
XMEGA ADC Oversampling

Features

- Increasing the AVR XMEGA ADC Resolution by Oversampling
- Averaging and Decimation
- Software has been Implemented as an Atmel START Example Project for XMEGA-A3BU Xplained Kit to Achieve 16-bit Resolution from 12-bit Resolution
- Results are Displayed on LCD Available on the XMEGA-A3BU Xplained Kit:
 - Raw ADC count and calculated analog input voltage (in volt) are displayed
 - For comparison, both oversampled and normal results are displayed
- Results are Displayed on LCD Using GFX Mono Library

Introduction

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The Microchip AVR[®] XMEGA[®] controller offers an Analog-to-Digital Converter (ADC) with 12-bit resolution. In most cases 12-bit resolution is sufficient, but in some cases higher accuracy is desired. Special signal processing techniques can be used to improve the resolution of the measurement. By using a method called 'Oversampling and Decimation' higher resolution might be achieved, without using an external ADC. For example, by using 12-bit XMEGA ADC a 16-bit result could be achieved with the oversampling technique. This application note explains the method and conditions needed to be fulfilled to make this method work properly. This application note also provides source code for the explained theory to achieve the oversampling technique.

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1. Theory of Operation

This chapter explains how oversampling works with all the necessary mathematical details.

1.1 Sampling Frequency

The Nyquist Theorem states that a signal must be sampled at least twice as fast as the bandwidth of the signal to accurately reconstruct the waveform; otherwise, the high-frequency content will alias at a frequency inside the spectrum of interest (pass band). The minimum required sampling frequency, in accordance to the Nyquist Theorem, is the Nyquist frequency.

Equation 1: The Nyquist frequency

$$f_{\text{nyquist}} > 2 \cdot f_{\text{signal}}$$

where f_{signal} is the highest frequency of interest in the input signal. Sampling frequencies above f_{nyquist} are called 'oversampling'. This sampling frequency, however, is just a theoretical absolute minimum sampling frequency. In practice the user usually wishes the highest possible sampling frequency, to give the best possible representation of the measured signal, in time domain. One could say that in most cases the input signal is already oversampled.

The sampling frequency is a result of prescaling the CPU clock, where a lower prescaling factor gives a higher ADC clock frequency. At a certain point, a higher ADC clock will decrease the accuracy of the conversion as the Effective Number of Bits, ENOB, will decrease. All ADCs have bandwidth limitations. For Microchip XMEGA A series devices, to get 12-bits resolution on the conversion result, the ADC clock frequency should be maximum 2 MHz. When the ADC clock is 2 MHz, the sampling frequency is 2 Msps, which confines the upper frequency in the sampled signal to ~1 MHz.

1.2 Oversampling and Decimation

The oversampling technique requires a higher amount of samples. These extra samples can be achieved by oversampling the signal. For each additional bit of resolution, n , the signal must be oversampled 4^n times. The frequency the signal has to be sampled with is given by the equation below:

Equation 1-1. Oversampling Frequency

$$f_{\text{oversampling}} = 4^n \times f_{\text{nyquist}}$$

1.3 Noise

To make this method work properly, the signal component of interest may not vary greatly during a conversion. However, another criterion for a successful enhancement of the resolution is that the input signal has to vary slightly when sampled. This may look like a contradiction, but in this case, variation means just a few LSB. The variation may be seen as the noise component of the signal. When oversampling a signal, there may be noise present to satisfy this demand of small variations in the signal. The quantization error of the ADC is at least 0.5 LSB. Therefore, the noise amplitude has to exceed 0.5 LSB to toggle the LSB. Noise amplitude of 1-2 LSB is even better because this will ensure that several samples do not end up getting the same value.

