

AN0021: Analog to Digital Converter (ADC)



This application note describes how to use the Analog to Digital Converter (ADC) of EFM32 Gecko Series 0 and 1 devices to convert an analog input voltage to a digital value. Many aspects of the ADC, including inputs, references, and the different operating modes are described. Calibration routines for offset and gain are also included.

The provided software examples show how to use the different operating modes of the ADC. The example projects are configured for the EFM32 Gecko Series 0 and 1 devices, but can easily be ported to other EZR32 Wireless MCU and EFR32 Wireless Gecko devices by changing the project settings.

For simplicity, EFM32 Wonder Gecko, Gecko, Giant Gecko, Leopard Gecko, Tiny Gecko, Zero Gecko, and Happy Gecko are a part of the EFM32 Gecko Series 0.

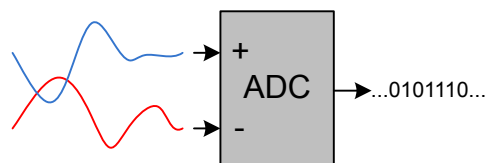
EZR32 Wonder Gecko, Leopard Gecko, and Happy Gecko are a part of the EZR32 Wireless MCU Series 0.

EFM32 Pearl Gecko and Jade Gecko (and future devices) are a part of the EFM32 Gecko Series 1.

EFR32 Blue Gecko, Flex Gecko, and Mighty Gecko are a part of the EFR32 Wireless Gecko Series 1.

KEY POINTS

- There are new ADC features in EFM32 Gecko Series 1 devices.
- This document discusses ADC operation and advanced features.
- The ADC supports offset and gain calibration.
- This application note includes:
 - This PDF document
 - Source files
 - Example C-code
 - Multiple IDE projects



1. Analog to Digital Converter

1.1 Introduction

The EFM32 Gecko ADC is a Successive Approximation Register (SAR) architecture. The maximum resolution is 12 bits, which can achieve one million samples per second (MSPS). The integrated input MUX can select the ADC input from external pins or internal signals. With PRS and DMA, the ADC can operate without CPU intervention, minimizing current consumption or allowing the core to do other work. The ADC can be clocked at different speeds and run using different warm-up modes to reduce the energy consumption even further.

This application note discusses general operation and usage of the ADC. In addition, advanced features and power saving techniques are described. Software examples of ADC operation both with DMA and PRS are included. Offset and Gain Calibration of the ADC is also described and included in the software examples.

For extremely low power periodic ADC sampling, a software example that enters Energy Mode 2 (EM2) between each ADC sample is also included. This is the best way to do low power ADC sampling for sampling frequencies below a couple of kHz.

1.2 Overview

The [Figure 1.1 ADC Overview of EFM32 Giant Gecko on page 2](#) and [Figure 1.2 ADC Overview of EFM32 Pearl Gecko on page 3](#) illustrate the internal connections of the inputs, reference selection, and registers.

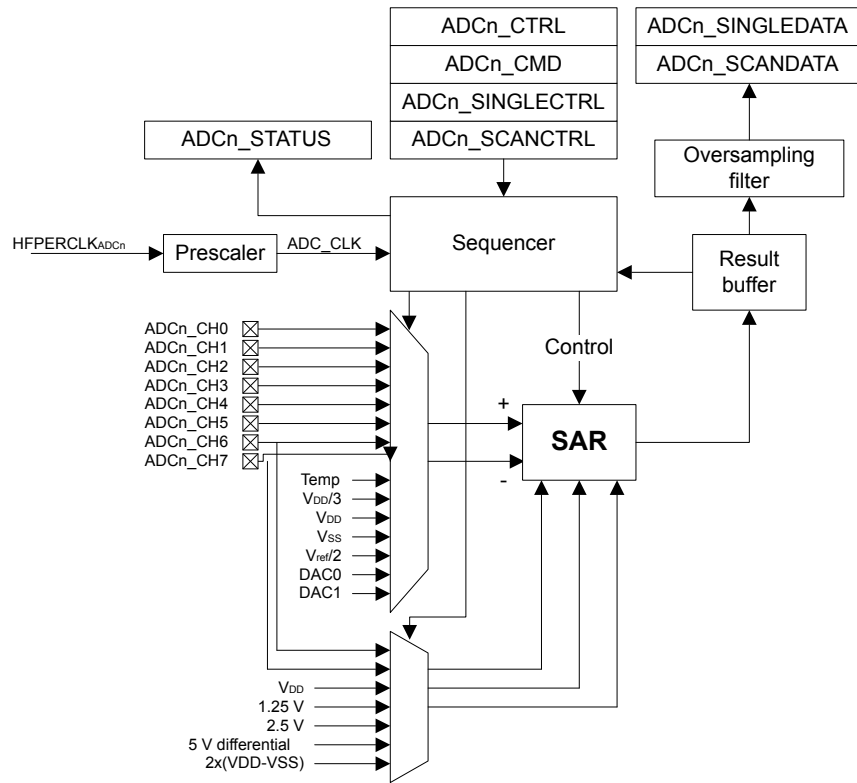


Figure 1.1. ADC Overview of EFM32 Giant Gecko

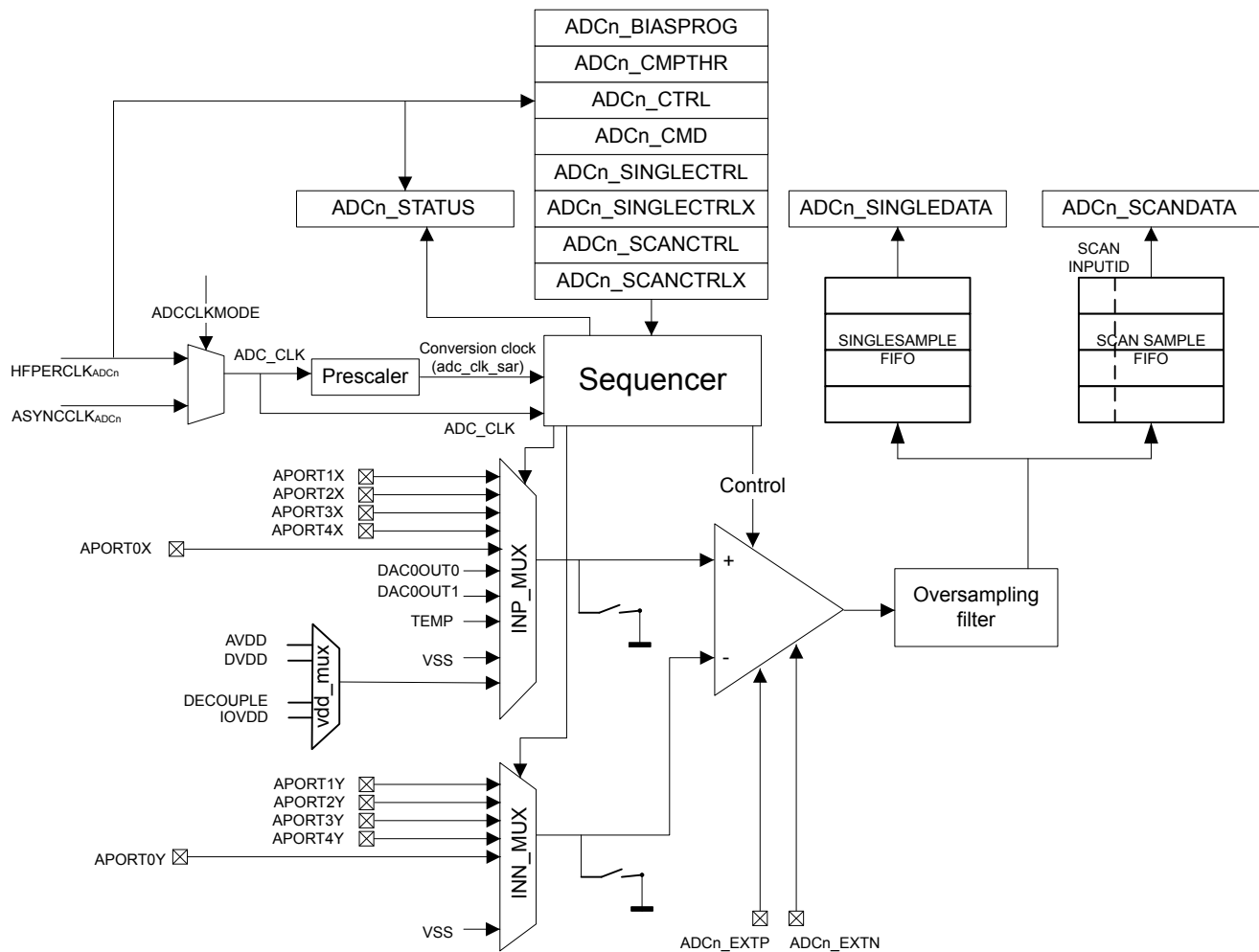


Figure 1.2. ADC Overview of EFM32 Pearl Gecko

Some new ADC features (see the list below) are added in the EFM32 Gecko Series 1 and EFR32 Wireless Gecko Series 1 devices.

- Externally controllable conversion start time using PRS in TIMED mode
- Can be run during EM2 and EM3, waking up the system upon various enabled interrupts
- Can be run during EM2 and EM3 with DMA enabled to pull data from the FIFOs without waking up the system
- Automated clock gating to save power when not converting
- Supports up to 144 external input channels and 11 internal inputs
 - Includes temperature sensor and random number generator function
- Programmable scan sequence
 - Up to 32 configurable samples in scan sequence
 - Four deep FIFOs to store conversion data along with a channel ID and an option to overwrite old data when full
 - Programmable watermark (DVL) to generate a SCAN interrupt
 - Supports window compare function
- Programmable single-channel conversion
 - Four deep FIFOs to store conversion data along with an option to overwrite old data when full
 - Programmable watermark (DVL) to generate a SINGLE interrupt
 - Supports window compare function
- Programmable and preset input full scale (peak-to-peak) range (VFS) with selectable reference sources
 - User-programmable dividers for flexible VFS options from internal, external, or supply voltage reference sources
- Interrupt generation and/or a DMA request when
 - Programmable number of converted data available in the single FIFO (also generates DMA request)

- Programmable number of converted data available in the scan FIFO (also generates DMA request)
- Single FIFO overflow or underflow
- Scan FIFO overflow or underflow
- Latest Single conversion tripped compare logic
- Latest Scan conversion tripped compare logic
- Analog over-voltage interrupt
- Programming Error interrupt due to APORT Bus Request conflict or NEGSEL programming error

2. General Operation

2.1 Clock Selection

The ADC has an internal pre-scaler which can divide the selected ADC conversion clock source. Any factor between 1 and 128 can be chosen by writing a value between 0 and 127 to the PRESC bit field in the ADCn_CTRL register.

The symbols for different clock sources can be found in [Figure 1.1 ADC Overview of EFM32 Giant Gecko on page 2](#) and [Figure 1.2 ADC Overview of EFM32 Pearl Gecko on page 3](#).

Table 2.1. ADC Clock Selection

Item	EFM32 Gecko Series 0 and EZR32 Series 0	EFM32 Gecko Series 1 and EFR32 Wireless Gecko Series 1
ADC peripheral clock source (register interface)	HFPERCLK	HFPERCLK
ADC conversion clock source	HFPERCLK	The ADC_CLK is selected by ADCCLKMODE bit field in the ADCn_CTRL register <ul style="list-style-type: none"> HFPERCLK (ADCCLKMODE = 0) ASYNCCLK (ADCCLKMODE = 1)
ASYNCCLK source	—	Selected by ADC0CLKSEL bit field in the CMU_ADCCTRL register <ul style="list-style-type: none"> Disabled (ADC0CLKSEL = 0) AUXHFRCO (ADC0CLKSEL = 1) HFXO (ADC0CLKSEL = 2) HFSRCCLK (ADC0CLKSEL = 3)
ADC conversion clock frequency	ADC_CLK = HFPERCLK / (1 to 128) Range is from 32 kHz to 13 MHz	adc_clk_sar = ADC_CLK / (1 to 128) Range is from 32 kHz to 16 MHz
Clock source for ADC operation in EM2 and EM3	—	AUXHFRCO (ASYNCCLK) is the only available option during EM2 or EM3

2.2 Input Selection

The external inputs can either be selected as single-ended inputs or combined to allow for differential inputs (see [3.6 Analog Port \(APORT\) for ADC](#)). The DIFF bit field in the ADCn_SINGLECTRL or ADCn_SCANCTRL register enables differential mode.

The ADC input signals are shielded fairly well against other noisy signals within the EFM32 Gecko. If high ADC accuracy is needed, it is advisable not to use any of the unused ADC input pins for noise-inducing activities, such as serial communication.

