Technical Design Report

Parallax

A simple data acquisition system

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Todo list

1 Hardware Design

1.1 Introduction

This chapter explains the hardware details of the measurement system, aiming to provide a clear understanding of why and how the hardware was designed. In principle the purpose of the measurement hardware is to map analog voltages from a wide input range to a smaller input range, which then can be measured using the PR2040 Microcontroller of the Raspberry Pi Pico Microcontroller board.

1.1.1 Measuring analog voltages

The core component of the data acquisition is the PR2040 Microcontroller which includes built-in Analog-to-Digital Converters(ADC). These ADCs convert electronic voltages ranging from Ground (0 V) to a reference voltage U_{ref} into a digital number defined by the resolution which is depicted in bits. The resolution for all the ADCs in the RP2040 IC is set to 12 bits, meaning that the digital result from an ADC is in between 0 and $2^{12} = 4096$. Within this conversion the mapping from the analog input voltage to a corresponding digital number should be proportional but has small uncertainties which are defined by the resolution as seen in Fig. 1.1. This picture also clearly shows that a value acquired by an ADC has an uncertainty of half the voltage to which the least significant bit (LSB) corresponds. This can be calculated as:

$$\sigma = \pm U_{ref} \cdot \frac{1}{2} \cdot \frac{1}{2^{resolution}} = \pm U_{ref} \cdot 2^{-(resolution+1)} \,.$$

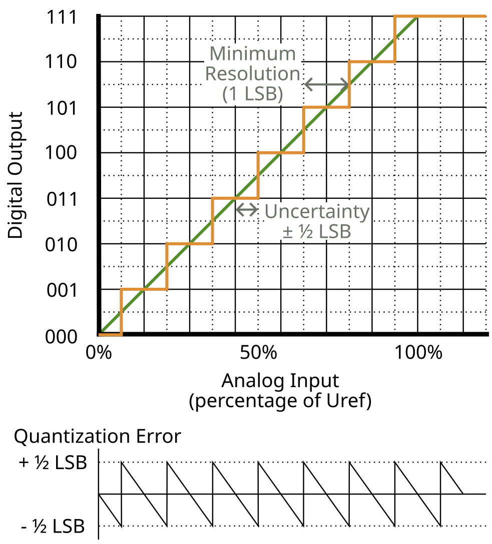

Figure 1.1: Conversion from an analog voltage do a digital number with an ADC

In reality there are multiple reasons for small short time fluctuations in the voltage which are greater than the quantization uncertainty of an ADC. Therefore the propper uncertainty of an

ADC in an electronic application can be measured with a calibration. The data sheet explains that four ADC channels (ADC0 to ADC3) are connected to GPIO Pins and the fifth ADC channel (ADC4) is connected to an internal temperature sensor. Notably the fourth channel ADC3 can be used to measure the VSYS voltage of the Raspberry Pi Pico board. Each channel is linked to a single Analog-to-Digital Converter (ADC) through an internal switch, allowing the selection of one channel at a time. The shared ADC operates with a maximum sampling rate of 500 kilosamples per second (KSps). This sampling rate can be used for measuring voltages on a single channel at the full sampling speed (simplex). Alternatively, it can simultaneously measure two channels by periodically switching between them, effectively dividing the sampling rate to 250 KSps per channel. The accuracy and the sampling rate are sufficient to use this as the core of a simple oscilloscope which acquires periodically ADC values and streams the data to another device for further processing.

An ADC can only measure voltages between $0\,\mathrm{V}$ and U_{ref} but we want to build an oscilloscope that can measure positive and negative voltages $\pm U_{max}$ within a range of p.ex. $U_{max} > 10\,\mathrm{V}$. It is the task of an analog front-end to map voltages from $-U_{max}$ to $+U_{max}$ into an analog voltage which is suitable for the ADC. Furthermore the range of the input voltage should be selectable and there should be some kind of over-voltage protection on the signal inputs. This allows to measure for higher voltages with less precision or lower voltages with higher precision.

1.1.2 Prerequisites

In order to discuss the structure of the analog front-end and the corresponding voltage ranges for the oscilloscope some basic knowledge in electronics engineering is assumed. This contains the following topics:

- The definition of Charge, Voltage and Current
- The definition of the electrical resistance, Ohms law and resistors as electrical components
- Capacitance and capacitors as electrical components
- The usage of a Diode and a Z-Diode
- A mathematical understanding of Reactance and Impedance, this will also be explained briefly when it comes up

1.2 Voltage Divider

One of them most important circuits in electronics is the voltage divider as depicted in Fig. 1.2. In this circuit two resistors R_1 and R_2 are between connected in series between a voltage source V_{cc} and Ground. Because this is a closed circuit there is a current flowing through the resistors and each resistor is responsible for an individual voltage drop. Can we calculate the voltage U_o between these two resistors?

It is simple to see that the current flowing in this circuit is the same for both resistors. When two resistors are connected in series their resistances sum up and this total resistance can be used to calculate the current with Ohms law:

$$I = \frac{U}{R} = \frac{V_{cc}}{R_1 + R_2}\,.$$

We also know that the voltage drop U_1 across R_1 and the voltage drop U_2 across R_2 sum up to the supply voltage: $U_1 + U_2 = V_{cc}$. The voltage drop across R_2 can be calculated using Ohms law again because we know the current and the resistance:

$$U_2 = R \cdot I = V_{cc} \cdot \frac{R_2}{R_1 + R_2}\,. \tag{1.1}$$

A similar behavior can be seen for R_1:

$$U_1 = R \cdot I = V_{cc} \cdot \frac{R_1}{R_1 + R_2}\,. \tag{1.2}$$

This shows us that we can calculate the voltage $U_o = U_2 = V_{cc} - U_1$ between the resistors. It is independent from the total current and only depending on the ratio of the two resistors. It would not make a difference if we use $R_1 = 10\,\mathrm{K\Omega}, R_2 = 2.2\,\mathrm{K\Omega}$ or $R_1 = 10\,\Omega, R_2 = 2.2\,\Omega$, the result would be the same.

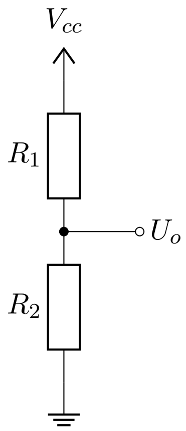

Figure 1.2: A voltage divider made with two resistors

We can use this circuit to reduce a voltage but its usability as a voltage source is limited. This can be shown in Fig. 1.3 by adding a load resistor R_L. Now the total resistance of the parallel resistors R_2 and R_L calculates to

$$R_x = \frac{1}{\frac{1}{R_2} + \frac{1}{R_L}}$$

and the result of this is smaller than R_2 and R_L. The load changes the voltage divider and this changes the output voltage U_o.

A voltage divider can only be used as a voltage source if there is no load attached to it. This means we cannot use it to drive an electric device but we will later see that there is a possibility to avoid this issue. Right now we only have discussed what happens when we have a fixed voltage V_{cc} driving this circuit. With an alternating voltage $U = U_0 \cdot \sin(\omega \cdot t)$ we will get into trouble.

1.2.1 The capacitive voltage divider

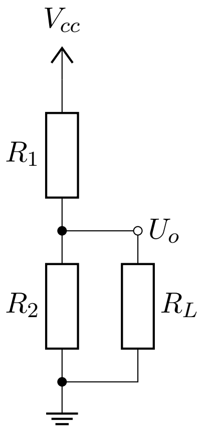

Figure 1.3: A loaded voltage divider