AN4885
Application note

High brightness LED dimming using the STM32F334 Discovery kit

Introduction

This application note illustrates the high brightness LED dimming feature embedded within the STM32F334 Discovery kit (32F3348DISCOVERY). This demo application has been built with the STM32F334xx Cortex® M4 microcontroller, designed for digital power conversion applications. It aims to demonstrate the usage of the various on-chip peripherals: the brand new 10-channel high-resolution timer (HRTIM), the digital-to-analog converter (DAC), the ultra-fast comparator (COMP), the direct memory access controller (DMA). This high level of integration inside the microcontroller is reducing the number of external required components generally included in LED dimming analog components based solutions. The direct hardware connections between DAC and COMP, COMP and HRTIM, HRTIM and DMA are also used in order to decrease the CPU load, and especially eliminating any latency in the system.

An additional description related to the triangle waveform generation from the high-resolution timer is included to this application note.

The STM32F334 Discovery kit also includes a buck/boost DC/DC converter that is described separately to this application note.

This application does not require any additional hardware or software. Once the STM32F334 Discovery kit is powered-up through a mini-B USB cable connected to the host PC, the user can access to the high brightness LED dimming demonstration software.

This example comes preloaded with your STM32F334 Discovery kit.

Reference documents

- Getting started with STM32F334 Discovery kit (UM1733).
- Discovery kit for STM32F334 microcontrollers (DB2343).
- Discovery kit for STM32F3 series with STM32F334C8 MCU User Manual (UM1735).

The above documents are available from STMicroelectronics web site (http://www.st.com).

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1 Application description

1.1 Hardware required

This application uses STM32F334 Discovery kit on-board high brightness LED (LD7), 4 signal LEDs (LD3 to LD6) and the User push-button B1. No additional components are required.

Note: This example and its hardware are totally independent of buck/boost DC/DC converter described in another document.

1.2 Hardware settings of the STM32F334 Discovery kit

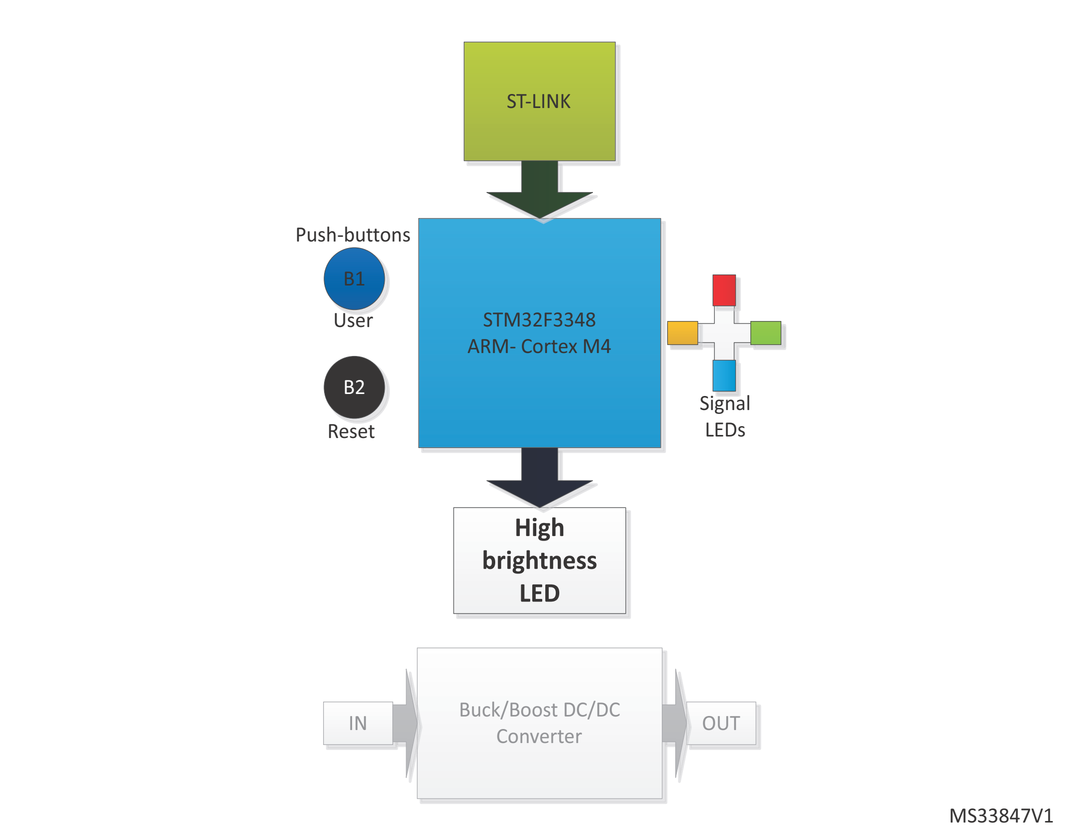
The Idd jumper JP3 must be fitted and all SBx solder bridges set in their initial factory configuration.