2.2.1 Single-Ended Mode

In single-ended mode the input signal is measured with ground as the negative input. The voltage span between 0 V and the selected reference is divided in small steps according to the selected resolution.

The result is an unsigned number between 0 and $2^{\text{resolution}} - 1$, indicating where the input voltage is located in the span between ground and the reference voltage.

2.2.2 Differential Mode

In differential mode the measured value is the difference between two inputs. Since one input is defined as the positive input and the other is defined as the negative input, the difference can be positive or negative depending on which input is higher. As a result, the conversion result is a signed number represented in two's complement form. If the negative input is higher than the positive input, the converted value is negative (see [4.3 Differential Inputs](#) and [5.3 Single and Scan Conversion with Differential Inputs](#)). Note that the ADC cannot convert negative voltages in reference to ground.

Table 2.2. ADC Input Selection

Item	EFM32 Gecko Series 0 and EZR32 Series 0	EFM32 Gecko Series 1 and EFR32 Wireless Gecko Series 1
External inputs for Single-Ended mode	Up to 8, fix on pins PD0 – PD7	Up to 144 through APORT
External inputs for Differential mode	Up to 8, fix on pins PD0 – PD7 <ul style="list-style-type: none"> Two neighboring inputs are used in differential mode, for instance channel 0 and channel 1 is one differential pair, channel 2 and channel 3 another The lowest channel number is the positive differential input 	Up to 72 through APORT
Internal inputs	6	Up to 11
Input filtering	Low pass RC filter or an internal decoupling capacitor	—
Temperature sensor	Set INPUTSEL bit field in the ADCn_SINGLECTRL register to TEMP	Set POSSEL bit field in the ADCn_SINGLECTRL register to TEMP
Offset calibration	Set INPUTSEL bit field in the ADCn_SINGLECTRL register to DIFF0 (short between positive and negative inputs)	Set POSSEL and NEGSEL bit fields in the ADCn_SINGLECTRL register to VSS

2.3 Reference Selection

To convert an analog voltage to a digital value, the ADC needs a reference voltage to which it compares the incoming analog voltage. Since the ADC cannot measure voltages larger than the reference voltage, the reference voltage should be above the maximum expected measured voltage.

The selected reference source is combined with internal circuitry to produce the full-scale voltage (VFS) for the converter. VFS is the full input range of the converter, from the lowest possible input voltage to the highest. For single-ended conversions, the input range on the selected positive input is from 0 to VFS. For differential conversions, the input to the converter is the difference between the positive and negative input selections. The ADC conversion result ranges from $-VFS/2$ to $+VFS/2$.

The maximum and minimum input voltage which the ADC can recognize at any external pin is limited to the supply voltages. If VFS is configured to be larger than the supply range (for example, VFS configured to 5 V when operating on a 3.3 V supply), the full ADC range is not available.

The ADC cannot measure negative voltages or voltages larger than the reference voltage. As a result, it is important to keep both inputs within the electrical limits of the device.

Table 2.3. ADC Reference Selection

Item	EFM32 Gecko Series 0 and EZR32 Series 0	EFM32 Gecko Series 1 and EFR32 Wireless Gecko Series 1
Internal bandgap reference	<ul style="list-style-type: none"> 1.25 V 2.5 V (supply voltage > 2.5 V) 5 V differential (supply voltage > 2.75 V) 	<ul style="list-style-type: none"> 1.25 V 2.5 V 5 V differential
Internal reference	<ul style="list-style-type: none"> VDD Unbuffered 2 x VDD 	<ul style="list-style-type: none"> AVDD 2 x AVDD
External single-ended reference	Pin PD6 as input	Use ADCn_EXTP pin as input
External differential reference	<ul style="list-style-type: none"> Use pin PD6 as positive input Use pin PD7 as negative input Reference = 2 x (PD6 – PD7) 	<ul style="list-style-type: none"> Use ADCn_EXTP pin as positive input Use ADCn_EXTN pin as negative input Reference = 2 x (ADCn_EXTP – ADCn_EXTN)
GPBIASACC bit field of the ADCn_BIASPROG register	—	<ul style="list-style-type: none"> Set to 0 (HIGHACC) when an internal bandgap reference source is used Set to 1 (LOWACC) when AVDD or an external pin reference is used

2.4 Conversions

A conversion consists of acquisition and approximation phases. The input is sampled in the acquisition phase before it is converted to digital representation during the approximation phase. The acquisition time can be configured independently for scan sequence and single channel conversions by setting AT bit field in the ADCn_SINGLECTRL or ADCn_SCANCTRL register.

The symbols for different clock sources can be found in [Figure 1.1 ADC Overview of EFM32 Giant Gecko on page 2](#) and [Figure 1.2 ADC Overview of EFM32 Pearl Gecko on page 3](#).

Table 2.4. ADC Conversions

Item	EFM32 Gecko Series 0 and EZR32 Series 0	EFM32 Gecko Series 1 and EFR32 Wireless Gecko Series 1
ADC_CLK	Pre-scaled HFPERCLK	HFPERCLK or ASYNCCLK
adc_clk_sar	—	Pre-scaled ADC_CLK
Acquisition time (AT)	1 to 256 (integer power of 2) ADC_CLK cycles	1 to 256 (integer power of 2) adc_clk_sar cycles
Minimum acquisition time for VDD/3	2 μ s	—
Minimum acquisition time for the internal temperature sensor	2 μ s	AT bit field of the ADCn_SINGLECTRL or ADCn_SCANCTRL register should be set to a value of 9 (256 adc_clk_sar cycles)
ADC warm-up time	Based on HFPERCLK	Based on ADC_CLK
ADC total conversion time per output <ul style="list-style-type: none"> Tacq equals the number of acquisition cycles N is the resolution in bits OVSRSSEL is the oversampling ratio when oversampling is enabled 	In ADC_CLK cycles $T_{conv} = (T_{acq} + N) \times OVSRSSEL$	In adc_clk_sar cycles $T_{conv} = (T_{acq} + (N + 1)) \times OVSRSSEL$

2.5 ADC Modes

The ADC contains two separate programmable modes: single channel mode and scan mode. Both modes have separate configuration and result registers. Both modes may be set up to run only once per trigger or to automatically repeat after each operation. The scan mode has priority over single channel mode.

2.5.1 Single Channel Mode

In single channel mode, the ADC converts one input either one time or continuously if the REP bit field in the ADCn_SINGLECTRL register is set (see [4.1 Single Conversion](#) and [5.1 Single and Scan Conversion](#)). The DIFF bit field in the ADCn_SINGLECTRL register selects whether differential or single-ended inputs are used.

Table 2.5. ADC Single Channel Mode

Item	EFM32 Gecko Series 0 and EZR32 Series 0	EFM32 Gecko Series 1 and EFR32 Wireless Gecko Series 1
Input selection	The input for single conversion is defined by the bit field INPUTSEL in the ADCn_SINGLECTRL register	The POSSEL and NEGSEL bit fields in the ADCn_SINGLECTRL register select the input signals
FIFO for conversion results	—	4 x 32 bit
Programmable FIFO watermark (DVL) to generate SINGLE interrupt	—	The DVL bit field of the ADCn_SINGLECTRLX register controls the FIFO watermark crossing which sets the SINGLEDV bit in the ADCn_STATUS register
SINGLEDV bit in the ADCn_STATUS register is set	Valid data in the ADCn_SINGLEDATA register	(DVL+1) number of single channel conversion results are available in single FIFO
SINGLEOF bit in ADCn_IF register is set	Result is not read before the next result is ready, the first result is overwritten	Signals that a result from a single channel FIFO has been overwritten before being read
ADCn_SINGLEFIFOCOUNT register	—	Number of unread data available in single FIFO
ADCn_SINGLEFIFOCLEAR register	—	Clear single FIFO content

2.5.2 Scan Mode

In scan mode, the ADC can be configured to convert a sequence of different inputs, either one time or continuously if the REP bit field in the ADCn_SCANCTRL register is set (see [4.2 Scan Conversion with DMA Transfer](#) and [5.1 Single and Scan Conversion](#)). The DIFF bit field in the ADCn_SCANCTRL register selects whether differential or single-ended inputs are used. DMA can be used to transfer results to RAM after each conversion. All the results can then be read from RAM after the sequence has finished.

Table 2.6. ADC Scan Mode

Item	EFM32 Gecko Series 0 and EZR32 Series 0	EFM32 Gecko Series 1 and EFR32 Wireless Gecko Series 1
Input selection	The inputs included in the scan sequence are defined by the bit field INPUTMASK in ADCn_SCANCTRL register	The inputs included in the scan sequence are defined by the ADCn_SCANMASK, ADCn_SCANINPUTSEL and ADCn_SCANNEGSEL registers
FIFO for conversion results	—	4 x 32 bit
Programmable FIFO watermark (DVL) to generate SCAN interrupt	—	The DVL field of the ADCn_SCANCTRLX register controls the FIFO watermark crossing which sets the SCANDV bit in the ADCn_STATUS register
SCANDV bit in the ADCn_STATUS register is set	Valid data in the ADCn_SCANDATA register	(DVL+1) number of scan conversion results are available in scan FIFO
SCANOF bit in ADCn_IF register is set	Result is not read before the next result is ready, the first result is overwritten	Signals that a result from a scan FIFO has been overwritten before being read
ADCn_SCANDATA register	—	The FIFO data is tagged with SCANINPUTID and can be read along with the scan data using this register
ADCn_SCANFIFOCOUNT register	—	Number of unread data available in scan FIFO
ADCn_SCANFIFOCLEAR register	—	Clear scan FIFO content

2.6 Warm-Up Modes

After power-on, the ADC requires some time for internal bias currents and references to settle prior to starting a conversion. This time period is called the warm-up time and is performed by hardware. Firmware must program the number of clock cycles required to count at least 1 μ s in the TIMEBASE bit field of the ADCn_CTRL register.

Normally, the ADC is warmed up only when samples are requested and is shut off when there are no more samples waiting. However, if lower latency is needed, configuring the WARMUPMODE bit field in the ADCn_CTRL allows the ADC and/or reference to stay warm between samples, reducing the warm-up time or eliminating it altogether. Note that keeping the ADC and/or reference enabled between samples increases the energy consumption of the ADC.

Note: Only the reference selected for scan mode is kept warm. To avoid warm-up time in single conversion mode, the single conversion reference needs to be the same as the scan conversion reference.

Table 2.7. ADC Warm-up Mode of EFM32 Gecko Series 0

Warmup Mode	EFM32 Gecko Series 0 and EZR32 Series 0
NORMAL	<ul style="list-style-type: none"> • ADC and references are shut off when there are no samples waiting • When entering Energy Mode 2 or 3, the ADC must be stopped and WARMUPMODE must be set to NORMAL • Total time = Bandgap reference warm-up time (5 μs) + ADC warm-up time (1 μs) + ADC conversion time
FASTBG	<ul style="list-style-type: none"> • Bandgap warm-up is eliminated, but with reduced reference accuracy • Total time = ADC warm-up time (1 μs) + ADC conversion time
KEEPSCANREFWARM	<ul style="list-style-type: none"> • The reference selected for scan mode is kept warm. The ADC will still need to be warmed up before conversion • Total time = ADC warm-up time (1 μs) + ADC conversion time
KEEPADCWARM	<ul style="list-style-type: none"> • The ADC and the reference selected for scan mode are kept warm • Total time = ADC conversion time

Table 2.8. ADC Warm-up Mode of EFM32 Gecko Series 1

Warmup Mode	EFM32 Gecko Series 0 and EZR32 Series 1
NORMAL	<ul style="list-style-type: none"> • ADC and references are shut off when there are no samples waiting • Total time = ADC warm-up time (5 μs) + ADC conversion time
KEEPINSTANDBY	<ul style="list-style-type: none"> • The reference selected for scan mode is kept warm, but the ADC is powered down • The ADC will initiate a 1 μs warm-up period before a conversion begins • Total time = ADC warm-up time (1 μs) + ADC conversion time
KEEPINSLOWACC	<ul style="list-style-type: none"> • It is similar to KEEPINSTANDBY, but continuously tracks the input, keeping the input multiplexer connected to the analog bus • Total time = ADC warm-up time (1 μs) + ADC conversion time
KEEPADCWARM	<ul style="list-style-type: none"> • The ADC and the reference selected for scan mode are kept warm • Total time = ADC conversion time

3. Advanced Features

3.1 Bias Current Programming

The current consumption of the ADC can be adjusted through the ADCn_BIASPROG register. Adjusting this bitfield also affects the performance and bandwidth of the ADC. The default register values should be used to ensure correct operation of the ADC within the specified clock speed range and with all configurations. The bias current settings should only be changed while the ADC is disabled (i.e., in NORMAL warm-up mode and no conversion in progress).

