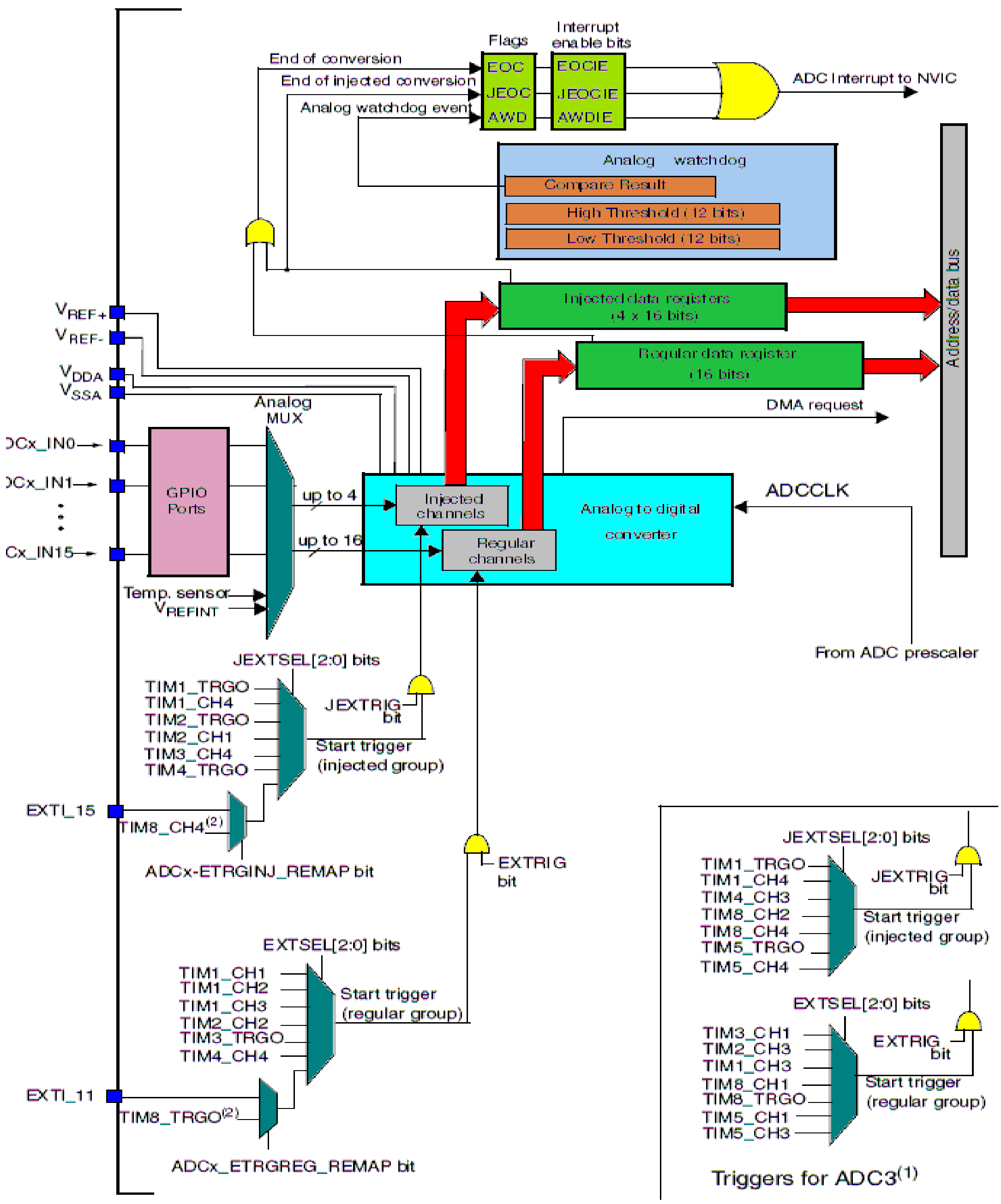
STM32 ADC

Most of us who have experienced 8-bit MCUs previously know how much important it is to have an ***Analogue-to-Digital Converter (ADC)*** built-in with a microcontroller. Apart from other hardware extensions unavailable in the early era microcontrollers, many former 8051 microcontroller users shifted primarily to more robust Atmel AVRs and Microchip PICs just for this important peripheral. I don't feel it necessary to restate the advantages of having such a peripheral embedded in a micro. In traditional 8-bit MCUs aforementioned, the ADC block is somewhat incomplete and users have to work out tricky methods to solve certain problems. The ADC block of STM32 micros is one of the most advanced and sophisticated element to deal with in the entire STM32 arena. There are way too many options for this block in a STM32 micro. In this issue, we will explore this block.



A Simplified Overview of STM32's ADC Block

The block diagram shown above might look a bit complex at first but it still worth having a look. It shows us the interfaces that are related to the ADC block and some key features. It seems that some external interrupt pins and internal timer peripherals have some kind of relation with the ADC block. Well these hardware peripherals can trigger ADC conversion. The more we go forward, the more we explore. In short I would like to point out some key features of a typical STM32 ADC:

- 12-bit successive approximation ADC.
- Maximum ADC conversion rate is 1MHz and more than 2MHz in some STM32 families.
- A/D conversion range: 0 – 3.6V DC.
- ADC power supply operating range: 2.4V – 3.6V DC.
- ADC input range: $V_{Ref-} \leq V_{In} \leq V_{Ref+}$ (V_{Ref-} and V_{Ref+} pins are available only in some devices and packages).
- Different modes of operation available for different measurement cases.
- Dual mode conversion on devices with at least 2 ADC units. Some devices have more than 2 ADCs.
- An integrated ADC sequencer ranks channels according to order.
- Channel-by-channel sample time programmability. Having this feature is an advantage because we can set different sampling time for different channels and the ADC block need not to be stopped for making such changes.
- Several external input channels are available. 10 external channels in STM32F103C8T6.
- Two internal ADC channels available with ADC1 (aka. *Master ADC*). These channels are connected to an internal band gap voltage reference source and an on-chip temperature sensor.
- An Analogue Watchdog (AWD) unit can detect if an ADC channel(s) is operating within a predefined ADC count window.
- DMA-based fast data transferability.
- Several hardware interrupts are available to flag important events.

The Basics of the STM32 ADC Block

The words *mode* and *conversion* in STM32 documentations are somewhat ambiguous unless you get them straight.

Down to the basics, there are two modes of operation primarily. These are:

- ***Independent mode.***
  It is just as the typical ADC use. Each ADC unit is operating on its own and without any mutual dependency.
- ***Dual mode.***
  In this mode two ADCs are converted simultaneously or with some (literally negligible) delay. Two ADC units mutually working together as if they are a single unit.

A/D conversion can be:

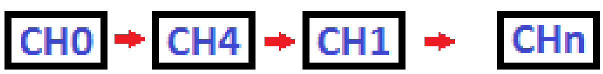
- ***Single Conversion.***
  One sample conversion at a given instant.
- ***Continuous Conversion.***
  Non-stop sample collection and conversion.
- ***Discontinuous Conversion.***
  Sequential conversion of some channels in a group.
- ***Scan Conversion.***
  Sequential sampling and converting of an array of channels one after another.

To start A/D conversion, an ADC unit needs to be stimulated with a trigger signal:

- ***Software Trigger.***
  A/D conversion as per demand from coded program.
- ***Hardware Trigger.***
  A/D conversion as per hardware events like external interrupts or timer events.

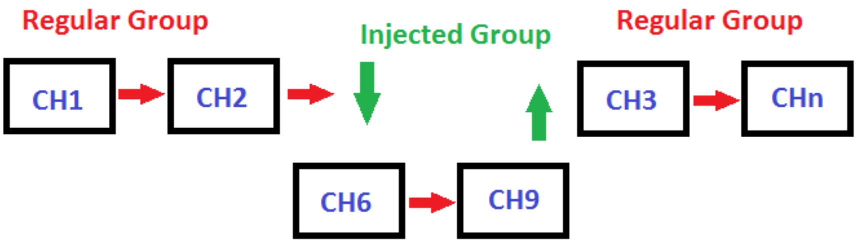
A/D conversions are done in groups. Group members are ADC channels and need not to be multiple channels. A group may consist of only one channel. Within these groups ADC channels are converted on a scheduled round-robin basis. The good stuff is the fact that unlike most micros we can program which channels belong in a group and with which sequence the A/D conversion is commenced. We can also set the sampling time for each channel separately. ADC groups can be categorized as follows:

- ***Regular Group.***
  A given fixed group of ADC channels are regularly converted. Up to 16 channels can be present in a regular group. A regular group is similar to a code running in the main loop.



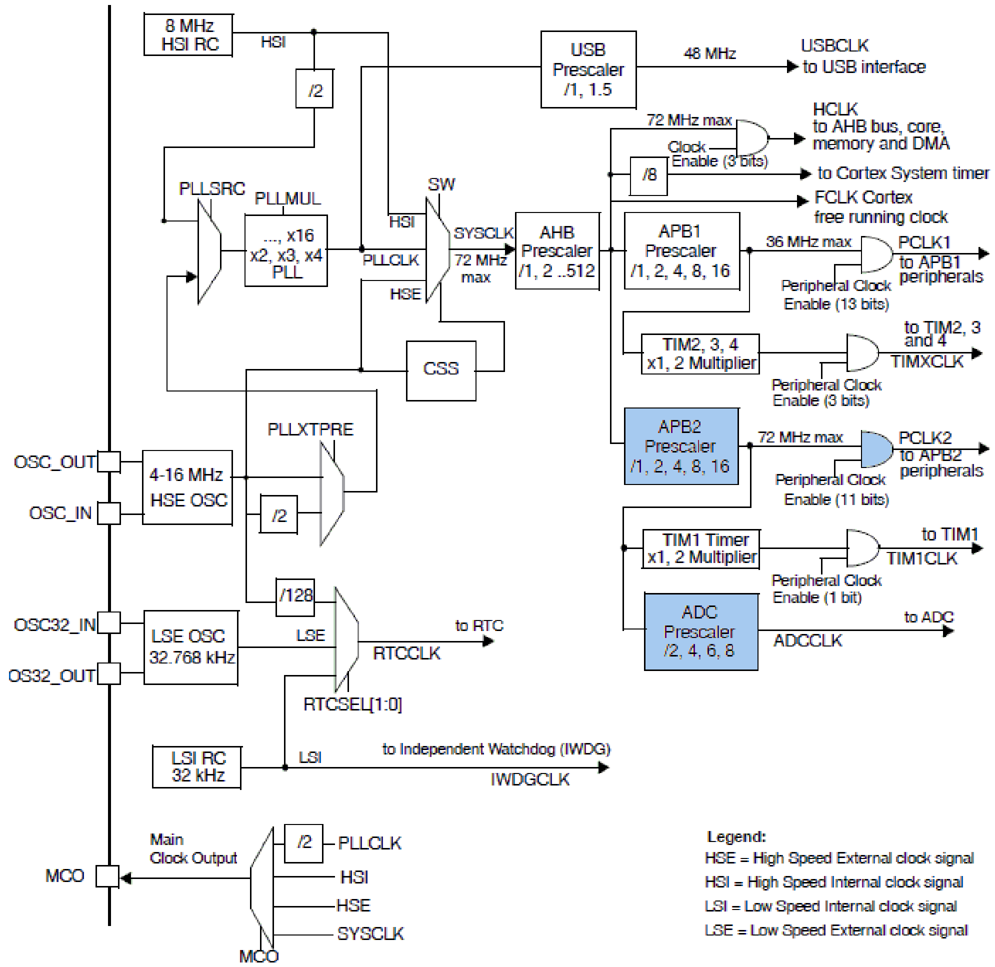
Regular Group Conversion

- ***Injected Group.***
  This group can interrupt a regular group conversion as it has a higher priority over the former. Up to 4 channels can be present in an injected group. When an injected group is present or injected over a regular group, all regular group conversions are halted temporarily. The injected group is processed first and then the regular groups are resumed. An injected group is analogous to having an interrupt over a running code. Alone without a regular group present, an injected group will behave like a regular group.



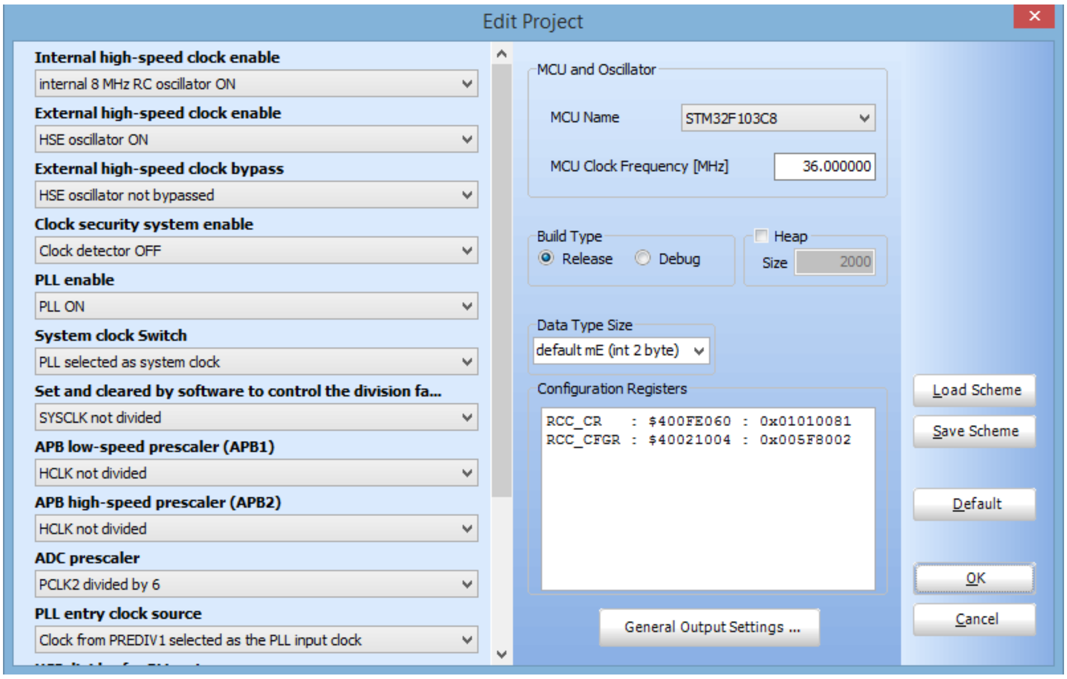
ADC Clock

Shown below is the STM32F10x clock tree. Notice some areas are highlighted. Check them out because these are related to the ADC block.

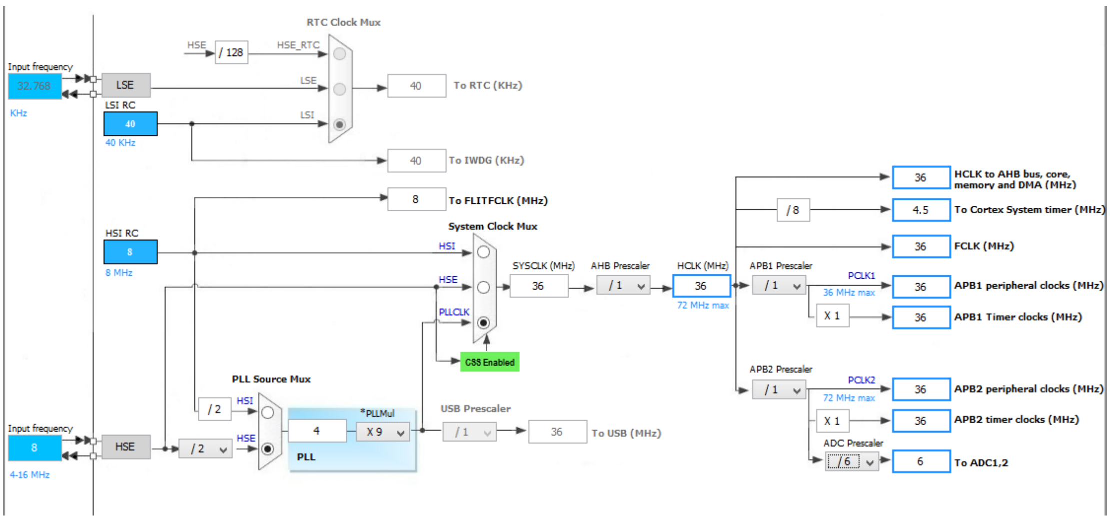


We can clearly see that the ADC peripheral is connected to the APB2 peripheral bus. If you can recall from my earlier post on STM32's clock options then you'll remember that APB2 can run at 72MHz speed which is by the way the maximum operating speed for STM32F10x series MCUs. ST recommends that the ADC be feed with no more than a 14MHz clock. Thus we should make sure that ADC clock is in the range of 600 kHz to 14MHz. Since it takes about 14 cycles to process ADC data the maximum possible number of conversions per second is one million.

I previously pointed out in one of my posts that MikroC's IDE provided an easy to use tool to configure clocks for various STM32 peripheral buses. I recommend using this tool to configure peripheral clocks rather than coding them on your own. Pay attention particularly to APB1, APB2 and PCLK2 clocks when setting clock for the ADC block. Wrong settings will lead to unpredictable/erratic behaviours.



Additionally you can use STM32CubeMX to verify if your clock configuration is okay. You can also use this software to check which I/O pins belong to which ADC channels and much more. However be aware, STM32CubeMX is not yet compatible with MikroC compiler. Personally I rarely use it.



The ADC Registers

There are several registers associated with each ADC unit. At first you may feel like getting lost in an ocean of 32-bit registers. However things aren't so. Of these there are two ADC control registers called ***ADC_CR1*** and ***ADC_CR2*** that set ADC properties and mode of operation. There's a status register, ***ADC_SR*** which flags important ADC events like end of a conversion, etc. These are the most important ones. I'm not going to explain every bit because they are well explained in the reference manual.

Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ADC_SR	Reserved																											STRT	JSTRT	JEOC	EOC	AWD
Reset value																												0	0	0	0	0
ADC_CR1	Reserved								AWDEN	JAWDEN	Reserved		DUALMOD [3:0]				DISC NUM [2:0]			JDISCEN	DISCEN	JAUTO	AWD SGL	SCAN	JEOC IE	AWDIE	EOCIE	AWDCH[4:0]				
Reset value									0	0			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ADC_CR2	Reserved								TSVREFE	SWSTART	JSWSTART	EXTTRIG	EXTSEL [2:0]			Reserved	JEXTTRIG	JEXTSEL [2:0]			ALIGN	Reserved		DMA	Reserved				RSTCAL	CAL	CONT	ADON
Reset value									0	0	0	0	0	0	0		0	0	0	0	0			0					0	0	0	0

The next set of registers are responsible for specifying channel sequence, sequence length, sampling times, offset and holding ADC conversion results. While dealing with the STM32 ADC block, you'll come across the letter ***J*** before many stuffs. These stuffs signify that they are related to in***J***ected group channels only. The rest of the stuffs are mostly related to regular groups and common uses.