See STM32F334 Discovery kit user manual for further information related to hardware.

1.3 Application schematics

Figure 1 shows the description of STM32F334 Discovery kit hardware.

Figure 1. Overview of STM32F334 Discovery kit



1.4 Application principles

1.4.1 Overview

The STM32F334 Discovery kit embeds the minimum components required to implement the LED dimming function. All the other needed functions are managed by the STM32F334xx microcontroller thanks to its embedded features: the LED current sense measurement and comparison with the target current is done with the internal comparator. The PWM generation to drive the power MOSFET and the current mode control is managed by internal high-resolution timer.

There are several modes available driving the high brightness LED:

- Automatic dimmer: This mode scans the entire brightness range.
- Flash mode: The high brightness LED is turned ON with a 10Hz frequency at full power (t_{ON} = 20 ms, t_{OFF} = 80 ms).
- Manual dimmer: The brightness can be adjusted manually by continuing to hold down push button B1 and it can be increased or decreased successively.

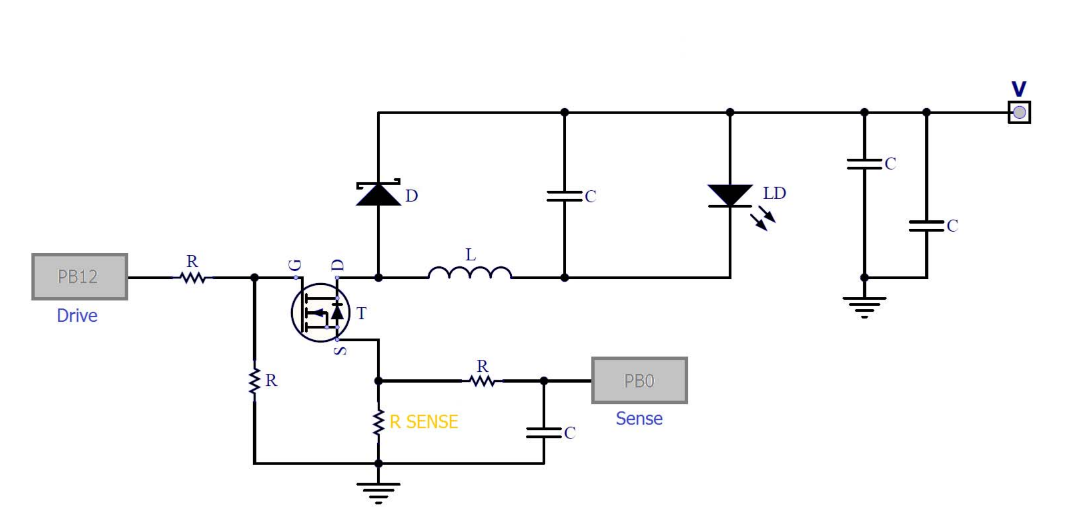
Note: For safety reasons, the maximum high brightness LED forward current has been limited by software to 250 mA and an optical cube-shaped protection has been placed over the LED. Do not override this current limitation and do not remove the optical protection while the LED is operating. These precautions must be taken due to the high luminous flux emitted by the high brightness LED. Do not expose your eyes to direct light.