Table 3.1. ADC Bias Current Programming

Item	EFM32 Gecko Series 0 and EZR32 Series 0	EFM32 Gecko Series 1 and EFR32 Wireless Gecko Series 1
BIASPROG and HALFBIAS bit fields of the ADCn_BIASPROG register	Scale the bias current of the bandgap reference	—
COMPBIAS bit field of the ADCn_BIASPROG register	Scale the bias current of the ADC comparator	—
ADCBIASPROG bit field of the ADCn_BIASPROG register	—	<ul style="list-style-type: none"> • Scale the internal bias of the ADC • For proper operation, the ADC conversion speed must be scaled accordingly

3.2 Oversampling

If higher than 12-bit accuracy is needed, the ADC can automatically sample and average the result in hardware. The number of samples for each averaged result can be selected as 2^n for $n = [1..12]$. If oversampling is enabled, the ADC result is not ready until all the samples are converted and averaged (see [4.4 Oversampling](#) and [5.2 Single and Scan Conversion with Oversampling](#)).

The result is averaged by accumulating samples and right shifting the result. For 2x, 4x, 8x and 16x oversampling the result is not right shifted. Instead, the result consists of more than 12 bits. See [Table 3.2 Oversampling Result Shifting and Resolution](#) on page 13 for oversampling result representation.

Table 3.2. Oversampling Result Shifting and Resolution

Oversampling Setting	Number of Right Shifts	Result Resolution (# bits)
2x	0	13
4x	0	14
8x	0	15
16x	0	16
32x	1	16
64x	2	16
128x	3	16
256x	4	16
512x	5	16
1024x	6	16
2048x	7	16
4096x	8	16

If the samples of the measured signal are affected by uncorrelated random noise added to each sample, oversampling and averaging can be used to increase the signal-to-noise ratio. The number of additional samples needed to get n additional bits of meaningful data in the result is given by the following equation.

Note: samples = 2^{2n}

Note that an accurate result requires more time to sample the signal. For example, this equation can be used to get a 16 bit accuracy at the expense of using more time per sample because the signal must be sampled many times. To get 4 additional bits of meaningful data for the 12-bit ADC in the EFM32 Gecko, the number of samples needed equals $2^{2 \cdot 4}$ which is 256 samples.

3.3 Peripheral Reflex System

The ADC can be configured as both a consumer and a producer of PRS signals. Both scan and single conversions can be triggered by a PRS signal and PRS signals can also be produced when a conversion is finished.

Often the ADC samples a voltage with fixed intervals and, preferably, without the CPU intervention. Periodic measurements can be achieved by using the Peripheral Reflex System and a timer (producer) that runs continuously and sends a PRS pulse to the ADC (consumer) with specific intervals. When the ADC receives a PRS pulse, it triggers a conversion start. A conversion-finished interrupt can then handle the result (see [4.5 PRS Triggered Sampling](#) and [5.4 Single Conversion Interrupt \(EM1\)](#)). The conversion result can also be directly transferred to RAM using DMA.

3.4 Direct Memory Access

After the DMA module is configured, the ADC can send requests to the DMA module when either a single conversion or a scan conversion finishes. The DMA module can then transfer the ADC result from the ADC register to memory without the CPU participating in the transaction (see [4.2 Scan Conversion with DMA Transfer](#), [5.8 Single Conversion LDMA \(EM1\)](#) and [5.10 Scan Conversion LDMA \(EM1\)](#)). The DMA request is cleared when the corresponding single or scan result register is read.

Table 3.3. ADC DMA Request

Item	EFM32 Gecko Series 0 and EZR32 Series 0	EFM32 Gecko Series 1 and EFR32 Wireless Gecko Series 1
SINGLE or SCAN DMA single request (SREQ)	Set when a single or scan conversion has completed	Set when the single or scan FIFO is not empty
SINGLE or SCAN DMA request (REQ)	—	<ul style="list-style-type: none"> • Set when a single or scan FIFO receives (DVL +1) number of samples • The request is cleared when the corresponding single or scan result register is read and corresponding FIFO count reaches lower than the Data Valid Level (DVL)

3.5 Calibration

To get the highest possible performance from the ADC, calibrate for offset and gain errors for each reference voltage (see [4.7 Calibration](#) and [5.15 Calibration](#)). Because devices differ due to production variations, the calibration functionality is necessary. During production, calibration values for offset and gain at 25 degrees Celsius for the internal references are programmed in the device.

The values are accessible to the user and the calibration values for the 1.25 V reference are written to the ADC calibration register after reset. If the EFM32 Gecko is operated at different temperatures or with external references, calibration should be performed at runtime to find the correct values for that temperature and reference.

In addition to offset and gain errors, the ADC result is affected by non-linear effects, such as INL (Integral Non-Linearity) and DNL (Differential Non Linearity). INL and DNL are further described in the datasheet for the device and are not subject to calibration.

3.5.1 Offset Calibration

An offset error is a constant offset of the real conversion result from the ideal result, which means that the output is offset by a constant amount over the entire conversion range. An offset error is shown in [Figure 3.1 ADC Offset Error on page 15](#).

The simplest way to calibrate the offset is to short the positive and negative inputs of the ADC in differential mode or to VSS. The ADC has a built-in feature for shorting the ADC inputs. This can be done in software without any external components.

The calibration register is then adjusted until the converted output is as close to 0 as it can get. Adjusting offset at 0 V also simplifies the gain calibration.

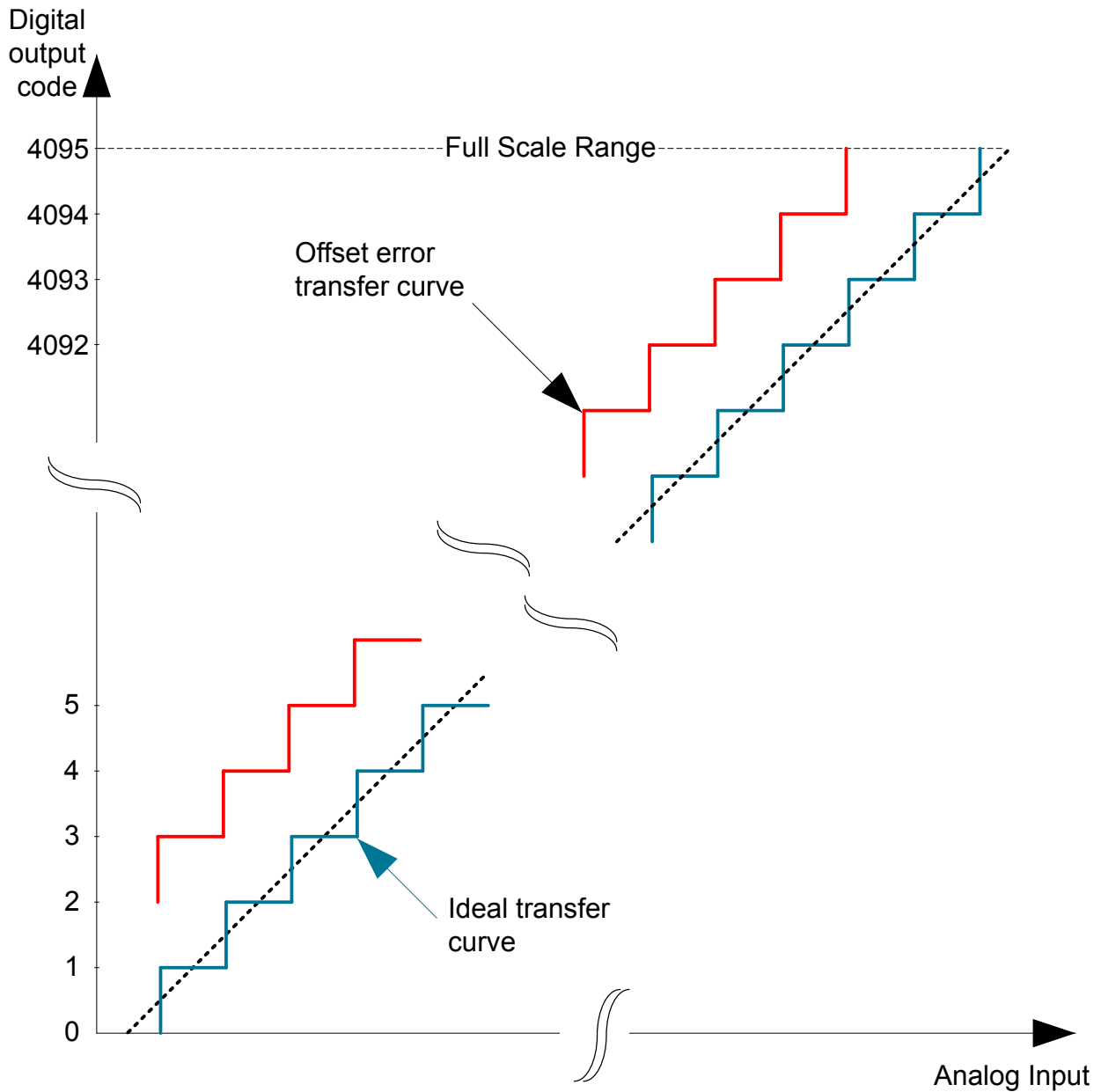


Figure 3.1. ADC Offset Error

ADC offset error gives a constant offset, either above or below the ideal output.

3.5.2 Gain Calibration

If the offset is calibrated at 0 V, a gain error is a linearly increasing offset from the correct conversion result as the input voltage increases. This is shown in [Figure 3.2 ADC Gain Error on page 16](#). Gain calibration should be done after the offset is calibrated correctly at 0 V because the gain calibration routine assumes that the measurement at 0 has 0 offset. Gain can then be calibrated by only looking at one other conversion point, preferably the top value, to get the highest possible accuracy.

By applying a known and fixed voltage that corresponds to the top of the ADC range, which is the ADC reference voltage, the gain can be corrected by adjusting the calibration register until the ADC output corresponds to the highest possible result value.

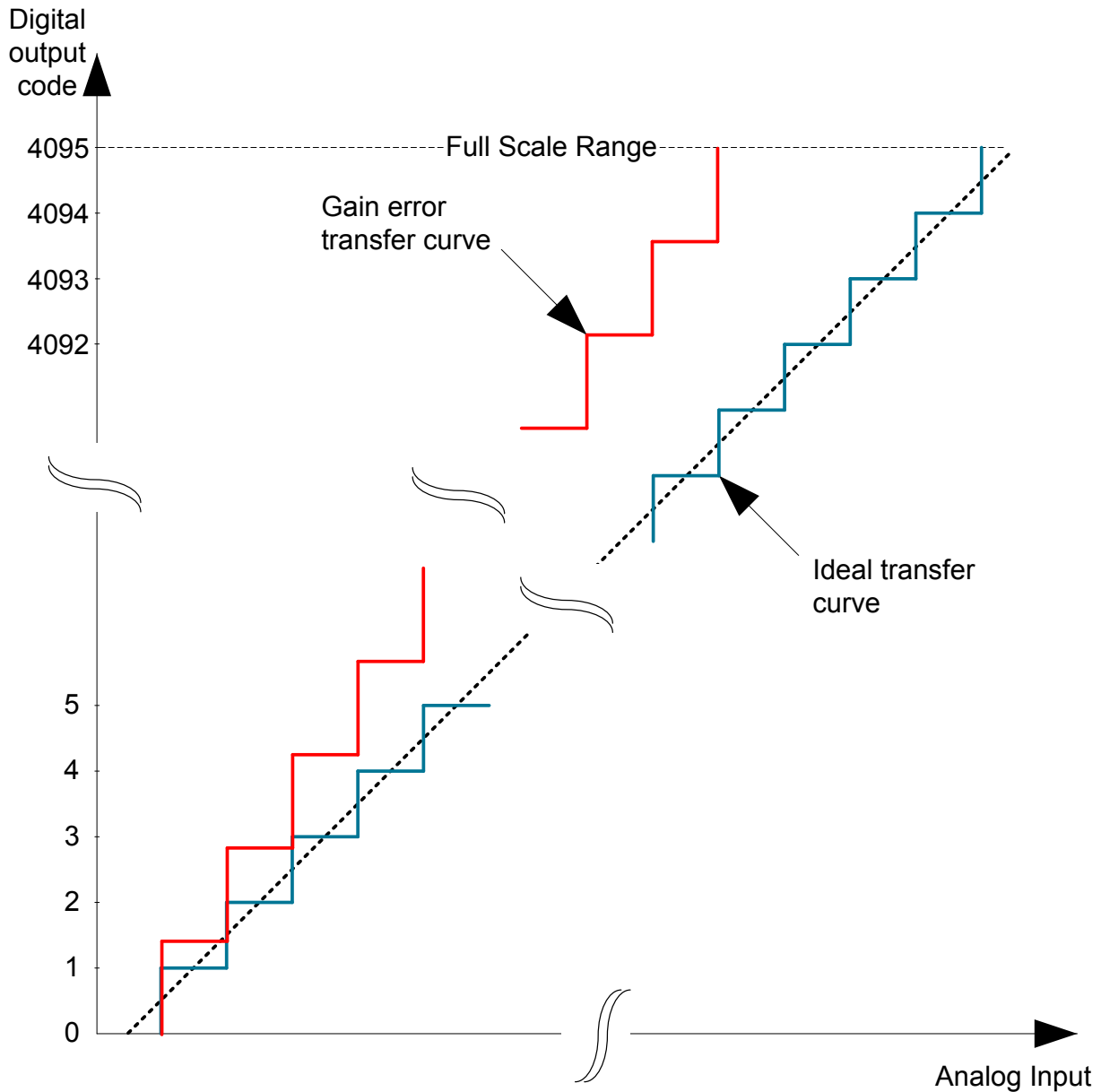


Figure 3.2. ADC Gain Error

If offset is calibrated at 0, an ADC gain error gives a linearly increasing offset either above or below the ideal output.

