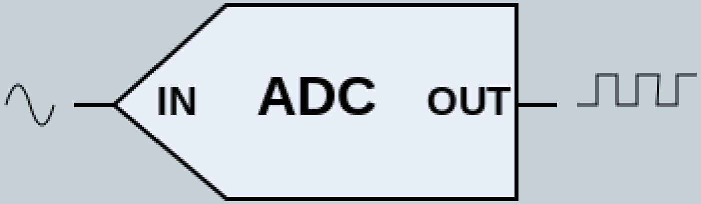
Étude des microcontrôleurs STM32 : Peripheral programming

ANALOG DIGITAL CONVERTER : ADC

Analog Digital Converter : ADC

- ADC is a device that converts a continuous physical quantity (usually voltage) to a digital number that represents the quantity's amplitude.
  - introduces a small amount of error
- Not single conversion but it performs the conversions ("samples" the input) periodically.
  - The result is a sequence of digital values
- The digital output may use different coding schemes.
  - Typically the digital output will be a two's complement binary number that is proportional to the input.



General presentation

- The voltage resolution of an ADC is equal to its overall voltage measurement range divided by the number of discrete values:
- Q= E_{FSR}/ 2^M-1 where M is the ADC's resolution in bits and E_{FSR} is the full scale voltage range (also called 'span').
- $E_{FSR} = V_{RefHi,-} V_{RefLow}$: where V_{RefHi} and V_{RefLow} are the upper and lower extremes, respectively, of the voltages that can be coded.

- Normally, the number of voltage intervals is given by N= 2^M-1 where M is the ADC's resolution in bits.

- Example:
  - Coding scheme as in figure 1 (assume input signal x(t) = Acos(t), A = 5V) Full scale measurement range = -5 to 5 volts
  - ADC resolution is 8 bits: $2^8 - 1 = 256 - 1 = 255$ quantization levels (codes)
  - ADC voltage resolution, Q = (10 V – 0 V) / 255 = 10 V / 255 ≈ 0.039 V ≈ 39 mV.

ADC main features

- The 12-bit ADC is a successive approximation analog-to-digital converter.
- ADC input range: VREF– ≤ *VIN* ≤ *VREF*+
- Interrupt generation at the
  - end of conversion,
  - end of injected conversion,
  - and in case of analog watchdog or overrun events
- The A/D conversion of the channels can be performed in single, continuous, scan or discontinuous mode and Dual/Triple mode (on devices with 2 ADCs or more)
  - Scan mode for automatic conversion of channel 0 to channel 'n'
- Channel-wise programmable sampling time
- Configurable DMA data storage in Dual/Triple ADC mode
- ADC conversion type (refer to the datasheets)

STM32 ADC

- It has up to 18 multiplexed channels allowing it to measure signals from
  - 16 external sources,
  - two internal sources
    - Internal reference voltage (Vrefint =1,2V)
    - Temprature sensor
- The result of the ADC is stored into a left or right-aligned 16-bit data register.
- Dual mode (on devices with 2 ADC) : 8 conversion mode

