MICROCHIP

AN4225

Maximizing the Signal: Tips and Tricks to Properly Acquiring Analog Signals

Introduction

Analog-to-Digital Converters (ADCs) are common peripherals on embedded microcontrollers (MCUs). While it is not difficult to set up and capture values with these peripherals, it is easy to end up with inaccurate or imprecise results. The objective of this guide is to discuss some of the pitfalls in setting up the ADC, sampling analog signals, and how and when to use the ADC features to help filter the signal while minimizing software computations.

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1. Acquiring Analog Signals

1.1 Configuring the I/O for Analog Sampling

The I/O pin used as the analog input must have its digital input buffer disabled when sampling an external signal. This will reduce any noise introduced by the digital logic buffers inside the pad. In addition, if the digital logic buffers are left enabled, they may increase current consumption.

1.2 Signal Impedance and Acquisition Time

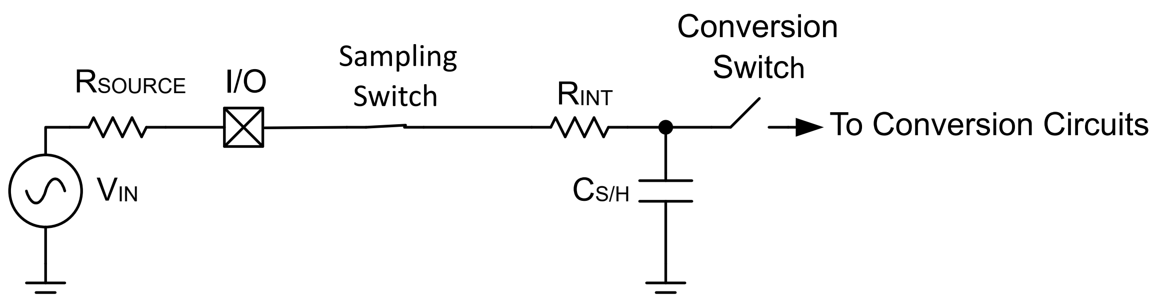
Input signals to the ADC are measured in two stages[(1)] – an acquisition stage and a conversion stage. The acquisition stage connects the input to an internal Sample-and-Hold (S/H) capacitor inside the ADC. Then the input is disconnected from the capacitor and internally connected to the conversion circuit inside the ADC.

To correctly measure an input signal, it is required that the internal S/H capacitor is charged to within 0.5 Least Significant Bits (LSbs). The value of an LSB can be computed by dividing the number of bits (n) by the reference voltage, as shown below.

$$V_{LSB} = \frac{V_{REF}}{2^n}$$

However, if not all bits are needed, set the number of valid bits (n) to a lower value. This reduces the acquisition time (t_{ACQ}) required[(2)]. To find the minimum t_{ACQ}, the input to the ADC can be modeled as an RC low-pass filter, as shown in the figure below.

Figure 1-1. ADC RC Circuit



With an RC approximation, the voltage on the S/H capacitor is an exponential function, with the following formulas[(3)]:

$$V_{DIFF} = |V_{IN} - V_{PREV}|$$

$$V_{ERR} = e^{-\frac{t}{RC}} * V_{DIFF}$$

Where: R is the sum of source impedance and internal ADC impedance, C is the capacitance inside the ADC, t is time, V_{IN} is the input voltage, V_{PREV} is the initial voltage of the capacitor, and V_{ERR} is the difference from 0.5 LSbs.

Important: Some devices specify the internal ADC impedance and S/H capacitance, while others do not. Devices that do not specify these parameters can be approximated with R_{INT} = 2 kΩ and $C_{S/H}$ = 15 pF.

Solving for an LSb of 0.5, the acquisition time can be estimated[(3)]:

$$t_{ACQ} = -RC * \ln\left(\frac{V_{REF}}{V_{DIFF} * 2^{n+1}}\right)$$

The worst-case acquisition time is where $V_{DIFF} = V_{REF}$, or:

$$t_{ACQ} = -RC * \ln\left(\frac{1}{2^{n+1}}\right)$$

The device data sheet gives information about the ADC timings.

Notes:

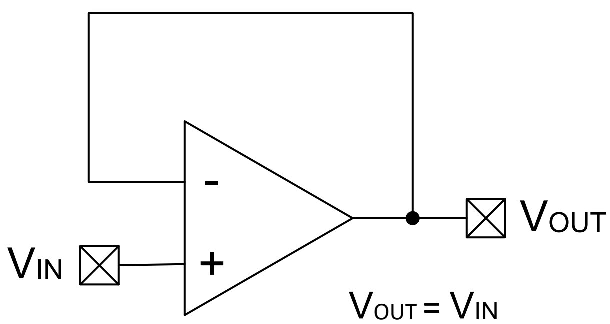
1. More stages may occur before acquisition and conversion when using features such as Capacitive Voltage Division (CVD), Programmable Gain Amplifier (PGA), or Double Sampling. The time delays associated with each stage can be added to find the total sampling time.
2. On some ADCs, the number of bits generated can be reduced, which may improve the conversion time (T_{CNV}).
3. Valid only if $\frac{V_{LSB}}{2} \leq V_{DIFF}, V_{DIFF} \leq V_{REF}$

1.2.1 Buffering with an Operational Amplifier

Op amps have high input impedances and low output impedances, which makes them ideal for buffering signals. While Microchip has a wide variety of discrete op amps, certain microcontroller families contain embedded op amps that reduce the Bill of Materials (BOM). However, discrete op amps generally have higher analog performance than embedded op amps.

