ADC_Filtering_1
for KIT_AURIX_TC297_TFT
ADC filtering
Scope of work

Four VADC channels are used to convert the same analog signal with different filters enabled.

The Versatile Analog-to-Digital Converter (VADC) module is configured to convert four channels in background scan mode. The data resulting from the conversions of three channels is automatically modified: one channel computes an average on 4 results, another channel applies a 3rd order Finite Impulse Response (FIR) filter and another channel applies a 1st order Infinite Impulse Response (IIR) filter. Finally, the last channel measures the same signal without Data Modification. The channels are continuously converted and, for each of them, the maximum and minimum values are stored, which are then sent through UART in order to be compared.
Introduction

› The Versatile Analog-to-Digital Converter module (VADC) of the AURIX™ TC29x comprises 11 independent analog to digital converters (VADC groups) with up to 8 analog input channels each.

› Each channel can convert analog inputs with a resolution of up to 12-bit.

› Analog/Digital conversions can be requested by several request sources:
  – Queued request source, specific to a single group
  – Channel scan request source, which comprises:
    – Group scan source, specific to a single group
    – Background scan source, which can request all channels of all groups

› The Channel scan request source issues conversion requests for a coherent sequence of input channels, starting with the highest enabled channel number.

› In background scan source (Channel scan request source), each channel is converted once per sequence. A conversion can be requested to be done once or repeatedly.

› A background scan source can access all analog input channels that are not assigned to any group request source. These conversions are executed with low priority.
Introduction

- The data resulting from conversions can be automatically modified before being used by an application to reduce the required CPU/DMA load to process the conversion.

- Three types of data modification are supported:
  - **Standard Data Reduction Mode**
  - **Result Filtering Mode**
  - **Difference Mode**

- With **Standard Data Reduction Mode**, the VADC accumulates up to 4 values before generating a result interrupt. This mode can be used on any result register of any group GxRES0..GxRES15, where x is the number of the group.

- When **Result Filtering Mode** is enabled, depending on the configuration, the VADC can apply either a 3rd order Finite Impulse Response (FIR) filter with selectable coefficients, or a 1st order Infinite Impulse Response (IIR) filter with selectable coefficients to the conversion results. This mode can be applied on the result registers GxRES7 and GxRES15 of any group, where x is the number of the group.

- The **Difference Mode** subtracts the contents of the result register GxRES0 from the conversion results. This mode can be used on the result registers GxRES1..GxRES15 of any group, where x is the number of the group.
Hardware setup

This code example has been developed for the board KIT_AURIX_TC297_TFT_BC-Step. In this example, the port pins AN0, AN2, AN3 and AN8 are used, connected to VCC_IN.

Note: VCC_IN supplies the power provided to the board. If the board is supplied via the USB port, VCC_IN supplies ~3,3V, if the board is supplied with an external power supply, VCC_IN can reach 40V, thus connect the 4 analog pins to a DC signal between 0 and 5V instead.
Implementation

Configuration of the VADC

The configuration of the VADC is done in the `initADC()` function in four different steps:

- Configuration of the VADC module
- Configuration of the VADC groups
- Configuration of the VADC channels
- Configuration of the data modification

Configuration of the VADC module

The default configuration of the VADC module, given by the iLLDs, can be used for this example. This is done by initializing an instance of the `IfxVadc_Adc_Config` structure and applying default values to its fields through the function `IfxVadc_Adc_initModuleConfig()`. Then, the configuration can be applied to the VADC module with the function `IfxVadc_Adc_initModule()`.
Implementation

Configuration of the VADC groups

The configuration of the VADC groups is done by initializing an instance of the `IfxVadc_Adc_GroupConfig` structure with default values through the function `IfxVadc_Adc_initGroupConfig()` and modifying the following fields:

- **arbiter** — a structure that represents the enabled request sources, which can be Group scan, Queue and/or Background sources. In this example, `arbiter.requestSlotBackgroundScanEnabled` is set to `TRUE`, thus enabling the Background scan source.
- **backgroundScanRequest** — a structure that allows to configure the Background Scan Request Source by setting:
  - `autoBackgroundScanEnabled` — a parameter to set the autoscan mode (conversions are requested continuously)
  - `triggerConfig` — a parameter that specifies the trigger configuration
- **master** — to indicate which converter is the master
- **groupId** — to select which converter to configure

While using multiple converters, they can have the same or different settings. In this example, the same configuration is applied to all the used converters by changing the `groupId` parameter in the `for` loop.