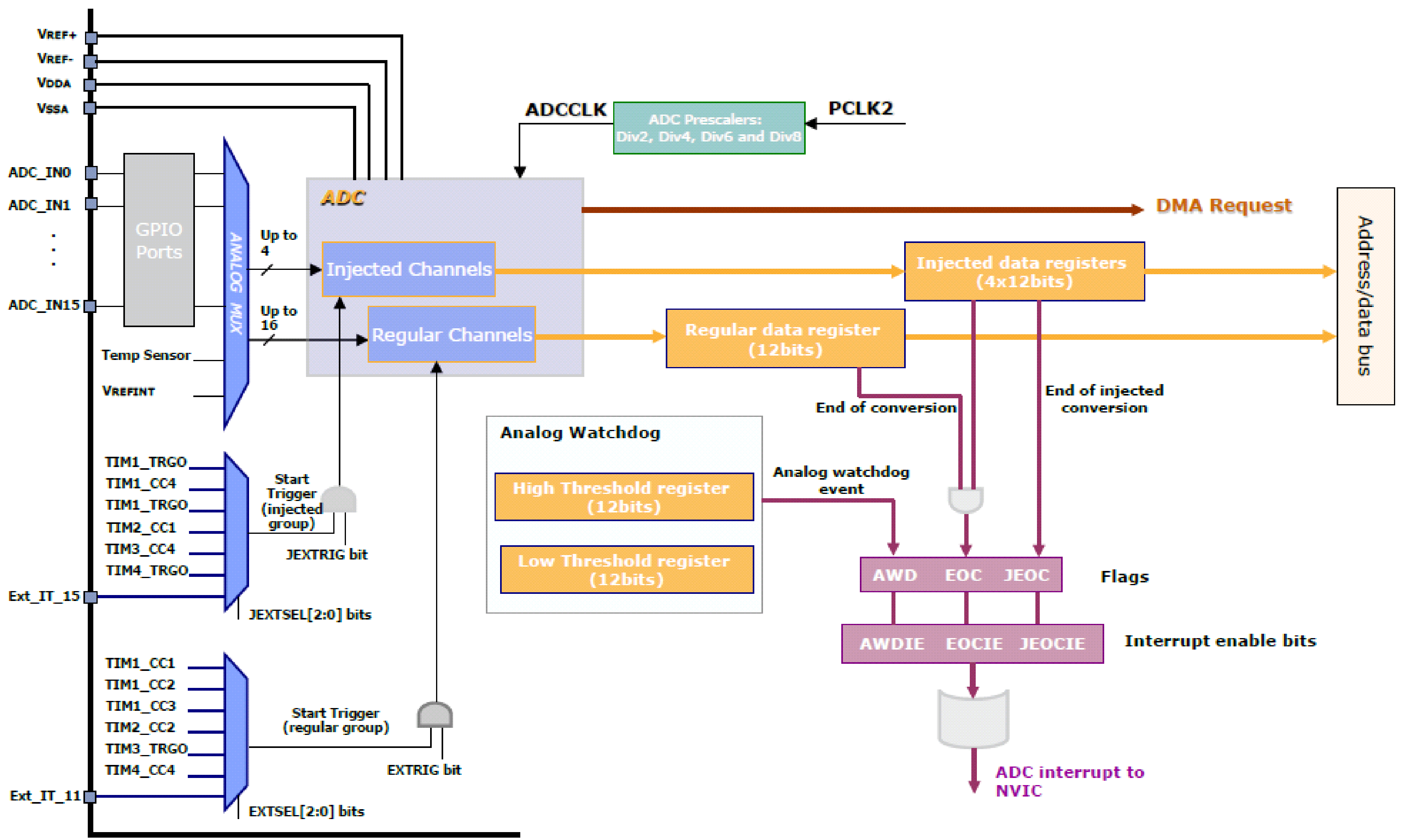
ADC Features

- Left or right Data alignment with inbuilt data coherency
- Analog watchdog on high and low thresholds
- Interrupt generation on:
  - End of conversion
  - End of Injected Conversion
  - Analog Watchdog
- DMA capability (only on ADC1)