3.6 Analog Port (APORT) for ADC

The analog port (APORT) expands the number of I/O pin inputs available to the ADC. This feature is not available in EFM32 Gecko Series 0 and EZR32 Series 0 devices.

The ADC samples and converts the analog voltage differential at its positive and negative voltage inputs. The input multiplexers of the ADC can connect these inputs to external signals via analog ports APORT0, APORT1, APORT2, APORT3, or APORT4 (see [Figure 1.2 ADC Overview of EFM32 Pearl Gecko on page 3](#)).

The analog ports, APORT1, APORT2, APORT3, and APORT4 connect to external pins via the shared analog buses (BUSA, BUSB, BUSC, and BUSD). APORT0 is reserved for dedicated I/O pin connections (BUSADC0).

Each analog bus is further split into two sub-buses: X bus and Y bus. All X buses connect to the INP_MUX (positive input terminal) and all Y buses connect to the INN_MUX (negative input terminal).

Table 3.4. APORT and Shared Analog Bus

APORT	Shared Bus	Channel	Number of Channels
APORT0X	BUSADC0X	CH0, 1, 2,...,16	16 (share with APORT0Y)
APORT0Y	BUSADC0Y	CH0, 1, 2,...,16	16 (share with APORT0X)
APORT1X	BUSAX	CH0, 2, 4,...,30	16 (Even)
APORT1Y	BUSAY	CH1, 3, 5,...,31	16 (Odd)
APORT2X	BUSBX	CH1, 3, 5,...,31	16 (Odd)
APORT2Y	BUSBY	CH0, 2, 4,...,30	16 (Even)
APORT3X	BUSCX	CH0, 2, 4,...,30	16 (Even)
APORT3Y	BUSCY	CH1, 3, 5,...,31	16 (Odd)
APORT4X	BUSDX	CH1, 3, 5,...,31	16 (Odd)
APORT4Y	BUSDY	CH0, 2, 4,...,30	16 (Even)

The ADC supports measurement on a maximum of $32 \times 4 = 128$ common channels (APORT1, APORT2, APORT3, and APORT4) and a maximum of 16 dedicated channels (APORT0). Not all selectable channels are available on a given device. The data sheet's APORT Client Map describes what is available in a given device.

See the APORT Client Map in the device data sheet for details about which set of I/O pins are connected to each analog bus. Enumeration selections for each I/O pin are also described in the APORT Client Map. For example, it may mention that external I/O PC6 is mapped to the ADC through BUSAX on the channel APORT1XCH6.

Table 3.5. APORT Client Map Example

Analog Module	Analog Module Channel	Shared Bus	Pin
ADC0	APORT1XCH6	BUSAX	PC6
	APORT1XCH8		PC8
ADC0	APORT1YCH7	BUSAY	PC7
	APORT1YCH9		PC9

Enumeration selections for each I/O pin can also be found by the Configurator tool in Simplicity Studio. Firmware can use these enumerations to connect external GPIO inputs to the ADC.

Procedure:

1. Create a new Configurator project for the selected EFM32 Pearl Gecko device (see *AN0823: Simplicity Configurator User's Guide* for details).
2. Click on the **[DefaultMode Peripherals tab]**.
3. Check the **[ADC0]** checkbox.

4. Click on the [Single sample mode] tab under [Properties].
5. Set [Single sample mode] to [Enabled].
6. Choose the ADC input pin under [Input] drop down menu.

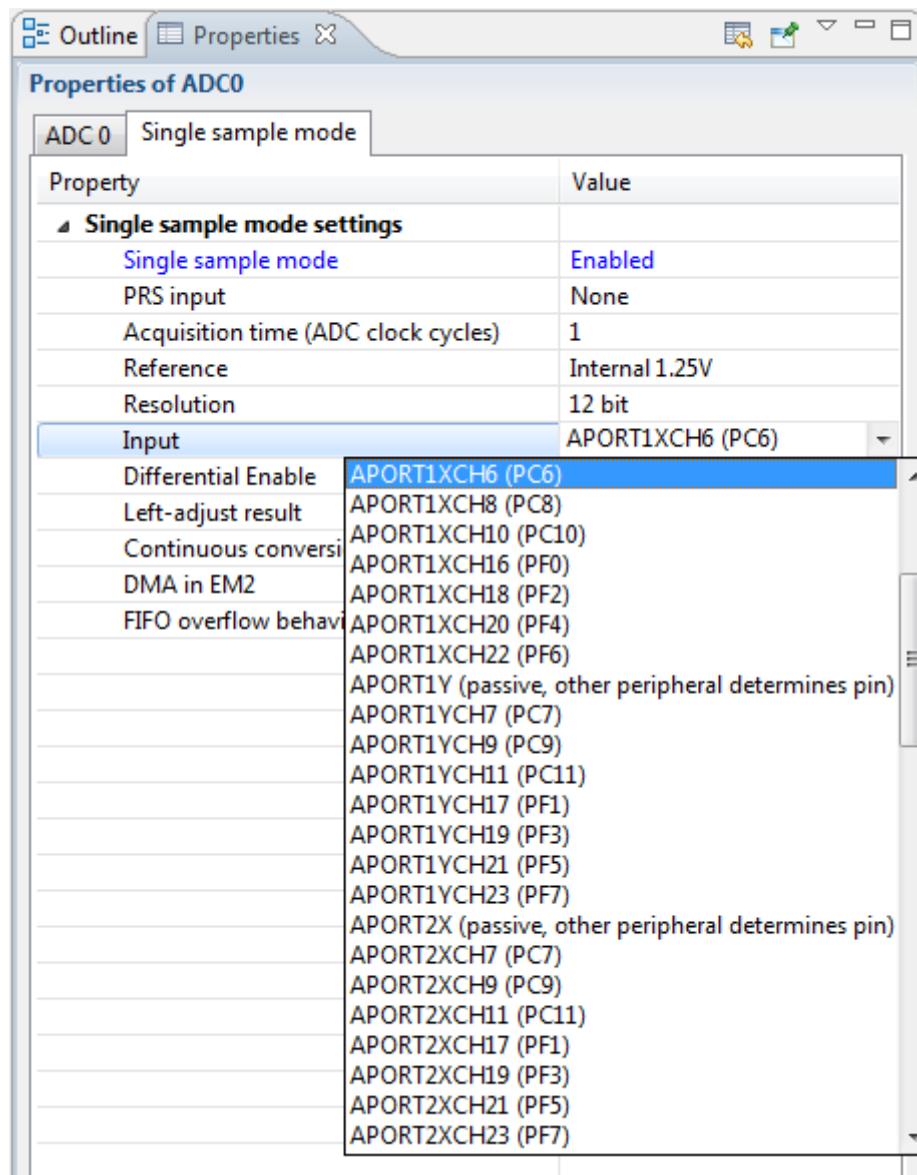


Figure 3.3. Configurator for ADC APORT

Configurator creates a file called InitDevice.c and the ADC input is setup by lines of code, as shown below with PC6 selected as the positive input.

```
extern void ADC0_enter_DefaultMode_from_RESET(void)
{
    // ...
    // ${ADC0_InputConfiguration}
    ADC_InitSingle_TypeDef ADC0_init_single = ADC_INITSINGLE_DEFAULT;

    /* Input(s) */
    ADC0_init_single.posSel = adcPosSelAPORT1XCH6;
    ADC0_init_single.negSel = adcNegSelVSS;
    // ...
}
```

3.6.1 APORT for Single Channel Mode

In single channel mode, the ADCn_SINGLECTRL register provides the POSSEL and NEGSEL bitfield for positive and negative channel selection of the ADC. The APORT Client Map provides the external pin to the internal bus channel mapping enumeration for a particular device.

Software can also choose internal nodes (see [Figure 1.2 ADC Overview of EFM32 Pearl Gecko on page 3](#)) for POSSEL. The internal inputs can only be sampled in single-sample, single-ended mode.

In single-ended conversion mode, X bus or Y bus can be selected for POSSEL and VSS must be selected in NEGSEL. Otherwise, the ADC behavior is undefined.

For differential measurements, one input needs to be chosen from X bus and one from the Y bus. Choosing both inputs from the X bus or both from the Y bus causes a programming error.

Table 3.6. APORT for Single Channel Mode (n = 0 to 4)

Mode	POSSEL	NEGSEL	Operation
Single-Ended	Pin from APORTnX	VSS	ADC performs a single-ended conversion
	Pin from APORTnY	VSS	ADC performs a negative single-ended conversion and then automatically inverts the result at the end
Differential	Pin from APORTnX	Pin from APORTnY	ADC performs a differential conversion
	Pin from APORTnY	Pin from APORTnX	ADC performs a differential conversion and then automatically inverts the result at the end
	Pin from APORTnX	Pin from APORTnX	Generate a PROGERR interrupt (if enabled) of NEGSEL-CONF type (checked in the ADCn_STATUS register)
	Pin from APORTnY	Pin from APORTnY	Generate a PROGERR interrupt (if enabled) of NEGSEL-CONF type (checked in the ADCn_STATUS register)

3.6.2 APORT for Scan Mode

In scan mode, the user can sample and convert up to 32 channels or channel pairs at each conversion trigger.

For single-ended scanning, the user chooses the 32 channels by programming the ADCn_SCANINPUTSEL register. Each chosen channel must be enabled for scanning by setting the corresponding bit in the ADCn_SCANMASK register.

The 32 channels are arranged into 4 groups. Each group provides channels from the same APORT bus. The choices in the ADCn_SCANINPUTSEL register for each group are described in the figure below.

SCANINPUTSEL	APORTaCHxTO(x+7)								APORTaCHxTO(x+7)								APORTaCHxTO(x+7)								APORTaCHxTO(x+7)															
	INPUT(x+7)	INPUT(x+6)	INPUT(x+5)	INPUT(x+4)	INPUT(x+3)	INPUT(x+2)	INPUT(x+1)	INPUTx	INPUT(x+7)	INPUT(x+6)	INPUT(x+5)	INPUT(x+4)	INPUT(x+3)	INPUT(x+2)	INPUT(x+1)	INPUTx	INPUT(x+7)	INPUT(x+6)	INPUT(x+5)	INPUT(x+4)	INPUT(x+3)	INPUT(x+2)	INPUT(x+1)	INPUTx	INPUT(x+7)	INPUT(x+6)	INPUT(x+5)	INPUT(x+4)	INPUT(x+3)	INPUT(x+2)	INPUT(x+1)	INPUTx								
SCANMASK	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1								
SCANINPUTID	31								24 23								16 15								8 7								0							

APORTa = APORT0, APORT1, APORT2, APORT3 or APORT4
X = 0, 8, 16 or 24 if a is 1,2,3 or 4
X= 0 or 8 if a is 0

Figure 3.4. ADC Single-ended Scan Mode Input Selection

The scan starts at SCANINPUTID0 and sequentially scans until it reaches the SCANINPUTID31 for every enabled channel.

The ADC `emlib` module includes the `ADC_ScanSingleEndedInputAdd()` function in `em_adc.c` to set up inputs for ADC single-ended scan mode.

The table below is an example of how to setup the ADC in single-ended scan mode for inputs PA0, PA1, PD10, and PD11 in EFM32 Pearl Gecko (see 5.1 Single and Scan Conversion).

