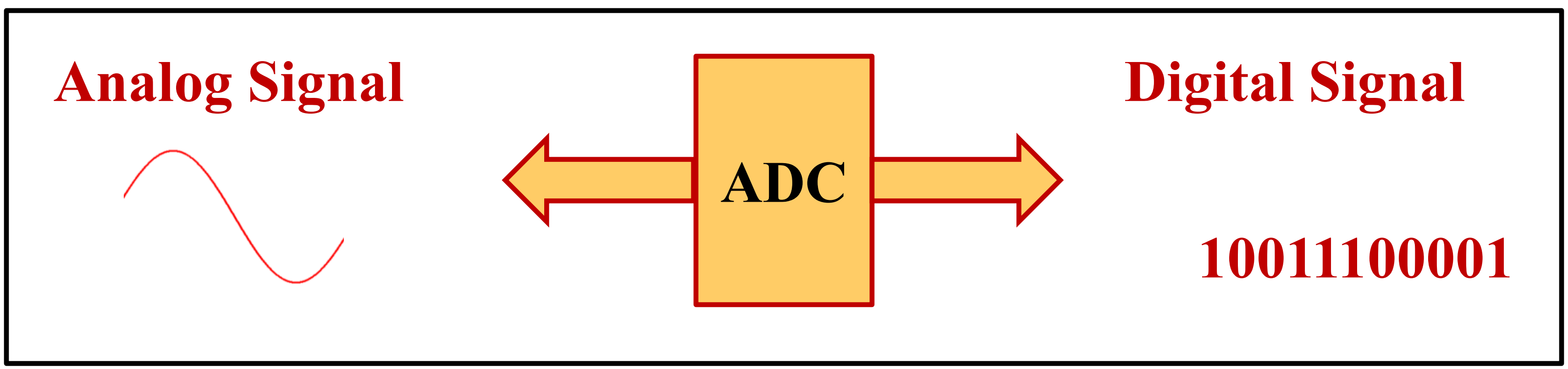
Analog to Digital Converters

What is Analog to Digital Conversion (ADC)

It is a way to represent a continuous, varying quantity with a sequence of discrete numerical values

Why do we need ADC

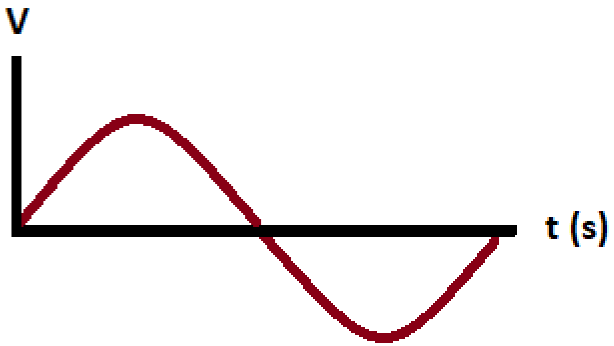
- Analog signals are time-varying quantities represented by a continuous waveform
- In order to store or manipulate the data, it must be converted into a readable binary form for the computer

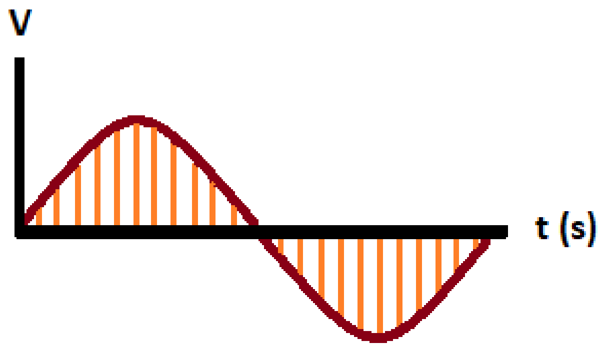


ADC Applications

- There are many applications for ADC from microphones to digital oscilloscopes
- Remember we are digitally recording an analog world so almost any modern sensor that records information will use an ADC at some point
- The MegaSat uses components such as temperature and humidity sensors which read analog voltage over a period of time