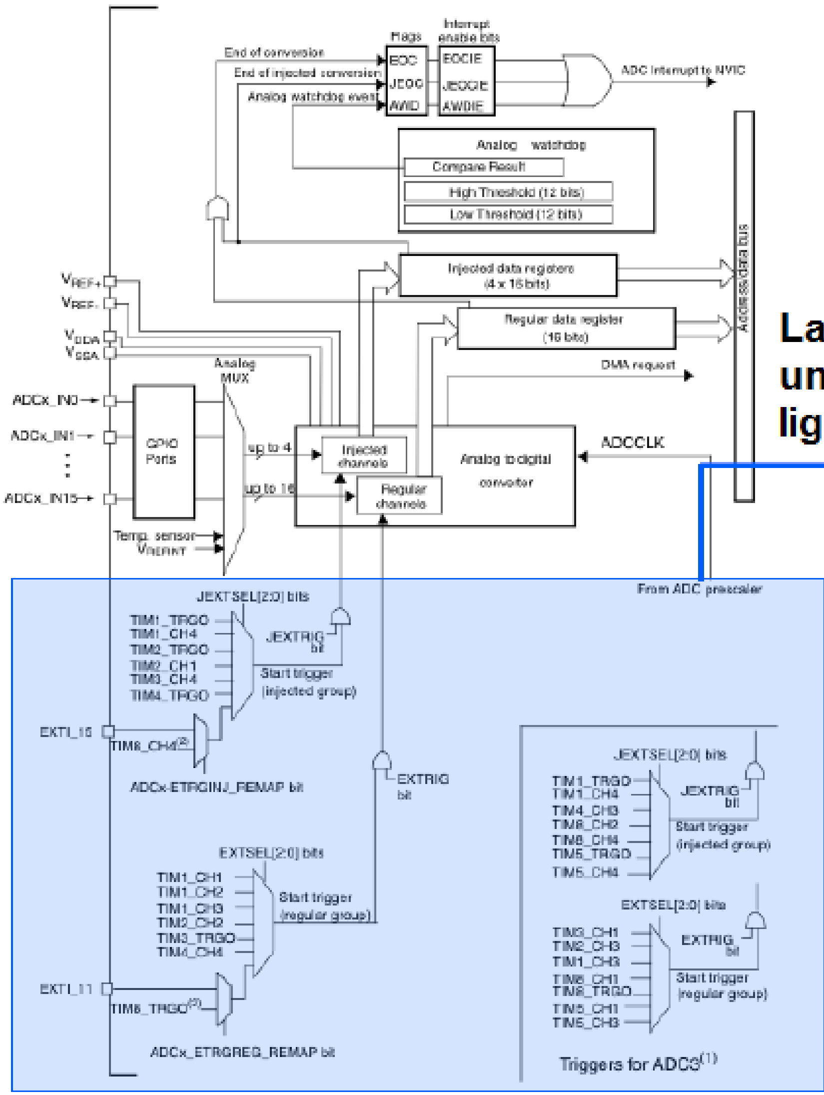
ADC regular Channels group

- Programmable number of regular channels: up to 16 channels
- Programmable sample time and conversion sequence
- Conversion started by
- Software through start bit
- External trigger generated by
  - Timer1 CC1
  - Timer1 CC2
  - Timer1 CC3
  - Timer2 CC2
  - Timer3 TRGO
  - Timer4 CC4
  - EXTI Line11

ADC Block Diagram



ADC_ExternalTrigConv



La conversion peut être déclenchée par un événement extérieur (Timer capture, la ligne EXIT)

ADC Clock and Pins

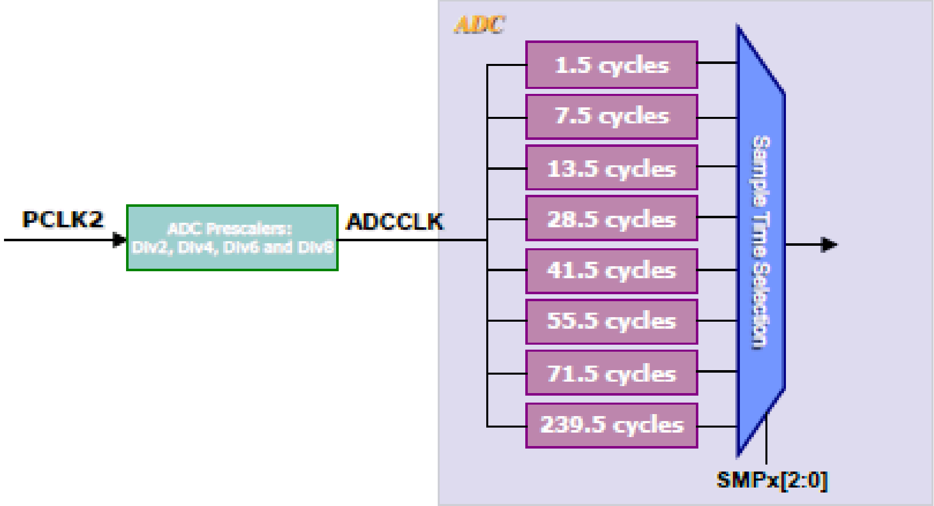
- The ADC features two clock schemes:
  - Clock for the analog circuitry: ADCCLK, common to all ADCs
    - This clock is generated from the APB2 clock divided by a programmable prescaler that allows the ADC to work at fPCLK2/2, /4, /6 or /8. Refer to the datasheets for the maximum value of ADCCLK.
  - Clock for the digital interface (used for registers read/write access)
    - This clock is equal to the APB2 clock. The digital interface clock can be enabled/disabled individually for each ADC through the RCC APB2 peripheral clock enable register (RCC_APB2ENR).

