



### Using STM32F05xx analog comparators in application cases

#### Introduction

This document describes six application cases of the two analog comparators embedded in the ultra-low power STM32F05xx product line. The application cases are:

- Analog voltage monitoring
- Analog watchdog during Stop mode
- Pulse width measurement
- Pulse width modulation (PWM) signal control
- Capacitance measurement
- Brightness control using a light dependent resistor (LDR)

The six application cases demonstrate the usefulness of analog comparators and show how they are integrated with other peripherals, for example, the digital-to-analog-converter (DAC) and timers.

To ensure a quick start, four application cases presented in this document are implemented in C language and available in *Project\STM32F0xx\_StdPeriph\_Examples\COMP* within the *STM32F0xx\_StdPeriph\_Lib* package.

Please note that this document is not intended to replace the comparator section in the product reference manual RM0091 (for STM32F05xx ).

The peripheral power consumption should be consulted in the device datasheets.

**Table 1. Applicable products**

| Type             | Part numbers |
|------------------|--------------|
| Microcontrollers | STM32F05xx   |

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# 1 Analog voltage monitoring

The STM32F05xx devices embed a 12-bit analog-to-digital converter (ADC) which is very fast with a sampling rate of 1 Msample/s. However, with a 1.5 mA typical consumption, it can jeopardize battery life time if left powered-on continuously. It is therefore recommended to use analog comparators in application cases where the analog input voltage (sensor output) needs to be measured as soon as a pre-defined threshold is exceeded.

In the STM32F05xx devices, analog comparators are useful for monitoring the analog input voltage and powering-on the ADC when required. While monitoring the analog voltage, the device can enter Stop mode at the same time that both comparators are still powered on. Consequently, better consumption is achieved and power is saved.

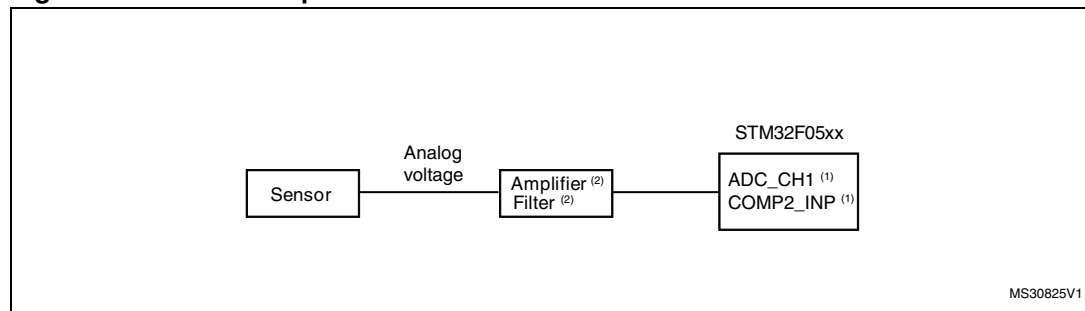
*Note: Analog comparators are powered by the internal reference voltage,  $V_{REFINT}$ , which is still powered-on in Stop mode. Once  $V_{REFINT}$  is disabled, the comparators can no longer be used.*

In an analog voltage monitoring application, where the sensor output voltage is lower than the threshold, the MCU remains in Stop mode, thereby saving power. As soon as the sensor output exceeds the threshold, the MCU is woken up, the ADC is powered on and the analog input voltage is measured. When the sensor output is under the threshold, the MCU re-enters Stop mode.

