

Step-down, step-up and buck-boost: choosing the right module

Lowering, raising or holding steady a voltage that changes: which converter you need, how to adjust it and which numbers to check before buying. With the current and efficiency math already worked out.

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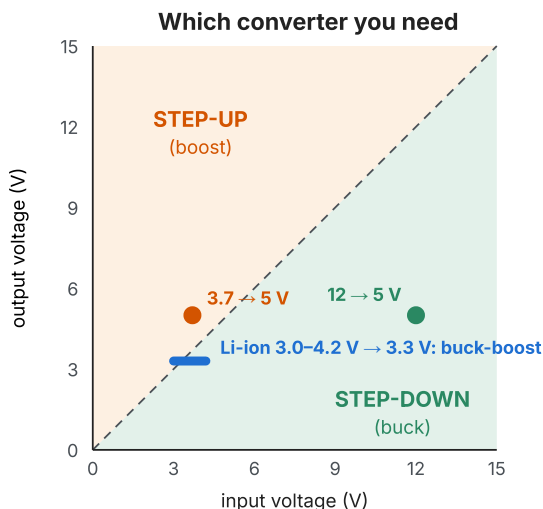


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IN SHORT

- **Step-down (buck):** output lower than the input, from 12 V to 5 V. **Step-up (boost):** output higher, from a 3.7 V battery to 5 V. **Buck-boost:** the input can be above or below the output.
- Power is not created: in a boost the **current drawn from the battery is higher** than the current that comes out.
- There are four numbers to look at: **minimum and maximum input voltage**, the real **output current** (not the switch rating), **efficiency** and heat.
- An adjustable module **is set with no load, using the multimeter**, before you connect the board to it.

Which one you need

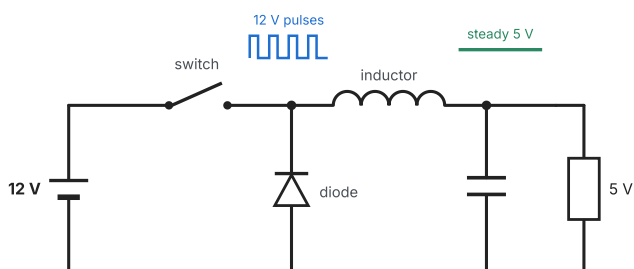


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If the input is always higher than the output, a step-down is enough; if it is always lower, a step-up. The in-between case is the lithium battery: it goes from 4.2 V when charged to 3.0 V when flat, so to get a steady 3.3 V it moves from above to below. That is where you need a **buck-boost** (or a low-dropout LDO, accepting that you lose the last part of the charge).

Step-down: how it works

Step-down (buck) switching regulator



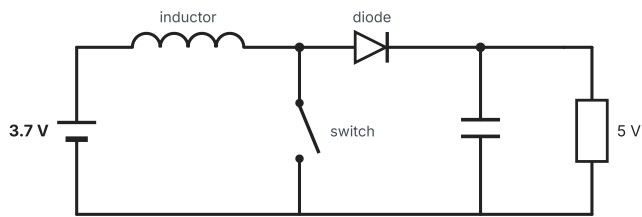
The switch is on only part of the time: energy flows in packets and little is lost.

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The switch stays on for part of the period, the **duty cycle**. In the ideal case $V_{out} = D \times V_{in}$: to get 5 V from 12 V it stays on about 42 % of the time. The output current can be higher than the current going in.

Step-up: how it works

Step-up (boost) regulator



Input current is higher than output current: power is not created, only converted.

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Here the switch connects the inductor to ground: it charges, then when the switch opens its voltage adds to the input voltage and goes through the diode to the output. In the ideal case $V_{out} = V_{in} \div (1 - D)$: from 3.7 to 5 V the duty cycle is about 26 %.

A confusing word. Texas Instruments also uses "buck-boost" for the circuit that gives a **negative** output. The modules sold to makers as buck-boost (for example the Pololu S7V8F5) keep the same polarity instead: always check the datasheet.

Working out the current

Output power = $V_{out} \times I_{out}$. Power taken at the input = output power $\div$ efficiency. So $I_{in} = V_{out} \times I_{out} \div (\eta \times V_{in})$.

Step-down from 12 V to 5 V, 2 A (assuming 85 % efficiency, the order of magnitude given for the LM2596 and XL4015 in their datasheets): the load uses 10 W, the power supply delivers $10 \div 0.85 = 11.8$ W, that is **about 1 A at 12 V**; 1.8 W stays in the module as heat.