ADC pins

Name	Signal type	Remarks
V_{REF+}	Input, analog reference positive	The higher/positive reference voltage for the ADC, $1.8\ V \leq V_{REF+} \leq V_{DDA}$
V_{DDA}	Input, analog supply	Analog power supply equal to V_{DD} and $2.4\ V \leq V_{DDA} \leq V_{DD}$ (3.6 V) for full speed $1.8\ V \leq V_{DDA} \leq V_{DD}$ (3.6 V) for reduced speed
V_{REF-}	Input, analog reference negative	The lower/negative reference voltage for the ADC, $V_{REF-} = V_{SSA}$
V_{SSA}	Input, analog supply ground	Ground for analog power supply equal to V_{SS}
ADCx_IN[15:0]	Analog input signals	16 analog input channels

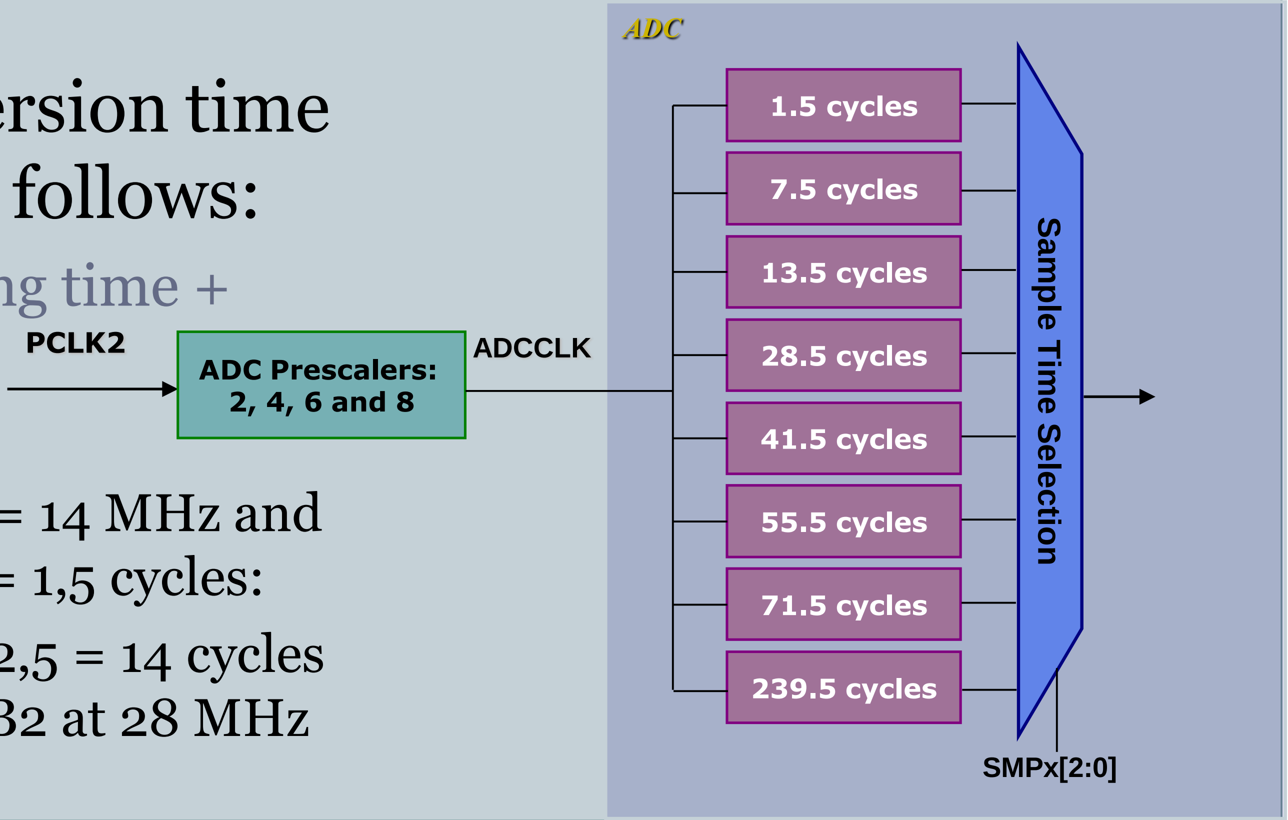
Analog Sample Time

- ADCCLK, up to 14MHz, taken from PCLK2 through a prescaler (Div2, Div4, Div6 and Div8)
- Three bits programmable sample time cycles for each channel:
  - 1.5 cycles
  - 7.5 cycles
  - 13.5 cycles
  - 28.5 cycles
  - 41.5 cycles
  - 55.5 cycles
  - 71.5 cycles
  - 239.5 cycles



ADC Sampling

- Each channel can be sampled with a different sampling time.
- The total conversion time is calculated as follows:
  - Tconv = Sampling time + 12,5 cycles
    - Example:
    - With ADCCLK = 14 MHz and sampling time = 1,5 cycles:
    - Tconv = 1,5 + 12,5 = 14 cycles = 1 µs with APB2 at 28 MHz

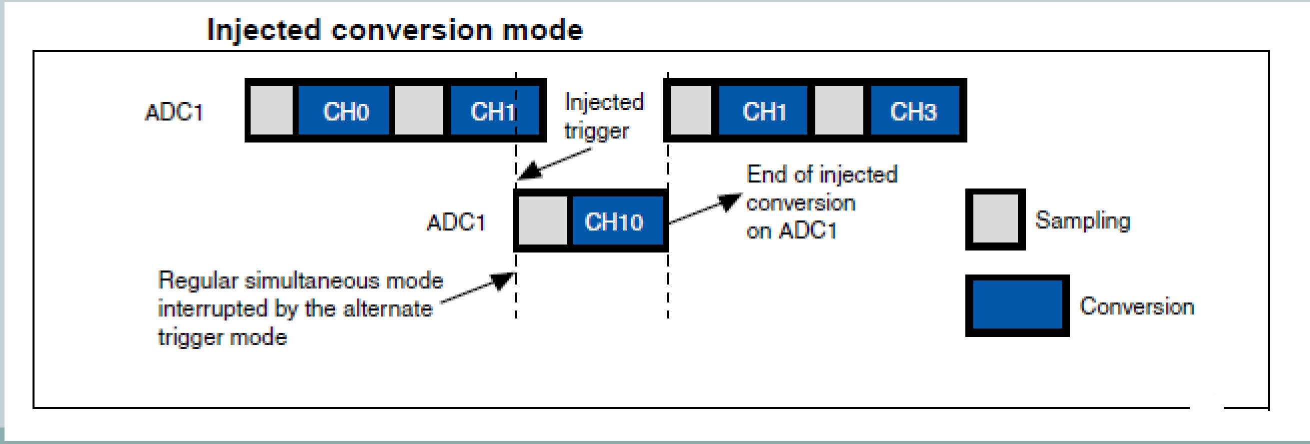


Channels selection

- There are 16 multiplexed channels. It is possible to organize the conversions in two groups: regular and injected.