Op amps can lower a signal's source impedance for faster acquisition times (see 1.2 Signal Impedance and Acquisition Time) and isolate the input signal from the capacitive dip caused by the ADC charging its capacitor. However, op amps add noise and offset to their output, which may reduce the Signal-to-Noise Ratio (SNR). If the input signal is low-impedance, then there is little benefit in buffering with an op amp. However, if the input signal is high-impedance, the op amp can significantly improve acquisition times. A simple unity gain (also called voltage follower) configuration of the op amp is shown in Figure 1-2.

Figure 1-2. Unity Gain

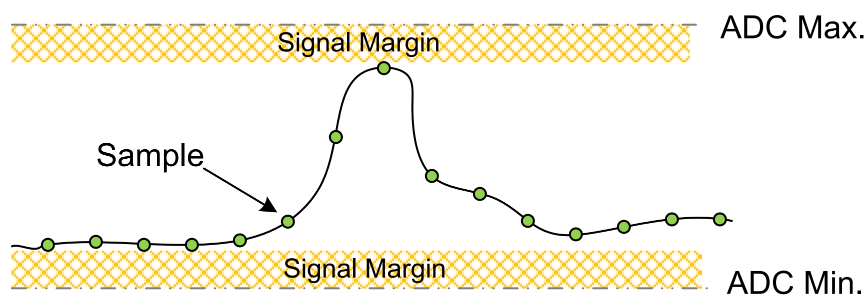


Note: In devices without an internal Unity Gain mode, use a wire or trace to connect the output to the inverting input.

1.3 Signal Scale and Resolution

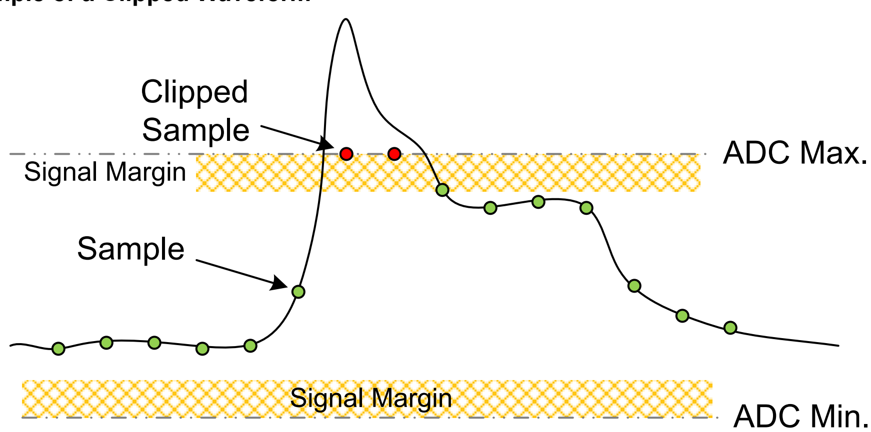
To maximize the resolution of a signal, scale the input signals to the measurement range of the ADC. Leaving signals underscaled effectively “leaves resolution on the table”, but it is also crucial to leave sufficient signal margins to account for tolerances in the signal chain. The figure below shows a correctly scaled signal with plenty of margins to account for noise or error in the signal chain.

Figure 1-3. Example of a Correctly Sized Signal



In terms of resolution, an overscaled signal is far worse than an underscaled one. Overscaled signals are clipped, meaning that the measurement is capped at the maximum value of the ADC, as shown in the following figure.

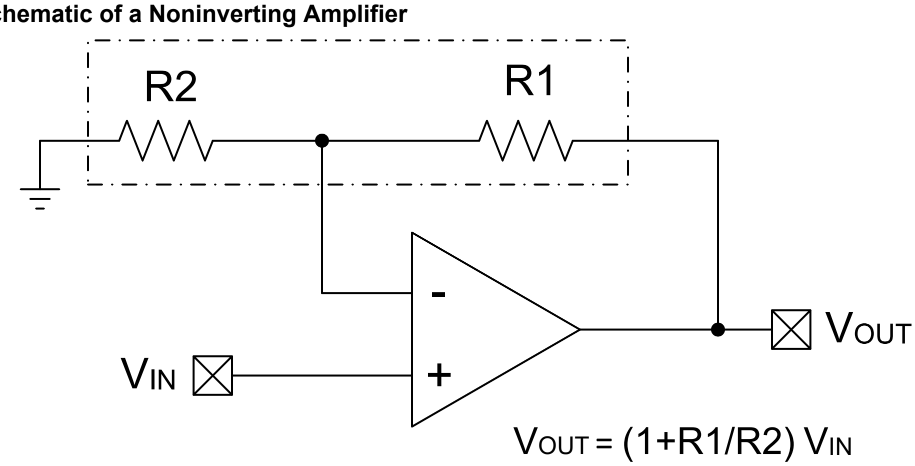
Figure 1-4. Example of a Clipped Waveform



1.3.1 Scaling with an Operational Amplifier Peripheral

One way to scale a signal dynamically is to use the operational amplifier peripheral. In the circuit shown in Figure 1-5, resistors R1 and R2 provide negative feedback that sets the gain of the op amp.