How Does ADC Work

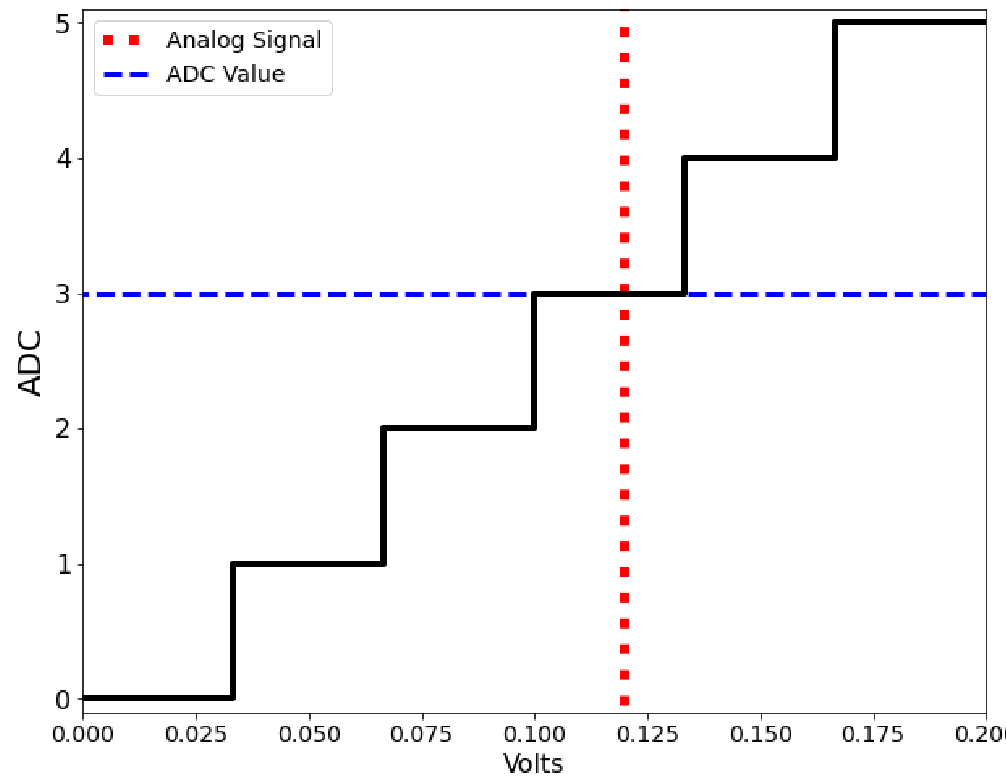




- We begin with an analog signal; in this case, a sine wave
- We partition the wave into individual sections
- At a single point in each section the voltage is sampled
- Each sample gets converted to a number based on the amplitude of its voltage

ADC Conversion

- The voltage sample is compared to several discrete voltage levels that correspond to integer values
- ADC outputs the binary number corresponding to integer value
- Many different types of circuits to perform this conversion with differing speed and resolutions



$2^{10} = 1024$

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ADC Resolution

- Number of integer bins determine the resolution of the ADC
- The Arduino Mega has a 10-bit ADC
- To calculate the number of ADC bins, use the formula 2^N
- $2^{10} = 1024$, which means it can hold values from 0 to 1023 that correspond with voltages from ~0 to ~5V
  - 0 and 5 values are not exact, so need to calibrate
- The resolution of a single ADC value is just the Voltage span divided by the max number bin
- $R = \frac{V_{max} - V_{min}}{N_{max}}$ $R = \frac{5V - 0V}{1023} = 0.005\frac{V}{bin}$
- A higher resolution gives better accuracy, but requires more memory

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Calculating Voltage from ADC

- We record ADC values but often want the voltage back
- We can just use the ratio

$$\frac{\text{Resolution of ADC}}{\text{System Voltage}} = \frac{\text{ADC Reading}}{\text{Analog Voltage Measured}}$$

$$\frac{1023}{5} = \frac{434}{x} \quad \text{where } x = \text{voltage reading from sensor}$$

- ADC 434=2.121+/-0.005V

Conversion Time

- Doing that conversion takes some amount of time
- This time sets an upper limit on how often the signal can be sampled
- The input signal can change while that conversion occurs and might miss a change we are interested in

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Sampling rate

- The sampling rate refers to the frequency by which sampling occurs
- Several factors should be considered when selecting the sampling rate
  - Science requirement
  - Processing speed
  - Storage capacity

Precision

- Increasing the rate will add more samples, providing more data points
  - This can improve the accuracy of your data
- Decreasing the rate will remove partitions, providing less data points
  - This can reduce the amount of memory used and it can free up the processor to perform other tasks

Shannon (Nyquist) Sampling Theorem

- To determine our minimum sampling rate, we use Shannon's sampling theorem
- It states that the sampling rate must be at least two times the highest frequency you are trying to capture

Choosing a Sampling Rate

1. Science requirements: What are you testing and what outcome is desired?
2. How much can your microprocessor handle?
3. How much memory do you have available for storage?