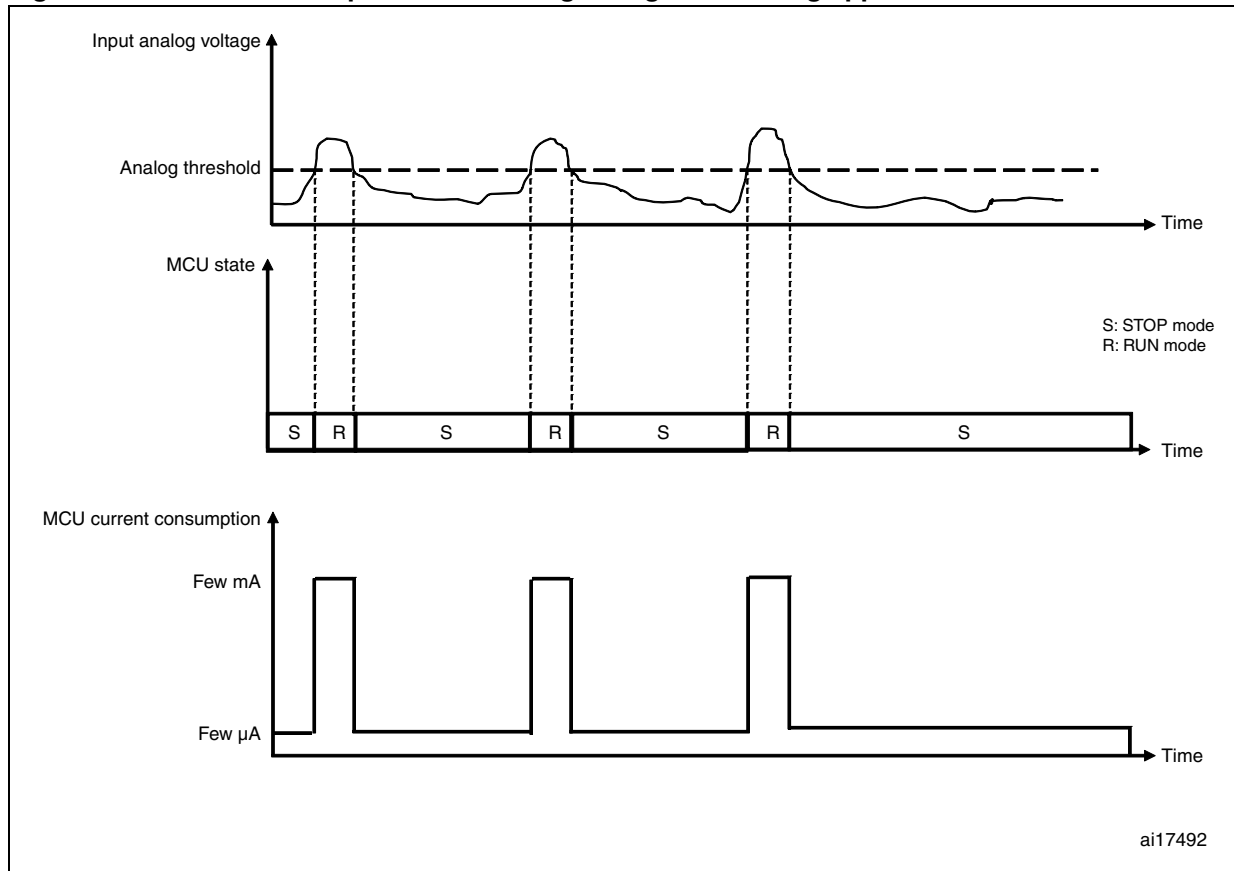
The average power consumption is dramatically reduced when compared with an application that continuously measures the analog voltage whatever the input value.

Figure 1 shows how to connect a sensor output (temperature sensor, pressure sensor, pyroelectric infrared detector, photodiode sensor) to an STM32F05xx device in an analog voltage monitoring application using comparator 2 (COMP2). COMP2 monitors the analog voltage in Stop mode while the ADC measures it in Run mode.

**Figure 1. Sensor output connection to COMP2**



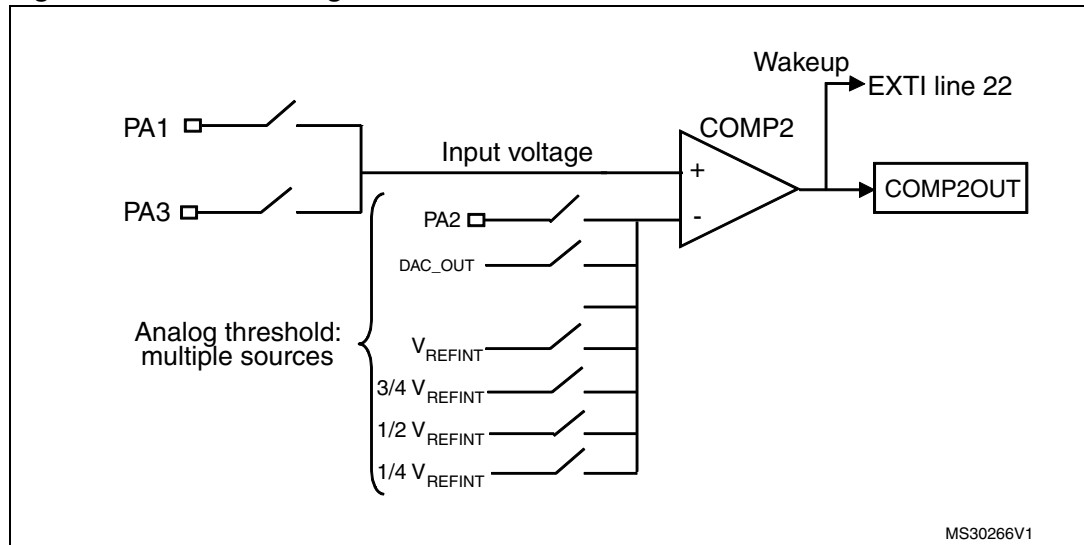
- 1. ADC\_CH1: AC channel 1  
COMP2\_INP: comparator 2 non-inverting input
- 2. Only if required.

**Figure 2. Power consumption in an analog voltage monitoring application**

The input analog voltage can be connected to PA1 for COMP1 or PA3 for COMP2. The analog threshold can be provided internally through  $V_{REFINT}$  and its submultiples or via an external pin through PA0 or PA5 for COMP1 or PA2 or PA5 for COMP2. DAC channel 1 (DAC\_OUT) cannot be used in such application cases since the DAC channel is powered off in Stop mode. COMPx wakes up the device from Stop mode through external interrupt lines (EXTI lines 21 and 22).

*Figure 3* shows the available configurations for inverting and non-inverting inputs.

Figure 3. COMP2 configuration



- 1. DAC\_OUT: DAC channel 1 output
- V\_REFINT: Internal reference voltage
- COMP2OUT: comparator 2 output (internal output)

When the device enters Stop mode, only COMP2 and the internal reference voltage, V\_REFINT, remain powered on.