ADC_SQRx registers specify channel sequences. There are three of these registers and of them ***ADC_SQR1*** also specifies the number of channels in a regular sequence. ***ADC_SQR3*** through ***ADC_SQR1*** are sequentially feed with channel numbers according to position in a given sequence. The injected group equivalent of the ***ADC_SQRx*** is the single ***ADC_JSQR*** register.

ADC_SMPR1 and ***ADC_SMPR2*** registers specify the sampling times of each channel. The sampling time is common to both regular and injected groups.

ADC_LTR and ***ADC_HTR*** registers hold the lower and upper analogue watchdog ADC count limits respectively. Again these are common for both groups.

ADC_JOFRx registers hold offset values for injected channels. The values in them are automatically subtracted from injected channel ADC conversion results.

Lastly the ***ADC_DR*** and ***ADC_JDRx*** registers hold ADC conversion results for regular and injected groups respectively. ***ADC_DR*** is common for all regular group channels. There are four ***ADC_JDRx*** registers for four injected channels. Recall that there can be up to four ADC channels for an injected group.

When coding there's no need to follow any specific sequence for programming registers. Just make sure you coded for the required ones correctly.

My Version of Standard Peripheral Library

Unlike any of my previous posts on STM32, I'm moving a bit faster toward coding section rather than giving detailed explanations at all steps. To fully realize the ADC block's various functionalities you need to code and experience it right after you have understood it. As I stated earlier, this block is a very complex one. It was not possible for me to give examples of every possible combination of operating modes. I'm here presenting only the basics needed to get started with STM32's ADC. I would highly recommend readers to read this document from ST:
http://www.st.com/web/en/resource/technical/document/application_note/CD00258017.pdf
and read the reference manual for STM32F10x series for more details. Even after all these, this is a mega post. None of my previous posts on STM32 is so long.

We all know that when it comes to handling 32-bit registers of 32-bit micros, programming turns into tiles of a tricky puzzle. Another big headache for programmers is the coding of registers with numeric jargons. I don't know for sure if it is for these reasons or for some others that most STM32 users are SPL dependent. Almost no one codes STM32s at raw level.

MikroC compiler simplifies things a lot of stuffs in several areas. It is easy to get started with it no matter if you are an expert or a novice. Personally I like MikroC compiler more than any other compiler for several reasons. I didn't want to change it when I planned to play with STM32-based ARM micros. When I finally chose MikroC for ARM over other more popular and widely used compilers like Keil and Coocox, I was aware of SPL's advantages and what I would go through next for selecting so. I wondered how to get rid of handling 32-bit registers effectively and at the same time develop a strategy to avoid memorizing the functional uses and names of different registers. I was looking for something similar to SPL that can be easily integrated with MikroC compiler. Personally I don't like to use ST's SPL and so I coded my version of SPL. From now on I'll be sharing my version of SPL codes with my posts. I recommend readers to check them out before using them.

Just for demo, check out my basic library for GPIO configuration:

```c
//I/O Modes

#define input_mode                          0x00
#define output_mode_low_speed               0x02
#define output_mode_medium_speed            0x01
#define output_mode_high_speed              0x03

//I/O Configurations

#define GPIO_PP_output                      0x00
#define GPIO_open_drain_output              0x04
#define AFIO_PP_output                      0x08
#define AFIO_open_drain_output              0x0C

#define analog_input                        0x00
#define floating_input                      0x04
#define input_without_pull_resistors        0x04
#define digital_input                       0x08

//Pull Resistor Configurations

#define pull_down                           0x00
#define pull_up                             0x01

//Miscellaneous

#define enable                              0x01
#define disable                             0x00

//CR Register Configuration Macro

#define pin_configure_low(reg, pin_no, io_type)     do{reg &= (~(0xF << (pin_no << 2))); reg |= (io_type << (pin_no << 2));}while(0)
#define pin_configure_high(reg, pin_no, io_type)    do{reg &= (~(0xF << ((pin_no - 8) << 2))); reg |= (io_type << ((pin_no - 8) << 2));}while(0)

//Bitwise Operations for GPIOs

#define bit_set(reg, bit_value)             (reg |= (1 << bit_value))
#define bit_clr(reg, bit_value)             (reg &= (~(1 << bit_value)))
#define get_bits(reg, mask)                 (reg & mask)
#define get_input(reg, bit_value)           (reg & (1 << bit_value))

//Pull Resistor Functions

#define pull_up_enable(reg, pin_no)         (reg |= (1 << pin_no))
#define pull_down_enable(reg, pin_no)       (reg &= (~(1 << pin_no)))

//GPIO Enabling Functions

#define enable_GPIOA(mode)                  RCC_APB2ENRbits.IOPAEN = mode
#define enable_GPIOB(mode)                  RCC_APB2ENRbits.IOPBEN = mode
#define enable_GPIOC(mode)                  RCC_APB2ENRbits.IOPCEN = mode
#define enable_GPIOD(mode)                  RCC_APB2ENRbits.IOPDEN = mode
#define enable_GPIOE(mode)                  RCC_APB2ENRbits.IOPEEN = mode
#define enable_GPIOF(mode)                  RCC_APB2ENRbits.IOPFEN = mode
#define enable_GPIOG(mode)                  RCC_APB2ENRbits.IOPGEN = mode
```

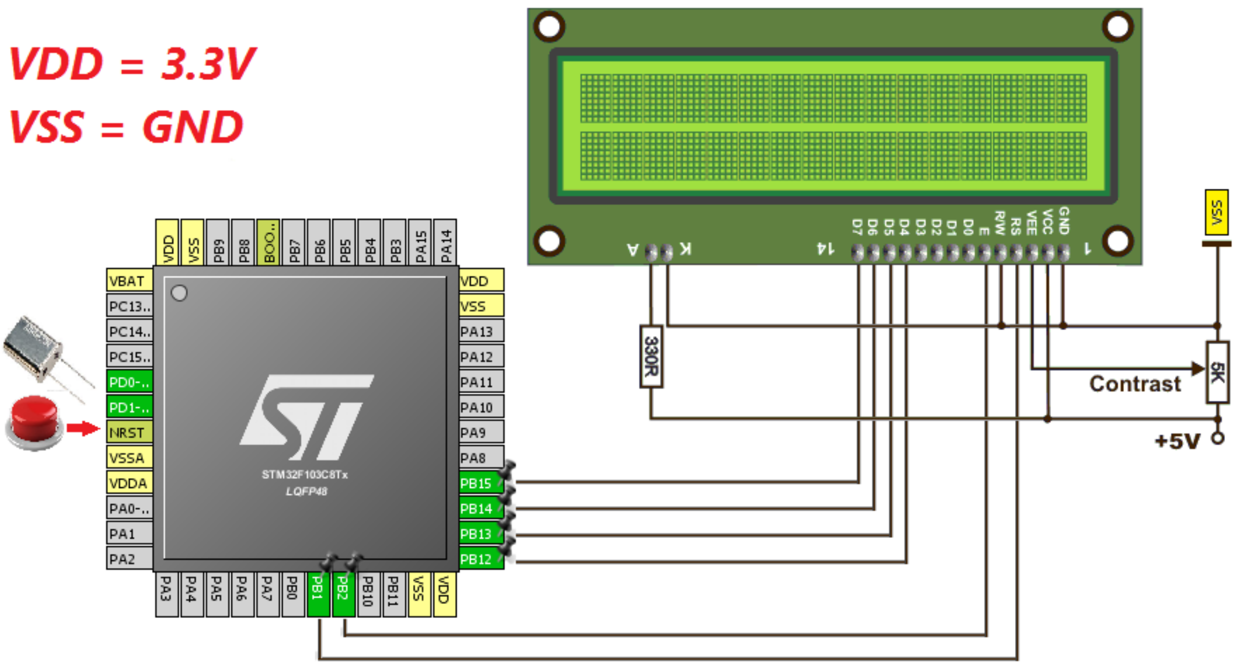
Now suppose you want to configure GPIO pins with this library. You can do so like this:

```
pin_configure_low(GPIOA_CRL, 6, (analog_input | input_mode));
pin_configure_high(GPIOB_CRH, 15, (GPIO_PP_output | output_mode_low_speed));
```

Now you can see that you don't need to handle 32-bit registers, bit positions and possible combinations of bit values. In fact sometimes you won't have remember the names of registers at all. All of these things are replaced with something more meaningful and easy to understand. Unlike ST's SPL you don't even have to be a programming wiz to use these libraries. Please check the header files for better understanding. At this point I must specify that I single headedly developed this idea and the libraries themselves. It took several months to develop, code, test and implement them. I tried my level best to keep things error-free and as per reference manuals. There could be some unintentional flaws in them. Should you spot one please notify me for correction.

Coding and Explanations

The more we code, the better picture we'll get about the STM32's ADC. At some point, you'll feel that the codes are self-explanatory. For demo purposes I used a STM32F103C8T6 micro embedded in a cheap STM32 test board. The basic connection looks like this:



All of the stuffs above except the connections for the ADC inputs and the LCD exist in most development boards. ADC pins are typically attached with GPIOA port.

MikroC ADC Library

Obviously the first example is based on MikroC's ADC library. MikroC compiler provided an easy to use ADC library. With this library you can do basic ADC readings and set up ADC units easily with minimum coding. MikroC's built-in ADC library functions are as follows:

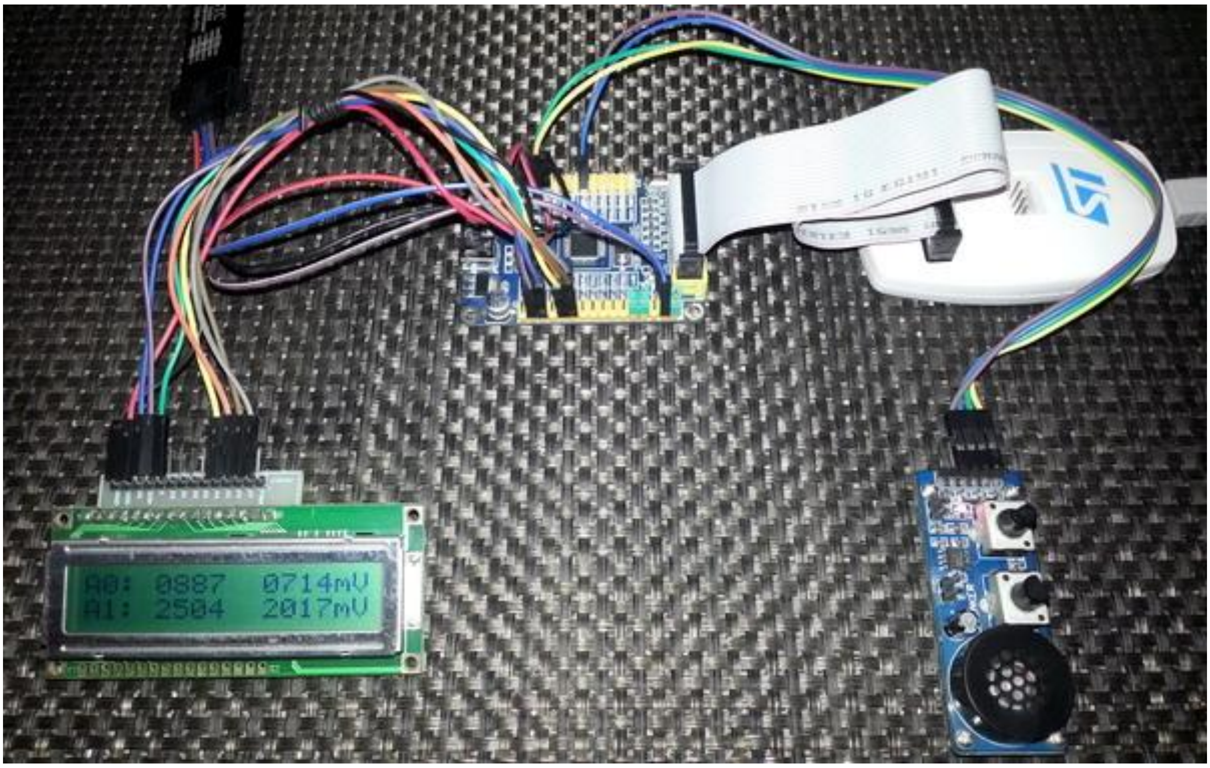
- *ADCx_Init*
- *ADCx_Init_Advanced*
- *ADC_Set_Input_Channel*
- *ADCx_Get_Sample*
- *ADCx_Read*

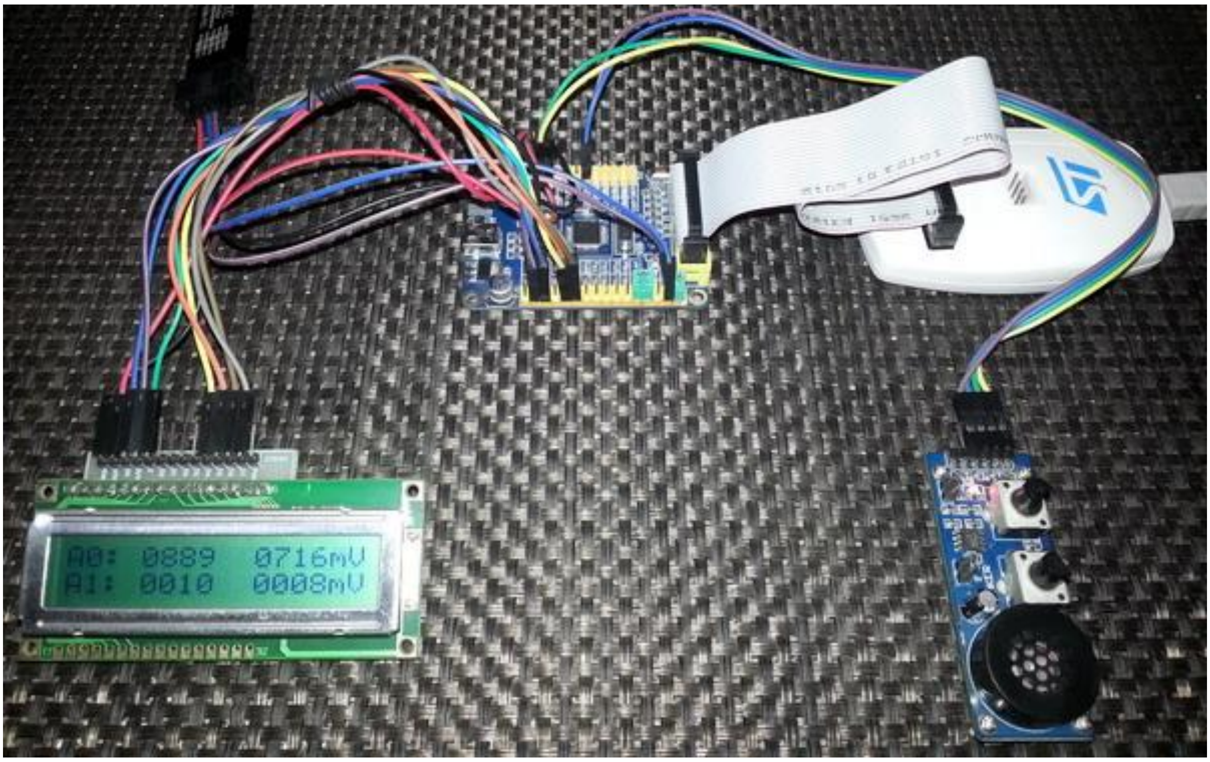
MikroC IDE's help section explains the purpose of these function.

```
sbit LCD_RS at GPIOB_ODR.B1;
sbit LCD_EN at GPIOB_ODR.B2;
sbit LCD_D4 at GPIOB_ODR.B12;
sbit LCD_D5 at GPIOB_ODR.B13;
sbit LCD_D6 at GPIOB_ODR.B14;
sbit LCD_D7 at GPIOB_ODR.B15;

void setup();
unsigned int adc_avg(unsigned char no_of_samples, unsigned char channel);
void lcd_print(unsigned char x_pos, unsigned char y_pos, unsigned int value);
float map(float v, float x_min, float x_max, float y_min, float y_max);

void main()
{
   unsigned char s = 0;
   register unsigned int adc_data = 0;
   float v = 0.0;

   setup();

   while(1)
   {
      for(s = 0; s <= 1; s++)
      {
           adc_data = adc_avg(10, s);
           v = map(adc_data, 0, 4095, 0, 3300);
           lcd_print(5, (s + 1), adc_data);
           lcd_print(11, (s + 1), v);
      }

      GPIOC_ODRbits.ODR13 ^= 1;
      delay_ms(600);
   };
}

void setup()
{
   GPIO_Clk_Enable(&GPIOA_BASE);
```

```
    GPIO_Clk_Enable(&GPIOB_BASE);
    GPIO_Clk_Enable(&GPIOC_BASE);
    GPIO_Config(&GPIOA_BASE, (_GPIO_PINMASK_0 | _GPIO_PINMASK_1), (_GPIO_CFG_MODE_ANALOG |
_GPIO_CFG_PULL_NO));
    GPIO_Config(&GPIOC_BASE, _GPIO_PINMASK_13, (_GPIO_CFG_MODE_OUTPUT | _GPIO_CFG_SPEED_MAX |
_GPIO_CFG_OTYPE_PP));

    ADC1_init();
    LCD_Init();
    LCD_Cmd(_LCD_CLEAR);
    LCD_Cmd(_LCD_CURSOR_OFF);

    lcd_out(1, 1, "A0:");
    lcd_out(2, 1, "A1:");
    lcd_out(1, 15, "mV");
    lcd_out(2, 15, "mV");
}

unsigned int adc_avg(unsigned char no_of_samples, unsigned char channel)
{
     unsigned long avg = 0;
     unsigned char samples = no_of_samples;

     while(samples > 0)
     {
        avg += ADC1_Get_Sample(channel);
        samples--;
     }
     avg /= no_of_samples;

     return avg;
}

void lcd_print(unsigned char x_pos, unsigned char y_pos, unsigned int value)
{
    unsigned char tmp = 0;

    tmp = (value / 1000);
    lcd_chr(y_pos, x_pos, (tmp + 48));
    tmp = ((value / 100) % 10);
    lcd_chr_cp((tmp + 48));
    tmp = ((value / 10) % 10);
    lcd_chr_cp((tmp + 48));
    tmp = (value % 10);
    lcd_chr_cp((tmp + 48));
}

float map(float v, float x_min, float x_max, float y_min, float y_max)
{
    return (y_min + (((y_max - y_min)/(x_max - x_min)) * (v - x_min)));
}
```

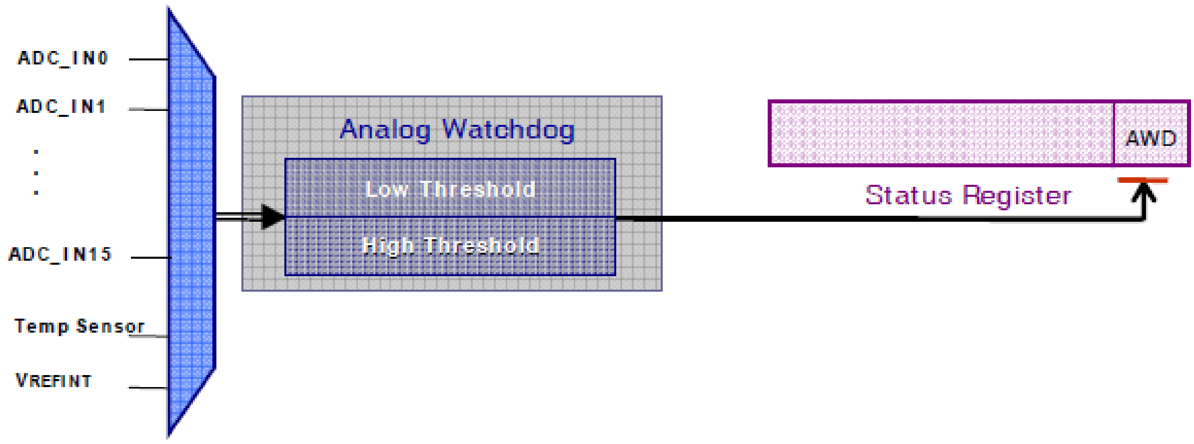
In this demo I just showed how to use MikroC's built-in ADC library functions to initialize, get average ADC counts from two ADC channels and show both ADC counts and voltage levels of each channel on a LCD display. Just a piece of cake. Not much to explain.