Figure 1-5. Schematic of a Noninverting Amplifier



Generally, resistors R1 and R2 are external components. But on some op amp peripherals, R1 and R2 are available from the internal resistor ladder, which removes these parts from the Bill of Materials (BOM).

Other op amp configurations are also possible, depending on the number of op amps on the device. A few of the possibilities are listed below:

- Inverting Amplifier (1 op amp)
- Differential Amplifier (2 op amps)
- Cascaded Amplifier (2+ op amps)
- Instrumentation Amplifier (3 op amps)

Find more information about these configurations in the device data sheet or related technical documentation.

1.3.2 Scaling with a Programmable Gain Amplifier (PGA)

PGA is a description for amplifiers set to specific discrete gains. PGA functionality can be implemented with an operational amplifier and an internal resistor ladder, as mentioned in 1.3.1 Scaling with an Operational Amplifier Peripheral.

However, some devices contain a dedicated PGA for the ADC. In this case, the PGA input is capacitive and will be treated as a direct input into the ADC. Capacitive PGAs can perform better than an op amp-based solution due to the lower noise voltage introduced into the signal. Using the PGA will increase the amount of time to sample a signal, which reduces the sampling rate and thus the bandwidth of the ADC.

1.4 Grounding and Measurements

Generally, ground is the voltage reference or zero point of a circuit. Ideally, everything connected to ground is also zero, with parasitic elements being negligible. On a Printed Circuit Board (PCB) with a solid and uninterrupted ground plane, the impedance from a ground point to any other point on the plane is very low.

However, this assumption may no longer be valid on a more complex design with interruptions in the ground plane or vias connecting a circuit on another layer to ground.

1.4.1 Ground Offsets and Single-Ended Signals

Ground offsets are especially dangerous when measuring single-ended signals. The ground return impedance can generate voltage offsets, which adds error to the measurement. The current (I_{FLOW}) flowing through the impedance of the ground return (Z_{GROUND}) generates voltage offsets (V_{OS}).

$$V_{OS} = I_{FLOW} \times Z_{GROUND}$$

From this formula, there are two ways to reduce the size of a voltage offset - one is to reduce the amount of current flowing through the ground return, and the other is to lower the impedance of the return.

Lowering the current flow through the ground return is straightforward. High current paths, such as those from a motor or a heating element, must be given their dedicated ground return isolated from the microcontroller’s ground return. In the case of a ground plane, the current will be dispersed throughout the copper plane.

Note: The microcontroller must use a dedicated via rather than a via shared with other devices when it uses a via to connect to ground or power.

The other way to lower the offset is to reduce the impedance of the ground return. Impedance has two components associated: A real resistance (R) and an imaginary reactance (X).

$$Z = R + jX$$

The actual resistance is derived from the resistivity of the material connecting point A to point B. Attaching the microcontroller directly to a ground plane is the best way to minimize the amount of resistivity. However, in many cases, it is necessary (from a layout perspective) to instead use a via to connect the device to a ground plane.

Note: Take caution whenever a ground plane is interrupted. This will increase the parasitic inductance and resistance (see 1.4.2 Tips for Measuring Single-Ended Signals for more information on the topic). For best performance, ground returns and planes must be uninterrupted and as short as possible.