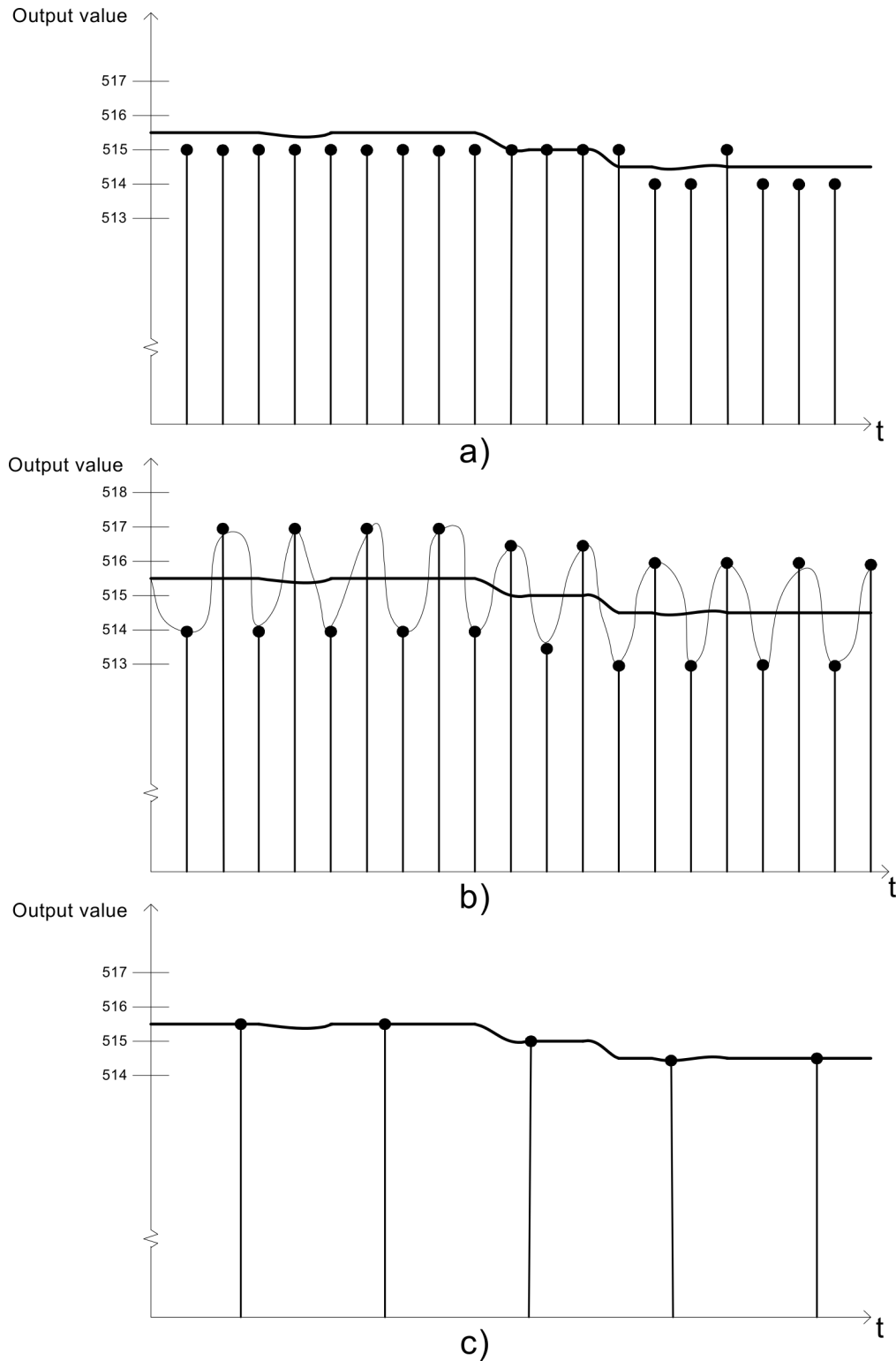
Criteria for noise when using the decimation technique:

- The signal component of interest may not vary significantly during a conversion

- There may be some noise present in the signal
- The amplitude of the noise may be at least 1 LSB

Normally, there will be some noise present during a conversion. The noise can be thermal noise, noise from the CPU core, switching of I/O-ports, variations in the power supply, and others. This noise will in most cases be enough to make this method work. In special cases though, it might be necessary to add some artificial noise to the input signal. This method is referred to as dithering. [Figure 1-1](#) (a) shows the problem of measuring a signal with a voltage value that is between two quantization steps. Averaging four samples will not help, since the same low value will be the result. [Figure 1-1](#) (b) shows that by adding some artificial noise to the input signal, the LSB of the conversion result will toggle. Adding four of these samples halves the quantization steps, producing results that give better representations of the input value, as shown in [Figure 1-1](#) (c). The ADCs 'virtual resolution' has increased from 10 to 11 bits. This method is referred to as Decimation and will be explained further in [Section 1.4 Averaging](#).