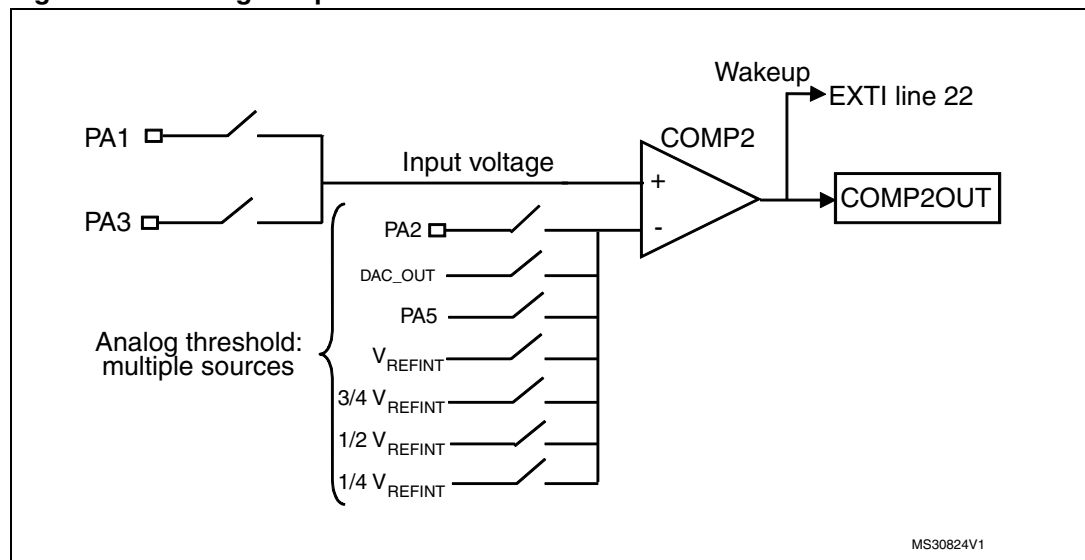
*Note:* Refer to the device datasheet for power consumption values.

## 2 Analog watchdog during Stop mode

The ADC in the STM32F05xx family can be used as an analog watchdog with programmable high and low thresholds. Nevertheless, the MCU must be kept in Run mode to be able to watch the analog voltage on the input since the ADC is powered off in Stop mode. For STM32F05xx devices, two analog comparators, COMP1 and COMP2, can be combined in window mode and used as an analog watchdog that remains powered on while the MCU is stopped. Consequently, lower consumption is achieved and power is saved.

[Figure 4](#) displays the configuration of two such analog comparators in window mode. Threshold1 is set to the internal reference voltage,  $V_{REFINT}$ , and threshold2 is configurable among  $V_{REFINT}$ ,  $3/4 V_{REFINT}$ ,  $1/2 V_{REFINT}$ ,  $3/4 V_{REFINT}$ , DAC\_OUT, or the external pin (PA2 or PA5). The analog input voltage can be applied on (PA1 or PA3) pin.

**Figure 4. Analog comparators combined in window mode**



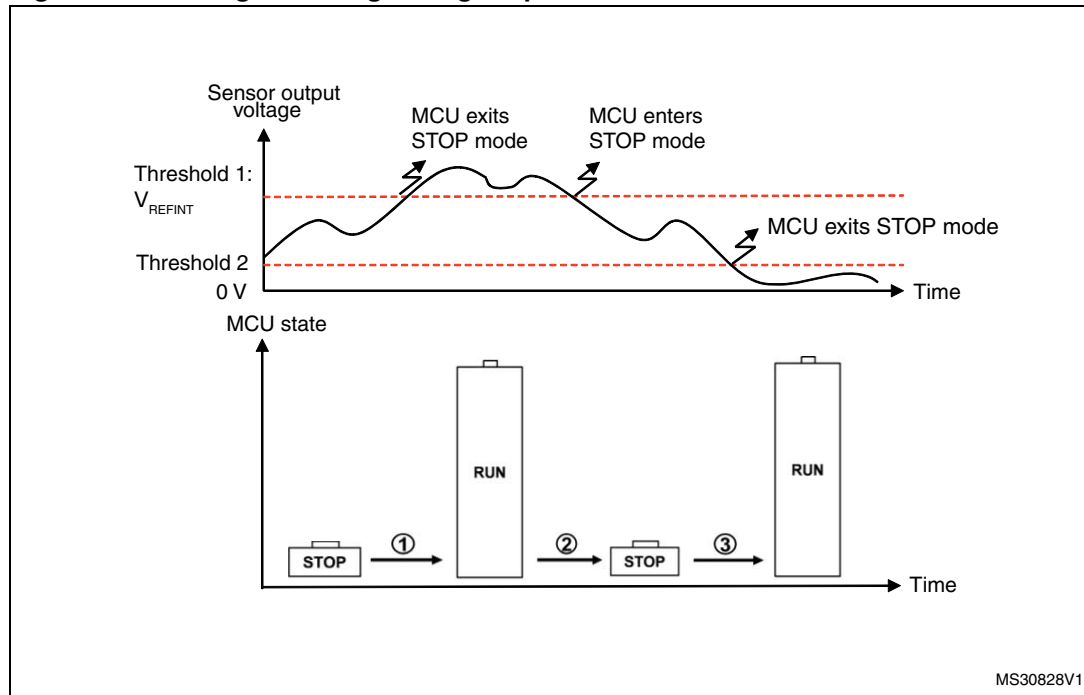
*Note:* DAC\_OUT1 cannot be used in Stop mode since the DAC peripheral is powered off.