Table 3.7. ADC Single-ended Scan Mode Example

Procedure	Result
Get the enumerations of the ADC inputs from device data sheet or Configurator	<ul style="list-style-type: none"> PA0 - <code>adcPosSelAPORT3XCH8</code> PA1 - <code>adcPosSelAPORT3YCH9</code> PD10 - <code>adcPosSelAPORT3XCH2</code> PD11 - <code>adcPosSelAPORT3YCH3</code>
Group inputs from the same APORT bus into one group	<ul style="list-style-type: none"> <code>adcScanInputGroup0</code>: PA0 and PA1 belong to <code>APORT3CH8TO15</code> <code>adcScanInputGroup1</code>: PD10 and PD11 belong to <code>APORT3CH0TO7</code>
Use <code>emlib</code> function <code>ADC_ScanSingleEndedInputAdd()</code> to setup the <code>ADCn_SCANINPUTSEL</code> and <code>ADCn_SCANMASK</code> registers	<pre>ADC_InitScan_TypeDef scanInit = ADC_INITSCAN_DEFAULT; ADC_ScanSingleEndedInputAdd(&scanInit, adcScanInputGroup0, adcPosSelAPORT3XCH8); ADC_ScanSingleEndedInputAdd(&scanInit, adcScanInputGroup0, adcPosSelAPORT3YCH9); ADC_ScanSingleEndedInputAdd(&scanInit, adcScanInputGroup1, adcPosSelAPORT3XCH2); ADC_ScanSingleEndedInputAdd(&scanInit, adcScanInputGroup1, adcPosSelAPORT3YCH3); scanInit.reference = adcRefVDD; ADC_InitScan(ADC0, &scanInit);</pre>

For differential scanning, choose 32 inputs for positive terminal, similarly to the single-ended scan use case, and enable the inputs for scan using ADCn_SCANMASK. In most cases, the negative terminal for each differential scan is automatically selected as the next channel from the same bus. This method creates a valid channel pair successfully because the odd and even channels of an APORT connect to opposite polarity terminals.

An exception to the rule for selecting the negative terminal is for channels in SCANINPUTID 0, 2, 4, 6 and for channels in SCANINPUTID 9, 11, 13, and 15. For each of these groups, the user can choose any of the four negative channels that would normally be paired with them. This gives the user ability to do scanning with a common channel selected as the negative terminal.

For details about this exception, see the ADC section in the EFM32 Gecko Series 1 and EFR32 Wireless Gecko Series 1 device reference manuals.

The ADC `emlib` module includes the `ADC_ScanDifferentialInputAdd()` function in `em_adc.c` to set up inputs for ADC differential scan mode.

The table below shows how to set up the ADC in differential scan mode for inputs PA0, PA1, PD10, and PD11 in EFM32 Pearl Gecko (see [5.3 Single and Scan Conversion with Differential Inputs](#)).

Table 3.8. ADC Differential Scan Mode Example

Procedure	Result
Get the enumerations of the ADC positive inputs from device data sheet or Configurator	<ul style="list-style-type: none"> PA0 - <code>adcPosSelAPORT3XCH8</code> PA1 - Negative input is the next channel from the same bus by default PD10 - <code>adcPosSelAPORT3XCH2</code> PD11 - Negative input is the next channel from the same bus by default
Group positive inputs from the same APORT bus into one group	<ul style="list-style-type: none"> <code>adcScanInputGroup0</code>: PA0 belongs to APORT3CH8TO15 <code>adcScanInputGroup1</code>: PD10 belongs to APORT3CH0TO7
Use <code>emlib</code> function <code>ADC_ScanDifferentialInputAdd()</code> to setup the ADCn_SCANINPUTSEL, ADCn_SCANNEGSEL and ADCn_SCANMASK registers	<pre>ADC_InitScan_TypeDef scanInit = ADC_INITSCAN_DEFAULT; ADC_ScanDifferentialInputAdd(&scanInit, adcScanInputGroup0, adcPosSelAPORT3XCH8, adcScanNegInputDefault); ADC_ScanDifferentialInputAdd(&scanInit, adcScanInputGroup1, adcPosSelAPORT3XCH2, adcScanNegInputDefault); scanInit.reference = adcRef2xVDD; scanInit.diff = true; ADC_InitScan(ADC0, &scanInit);</pre>

If asserts are enabled (`DEBUG_EFM` is defined) in the DEBUG build, the `emlib` functions `ADC_ScanSingleEndedInputAdd()` and `ADC_ScanDifferentialInputAdd()` assert on error (`EFM_ASSERT(false);`) if there are any invalid input settings for the single-ended and differential ADC scan mode.

3.6.3 APORT Conflict

If multiple analog peripherals (ADC, ACMP, IDAC) request the same shared analog bus (X or Y) at the same time, a collision occurs and none of the peripherals is granted control to that shared analog bus control switch. In this case, the bus is kept floating. If this happens with the ADC, the `PROGERR` bit field in the `ADCn_STATUS` register is set to `BUSCONF` and the `PROGERR` interrupt may be generated (if enabled).

The ADC provides a number of status registers to help debugging over-utilization of APORT resources. The `ADCn_APORTREQ` register indicates which APORT the ADC is requesting given the setting of the input select registers. The `ADCn_APORTCONFLICT` register indicates whether any selections are in conflict, internally or externally.

3.7 Advanced Full-Scale Voltage (VFS) Configuration

For most applications, the pre-defined VFS options described in [Table 2.3 ADC Reference Selection on page 7](#) are sufficient. However, advanced VFS configurations are also available by programming the REF bit field in ADCn_SINGLECTRL or ADCn_SCANCTRL register to the CONF option.

Programming the REF bit field to CONF allows the user to select the specific VREF source and adjust the programmable input and reference divider options directly. This feature is not available in EFM32 Gecko Series 0 and EZR32 Series 0 devices.

Procedure (see [5.13 Advanced Full-Scale Voltage \(VFS\) Configuration](#)):

1. Set the REF bit field in the ADCn_SINGLECTRLX or ADCn_SCANCTRLX register to CONF.
2. Select the voltage reference source (VREF) using the VREFSEL bit field in the ADCn_SINGLECTRLX or ADCn_SCANCTRLX register.
3. Configure the VREFATTFIX and VREFATT bit fields in the ADCn_SINGLECTRLX or ADCn_SCANCTRLX register to ensure that the reference voltage at the ADC is between 0.7 V and 1.05 V.
4. Configure the VINATT bit field in the ADCn_SINGLECTRLX or ADCn_SCANCTRLX register to achieve the desired full-scale voltage.

The VREF attenuation factor (ATT_{VREF}) is used to scale the reference voltage and determined by the VREFATT or VREFATTFIX bit field.

The VIN attenuation factor (ATT_{VIN}) is used to widen the available input range of the ADC beyond the reference source and determined by VINATT bit field.

Table 3.9. VREF and VIN Attenuation Factor

	VREFATTFIX = 1 VREFATT > 0	VREFATTFIX = 1 VREFATT = 0	VREFATTFIX = 0 VREFATT < 13	VREFATTFIX = 0 VREFATT ≥ 13	VINATT ≥ 3 Illegal: 0, 1, 2
ATT_{VREF}	1/3	1/4	$(VREFATT + 6) / 24$	$(VREFATT - 3) / 12$	—
ATT_{VIN}	—	—	—	—	VINATT / 12

The VFS can be calculated by the formula given below for any given VREF source, VREF attenuation, and VIN attenuation:

$$\text{VFS (full scale voltage)} = \frac{2 \times VREF \times ATT_{VREF}}{ATT_{VIN}}$$

Note: The ATT_{VREF} only applies when ADCn_EXTP or AVDD is chosen as VREF. The $ATT_{VREF} = 1$ when selecting an internal bandgap as the VREF source.

For external references, the calibration must be determined for the specific application and set by the user. Calibration data is also not available for the internal references VBGR, VENTROPY, and VBGRLOW.

The combination of VREF, ATT_{VREF} and ATT_{VIN} can produce a wide range of full-scale voltage options for the converter. The table below shows some example VFS configurations using AVDD as a reference source.

Table 3.10. Advanced VFS Configuration: VREF = AVDD

AVDD Voltage	VREF Attenuation Settings	Reference voltage at ADC (AVDD x ATT_{VREF})	VIN Attenuation Settings	VFS
3.0 V	VREFATTFIX = 0 VREFATT = 2 $ATT_{VREF} = 1/3$	1.0 V	VINATT = 4 $ATT_{VIN} = 1/3$	6.0 V (+/- 3 V differential)
3.3 V	VREFATTFIX = 0 VREFATT = 0 $ATT_{VREF} = 1/4$	0.825 V	VINATT = 9 $ATT_{VIN} = 3/4$	2.2 V (+/- 1.1 V differential)

AVDD Voltage	VREF Attenuation Settings	Reference voltage at ADC ($AVDD \times ATT_{VREF}$)	VIN Attenuation Settings	VFS
3.6 V	VREFATTFIX = 1 VREFATT = 0 $ATT_{VREF} = 1/4$	0.9 V	VINATT = 6 $ATT_{VIN} = 1/2$	3.6 V (+/- 1.8 V differential)

3.8 Random Number Generator

The ADC can be used as random number generator. This feature is not available in EFM32 Gecko Series 0 and EZR32 Series 0 devices.

Procedure (see [5.14 Random Number Generator](#)):

1. Set REF bit field in the ADCn_SINGLECTRL register to CONF.
2. Set VREFSEL bit field in the ADCn_SINGLECTRLX register to VENTROPY.
3. Set VINATT bit field in the ADCn_SINGLECTRLX register to 15.
4. Set DIFF bit field in the ADCn_SINGLECTRL register to 1.
5. Set RES bit field in the ADCn_SINGLECTRL register to 0.
6. Trigger a single channel conversion and then read ADCn_SINGLEDATA register when the conversion finishes.

The LSB[2:0] of each sample is a random number.

3.9 Window Compare Function

This feature is not available in EFM32 Gecko Series 0 and EZR32 Series 0 devices.

The ADC supports a window compare function on both the latest single and scan outputs. The compare thresholds, ADGT and ADLT are defined in the ADCn_CMPTHR register. These are 16-bit values whose format must match the type of conversion either single-ended or differential.

There is a single set of ADLT and ADGT thresholds for both single and scan compare. However, the user can enable single or scan compare logic individually by enabling CMPEN bit field in the ADCn_SINGLECTRL or ADCn_SCANCTRL register (see 5.4 Single Conversion Interrupt (EM1) to 5.11 Scan Conversion LDMA (EM2)).

The user can perform comparisons both within or outside of the window defined by ADGT and ADLT. If ADLT is greater than ADGT, the ADC compares whether the current sample is within the window. Otherwise, the ADC compares whether the current sample is outside of the window.

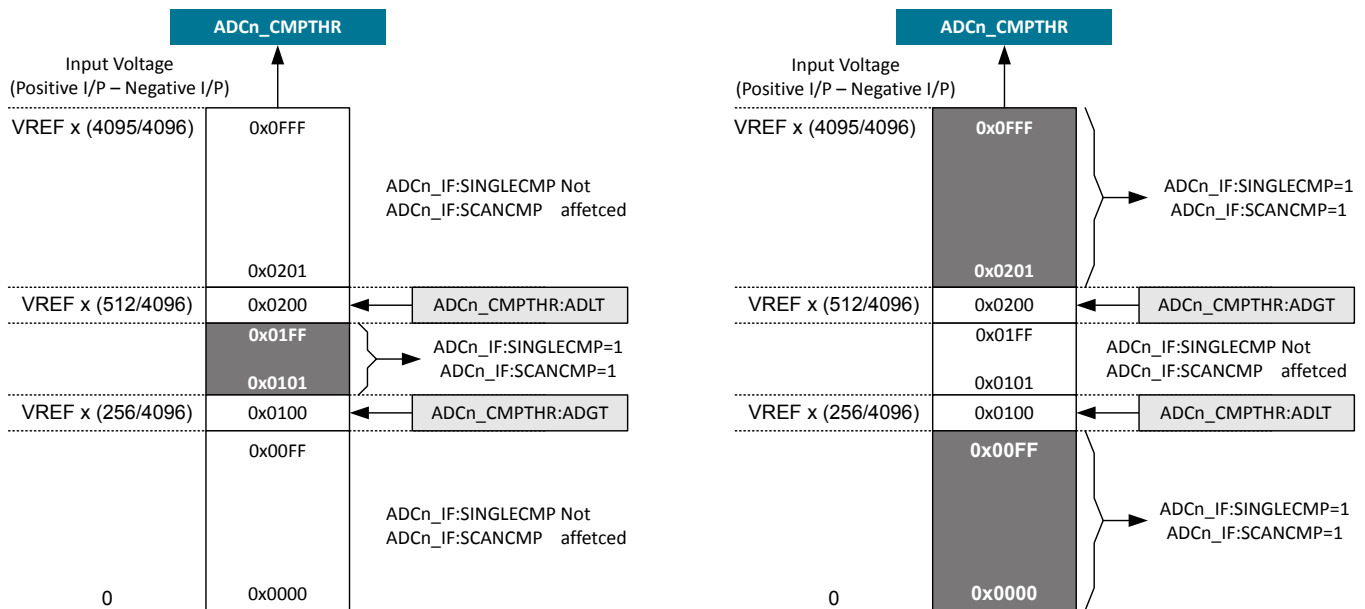


Figure 3.5. ADC Window Compare Function

3.10 EM2 or EM3 Operation

This feature is not available in EFM32 Gecko Series 0 and EZR32 Series 0 devices.