Figure 1-1. Increasing the Resolution from 10-Bit to 11-Bit

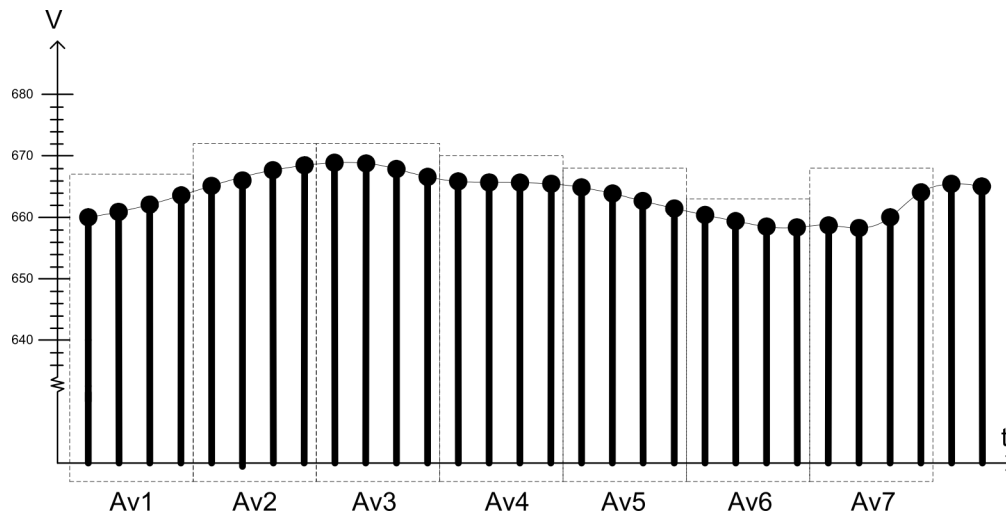


Another reason to use this method is to increase the signal-to-noise ratio. Enhancing the Effective Number of Bits, ENOB, will spread the noise over an increased binary number. The noise influence on each binary digit will decrease. Doubling the sampling frequency will lower the in-band noise by 3 dB, and increase the resolution of the measurement by 0.5 bits.

1.4 Averaging

The conventional meaning of averaging is adding m samples, and dividing the result by m , which is referred to as normal averaging. Averaging data from an ADC measurement is equivalent to a low-pass filter and has the advantage of attenuating signal fluctuation or noise and it will flatten out peaks in the input signal. The Moving Average method is very often used to do this. It works by taking m readings, place them in a cyclic queue and average the most recent m . This will give a slight time delay because each sample is a representation of the last m samples. This can be done with or without overlapping windows. The figure below shows seven ($Av1$ - $Av7$), independently Moving Average results without overlapping.

Figure 1-2. Moving Average Principle



It is important to remember that normal averaging does not increase the resolution of the conversion. Decimation, or interpolation, is the averaging method, which combined with oversampling, increases the resolution.

