Analog to Digital Conversion for small Unmanned Aerial Vehicles (UAVs)

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Introduction

When microcontrollers are used to detect signals in the environment, they must convert the signals from the analog world into the digital world which can be understood by digital systems. This happens all around us, from aircraft, to cars, to our cell phones. Each of those systems use signals to make decisions based on inputs. The class of devices that can perform this transformation are called Analog to Digital Converters.

Voltages and Currents to Bits

Most sensors use a voltage or a current to represent the physical quantity being measured. For example, a tire pressure sensor in a vehicle might produce a voltage that corresponds to a certain pressure level (20 psi → 0 V, 30 psi → 10V, 40 psi → 20V). This representation is useful as represents a physical quantity in the circuit. In analog electronics, this voltage could be used to feedback into a control loop that uses devices like amplifiers and transistors to control the pressure level in the tire.

However, most modern devices take advantage of digital systems to do much more than simple feedback loops. Modern vehicles and devices have complex logging tools that allow viewing of historical data. Additionally, digital circuitry enables greater flexibility by creating new applications that can be used without changing the underlying hardware.

ADCs are crucial in our increasingly digital world as they convert these analog voltages into a stream of bits that can be stored, transmitted, or manipulated in the digital domain.

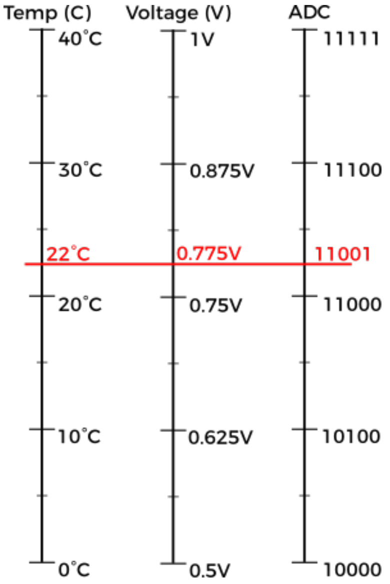


Figure 1. Conversion of a physical measurement into a digital signal. Temperature to Voltage is done by some type of electrical sensor and that voltage is converted to a digital value by an ADC

ADC Figures of Merit

For an ADC to be useful it must be able to accurately represent the original analog signal it is trying to convert. To do this there are dozens of parameters used to convey for what signals an ADC is capable of accurately translating from the Analog to Digital domains. In particular, two are critical parameters for all ADCs.

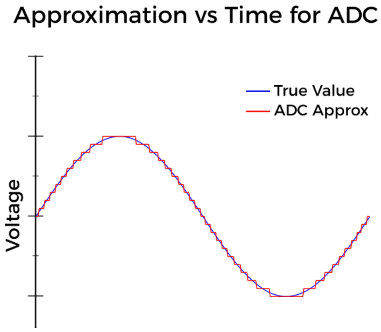


Figure 2. ADCs can only approximate the signal, not achieve a perfect representation

Resolution

One of those

precisely the voltage can be determined. For example, a 3.3V signal could be represented as 3V (rounded to 1 SF), 3.3 (2 SFs), 3.30 (3 SFs) and so on. ADCs and microcontrollers are binary base-2 devices they represent precision in the number of bits. So, in our example one bit of precision would be represented as a 0 or 1. These 0s or 1s represent a high or low relative to a reference voltage. So, if the reference voltage was 5V anything above 2.5V is a 1 and anything below is a zero. This can be continued to more and more significant bits, for two bits the space between 0 and the reference voltage would be split into four equal sections.

In most real-world ADCs their precision varies from 8 to 24 bits of precision meaning that there are between 256 and 16,777,216 levels between 0 and the reference voltage. This means that the smallest voltage or voltage difference that can be measured can vary wildly from sub-microvolts to a few millivolts!

Most embedded microcontroller ADCs have resolutions around 10-12 bits which means between 1024 and 4096 levels between ground and the reference voltage.[1] While this may be sufficient for most applications, one should keep this in mind if the signal being sensed is particularly small.

Sampling Rate and Frequency

Another crucial figure of merit is the sampling rate of the ADC. It is crucial to select an ADC that samples as fast or faster than necessary to recover the signal of interest.

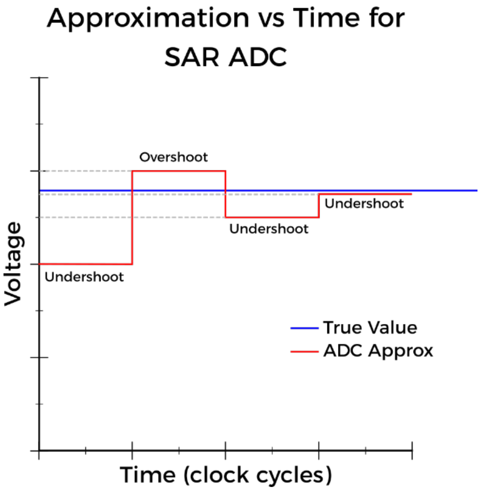
This is of concern if the aim is to sample a time varying signal such as a pulse or periodic signal. To sample a signal with a frequency of f it must be sampled at the Nyquist frequency or 2f. This must be done to fully recover the signal. Otherwise aliasing can occur where the correct signal is not recovered and instead a lower frequency ghost signal is. [2]

Successive Approximation Register (SAR) ADCs

One ADC of interest to this project is the Successive Approximation Register (SAR) ADC. This ADC provides a strong middle ground between sample rate and resolution. [4] Unlike higher speed ADCs, each bit is not individually sampled. Instead, a search is performed using one comparator. This works by performing a binary search of sorts. It will first check if the voltage is above or below ½ the reference voltage and if it is below half it will see if it's above or below ¼ and then if it's above it will look whether the voltage is above 3/8 the reference voltage and so on.

This search method allows a direct tradeoff between sample rate and precision. The longer the SAR search can run (slower), the higher the resolution. However, this tradeoff is much better than alternative ADCs which consume substantial power or lack a high enough sampling rate. [5]

Figure 3. The SAR approximation gets closer and closer to the true value by performing a binary search



Analog to Digital Conversion in Unmanned Aerial Vehicles

In airborne sensors where conversion speed and accuracy are critical and noise can be high it is crucially important to use ADCs that have the sampling rate and resolution to acquire a representative waveform. Additionally, they have a myriad of other constraints such as low power consumption and multiple simultaneous acquisition channels. [3]

These unique challenges require careful selection of the proper ADC in order to maximize drone flight endurance as while also maximizing sensor accuracy.

References

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