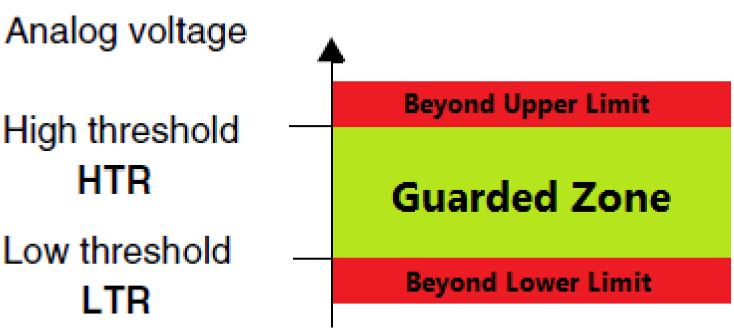


Demo video link: https://www.youtube.com/watch?v=TwMTOLkWt-Q.

One of the cool feature of STM32 micros is the ***Analogue Watchdog (AWD)*** unit. In traditional micros, a programmer needs to add an *if-else* clause to monitor if the ADC readouts are within some predefined limits. There are, therefore, some coding and resource involved. The AWD unit of STM32 micros can monitor if an ADC channel or all ADC channels are exceeding or within predefine upper and lower ADC count limits. In this way we can effectively set an analogue voltage level window for the ADC block. Thus this unit allows users to easily implement signal level monitors, zero-crossing detectors, analogue comparators and many other stuffs. Thanks to ST for hardcoding this useful feature with the ADC block.



The upper and lower limit 12-bit values are stored in the ***High Threshold (HTR) and Lower Threshold (LTR)*** registers respectively. When the analogue input to be monitored is within these limits or inside guarded zone the AWD unit stays idle. When it is the other way around, the AWD wakes up. An AWD event interrupt can be generated if the AWD interrupt is enabled.

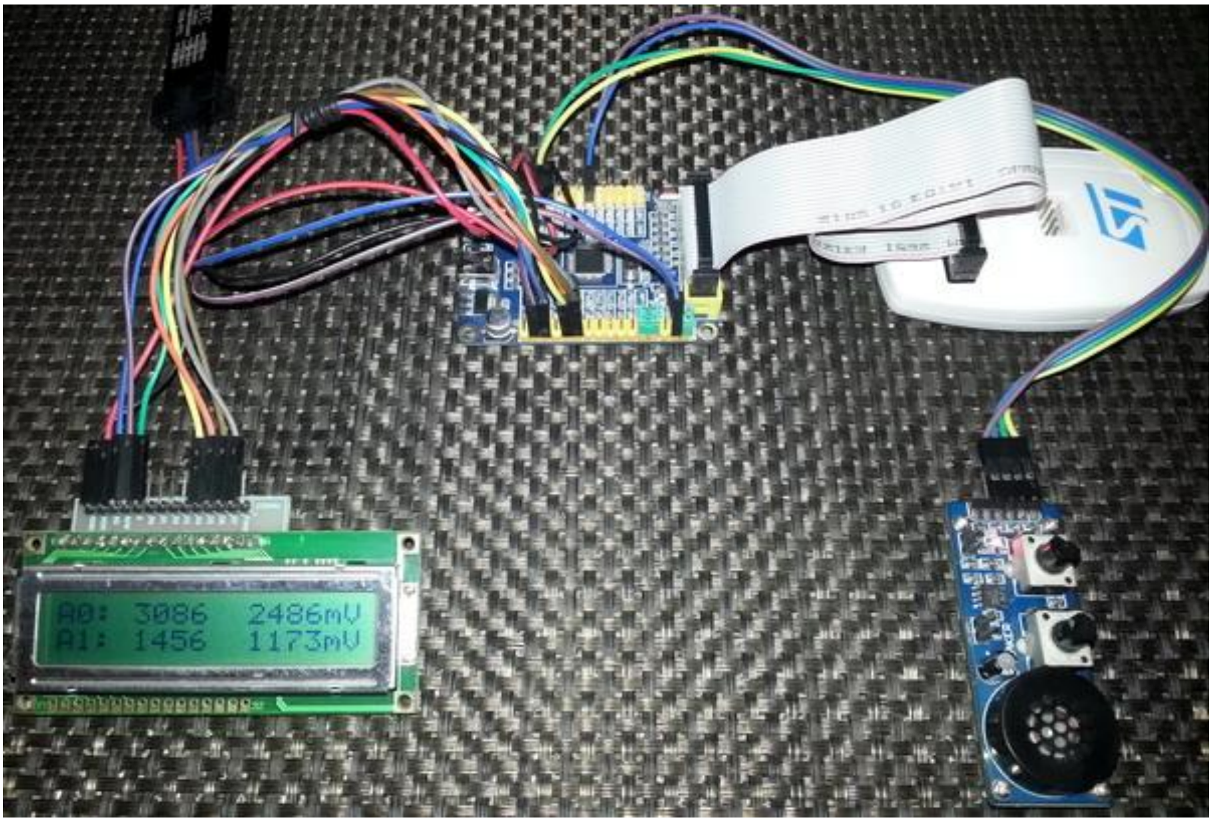


Setting ***AWDSGL bit, AWDEN bit*** and ***JAWDEN bit*** in the ***ADC_CR1*** select which channel types the AWD unit would monitor.

The demo code for AWD is just same as the previous one but this time the AWD is also used to monitor all regular ADC channels. If the ADC readings exceed the guarded zone of 400 to 3695 ADC counts, the AWD fires. This mark starts to blink a LED connected to PC13, indicating an AWD event.

```
sbit LCD_RS at GPIOB_ODR.B1;
sbit LCD_EN at GPIOB_ODR.B2;
sbit LCD_D4 at GPIOB_ODR.B12;
sbit LCD_D5 at GPIOB_ODR.B13;
sbit LCD_D6 at GPIOB_ODR.B14;
sbit LCD_D7 at GPIOB_ODR.B15;

#define high_level      3695
#define low_level        400

void setup();
unsigned int adc_avg(unsigned char no_of_samples, unsigned char channel);
void lcd_print(unsigned char x_pos, unsigned char y_pos, unsigned int value);
float map(float v, float x_min, float x_max, float y_min, float y_max);

void main()
{
   unsigned char s = 0;
   register unsigned int adc_data = 0;
   float v = 0.0;

   setup();

   while(1)
   {
      for(s = 0; s < 2; s++)
      {
           adc_data = adc_avg(20, s);
           v = map(adc_data, 0, 4095, 0, 3300);
           lcd_print(5, (s + 1), adc_data);
           lcd_print(11, (s + 1), v);
      }

      if(ADC1_SRbits.AWD == 1)
      {
         GPIOC_ODRbits.ODR13 ^= 1;
         ADC1_SRbits.AWD = 0;
      }
      else
      {
         GPIOC_ODRbits.ODR13 = 0;
      }
      delay_ms(400);
   };
}

void setup()
{
   GPIO_Clk_Enable(&GPIOA_BASE);
   GPIO_Clk_Enable(&GPIOB_BASE);
   GPIO_Clk_Enable(&GPIOC_BASE);
   GPIO_Config(&GPIOA_BASE, (_GPIO_PINMASK_0 | _GPIO_PINMASK_1), (_GPIO_CFG_MODE_ANALOG |
_GPIO_CFG_PULL_NO));
   GPIO_Config(&GPIOC_BASE, _GPIO_PINMASK_13, (_GPIO_CFG_MODE_OUTPUT | _GPIO_CFG_SPEED_MAX |
_GPIO_CFG_OTYPE_PP));

   ADC1_init();
   ADC1_LTR = low_level;
```

```
    ADC1_HTR = high_level;
    ADC1_CR1bits.AWDEN = 1;

    LCD_Init();
    LCD_Cmd(_LCD_CLEAR);
    LCD_Cmd(_LCD_CURSOR_OFF);

    lcd_out(1, 1, "A0:");
    lcd_out(2, 1, "A1:");
    lcd_out(1, 15, "mV");
    lcd_out(2, 15, "mV");
}

unsigned int adc_avg(unsigned char no_of_samples, unsigned char channel)
{
     register unsigned long avg = 0;
     unsigned char samples = no_of_samples;

     while(samples > 0)
     {
         avg += ADC1_Get_Sample(channel);
         samples--;
     }
     avg /= no_of_samples;

     return avg;
}

void lcd_print(unsigned char x_pos, unsigned char y_pos, unsigned int value)
{
     unsigned char tmp = 0;

     tmp = (value / 1000);
     lcd_chr(y_pos, x_pos, (tmp + 48));
     tmp = ((value / 100) % 10);
     lcd_chr_cp((tmp + 48));
     tmp = ((value / 10) % 10);
     lcd_chr_cp((tmp + 48));
     tmp = (value % 10);
     lcd_chr_cp((tmp + 48));
}

float map(float v, float x_min, float x_max, float y_min, float y_max)
{
    return (y_min + (((y_max - y_min)/(x_max - x_min)) * (v - x_min)));
}
```



Demo video link: https://www.youtube.com/watch?v=xMDIaEq-Q8o.

Interrupt-Driven Single Channel Continuous Conversion Mode

Many of us may overlook one feature of STM32 micros and that is no other than the presence of an on-chip temperature sensor. All STM32 micros have this sensor. Although it is not recommended for precise temperature measurements, it can be used to estimate PCB or surrounding temperatures around a STM32 micro.

The single channel continuous conversion mode is one of the most basic ADC mode. In this mode, once an ADC is triggered a single channel associated with it is continuously converted. In this demo, the single channel is the temperature sensor. The end of conversion interrupt is used to extract ADC conversion result after a conversion finishes. In this way, the CPU is not busy waiting for the ADC to finish conversion. After the end of a conversion, the entire process is repeated and this makes it continuous.

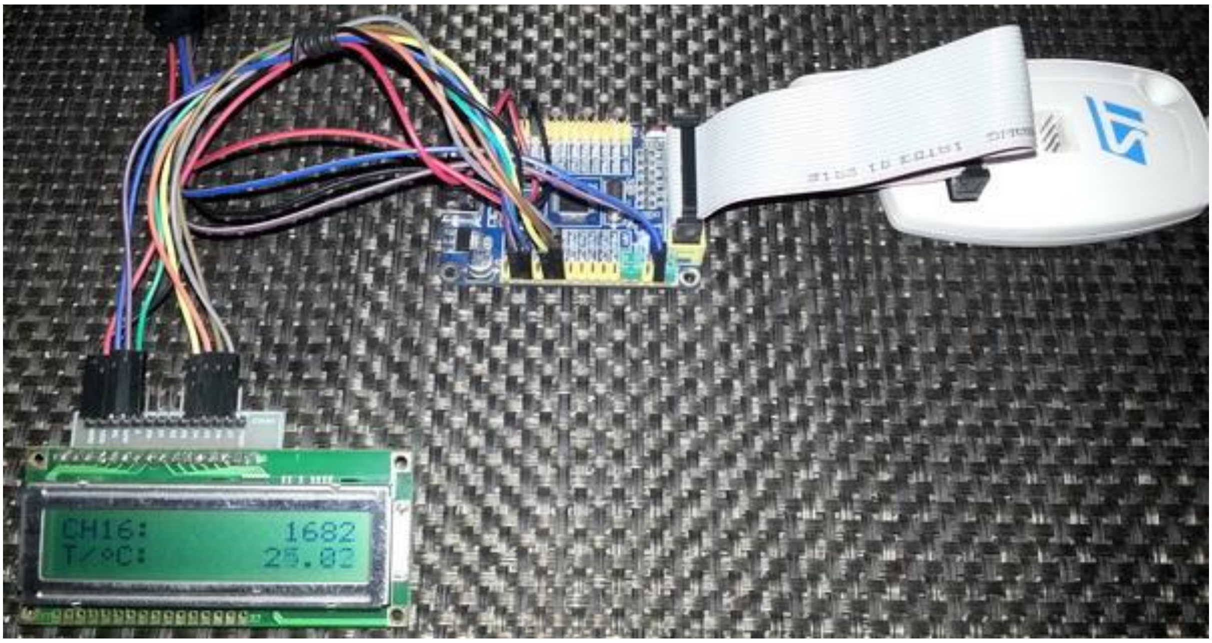
From this example onwards you'll mostly see me incorporating header file from my own SPL with my codes. Take this into account.

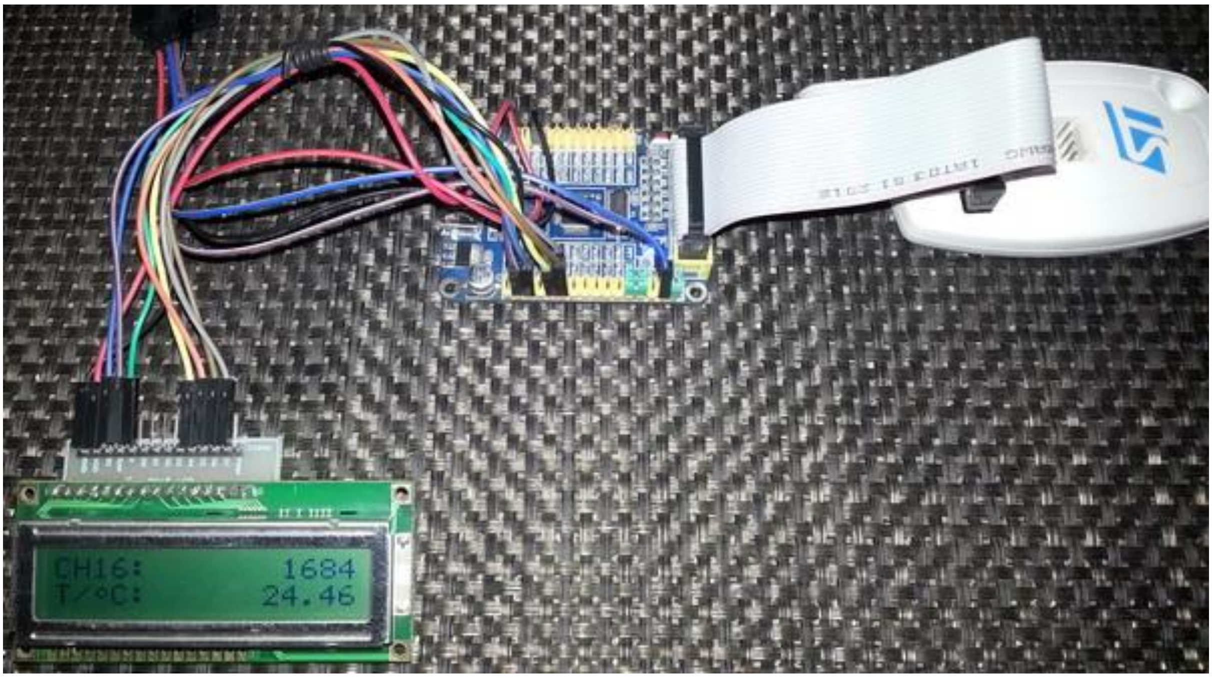
In the reference manual for STM32F10x series, there's an entire section dedicated to this temperature sensor. I suggest that you check it out first before trying to understand the code example.

```
#include "ADC.h"
#include "GPIO.h"

#define V25          1430
#define T_offset     17.5

sbit LCD_RS at GPIOB_ODR.B1;
sbit LCD_EN at GPIOB_ODR.B2;
sbit LCD_D4 at GPIOB_ODR.B12;
sbit LCD_D5 at GPIOB_ODR.B13;
sbit LCD_D6 at GPIOB_ODR.B14;
sbit LCD_D7 at GPIOB_ODR.B15;

register unsigned int adc_data = 0;

const char symbol[8] = {0x00, 0x06, 0x09, 0x09, 0x06, 0x00, 0x00, 0x00};

void setup();
void GPIO_init();
void ADC_init();
void CustomChar(unsigned char y_pos, unsigned char x_pos);
void lcd_print(unsigned char x_pos, unsigned char y_pos, unsigned int value, unsigned char disp_type);
float map(float v, float x_min, float x_max, float y_min, float y_max);

void ADC_ISR()
iv IVT_INT_ADC1_2
ics ICS_AUTO
{
    adc_data = (ADC1_DR & 0x0FFF);
    bit_set(GPIOC_ODR, 13);
```

```
}

void main()
{
    register float t = 0.0;

    setup();

    while(1)
    {
        t = map(adc_data, 0, 4095, 0, 3300);
        t = (((V25 - t) / 4.3) + 25);
        t -=  T_offset;
        t *= 100;

        if(t <= 0)
        {
            t = 0;
        }
        if(t >= 9999)
        {
            t = 9999;
        }

        lcd_print(13, 1, adc_data, 1);
        lcd_print(12, 2, t, 0);

        bit_clr(GPIOC_ODR, 13);
        delay_ms(90);
    };
}

void setup()
{
    GPIO_init();
    ADC_init();
    LCD_Init();

    LCD_Cmd(_LCD_CLEAR);
    LCD_Cmd(_LCD_CURSOR_OFF);

    lcd_out(1, 1, "CH16:");
    lcd_out(2, 1, "T/ C:");
    CustomChar(2, 3);
}

void GPIO_init()
{
     enable_GPIOB(enable);
     enable_GPIOC(enable);
     pin_configure_high(GPIOC_CRH, 13, (GPIO_PP_output | output_mode_low_speed));
}

void ADC_init()
{
     ADC1_Enable();
     clr_ADC1_settings();
     set_ADC_mode(independent_mode);
```

```
     set_ADC1_data_alignment(right_alignment);
     set_ADC1_scan_conversion_mode(disable);
     set_ADC1_continuous_conversion_mode(enable);
     set_ADC1_external_trigger_regular_conversion_edge(SWSTART_trigger);
     set_ADC1_regular_number_of_conversions(1);
     set_ADC1_sample_time(sample_time_13_5_cycles, 16);
     set_ADC1_regular_sequence(1, 16);
     set_ADC1_reference_and_temperature_sensor(enable);
     set_ADC1_regular_end_of_conversion_interrupt(enable);
     NVIC_IntEnable(IVT_INT_ADC1_2);
     EnableInterrupts;
     ADC1_calibrate();
     start_ADC1();
}

void CustomChar(unsigned char y_pos, unsigned char x_pos)
{
    unsigned char i = 0;

    Lcd_Cmd(64);
    for (i = 0; i < 8; i += 1)
    {
        Lcd_Chr_CP(symbol[i]);
    }
    Lcd_Cmd(_LCD_RETURN_HOME);
    Lcd_Chr(y_pos, x_pos, 0);
}

void lcd_print(unsigned char x_pos, unsigned char y_pos, unsigned int value, unsigned char disp_type)
{
     unsigned char tmp = 0;

     tmp = (value / 1000);
     lcd_chr(y_pos, x_pos, (tmp + 48));
     tmp = ((value / 100) % 10);
     lcd_chr_cp((tmp + 48));
     switch(disp_type)
     {
        case 0:
        {
            lcd_chr_cp(46);
            break;
        }
        case 1:
        {
            break;
        }
     }
     tmp = ((value / 10) % 10);
     lcd_chr_cp((tmp + 48));
     tmp = (value % 10);
     lcd_chr_cp((tmp + 48));
}

float map(float v, float x_min, float x_max, float y_min, float y_max)
{
    return (y_min + (((y_max - y_min)/(x_max - x_min)) * (v - x_min)));
}
```





