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ADC Noise In A Raspberry Pi Pico Under Breadboard Interference

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***Abstract*— This paper measures analog-to-digital converter noise on a Raspberry Pi Pico built around the RP2040 microcontroller. A resistive divider created a fixed mid scale input voltage near 1.65 V. Each run captured 5000 samples at 500 µs spacing and computed the mean and standard deviation. Three bench conditions served as test cases. The first used only USB power from a desktop computer. The second placed a laboratory supply on the breadboard rails without electrical connection to the Pico. The third added a 0.1 µF ceramic capacitor from the ADC node to ground. The external supply raised the standard deviation by about fifteen percent relative to baseline. The capacitor reduced noise by roughly one half. These results show that simple wiring choices and nearby equipment alter ADC statistics in repeatable ways.**

Keywords—ADC, RP2040, Raspberry Pi Pico, noise measurement, breadboard interference, input filtering

1. Introduction

Low cost microcontrollers appear in teaching labs and early prototypes. Many projects rely on built in ADC blocks for voltage sensing. Breadboards and USB cables simplify assembly but introduce coupling paths for electrical interference. Engineers often assume that a stable DC source and short wires provide clean measurements. This work tests that assumption with controlled bench experiments.

The study asks three questions and answers each through repeated trials. Does a nearby power supply alter ADC noise statistics. Can loose conductors near the input node create spikes. Does a small ceramic capacitor at the input node reduce those effects.

2. Mathematical Formulation

The ADC converts an input voltage **Vin** into a digital code:

$$V_{in} = \frac{Code}{2^N - 1} \cdot V_{ref}$$

Each run collected **N=5000** samples **xi**.
The sample mean:

$$\mu = \frac{1}{N}\sum_{i=1}^{N} x_i$$

The unbiased sample standard deviation:

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \mu)^2}$$

Noise change between two conditions:

$$\Delta_{\%} = \frac{\sigma_2 - \sigma_1}{\sigma_1} \times 100$$

Noise reduction from the capacitor:

$$R_{\%} = \frac{\sigma_{\text{no cap}} - \sigma_{\text{cap}}}{\sigma_{\text{no cap}}} \times 100$$

3. Experimental Setup

3.1 Hardware

The test platform used a Raspberry Pi Pico with an RP2040 microcontroller. USB power came from a desktop computer. Two 100 kΩ resistors formed a divider from the 3.3 V rail to ground. The midpoint node fed GP26 or ADC0. A 0.1 µF ceramic capacitor connected from that node to ground during selected trials. A bench power supply connected only to the breadboard rails and never to the Pico.

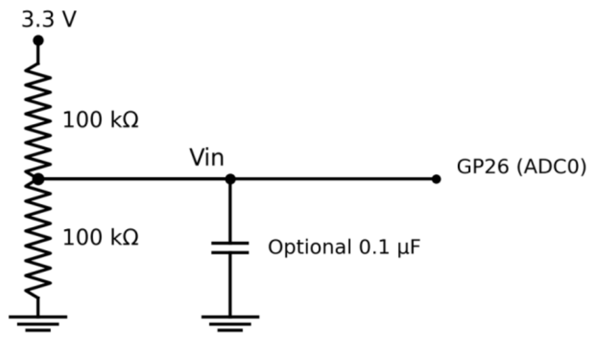

Figure 1. Divider network, ADC pin, and optional capacitor connection.

3.2 Procedure

A MicroPython script sampled the ADC every 500 µs. Each run stored 5000 values and printed the standard deviation and range. The wiring layout stayed fixed within each test block.

Three test conditions ran for twenty measurements each.

- Baseline without external supply or capacitor
- External supply present on the rails without capacitor
- External supply present with the 0.1 µF capacitor

4. Results

Baseline trials produced a mean standard deviation near 102 counts. Placing the external supply on the rails raised that value to about 117 to 118 counts. That change equals roughly a fifteen percent increase.