The configuration is applied through the function `IfxVadc_Adc_initGroup()` inside the `for` loop.
Implementation

Configuration of the VADC channels

The configuration of each channel is done by initializing an instance of the `IfxVadc_Adc_ChannelConfig` structure with default values through the function `IfxVadc_Adc_initChannelConfig()` and modifying the following fields:

- `channelId` – to select the channel to configure
- `resultRegister` – to indicate the register where the A/D conversion value is stored
- `backgroundChannel` – to specify that the selected channel is used as a background channel

Then, the configuration is applied with the function `IfxVadc_Adc_initChannel()` and the channel is added to the background scan sequence through the function `IfxVadc_Adc_setBackgroundScan()`.

Finally, the result registers used for storing the conversion results can be configured to use data modification, in order to enable the filtering.

Configuration of the data modification

The data modification is configured in the `applyFiltering()` function.

The iLLDs for AURIX™ TC2xx do not support the VADC data modification, thus it is needed to directly modify the Group Result Control Registers (GxRCRy, with x indicating the Group number and y indicating the result register where to apply the filtering).
Implementation

Configuration of the data modification

To enable the **Standard Data Reduction Mode** on a specific result register, the Data Modification Mode (DMM) bit field of the associated GxRCRy register must be set to 00\(_B\) and the Data Reduction Control (DRCTR) bit field of the same can be set to one of the following values:

<table>
<thead>
<tr>
<th>DMM</th>
<th>DRCTR</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>00(_B)</td>
<td>0000(_B) = 0x0</td>
<td>Data Reduction disabled</td>
</tr>
<tr>
<td>00(_B)</td>
<td>0001(_B) = 0x1</td>
<td>Accumulate 2 result values</td>
</tr>
<tr>
<td>00(_B)</td>
<td>0010(_B) = 0x2</td>
<td>Accumulate 3 result values</td>
</tr>
<tr>
<td>00(_B)</td>
<td>0011(_B) = 0x3</td>
<td>Accumulate 4 result values</td>
</tr>
</tbody>
</table>

When the conversion is ready, depending on the configuration of the DRCTR bit field, the result register contains the sum of up to 4 result values, thus it is needed to divide the content of the result register GxRESy by the number of the accumulated values in order to obtain an average of the measurements.

**Note:** Using Standard Data Reduction Mode, the final result must be read before the next data reduction sequence starts (before t5 or t9 in the example), otherwise the Valid Flag (VF) bitfield will not be cleared. In order to read a correct measurement, VF must be 1 and Data Reduction Counter (DRC) bitfield must be 0.
Implementation

Configuration of the data modification

To enable the **Result Filtering Mode** on a specific result register, the Data Modification Mode (DMM) bit field of the associated GxRCRy register must be set to 01\textsubscript{B} and the Data Reduction Control (DRCTR) bit field of the same register can be set to enable either a 3\textsuperscript{rd} order Finite Impulse Response (FIR) filter or a 1\textsuperscript{st} order Infinite Impulse Response (IIR) filter, both with selectable coefficients, according to the values in **Table 3**.

When a **FIR filter** is enabled, depending on the selected coefficients, a gain of 3 or 4 (the DC gain of a FIR filter is equal to the sum of its coefficients) is applied to the ADC result, producing a 14-bit value. Therefore, in order to obtain the filtered measurement, it is needed to divide the content of the result register by the sum of the selected coefficients.