When the ADC runs in EM2 or EM3, only AUXHFRCO can provide the ADC_CLK to the ADC. Therefore, firmware needs to set the ADCCLKMODE bitfield in the ADCn_CTRL register to ASYNC and set up the CMU to provide the AUXHFRCO clock as ASYNCCLK (see [Figure 1.2 ADC Overview of EFM32 Pearl Gecko on page 3](#) and [2.1 Clock Selection](#)).

When the ADC_CLK is chosen to source from ASYNCCLK, the ADC_CLK and the ADC peripheral clock (HFPERCLK) are considered asynchronous. Due to a synchronization delay, accessing the following registers takes extra time (up to 7 additional HFPERCLK cycles).

- ADCn_SINGLEDATA and ADCn_SINGLEDATAP
- ADCn_SCANDATA and ADCn_SCANDATAP
- ADCn_SCANDATAAX and ADCn_SCANDATAAXP
- ADCn_SINGLEFIFOCOUNT and ADCn_SCANFIFOCOUNT
- ADCn_SINGLEFIFOCLEAR and ADCn_SCANFIFOCLEAR

Firmware may choose a clock request generation scheme by programming the ASYNCCLKEN and WARMMODE bit field of the ADCn_CTRL register. If the ASYNCCLKEN is set to ASNEEDED with WARMMODE set to NORMAL, the ADC requests ASYNCCLK only when a conversion trigger is activated. The ASYNCCLK request is withdrawn after the conversion is complete. This option saves power at the expense of introducing a delay to start the AUXHFRCO oscillator.

While in EM2 or EM3, the ADC can wake the system to EM0 on enabled interrupts. For example, the compare interrupt or SCAN or SINGLE interrupt indicate that the corresponding FIFO has reached the DVL watermark. The ADC also works with the DMA so that the system does not have to wake up to consume data. This is enabled if the SCAN or SINGLE interrupt is disabled and the SINGLEDMA-WU or SCANDMAWU bit field in the ADCn_CTRL register is set.

The ADC triggers the DMA when DVL+1 samples become available in the corresponding FIFO. The DMA then pops all the elements of the corresponding FIFO and puts the system back into the low power state. A system-level wake up occurs upon the DMA done interrupt. Note that other enabled ADC interrupts can still wake the system when operating with the DMA. For example, the user can configure the window compare function to trip when the result reaches a certain threshold while gathering ADC data in EM2 or EM3 (see [5.9 Single Conversion LDMA \(EM2\)](#) and [5.11 Scan Conversion LDMA \(EM2\)](#)).

4. Software Examples for EFM32 Gecko Series 0

The software examples below are run on the EFM32 Gecko (project `adc_example_gecko` or `STKXXX_adc_example`), Tiny Gecko (project `adc_example_tg` or `STK3300_adc_example`), and Giant Gecko Starter Kit (project `adc_example_gg` or `STK3700_adc_example`) with common source file `main_adc_example_gecko_s0.c`.

The clock configurations below are common to all examples.

- Core clock — 11 MHz HFRCO
- HFPERCLK — 11 MHz
- ADC_CLK — 11 MHz in single conversion, 5.5 MHz in scan conversion
- Segment LCD driver — Use 32768 Hz LFRCO as clock source
- RTC — Use 32768 Hz LFRCO as clock source

The ADC input pins and voltages below are used in corresponding examples.

- ADC input 0 — ~1.8 V on PD3 (pin 10 of EXP header on Starter Kit)
- ADC input 1 — ~1.25 V on PD4 (pin 12 of EXP header on Starter Kit)
- ADC input 2 — ~2.5 V on PD5 (pin 14 of EXP header on Starter Kit)

ADC conversion resolution is 12-bit except in the ADC oversampling mode.

The example is selected by the menu displayed on the segment LCD, push button PB0 is used to browse the menu, and push button PB1 is used to execute the selected menu item.

4.1 Single Conversion

This example configures the ADC to sample VDD/3 with the 1.25 V bandgap reference.

ADC configurations for this example are listed below.

- Acquisition time — 32 ADC_CLK cycles (must be > 2 μ s)
- Reference — 1.25 V internal bandgap
- Input — Internal VDD/3

Press the push button PB0 to select “SING”. Press the push button PB1 to display the ADC converted voltage, for example 3.249 V for VDD, on the segment LCD as shown below.

```
3249
SING
```

4.2 Scan Conversion with DMA Transfer

In this example, the ADC is configured to use scan mode on three channels. The DMA is set up to transfer the ADC result from one conversion to RAM while the ADC continues with the next conversion.

ADC configurations for this example are listed as below.

- Acquisition time — 1 ADC_CLK cycle
- Reference — VDD
- Input — Channel 3 (PD3), Channel 4 (PD4) and Channel 5 (PD5)
- ADC DMA request — ADC SCAN single request (SREQ)

Press push button PB0 to select “SCAN”.

```
SCAN
```

Press push button PB1 to display the ADC converted voltages of three channels on the segment LCD as below. The first row is the voltage of PD5, for example 2.457 V, the first three digits of second row is the voltage of PD3, for example 1.78 V, and last four digits is the voltage of PD4, for example 1.247 V.

```
2457
1781247
```

4.3 Differential Inputs

This example configures the ADC to sample the inputs for differential operation.

ADC configurations for this example are listed as below.

- Acquisition time — 1 ADC_CLK cycle
- Reference — Unbuffered 2xVDD
- Input — Channel 4 (PD4) and Channel 5 (PD5) for differential mode

Press push button PB0 to select “DIFF”, press push button PB1 to display the ADC converted voltage on the segment LCD as below.

Channel 4 is 1.25 V, channel 5 is 2.5 V, and the ADC output is $1.25\text{ V} - 2.5\text{ V} = -1.25\text{ V}$.

```
-125  
DIFF
```

4.4 Oversampling

The single conversion example is expanded to include oversampling, which should produce a more stable result.

ADC configurations for this example are listed below.

- Oversampling — x256
- Acquisition time — 32 ADC_CLK cycles (must > 2 μs)
- Reference — 1.25 V internal bandgap
- Input — Internal VDD/3
- ADC conversion resolution — 16-bit by oversampling

Press the push button PB0 to select “OVS”. Then, press the push button PB1 to display the ADC converted voltage, for example 3.242 V for VDD, on the segment LCD as below.

```
3242  
OVS
```

4.5 PRS Triggered Sampling

This example configures the TIMER0 to overflow roughly 3 times each second. On each overflow, a PRS signal is sent to the ADC, which, in turn, triggers a single conversion. The EFM32 Gecko stays in Energy Mode 1 (EM1) and wakes up by the ADC SINGLE interrupt when the conversion is completed.

ADC configurations for this example are listed below.

- PRS enable — Trigger from PRS channel 0
- Acquisition time — 1 ADC_CLK cycle
- Reference — VDD
- Input — Channel 3 (PD3)

Press the push button PB0 to select the “PRS”.

```
PRS
```

Press the push button PB1 to run this example continuously. The ADC converted voltage, for example 1.753 V, displays on the segment LCD as shown below. Press the push button PB0 to exit the “PRS” example.

```
1753  
PRS RUN
```

4.6 Enter EM2 Between ADC Samples

The two ADC + EM2 examples demonstrate the ultra-low energy consumption achievable for low sampling frequency by using deep sleep mode (Energy Mode 2) between each ADC sample. The debugger must be disconnected from the IDE and the MCU reset before it can enter Energy Mode 2 (EM2) or lower power modes.

4.6.1 Interrupt-driven ADC + EM2 Example

This example starts each ADC sample inside the RTC interrupt routine. This approach allows other peripherals to issue interrupts while the ADC sampling sequence is active. The drawback is twice the average energy consumption compared to the optimized approach. For the interrupt-driven example, the break-even sampling frequency compared to the standard Energy Mode 1 (ADC + PRS + DMA) approach is approximately 5 kHz.

ADC configurations for this example are listed below.

- Acquisition time — 1 ADC_CLK cycle
- Reference — VDD
- Input — Channel 3 (PD3)
- ADC sampling frequency — 100 Hz (wakes up by RTC interrupt from EM2)
- ADC sample size — 512 (total time is around 5.12 s)

Press the push button PB0 to select “INT”.

```
INT
```

Press the push button PB1 to start the interrupt-driven ADC sampling. The segment LCD turns off to reduce the EM2 power consumption and displays “INT END” when the sampling process is completed.

```
INT END
```

4.6.2 Optimized Loop ADC + EM2 Example

For the optimized example, the time spent in Energy Mode 0 or 1 (EM0/EM1) during each ADC conversion is minimized. The sample loop is optimized with the “Wait For Event” (WFE) instruction instead of interrupts (see *AN0039: EFM32 Interrupt Handling*).

Even though the ADC in 12-bit mode can finish each sample in 13 clock cycles + warm-up time, the amount of clock cycles spent in EM0/EM1 is a bit higher. The overhead is caused by the delay until the first instruction is executed, the clearing of interrupt flags, storing the ADC sample, and switching between energy modes.

For the optimized loop example, the break-even sampling frequency compared to the autonomous EM1 approach is around 20 kHz. The EM1 approach which utilizes PRS triggering and DMA is described in the *AN0013: Direct Memory Access* application note.

ADC configurations for this example are listed below.

- Acquisition time — 1 ADC_CLK cycle
- Reference — VDD
- Input — Channel 3 (PD3)
- ADC sampling frequency — 100 Hz (wakes up by RTC WFE from EM2)
- ADC sample size — 512 (total time is around 5.12 s)

Press the push button PB0 to select the “WFE”.

```
WFE
```

Press the push button PB1 to start the WFE ADC sampling. The segment LCD turns off to reduce EM2 power consumption and displays “WFE END” when the sampling process is completed.

```
WFE END
```

4.6.3 Typical ADC Current Consumption

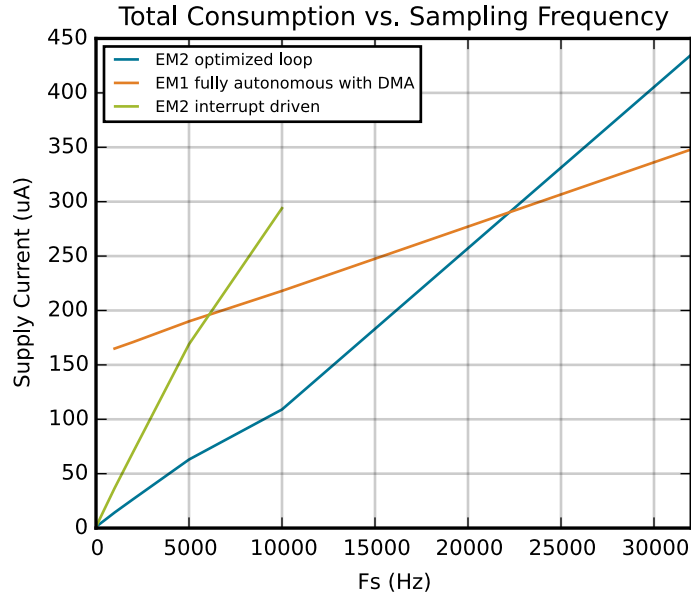


Figure 4.1. Total Current Consumption when Sampling at Different Frequencies

Table 4.1. Total Current Consumption when Sampling at Different Frequencies

Test Case	Sampling Frequency (Hz)	Supply Current (µA)
EM2 optimized loop	10	1.2
	100	2.5
	200	3.8
	500	7.7
	1000	14.3
	2000	26.6
	5000	63
	10000	109
	32000	435
EM1 fully autonomous with DMA	1000	165
	2000	171
	5000	190
	10000	218
	32000	348

Test Case	Sampling Frequency (Hz)	Supply Current (μA)
EM2 interrupt-driven	10	1.4
	100	4.7
	200	8.3
	500	19
	1000	36.7
	2000	70
	5000	169
	10000	294

The graph and table above indicate the average current consumption for 12-bit samples at different sampling frequencies with conditions of 3.3 V and room temperature for EFM32TG840F32 (software is compiled with -O3 optimization in Simplicity IDE).