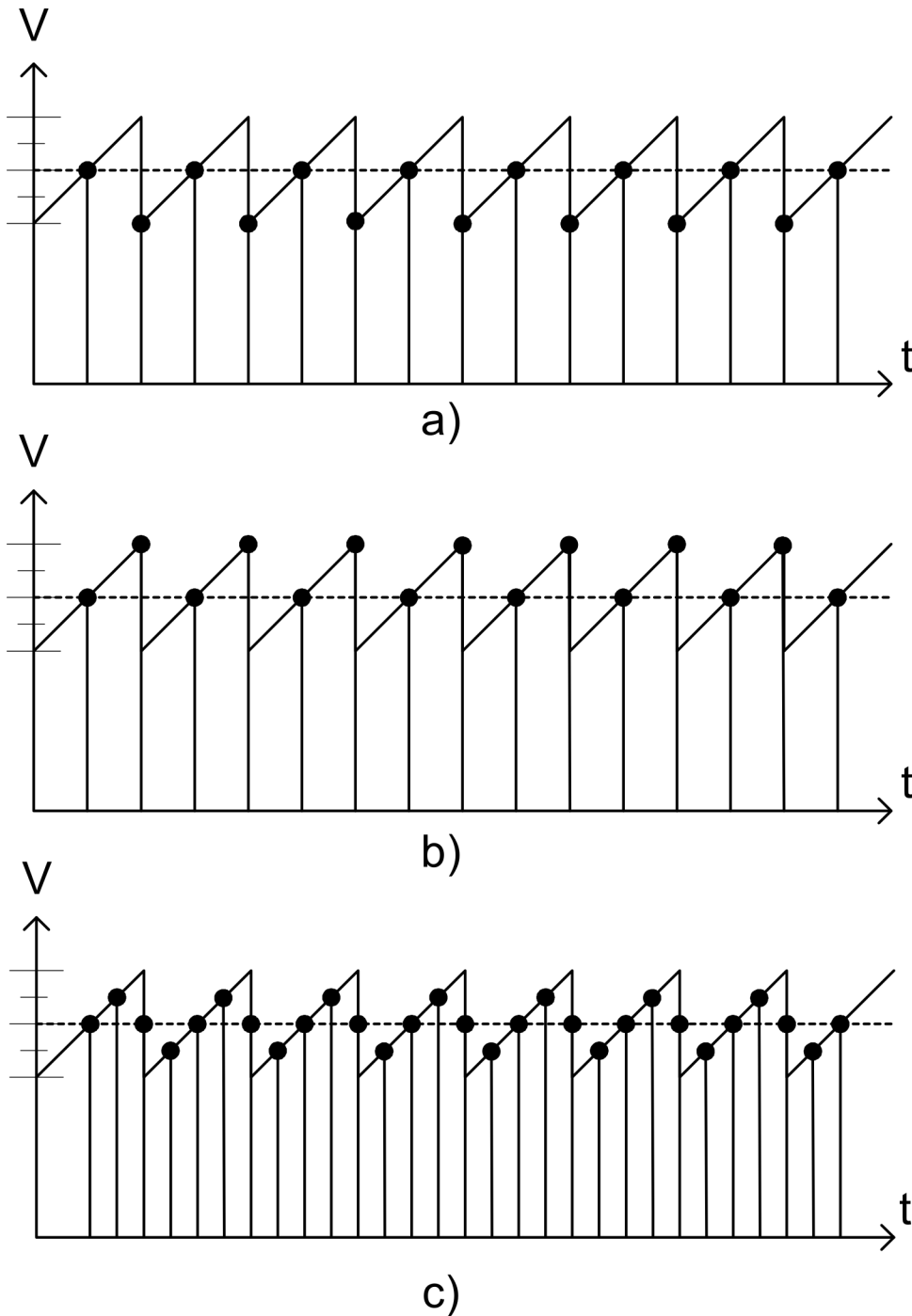
The extra samples, m , achieved by oversampling the signal are summed up, just as in normal averaging, but the result is not divided by m as in normal averaging. Instead, the result is right shifted by n , where n is the desired extra bit of resolution, to scale the answer correctly. Right shifting a binary number once is equal to dividing the binary number by a factor of 2.

1.5 When Will 'Oversampling and Decimation' Work?

Normally a signal contains some noise. This noise very often has the characteristic of Gaussian noise, more commonly known as white noise or thermal noise, recognized by the wide frequency spectrum and that the total energy is equally divided over the entire frequency range. In these cases the method of 'Oversampling and decimation' will work, if the amplitude of the noise is sufficient to toggle the LSB of the ADC conversion.

In other cases, it might be necessary to add an artificial noise signal to the input signal. This method is referred to as dithering. The waveform of this noise may be Gaussian noise, but a periodical waveform will also work. What frequency this noise signal may have, depends on the sampling frequency. A rule of thumb is: "When adding m samples, the noise signals period may not exceed the period of m samples". The amplitude of the noise may be at least 1 LSB. When adding artificial noise to a signal, it is important to remember that noise has a mean value of zero; insufficient oversampling therefore may cause an offset, as shown in the following figure.

Figure 1-3. Offset Caused by Insufficient Sampling



The stippled line illustrates the averaged value of the saw-tooth signal. The sampling shown in figure (a) above will cause a negative offset, while the sampling in (b) will cause a positive offset. In figure (c) the sampling is sufficient, and offset is avoided. To create an artificial noise signal, one of the AVR[®] counters can be used. Since the counter and the ADC are using the same clock source, this gives the possibility of synchronizing the noise and the sampling frequencies to avoid offset.