Demo video link: https://www.youtube.com/watch?v=01sV-vgegtk.

Interrupt-Driven Single Channel Single Conversion Mode

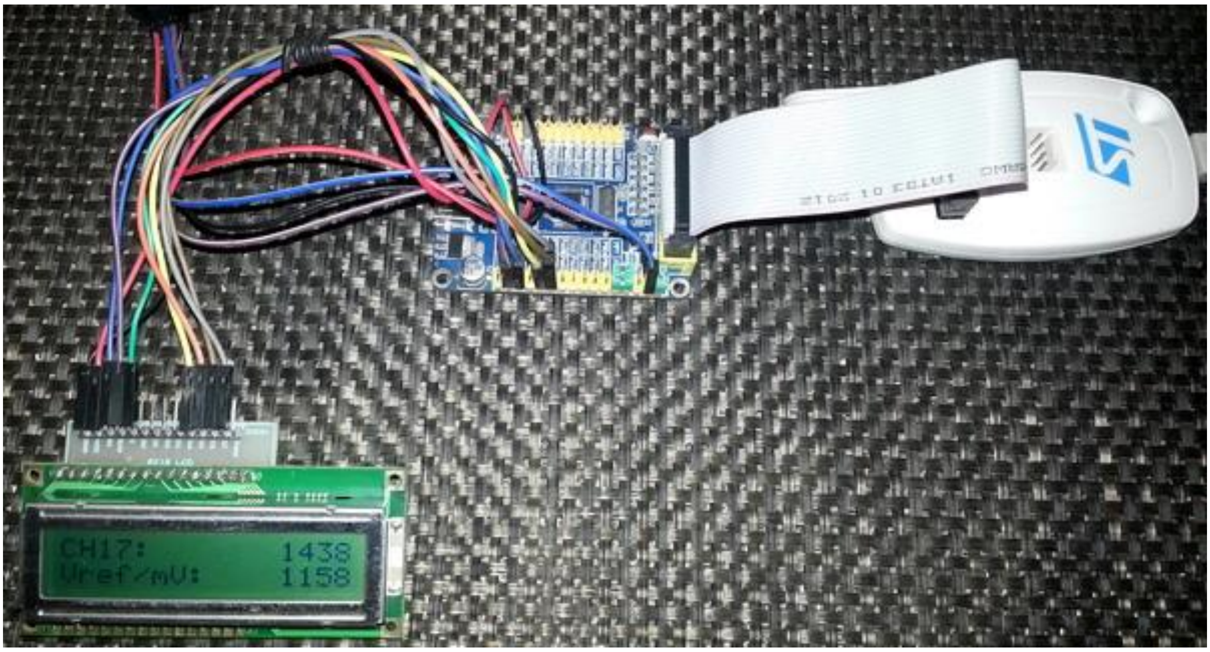
STM32 micros have an internal bandgap voltage reference source. The internal voltage reference source is not used by the ADC unlike other micros. It can, however, be used as a comparator input for zero-crossing detection. It may also be possible to use it to calibrate external readings or the V_{Ref+} pin.

The single channel single conversion mode is another basic ADC mode. In this mode a single channel (the internal reference source as in this example) is converted once when triggered. A single software trigger is used to invoke one ADC conversion. The end of conversion interrupt is used to notify the completion of ADC conversion and then the ADC stops. The only difference between the previous example and this one is how often the ADC conversion is done.

```
#include "ADC.h"
#include "GPIO.h"

sbit LCD_RS at GPIOB_ODR.B1;
sbit LCD_EN at GPIOB_ODR.B2;
sbit LCD_D4 at GPIOB_ODR.B12;
sbit LCD_D5 at GPIOB_ODR.B13;
sbit LCD_D6 at GPIOB_ODR.B14;
sbit LCD_D7 at GPIOB_ODR.B15;

register unsigned int adc_data = 0;

void setup();
void GPIO_init();
void ADC_init();
void lcd_print(unsigned char x_pos, unsigned char y_pos, unsigned int value);
float map(float v, float x_min, float x_max, float y_min, float y_max);

void ADC_ISR()
iv IVT_INT_ADC1_2
ics ICS_AUTO
{
    adc_data = (ADC1_DR & 0x0FFF);
    bit_clr(GPIOC_ODR, 13);
}

void main()
{
   register float V = 0;

   setup();

   while(1)
   {
      set_ADC1_regular_conversions(enable);
      bit_set(GPIOC_ODR, 13);

      V = map(adc_data, 0, 4095, 0, 3300);
```

```
        lcd_print(13, 1, adc_data);
        lcd_print(13, 2, V);
        delay_ms(90);
    };
}
void setup()
{
    GPIO_init();
    ADC_init();
    LCD_Init();

    LCD_Cmd(_LCD_CLEAR);
    LCD_Cmd(_LCD_CURSOR_OFF);

    lcd_out(1, 1, "CH17:");
    lcd_out(2, 1, "Vref/mV:");
}

void GPIO_init()
{
     enable_GPIOB(enable);
     enable_GPIOC(enable);
     pin_configure_high(GPIOC_CRH, 13, (GPIO_PP_output | output_mode_low_speed));
}

void ADC_init()
{
     ADC1_Enable();
     clr_ADC1_settings();
     set_ADC_mode(independent_mode);
     set_ADC1_data_alignment(right_alignment);
     set_ADC1_scan_conversion_mode(disable);
     set_ADC1_continuous_conversion_mode(disable);
     set_ADC1_external_trigger_regular_conversion_edge(SWSTART_trigger);
     set_ADC1_regular_number_of_conversions(1);
     set_ADC1_sample_time(sample_time_13_5_cycles, 17);
     set_ADC1_regular_sequence(1, 17);
     set_ADC1_reference_and_temperature_sensor(enable);
     set_ADC1_regular_end_of_conversion_interrupt(enable);
     NVIC_IntEnable(IVT_INT_ADC1_2);
     EnableInterrupts();
     ADC1_calibrate();
     start_ADC1();
}

void lcd_print(unsigned char x_pos, unsigned char y_pos, unsigned int value)
{
     unsigned char tmp = 0;

     tmp = (value / 1000);
     lcd_chr(y_pos, x_pos, (tmp + 48));
     tmp = ((value / 100) % 10);
     lcd_chr_cp((tmp + 48));
     tmp = ((value / 10) % 10);
     lcd_chr_cp((tmp + 48));
     tmp = (value % 10);
     lcd_chr_cp((tmp + 48));
}
```

```
float map(float v, float x_min, float x_max, float y_min, float y_max)
{
    return (y_min + (((y_max - y_min)/(x_max - x_min)) * (v - x_min)));
}
```



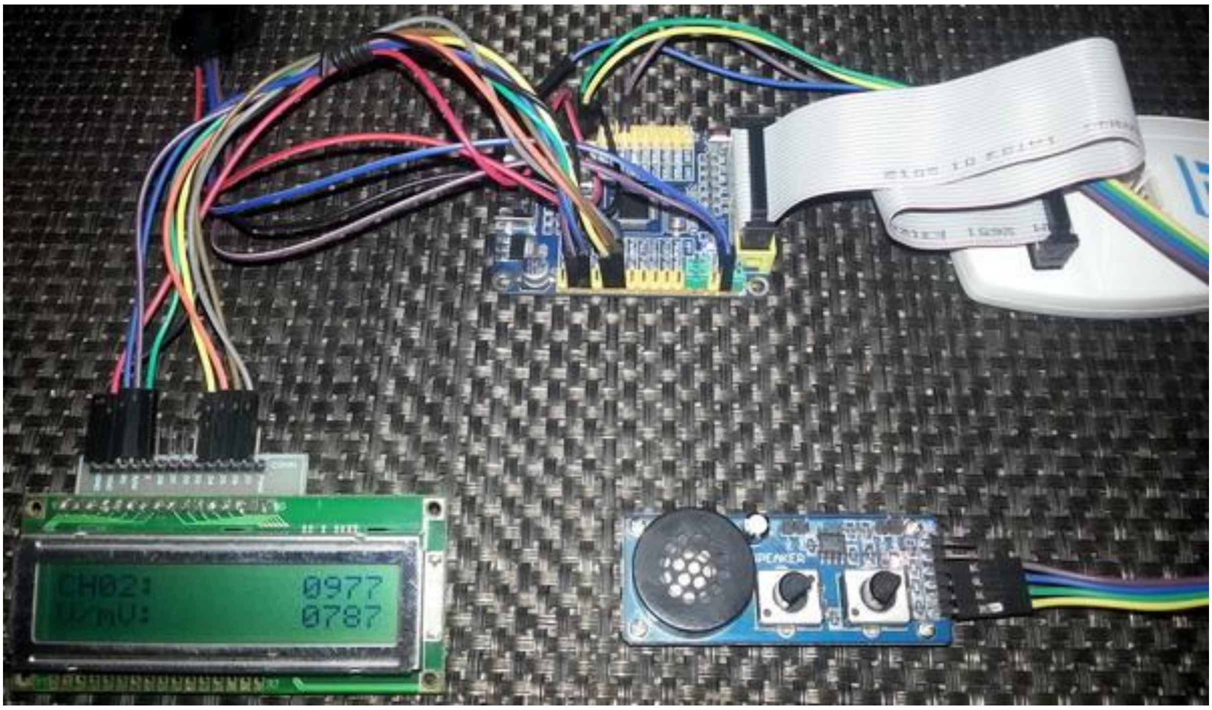
Demo video link: https://www.youtube.com/watch?v=BpiCa0ANWVI.

Single Channel Continuous Conversion Mode

This is similar to the third ADC example but this one is based on polling method rather than end of conversion interrupt-based one. This example is another basic example but I would prefer interrupt-based ADC conversion rather than this one as it will slow down other tasks.

```
#include "ADC.h"
#include "GPIO.h"

sbit LCD_RS at GPIOB_ODR.B1;
sbit LCD_EN at GPIOB_ODR.B2;
sbit LCD_D4 at GPIOB_ODR.B12;
sbit LCD_D5 at GPIOB_ODR.B13;
sbit LCD_D6 at GPIOB_ODR.B14;
sbit LCD_D7 at GPIOB_ODR.B15;

void setup();
void GPIO_init();
void ADC_init();
unsigned int read_ADC1();
void lcd_print(unsigned char x_pos, unsigned char y_pos, unsigned int value);
float map(float v, float x_min, float x_max, float y_min, float y_max);

void main()
{
   unsigned int adc_data = 0;
   float V = 0.0;

   setup();

   while(1)
   {
      bit_set(GPIOC_ODR, 13);
      delay_ms(10);

      adc_data = read_ADC1();
      V = map(adc_data, 0, 4095, 0, 3300);
      lcd_print(13, 1, adc_data);
      lcd_print(13, 2, V);

      bit_clr(GPIOC_ODR, 13);
      delay_ms(90);
   };
}

void setup()
{
   GPIO_init();
   ADC_init();
   LCD_Init();

   LCD_Cmd(_LCD_CLEAR);
   LCD_Cmd(_LCD_CURSOR_OFF);
```

```
    lcd_out(1, 1, "CH02:");
    lcd_out(2, 1, "V/mV:");
}

void GPIO_init()
{
     enable_GPIOA(enable);
     enable_GPIOB(enable);
     enable_GPIOC(enable);
     pin_configure_low(GPIOA_CRL, 2, (analog_input | input_mode));
     pin_configure_high(GPIOC_CRH, 13, (GPIO_PP_output | output_mode_low_speed));
}

void ADC_init()
{
     ADC1_Enable();
     clr_ADC1_settings();
     set_ADC_mode(independent_mode);
     set_ADC1_data_alignment(right_alignment);
     set_ADC1_scan_conversion_mode(disable);
     set_ADC1_continuous_conversion_mode(enable);
     set_ADC1_regular_number_of_conversions(1);
     set_ADC1_sample_time(sample_time_41_5_cycles, 2);
     set_ADC1_regular_sequence(1, 2);
     set_ADC1_external_trigger_regular_conversion_edge(SWSTART_trigger);
     ADC1_calibrate();
     start_ADC1();
}

unsigned int read_ADC1()
{
     while(ADC1_SRbits.EOC == 0);
     return (ADC1_DR & 0x0FFF);
}

void lcd_print(unsigned char x_pos, unsigned char y_pos, unsigned int value)
{
     unsigned char tmp = 0;

     tmp = (value / 1000);
     lcd_chr(y_pos, x_pos, (tmp + 48));
     tmp = ((value / 100) % 10);
     lcd_chr_cp((tmp + 48));
     tmp = ((value / 10) % 10);
     lcd_chr_cp((tmp + 48));
     tmp = (value % 10);
     lcd_chr_cp((tmp + 48));
}

float map(float v, float x_min, float x_max, float y_min, float y_max)
{
    return (y_min + (((y_max - y_min)/(x_max - x_min)) * (v - x_min)));
}
```



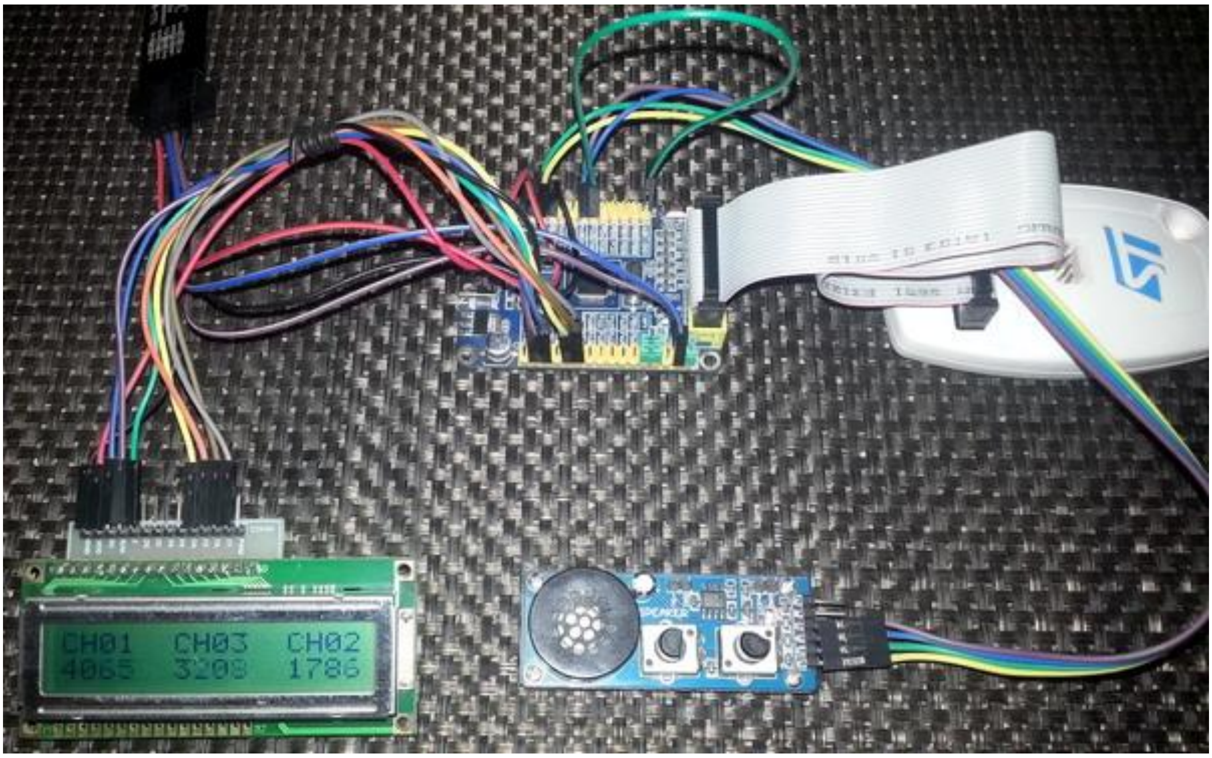
Demo video link: https://www.youtube.com/watch?v=8fh1-rkpFAw.