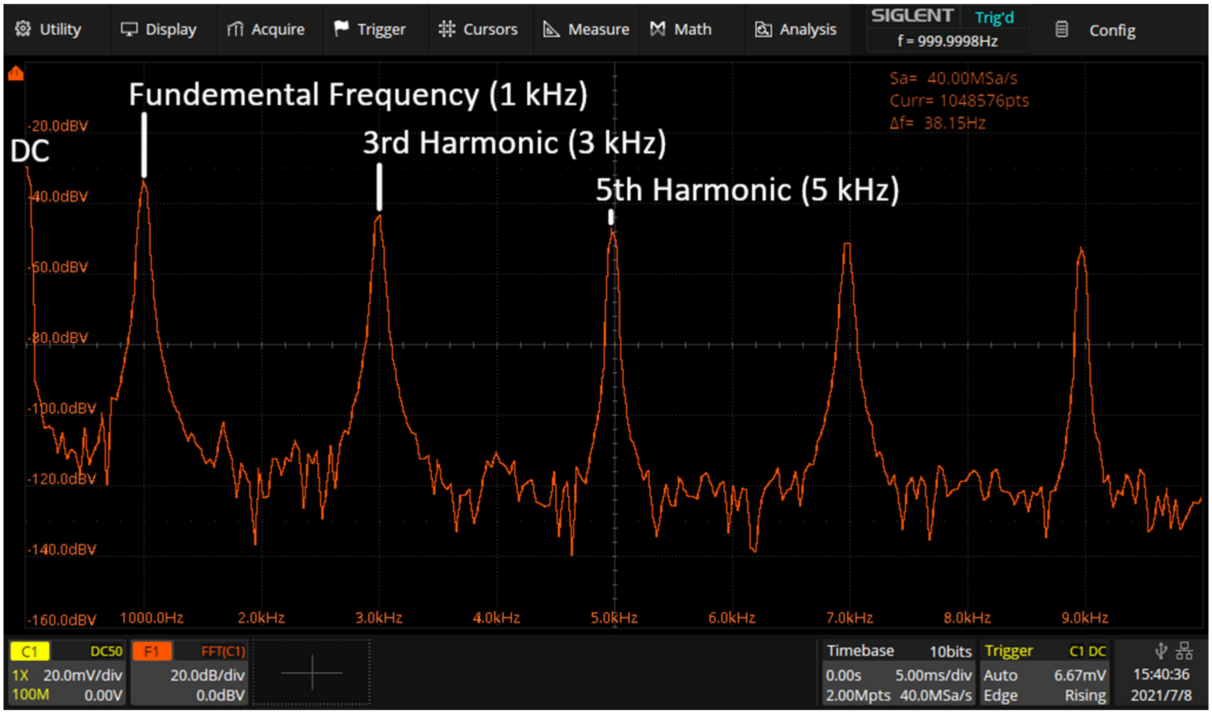
The reactance of the ground return is created primarily from the parasitic inductance (L). This causes the reactance to increase as the frequency (f) rises.

$$X = 2\pi fL$$

One of the challenges with digital signals is that they are not composed of a single frequency like sine waves. Instead, square waves are composed of odd-numbered sinusoidal harmonics of their switching frequency (f). For example: 3f, 5f, 7f, etc., as shown in Figure 1-6.

One of the ways to suppress the high-frequency currents by digital logic is by placing decoupling capacitors near the microcontroller. These capacitors act as short-circuits to the high-frequency elements, which reduces the reactance and the impedance seen by these elements.

Figure 1-6. Spectrum of a Generated 1 kHz Square Wave; 0 to 100 mV, 50Ω Termination at Receiver (amplitudes are in dBV)



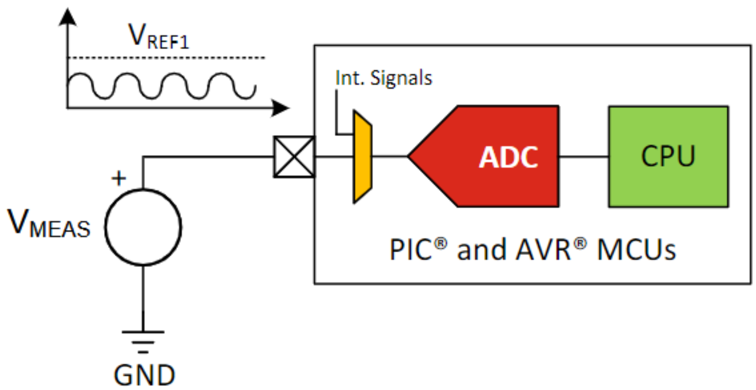
1.4.2 Tips for Measuring Single-Ended Signals

1. Use a solid, uninterrupted ground plane.
   – If that is not possible, STAR grounding (where each ground return is isolated from each other except at a central point) is recommended
2. Properly decouple the microcontroller and other digital logic devices.
   – The decoupling capacitors short-circuit high-frequency currents
   – X5R and X7R dielectrics are recommended for these capacitors
   – See the device data sheet for recommended typical values
3. When interfacing with a noisy analog signal, filtering the signal can improve the Signal-to-Noise Ratio (SNR). Information about digital filtering with the ADC can be found in 3. Sampling Methods.
4. Shutdown switching logic (clocks, I/O, etc.) when sampling.
   – Shutting down all nonessential switching signals will yield the lowest noise possible for the ADC. Many embedded ADCs can operate in the microcontroller's sleep mode for this reason. The device data sheet provides more information about the setup and operation of the ADC in sleep.

1.4.3 The Advantage of Differential Inputs

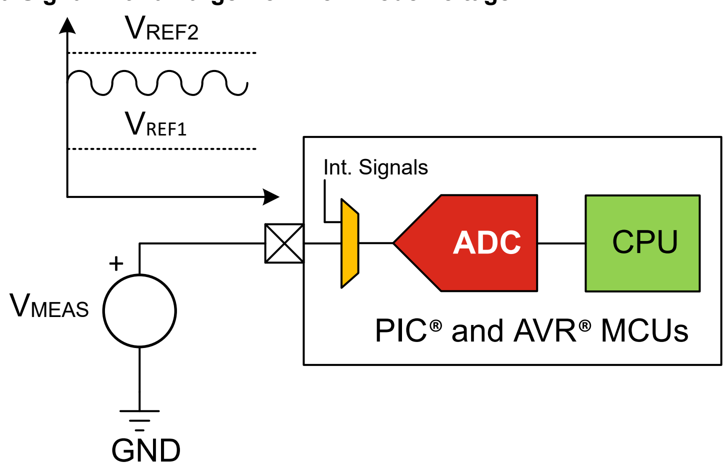
A relatively new feature on some microcontrollers is the ability to sample a signal differentially. Single-ended sampling is a measurement of a signal concerning the ADC ground. Figure 1-7 shows a simple single-ended signal being acquired.