Example Sampling Rate: Requirements

- Requirement: Observe temperature changes from ground level through an ascent of 100,000 feet during a scientific balloon flight
- Requirement: Observe Changes if 1ºC
- Requirement store temperature as plain text

Example Sampling Rate: Research

- The standard atmosphere shows temperature changes with altitude at a max of ~3°C/1000 ft
- The average scientific balloon rises at ~1000 ft/min and stays in flight for ~ 4 hours (include prelaunch time)
- We expect to experience temperature changes up to 3°C/min
- Over the flight we expect to see temperatures as low as -50°C and high as 50°C
- Will take 3 characters->3 bytes to store a temperature
  - 1 for +/- and 2 for the numbers

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Example: Choosing Sampling Rate

- You want to collect data that will observe changes in temperature by 1ºC we want to take one sample every 10 seconds

$$\frac{60s}{3} = 20\ s = \frac{1}{20s} = 0.05\ Hz * (2) = 0.1\ Hz$$

- We want a sample rate of at least 0.1 Hz
- How much storage do we need?

$$4\ hrs * \frac{3600\ s}{1\ hr} * \frac{0.1 samples}{1\ s} * \frac{3 bytes}{sample} = 4320\ bytes$$

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Example: Desired Range and ADC characteristics

Consider the following situation:

We want to have temperature sensor read out by an ADC with the following characteristics

Read Temperatures at least as low as -50 ° C (can be lower)

Read Temperatures at least as High as +50 ° C (could be higher)

Have a Temperature resolution of at least 1° C (could be smaller)

Our ADC is 0-5V and bit resolution (0-1023)

Example: Temperature to Voltage: Minimum Slope

The resolution is going to give us the set a minimum value for of temperature to voltage change being sent to the ADC

ADC changes in integer values – Smallest ADC changes 1 ADC unit

Smallest voltage change is 5V/1023 (ADC Voltage/ADC Resolution) = ~0.005 V

A 1 degree temperature change needs to be change the voltage at the ADC by at least 0.005 for the ADC to be able to see it

At a minimum we need 0.005V/C ° (Higher is ok, that would just give a smaller/better resolution)

Example: Temperature to Voltage: Maximum Slope

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The range is going to give us the set a maximum value for of temperature to voltage change being sent to the ADC

Our Temperature Range is 100°C (-50 to + 50)

Our ADC Range is 0-5V

Largest voltage change is 5V/100°C (ADC Voltage/ADC Resolution) = ~0.05 V/°C

If its larger than that we will not be able to read 100°C from min to max, it can be smaller that just gives a wider ranger

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Example: Signal Requirements

ADC resolution: 0.005 V (5V/1023)

Our sensor and signal conditioning must have a change >0.005V/ °C

Range of Temps :100°C (-50 to +50°C)

ADC Range: 0-5V

Our sensor and signal conditioning must have a change <0.05V/ °C

Example: Amplifying Circuit – Does this meet requirement

Temperature sensor: 450 mV to 800 mV at (-50 and +50

- BASE = 450 mV, SPAN = 350 mV

Signal Conditioning Output: 1V to 4V (to make sure we aren't hitting the ADC limit)

- BASE = 1V, SPAN = 3V

Gives us a change of 0.03V/°C (in our desired range)

Need to design amplifying circuit so our transfer function to be:

$$V_{out} = 8.57V_{in} - 2.86$$

Arduino ADC Programming

- Keyword: analogRead(pin)
- Can use the constants analogRead(A3)
- Pin layout: A0-A15
- Resolution: 0-1023 for 10 bits
- But will return an int which require 16 bits