

# Linear or switching regulator: which one to choose



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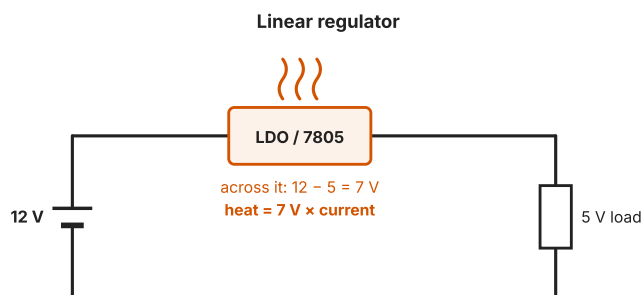
There are two ways to bring a voltage down: burn off the difference as heat, or “chop it up” with a fast switch. How they work, how hot they get, how much is lost, with the calculations already done.

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## IN SHORT

- A **linear** regulator (7805, AMS1117, LDO) lets through the same current that goes out and turns the extra voltage into **heat**: simple and quiet, but it wastes a lot when the difference is large.
- A **switching** regulator (buck, step-down) turns a switch on and off thousands of times per second: it loses little (often 80–90 % efficiency) but leaves a small **ripple** on the output.
- Rule of thumb: heat in a linear regulator = **(Vin – Vout) × current**. If it goes above a few tenths of a watt, consider a switching one.
- Every regulator needs a minimum margin between input and output (**dropout**): a 3.3 V AMS1117 wants at least about 4.6 V.

## How a linear regulator works

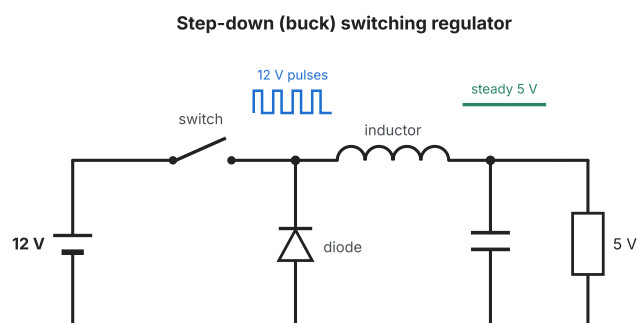


The current in equals the current out: the extra voltage is lost as heat.

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Inside there is a transistor that acts as an adjustable resistor: it opens or closes as much as needed to hold the output steady. The current going out is (almost) the same as the current coming in, so the “leftover” voltage stays across the regulator and becomes heat. The advantage is a very clean output: the noise of a 7805 is a few tens of microvolts.

## How a switching regulator works



The switch is on only part of the time: energy flows in packets and little is lost.

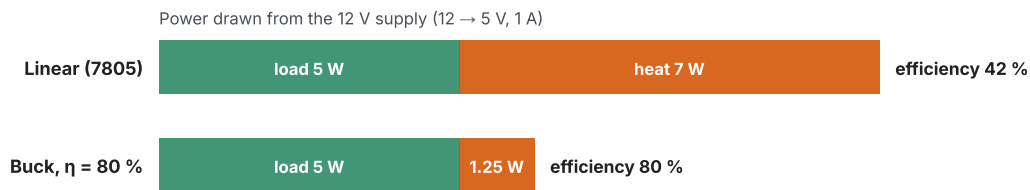
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Here the transistor is used as a **switch**: fully on or fully off, so it gets only slightly warm. The ratio between the on time and the period (duty cycle) sets the voltage: to go from 12 to 5 V it stays on about 42 % of the time. The inductor and the capacitor turn the pulses into a DC voltage; the diode (or a second transistor) closes the circuit while the switch is open.

## How much is lost: the calculation

For a linear regulator the heat is  $P = (V_{in} - V_{out}) \times I + V_{in} \times I_q$ , where  $I_q$  is the current the regulator uses for itself; efficiency is about  $V_{out} \div V_{in}$ . For a switching regulator you start from the stated efficiency: the

losses are  $P_{out} \times (1 \div \eta - 1)$ .

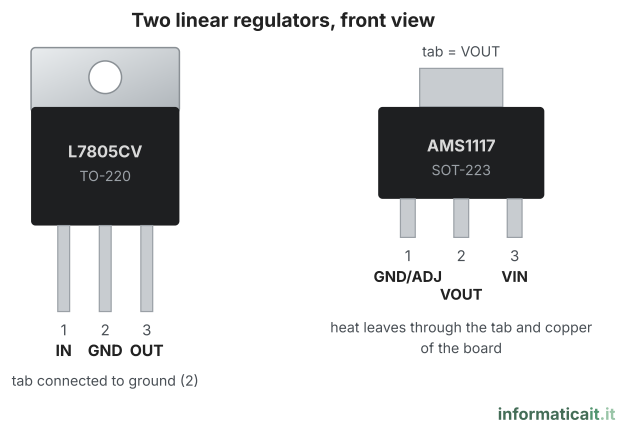


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**Example: 12 V → 5 V, 1 A.** The load uses  $5\text{ V} \times 1\text{ A} = 5\text{ W}$ . With a 7805,  $12 - 5 = 7\text{ V}$  are left across the regulator, that is **7 W of heat** (plus about 0.1 W for its internal current): efficiency around 42 %. With a switching regulator at 80 % (the efficiency TI states for the LM2596 from 12 to 5 V at 3 A) the losses are  $5 \times (1 \div 0.8 - 1) = 1.25\text{ W}$ .

## How hot it really gets

The chip temperature is  $T_J = T_{ambient} + P \times \theta_{JA}$ , where  $\theta_{JA}$  (in  $^{\circ}\text{C/W}$ ) is the thermal resistance from the package to the air, given in the datasheet. The limit for the AMS1117 is  $125\text{ }^{\circ}\text{C}$ .



