

# THE ADC: READING AN ANALOG VOLTAGE

*How an ADC turns a voltage into a number, what resolution and reference voltage set, and how the ESP32's attenuation stretches its range toward 3.3 V. With a divider calculator.*

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An ADC, for analog-to-digital converter, turns a voltage into a number the program can read. Its resolution sets how finely it splits the range, its reference sets the top of that range, and on the ESP32 an attenuation setting stretches the range toward the **3.3 V** rail. A plain GPIO reads only high or low; the ADC reads everything in between.

## RESOLUTION: BITS BECOME STEPS

An ADC with **N** bits splits its input range into two-to-the-**N** steps. The ESP32's is 12-bit, so it splits the range into **4096** steps. Each step is the smallest voltage change the converter can tell apart, its least-significant bit, or LSB. More bits mean finer steps and a more precise reading.

$$V_{\text{lsb}} = V_{\text{ref}} / 2^N$$

## REFERENCE AND RANGE

The reference voltage is the input that reads full scale, the very top step. The ESP32's raw ADC range is small (its internal reference is about **1.1 V**), so it offers attenuation settings that scale the incoming voltage down first, which extends the usable input range to roughly **0** to **3.1 V** at the highest attenuation, close to the rail (ESP32-S3 datasheet, ADC characteristics). Pick the attenuation for the voltage you expect to measure, and the reading uses the whole range instead of a sliver of it.

- [Espressif. ESP32-S3 Series Datasheet \(ADC characteristics: attenuation and measurable input range\).](#) [espressif.com](#)

## SCALING A BIGGER VOLTAGE IN

To read a voltage above the ADC's range, a battery above the rail for instance, put a voltage divider in front of the input to bring it down into range. The ADC pin draws almost no current, which is exactly the light, high-impedance load a divider needs to hold its ratio. Scale the voltage down by a known fraction, read it, and multiply back in firmware.

**CALCULATOR · VOLTAGE DIVIDER CALCULATOR (VOUT, R1, R2)**

Compute a resistive divider's output voltage and quiescent current from  $V_{in}$ ,  $R_1$ , and  $R_2$ . Sized for fitting a higher voltage into an ESP32's 3.3 V ADC.

Interactive calculator: [academy.onethousanddrones.com/tools/voltage-divider](https://academy.onethousanddrones.com/tools/voltage-divider)

SCALE A HIGHER VOLTAGE DOWN INTO THE ESP32'S ADC RANGE.

**DEEP DIVE · CLEANING UP THE READING IN FIRMWARE**

The raw number an ADC hands back jitters a little, from electrical noise and the converter's own offset. Two cheap habits fix it. First, average: read the pin several times in a row and take the mean, and the random jitter shrinks.

Second, calibrate: measure the known error once against a trusted meter, store it, and correct every future reading.

Espressif's ESP-IDF ships an ADC calibration API for exactly this, so the hardware sets the ballpark and a few lines of firmware make it accurate. This is the same averaging idea the voltage-dividers guide uses.

- [Espressif. ESP-IDF Programming Guide: ADC Oneshot Mode \(attenuation config, ADC calibration API\)](https://docs.espressif.com). docs.espressif.com

A VOLTAGE BECOMES A NUMBER: THE REFERENCE MARKS FULL SCALE, THE BITS SET THE STEP SIZE.

- [SparkFun. Analog to Digital Conversion tutorial \(resolution and reference voltage\)](https://learn.sparkfun.com). learn.sparkfun.com

**CHECKPOINT****1. What sets the top of an ADC's input range?**

- The number of bits it has
- Its reference voltage, and on the ESP32 the attenuation setting**
- The length of the wire to the sensor

ANSWER · B

*The reference (scaled by the ESP32's attenuation) sets full scale; the bit count sets how fine each step is, while the reference sets the top.*

**2. A 12-bit ADC splits its input range into how many steps?**

- 4096**
- 12
- 144

ANSWER · A

*Two to the twelfth is 4096 steps.*

**3. To read a voltage higher than the ADC's range, what do you add in front of it?**

- A larger battery
- A second ADC
- A voltage divider to scale it down**

ANSWER · C

*A divider brings the voltage into range, and the high-impedance ADC input is the light load a divider needs.*

- Prerequisite: voltage dividers
- Calculate it: the voltage divider calculator
- Next: PWM, a fake analog output