Figure 1-7. Signal Ended Sampling



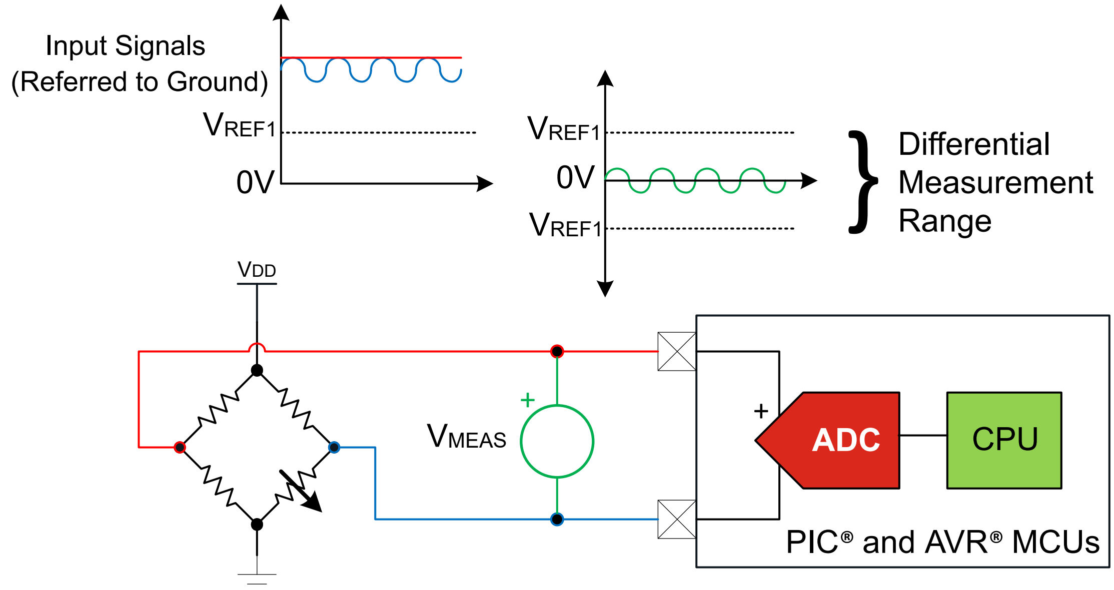
However, if the single-ended sample has a large common-mode voltage with a small signal on top, it is hard to get a good measurement since the resolution of the ADC must encompass both the signals. Amplifying the entire signal with an op amp or similar will increase the common-mode voltage and the desired signal.

Figure 1-8. Example of a Signal with a Large Common-Mode Voltage



An alternative method is to acquire the signal differentially. In this configuration, the ADC measures the difference between its inputs. The common-mode voltage is significantly attenuated, which leaves only the differential element to be measured and reduces the reference voltage required to acquire the signal (see 1.3 Signal Scale and Resolution) without clipping, which further improves the resolution of the measurement. See Figure 1-9.

Figure 1-9. Differential Measurement of a Wheatstone Bridge



Note: Always keep input signals within the absolute maximum ratings specified in the data sheet, or permanent damage may occur.

1.5 Crosstalk and PCB Routing

When measuring analog signals, especially signals with a high quantity of source impedance, keep signals with fast rising/falling edges far away. Use the Peripheral Pin Select (PPS) feature on PIC® MCUs or the Port Multiplexer (PORTMUX) on AVR® MCUs to increase the routing flexibility during PCB layout.

Besides distance, there are a few other ways to reduce or minimize crosstalk. Since crosstalk occurs from the edges of digital signals, slowing the edges down will reduce the amount of interference generated. Some microcontrollers contain a Slew Rate Control (SLRCONx) register, which can be used to lower the switching speed of the I/O. On devices without this register, using a small resistor in series can have a similar effect.

An alternative method to distance may be to shield the analog signal with ground. This is effective against capacitive coupling but not inductive coupling[(1)].

Another way to reduce crosstalk is to change the digital I/O when not sampling. The easiest way to implement this is by putting the device into a sleep mode while sampling occurs and then wake up and apply changes when complete.

Note:

1. Inductive coupling is created from changes in current, whereas capacitive coupling is created from changes in voltage. Digital logic on the microcontroller almost always acts capacitively.

1.6 Channel to Channel Crosstalk and Error

Another possible source of crosstalk is from another analog channel. This can be created by fast edges, like digital logic (see 1.5 Crosstalk and PCB Routing), or an error can be transferred through the sample-and-hold capacitor (C_{SAMPLE}) inside the ADC. The remaining charge on the sample-and-hold capacitor is transferred into the second channel if the ADC first samples a channel that charges the capacitor and then attempts to measure another channel. For a low-Z signal source on the second channel, the charge dissipates quickly. A high-Z signal source on the second channel will dissipate this charge at a much slower rate.