2. Source Code Overview

This chapter explains how the oversampling demo application works, and also how different configuration parameters can be changed to obtain different oversampling levels.

This software has been developed and tested on the Microchip XMEGA-A3BU Xplained board.

The application takes care of ADC offset and gain error. For best results the user must configure the correct gain error value, which will vary from device to device, by changing the macro `ADC_GAIN_ERROR_FACTOR` in *adc_oversampling.h*.

Application configuration:

- CPU clock: 2 MHz (default)
- Peripherals used:
 - USARTD0:
 - USART in SPI mode, at 125 kHz baud-rate.
 - ADCB:
 - Signed, 12-bit resolution, running at 250 kSPS, with external reference: AREFB
 - PB0 - External reference
 - PB1 - ADC Positive input
 - PB2 - ADC Negative input
 - PB3 - ADC Offset
 - GPIO
 - PE4 - LCD Backlight
 - PA3 - LCD Reset
 - PD0 - LCD A0-Register Select
 - PF3 - LCD Chip Select
 - PD1 - LCD Serial Clock (USARTD0 XCK)
 - PD2 - LCD serial Data (USARTD0 TX)

The application is configured in Atmel START, which generates peripheral drivers and all necessary configuration files, as well as a `main()` function that calls all necessary function to initialize drivers.

- Driver header and source files are located in the *src* and *include* folder.
- *atmel_start.c* contains the function `atmel_start_init()`, which initializes the system, drivers, and middlewares in the project.
- The GFX mono library is found in the *gfx_mono* folder.

2.1 How the Oversampling Demo Project Works

The oversampling demo project has been prepared and tested for the XMEGA-A3BU Xplained kit. Refer “[AN_8394 - AVR1923: XMEGA-A3BU Xplained Hardware User Guide](#)” application note for more details about XMEGA-A3BU Xplained kit.

ADCB from the target device Microchip ATxmega256A3BU has been used for sampling the input signal, and this ADC has been configured in differential, signed, 12-bit resolution, 250kSPS and external reference on the AREFB pin.

During ADC initialization, the ADC offset error will be calculated with a similar ADC configuration, which will be used for input signal sampling. By using this offset value, the offset error correction will be done each time a sample is read from the ADC. In the current configuration of the application an external reference must be present on the AREFB pin. This reference is used to measure the offset error on start-up. Otherwise, the measured ADC reading will not be accurate because of a wrong offset error calculation.

After an offset error correction, ADCB will be configured in Free-Running mode to sample the input signal.

2.1.1 Oversampling Configuration

The different parameters that controls the oversampling portion of the application can be found in the header file *adc_oversampling.h*. For example, it is possible to change the result resolution. More details can be found in the code comments available in the header file itself.

2.1.2 Getting Started with the Demo Project

To get started using this application, given default configuration parameters in *adc_oversampling.h*, the following hardware connections are needed on the XMEGA-A3BU Xplained board:

- Connect a 3.0V reference to pin 1 on header J2 (marked as ADC0)
- Connect the positive input of an external analog signal, which has to be measured in Differential mode to pin 2 on header J2 (marked as ADC1)
- Connect the negative input of an external analog signal to pin 3 on header J2 (marked as ADC2)

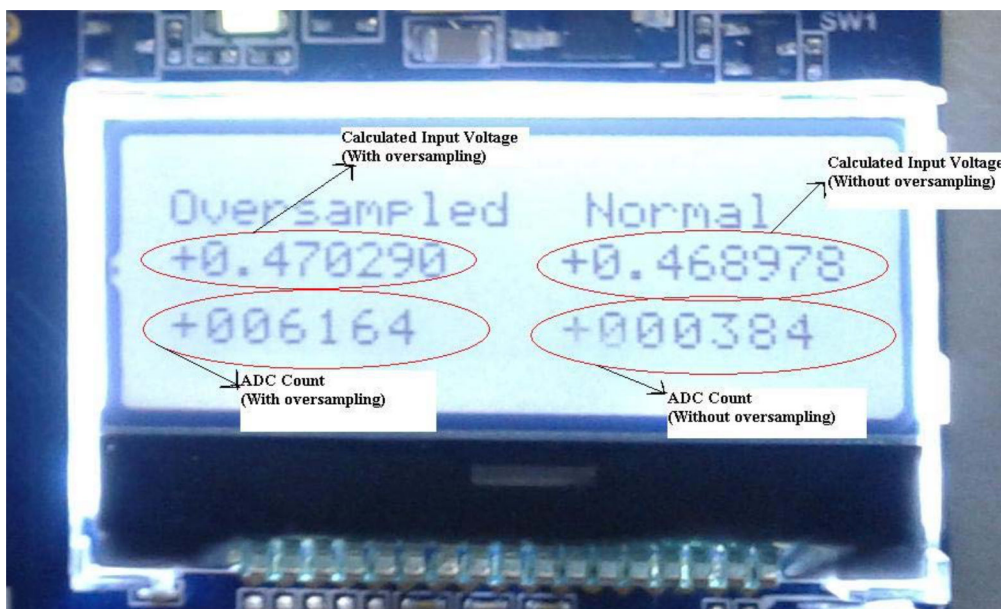
After completing the necessary hardware connections, program the application hex file to the target, and observe the ADC results on the LCD.

