Customer training workshop 32-bit Arm® Cortex®-M7 microcontroller XMC7000 – SAR ADC

Target products

› Target product list for this training material:

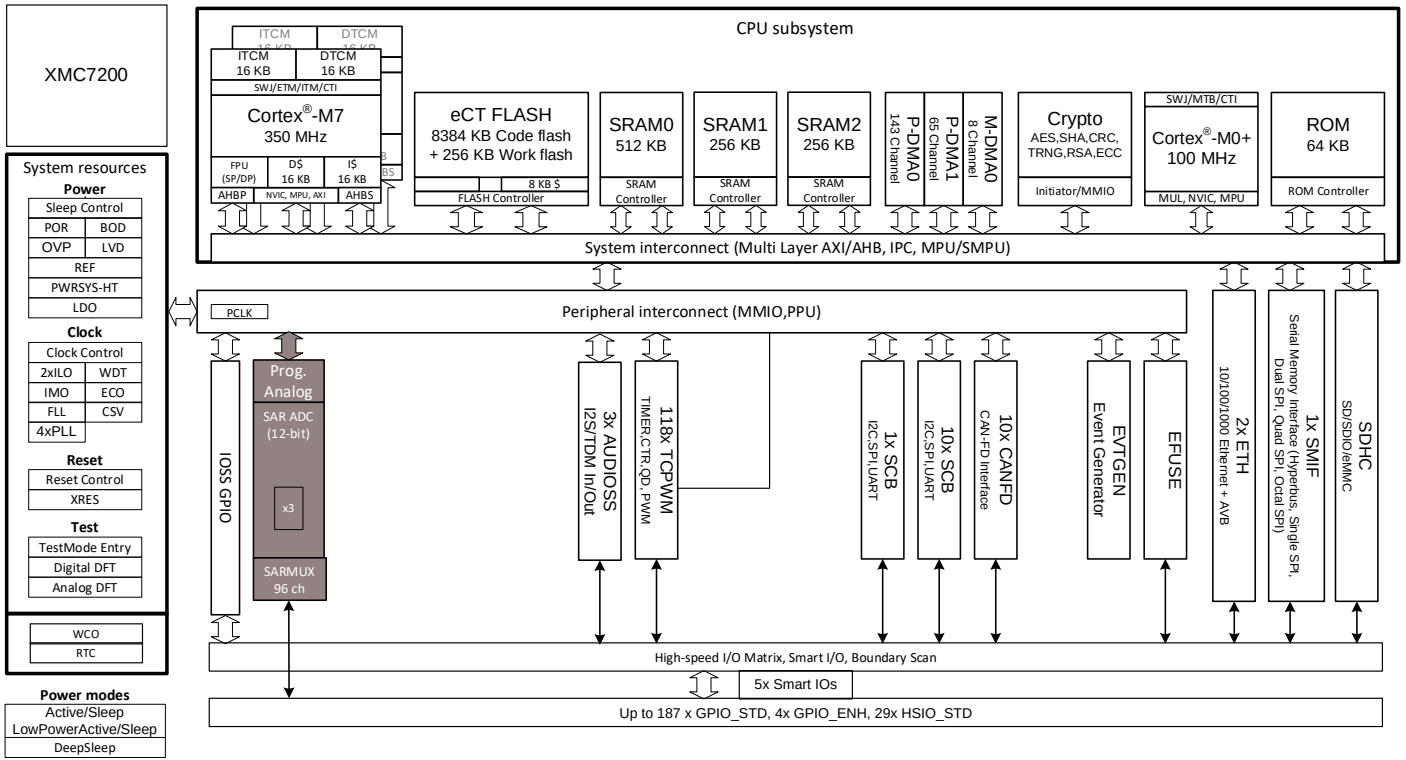
Family category	Series	Code flash memory size
XMC7200	XMC7200-8M	Up to 8384 KB
XMC7100	XMC7100-4M	Up to 4160 KB

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XMC7200 - 8M family

Introduction to XMC7200 – 8M

SAR ADC is part of the peripheral blocks



Hint Bar

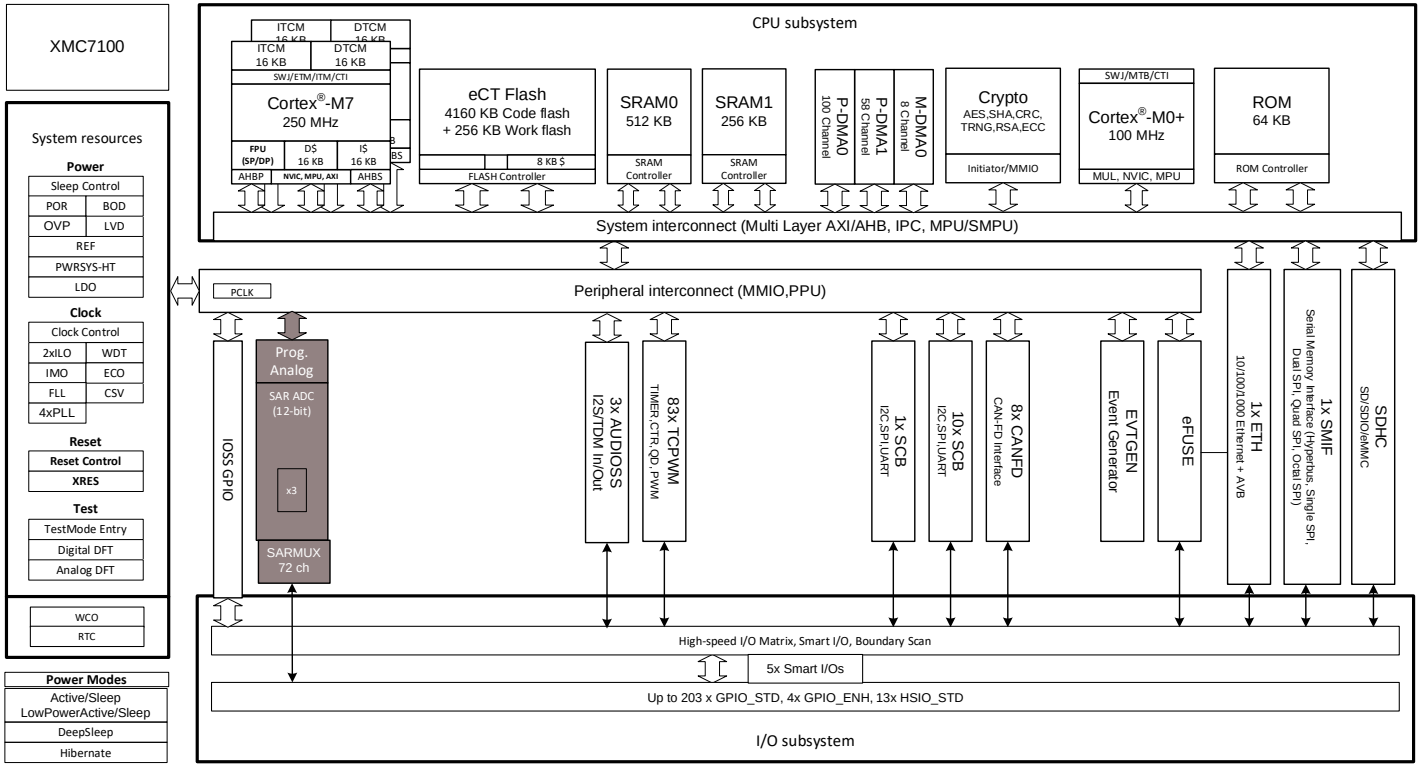
Review TRM chapter 33 for additional details

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XMC7100 - 4M family

Introduction to XMC7100 – 4M

› SAR ADC is part of the peripheral blocks



Hint Bar

Review TRM chapter 33 for additional details

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SAR ADC overview

- Overview
  - 12-bit resolution with a maximum sample rate of 1 Msps[1]
  - Up to three units in XMC7000
- Features (1/2)
  - Programmable sample time for each channel
  - Each logical channel can select an input from
    - Up to 32 analog input pins per unit
    - Diagnostic signals
  - Channels can be individual or grouped
    - Eight priorities, programmable per group
  - Triggered by TCPWM, software, pins, continuous (idle trigger), or generic[2]
    - Multiple ADC units can be triggered by the same trigger
  - Optional debug freeze

Hint Bar

Review the datasheet and section 33.1 in the TRM chapter for additional details

[1] 1 Msps: 2.7 V ≤ VDDA ≤ 5.5 V
[2] Review the Triggers section for alternative trigger sources

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SAR ADC overview

- Features (2/2)
  - Programmable post-processing options for each channel
    - Averaging: First order accumulate and dump, up to 256 samples
    - Range detection: Below/above threshold, inside/outside range
    - Pulse detection: Programmable positive and negative event counters
  - Interrupt generation per channel or group
  - Output trigger generation per channel (can trigger DMA transfer)
  - Support for diagnostic measurements including broken wire detection
  - Programmable offset and gain calibration