In an analog watchdog application, COMP1 is configured through external interrupt line 21 (EXTI line 21) to exit the MCU from Stop mode when the analog input voltage exceeds  $V_{REFINT}$ . COMP2 is set, through EXTI line 22, to exit the MCU from Stop mode when the analog voltage goes below the lower threshold. Throughout the time the analog voltage is within the defined thresholds, the MCU is in Stop mode and power consumption is reduced.

When the analog voltage exceeds the defined thresholds, the average power consumption can be reduced by switching to Run mode.

[Figure 5](#) gives an overview of an analog watchdog application with threshold1 higher than threshold2.

Figure 5. Analog watchdog during Stop mode



1. While the MCU is in Stop mode, the input voltage exceeds threshold1 and the MCU exits Stop mode.
2. While the MCU is in Run mode, the input voltage goes below threshold1 and the MCU enters Stop mode.
3. While the MCU is in Stop mode, the input voltage goes below threshold2 and the MCU exits Stop mode.

Note: In Stop mode, only COMP1, COMP2 and  $V_{REFINT}$  continue to consume power. Refer to the specific device datasheet for power consumption values.



### 3 Pulse width measurement

In STM32F05xx devices, the COMP2 output can be redirected to the BKIN (Break input) of the embedded timer TIM1. Redirecting the COMP2 output allows a signal width or frequency with specific low and high levels (for example, a shifted signal) to be measured. [Figure 6](#) displays all the possible output redirections of the COMP2 output.

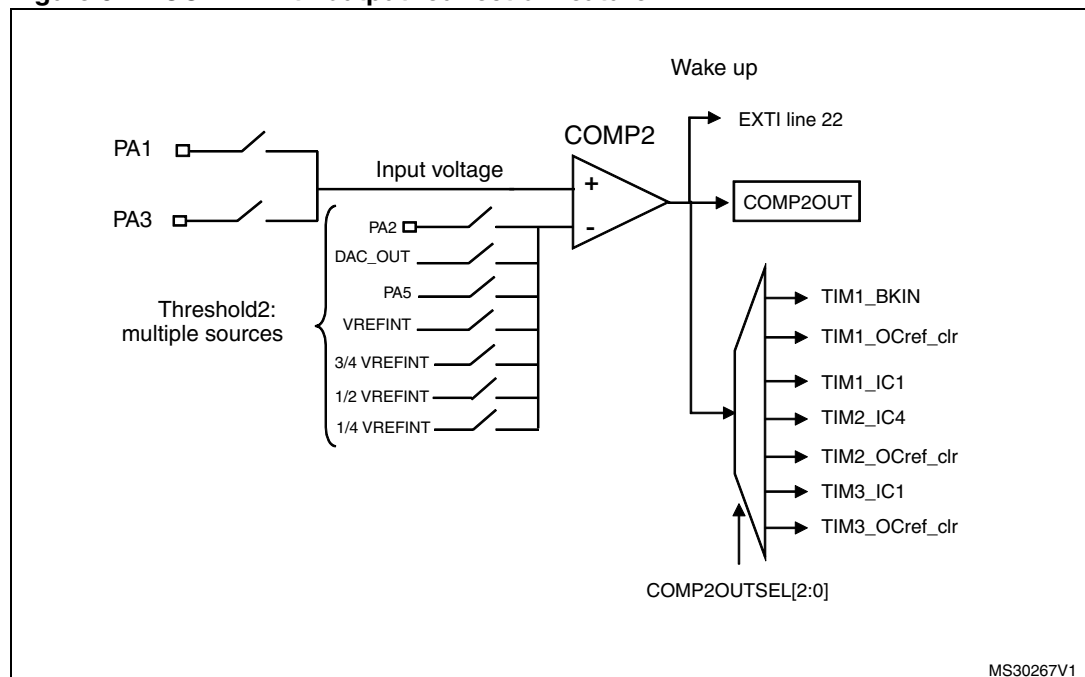
The input signal, whose signal width should be measured, is connected to (PA3 or PA1). The reference signal can be powered by:

- an internal reference ( $V_{REFINT}$ ,  $3/4 V_{REFINT}$ ,  $1/2 V_{REFINT}$ , or  $1/4 V_{REFINT}$ )
- the built-in DAC (channel 1)
- an external pin through PA2

The COMP2 output redirection is achieved through the COMP2OUTSEL[2:0] bits.