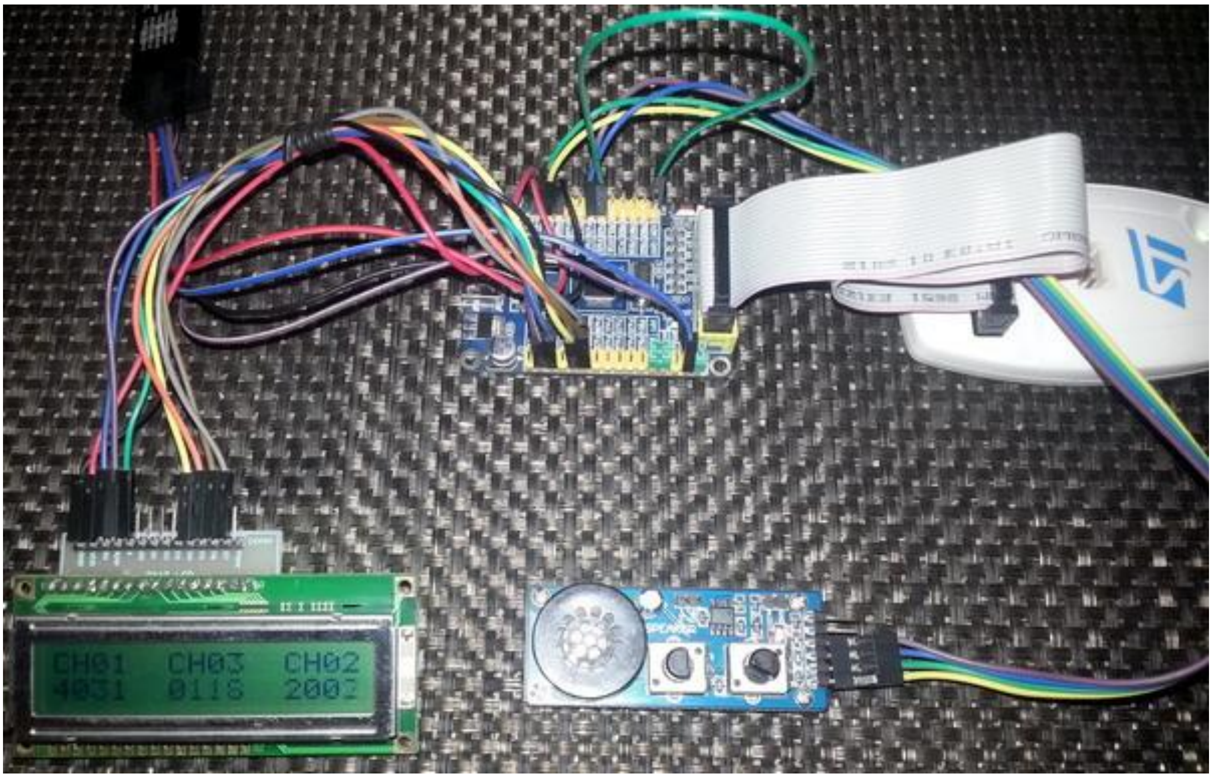
Multi-Single Channel Single Conversion Mode

This example is similar to the 4th example of this post but instead of reading a single channel multiple single channels with different sampling times are read. It is useful when you need to read multiple channels without scanning them.

```
#include "ADC.h"
#include "GPIO.h"

sbit LCD_RS at GPIOB_ODR.B1;
sbit LCD_EN at GPIOB_ODR.B2;
sbit LCD_D4 at GPIOB_ODR.B12;
sbit LCD_D5 at GPIOB_ODR.B13;
sbit LCD_D6 at GPIOB_ODR.B14;
sbit LCD_D7 at GPIOB_ODR.B15;

void setup();
void GPIO_init();
void ADC_init();
unsigned int read_ADC1(unsigned char channel, unsigned char sample_time);
void lcd_print(unsigned char x_pos, unsigned char y_pos, unsigned int value);

void main()
{
  unsigned int ch_a = 0;
  unsigned int ch_b = 0;
  unsigned int ch_c = 0;

  setup();

  while(1)
  {
    ch_a = read_ADC1(1, sample_time_239_5_cycles);
    ch_b = read_ADC1(3, sample_time_1_5_cycles);
    ch_c = read_ADC1(2, sample_time_28_5_cycles);

    lcd_print(1, 2, ch_a);
    lcd_print(7, 2, ch_b);
    lcd_print(13, 2, ch_c);

    bit_set(GPIOC_ODR, 13);
    delay_ms(10);
    bit_clr(GPIOC_ODR, 13);
    delay_ms(90);
  };
}

void setup()
{
  GPIO_init();
  ADC_init();
  LCD_Init();
```

```
    LCD_Cmd(_LCD_CLEAR);
    LCD_Cmd(_LCD_CURSOR_OFF);

    lcd_out(1, 1, "CH01  CH03  CH02");
}

void GPIO_init()
{
     enable_GPIOA(enable);
     enable_GPIOB(enable);
     enable_GPIOC(enable);
     pin_configure_low(GPIOA_CRL, 1, (analog_input | input_mode));
     pin_configure_low(GPIOA_CRL, 2, (analog_input | input_mode));
     pin_configure_low(GPIOA_CRL, 3, (analog_input | input_mode));
     pin_configure_high(GPIOC_CRH, 13, (GPIO_PP_output | output_mode_low_speed));
}

void ADC_init()
{
     ADC1_Enable();
     clr_ADC1_settings();
     set_ADC_mode(independent_mode);
     set_ADC1_data_alignment(right_alignment);
     set_ADC1_continuous_conversion_mode(disable);
     set_ADC1_regular_number_of_conversions(1);
     set_ADC1_external_trigger_regular_conversion_edge(SWSTART_trigger);
     ADC1_calibrate();
     start_ADC1();
}

unsigned int read_ADC1(unsigned char channel, unsigned char sample_time)
{
     ADC1_JSQR = 0x00000000;
     ADC1_SQR1 = 0x00000000;
     ADC1_SQR2 = 0x00000000;
     ADC1_SQR3 = 0x00000000;
     ADC1_SMPR1 = 0x00000000;
     ADC1_SMPR2 = 0x00000000;
     set_ADC1_regular_sequence(1, channel);
     set_ADC1_sample_time(sample_time, channel);
     set_ADC1_regular_conversions(enable);
     while(ADC1_SRbits.EOC == reset);
     return (0x0FFF & ADC1_DR);
}

void lcd_print(unsigned char x_pos, unsigned char y_pos, unsigned int value)
{
     unsigned char tmp = 0;

     tmp = (value / 1000);
     lcd_chr(y_pos, x_pos, (tmp + 48));
     tmp = ((value / 100) % 10);
     lcd_chr_cp((tmp + 48));
     tmp = ((value / 10) % 10);
     lcd_chr_cp((tmp + 48));
     tmp = (value % 10);
     lcd_chr_cp((tmp + 48));
}
```





Demo video link: https://www.youtube.com/watch?v=hcGHQFFkdfs.

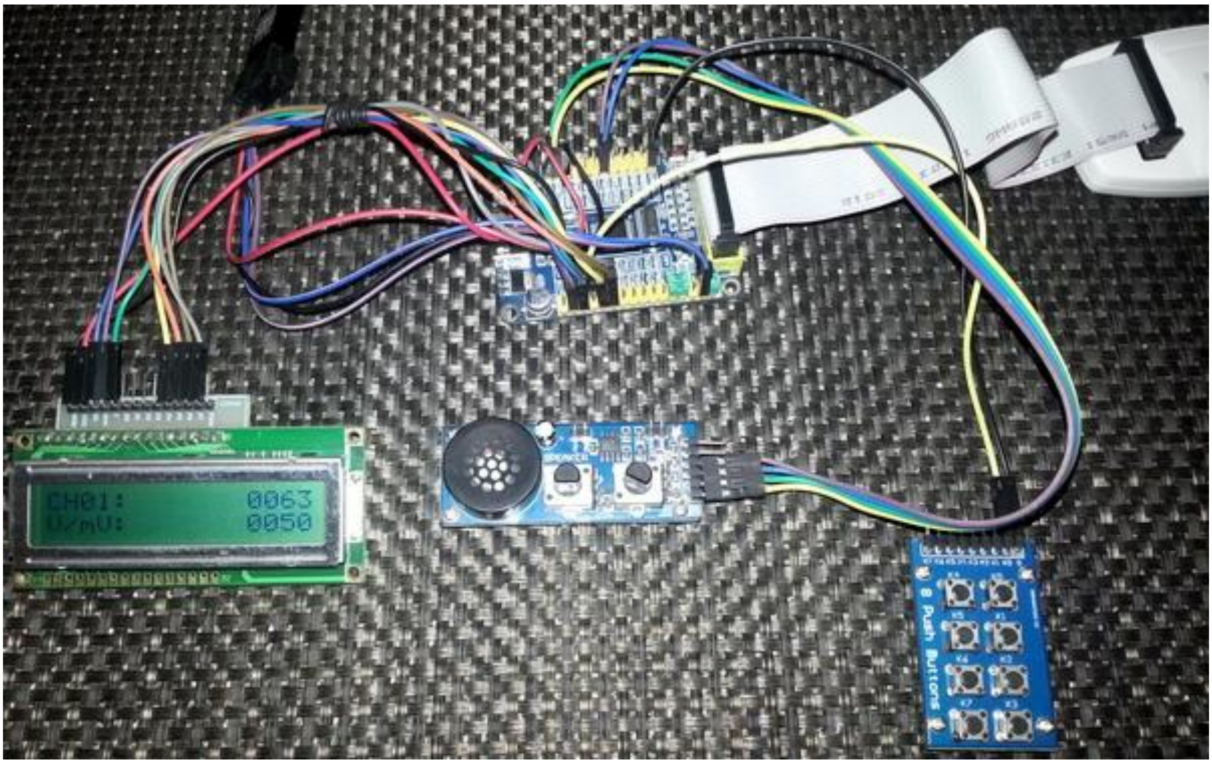
External Interrupt Triggered Single Channel Single Conversion Mode

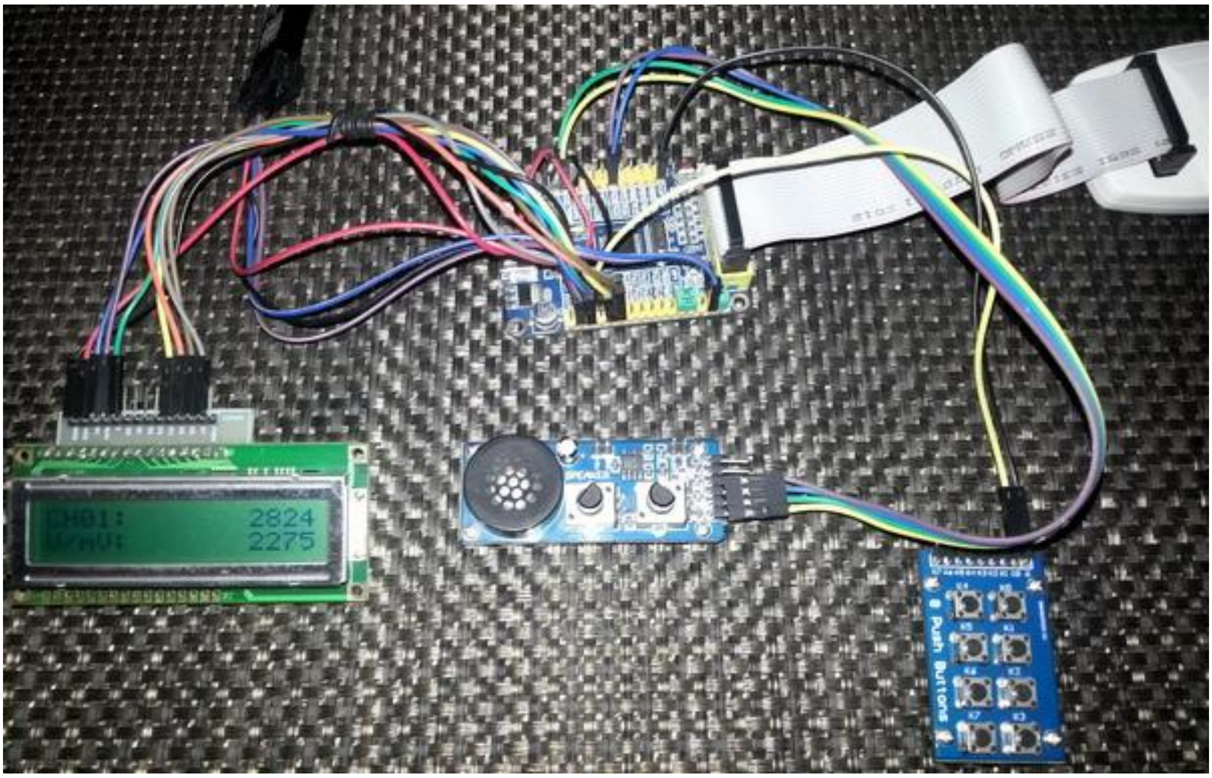
Up till now the ADC trigger was given from the software end. However STM32 micros can perform ADC conversions when triggered externally by some other hardware. In this example, an external interrupt pin is used to trigger a single ADC conversion. After completing an ADC conversion the ADC halts. We can also use timer events as trigger sources too.

```
#include "ADC.h"
#include "GPIO.h"
#include "AFIO.h"
#include "Ex_Int.h"

sbit LCD_RS at GPIOB_ODR.B1;
sbit LCD_EN at GPIOB_ODR.B2;
sbit LCD_D4 at GPIOB_ODR.B12;
sbit LCD_D5 at GPIOB_ODR.B13;
sbit LCD_D6 at GPIOB_ODR.B14;
sbit LCD_D7 at GPIOB_ODR.B15;

register unsigned int adc_data = 0;

void setup();
void GPIO_init();
void ADC_init();
void interrupts_init();
void lcd_print(unsigned char x_pos, unsigned char y_pos, unsigned int value);
float map(float v, float x_min, float x_max, float y_min, float y_max);

void void EXTI11_ISR()
iv IVT_INT_EXTI15_10
ics ICS_AUTO
{
   if(read_pending_reg(11) != 0)
   {
      bit_set(GPIOC_ODR, 13);
      delay_ms(10);
      bit_clr(GPIOC_ODR, 13);
      pending_clr(11);
   }
}

void void ADC1_ISR()
iv IVT_INT_ADC1_2
ics ICS_AUTO
{
   adc_data = (ADC1_DR & 0x0FFF);
}

void main()
{
   float v = 0;
```

```
    setup();

    while(1)
    {
        v = map(adc_data, 0, 4095, 0, 3300);
        lcd_print(13, 1, adc_data);
        lcd_print(13, 2, v);
    };
}

void setup()
{
    GPIO_init();
    ADC_init();
    LCD_Init();
    interrupts_init();

    LCD_Cmd(_LCD_CLEAR);
    LCD_Cmd(_LCD_CURSOR_OFF);

    lcd_out(1, 1, "CH01:");
    lcd_out(2, 1, "V/mV:");
}

void GPIO_init()
{
     enable_GPIOA(enable);
     enable_GPIOB(enable);
     enable_GPIOC(enable);

     pin_configure_low(GPIOA_CRL, 1, (analog_input | input_mode));
     pin_configure_high(GPIOC_CRH, 13, (GPIO_PP_output | output_mode_medium_speed));
     pin_configure_high(GPIOB_CRH, 11, (digital_input | input_mode));
     pull_up_enable(GPIOB_ODR, 11);
}

void ADC_init()
{
     ADC1_Enable();
     clr_ADC1_settings();
     set_ADC_mode(independent_mode);
     set_ADC1_data_alignment(right_alignment);
     set_ADC1_scan_conversion_mode(disable);
     set_ADC1_continuous_conversion_mode(disable);
     set_ADC1_sample_time(sample_time_71_5_cycles, 1);
     set_ADC1_external_trigger_regular_conversion_edge(EXTI_11_trigger);
     set_ADC1_regular_number_of_conversions(1);
     set_ADC1_regular_sequence(1, 1);
     set_ADC1_regular_end_of_conversion_interrupt(enable);
     ADC1_calibrate();
     start_ADC1();
}

void interrupts_init()
{
     AFIO_enable(enable);
     falling_edge_selector(11);
     set_EXTI8_11(11, PB_pin);
```

```
    interrupt_mask(11);
    NVIC_IntEnable(IVT_INT_EXTI15_10);
    NVIC_IntEnable(IVT_INT_ADC1_2);
    EnableInterrupts();
}

void lcd_print(unsigned char x_pos, unsigned char y_pos, unsigned int value)
{
    unsigned char tmp = 0;

    tmp = (value / 1000);
    lcd_chr(y_pos, x_pos, (tmp + 48));
    tmp = ((value / 100) % 10);
    lcd_chr_cp((tmp + 48));
    tmp = ((value / 10) % 10);
    lcd_chr_cp((tmp + 48));
    tmp = (value % 10);
    lcd_chr_cp((tmp + 48));
}

float map(float v, float x_min, float x_max, float y_min, float y_max)
{
   return (y_min + (((y_max - y_min)/(x_max - x_min)) * (v - x_min)));
}
```





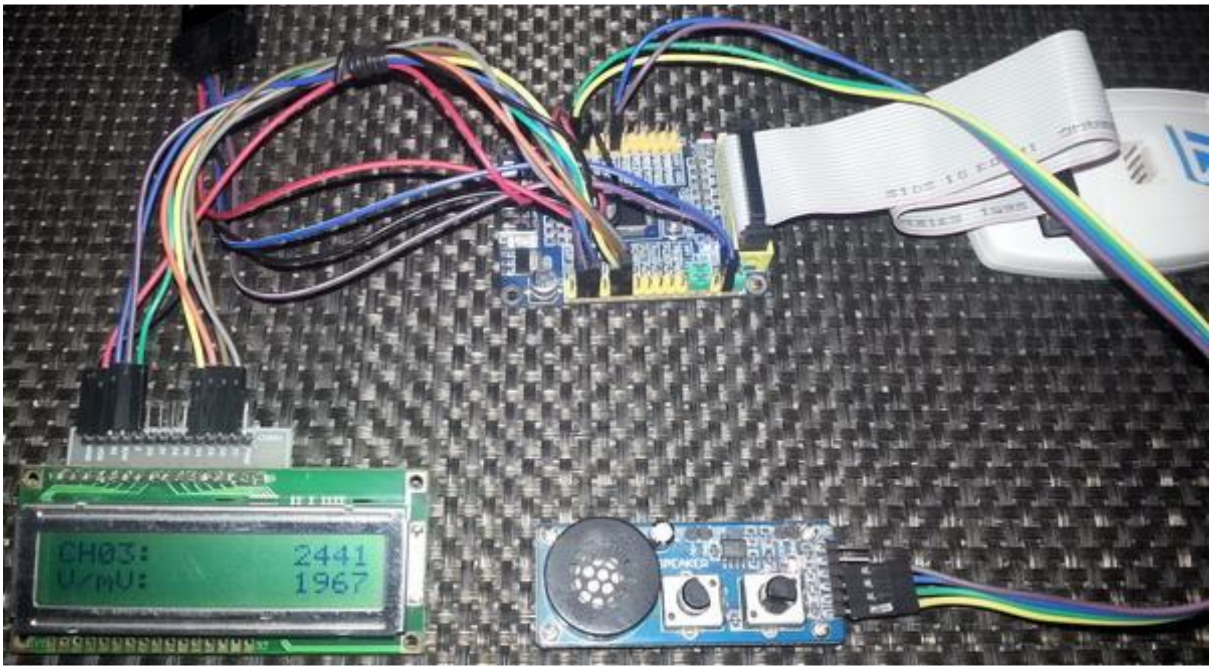
Demo video link: https://www.youtube.com/watch?v=dT5wkXKs42E.