**Example: AMS1117 from 5 V to 3.3 V at 0.5 A,** SOT-223 package ( $\theta_{JA} = 90\text{ }^{\circ}\text{C/W}$  according to the AMS datasheet, less if there is plenty of copper on the board).  $P = 1.7\text{ V} \times 0.5\text{ A} + 5\text{ V} \times 5\text{ mA} \approx 0.88\text{ W} \rightarrow$  the chip rises by about  $79\text{ }^{\circ}\text{C}$ : at  $25\text{ }^{\circ}\text{C}$  ambient it reaches  $104\text{ }^{\circ}\text{C}$ , close to the limit. The same regulator from 12 V to 3.3 V at 0.5 A would have to dissipate 4.35 W: impossible without reducing the current.

Where the heat goes. The TI 7805 datasheet gives input, ground and output on pins 1, 2, 3; the AMS1117 in SOT-223 has its tab connected to the output and gets rid of the heat through the copper on the board.

## Linear and switching compared

|                          | Linear (7805, AMS1117, LDO)                                                | Switching (buck)                                                  |
|--------------------------|----------------------------------------------------------------------------|-------------------------------------------------------------------|
| Efficiency               | about $V_{out} \div V_{in}$ : good only with a small difference            | usually 80–90 % or more                                           |
| Heat                     | $(V_{in} - V_{out}) \times I$                                              | little: the losses are a small part of the power                  |
| Output noise             | tens of $\mu\text{V}$ (7805: 40 $\mu\text{V}$ ; AP2112: 50 $\mu\text{V}$ ) | ripple of 0.5–3 % of $V_{out}$ (LM2596), that is 25–150 mV at 5 V |
| Output higher than input | impossible                                                                 | possible with step-up converters                                  |
| Components               | the regulator and two capacitors                                           | inductor, diode, capacitors, more critical layout                 |
| No-load current          | from 1.6 $\mu\text{A}$ (MCP1700) to 5 mA (AMS1117)                         | from a few tens of $\mu\text{A}$ to a few mA (LM2596: 5–10 mA)    |

## Some common regulators (datasheet figures)

| Regulator | Type   | Input            | Current | Typical dropout            | Quiescent current |
|-----------|--------|------------------|---------|----------------------------|-------------------|
| AMS1117   | linear | up to 15 V       | 1 A     | 1.1 V (1.3 V max) at 0.8 A | 5 mA              |
| LM7805    | linear | from 7.5 to 35 V | 1.5 A   | 2 V at 1 A                 | 8 mA max          |
| MCP1700   | LDO    | 2.3–6 V          | 250 mA  | 178 mV at 250 mA           | 1.6 $\mu$ A       |
| AP2112    | LDO    | 2.5–6 V          | 600 mA  | 250 mV at 600 mA           | 55 $\mu$ A        |
| LM2596    | buck   | up to 40 V       | 3 A     | $\approx$ 1.3 V at 3 A     | 5–10 mA           |
| XL4015    | buck   | 8–36 V           | 5 A     | —                          | 2.1 mA            |

## Which one to choose

- **Linear:** small difference (5  $\rightarrow$  3.3 V), low current (up to a few hundred mA), or when you need a clean output for analog sensors, ADCs and audio.
- **LDO with low dropout and low quiescent current** (MCP1700, AP2112): from a lithium battery (3.0–4.2 V) to 3.3 V, where the AMS1117 can't cope.
- **Switching:** from 12 or 24 V down to 5 or 3.3 V, currents of an amp and up, battery projects where every watt counts.
- **Both together:** a switching regulator that brings the voltage close to the final value, followed by an LDO that cleans up the ripple (this is the solution TI describes for noise-sensitive circuits).

## Common mistakes

| What happens                                       | Why                                                                                   | Fix                                                  |
|----------------------------------------------------|---------------------------------------------------------------------------------------|------------------------------------------------------|
| The 3.3 V from a lithium battery sags or “wobbles” | AMS1117 powered at 3.7–4.2 V: it needs about 1.1–1.3 V of margin                      | low-dropout LDO (MCP1700, AP2112) or a buck-boost    |
| The 7805 gets very hot and then shuts down         | 12 $\rightarrow$ 5 V at 1 A = 7 W: the thermal protection kicks in                    | a suitable heat sink, or a switching regulator       |
| Unstable analog readings                           | switching ripple on the supply of the ADC or the sensor                               | filter or LDO after the switching regulator          |
| The battery drains even when idle                  | regulator with high quiescent current (the AMS1117's 5 mA add up to 120 mAh a day)    | low-power LDO                                        |
| Unstable output with almost no load                | the AMS1117 needs a minimum load of 10 mA for the stated regulation                   | minimum load resistor or a different regulator       |
| The switching regulator doesn't regulate           | input too close to the output (below its dropout) or below the chip's minimum voltage | check the minimum $V_{in}$ in the module's datasheet |

**In practice.** The Arduino UNO already has a linear regulator after the barrel jack: powered at 12 V, it gets hotter the more current the modules on its 5 V pin draw. An ESP32 powered from 12 V is the typical case for a step-down. For a precision analog sensor or an ADS1115, a clean linear supply is the better choice.

**Sources:** Texas Instruments, SNVA558 “Linear and Switching Voltage Regulator Fundamentals”, SNVA559C “Switching regulator fundamentals”, SLVA079 (LDO terms), SNVA871 (DC/DC noise filtering) · Advanced Monolithic Systems, AMS1117 datasheet; Texas Instruments, LM340/LM7805 (SNOSBT0L) and LM2596 (SNVS124G) · Microchip, MCP1700 (DS20001826E); Diodes Inc., AP2112 (DS39724); XLsemi, XL4015 Rev 2.0