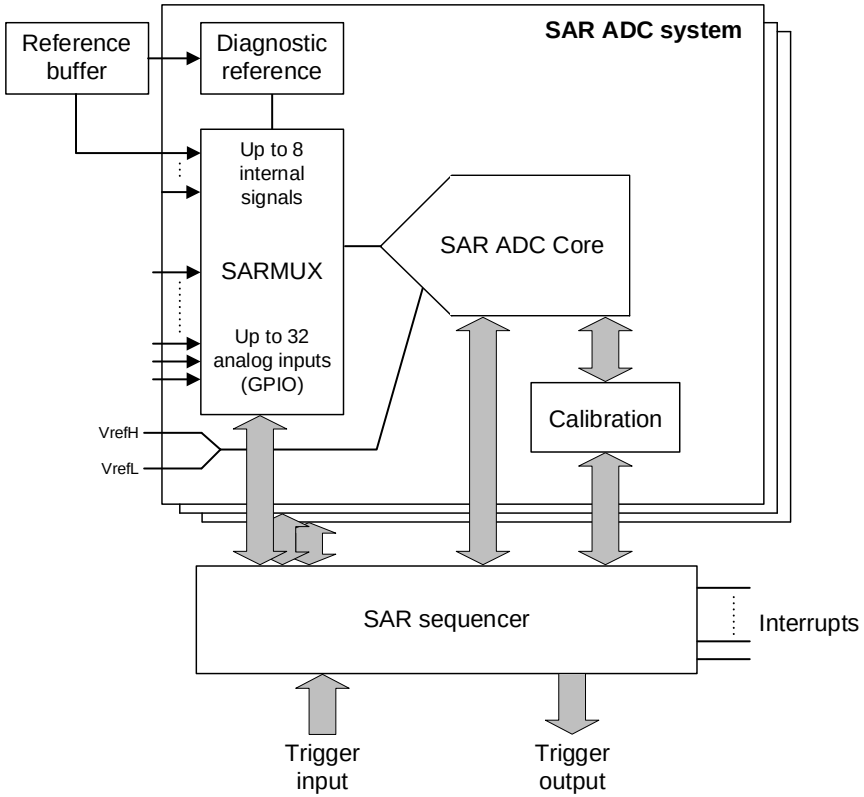
Hint Bar

Review the datasheet and section 33.1 in the TRM chapter for additional details

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SAR ADC block diagram

- SAR ADC components



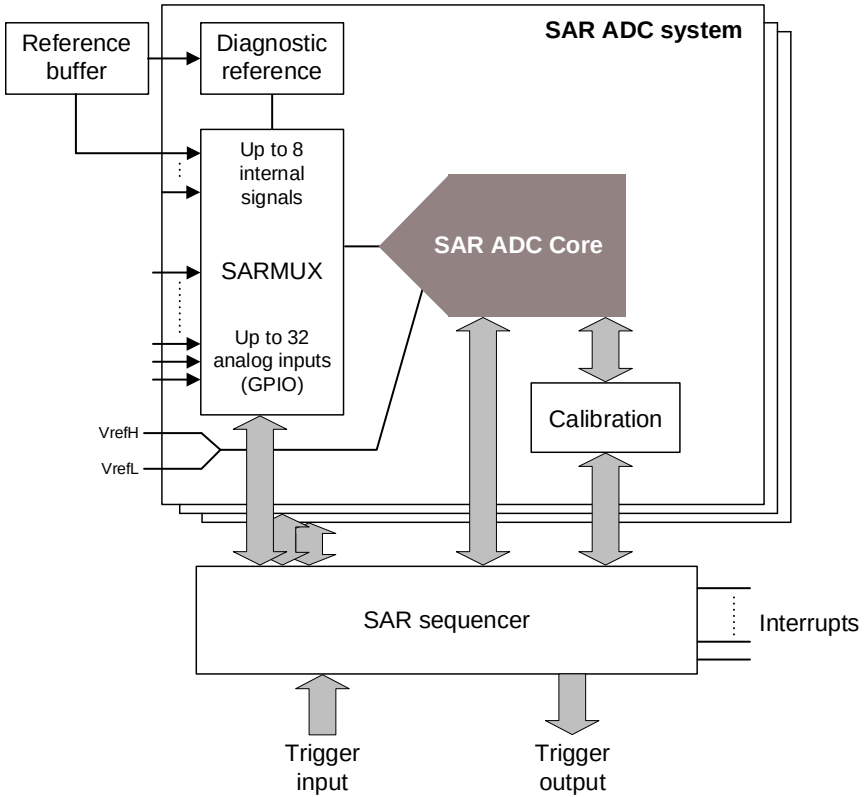
Hint Bar

Review section 33.2 in the TRM chapter for additional details

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SAR ADC block diagram

- SAR ADC components
  - SAR ADC Core
    - ADC acquisition time
    - Result data format



Hint Bar

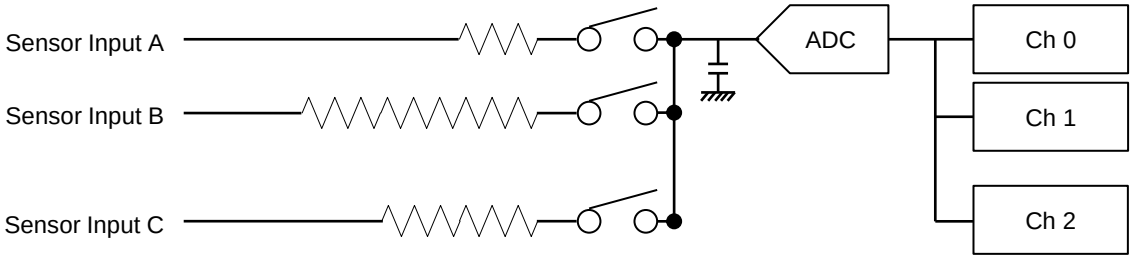
Review section 33.2 in the TRM chapter for additional details

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ADC conversion time

- A/D conversion time = sample time + comparison time
  - Comparison time:
    - 15 ADC clock cycles
      (Maximum ADC clock frequency: 26.7 MHz[1])
  - Sample time:
    - Programmable sample time per channel (SAMPLE_TIME)
    - Recommended sample time is 11 clock cycles or more at 26.7 MHz

Use Case: External impedance differs per channel



Hint Bar

Review section 33.3.3 in the TRM chapter for additional details

Advantage:

- **An accurate conversion can be achieved by allowing the sampling capacitor sufficient time to charge, even if the external impedance differs per channel**

[1] Peripheral clock (CLK_PERI). Minimum comparison time: $\frac{15}{26.7\ M}$ = 0.56 µs; minimum sample time: $\frac{11}{26.7\ M}$ = 0.41 µs

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Result data format

- Signed/Unsigned result
  - Can be treated as signed or unsigned (default)
- Alignment
  - Can be right aligned (default) or left aligned

Alignment	Signed/ Unsigned	Result Register															
		15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Right	Unsigned	-[1]	-[1]	-[1]	-[1]	11	10	9	8	7	6	5	4	3	2	1	0
Right	Signed	11	11	11	11	11	10	9	8	7	6	5	4	3	2	1	0
Left	-	11	10	9	8	7	6	5	4	3	2	1	0	-[1]	-[1]	-[1]	-[1]

Hint Bar

Review section 33.33.2 in the TRM chapter for additional details

Alignment use case:

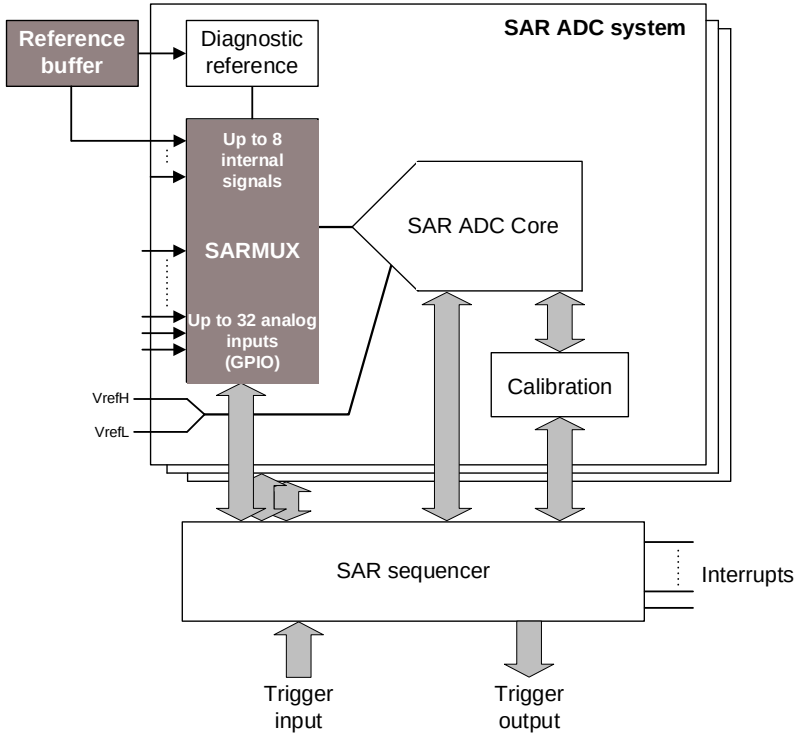
- **Left alignment allows fixed-point arithmetic of values with different resolution**
- **Compare 12-bit value with 8-bit value**
- **Compare 16-bit averaged value with 12-bit value without averaging**

[1] This bit is zero

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SAR ADC block diagram

- SAR ADC components
  - SARMUX
    - Analog input selection
    - Reference buffer
    - Preconditioning



Hint Bar

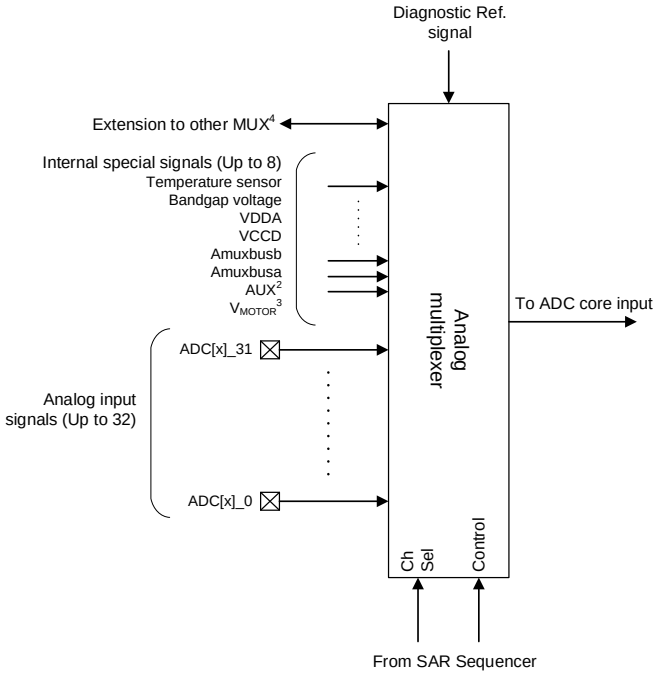
Review section 33.4 in the TRM chapter for additional details

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Analog input selection

- Configuration
  - Up to 32 analog pins per unit[1]
  - Up to eight special analog signals
  - Supports the external analog multiplexer[4]
    - Each channel configuration has its own 3-bit wide external mux select value (EXT_MUX_SEL)
    - The per channel external mux enable bit (EXT_MUX_EN) is used as a chip select for the external mux select device

SARMUX block diagram



Hint Bar

Review section 33.4 in the TRM chapter and Register TRM for additional details

External Analog Multiplexer Advantage:

This can be used to expand the number of analog signals that can be sampled beyond the number of analog pins

[1] XMC7100 (176/272-pin) supports 3 units with the following analog pins: Unit 0: ADC[0]_0-31, Unit 1: ADC[1]_0-31, and Unit 2: ADC[2]_0-7
For other devices, refer to the respective device datasheet
[2] External analog multiplexer pins: EXT_MUX[x]_y - External Analog Multiplexer Select Input and EXT_MUX[x]_EN: External Analog Multiplexer Enable
[3] XMC7000 does not support AUX (auxiliary input)
[4] V_{MOTOR} is connected to the P11[2:0]/ADC[2:0]_M pins