1.4.2 High brightness LED dimming

Figure 3 shows the high brightness LED dimming block diagram and the different microcontroller resources used in this application.

One of the high-resolution timer outputs is connected to the power control MOSFET driving the high brightness LED. This unit uses an inverter buck converter topology and includes an inductor connected serially between the MOSFET drain pin and the high brightness LED. A sense resistor (R SENSE) is connected to the MOSFET source pin and this voltage level is fed back to the internal comparator COMP4 (PB0). The electrical scheme is shown in *Figure 2*.

Figure 2. High brightness LED buck converter

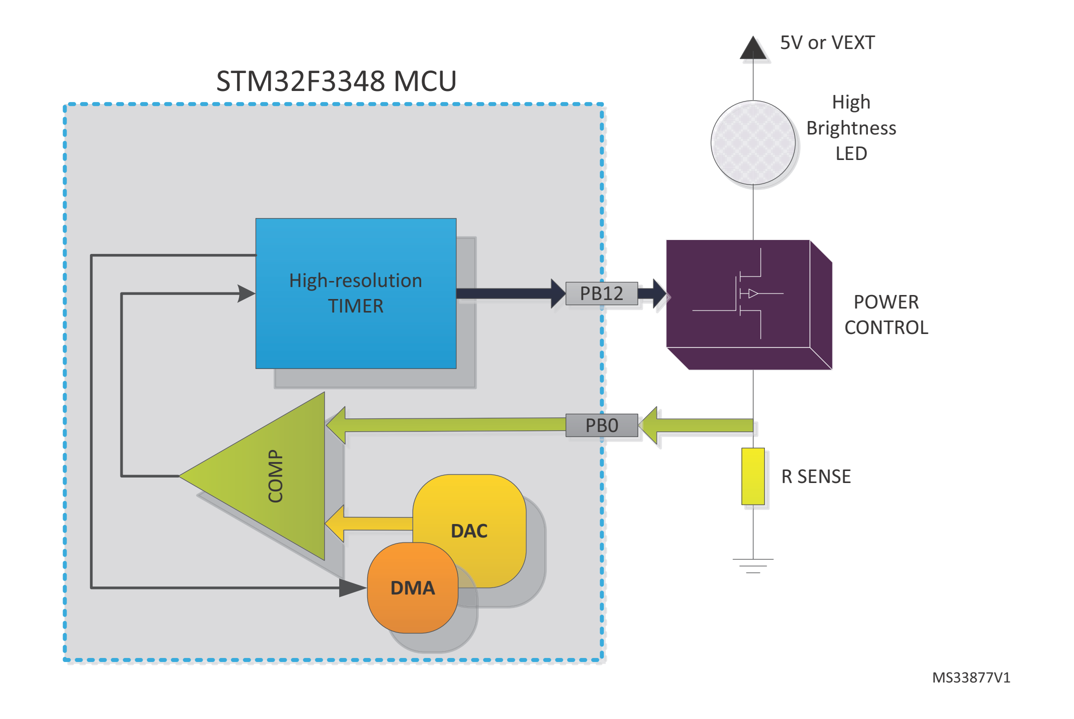


This voltage is the image of the high brightness LED forward current.

The second input of COMP4 is driven by the DAC peripheral that provides the threshold level controlling the LED forward current.

A DMA channel is used to service all DAC channel DMA requests. Finally, the comparator output is then connected to the high-resolution timer to trigger and turns off the PWM generation once the current level is reached through the R SENSE resistor level voltage.