There are three ways to reduce this type of crosstalk:

1. Buffer the high-Z channel to reduce the source impedance (see 1.2.1 Buffering with an Operational Amplifier).
2. Discharge the sample-and-hold capacitor before switching to the high-Z channel.

– Do this by selecting the VSS/GND channel in the device or grounding an analog input pin and measuring that channel.

3. Add an external capacitor to the high-Z channel.

The purpose of the external capacitor on the high-Z channel in suggestion c. is to provide a relatively large amount of reserve charge to minimize the change in voltage. The amount of charge on the capacitor is equal to:

$$Q = CV$$

Where: Q is the stored charge (in Coulombs), C is capacitance, and V is voltage.

If a capacitor of size C_{EXT} is connected to the high-Z channel, the change in voltage can be estimated based on the change in total capacitance. The worst-case change occurs when the C_{EXT} is fully discharged, and C_{SAMPLE} is fully charged.

$$V_{ERROR(MAX)} = V_{REF} * \frac{C_{SAMPLE}}{C_{SAMPLE} + C_{EXT}}$$

However, adding external capacitance to a channel causes two other changes of note. Firstly, the time constant significantly increases, which reduces the bandwidth of the channel. But, if C_{EXT} is already charged and has a much larger capacitance than C_{SAMPLE}, the acquisition time significantly reduces[(1)] if the capacitor voltage (after connecting C_{EXT} and C_{SAMPLE}) is within 0.5 LSbs of the input signal.

The worst-case for balancing charge occurs when C_{SAMPLE} is fully discharged, and C_{EXT} is fully charged. In this scenario, estimate the optimal external capacitance[(2)(3)] with the following formula:

$$C_{EXT} = C_{SAMPLE}\left(2^{n+1} - 1\right)$$

Where: n = the number of bits in the result.

Notes:

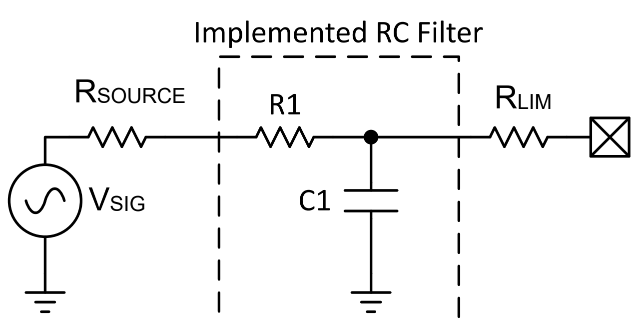
1. Assuming the resistance of C_{EXT} is negligible.
2. For stability, select a capacitor dielectric with a low voltage coefficient, such as NP0 or C0G.
3. Caution must be used when a large capacitor is on an I/O line. The ESD diodes will discharge the capacitor into the power rail, which may cause unusual issues with a device reset and potentially damage the device if the microcontroller powers off with this capacitor fully charged.

1.7 Aliasing

When sampling a signal, there is a limit to the visualized input frequency. The Nyquist-Shannon Sampling Theorem states that at the sampling frequency, the highest frequency seen in the input is at half of the sampling frequency. After this point, higher frequency components or signals will appear as lower-frequency aliases of the original. Implement an analog low-pass filter before the ADC to prevent aliasing, which usually appears as noise in the measurements.

There are many ways to implement a low-pass filter – the simplest way is to use an RC network, as shown in Figure 1-10.

Figure 1-10. Simple RC Low-Pass Filter



The RC network has a -3 dB point set by the following formula (excluding R_{LIM}):

$$f_{-3dB} = \frac{1}{2\pi(\Sigma R)C}$$

Note: Resistor R_{LIM} will only be used if the capacitor (C1) is very large. In this case, a fully charged capacitor can discharge current into the microcontroller on power-down through the ESD diodes. Adding R_{LIM} will increase the source impedance. Using an integrated op amp to buffer the input allows R_{LIM} to be sizable, but some noise will be added from the op amp into the signal.

When selecting R1 and C1 for the filter, it is of importance to keep the following in mind:

- Small resistances reduce source impedance for faster signal acquisitions
- Capacitors must be much larger than parasitic capacitance but not excessively large

2. Advanced Analog Sampling

2.1 All About Voltage References

2.1.1 Using the Supply Voltage as a Reference

There are times when using the microcontroller's supply as a voltage reference is required. However, if not done correctly, this supply can introduce errors into the measurement.

The biggest pitfall with using the supply voltage is power-supply ripple and noise. The following list contains some techniques for minimizing the noise of the power supply:

- On noisy power supplies, use a ferrite bead in series with the power input
  - The ferrite bead helps to eliminate switching noise on the power supply
- Use a linear regulator instead of a switching regulator
  - Switching regulators generate a lot of electrical noise. The noise is not usually an issue with digital devices. However, analog circuits are particularly vulnerable.
- Enable slew-rate controls on the I/O
  - Some microcontrollers can slow the transition time of the I/O, which reduces the amplitude of current spikes when switching
  - Alternatively, adding small resistors in series with the I/O can slow the transition time

Note: Some of the information from 1.4.2 Tips for Measuring Single-Ended Signals also applies here (e.g., decoupling).