Single Injected Channel Continuous Conversion Mode

Previously I stated that injected groups are no different than regular groups when used alone. They will behave like regular groups if regular groups are absent. In this demo there's no regular group channel and you'll see that the injected group channel is behaving like a regular group channel.

```
#include "ADC.h"
#include "GPIO.h"

sbit LCD_RS at GPIOB_ODR.B1;
sbit LCD_EN at GPIOB_ODR.B2;
sbit LCD_D4 at GPIOB_ODR.B12;
sbit LCD_D5 at GPIOB_ODR.B13;
sbit LCD_D6 at GPIOB_ODR.B14;
sbit LCD_D7 at GPIOB_ODR.B15;

void setup();
void GPIO_init();
void ADC_init();
unsigned int read_ADC1();
void lcd_print(unsigned char x_pos, unsigned char y_pos, unsigned int value);
float map(float v, float x_min, float x_max, float y_min, float y_max);

void main()
{
   register unsigned int adc_data = 0;
   float V = 0.0;

   setup();

   while(1)
   {
      bit_set(GPIOC_ODR, 13);
      delay_ms(10);

      adc_data = read_ADC1();
      V = map(adc_data, 0, 4095, 0, 3300);
      lcd_print(13, 1, adc_data);
      lcd_print(13, 2, V);

      bit_clr(GPIOC_ODR, 13);
      delay_ms(90);
   };
}

void setup()
{
   GPIO_init();
   ADC_init();
   LCD_Init();

   LCD_Cmd(_LCD_CLEAR);
   LCD_Cmd(_LCD_CURSOR_OFF);
```

```
    lcd_out(1, 1, "CH03:");
    lcd_out(2, 1, "V/mV:");
}

void GPIO_init()
{
     enable_GPIOA(enable);
     enable_GPIOB(enable);
     enable_GPIOC(enable);
     pin_configure_low(GPIOA_CRL, 3, (analog_input | input_mode));
     pin_configure_high(GPIOC_CRH, 13, (GPIO_PP_output | output_mode_low_speed));
}

void ADC_init()
{
     ADC1_Enable();
     clr_ADC1_settings();
     set_ADC_mode(independent_mode);
     set_ADC1_data_alignment(right_alignment);
     set_ADC1_scan_conversion_mode(disable);
     set_ADC1_continuous_conversion_mode(enable);
     set_ADC1_injected_number_of_conversions(1);
     set_ADC1_sample_time(sample_time_239_5_cycles, 3);
     set_ADC1_injected_sequence(4, 3);
     set_ADC1_external_trigger_injected_conversion_edge(JSWSTART_trigger);
     ADC1_calibrate();
     start_ADC1();
}

unsigned int read_ADC1()
{
     set_ADC1_injected_conversions(enable);
     while(ADC1_SRbits.JEOC == 0);
     return (ADC1_JDR1 & 0x0FFF);
}

void lcd_print(unsigned char x_pos, unsigned char y_pos, unsigned int value)
{
     unsigned char tmp = 0;

     tmp = (value / 1000);
     lcd_chr(y_pos, x_pos, (tmp + 48));
     tmp = ((value / 100) % 10);
     lcd_chr_cp((tmp + 48));
     tmp = ((value / 10) % 10);
     lcd_chr_cp((tmp + 48));
     tmp = (value % 10);
     lcd_chr_cp((tmp + 48));
}

float map(float v, float x_min, float x_max, float y_min, float y_max)
{
    return (y_min + (((y_max - y_min)/(x_max - x_min)) * (v - x_min)));
}
```



Demo video link: https://www.youtube.com/watch?v=R1MuJaWrfn8.

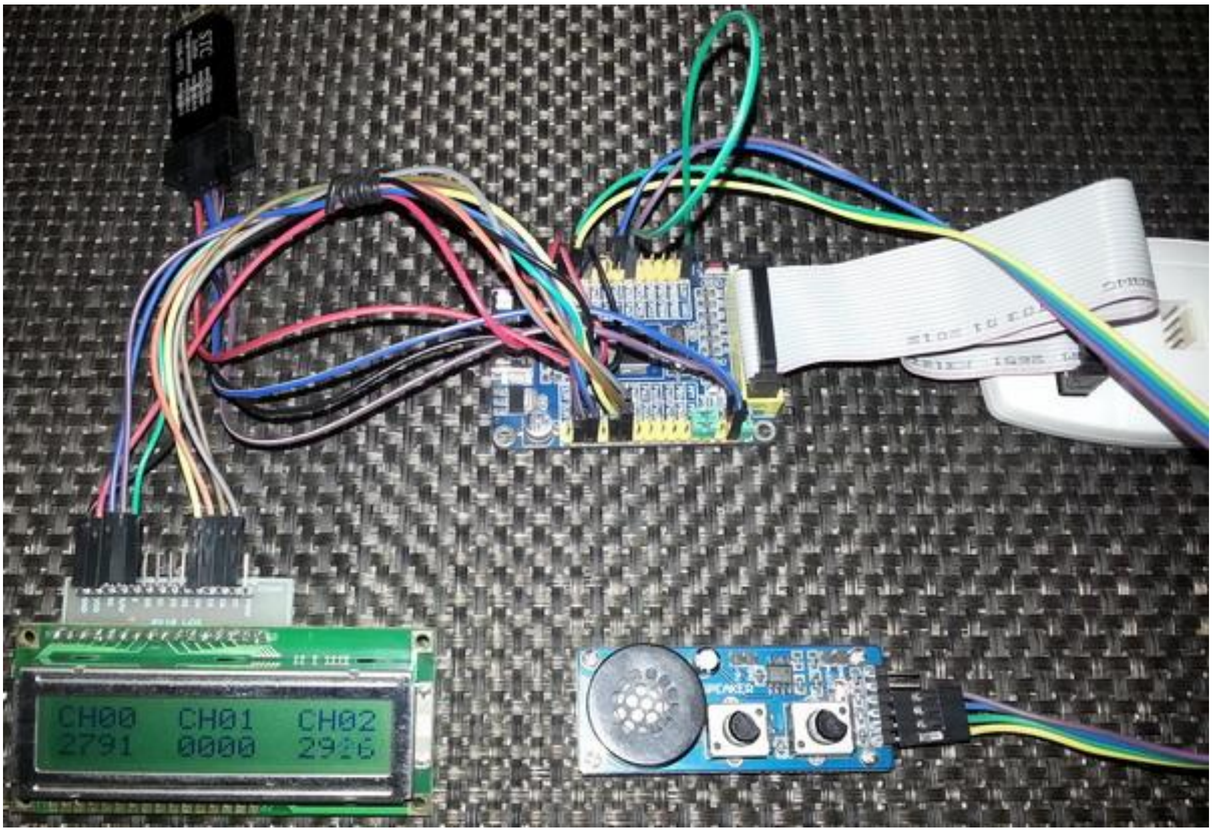
Multiple Injected Channels in Discontinuous Conversion Mode

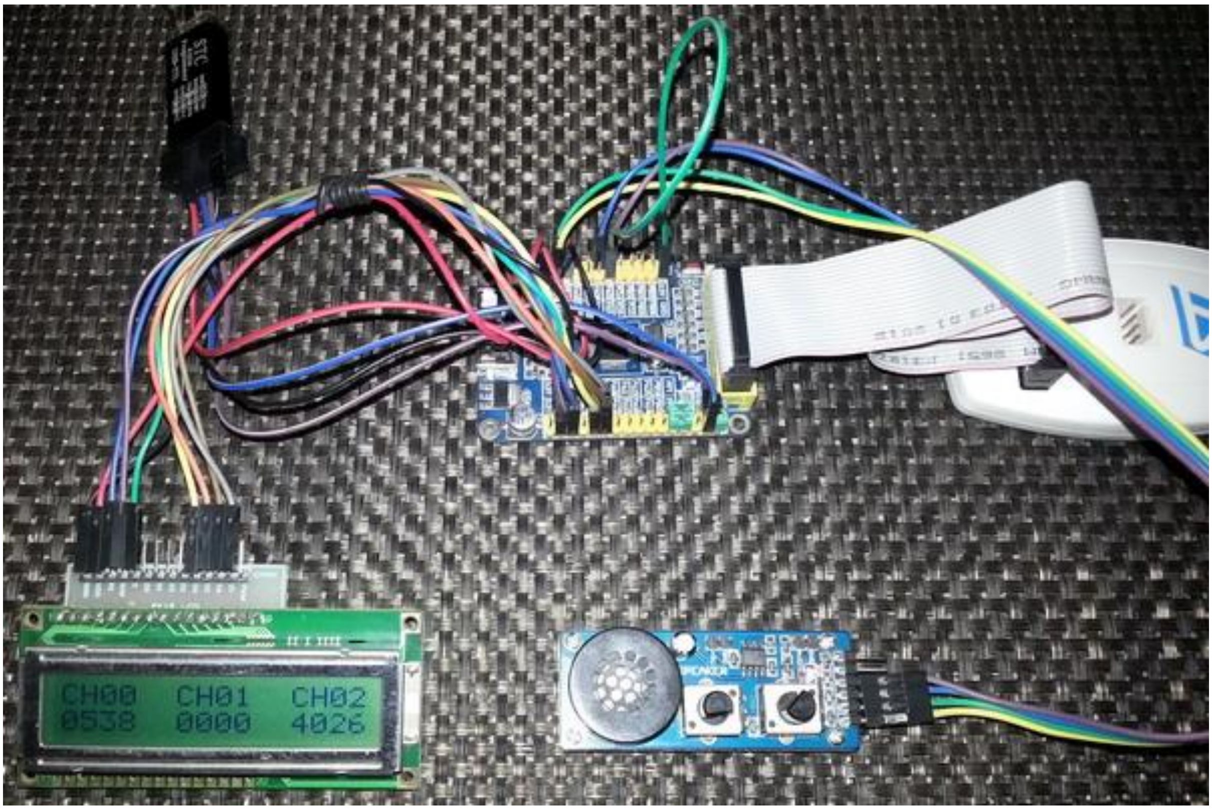
In discontinuous mode, each injected group channel is converted according to a sequence and after each channel conversion an injected channel end of conversion flag is set. Since there can be four channels in an injected group, their conversion results are stored in four separate data registers. We just need to read those data registers when valid data values are ready. To use discontinuous mode we must specify the number of channels in the discontinuous mode apart from how many channels that are actually present in the group.

```
#include "ADC.h"
#include "GPIO.h"

sbit LCD_RS at GPIOB_ODR.B1;
sbit LCD_EN at GPIOB_ODR.B2;
sbit LCD_D4 at GPIOB_ODR.B12;
sbit LCD_D5 at GPIOB_ODR.B13;
sbit LCD_D6 at GPIOB_ODR.B14;
sbit LCD_D7 at GPIOB_ODR.B15;

void setup();
void GPIO_init();
void ADC_init();
void read_ADC1_injected(unsigned int temp_data[3]);
void lcd_print(unsigned char x_pos, unsigned char y_pos, unsigned int value);

void main()
{
   unsigned int channel_data[3];

   setup();

   while(1)
   {
      read_ADC1_injected(channel_data);
      lcd_print(1, 2, channel_data[0]);
      lcd_print(7, 2, channel_data[1]);
      lcd_print(13, 2, channel_data[2]);

      bit_set(GPIOC_ODR, 13);
      delay_ms(10);
      bit_clr(GPIOC_ODR, 13);
      delay_ms(90);
   };
}

void setup()
{
   GPIO_init();
```

```
    ADC_init();
    LCD_Init();

    LCD_Cmd(_LCD_CLEAR);
    LCD_Cmd(_LCD_CURSOR_OFF);

    lcd_out(1, 1, "CH00  CH01  CH02");
}

void GPIO_init()
{
     enable_GPIOA(enable);
     enable_GPIOB(enable);
     enable_GPIOC(enable);
     pin_configure_low(GPIOA_CRL, 0, (analog_input | input_mode));
     pin_configure_low(GPIOA_CRL, 1, (analog_input | input_mode));
     pin_configure_low(GPIOA_CRL, 2, (analog_input | input_mode));
     pin_configure_high(GPIOC_CRH, 13, (GPIO_PP_output | output_mode_low_speed));
}

void ADC_init()
{
     ADC1_Enable();
     clr_ADC1_settings();
     set_ADC_mode(independent_mode);
     set_ADC1_data_alignment(right_alignment);
     set_ADC1_scan_conversion_mode(disable);
     set_ADC1_continuous_conversion_mode(disable);
     set_ADC1_injected_number_of_conversions(3);
     set_ADC1_sample_time(sample_time_28_5_cycles, 0);
     set_ADC1_sample_time(sample_time_41_5_cycles, 1);
     set_ADC1_sample_time(sample_time_13_5_cycles, 2);
     set_ADC1_injected_sequence(1, 0);
     set_ADC1_injected_sequence(2, 2);
     set_ADC1_injected_sequence(3, 1);
     set_ADC1_number_of_discontinuous_conversions(3);
     set_ADC1_external_trigger_injected_conversion_edge(JSWSTART_trigger);
     set_ADC1_discontinuous_conversion_mode_in_injected_mode(enable);
     ADC1_calibrate();
     start_ADC1();
}

void read_ADC1_injected(unsigned int temp_data[3])
{
     set_ADC1_injected_conversions(enable);
     while(ADC1_SRbits.JEOC == 0);
     temp_data[0] = (ADC1_JDR3 & 0x0FFF);
     set_ADC1_injected_conversions(enable);
     while(ADC1_SRbits.JEOC == 0);
     temp_data[1] = (ADC1_JDR2 & 0x0FFF);
     set_ADC1_injected_conversions(enable);
     while(ADC1_SRbits.JEOC == 0);
     temp_data[2] = (ADC1_JDR1 & 0x0FFF);
}

void lcd_print(unsigned char x_pos, unsigned char y_pos, unsigned int value)
{
     unsigned char tmp = 0;
```

```
    tmp = (value / 1000);
    lcd_chr(y_pos, x_pos, (tmp + 48));
    tmp = ((value / 100) % 10);
    lcd_chr_cp((tmp + 48));
    tmp = ((value / 10) % 10);
    lcd_chr_cp((tmp + 48));
    tmp = (value % 10);
    lcd_chr_cp((tmp + 48));
}
```





Demo video link: https://www.youtube.com/watch?v=YwymJs8LlNU.

Multiple Injected Channels in Scan Conversion Mode

Scan mode is another interesting mode. In scan mode all ADC channels are scanned as per sequence. One conversion is performed for each channel. After having completed a scan an injected channel end of conversion flag is set. If interrupt is used then an end of conversion interrupt is issued. Scan mode is useful when we need to monitor several ADC channels, for example temperature and relative humidity. There's a word of caution for using scan mode. STM32 reference manual states it like this:

> *Unlike a regular conversion sequence, if JL[1:0] length is less than four, the channels are converted in a sequence starting from (4-JL). Example: ADC_JSQR[21:0] = 10 00011 00011 00111 00010 means that a scan conversion will convert the following channel sequence: 7, 3, 3. (not 2, 7, 3)*

This is why you'll see some anomalies in this code example:

```
set_ADC2_injected_sequence(3, 4);
set_ADC2_injected_sequence(4, 6);

void ADC1_2_ISR()
iv IVT_INT_ADC1_2
ics ICS_AUTO
{
    ADC2_SRbits.JEOC = 0;
    channel_data[0] = (ADC2_JDR1 & 0x0FFF);
    channel_data[1] = (ADC2_JDR2 & 0x0FFF);
}
```

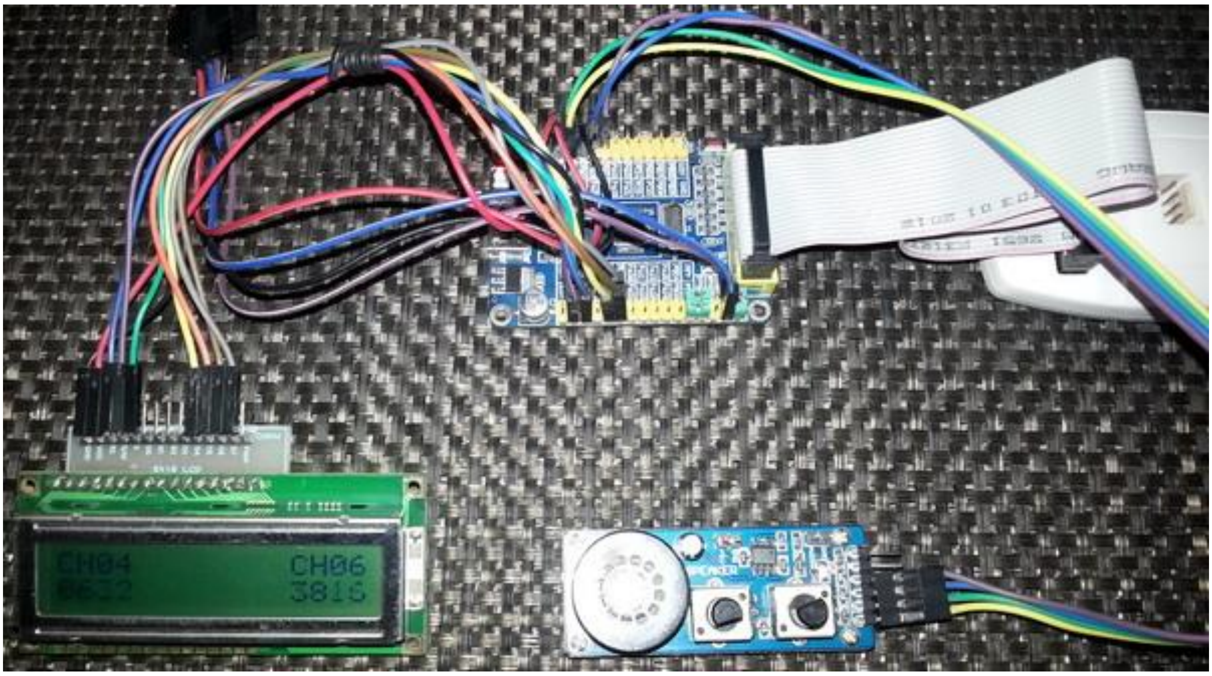
Notice the sequence order and how the data is actually extracted. Keep this in mind while coding for injected groups in scan mode. Also note that in this code I used ADC2 instead of ADC1. This is not mandatory. I did so just to show that you can also use ADC2 rather than ADC1.