The three different graphs show the consumption for the optimized EM2 example, the interrupt driven EM2 example, and the EM1 only example included with the *AN0013: Direct Memory Access* application note.

4.7 Calibration

This example combines both the offset and gain calibration routines in one function called `ADC_Calibration()`, which resets and configures the ADC before performing the offset and gain calibrations.

4.7.1 Offset Calibration

The offset calibration routine must be performed before the gain calibration.

ADC configurations for offset calibration are listed below.

- Oversampling — x4096
- Acquisition time — 16 ADC_CLK cycles
- Reference — Internal or external reference for calibration (internal 1.25 V is selected in this example)
- Input — Differential DIFF0 (short between positive and negative inputs)
- ADC conversion resolution — 16-bit by oversampling

A binary search is used to find the offset calibration value. The result of the binary search is written to the ADC calibration register (`ADCn_CAL`).

4.7.2 Gain Calibration

Note: There is no hardware gain calibration for the unbuffered differential $2xVDD$ reference.

ADC configurations for offset calibration are listed below.

- Oversampling — x4096
- Acquisition time — 16 ADC_CLK cycles
- Reference — Internal or external reference for calibration (internal 1.25 V is selected in this example)
- Input — Channel 4 (PD4), stable voltage equal to the reference for calibration (1.25 V in this example)
- ADC conversion resolution — 16 bit by oversampling

A binary search is used to find the gain calibration value. The search terminates on a value a few LSBs lower than the maximum ADC value to avoid an overshoot. The result of the binary search is written to the ADC calibration register (ADCn_CAL).

Press the push button PB0 to select “CAL”.

```
CAL
```

Press the push button PB1 to run the offset and gain calibration.

```
CAL RUN
```

The ADC calibration register value (SINGLEOFFSET and SINGLEGAIN) in hexadecimal notation is displayed on the segment LCD as shown below. The first row is the hexadecimal value, for example 0x2A0A, before calibration. The second row is the hexadecimal value, for example 0x3308, after calibration. Press the push button PB0 to exit the “CAL” example.

```
  2A0A  
CAb 3308
```


5. Software Examples for EFM32 Gecko Series 1

The software examples below are run on the EFM32 Peral Gecko Starter Kit (SLSTK3401A_EFM32PG). These examples are grouped into one project (`adc_example_pg` or `SLSTK3401A_adc_example`) with source file `main_adc_example_gecko_s1.c`.

The clock configurations below are common to all examples.

- Core clock — 4 MHz HFRCO
- ADC_CLK — 4 MHz HPPERCLK in SYNC mode and 4 MHz AUXHFRCO in ASYNC mode
- `adc_clk_sar` — 1 MHz in SYNC and ASYNC mode
- RTCC — Use 32768 Hz LFXO as clock source

The ADC input pins and voltages below are used in the corresponding examples.

- ADC input 0 — ~1.25 V on PA0 (pin 12 of EXP header on Starter Kit)
- ADC input 1 — ~2.5 V on PA1 (pin 14 of EXP header on Starter Kit)
- ADC input 2 — ~1.8 V on PD10 (pin 9 of EXP header on Starter Kit)
- ADC input 3 — ~1.1 V on PD11 (pin 11 of EXP header on Starter Kit)

ADC acquisition time is one `adc_clk_sar` cycle except in the calibration example.

ADC conversion resolution is 12-bit except in ADC oversampling mode.

The ADC compare thresholds below are used in the corresponding examples.

- ADC ADGT — 3724 (~3 V for AVDD = 3.3 V)
- ADC ADLT — 620 (~0.5 V for AVDD = 3.3 V)

The ADC compare matched interrupt is triggered when one of the single and scan channel input voltages is lower than the ADLT threshold or higher than the ADGT threshold (see [3.9 Window Compare Function](#)).

The example is selected by the menu displayed on the Memory LCD, push button BTN1 is used to browse the menu, and push button BTN0 is used to execute the selected menu item.

```
Example 1
ADC Single and
Scan Conversion

Press BTN1 to next
menu
Press BTN0 to start
```

5.1 Single and Scan Conversion

This example configures the ADC to sample single and scan inputs with the AVDD reference.

ADC configurations for this example are listed below.

- Reference — AVDD
- Input — PA0 (single conversion)
- Input — PA0, PA1, PD10, and PD11 (scan conversion)
- Single FIFO DVL# — 0 (one sample)
- Scan FIFO DVL# — 3 (four samples)

Press the push button BTN1 to select the “ADC Single and Scan Conversion”. Press the push button BTN0 to display the ADC converted voltages on the Memory LCD as shown below.

```
Example 1
ADC Single and
Scan Conversion

Single PA0: 1.2448V
Scan PA0: 1.2456V
Scan PA1: 2.5064V
Scan PD10: 1.7934V
Scan PD11: 1.1070V
```

5.2 Single and Scan Conversion with Oversampling

The oversampling feature is used in this example, which should produce more stable results.

ADC configurations for this example are listed below.

- Oversampling — x256
- Reference — AVDD
- Input — PA0 (single conversion)
- Input — PA0, PA1, PD10, and PD11 (scan conversion)
- Single FIFO DVL# — 0 (one sample)
- Scan FIFO DVL# — 3 (four samples)
- ADC conversion resolution — 16-bit by oversampling

Press the push button BTN1 to select the “ADC Single and Scan Conversion (Oversampling)”. Press the push button BTN0 to display the ADC converted voltages on the Memory LCD as shown below.

```
Example 2
ADC Single and
Scan Conversion
(Oversampling)

Single PA0: 1.2450V
Scan PA0: 1.2449V
Scan PA1: 2.5063V
Scan PD10: 1.7924V
Scan PD11: 1.1073V
```

5.3 Single and Scan Conversion with Differential Inputs

This example configures the ADC to sample differential single and scan inputs with the 2xAVDD reference.

ADC configurations for this example are listed below.

- Reference — 2xAVDD
- Input — PA0 & PA1 (single differential conversion)
- Input — PA0 & PA1 and PD10 & PD11 (scan differential conversion)
- Single FIFO DVL# — 0 (one differential sample)
- Scan FIFO DVL# — 1 (two differential samples)

The single differential conversion is the voltage difference between PA0 & PA1, $1.25\text{ V} - 2.5\text{ V} = -1.25\text{ V}$.

The scan differential conversion is the voltage difference between PA0 & PA1, $1.25\text{ V} - 2.5\text{ V} = -1.25\text{ V}$, and PD10 & PD11, $1.8\text{ V} - 1.1\text{ V} = 0.7\text{ V}$.

Press the push button BTN1 to select the “ADC Single and Scan Conversion (Differential Inputs)”. Press the push button BTN0 to display the ADC converted voltages on the Memory LCD as shown below.

```
Example 3
ADC Single and
Scan Conversion
(Differential Inputs)

Single Differential
PA0-PA1: -1.2633V

Scan Differential
PA0-PA1: -1.2633V
PD10-PD11: 0.6864V
```

5.4 Single Conversion Interrupt (EM1)

This example configures the RTCC as a PRS producer to trigger the ADC single conversion at 100 Hz. The EFM32 Pearl Gecko stays in Energy Mode 1 (EM1) and wakes up with the ADC SINGLE and SINGLECMP interrupt.

ADC configurations for this example are listed below.

- PRS enable — Trigger from PRS channel 0
- Reference — AVDD
- Input — PA0 (single conversion)
- Single FIFO DVL# — 3 (four samples to generate interrupt request)
- ADC sampling frequency — 100 Hz (triggers by RTCC PRS in EM1)
- ADC interrupt — Single channel results (DVL# + 1) are available (SINGLE) and single result compare matched (SINGLECMP)

Press the push button BTN1 to select the “ADC Single Conversion Interrupt (EM1)”. Press the push button BTN0 to run the example. The example exits when the ADC SINGCMP interrupt triggers and voltages in the latest single FIFO display on the Memory LCD as shown below.

```
Example 4
ADC Single Conversion
Interrupt (EM1) - Run

Exit if voltage in
PA0 is outside the
compare window
(0.5V-3V)

FIFO 0: 1.2448V
FIFO 1: 0.0008V
```

5.5 Single Conversion Interrupt (EM2)

This example configures the RTCC as a PRS producer to trigger the ADC single conversion at 100 Hz. The EFM32 Pearl Gecko stays in Energy Mode 2 (EM2) and wakes up with the ADC SINGLE and SINGLECMP interrupt.

ADC configurations for this example are listed below.

- PRS enable — Trigger from PRS channel 0
- Reference — AVDD
- Input — PA0 (single conversion)
- Single FIFO DVL# — 3 (four samples to generate interrupt request)
- ADC bias programming — Set GPBIASACC bit field in the ADCn_BIASPROG register to LOWACC
- ADC clock mode — ASYNC and use AUXHFRCO as clock source for EM2 operation
- ADC sampling frequency — 100 Hz (triggers by RTCC PRS in EM2)
- ADC interrupt — Single channel results (DVL# + 1) are available (SINGLE) and single result compare matched (SINGLECMP)

Press the push button BTN1 to select the “ADC Single Conversion Interrupt (EM2)”. Press the push button BTN0 to run the example. The Memory LCD turns off to reduce the EM2 power consumption. The example exits when the ADC SINGCMP interrupt triggers and voltages in the latest single FIFO display on the Memory LCD as shown below.

```
Example 5
ADC Single Conversion
Interrupt (EM2) - Run

FIFO 0: 1.2439V
FIFO 1: 1.2435V
FIFO 2: 0.0008V
```

5.6 Scan Conversion Interrupt (EM1)

This example configures the RTCC as a PRS producer to trigger the ADC scan conversion at 100 Hz. The EFM32 Pearl Gecko stays in Energy Mode 1 (EM1) and wakes up with the ADC SCAN and SCANCMP interrupt.

ADC configurations for this example are listed below.

- PRS enable — Trigger from PRS channel 0
- Reference — AVDD
- Input — PA0, PA1, PD10, and PD11 (scan conversion)
- Scan FIFO DVL# — 3 (four samples to generate interrupt request)
- ADC sampling frequency — 100 Hz (triggers by RTCC PRS in EM1)
- ADC interrupt — Scan channel results (DVL# + 1) are available (SCAN) and scan result compare matched (SCANCMP)

Press the push button BTN1 to select the “ADC Scan Conversion Interrupt (EM1)”. Press the push button BTN0 to run the example. The example exits when the ADC SCANCMP interrupt triggers and voltages in the latest scan FIFO display on the Memory LCD as shown below, for example compare matched interrupt on input PA0.

```
Example 6
ADC Scan Conversion
Interrupt (EM1) - Run

Exit if voltage in
any scan channels is
outside the compare
window (0.5V-3V)

Scan PA0: 0.0016V
Scan PA1: 2.5032V
Scan PD10: 1.7918V
Scan PD11: 1.1054V
```

5.7 Scan Conversion Interrupt (EM2)

This example configures the RTCC as a PRS producer to trigger the ADC scan conversion at 100 Hz. The EFM32 Pearl Gecko stays in Energy Mode 2 (EM2) and wakes up with the ADC SCAN and SCANCMP interrupt.

ADC configurations for this example are listed below.

- PRS enable — Trigger from PRS channel 0
- Reference — AVDD
- Input — PA0, PA1, PD10, and PD11 (scan conversion)
- Scan FIFO DVL# — 3 (four samples to generate interrupt request)
- ADC bias programming — Set GPBIASACC bit field in the ADCn_BIASPROG register to LOWACC
- ADC clock mode — ASYNC and use AUXHFRCO as clock source for EM2 operation
- ADC sampling frequency — 100 Hz (triggers by RTCC PRS in EM2)
- ADC interrupt — Scan channel results (DVL# + 1) are available (SCAN) and scan result compare matched (SCANCMP)

Press the push button BTN1 to select the “ADC Scan Conversion Interrupt (EM2)”. Press the push button BTN0 to run the example. The Memory LCD turns off to reduce the EM2 power consumption. The example exits when the ADC SCANCMP interrupt triggers and voltages in the latest scan FIFO display on the Memory LCD as shown below, for example compare the matched interrupt on input PA1.

```
Example 7
ADC Scan Conversion
Interrupt (EM2) - Run

Scan PA0: 1.2439V
Scan PA1: 0.0016V
Scan PD10: 1.7926V
Scan PD11: 1.1070V
```

5.8 Single Conversion LDMA (EM1)

This example configures the RTCC as a PRS producer to trigger the ADC single conversion at 100 Hz. The LDMA is set up to transfer the ADC result from single FIFO to RAM buffer while the ADC continues with the next conversion. The EFM32 Pearl Gecko stays in Energy Mode 1 (EM1) and wakes up with the LDMA DONE (64 samples) and ADC SINGLECMP interrupt.