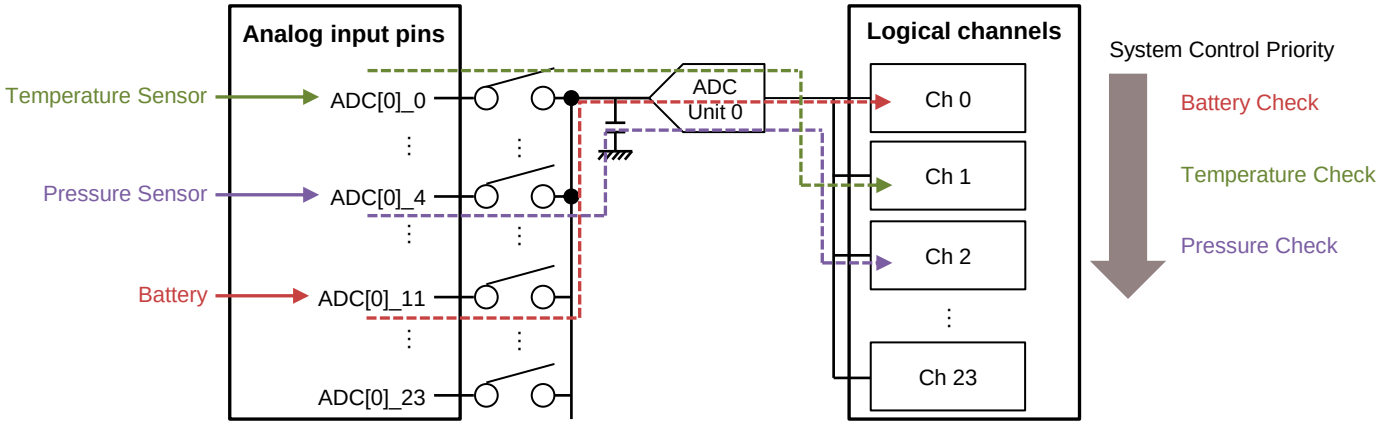
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Analog input selection

- Advantage
  - Each analog input pin can connect with each channel per ADC unit
- Use case
  - Scan in order of system control priority without physical constraints from pinout and PCB layout

Example XMC7000 Unit 0

ADC[0]_0–23 input pins can be freely connected with logical channels 0–23, but not with channels 24 and higher



Hint Bar

Review each device datasheet for each unit channel configuration

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Reference buffer

- Four functions
  - Power Supply Monitoring
  - Buffering the 0.9-V bandgap signal from the System Resource Sub System (SRSS)
    - Connects to SAR and diagnostic reference generator multiplexer inputs
  - Scaling 1 µA (4x 250 nA currents in parallel) from the SRSS to 10 µA and replicating this current (both source and sink) for diagnostic reference generators
  - Use case:
    - Broken wire detection
  - Providing a temperature-dependent voltage for one-die temperature sensing

Hint Bar

Review section 33.11 in the TRM chapter for additional details

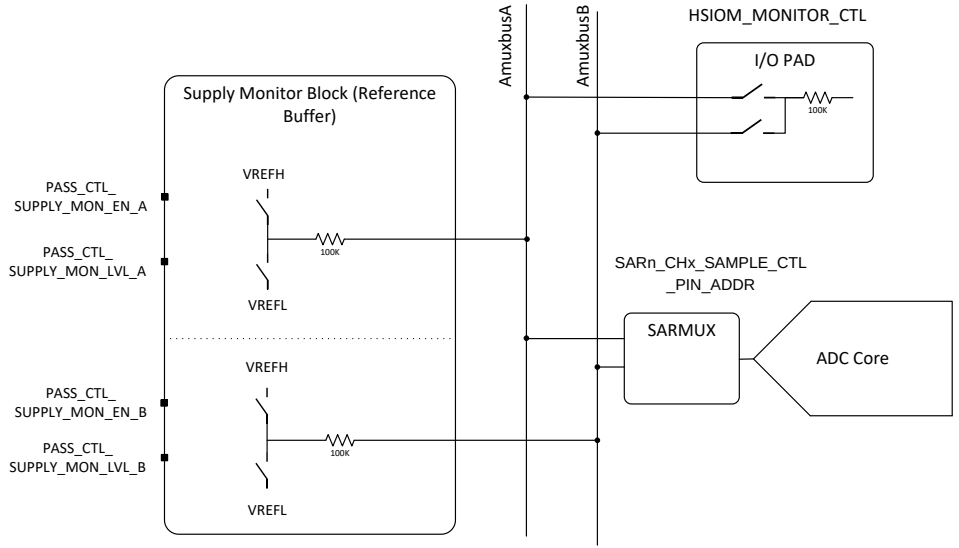
Review section 33.9 in the TRM chapter for temperature sensor measurement

Review the device datasheet for temperature sensor spec

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Voltage monitoring by ADC

- ADC is used for all other power supplies
- A monitor switch is provided between power/ground pins and Amuxbus A/B by the HSIOM_MONITOR_CTL_0 register
- The midpoint of the signal (Amuxbus A/B) is connected to the SARMUX (internal signals) and can be selected for ADC by a channel



Hint Bar

Review section 33.11 in the TRM chapter for additional details

Review TRM section 16.3.6 for the relation between HSIOM_MONITOR_CTL_0 register and power/ground pins

Figure 33-14

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Preconditioning

- Four possible selections per channel
  - No preconditioning
  - Discharge to VREFL
  - Charge to VREFH
  - Connect to diagnostic reference output

Hint Bar

Advantage:

- **Detect broken wire by charging or discharging the ADC sampling capacitor before sampling the input signal for functional safety and diagnostics**

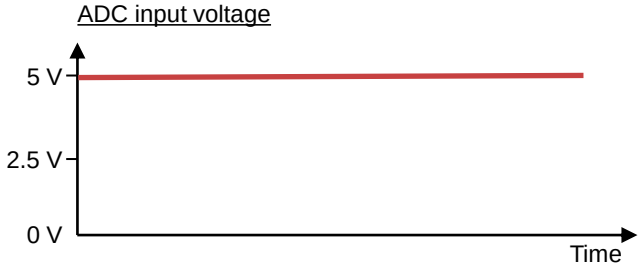
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Broken wire detection by preconditioning

› “open” detection with two preconditions

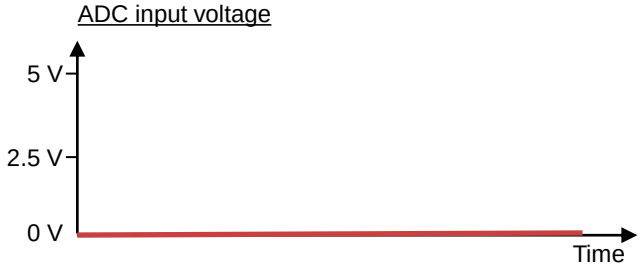


– Preconditioning = VREFH



Note: When there is an open load, the conversion result will still be almost 5 V

– Preconditioning = VREFL

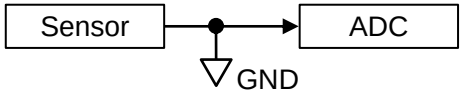


Note: When there is an open load, the conversion result will still be 0 V

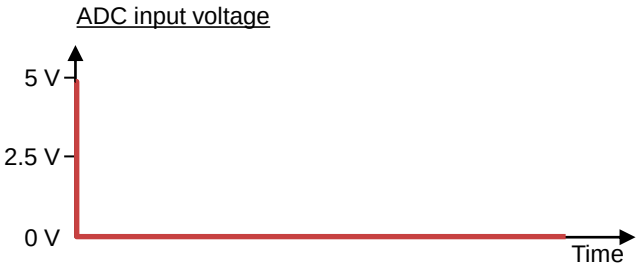
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Broken wire detection by preconditioning

› “short to GND” detection preconditions

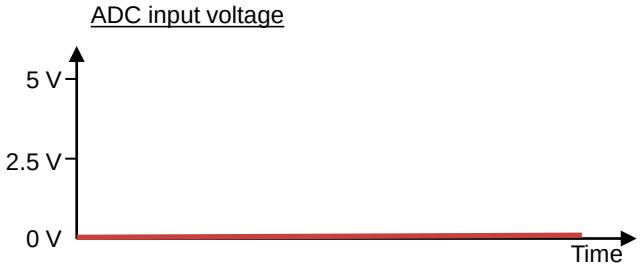


– Preconditioning = VREFH



Note: When there is a short circuit to GND,
the conversion result will immediately be 0 V

– Preconditioning = VREFL

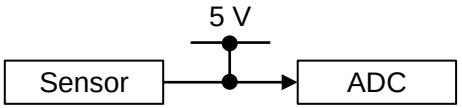


Note: When there is a short circuit to GND,
the conversion result will still be 0 V

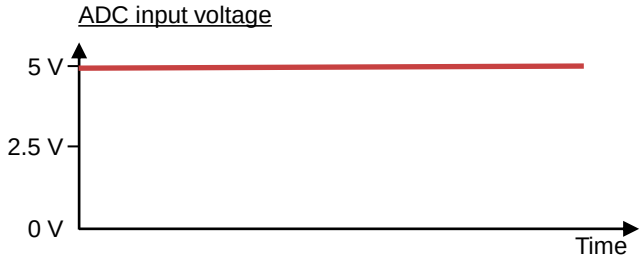
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Broken wire detection by preconditioning

› “short to 5 V” detection preconditions

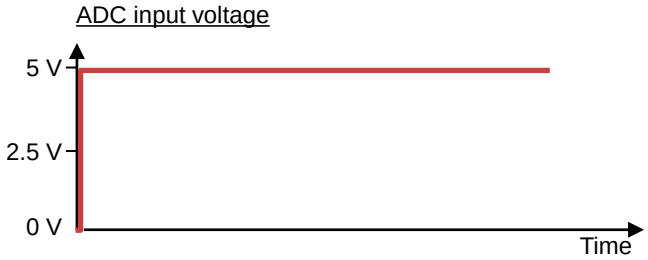


– Preconditioning = VREFH



Note: When there is a short circuit to 5 V, the conversion result will still be 5 V