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Implementation

Configuration of the data modification

The selectable coefficients for an IIR filter lead to a gain of 4 to the ADC result, producing a 14-bit value. Consequently, in order to obtain the filtered measurement, the content of the result register needs to be divided by 4.

All the measurement’s divisions are carried out in the Cpu0_main.c file, after reading the conversion result from the result register.

The FIR and IIR filters needs to be initialized, otherwise the first values are incorrect (see the figures for the two filters).

**Note:** In this example, a delay before starting to read the conversion results is needed. This ensures that reading spikes in the VCC_IN supply due to the initialization of the device are avoided and that incorrect values are not read due to the filters not being yet at full speed.
Implementation

Configuration of the data modification

Result Filtering Mode: Available coefficients for FIR and IIR filters are listed in Table 3.

In this example, the converted channels are configured as it follows:

Table 2

<table>
<thead>
<tr>
<th>Channel</th>
<th>Data Modification Mode enabled</th>
</tr>
</thead>
<tbody>
<tr>
<td>AN0</td>
<td>Standard Data Reduction Mode</td>
</tr>
<tr>
<td>AN2</td>
<td>Result Filtering Mode: FIR filter</td>
</tr>
<tr>
<td>AN3</td>
<td>Result Filtering Mode: IIR filter</td>
</tr>
<tr>
<td>AN8</td>
<td>No Data Modification Mode enabled</td>
</tr>
</tbody>
</table>

The channel AN8 has no data modification enabled in order to use it as a comparison.

Table 3

<table>
<thead>
<tr>
<th>DMM</th>
<th>DRCTR</th>
<th>Filter coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>01B</td>
<td>0000B = 0x0</td>
<td>FIR filter: a=2, b=1, c=0</td>
</tr>
<tr>
<td>01B</td>
<td>0001B = 0x1</td>
<td>FIR filter: a=1, b=2, c=0</td>
</tr>
<tr>
<td>01B</td>
<td>0010B = 0x2</td>
<td>FIR filter: a=2, b=0, c=1</td>
</tr>
<tr>
<td>01B</td>
<td>0011B = 0x3</td>
<td>FIR filter: a=1, b=1, c=1</td>
</tr>
<tr>
<td>01B</td>
<td>0100B = 0x4</td>
<td>FIR filter: a=1, b=0, c=2</td>
</tr>
<tr>
<td>01B</td>
<td>0101B = 0x5</td>
<td>FIR filter: a=3, b=1, c=0</td>
</tr>
<tr>
<td>01B</td>
<td>0110B = 0x6</td>
<td>FIR filter: a=2, b=2, c=0</td>
</tr>
<tr>
<td>01B</td>
<td>0111B = 0x7</td>
<td>FIR filter: a=1, b=3, c=0</td>
</tr>
<tr>
<td>01B</td>
<td>1000B = 0x8</td>
<td>FIR filter: a=3, b=0, c=1</td>
</tr>
<tr>
<td>01B</td>
<td>1001B = 0x9</td>
<td>FIR filter: a=2, b=1, c=1</td>
</tr>
<tr>
<td>01B</td>
<td>1010B = 0xA</td>
<td>FIR filter: a=1, b=2, c=1</td>
</tr>
<tr>
<td>01B</td>
<td>1011B = 0xB</td>
<td>FIR filter: a=2, b=0, c=2</td>
</tr>
<tr>
<td>01B</td>
<td>1100B = 0xC</td>
<td>FIR filter: a=1, b=1, c=2</td>
</tr>
<tr>
<td>01B</td>
<td>1101B = 0xD</td>
<td>FIR filter: a=1, b=0, c=3</td>
</tr>
<tr>
<td>01B</td>
<td>1110B = 0xEE</td>
<td>IIR filter: a=2, b=2</td>
</tr>
<tr>
<td>01B</td>
<td>1111B = 0xF</td>
<td>IIR filter: a=3, b=4</td>
</tr>
</tbody>
</table>
Implementation

Configuration of the VADC

When the VADC module and its groups and channels are configured and the Data Modification registers are correctly configured, the scan sequence is started with the function `IfxVadc_Adc_startBackgroundScan()`. 

