive calculator: academy.onethousanddrones.com/tools/ldo-headroom

CHECK AN LDO'S HEADROOM AGAINST ITS DROPOUT AND FIND THE HEAT IT DISSIPATES.

THE THERMAL LIMIT

That heat raises the chip's temperature above the air around it, by an amount set by its junction-to-ambient thermal resistance from the datasheet. A small SOT-23-5 package has a high thermal resistance and little copper to shed heat into, so an LDO's real ceiling is thermal: the point where the die would exceed its rated temperature. It is the same relationship the Fundamentals power and heat guide sets out.

$$Tj = Ta + P \times R(theta\text{-}JA)$$

AN LDO BURNS (VIN MINUS VOUT) TIMES THE LOAD CURRENT AS HEAT.

DEEP DIVE · WHEN AN LDO IS EXACTLY THE RIGHT PART

An LDO is the correct choice in three cases. When the drop is small, the wasted power is small, so a 3.3 V LDO from a 3.7 V cell is efficient. When the current is low, even a larger drop makes little heat. And when a rail feeds noise-sensitive analog parts, an LDO's quiet, ripple-free output beats a switching regulator's chopped one. Reach for a switcher when the drop is large and the current is high; reach for an LDO when the drop is small, the current is low, or the rail must be clean.

- Diodes Incorporated. AP2112 600mA CMOS LDO Regulator datasheet (dropout, thermal resistance, SOT-23-5). diodes.com
- Texas Instruments. Understanding the Terms and Definitions of LDO Voltage Regulators (SLVA079). ti.com

CHECKPOINT

1. What limits how much an LDO can step down at high current?

a. The heat from (Vin minus Vout) times the current

b. The value of its output capacitor

c. Its dropout voltage alone, no matter the current

ANSWER · A

The dropped voltage times the current becomes heat, and the thermal ceiling is the real limit.

2. What is an LDO's dropout voltage?

a. The output voltage it produces

b. The minimum input-to-output gap it needs to keep regulating

c. The maximum current it can pass

ANSWER · B

Below the dropout the output falls out of regulation and follows the input down.

3. When is an LDO a good choice?

a. A large drop at high current

b. A small drop, low current, or a rail that must be quiet

c. Whenever efficiency is the top priority

ANSWER · B

Small drop, low current, or a noise-sensitive rail: those favor an LDO over a switcher.

- Prerequisite: power and heat
- Calculate it: the LDO headroom calculator
- Next: buck regulators (step-down)