– Preconditioning = VREFL

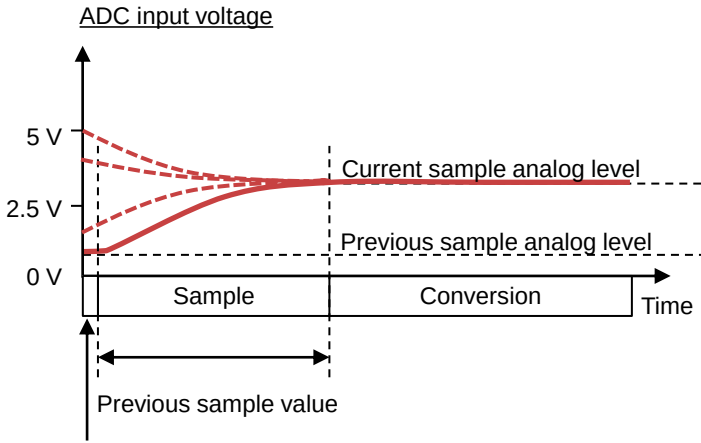


Note: When there is a short circuit to 5 V, the conversion result will immediately be 5 V

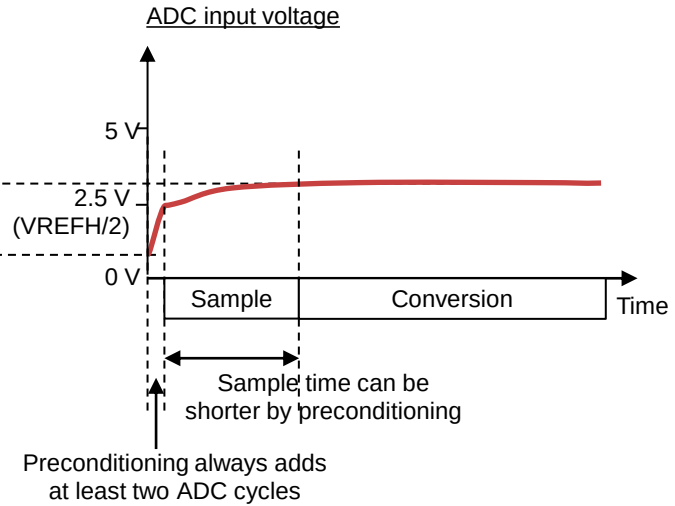
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Advantage of preconditioning

› Preconditioning = “OFF”



› Preconditioning = “DIAG” = VREFH/2



Hint Bar

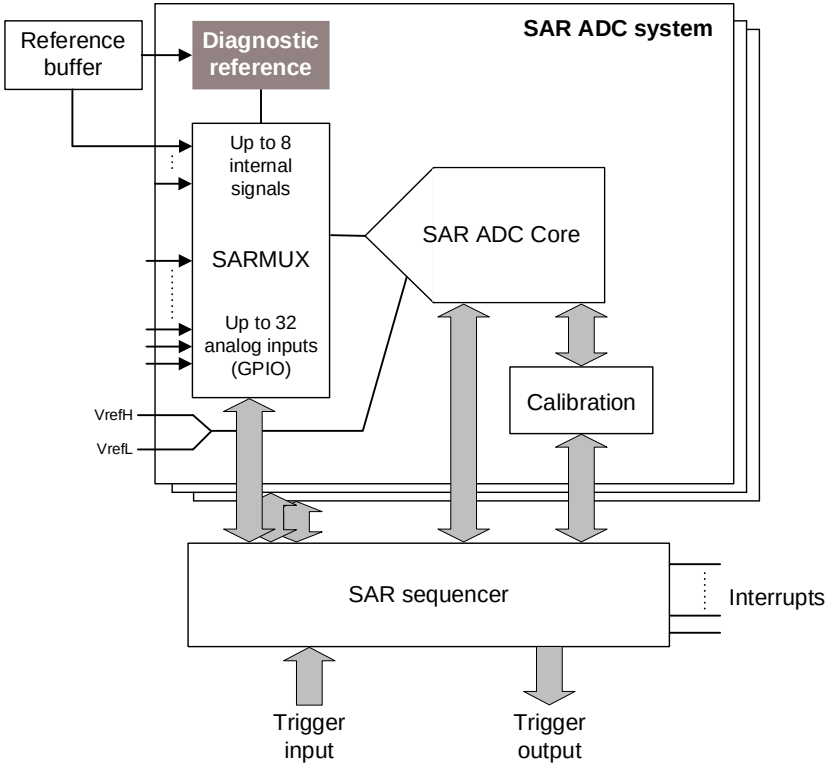
Review Register TRM and sections 33.4.1 and 33.10 in the TRM chapter for additional details

Review the Diagnostic Reference Generator section for more details

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SAR ADC block diagram

- SAR ADC components
  - Diagnostic reference
    - Diagnostic reference generator



Hint Bar

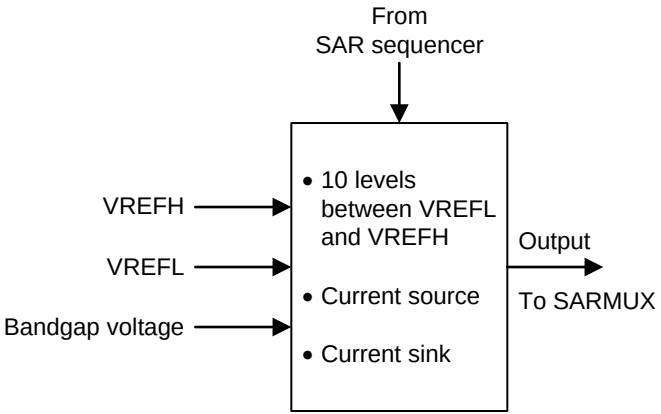
Review section 33.10 in the TRM chapter for additional details

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Diagnostic reference generator

- Provides voltages and currents for diagnostics
  - VREFL, VREFH
  - VREFH x 1/8, x 2/8, x 3/8, x 4/8, x 5/8, x 6/8, x 7/8, x 199/200
  - Bandgap voltage
  - Current source (10 µA)
  - Current sink (10 µA)

Diagnostic reference generator



Hint Bar

Review Register TRM and section 33.10 in the TRM chapter for additional details

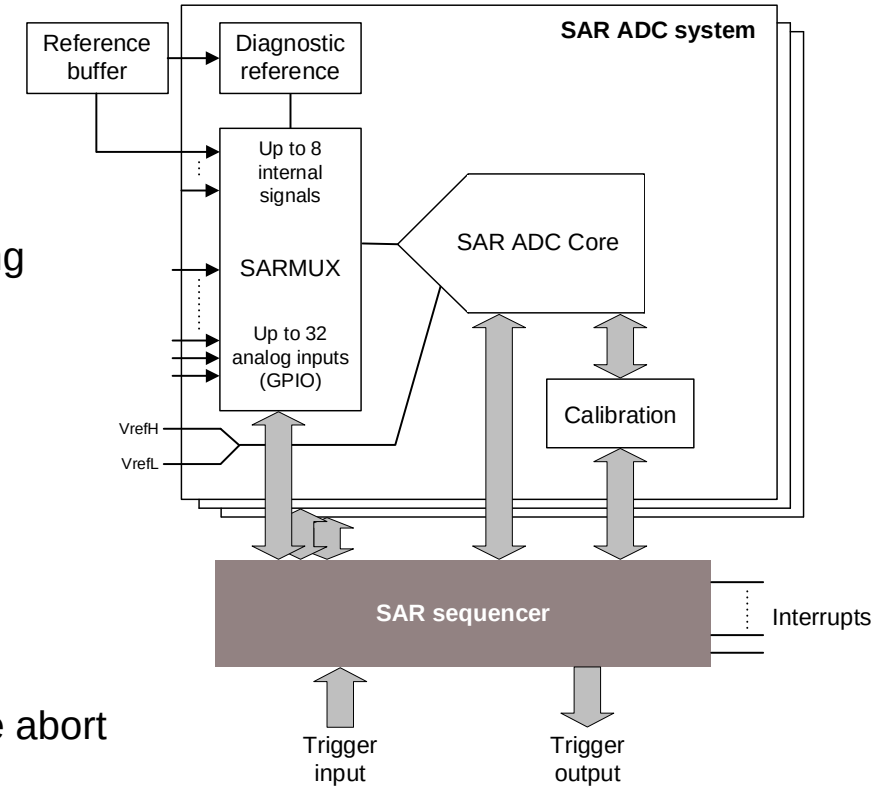
Advantage:

Test internal and external signal connection by injecting voltage near pads

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SAR ADC block diagram

- SAR ADC components
  - Channel grouping
  - Triggers
  - Arbitration, preemption, and acquisition scheduling
  - Averaging
  - Range detect
  - Pulse detect
  - Interrupts
  - Trigger outputs
  - Debug freeze
  - Auto power down
  - Channel disable/software abort



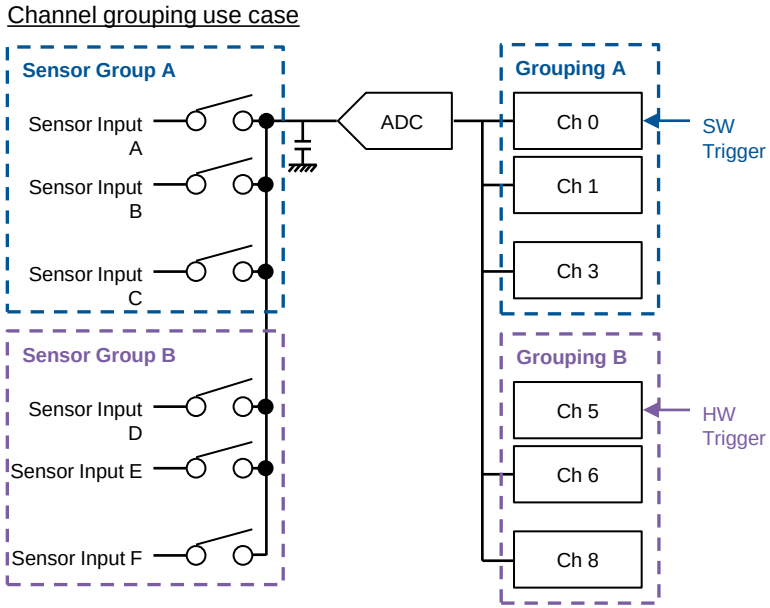
Hint Bar

Review sections 5, 6, and 7 in the TRM chapter 33 for additional details

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Channel grouping

- All the (up to 32) channels of the SAR ADC can be grouped
- The first channel defines the trigger for a group
- The last channel defines the end for a group
- A channel in the group may be disabled, in which case it will be skipped
- The grouping can only contain sequential channels, and cannot have overlapping groups or a group within a group