Step-up from a battery to 5 V, 1 A (same 85 % efficiency): you need 5.9 W. With the battery charged at 3.7 V that is **1.6 A**; when it drops to 3.0 V it becomes **almost 2 A**. This is why a "2 A" boost does not give 2 A at the output: the number is usually the switch limit, which carries the input current plus the inductor ripple.

The adjustable module

A typical adjustable module



Generic drawing: terminal names and positions change between modules, read the marking on yours.

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Almost all adjustable modules have four terminals (input + and -, output + and -), a chip, an inductor and a **trimmer** that changes the feedback divider: $V_{out} = V_{ref} \times (1 + R2 \div R1)$, with V_{ref} given in the chip datasheet (1.25 V for the XL4015, 0.6 V for the MT3608, 0.8 V for the MP1584).

How to adjust it without breaking anything

- 1 Connect only the input supply, no load.
- 2 Put the multimeter on the output terminals, set to DC voltage.
- 3 Turn the trimmer slowly until you reach the value you need; with a multi-turn trimmer it can take several turns before you see any change.
- 4 Switch off, connect the load, switch back on and check again: under load the voltage can drop a little.

Common chips and modules (datasheet figures)

	Type	Input	Output	Current	Frequency
LM2596	step-down	up to 40 V	1.2–37 V	3 A	150 kHz
XL4015	step-down	8–36 V	1.25–32 V	5 A	180 kHz
MP1584	step-down	4.5–28 V	0.8–25 V	3 A	100 kHz–1.5 MHz
MT3608	step-up	2–24 V	up to 28 V	switch limited to 4 A	1.2 MHz
Pololu S7V8F5	buck-boost	2.7–11.8 V	fixed 5 V	0.5 to 1 A depending on voltage	—
Pololu U1V10F5	step-up	0.5–5.5 V	fixed 5 V	switch 1.2 A	—

The MP1584 is marked by the manufacturer as “not recommended for new designs” (replacement: MP2338). The MT3608 datasheet is not published on the manufacturer's website: the figures come from a copy distributed by Olimex.

Things to check before buying

- **Minimum input voltage.** Every chip has a threshold below which it shuts down (MP1584: 3.0 V; the XL4015 needs at least 8 V), and a step-down needs some headroom above the output: the LM2596 loses about 1.3 V at 3 A.
- **Real output current.** On boost modules the big number on the package is often the switch rating; the output current is lower.
- **Efficiency.** It changes with input voltage and load: the Pololu D24V10F5 goes from about 92 % at 9 V to about 84 % at 32 V.
- **Heat.** Even at 90 %, a module delivering 20 W dissipates about 2 W: Pololu warns that its regulators can get hot enough to burn you.
- **Polarity.** Many modules are not protected against reversed input wires.
- **Spikes at power-on.** With long cables and high input voltages, overvoltage spikes can occur: above 20 V Pololu recommends a 33 µF electrolytic capacitor close to the input (D24V10F5).

Common mistakes

What happens	Why	Fix
Board burned as soon as it is connected	trimmer left at maximum: the output was almost at the input voltage	always adjust with no load, using the multimeter
The step-up shuts down or the battery “dies” early	current drawn from the battery higher than expected, especially when it is nearly flat	redo the math with the battery's minimum voltage
Step-down that does not regulate	input too close to the output or below the chip threshold	choose a buck-boost or raise the input
ESP32 that resets while transmitting	the converter cannot handle the current peaks	a module with more headroom and a capacitor on the output
Noisy analog readings	switching ripple on the sensors' supply	a filter or an LDO after the converter

Use cases. ESP32 or Arduino from a 12 or 24 V power supply: step-down. Lithium battery project with a 5 V module: step-up. 3.3 V sensor from a lithium cell that discharges: buck-boost. Solar panel with variable voltage: check the input range.

Sources: Texas Instruments, SLVA477C (calculating the power stage of a buck), SLVA372D (boost), SNVA559C “Switching regulator fundamentals” · Texas Instruments, LM2596 datasheet (SNVS124G); XLSemi, XL4015 datasheet Rev 2.0; MPS, MP1584 datasheet Rev 1.0 · Aerosemi, MT3608 datasheet (copy distributed by Olimex) · Pololu, product pages for S7V8F5, D24V10F5 and U1V10F5 (data and graphs)