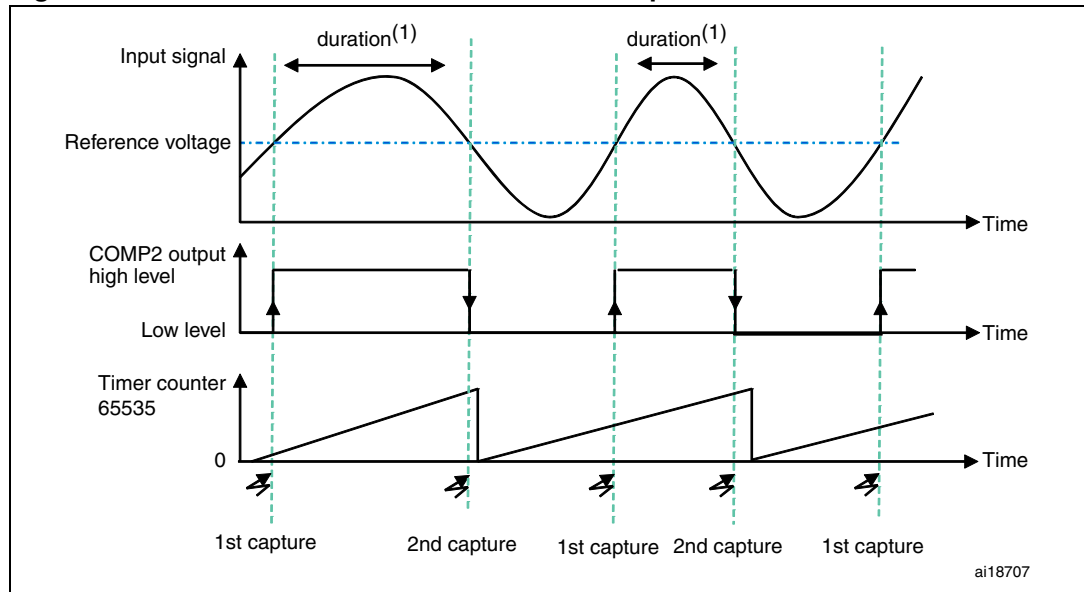
The timer input capture channel is configured to save the timer counter at both rising and falling edges. When the input signal goes above the reference voltage, the COMP2 output is at a high level, generating a rising edge on the timer input capture. When the input signal goes under the reference voltage, the COMP2 output is at low level, generating a falling edge. The elapsed time between the two consecutive events (falling then rising edge or rising then falling edge) represents the pulse width. Hence, the pulse width measurement is performed by simple subtraction of the counter values. [Figure 7](#) gives an overview of the pulse width measurement as measured by COMP2.

**Figure 6. COMP2 with output redirection feature**



1. DAC\_OUT: DAC channel 1 output  
 $V_{REFINT}$ : Internal reference voltage  
 COMP2OUT: Comparator 2 output (internal output)  
 TIM1\_BK1: Timer 1 Break input  
 TIMx ICy: Timer x input capture channel y  
 TIMx\_OCref\_clr: Timer x output compare reference clear

Figure 7. Pulse width measurement: COMP2 output redirection to timer



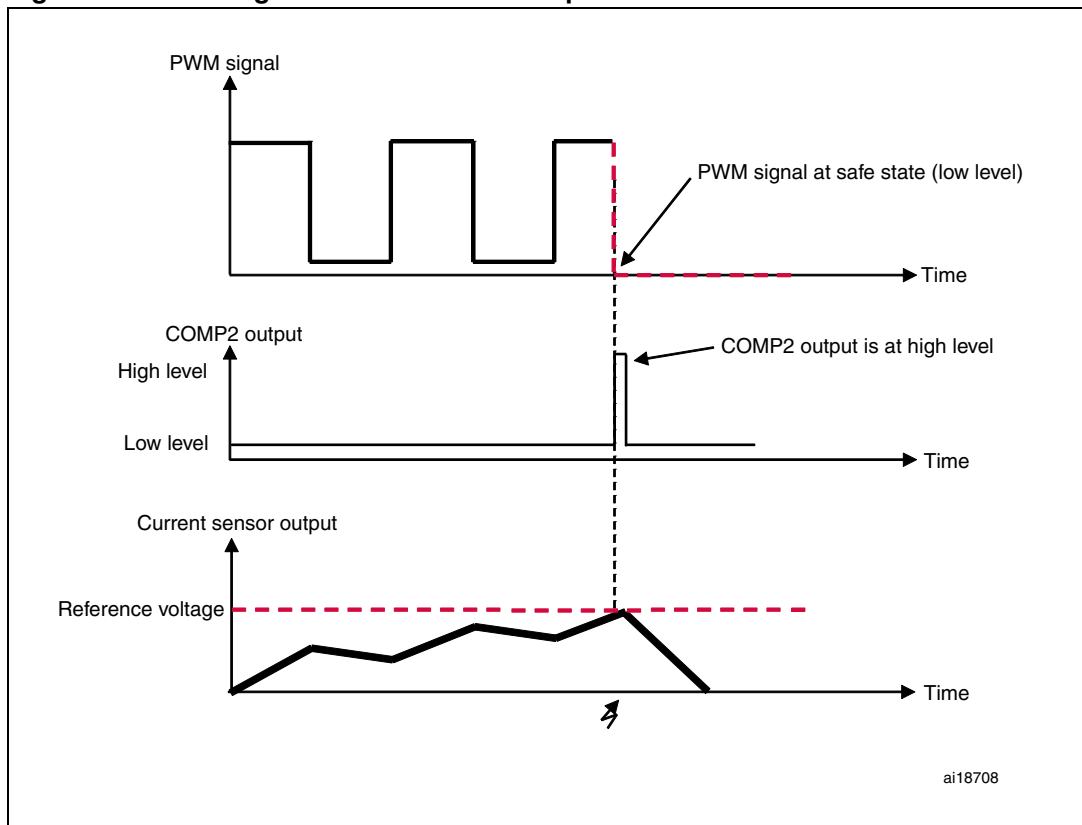
1. The duration that should be measured.