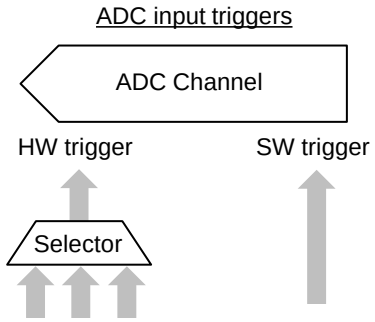
Hint Bar

Review the datasheet, Register TRM, and section 33.6.1 in the TRM chapter for additional details

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Triggers

- A trigger for a group causes the acquisitions, as defined by the configurations of the channels in the group, to be executed
- There are seven possible hardware (HW) triggers and one software (SW) trigger
  - The hardware trigger options are:
    - TCPWM: 1-to-1 trigger output from a corresponding 16-bit TCPWM
    - GENERIC0-4: Five generic input triggers routed to this ADC
      - GPIO, ADC, event generator, 32-bit TCPWM, 16-bit TCPWM for motor
    - CONTINUOUS: This trigger is always high, making the group always triggered or in other words, Idle trigger
    - OFF: No hardware trigger
- The group can be software-triggered if it is configured to use a hardware trigger



Hint Bar

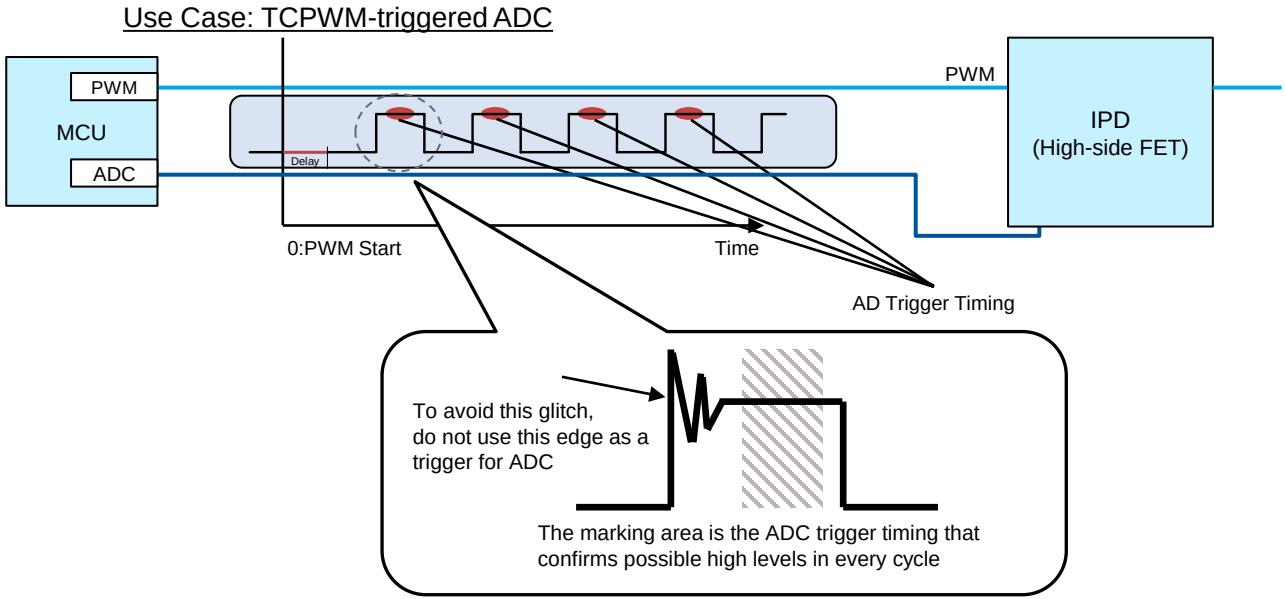
Review register TRM and section 33.6.2 in the TRM chapter for additional details

Review Arbitration/ Preemption and Acquisition Scheduling for more information about channel priority

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TCPWM-triggered ADC

- PWM signals are mainly used to control power supplied to electrical devices. In the industrial market these are mostly LEDs (or other lights) and motors
- To check the correct function, the voltage and/or current controlled by the PWM signal is measured by the ADC



Hint Bar

Review Register TRM and section 33.6.2 in the TRM chapter for additional details

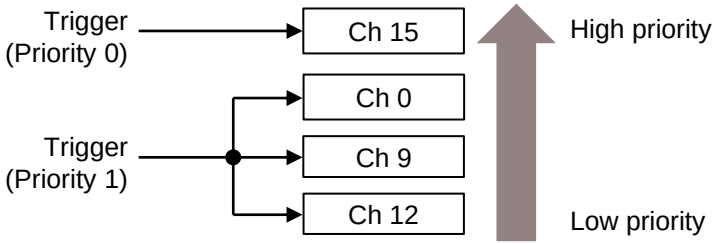
Review TCPWM and Trigger Multiplexer training sections for more information about PWMs and triggers

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Arbitration/Preemption and Acquisition Scheduling

- Arbitration of the pending triggers is based on both an explicit and an implicit priority
  - Priority
    - The explicit priority is set as a trigger attribute by software
    - There are eight explicit priority levels, 0 being the highest
    - The implicit priority is defined by the channel ordering as follows:
      - A lower channel has a higher priority than a higher channel with the same explicit priority

Example of priority



Hint Bar

Review Register TRM and section 33.6.3 in the TRM chapter for additional details

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Arbitration/Preemption and Acquisition Scheduling

- Preemption and Acquisition Scheduling
  - The scheduler determines whether preemption occurs or not, based on the explicit priority level and the trigger preemption type of the ongoing group scan
  - Available preemption types: ABORT_RESUME, ABORT_RESTART, ABORT_CANCEL, and FINISH_RESUME

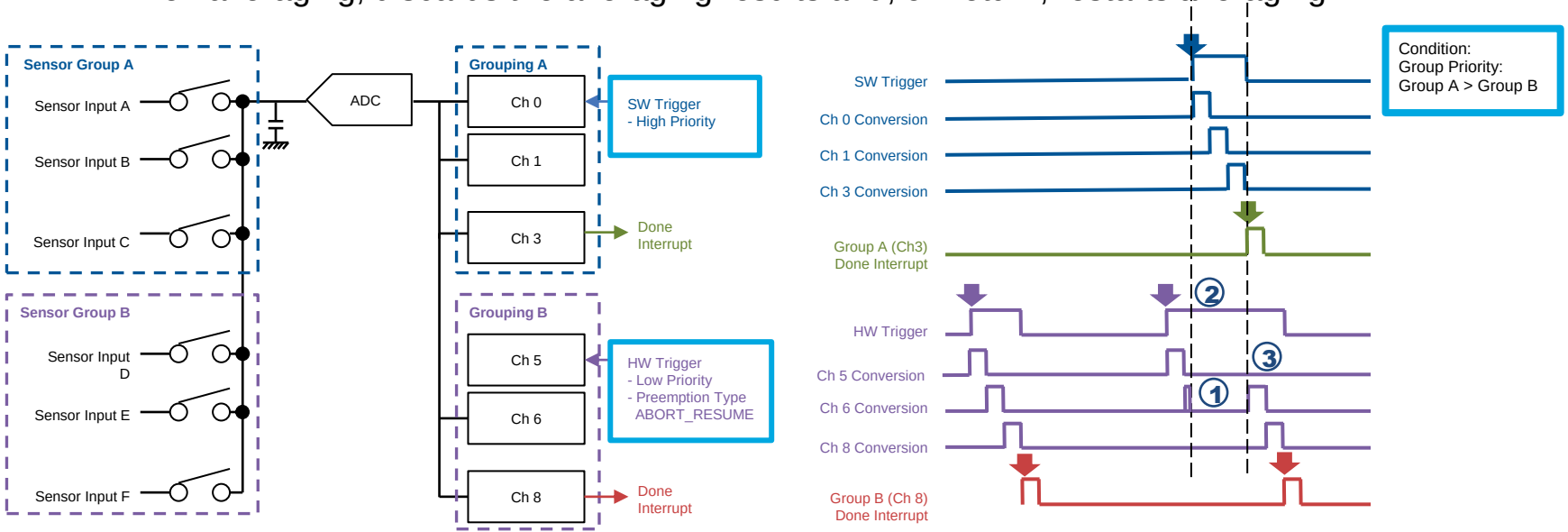
Hint Bar

Review Register TRM and section 33.6.3 in the TRM chapter for additional details

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Type 1

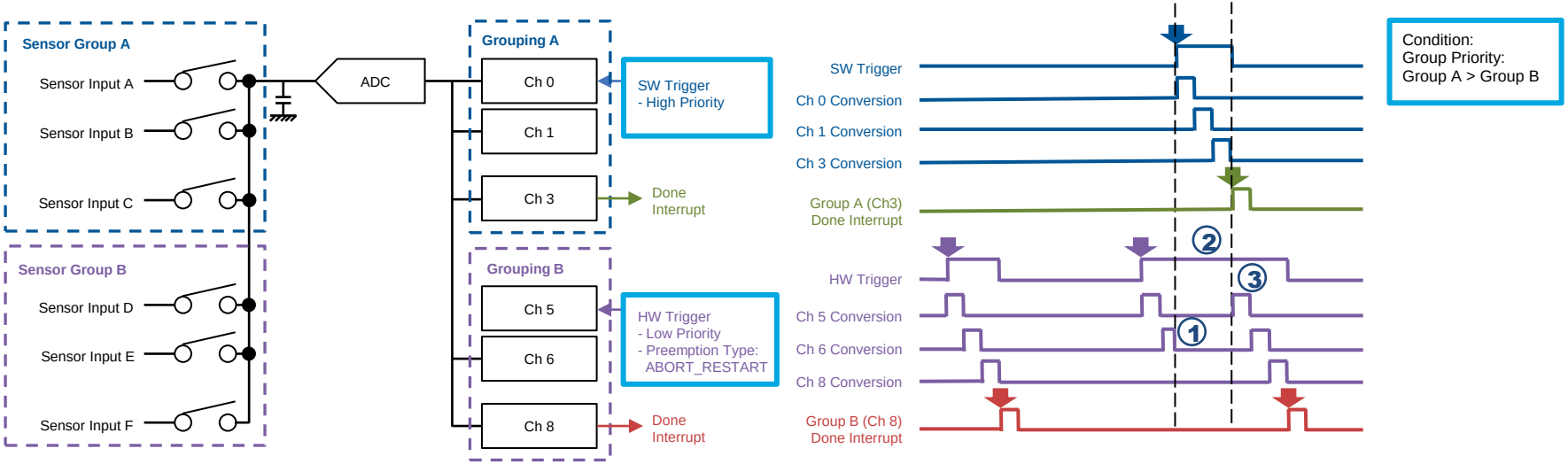
- ABORT_RESUME
  1. Immediately aborts the ongoing acquisition
  2. Keeps the pending trigger of the aborted group
  3. After the high-priority group is done, resumes the group scan starting with the aborted channel
     - When averaging, discards the averaging results and, on return, restarts averaging