- A group consists of a sequence of conversions
  - can be done on any channel
  - And in any order.
    - Example: implement the conversion sequence in the following order: ADC_IN3, ADC_IN8, ADC_IN2, ADC_IN2, ADC_IN0, ADC_IN2, ADC_IN2, ADC_IN15.
- Two groups
  - A regular group
    - up to 16 conversions.
    - The regular channels and their order in the conversion sequence must be selected in the ADC_SQRx registers.
    - Thetotal number of conversions in the regular group must be written in the L[3:0] bits in the ADC_SQR1 register.
  - An injected group
    - up to 4 conversions.
    - The injected channels and their order in the conversion sequence must be selected in the ADC_JSQR register

Conversion modes : Regular/injected

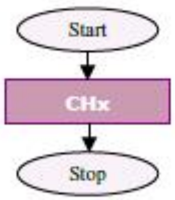
- Regular mode
  - used to see in many types of microcontroller
  - all channels share same data register.
  - Various regular modes can be possible, like single, continuous and group.
  - More interesting here is group conversion where channels are specified to convert in round robin mode – cycle through channels.
  - collect data from register in time
    - through conversion complete interrupt or using DMA.
- Injected conversion mode
  - Injected group can perform conversion of selected four channels.
  - Simply speaking injected group have a priority over normal conversion group scan.