- Note:
- 1 The signal frequency can be achieved by configuring the timer input capture channel to save the counter value on only a rising or falling edge.
  - 2 The DAC outputs (DAC\_OUT) can be used as inverting inputs to allow the reference voltage level (threshold) to be internally provided and programmable by software from 0 V to  $V_{REF+}$ .

## 4 PWM signal control

In STM32F05xx devices, the COMP2 output can be redirected to the BKIN input(Break Input)of the embedded timer TIM1(refer to [Figure 6: COMP2 with output redirection feature](#)). The possibility of redirecting the COMP2 output can be used to provide a fast response time that is independent from the system frequency when an analog event occurs. This application case controls a PWM signal for motor control when the current sensor output is connected to the COMP2 non-inverting input. In this situation, the reference voltage is connected to the COMP2 inverting input. When the current sensor output exceeds the selected threshold, the COMP2 output goes high and the PWM signals switch to safe state.

**Figure 8. PWM signal control: COMP2 output redirection to timer**



*Note:* When the current sensor voltage reaches the reference voltage, the COMP2 output goes high. Consequently, the PWM and output compare reference signals go low (to safe state).

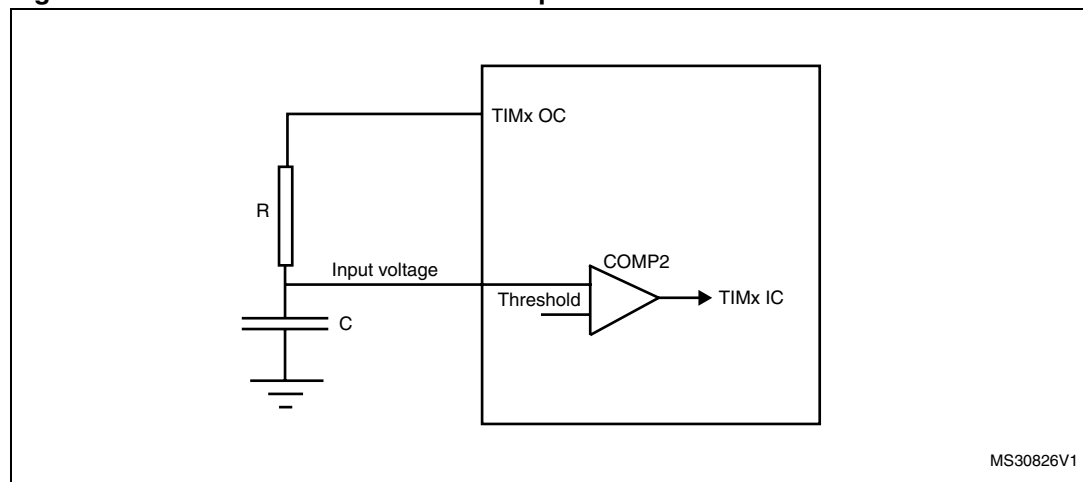
## 5 Capacitance measurement

The ability to connect the COMP2 output to the input capture channels of the timers allows the capacitance value to be measured. The principle is based on measuring the charge time of a resistor-capacitor (RC) network as follows:

- the charge time is measured
- the charge resistor (R) is already known
- the unknown capacitance (C) can be computed

*Figure 9* shows the hardware connection of the RC network to an STM32F05xx device.

**Figure 9. RC network connection for capacitance measurement**



The capacitance measurement procedure consists of charging and discharging the capacitor through the resistor. The charge/discharge function follows an exponential curve.

The charge function is given by *Example 1*.

### Example 1

$$\text{Input voltage} = V_{DD}(1 - \exp(-t/T))$$

where:

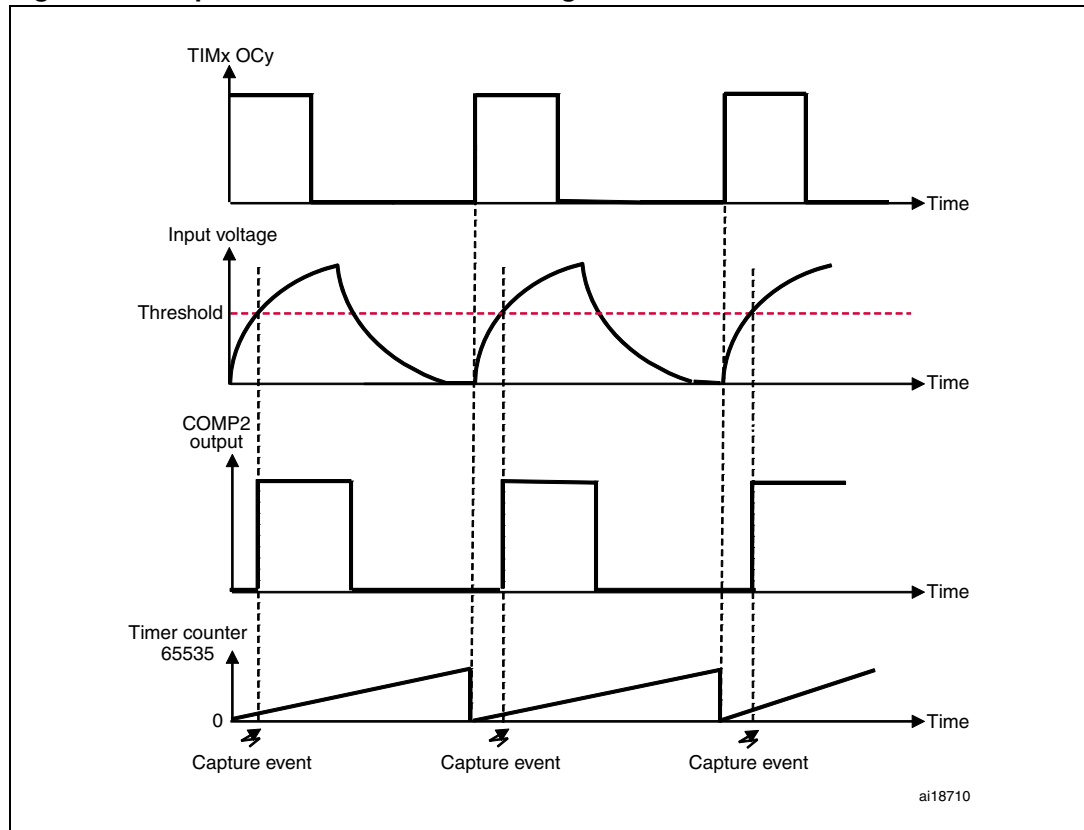
- $V_{DD}$  is the positive supply voltage
- $t$  is the time
- $T$  is the RC constant

Charging and discharging the RC network is ensured by the timer output compare channel (TIMx OC) configured in PWM mode. The timer channel is connected to the resistor.

The input voltage is connected to the COMP2 non-inverting input while the threshold is connected to the COMP2 inverting input. When the input voltage crosses the threshold, the COMP2 output switches to high level and a capture event occurs saving the counter value.

*Figure 10* shows the capacitance measurement.

**Figure 10. Capacitance measurement using COMP2**



At the moment where the input voltage crosses the threshold and the COMP2 output switches to high level, the charge function is given by [Equation 1](#).

**Equation 1**

$$\text{Threshold} = V_{DD}(1 - \exp(-t_c/T))$$

where "tc" is the time when the input voltage crosses the threshold.

Using [Equation 1](#) the capacitance value can be computed by [Equation 2](#).

**Equation 2**

$$C = -t/(R \times \ln(1-\text{threshold}/(V_{DD})))$$

Usually R, the threshold, and  $V_{DD}$  are constant, so, measuring the capacitance is reduced to solving for [Equation 3](#).

**Equation 3**

$$C = -t/K$$

where K is solved using [Equation 4](#)