Figure 3. LED dimming function block diagram

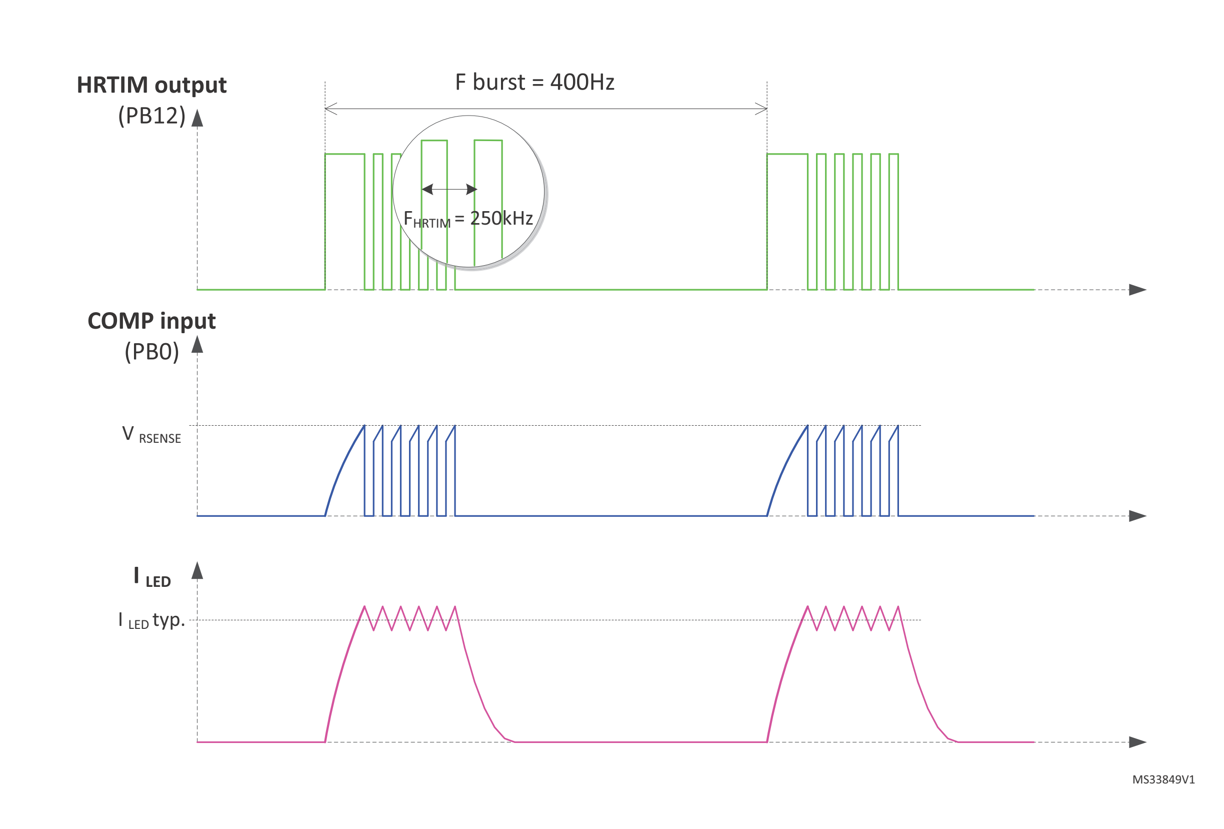


The high-resolution timer is set to have a PWM frequency of 250kHz then the high brightness LED is driven for a maximum period of 4 µs. At the LED ignition, this time is lengthened for the first pulse as the current starts flowing.

When the high-resolution timer switches the high brightness LED ON via the power control transistor, the forward current increases through the LED until it reaches its maximum value of 250 mA detected on the comparator by the way of R SENSE resistor level. The high brightness LED is then turned OFF. The LED brightness is adjusted proportionally to the number of pulses delivered by the high-resolution timer. The dimming function is achieved by alternating pulses of 250mA current controlled (250kHz PWM), and sequences with no current (the MOSFET is no more driven). To prevent any flickering effect that the human eye would be able to detect, the driven pulses are repeated in a burst mode at a frequency equal to 400 Hz.

Figure 4 shows the waveforms output by the high-resolution timer and the R SENSE voltage feedback to the microcontroller. The current across the high brightness LED is also represented. The brightness of the LED is proportional with the increase in forward conduction current. As soon as the comparator threshold has been reached, the high brightness LED current is regulated at the average value corresponding to I_{LED} typical value. The dimming is performed at constant current (CC) also called current-mode control (CMC) and the LED is directly driven by the power supply. This technique prevents for any change in color temperature that can be observed with variations in the LED forward current and is a key point for dimming applications.