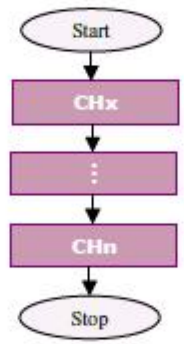
ADC modes (1)

- **Independent modes**
  - **Single conversion mode**
    - **Single-channel**
    - **Multichannel (scan)**
  - **Continuous conversion mode**
    - **Single-channel**
    - **Multichannel (scan)**
      - **Regular channels**
        - **Same register**
        - **→ save iterrupts or DMA**
      - **Injected channels**
  - **Discontinuous mode (Multichannel) :**
    - In discontinuous mode parts of group can be triggered to convert. For instance if we select group to be 16 channels then we can program to convert first 3 channels on trigger, then wait for another trigger and convert next three channels and so on.
  - **Fast conversion mode**
- **Multi ADC mode**

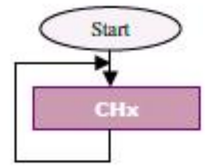
ADC modes (2)



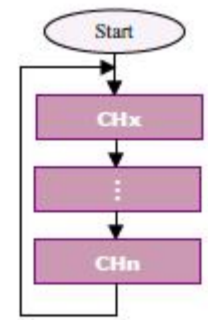
Single channel single conversion mode



Multi-channels (Scan) single conversion mode



Single channel continuous conversion mode



Multi-channels (Scan) continuous conversion mode

Applications:

- **Single Channel**
  - **Single conversion mode**
    - This mode can be used for the measurement of a voltage level to decide if the system can be started or not. Measure the voltage level of the battery before starting the system: if the battery has a low level, the “low battery” message appears. In this case, do not start the system.
  - **Continuous conversion mode**
    - This ADC mode can be implemented to monitor a battery voltage, the measurement and regulation of an oven temperature, etc. In the case of the oven temperature regulation, the temperature is read and compared to the temperature set by the user. When the oven temperature reaches the desired temperature, the heating resistor is powered off.

- **Multichannel,**
  - **single conversion mode**
    - This mode can also be used to make single measurements of multiple signal levels (voltage, pressure, temperature, etc.) to decide if the system can be started or not in order to protect the people and equipment.
  - **Continuous conversion mode**
    - This mode can be used to monitor multiple voltages and temperatures in a multiple battery charger. The voltage and temperature of each battery are read during the charging process. When the voltage or the temperature reaches the maximum level, the corresponding battery should be disconnected from the charger.

How to use the STM32 ADC driver

- 1. Enable the ADC interface clock using
  - RCC_APB2PeriphClockCmd(RCC_APB2Periph_ADCx, ENABLE);

- 2. ADC pins configuration
  - Enable the clock for the ADC GPIOs using the following function:
    - RCC_AHB1PeriphClockCmd(RCC_AHB1Periph_GPIOx, ENABLE);
  - Configure these ADC pins in analog mode using GPIO_Init();
- 3. Configure the ADC Prescaler, conversion resolution and data alignment using the ADC_Init() function.
- 4. Activate the ADC peripheral using ADC_Cmd() function.

Regular channels group configuration

- To configure the ADC regular channels group features, use
  - ADC_Init() and ADC_RegularChannelConfig() functions.
- To read the ADC converted values, use the
  - ADC_GetConversionValue() function.

Injected channels group configuration

- To configure the ADC Injected channels group features, use
  - ADC_InjectedChannelConfig() function and
  - ADC_InjectedSequencerLengthConfig() function.
- To read the ADC converted values, use the
  - ADC_GetInjectedConversionValue() function.

ADC Lab

- Objective: detect temperature using a temperature sensor LM35 and print it using 7segment circuit