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Type 2

- ABORT_RESTART
  1. Immediately aborts the ongoing acquisition
  2. Keeps the pending trigger of the aborted group
  3. After the high-priority group is done, restarts the group scan from the first channel of the group

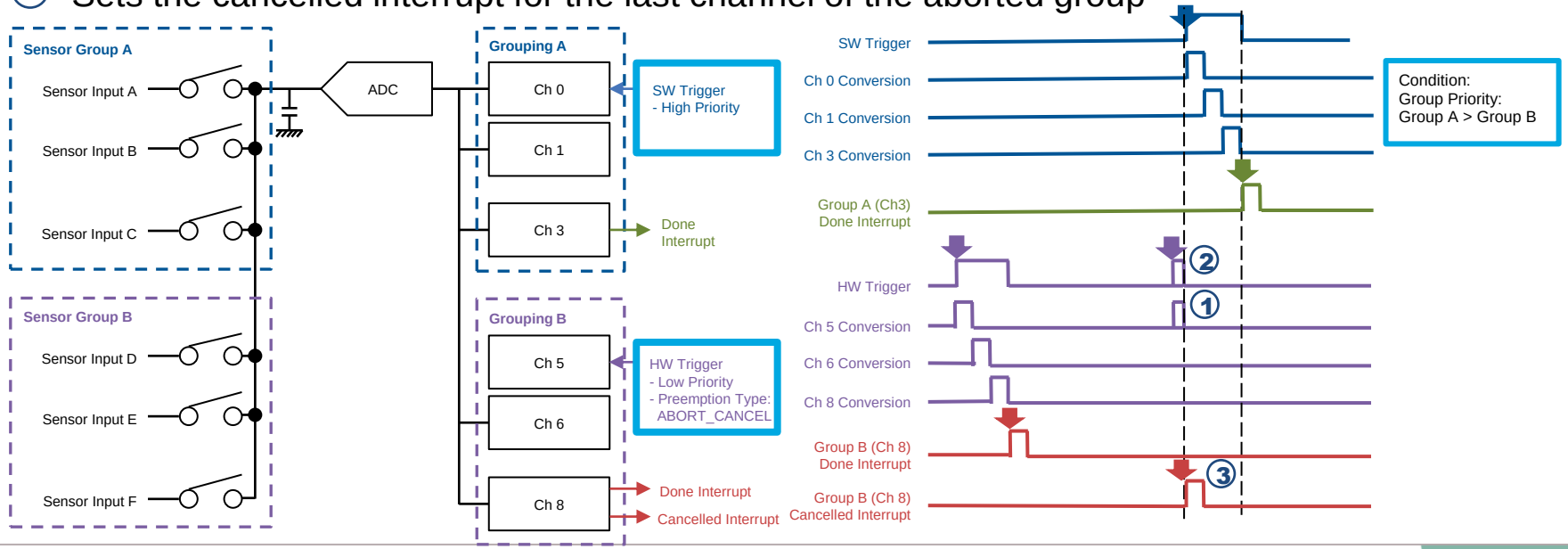


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Type 3

ABORT_CANCEL

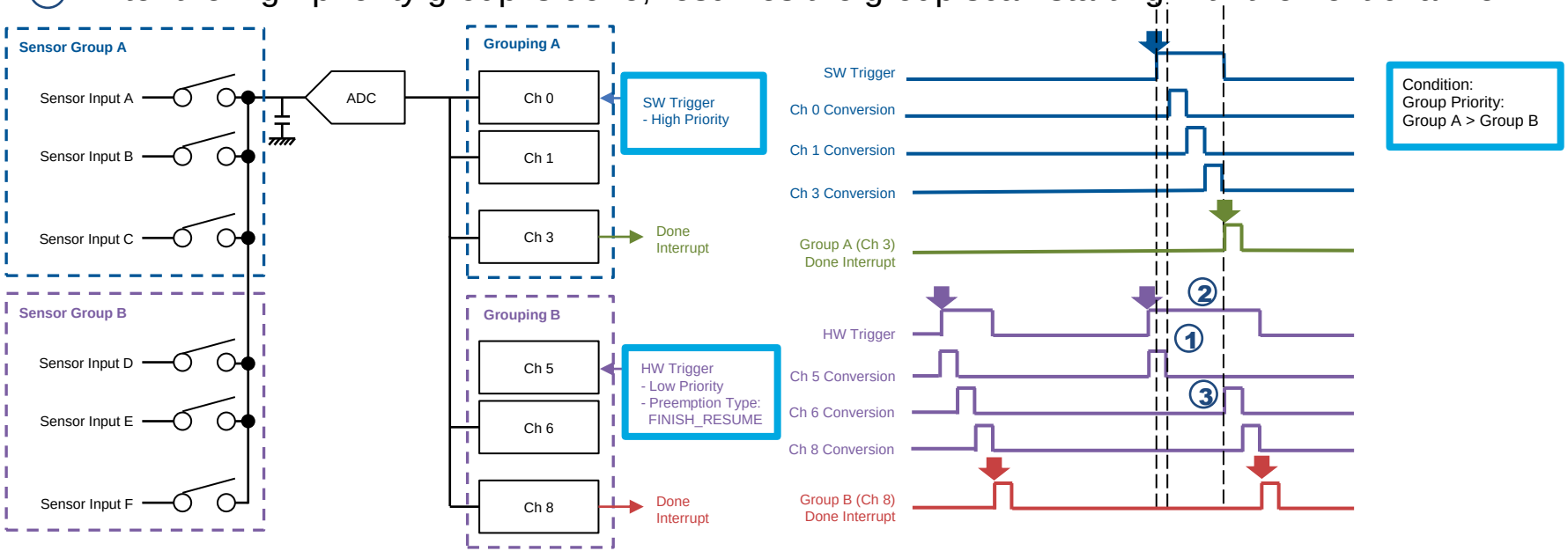
1. Immediately aborts the ongoing acquisition and do not return
2. Clears the pending trigger of the aborted group
3. Sets the cancelled interrupt for the last channel of the aborted group



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Type 4

- FINISH_RESUME
  1. Before preempting, completes the ongoing acquisition (including averaging)
  2. Keeps the pending trigger of the aborted group
  3. After the high-priority group is done, resumes the group scan starting with the next channel

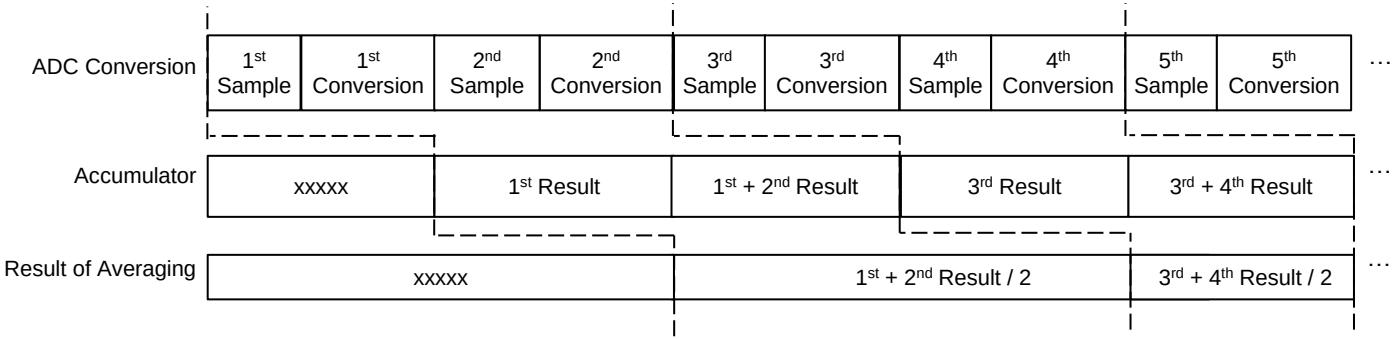


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Averaging

- Averaging functionality for every channel
- Accumulate the results (after sign extension) in a 20-bit accumulator
- Up to 256 samples can be averaged

Use Case: Two-sample averaging (Continuous)



Hint Bar

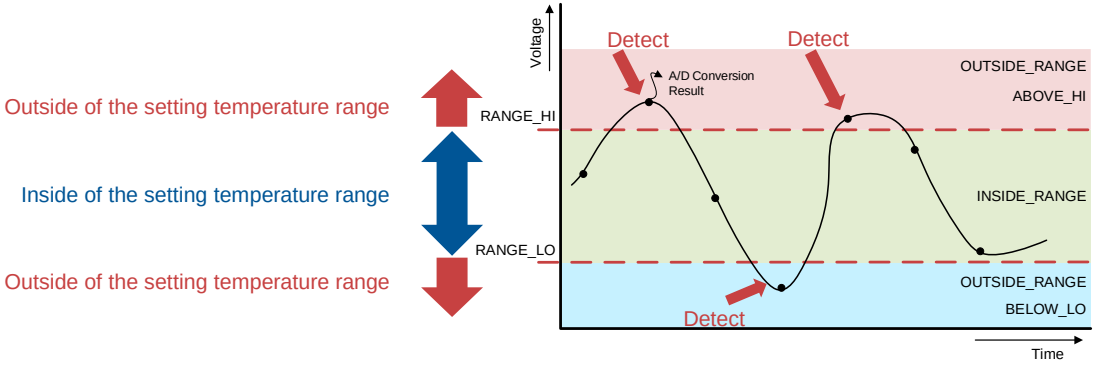
Review Register TRM and section 33.5.4 in the TRM chapter for additional details

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Range Detect

- Range Detect can check the ADC result without CPU involvement:
  - Two programmable threshold values per channel
    - RANGE_LO, RANGE_HI
  - Four modes per channel:
    - BELOW_LO: RESULT < RANGE_LO
    - INSIDE_RANGE: RANGE_LO ≤ RESULT < RANGE_HI
    - ABOVE_HI: RANGE_HI ≤ RESULT
    - OUTSIDE_RANGE: (RESULT < RANGE_LO) || (RANGE_HI ≤ RESULT)