Figure 4. LED dimming signals generation



1.4.3 Anti-flicker with dithering techniques

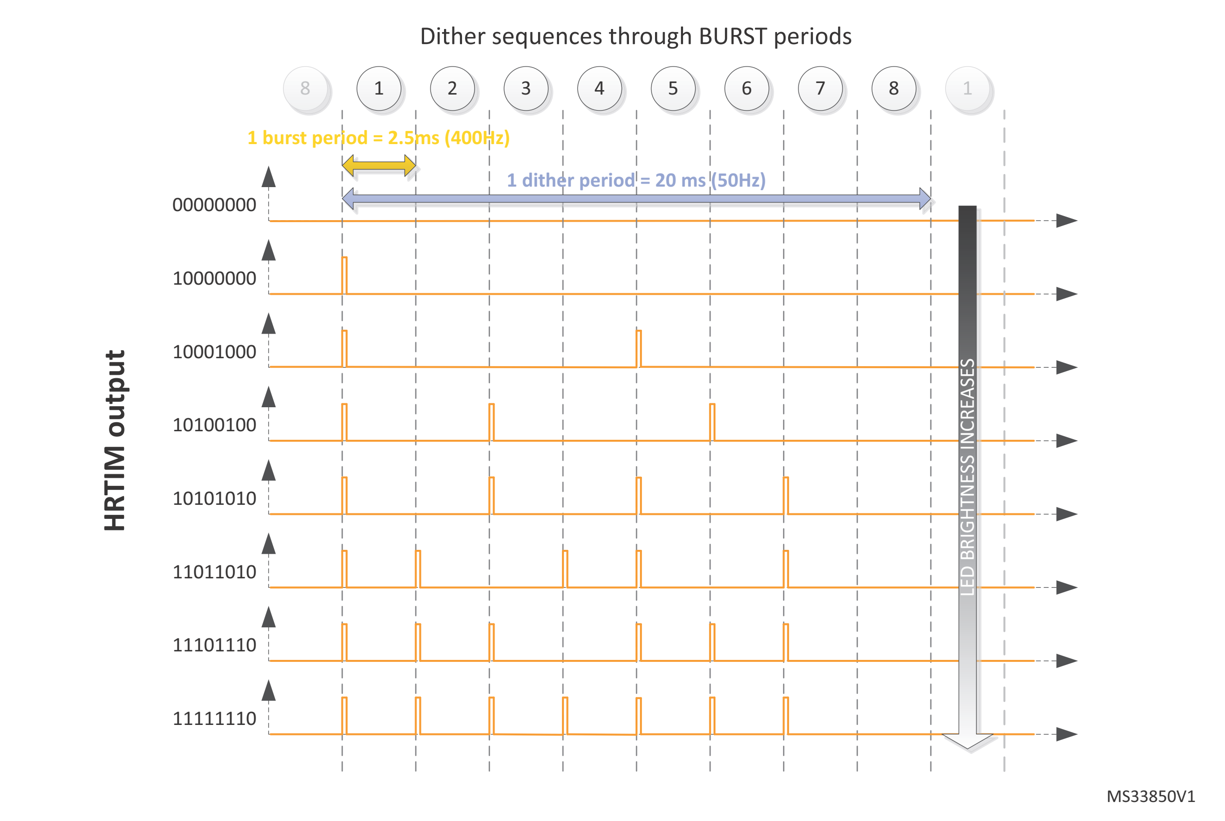
In this demonstration, an automatic dimmer mode is available where the high brightness LED is driven from the minimum brightness till its maximum. This allows scanning the entire brightness range of the LED. This mode is performed by using some advanced techniques such as the dither sequences. As the high brightness LED is driven using a current-mode control, the PWM duty cycle is controlled automatically so that the high-resolution timer output, and consequently the LED itself, shuts down only since the LED current level goes over the internal comparator threshold. As soon as the high brightness LED is turned ON, the high-resolution timer output remains high until the necessary LED current is achieved. If the high brightness LED must be controlled with the minimum luminous flux, only 1 pulse is applied and repeated each 2.5ms (t = 1/400) at every burst period. However, this only pulse can be perceived by the human eye and the minimum amount of brightness cannot be reduced in that case.