Read the VADC measurements

Finally, to read a conversion, the function `readADCValue()` is used, which calls the `IfxVadc_Adc_getResult()` function from iLLDs until a new measurement is returned (a new measurement is considered correct only when both the Valid Flag and the Data Reduction Counter bitfield are set to 1 and respectively 0, the latter is needed because the Standard Data Reduction Mode is enabled on the AN0 pin).

All the functions used to get a conversion and configuring the VADC module, its group and channels can be found in the iLLD header `IfxVadc_Adc.h`. 
Implementation

Configuration of the UART

In this example, the UART connection is used to make the debugging more convenient and easier to understand. The configured VADC channels are continuously read, but the maximum and minimum values, together with the computed $V_{pp}$ are printed using UART communication only when the user requests them.

The `initUART()` function initializes the UART communication.

The iLLD function `IfxAsclin_Asc_initModuleConfig()` fills the configuration structure `ascConf` with default values. Then, the parameters used to configure the module are set, depending on the needed connection: baudrate, Tx and Rx buffers, Tx and Rx pin configuration etc.

Finally, `IfxAsclin_Asc_initModule()` initializes the module with the user configuration and `IfxAsclin_Asc_stdlfDPipeInit()` initializes the standard interface to use the ASCLIN module.

The functions `isDataAvailable()` and `receiveData()` are used to interface with the ASCLIN module to check if new data is available through the function `IfxAsclin_Asc_getReadCount()` and, respectively, to receive data over the UART communication through the function `IfxAsclin_Asc_read()`.

The function `IfxStdlf_DPipe_print()` is used to print the stored processed values.

The functions used to interface and initialize the ASCLIN module can be found in the iLLD header `IfxAsclin_Asc.h`, while the latter can be found in the iLLD header `IfxStdlf_DPipe.h`. 
Run and Test

For this training, a serial monitor is required for visualizing the values. The monitor can be opened inside the AURIX™ Development Studio using the following icon:

The serial monitor must be configured with the following parameters to enable the communication between the board and the PC:
- Speed (baud): 115200
- Data bits: 8
- Stop bit: 1
After code compilation and flashing the device, perform the following steps:

- Connect the channels AN0, AN2, AN3 and AN8 to the VCC_IN pin (~3.3V), or to any DC signal between 0 and 5V
- Open the serial monitor and start the serial communication, linked with the appropriate COMx port (this can be checked in the Device Manager)
- After a few seconds, send the character “1” to print the maximum and minimum values read by the channels, together with the computed $V_{pp}$

![Serial Monitor Output](image)

The maximum and minimum values are expressed as a 12-bits integer value, in decimal format (0 - 4095 range), while the $V_{pp}$ is expressed in Volts.

It can be noticed that for this signal, the filter applying an average is the most effective one to reduce the $V_{pp}$ range.
References

- AURIX™ Development Studio is available online:
  - [https://www.infineon.com/aurixdevelopmentstudio](https://www.infineon.com/aurixdevelopmentstudio)
  - Use the „Import...“ function to get access to more code examples.

- More code examples can be found on the GIT repository:
  - [https://github.com/Infineon/AURIX_code_examples](https://github.com/Infineon/AURIX_code_examples)

- For additional trainings, visit our webpage:
  - [https://www.infineon.com/aurix-expert-training](https://www.infineon.com/aurix-expert-training)

- For questions and support, use the AURIX™ Forum:
## Revision history

<table>
<thead>
<tr>
<th>Revision</th>
<th>Description of change</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1.0.1</td>
<td>Update of version to be in line with the code example’s version</td>
</tr>
<tr>
<td>V1.0.0</td>
<td>Initial version</td>
</tr>
</tbody>
</table>
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