Use Case: Detecting out of the setting temperature range



Hint Bar

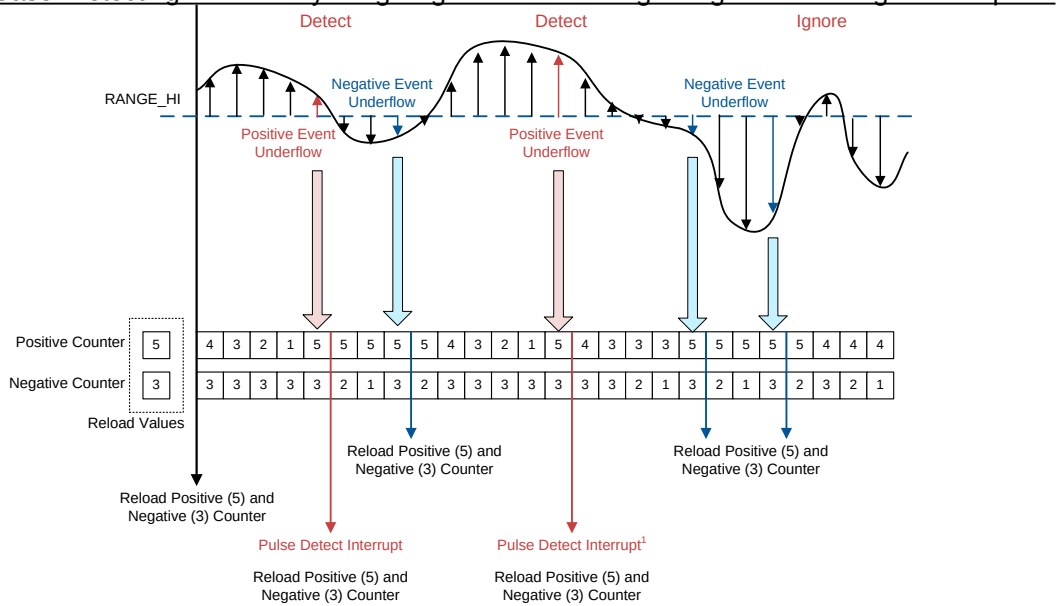
Review Register TRM and section 33.5.5 in the TRM chapter for additional details

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Pulse Detect

- Pulse Detect filters input signal level by counting the Range Detect events
  - Positive counter: 8-bit
  - Negative counter: 5-bit

Use Case: Detecting “Sufficiently Long” High Pulses While Ignoring “Short Enough” Low Spikes



[1] Overflow interrupt is generated if the previous Pulse Detect interrupt is still not cleared

Hint Bar

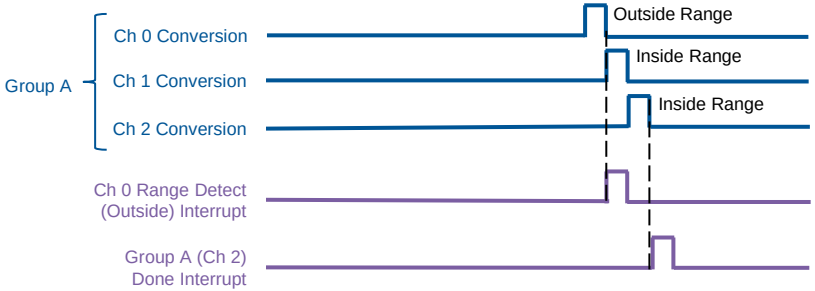
Review Register TRM and section 33.5.6 in the TRM chapter for additional details

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Interrupts

- Group interrupt (group done) and channel interrupt (range detect) can occur independently
  - Can generate the range detect interrupt during group conversion

Interrupts	Per Channel	Per Group[1]	Description
Range Detect	✓		Interrupt by range detection
Pulse Detect	✓		Interrupt for pulse detection
Overflow	✓	✓	Interrupt is set if the new ADC completes while the results from the previous completion have not yet been handled
Group Done		✓	Interrupt by group scan completion
Group Cancelled		✓	Interrupt is set by ABORT_CANCEL operation



[1] Can be set for the last channel of a group

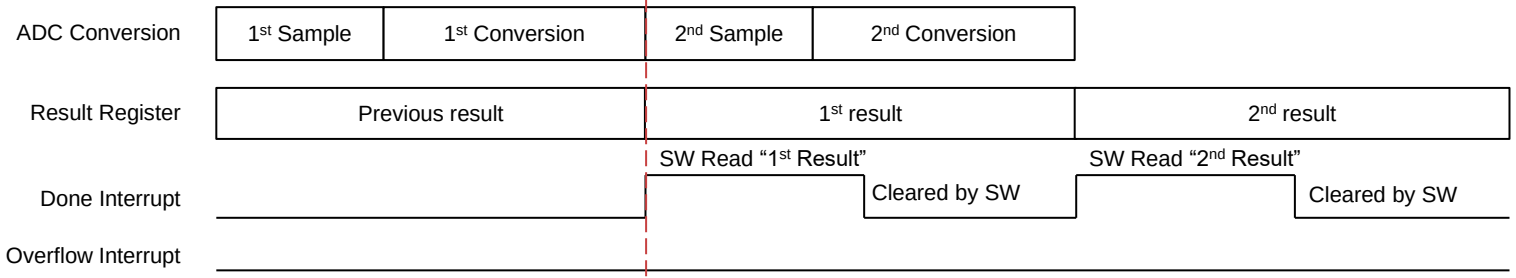
Hint Bar

Review Register TRM and sections 33.7.2 and 33.7.3 in the TRM chapter for additional details

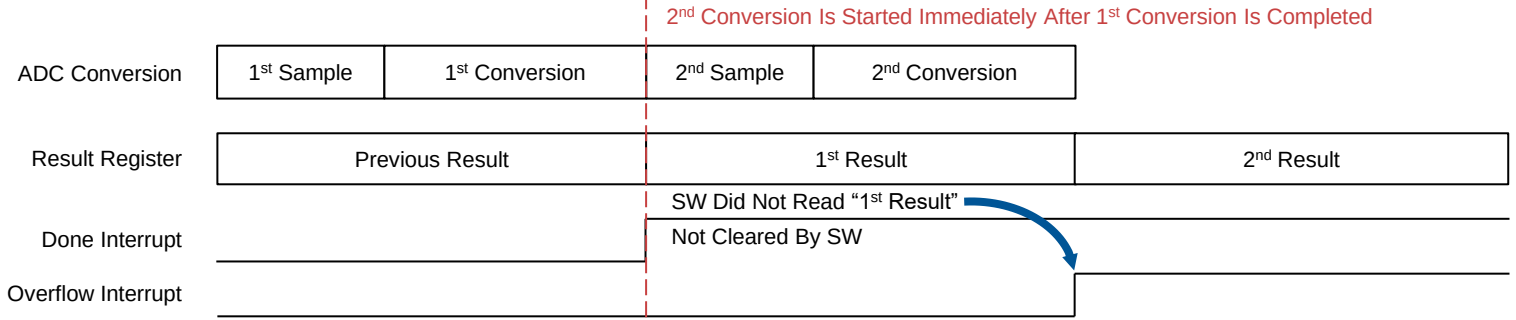
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ADC interrupt timing for overflow

- Single channel with continuous trigger
  - Normal case (no overflow)



  - Overflow case

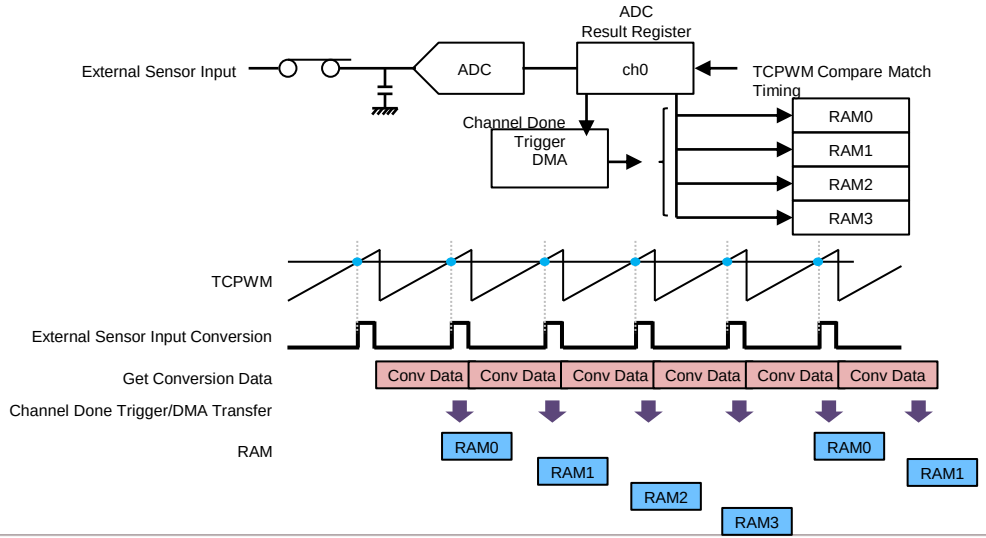


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Channel Done trigger output

- Channel Done trigger output can be generated per enabled channel
- Indicates that the data for channel is available in the Result register
- Can be used to retrieve external sensor data over a constant period for CPU to handle (see figure below)

Use Case: DMA trigger



Hint Bar

Review Register TRM and section 33.7.1 in the TRM chapter for additional details

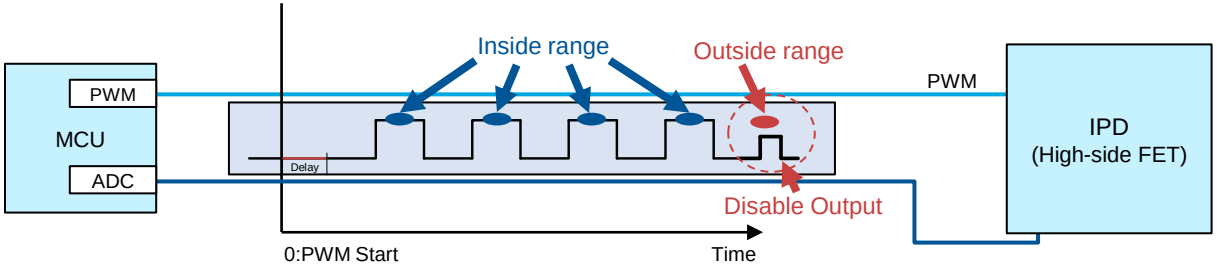
Review the DMA and Trigger Multiplexer training sections for more information about DMA and triggers

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Range violation trigger output

- Range Violation trigger output can be generated per enabled channel
- ADC generates a pulse if the acquisition result for the channel causes a Range Detect event
- The TCPWM output can be disabled when an abnormal voltage range is detected by the ADC if the TCPWM LED has control