2.1.3 ADC Results on the LCD Display

The results will be displayed on the LCD available on the XMEGA-A3BU Xplained kit. For comparison, both the oversampled result and the single sample result are displayed on the LCD. Both ADC count and calculated analog input voltage are displayed.

A screenshot of the LCD display is shown in the [Figure 2-1](#).

Figure 2-1. Screenshot of the LCD Display



3. Get Source Code from Atmel | START

The example code is available through Atmel | START, which is a web-based tool that enables configuration of application code through a Graphical User Interface (GUI). The code can be downloaded for both Atmel Studio and IAR Embedded Workbench® via the direct example code-link below or the *Browse examples* button on the Atmel | START front page.

Atmel | START web page: <http://start.atmel.com/>

Example Code

AVR1629 XMEGA ADC Oversampling

- http://start.atmel.com/#example/Atmel:avr1629_xmega_adc_oversampling::01.0.0::Application:AVR1629_XMEGA_ADC_Oversampling:

Click *User guide* in Atmel | START for details and information about example projects. The *User guide* button can be found in the example browser, and by clicking the project name in the dashboard view within the Atmel | START project configurator.

Atmel Studio

Download the code as an `.atzip` file for Atmel Studio from the example browser in Atmel | START, by clicking *Download selected example*. To download the file from within Atmel | START, click *Export project* followed by *Download pack*.

Double-click the downloaded `.atzip` file and the project will be imported to Atmel Studio 7.0.

IAR Embedded Workbench

For information on how to import the project in IAR Embedded Workbench, open the [Atmel | START user guide](#), select *Using Atmel Start Output in External Tools*, and *IAR Embedded Workbench*. A link to the Atmel | START user guide can be found by clicking *Help* from the Atmel | START front page or *Help And Support* within the project configurator, both located in the upper right corner of the page.

4. Recommended Reading

It is recommended to read the following application notes to get to know more on the Microchip XMEGA ADC and oversampling theory.

Below are listed application notes and other XMEGA related application notes with source code, which are available from the Microchip website link:

- Various [Application Notes](#) are available on this device page on the document tab.
- [AN_2559: AVR120 - Characterization and Calibration of the ADC on an AVR](#) This application note explains various ADC characterization parameters given in the data sheets and how they effect ADC measurements.
- [AN2535: AVR1300 - Using the XMEGA ADC](#) This application note describes the basic functionality of the XMEGA ADC with code examples to get up and running quickly.
- [AN_8320: AVR1505 - XMEGA training - ADC](#) This application note is a training document on how to use the ADC from the AVR Xplained evaluation kit, which features the Microchip ATXMEGA128A1 microcontroller examples to get up and running quickly.
- [AVR042: AVR Hardware Design Considerations](#) This application note covers most of the problems encountered with the power supply design and other physical design problems.
- [AN_8394: AVR1923 - XMEGA-A3BU Xplained Hardware User Guide](#) This is a hardware user guide to start working with XMEGA-A3BU Xplained kit.

5. Resources

- [XMEGA manual and data sheets](#)
- [Atmel Studio 7](#)
- [IAR Embedded Workbench® compiler](#)

6. Revision History

Doc. Rev.	Date	Comments
A	09/2018	• Microchip DS00002777A replaces AVR8498A. • New template and Source Code Overview updated as per Atmel START example
8498A	03/2012	Initial document release

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