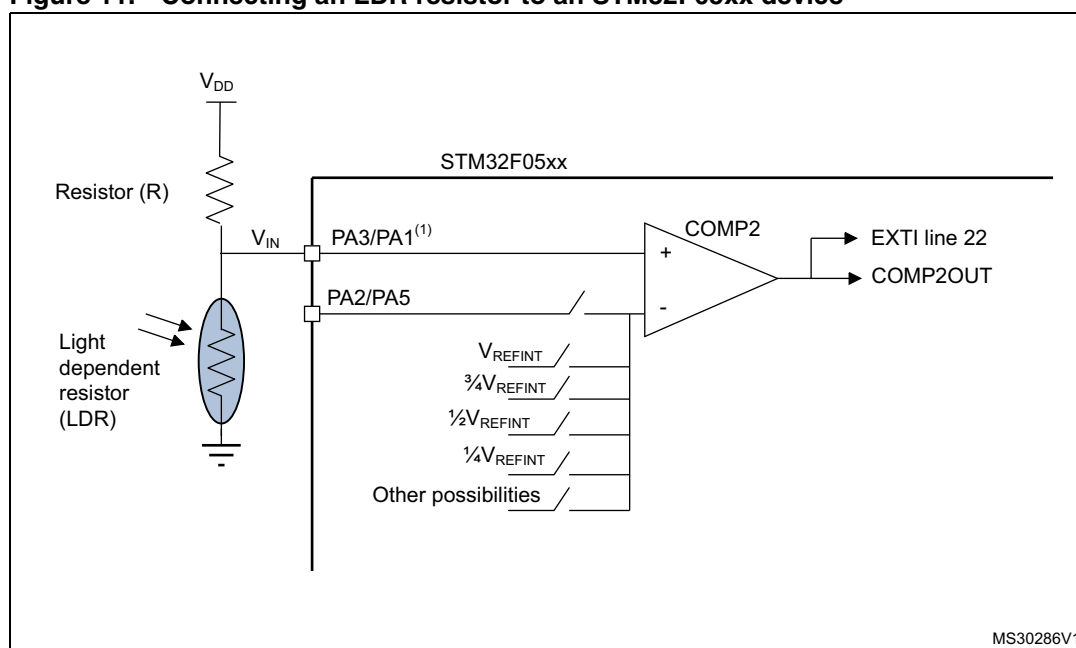
**Equation 4**

$$K = R \times \ln(1-\text{threshold}/(V_{DD}))$$

## 6 Brightness control using a light dependent resistor (LDR)

In some battery operated applications, the microcontroller needs to be powered if the environment is lit; otherwise, it must be kept powered off. For such applications, a light dependent resistor (LDR), whose resistance depends on light intensity, is useful to control the microcontroller state. Using an LDR sensor, the microcontroller can switch to/from low power mode depending on the voltage provided by the LDR resistor. *Figure 11* shows how to connect an LDR resistor to an STM32F05xx device. The COMP2 non-inverting input can be connected to an LDR resistor through a voltage divider ( $V_{IN}$ ). The threshold can be set externally to the PA2 or PA5 pin or set internally to  $V_{REFINT}$ ,  $3/4 V_{REFINT}$ ,  $1/2 V_{REFINT}$ , or  $1/4 V_{REFINT}$ . The COMP2 output (COMP2OUT) can be internally connected to EXTI line 22 which, when configured to detect both rising and falling edges on COMP2OUT, can be used as an interrupt source to switch to/from low power mode.

**Figure 11. Connecting an LDR resistor to an STM32F05xx device**



1. PA3 or PA1 can be used as COMP2 non-inverting input. Thus,  $V_{IN}$  can be connected to PA3 or PA1. The voltage  $V_{IN}$  can be computed using [Equation 5](#).

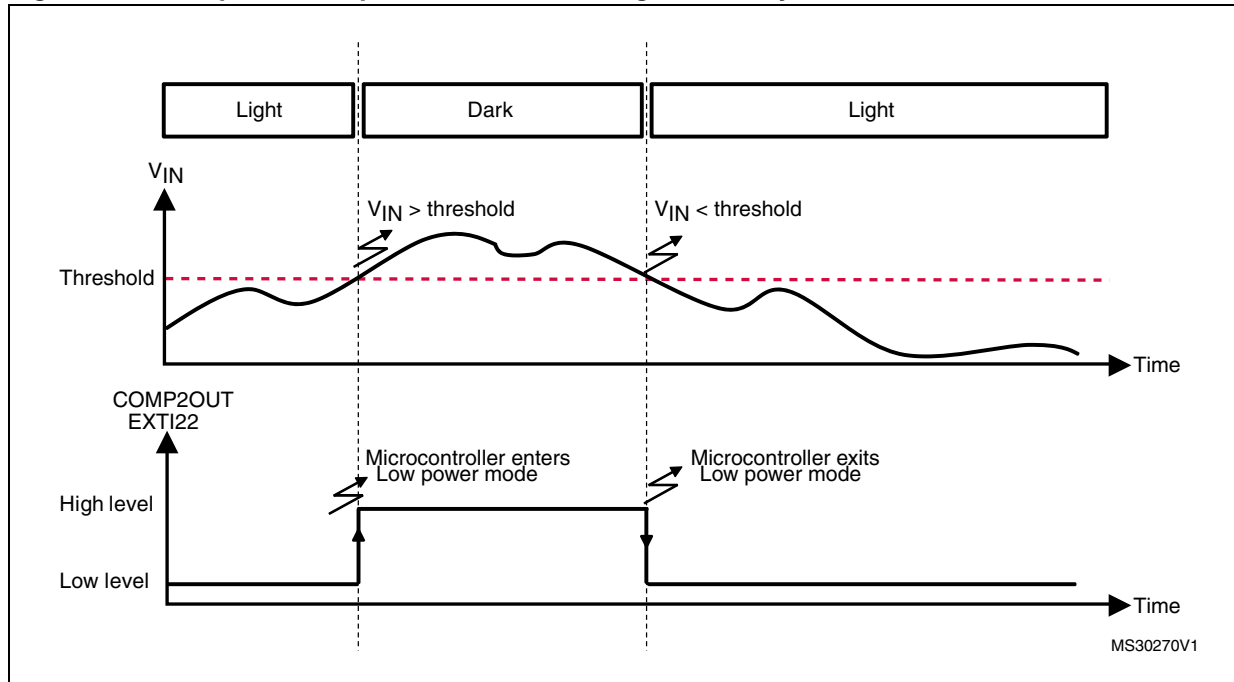
**Equation 5**

$$V_{IN} = \frac{LDR}{(LDR + R)} \times V_{DD}$$

As the LDR resistance decreases with increasing light intensity, the voltage  $V_{IN}$  decreases as more light shines on the LDR.

The top part of [Figure 12](#) shows the evolution of  $V_{IN}$  as a function of light variation. The selected threshold (COMP2 inverting input) defines the limit of dark/light. The bottom part of [Figure 12](#) shows that the COMP2 output (COMP2OUT) level depends on  $V_{IN}$  and consequently on light intensity. Using EXTI line 22 (which is internally connected to COMP2OUT), the microcontroller can detect the COMP2OUT level switch (from a high level to a low level or *vice versa*).

**Figure 12. Comparator output behavior versus light intensity**



The LDR resistor can be used in other microcontroller-based applications rather than darkness control (for example: DC relay control and AutoFocus).

For other uses of analog comparators using LDR resistors, refer to the STM320518-EVAL (for STM32F05xx devices) demonstration firmware.

In this demonstration, when the luminosity changes, the progress bar displayed on the color LCD changes according to light intensity level detected using the comparator.

## 7 Revision history

**Table 1. Document revision history**

| Date        | Revision | Changes          |
|-------------|----------|------------------|
| 26-Jun-2012 | 1        | Initial release. |



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