Use Case: TCPWM LED Control



Hint Bar

Review Register TRM and section 33.7.1 in the TRM chapter for additional details

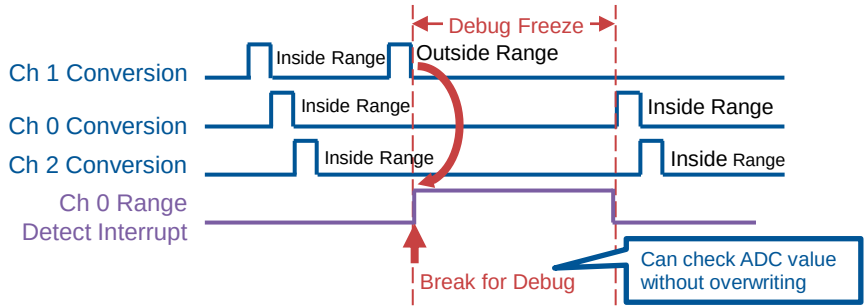
Review the TCPWM and Trigger Multiplexer training sections for more information about PWM and triggers

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Debug freeze

- Debug freeze prevents the scheduler from starting acquisitions for a new channel
- At averaging, ADC will complete even if the debug freeze trigger is asserted
- Debug freeze is available for each ADC unit
- Debug freeze allows system halting without overwriting ADC values
  - Converted values fit into debug session, avoiding corruption caused by overwritten ADC values (for example, range detect interrupt)

Use Case: System halting



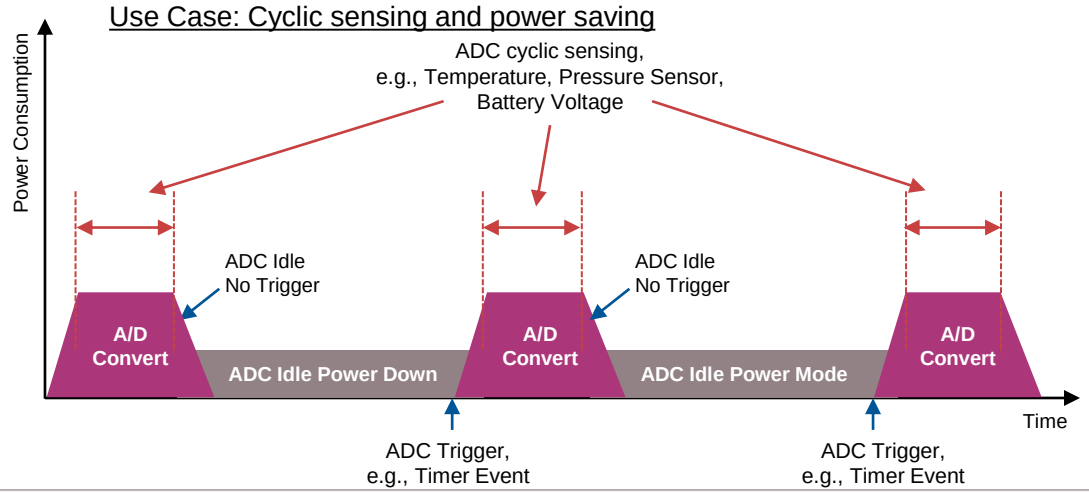
Hint Bar

Review Register TRM (PASS_CTL.DEBUG_FREEZE_EN) and section 33.6.4 in the TRM chapter for additional details

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Auto Idle Power Down

- Automatically powers down the analog circuit when the ADC is idle
- The analog circuit automatically powers up when a trigger inputs
- After power-up, the analog circuit must settle for some time before it can make accurate acquisitions (1 µs, minimum)



Hint Bar

Review Register TRM (CTL.PWRUP_TIME) and section 33.6.5 in the TRM chapter for additional details

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Channel disable/software abort

- Can disable the ADC channel with software for the unused channel
- Can abort the ADC using software during A/D conversion
- Use cases
  - Emergency stop due to low battery or system down
  - Reconfiguration by changing the external environment (for example, temperature)

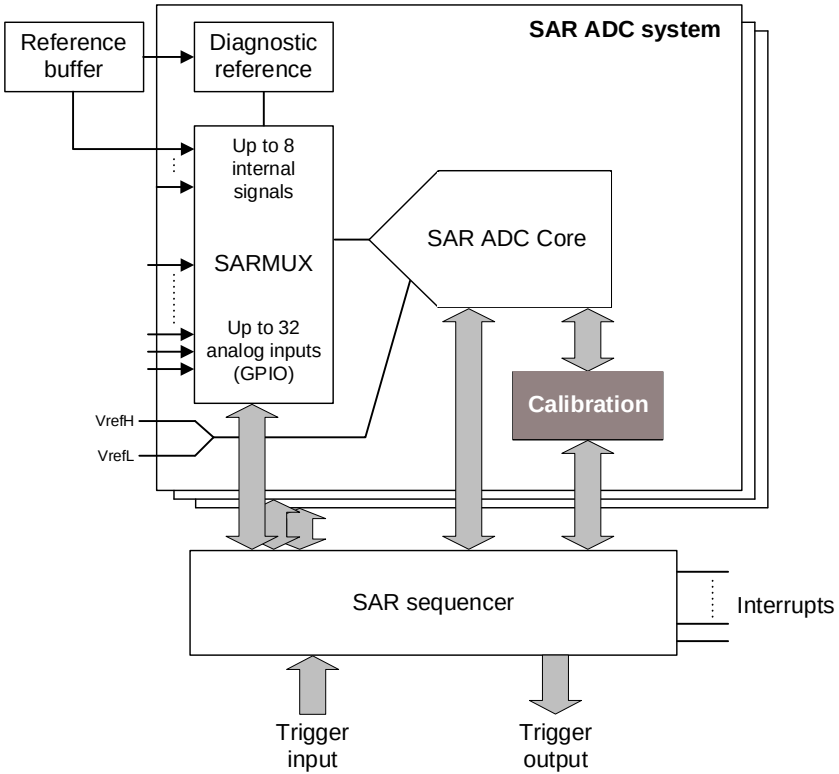
Hint Bar

Review Register TRM and section 33.6.6 in the TRM chapter for additional details

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SAR ADC block diagram

- SAR ADC components
  - Calibration
    - Analog
    - Alternate
    - Coherent



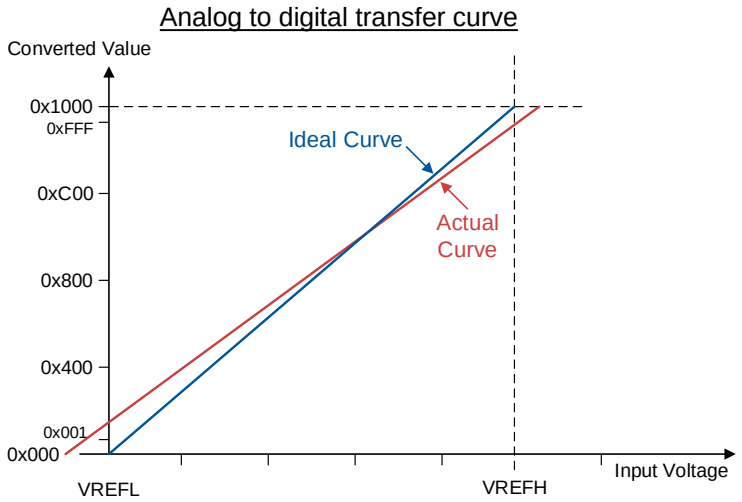
Hint Bar

Review section 33.8 in the TRM chapter for additional details

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Analog calibration

- Brings the actual ADC transfer curve closer to the ideal transfer curve
- Adjusts an offset and a gain value using software to satisfy the following
  - Transition between values 0x000 and 0x001 for VREFL + 0.5 LSB input voltage
  - Transition between values 0xFFE and 0xFFF for VREFH – 1.5 LSB input voltage
- Total error can be ±5 LSB after offset and gain adjustment



Hint Bar

Review Register TRM and section 33.8.1 in the TRM chapter for additional details

Preconditions:

Before the ADC is used for acquisitions, it must be set to the correct values (e.g., periodic calibration of the production line due to temperature shift and age)

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Alternate calibration/Coherent calibration update

- Alternate calibration
  - Runs the recalibration algorithm in the background while the main application runs undisturbed using the active calibration values
    - Changing the calibration in the middle of a group scan leads to incoherent results within that group scan
- Coherent Calibration Update
  - Waits for the right moment to coherently copy values from the alternate calibration registers to the regular calibration registers
    - The right moment for a coherent calibration update is when the ADC becomes idle, or a continuous triggered group completes

Hint Bar

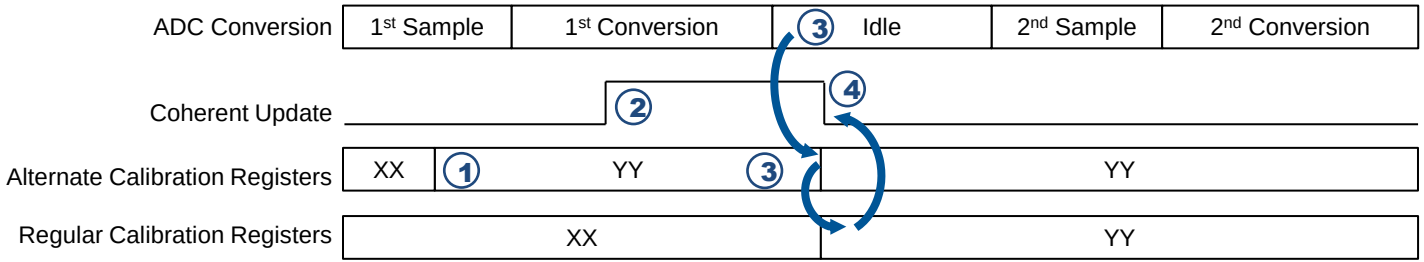
Review Register TRM and sections 33.8.2 and 33.8.3 in the TRM chapter for additional details

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Coherent calibration update using Alternate calibration

- Use cases
  1. Alternate calibration values are set by software
  2. Coherent calibration update is enabled by software
  3. ADC waits for the Idle to coherently copy values from the alternate calibration registers to the regular calibration registers by hardware
  4. Coherent calibration update is disabled by hardware

Coherent Calibration Update Timing by Using Alternate Calibration



Hint Bar

Review Register TRM and sections 33.8.2 and 33.8.3 in the TRM chapter for additional details

Advantage:

The periodic recalibration algorithm can run quietly in the background while the main application runs undisturbed using the active calibration values



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Revision History

Revision	ECN	Submission Data	Description of Change
**	7761213	2022-11-05	Initial release

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