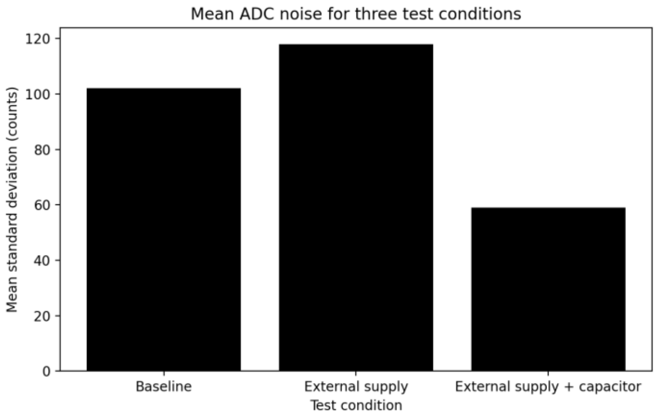

Figure 2. Boxplot of standard deviation for all three conditions.

Adding the 0.1 µF capacitor dropped the standard deviation to about 58 to 59 counts. That drop equals about fifty percent relative to baseline and close to sixty five percent relative to the disturbed case.

Condition	**Mean σ (counts)**
Baseline	~102
External supply	~118
External supply + capacitor	~59

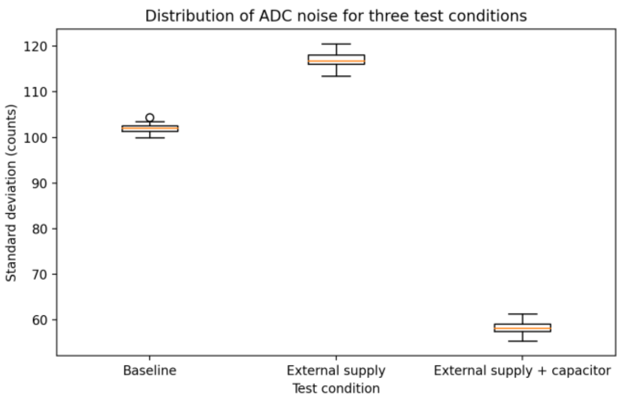

Figure 3. Histogram of ADC codes for baseline and disturbed cases.

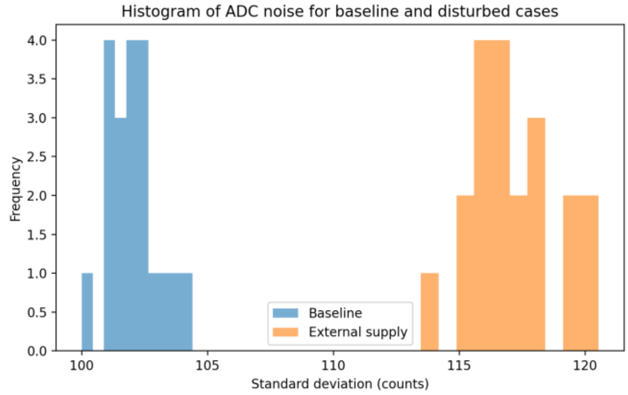

Figure 4. Mean standard deviation with error bars across repeated runs.

5. Discussion

The nearby power supply increased ADC noise even though it never powered the Pico. Breadboard rails and jumper wires formed paths for coupled interference. Earlier trials showed spikes when loose conductors approached the ADC node. The ceramic capacitor shunted high frequency components to ground and stabilized that node. That single part cut noise by more than half.

Repeated runs under fixed geometry produced consistent clusters of values. That pattern supports repeatability within this bench layout.

6. Conclusions

Breadboard wiring and nearby power equipment change ADC noise on a Raspberry Pi Pico. A laboratory supply raised the standard deviation by about fifteen percent when placed on the same rails. A single 0.1 µF ceramic capacitor at the ADC input reduced noise by roughly one half. These results support routine input filtering during bench measurements and early prototypes.

Patents

No patents result from the work reported in this manuscript.

Supplementary Materials:
Supplementary materials are available with this manuscript. Figure S1: Extended histograms for all entropy sources. Table S1: Full statistical metrics for each dataset.

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