2.1.2 Measuring the Supply Voltage with the Fixed Voltage Reference

On recent PIC MCUs, Device Information Area (DIA) fields are included on the device. These fields contain the factory measured values of the internal voltage reference and other calibration constants.

It is also possible to calculate the value of V_{DD} on the device using the DIA fields with the Fixed Voltage Reference (FVR). This allows using V_{DD} as a reference, which has the widest input range for signals. To measure V_{DD}:

- Set the ADC to use V_{DD} as a reference
- For the input channel to the ADC, select the Fixed Voltage Reference (FVR) channel
- Measure the FVR
- Read the DIA field that matches the voltage output of the FVR channel
- Solve for V_{DD} using the following formula:

  $$\frac{DIA << N}{MEASURED} = V_{DD(in\,mV)}$$

  Where: DIA is the programmed value, MEASURED is the value acquired by the ADC, and N is the number of bits in the ADC.

2.2 Measuring with the Temperature Indicator

The temperature indicator peripheral allows for integrated temperature measurements by the microcontroller. This peripheral is best used for die-temperature measurements or simple thermometer operation. For more accuracy, a dedicated temperature sensor is recommended.

For information about using the temperature indicator, consult the device data sheet and related documentation.

2.3 Touch Sensing

The microcontroller can perform capacitive touch sensing. For PIC MCUs, the Capacitive Voltage Divider (CVD) feature inside some ADCs allows for touch detection. For AVR MCUs, use a dedicated Peripheral Touch Controller (PTC) that interfaces with the ADC.

In both cases, the measurement starts by charging a capacitor to a known voltage, then connecting to a discharged capacitor. Assuming all charge from the original capacitor is conserved, the voltage across both capacitors is related to the total amount of capacitance in the system.

The system capacitance changes when a capacitive button is approached or touched and affects the voltage across both capacitors and detects a touch.

For more information on using this feature, consult the device data sheet and related technical documents.

3. Sampling Methods

The Analog-to-Digital Converters (ADCs) on MCUs are designed with advanced features to minimize the amount of work the CPU must do to acquire a signal. Supported sampling modes vary by device and by on-board peripheral.

3.1 Basic

Basic Acquisition mode is the standard operating mode for ADCs. The ADC acquires a sample and returns a result.

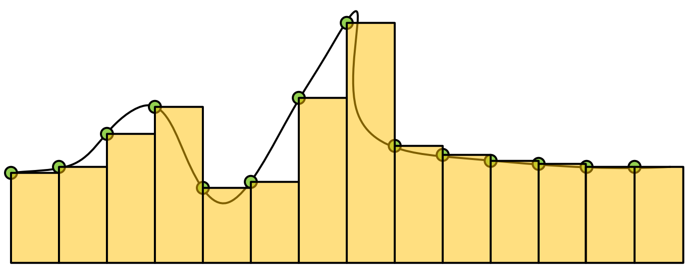
3.1.1 When to Use

The basic Operation mode is the fastest mode of operation, as there is no computation or multi-sampling accumulation. Basic Acquisition mode is best used for high-speed acquisition of results or use when porting code from a legacy device.

3.2 Accumulate

In Accumulation mode, the ADC acquires samples and sums them in an internal accumulator. Accumulation is a kind of signal integration, with each sample added together. See Figure 3-1.

Figure 3-1. Example Integration of an Accumulated Signal



Using the computation features of the ADC, perform accumulation to find the time to reach a value by using the threshold interrupt features of the ADC. See the mathematical expression below.

$Value \geq \Delta t \sum_{n=0} u(n * \Delta t)$

$T \approx n * \Delta t$

Where: n = sample number, Value = result to stop at, Δt = time between samples

Integrate for a set length of time (T) is an alternative way to use this feature. For example:

$k = floor\left(\frac{T}{\Delta t}\right)$

$$\text{Result} \approx \Delta t \sum_{n=0}^{k} u(n * \Delta t)$$

Where: n = sample number, k = number of samples to acquire, Δt = time between samples, T = length of integration

3.2.1 When to Use

The Accumulation mode is used best for the integration of samples. Accumulation can also be used for averaging in software if the number of samples to average is variable or not a power of two (see average and burst-average modes for more details).

3.3 Average and Burst-Average

In Average and Burst-Average modes, the ADC accumulates a set number of samples, then generates the average. To divide the accumulation, the ADC right-shifts the accumulated results by a set number of bits. For proper calculation of the average in these modes, the number of samples acquired must be a power of two, and the number of bits to shift must be a base-2 logarithm of the number of samples, as shown below.

$n_{shift} = \log_2(n_{samples})$

The difference between the Burst-Average and Average modes is how the samples are acquired. The Averaging mode acquires a single sample per ADC conversion, whereas the Burst-Averaging mode acquires all the samples back-to-back once the ADC has been triggered.