ADC configurations for this example are listed below.

- PRS enable — Trigger from PRS channel 0
- Reference — AVDD
- Input — PA0 (single conversion)
- Single FIFO DVL# — 3 (four samples to generate DMA request)
- ADC sampling frequency — 100 Hz (triggers by RTCC PRS in EM1)
- ADC interrupt — Single result compare matched (SINGLECMP)
- ADC DMA request — ADC SINGLE request (REQ)

Press the push button BTN1 to select the “ADC Single Conversion LDMA (EM1)”. Press the push button BTN0 to run the example. The example exits when the ADC SINGCMP interrupt triggers and voltages in the latest single FIFO display on the Memory LCD as shown below.

```
Example 8
ADC Single Conversion
LDMA (EM1) - Run

Exit if voltage in
PA0 is outside the
compare window

FIFO 0: 1.2448V
FIFO 1: 0.0008V
```

5.9 Single Conversion LDMA (EM2)

This example configures the RTCC as a PRS producer to trigger the ADC single conversion at 100 Hz. The LDMA is set up to transfer the ADC result from single FIFO to RAM buffer while the ADC continues with the next conversion. The EFM32 Pearl Gecko stays in Energy Mode 2 (EM2) and wakes up with the LDMA DONE (64 samples) and ADC SINGLECMP interrupt.

ADC configurations for this example are listed below.

- PRS enable — Trigger from PRS channel 0
- Reference — AVDD
- Input — PA0 (single conversion)
- Single FIFO DVL# — 3 (four samples to generate DMA request)
- ADC bias programming — Set GPBIASACC bit field in the ADCn_BIASPROG register to LOWACC
- ADC clock mode — ASYNC and use AUXHFRCO as clock source for EM2 operation
- ADC sampling frequency — 100 Hz (triggers by RTCC PRS in EM2)
- ADC interrupt — Single result compare matched (SINGLECMP)
- ADC DMA request — ADC SINGLE request (REQ)

Press the push button BTN1 to select the “ADC Single Conversion LDMA (EM2)”. Press the push button BTN0 to run the example. The Memory LCD turns off to reduce the EM2 power consumption. The example exits when the ADC SINGCMP interrupt triggers and voltages in the latest single FIFO display on the Memory LCD as shown below.

```
Example 9
ADC Single Conversion
LDMA (EM2) - Run

FIFO 0: 1.2439V
FIFO 1: 1.2435V
FIFO 2: 0.0008V
```

5.10 Scan Conversion LDMA (EM1)

This example configures the RTCC as a PRS producer to trigger the ADC scan conversion at 100 Hz. The LDMA is set up to transfer the ADC result from scan FIFO to RAM buffer while the ADC continues with the next conversion. The EFM32 Pearl Gecko stays in Energy Mode 1 (EM1) and wakes up by the LDMA DONE (64 samples) and ADC SCNACMP interrupt.

ADC configurations for this example are listed below.

- PRS enable — Trigger from PRS channel 0
- Reference — AVDD
- Input — PA0, PA1, PD10, and PD11 (scan conversion)
- Scan FIFO DVL# — 3 (four samples to generate DMA request)
- ADC sampling frequency — 100 Hz (triggers by RTCC PRS in EM1)
- ADC interrupt — Scan result compare matched (SCNACMP)
- ADC DMA request — ADC SCAN request (REQ)

Press the push button BTN1 to select the “ADC Scan Conversion LDMA (EM1)”. Press the push button BTN0 to run the example. The example exits when the ADC SCNACMP interrupt triggers and voltages in the latest scan FIFO display on the Memory LCD as shown below, for example compare the matched interrupt on input PD10.

```
Example 10
ADC Scan Conversion
LDMA (EM1) - Run

Exit if voltage in
any scan channels is
outside the compare
window (0.5V-3V)

Scan PA0: 1.2448V
Scan PA1: 2.5056V
Scan PD10: 0.0008V
Scan PD11: 1.1078V
```

5.11 Scan Conversion LDMA (EM2)

This example configures the RTCC as a PRS producer to trigger the ADC scan conversion at 100 Hz. The LDMA is set up to transfer the ADC result from scan FIFO to RAM buffer while the ADC continues with the next conversion. The EFM32 Pearl Gecko stays in Energy Mode 2 (EM2) and wakes up with the LDMA DONE (64 samples) and an ADC SCNACMP interrupt.

ADC configurations for this example are listed as below.

- PRS enable — Trigger from PRS channel 0
- Reference — AVDD
- Input — PA0, PA1, PD10, and PD11 (scan conversion)
- Scan FIFO DVL# — 3 (four samples to generate DMA request)
- ADC bias programming — Set GPBIASACC bit field in the ADCn_BIASPROG register to LOWACC
- ADC clock mode — ASYNC and use AUXHFRCO as clock source for EM2 operation
- ADC sampling frequency — 100 Hz (triggers by RTCC PRS in EM2)
- ADC interrupt — Scan result compare matched (SCNACMP)
- ADC DMA request — ADC SCAN request (REQ)

Press the push button BTN1 to select the “ADC Scan Conversion LDMA (EM2)”. Press the push button BTN0 to run the example. The Memory LCD turns off to reduce the EM2 power consumption. The example exits when the ADC SCNACMP interrupt is triggered and voltages in the latest scan FIFO display on the Memory LCD as shown below, for example compare matched interrupt on input PD11.

```
Example 11
ADC Scan Conversion
LDMA (EM2) - Run

Scan PA0: 1.2439V
Scan PA1: 2.5056V
Scan PD10: 1.7926V
Scan PD11: 0.0016V
```

5.12 ADC Current Consumption

The table below shows the ADC current consumption of examples [5.4 Single Conversion Interrupt \(EM1\)](#) to [5.11 Scan Conversion LDMA \(EM2\)](#).

The EM2 current consumption of examples [5.5 Single Conversion Interrupt \(EM2\)](#) and [5.7 Scan Conversion Interrupt \(EM2\)](#) can be reduced by only enabling the SINGLECMP and SCANCMP interrupts.

The software is compiled with -O3 optimizer (Release Build) in the Simplicity IDE and the current consumption is measured by the Energy Profiler in the Simplicity Studio.

To measure the current consumption in Energy Mode 2 (EM2), disconnect the debugger from the IDE. Then, switch the power selector on the EFM32 Peral Gecko Starter Kit to the "BAT" position and then back to the "AEM" position to provide a Power-on Reset (POR) to the DC-DC converter.

Table 5.1. ADC Current Consumption

Example	EM1 Current (µA)	EM2 Current (µA)
Single Conversion Interrupt (SINGLE and SINGLECMP interrupt)	624	5.49
Single Conversion Interrupt (SINGLECMP interrupt only)	623	2.6
Scan Conversion Interrupt (SCAN and SCANCMP interrupt)	625	14.98
Scan Conversion Interrupt (SCANCMP interrupt only)	624	3.52
Single Conversion LDMA	627	3.94
Scan Conversion LDMA	627	8.27

5.13 Advanced Full-Scale Voltage (VFS) Configuration

This example configures the ADC to use a programmable reference for single conversion.

ADC configurations for this example are listed below (see [Table 3.10 Advanced VFS Configuration: VREF = AVDD on page 22](#)).

- Reference — Select VDDXWATT (scaled AVDD) in CONF
- VINATT — 9
- VREFATTFIX — 0
- VREFATT — 0
- Input — PA0 (single conversion)
- Single FIFO DVL# — 0 (one sample)

$$\text{VFS (full scale voltage)} = \frac{2 \times \text{AVDD} \times \frac{\text{VREFATT} + 6}{24}}{\frac{\text{VINATT}}{12}} = 2.2 \text{ V (for AVDD = 3.3 V)}$$

Press the push button BTN1 to select the "ADC VFS Configuration". Press the push button BTN0 to display the ADC converted voltage on the Memory LCD as shown below.

```
Example 12
ADC VFS
Configuration - Run
Single PA0: 1.2574V
```

5.14 Random Number Generator

This example configures the ADC as a random number generator.

ADC configurations for this example are listed below.

- Reference — Select VENTROPY in CONF
- VINATT — 15
- Input — POSSEL = NEGSEL = VSS (single differential conversion)
- Single FIFO DVL# — 0 (one sample)

Press the push button BTN1 to select the “ADC Random Number Generator”. Press the push button BTN0 to display a random number on the Memory LCD as shown below.

```
Example 13  
ADC Random Number  
Generator - Run
```

```
Random Number:  
189019851
```

5.15 Calibration

This example combines both the offset and gain calibration routines in one function called `ADC_Calibration()`. It resets and configures the ADC before performing the offset and gain calibrations.

5.15.1 Offset Calibration

The offset calibration routine must be performed before the gain calibration. This example performs both single-ended offset calibration and negative single-ended offset calibration.

ADC configurations for offset calibration are listed below.

- Oversampling — x4096
- Acquisition time — 16 `adc_clk_sar` cycles
- Reference — Internal or external reference for calibration (internal 1.25 V is selected in this example)
- Input — Set the POSSEL and NEGSEL bit field of `ADCn_SINGCTRL` register to VSS
- ADC conversion resolution — 16-bit by oversampling

A sequential search is used to find the offset calibration value. The result of the sequential search is written to the ADC calibration register (`ADCn_CAL`).

5.15.2 Gain Calibration

Note: There is no hardware gain calibration for an external reference and VDD references.

ADC configurations for offset calibration are listed below.

- Oversampling — x4096
- Acquisition time — 16 `adc_clk_sar` cycles
- Reference — Internal or external reference for calibration (internal 1.25 V is selected in this example)
- Input — PA0, stable voltage equal to the reference for calibration (1.25 V in this example)
- ADC conversion resolution — 16-bit by oversampling

A binary search is used to find the gain calibration value. The search terminates on a value a few LSBs lower than the maximum ADC value to avoid an overshoot. The result of the binary search is written to the ADC calibration register (`ADCn_CAL`).

Press the push button `BTN1` to select the “ADC Calibration”. Press the push button `BTN0` to run the offset and gain calibration. The results display on the Memory LCD as shown below.

```
Example 14
ADC Calibration - Run

ADC CAL Register
before calibration
(1.25V): 0x39783978

ADC CAL Register
after calibration
(1.25V): 0x3DB63DB6
```

6. Revision History

6.1 Revision 1.11

2016-09-18

Updated example code for EFM32 Gecko Series 0

Added example code for EFM32 Gecko Series 1

Updated document for EFM32 Gecko Series 1

6.2 Revision 1.10

2014-05-07

Updated example code to CMSIS 3.20.5

Changed to Silicon Labs license on code examples

Added project files for Simplicity IDE

Removed makefiles for Sourcery CodeBench Lite

6.3 Revision 1.09

2013-10-14

New cover layout

6.4 Revision 1.08

2013-05-08

Added software projects for ARM-GCC and Atollic TrueStudio.

Added comment about noise coupled between ADC pins if doing serial communication on ADC pins.

6.5 Revision 1.07

2012-11-12

Adapted software projects to new kit-driver and bsp structure.

6.6 Revision 1.06

Updated EM2 ADC sampling graph with values for EFM32 TG.

Added EM2 ADC sampling examples for Tiny Gecko.

6.7 Revision 1.05

2012-08-13

Added projects for the Tiny and Giant Gecko STKs.

Added EM2 ADC sampling software examples.

6.8 Revision 1.04

2012-04-20

Adapted software projects to new peripheral library naming and CMSIS_V3.

6.9 Revision 1.03

2011-11-17

Updated IDE project paths with new kits directory.

6.10 Revision 1.02

2011-05-18

Updated projects to align with new bsp version

6.11 Revision 1.01

2010-11-16

Changed example folder structure, removed build and src folders.

Updated chip init function to newest efm32lib version.

Updated register defines in code to match newest efm32lib release.

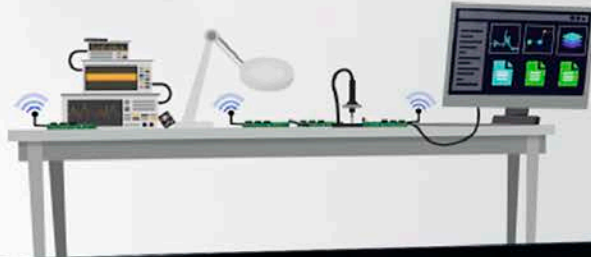
6.12 Revision 1.00

2010-10-14

Initial revision.

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