For regular group channels the scan mode is DMA dependent because for regular group channels there's only one data register for all the regular channels. I didn't find a good way to avoid using the DMA unit. Of course using DMA is a much more clever approach. Since I won't be discussing about DMA in this issue, I'm skipping this part for future.

```
#include "ADC.h"
#include "GPIO.h"

sbit LCD_RS at GPIOB_ODR.B1;
sbit LCD_EN at GPIOB_ODR.B2;
sbit LCD_D4 at GPIOB_ODR.B12;
sbit LCD_D5 at GPIOB_ODR.B13;
sbit LCD_D6 at GPIOB_ODR.B14;
sbit LCD_D7 at GPIOB_ODR.B15;

unsigned int channel_data[2];
```

```
void setup();
void GPIO_init();
void ADC_init();
void lcd_print(unsigned char x_pos, unsigned char y_pos, unsigned int value);

void ADC1_2_ISR()
iv IVT_INT_ADC1_2
ics ICS_AUTO
{
     ADC2_SRbits.JEOC = 0;
     channel_data[0] = (ADC2_JDR1 & 0x0FFF);
     channel_data[1] = (ADC2_JDR2 & 0x0FFF);
}

void main()
{
    setup();

    while(1)
    {
        bit_set(GPIOC_ODR, 13);
        set_ADC2_injected_conversions(enable);
        delay_ms(10);
        lcd_print(1, 2, channel_data[0]);
        lcd_print(13, 2, channel_data[1]);
        bit_clr(GPIOC_ODR, 13);
        delay_ms(90);
    };
}

void setup()
{
    GPIO_init();
    LCD_Init();
    ADC_init();

    LCD_Cmd(_LCD_CLEAR);
    LCD_Cmd(_LCD_CURSOR_OFF);

    lcd_out(1, 1, "CH04        CH06");
}

void GPIO_init()
{
     enable_GPIOA(enable);
     enable_GPIOB(enable);
     enable_GPIOC(enable);
     pin_configure_low(GPIOA_CRL, 4, (analog_input | input_mode));
     pin_configure_low(GPIOA_CRL, 6, (analog_input | input_mode));
     pin_configure_high(GPIOC_CRH, 13, (GPIO_PP_output | output_mode_low_speed));
}

void ADC_init()
{
     ADC2_Enable();
     clr_ADC2_settings();
     set_ADC_mode(independent_mode);
     set_ADC2_data_alignment(right_alignment);
```

```
    set_ADC2_scan_conversion_mode(enable);
    set_ADC2_continuous_conversion_mode(disable);
    set_ADC2_sample_time(sample_time_1_5_cycles, 4);
    set_ADC2_sample_time(sample_time_13_5_cycles, 6);
    set_ADC2_external_trigger_injected_conversion_edge(JSWSTART_trigger);
    set_ADC2_injected_number_of_conversions(2);
    set_ADC2_injected_sequence(3, 4);
    set_ADC2_injected_sequence(4, 6);
    set_ADC2_injected_end_of_conversion_interrupt(enable);
    NVIC_IntEnable(IVT_INT_ADC1_2);
    EnableInterrupts();
    ADC2_calibrate();
    start_ADC2();
}

void lcd_print(unsigned char x_pos, unsigned char y_pos, unsigned int value)
{
    unsigned char tmp = 0;

    tmp = (value / 1000);
    lcd_chr(y_pos, x_pos, (tmp + 48));
    tmp = ((value / 100) % 10);
    lcd_chr_cp((tmp + 48));
    tmp = ((value / 10) % 10);
    lcd_chr_cp((tmp + 48));
    tmp = (value % 10);
    lcd_chr_cp((tmp + 48));
}
```



Demo video link: https://www.youtube.com/watch?v=Mjax8dwClGE.

Regular Group Channels Discontinuous in Mode

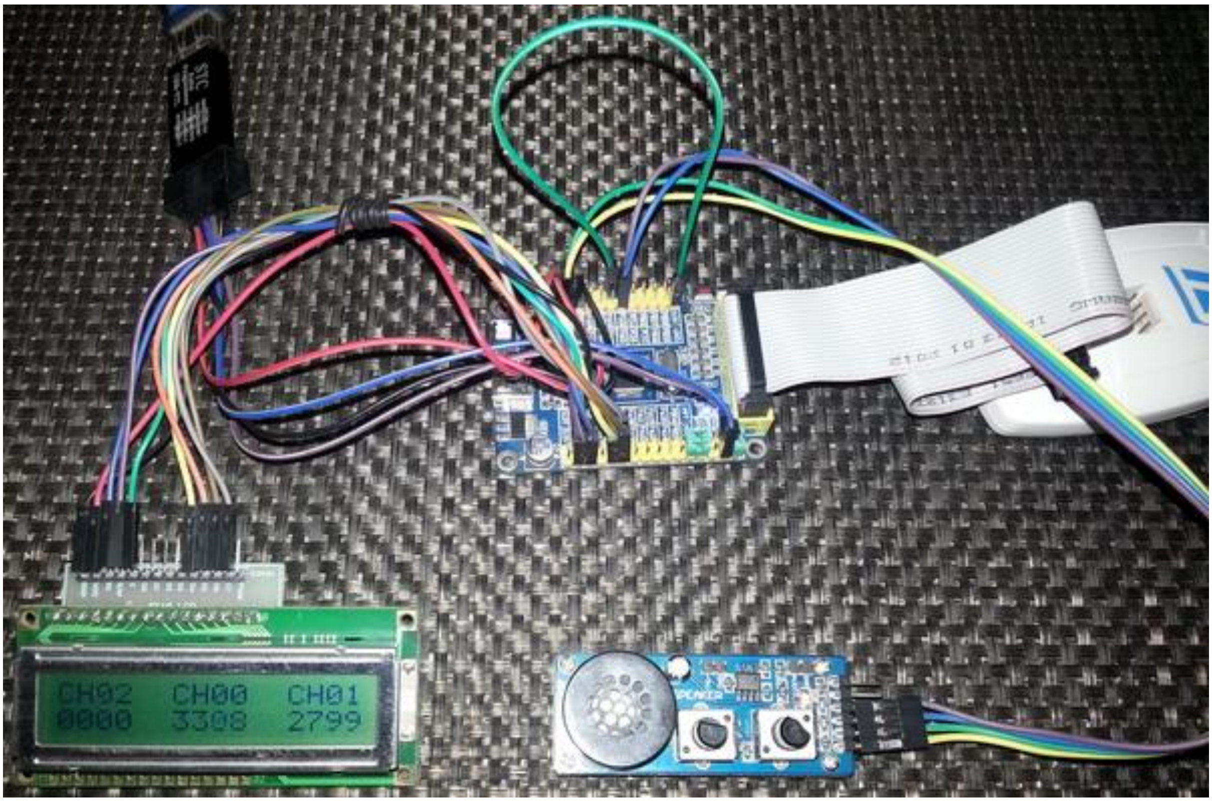
This example is similar to the one I coded for injected group channels. It is somewhat an alternative of scan mode for regular group though technically they are not same. You can use this mode to monitor several ADC channels in a systematic order.

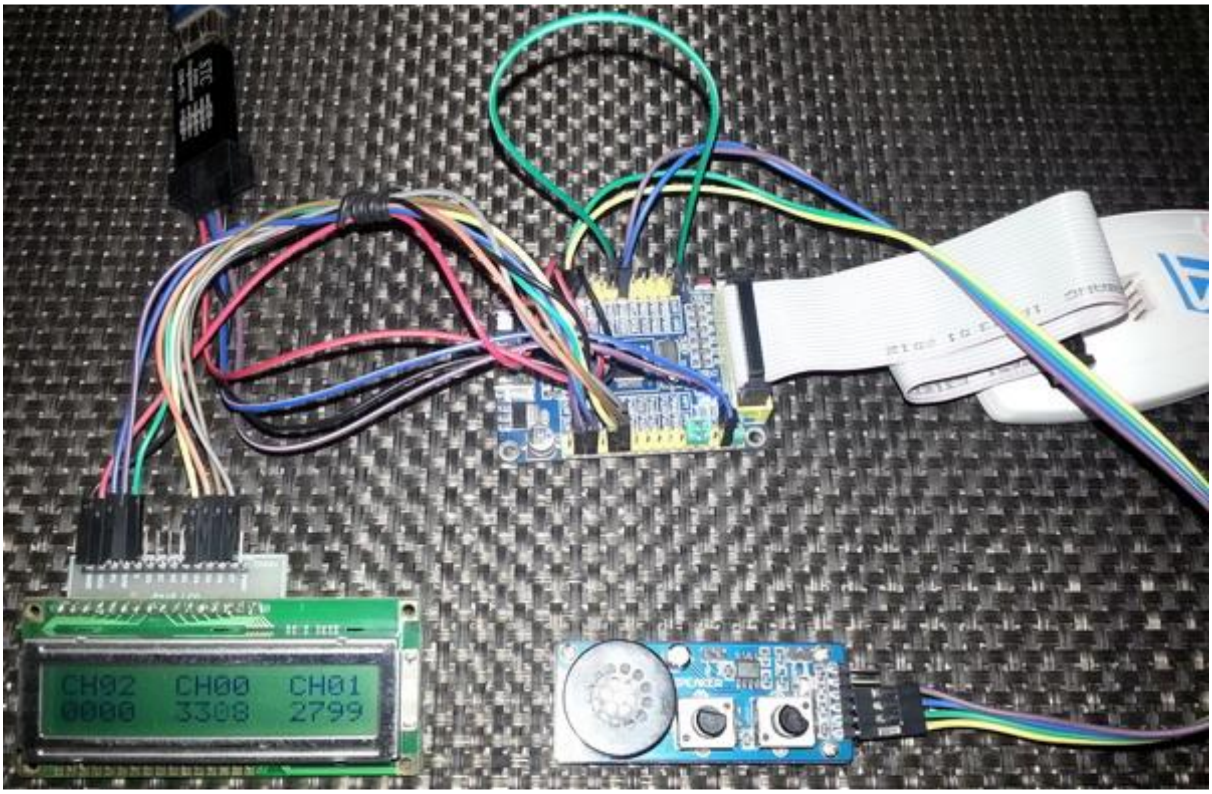
```
#include "ADC.h"
#include "GPIO.h"

sbit LCD_RS at GPIOB_ODR.B1;
sbit LCD_EN at GPIOB_ODR.B2;
sbit LCD_D4 at GPIOB_ODR.B12;
sbit LCD_D5 at GPIOB_ODR.B13;
sbit LCD_D6 at GPIOB_ODR.B14;
sbit LCD_D7 at GPIOB_ODR.B15;

unsigned char channel_no = 0;
unsigned int ch_data[3] = {0x0000, 0x0000, 0x0000};

void setup();
void GPIO_init();
void ADC_init();
void lcd_print(unsigned char x_pos, unsigned char y_pos, unsigned int value);

void ADC1_2_ISR()
iv IVT_INT_ADC1_2
ics ICS_AUTO
{
   ADC2_SRbits.EOC = 0;
   ch_data[channel_no] = (ADC2_DR & 0x0FFF);
   channel_no++;
}

void main()
{
   unsigned char s = 0;

   setup();

   while(1)
   {
      bit_set(GPIOC_ODR, 13);
      set_ADC2_regular_conversions(enable);
      while(channel_no < 3);
      channel_no = 0;
      for(s = 0 ; s < 3; s++)
      {
         lcd_print(((s * 6) + 1), 2, ch_data[s]);
      }
      bit_clr(GPIOC_ODR, 13);
   };
}
```

```
void setup()
{
   GPIO_init();
   ADC_init();
   LCD_Init();

   LCD_Cmd(_LCD_CLEAR);
   LCD_Cmd(_LCD_CURSOR_OFF);

   lcd_out(1, 1, "CH02  CH00  CH01");
}

void GPIO_init()
{
    enable_GPIOA(enable);
    enable_GPIOB(enable);
    enable_GPIOC(enable);
    pin_configure_low(GPIOA_CRL, 0, (analog_input | input_mode));
    pin_configure_low(GPIOA_CRL, 1, (analog_input | input_mode));
    pin_configure_low(GPIOA_CRL, 2, (analog_input | input_mode));
    pin_configure_high(GPIOC_CRH, 13, (GPIO_PP_output | output_mode_low_speed));
}

void ADC_init()
{
    ADC2_Enable();
    clr_ADC2_settings();
    set_ADC_mode(independent_mode);
    set_ADC2_data_alignment(right_alignment);
    set_ADC2_scan_conversion_mode(disable);
    set_ADC2_continuous_conversion_mode(disable);
    set_ADC2_regular_number_of_conversions(3);
    set_ADC2_number_of_discontinuous_conversions(3);
    set_ADC2_sample_time(sample_time_41_5_cycles, 0);
    set_ADC2_sample_time(sample_time_13_5_cycles, 1);
    set_ADC2_sample_time(sample_time_28_5_cycles, 2);
    set_ADC2_regular_sequence(1, 0);
    set_ADC2_regular_sequence(2, 1);
    set_ADC2_regular_sequence(3, 2);
    set_ADC2_external_trigger_regular_conversion_edge(SWSTART_trigger);
    set_ADC2_discontinuous_conversion_mode_in_regular_mode(enable);
    set_ADC2_regular_end_of_conversion_interrupt(enable);
    NVIC_IntEnable(IVT_INT_ADC1_2);
    EnableInterrupts();
    ADC2_calibrate();
    start_ADC2();
}

void lcd_print(unsigned char x_pos, unsigned char y_pos, unsigned int value)
{
    unsigned char tmp = 0;

    tmp = (value / 1000);
    lcd_chr(y_pos, x_pos, (tmp + 48));
    tmp = ((value / 100) % 10);
    lcd_chr_cp((tmp + 48));
    tmp = ((value / 10) % 10);
```

```
    lcd_chr_cp((tmp + 48));
    tmp = (value % 10);
    lcd_chr_cp((tmp + 48));
}
```

Demo video link: https://www.youtube.com/watch?v=pz-y_W2Lxr8.





Demo video link: https://www.youtube.com/watch?v=pz-y_W2Lxr8.

Dual Conversion Mode

One of the cool feature of STM32's ADC is its ability to simultaneous convert two ADC channels. This ability is sometimes highly demanded in some applications. For example in an energy meter you'll need to measure both voltage and current simultaneous if you want precision. Applications like such demand the use of dual ADC mode. Please note that this feature is available only in those STM32 micros that have at least two ADC units. Fortunately there are only a few STM32 micros that have only one ADC unit.

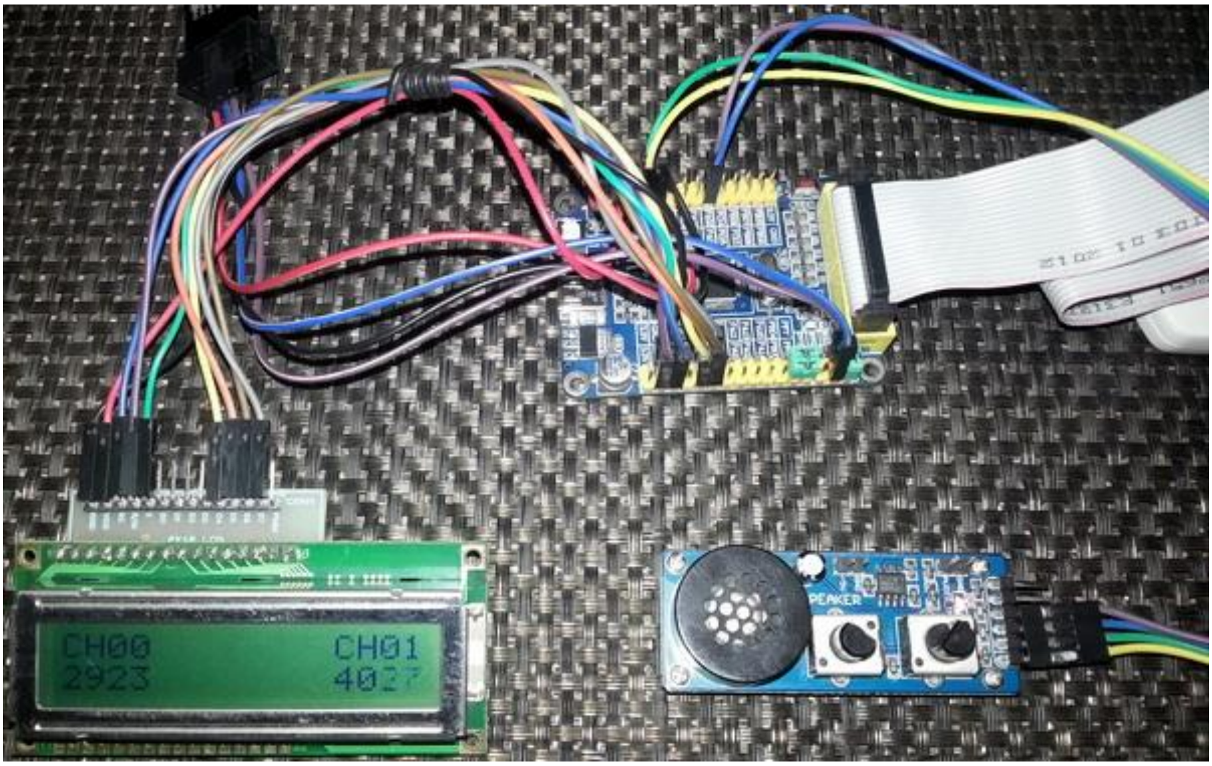
ST provided several sub modes for dual ADC modes but none attracted me much because those seemed to my achievable using one ADC and some programming tricks. It's just my instinct. I could be wrong.