3.3.1 When to Use

The difference between the modes is in how quickly samples are acquired.

Burst average sampling is used best for a quick, short-term averaging operation. For extended periods, Averaging mode is a better choice.

However, it is possible to get the benefits of both Averaging modes by using a little bit of software. Rather than taking one sample for each point of the long-term average, use the burst-average to acquire a short-term average at each point. This has two benefits; averaging out short-term noise and obtaining a higher resolution from the ADC by oversampling the signal.

Oversampling a signal increases the effective resolution of the ADC by 1 bit for every $\log_2$(# of samples). For instance, oversampling a signal by four will generate a result with two additional bits of resolution[(1)].

To compute the long-term average, take the sum of the results from the burst average and add them up in software. Then, divide (or bit-shift) the accumulation to get the long-term average.

Note:

1. The extra bits of resolution will have more statistical noise than the standard bits of the ADC. However, averaging the accumulated result down will reduce the amount of noise present in the result. In other words, collecting 16 results and right-shifting by two will yield two additional bits with lower noise than accumulating eight results and shifting by 1.

3.4 Low-Pass Filter

The Low-Pass Filter operating mode has two phases - a start-up phase and an operating phase. In this mode, each sample acquired causes the ADC to subtract a fraction of its current accumulation, then add the new measurement to the accumulated sum.

When the filter is starting up, the threshold interrupts are disabled to prevent negligent activation. Once the set number of samples is collected, threshold interrupts are enabled. The device data sheet and related technical documentation provide more information about the low-pass filter.

3.4.1 When to Use

The Low-Pass Filter mode is the best to use for repetitive sampling applications where momentary glitches or high-frequency noise is present in the signal.

For the best performance with the low-pass filter, keep the timing between each sample at a stable sampling rate. Hardware-based triggering is strongly recommended for this operating mode.

4. Documentation

4.1 Operational Amplifiers

4.1.1 For PIC® MCUs

1. AN3521 - Analog Sensor Measurement and Acquisition
2. TB3293 - Using the MPLAB® Mindi™ Analog Simulator with the 8-Bit Operational Amplifier Module
3. TB3280 - Using the Operational Amplifier on PIC16 and PIC18
4. TB3279 - Optimizing Internal Operational Amplifiers for Analog Signal Conditioning

4.1.2 For AVR® MCUs

1. AN3860 - Overcurrent Protection Using the Integrated Op Amps on AVR DB
2. AN3633 - Gain and Offset Calibration of the Analog Signal Conditioning (OPAMP) Peripheral
3. AN3632 - Constant-Current Driver Using the Analog Signal Conditioning (OPAMP) Peripheral
4. AN3631 - Low-BOM Microphone Interface Using the Analog Signal Conditioning (OPAMP) Peripheral
5. TB3286 - Getting Started with Analog Signal Conditioning (OPAMP)

4.2 Analog-to-Digital Converters

4.2.1 For PIC® MCUs

1. AN3382 - ADC with Computation and Context Switching Using DMA
2. AN2749 - Using PIC18F26K42's 12-bit ADC² in Low-Pass Filter Mode
3. TB3194 - PIC16/PIC18 ADC² Technical Brief

4.2.2 For AVR® MCUs

1. AN3641 - Low-Power, Cost-Efficient PIR Motion Detection Using the tinyAVR® 2 Family
2. TB3257 - How to Use the 12-Bit Differential ADC with PGA in Series Accumulation Mode
3. TB3256 - How to Use the 12-Bit Differential ADC with PGA in Single Mode
4. TB3254 - How to Use the 12-Bit Differential ADC with PGA in Burst Accumulation Mode
5. TB3245 - Using 12-Bit ADC for Conversions, Accumulation, and Triggering Events

4.2.3 Temperature Indicator

AN2798 - Using the PIC16F/PIC18F Ground Referenced Temperature Indicator Module

TB3165 - Temperature Indicator Module on 8-Bit Microcontrollers

4.2.4 Capacitive Voltage Divider (CVD)

TB3198 - Capacitive Voltage Divider (CVD) operation on 8-Bit PIC® Microcontrollers

4.2.5 Peripheral Touch Controller (PTC)

QTouch® Library Peripheral Touch Controller – User Guide

5. Revision History

Document Revision	Date	Comments
A	10/2021	Initial document release

The Microchip Website

Microchip provides online support via our website at www.microchip.com/. This website is used to make files and information easily available to customers. Some of the content available includes:

- **Product Support** – Data sheets and errata, application notes and sample programs, design resources, user's guides and hardware support documents, latest software releases and archived software
- **General Technical Support** – Frequently Asked Questions (FAQs), technical support requests, online discussion groups, Microchip design partner program member listing
- **Business of Microchip** – Product selector and ordering guides, latest Microchip press releases, listing of seminars and events, listings of Microchip sales offices, distributors and factory representatives

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Customer Support

Users of Microchip products can receive assistance through several channels:

- Distributor or Representative
- Local Sales Office
- Embedded Solutions Engineer (ESE)
- Technical Support

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