To use dual ADC mode, we need to configure two ADC units separately. They'll have some common setups. The individual ADCs are configured as such that as if they are configured for single ADC operation. The common settings are just ADC mode of operation setting and interrupt configuration. The results of ADC conversions of both channels are stored in ADC1_DR register Please note that ST recommends that we set the DMA bit for ADC1 even if we don't use the DMA block itself.

```
#include "ADC.h"
#include "GPIO.h"

sbit LCD_RS at GPIOB_ODR.B1;
sbit LCD_EN at GPIOB_ODR.B2;
sbit LCD_D4 at GPIOB_ODR.B12;
sbit LCD_D5 at GPIOB_ODR.B13;
sbit LCD_D6 at GPIOB_ODR.B14;
sbit LCD_D7 at GPIOB_ODR.B15;

register unsigned long adc_data = 0;

void setup();
void GPIO_init();
void ADC_init();
void setup_ADC1();
void setup_ADC2();
void setup_common_ADC_settings();
void lcd_print(unsigned char x_pos, unsigned char y_pos, unsigned int value);

void ADC1_2_ISR()
iv IVT_INT_ADC1_2
ics ICS_AUTO
{
   ADC1_SRbits.EOC = 0;
   ADC2_SRbits.EOC = 0;
   adc_data = adc1_dr;
   bit_set(GPIOC_ODR, 13);
}
```

```
void main()
{
   unsigned int adc1_data = 0;
   unsigned int adc2_data = 0;

   setup();

   while(1)
   {
      set_ADC1_regular_conversions(enable);

      adc1_data = (adc_data & 0x00000FFF);
      adc2_data = ((adc_data & 0x0FFF0000) >> 16);

      lcd_print(1, 2, adc1_data);
      lcd_print(13, 2, adc2_data);

      bit_clr(GPIOC_ODR, 13);
      delay_ms(90);
   };
}

void setup()
{
   GPIO_init();
   ADC_init();
   LCD_Init();

   LCD_Cmd(_LCD_CLEAR);
   LCD_Cmd(_LCD_CURSOR_OFF);

   lcd_out(1, 1, "CH00        CH01");
}

void GPIO_init()
{
    enable_GPIOA(enable);
    enable_GPIOB(enable);
    enable_GPIOC(enable);
    pin_configure_low(GPIOA_CRL, 0, (analog_input | input_mode));
    pin_configure_low(GPIOA_CRL, 1, (analog_input | input_mode));
    pin_configure_high(GPIOC_CRH, 13, (GPIO_PP_output | output_mode_low_speed));
}

void ADC_init()
{
    setup_ADC1();
    setup_ADC2();
    setup_common_ADC_settings();
}

void setup_ADC1()
{
    ADC1_Enable();
    clr_ADC1_settings();
    set_ADC1_data_alignment(right_alignment);
    set_ADC1_scan_conversion_mode(disable);
    set_ADC1_continuous_conversion_mode(disable);
```

```
    set_ADC1_sample_time(sample_time_41_5_cycles, 0);
    set_ADC1_external_trigger_regular_conversion_edge(SWSTART_trigger);
    set_ADC1_regular_number_of_conversions(1);
    set_ADC1_regular_sequence(1, 0);
    set_ADC1_regular_end_of_conversion_interrupt(enable);
    ADC1_calibrate();
    start_ADC1();
}

void setup_ADC2()
{
    ADC2_Enable();
    clr_ADC2_settings();
    set_ADC2_data_alignment(right_alignment);
    set_ADC2_scan_conversion_mode(disable);
    set_ADC2_continuous_conversion_mode(disable);
    set_ADC2_sample_time(sample_time_41_5_cycles, 1);
    set_ADC2_external_trigger_regular_conversion_edge(SWSTART_trigger);
    set_ADC2_regular_number_of_conversions(1);
    set_ADC2_regular_sequence(1, 1);
    set_ADC2_regular_end_of_conversion_interrupt(enable);
    ADC2_calibrate();
    start_ADC2();
}

void setup_common_ADC_settings()
{
    set_ADC1_DMA(enable);
    set_ADC_mode(regular_simultaneous_mode_only);
    NVIC_IntEnable(IVT_INT_ADC1_2);
    EnableInterrupts();
}

void lcd_print(unsigned char x_pos, unsigned char y_pos, unsigned int value)
{
    unsigned char tmp = 0;

    tmp = (value / 1000);
    lcd_chr(y_pos, x_pos, (tmp + 48));
    tmp = ((value / 100) % 10);
    lcd_chr_cp((tmp + 48));
    tmp = ((value / 10) % 10);
    lcd_chr_cp((tmp + 48));
    tmp = (value % 10);
    lcd_chr_cp((tmp + 48));
}
```



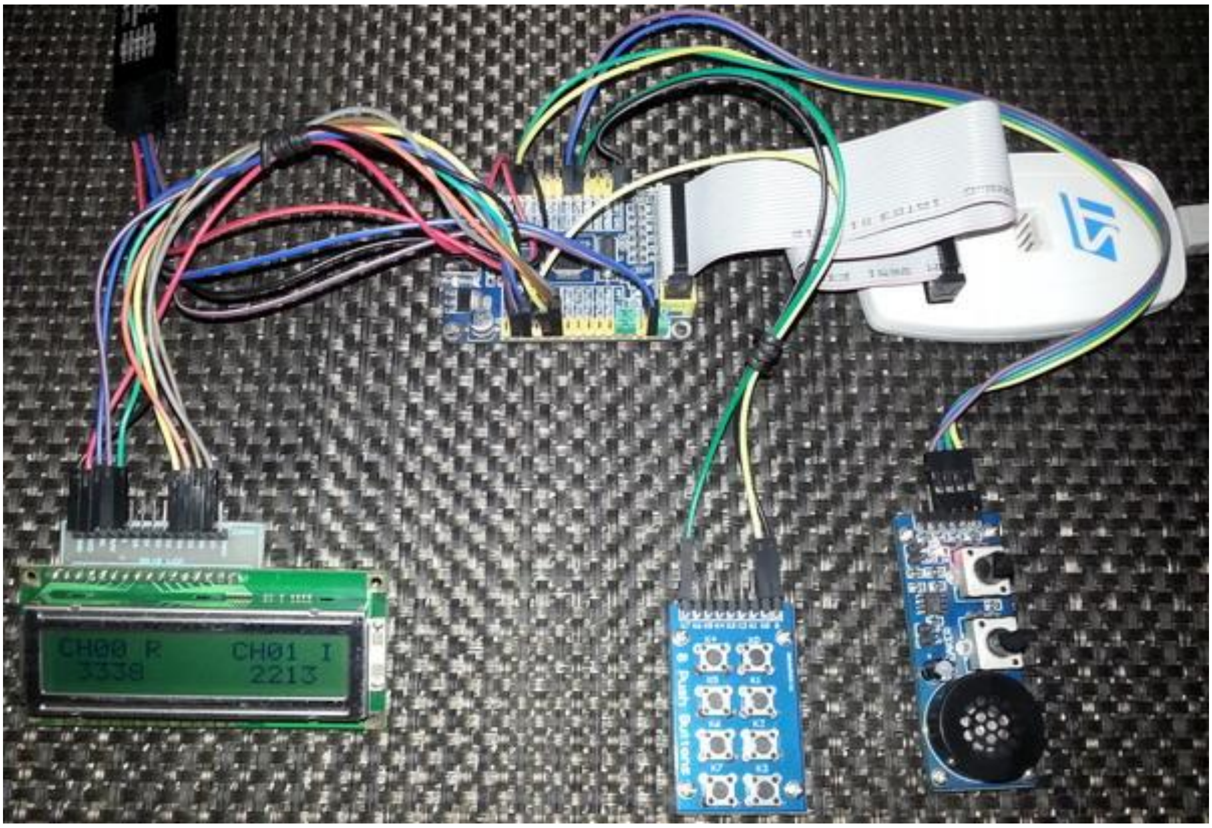
Demo video link: https://www.youtube.com/watch?v=sSGJUkX-mSg.

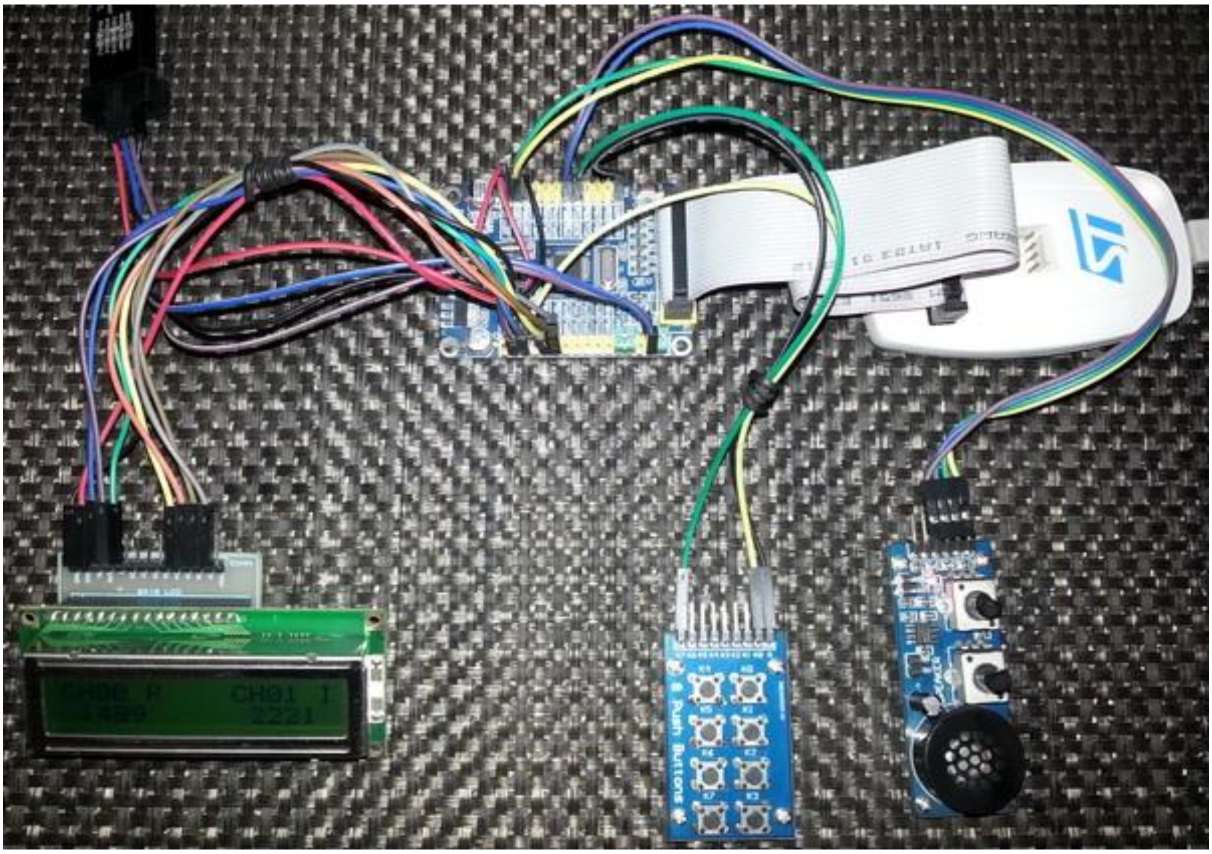
Till now we saw regular and injected groups independently. In this example we'll see them together. There are two ADC channels. One of them belongs to regular group while the other belongs to injected group. We'll see that the injected channel will override the conversion of regular channel. Both of these groups are triggered externally. A flashing LED is indicated which conversion is going on. Please check the video for better understanding.

```
#include "ADC.h"
#include "GPIO.h"
#include "AFIO.h"
#include "Ex_Int.h"

sbit LCD_RS at GPIOB_ODR.B1;
sbit LCD_EN at GPIOB_ODR.B2;
sbit LCD_D4 at GPIOB_ODR.B12;
sbit LCD_D5 at GPIOB_ODR.B13;
sbit LCD_D6 at GPIOB_ODR.B14;
sbit LCD_D7 at GPIOB_ODR.B15;

register unsigned int regular_adc_data = 0;
register unsigned int injected_adc_data = 0;

void setup();
void GPIO_init();
void ADC_init();
void exeternal_interrupt_init();
void lcd_print(unsigned char x_pos, unsigned char y_pos, unsigned int value);

void ADC1_2_ISR()
iv IVT_INT_ADC1_2
ics ICS_AUTO
{
   if(ADC1_SRbits.EOC)
   {
      ADC1_SRbits.EOC = 0;
      regular_adc_data = (ADC1_DR & 0x0FFF);
   }
   if(ADC1_SRbits.JEOC)
   {
      ADC1_SRbits.JEOC = 0;
      injected_adc_data = (ADC1_JDR1 & 0x0FFF);
   }
}

void void EXTI11_ISR()
iv IVT_INT_EXTI15_10
ics ICS_AUTO
{
   unsigned char s = 0;

   if(read_pending_reg(15) != 0)
   {
```

```
        for(s = 0; s < 3; s++)
        {
            bit_set(GPIOC_ODR, 13);
            delay_ms(10);
            bit_clr(GPIOC_ODR, 13);
            delay_ms(10);
        }
        pending_clr(15);
    }

    if(read_pending_reg(11) != 0)
    {
        for(s = 0; s < 6; s++)
        {
            bit_set(GPIOC_ODR, 13);
            delay_ms(90);
            bit_clr(GPIOC_ODR, 13);
            delay_ms(90);
        }
        pending_clr(11);
    }
}

void main()
{
    setup();

    while(1)
    {
        lcd_print(2, 2, regular_adc_data);
        lcd_print(12, 2, injected_adc_data);
    };
}

void setup()
{
    GPIO_init();
    ADC_init();
    exeternal_interrupt_init();
    LCD_Init();

    LCD_Cmd(_LCD_CLEAR);
    LCD_Cmd(_LCD_CURSOR_OFF);

    lcd_out(1, 1, "CH00 R");
    lcd_out(1, 11, "CH01 I");
}

void GPIO_init()
{
     enable_GPIOA(enable);
     enable_GPIOB(enable);
     enable_GPIOC(enable);
     pin_configure_low(GPIOA_CRL, 0, (analog_input | input_mode));
     pin_configure_low(GPIOA_CRL, 1, (analog_input | input_mode));
     pin_configure_high(GPIOB_CRH, 11, (digital_input | input_mode));
     pin_configure_high(GPIOC_CRH, 15, (digital_input | input_mode));
     pin_configure_high(GPIOC_CRH, 13, (GPIO_PP_output | output_mode_low_speed));
```

```
    pull_up_enable(GPIOB_ODR, 11);
    pull_up_enable(GPIOC_ODR, 15);
}

void ADC_init()
{
    ADC1_Enable();
    clr_ADC1_settings();
    set_ADC_mode(independent_mode);
    set_ADC1_data_alignment(right_alignment);
    set_ADC1_scan_conversion_mode(disable);
    set_ADC1_continuous_conversion_mode(disable);
    set_ADC1_sample_time(sample_time_239_5_cycles, 0);
    set_ADC1_sample_time(sample_time_239_5_cycles, 1);

    set_ADC1_injected_sequence(4, 1);
    set_ADC1_injected_number_of_conversions(1);
    set_ADC1_external_trigger_injected_conversion_edge(EXTI_15_trigger);
    set_ADC1_injected_end_of_conversion_interrupt(enable);

    set_ADC1_regular_sequence(1, 1);
    set_ADC1_regular_number_of_conversions(1);
    set_ADC1_external_trigger_regular_conversion_edge(EXTI_11_trigger);
    set_ADC1_regular_end_of_conversion_interrupt(enable);

    NVIC_IntEnable(IVT_INT_ADC1_2);
    EnableInterrupts();
    ADC1_calibrate();
    start_ADC1();
}

void exeternal_interrupt_init()
{
    AFIO_enable(enable);
    falling_edge_selector(11);
    falling_edge_selector(15);
    set_EXTI8_11(11, PB_pin);
    set_EXTI12_15(15, PC_pin);
    interrupt_mask(11);
    interrupt_mask(15);
    NVIC_IntEnable(IVT_INT_EXTI15_10);
}

void lcd_print(unsigned char x_pos, unsigned char y_pos, unsigned int value)
{
    unsigned char tmp = 0;

    tmp = (value / 1000);
    lcd_chr(y_pos, x_pos, (tmp + 48));
    tmp = ((value / 100) % 10);
    lcd_chr_cp((tmp + 48));
    tmp = ((value / 10) % 10);
    lcd_chr_cp((tmp + 48));
    tmp = (value % 10);
    lcd_chr_cp((tmp + 48));
}
```





Demo video link: https://www.youtube.com/watch?v=K5XTYtVEoSo.

Common Pitfalls

When dealing with new stuffs, we often make some silly mistakes. In the case of STM32 ADC, the following mistakes are pretty much common:

- ADC not powered.
- ADC not calibrated.
- ADC settings not cleared/reset to defaults.
- Incorrect GPIO port selection and configuration. If a pin is to be set for an analogue input channel then it should be either kept floating or configured as analogue input.
- Wrong mode of operation selected.
- Incorrect peripheral clock selection.
- Same channels configured for different ADCs, for example CH0 configured for ADC1 and 2.
- Different sampling times for two simultaneous channels in dual conversion mode.
- Interrupts not enabled when using them. MikroC's interrupt assistant feature should be used to avoid such mistakes. The interrupt assistant also help in code generation.
- Improper selection of regular and injected modes.
- Incorrect data alignment. Right alignment should always be used unless needed otherwise.
- Wrong variable type declaration. If the resulting data from a conversion is signed then signed integers should be used.
- Wrong ADC channel sequencing with incorrect channel order.

Final Words

There are many ways to meet a specific measurement case with STM32 ADCs. Imagination is the limit for so. As I stated earlier it is not possible for me to show all ADC operations in this post. Thus I would like readers to try and experiment whatever I showed. If you can take the challenge and if you have understood the basics then I would suggest that you experiment those stuffs which I didn't cover.

Finally there's a saying

ADC + DMA = Unbeatable Assets

Of course the DMA block is an asset and when there's an ADC-DMA collaboration, the result is a revolution in measurement. This issue was not regarding DMA and so when I cover the DMA block, I'll show more about ADC. For now this post is enough to introduce the basics of STM32 ADC.

Happy coding.

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