Therefore a method has been introduced in this demonstration that makes use of the dither generation scheme. Instead of setting ON the high brightness LED at each burst sequence, the command can vary according to the amount of desired luminous flux and add some extra ON states during the periodic LED ignitions.

This technique consists of different sequences and patterns that are scheduled in each of the 8 repetitive burst periods. This design flexibility can be achieved with the features of the embedded high-resolution timer of STM32F334xx device. The diagram below shows how the brightness can be set gradually according to different dither patterns. This method is used for the lowest brightness range but also during the automatic dimming mode. In this first operating range, this allows dimming for the LED at the minimum brightness and for all other cases to eliminate any flickering effect during the fast dimming of the LED where transitions can be visible.

The burst frequency is 400Hz. If the dither patterns are repeated for each of the 8 burst periods, a new dither sequence can be applied every 20ms and repeated indefinitely for constant current settings. This 20ms value is still suitable to prevent any eye flicker perception.

Figure 5. Dithering techniques

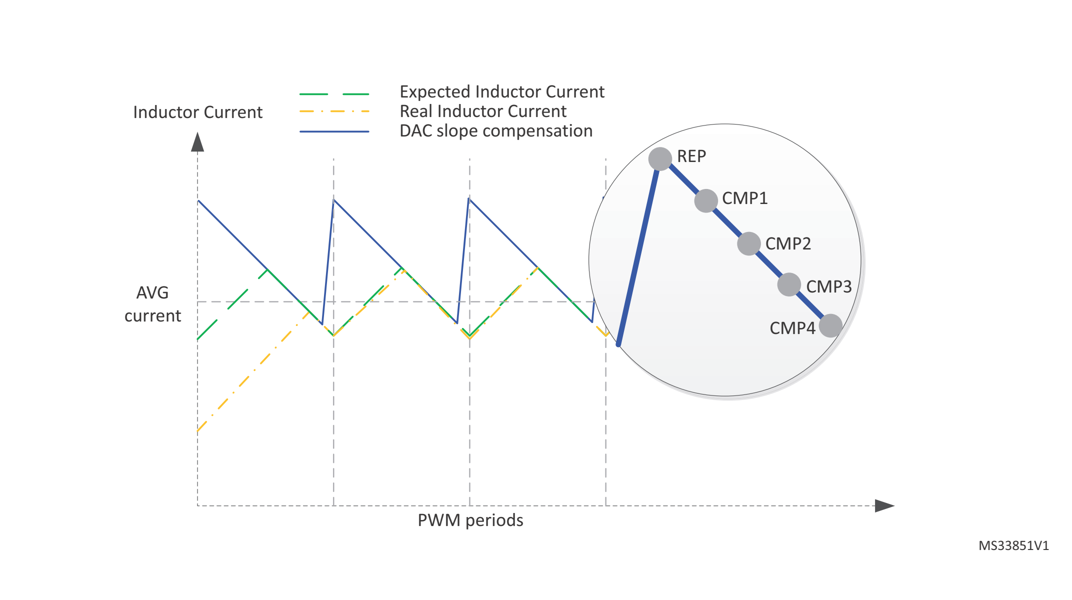


1.4.4 Slope compensation

By using a current-mode buck converter topology, the energy applied into the inductor at every PWM pulse is converted through the R SENSE resistor and fed back to the microcontroller as a current regulation control loop. This voltage level is directly connected to one comparator input when the other input is fed by the DAC peripheral which is able to deliver a linear ramp which creates slope compensation.

Drawback of the current-mode convert is subharmonic oscillation that can be observed if the PWM duty cycles applied in the switching frequency are greater than 50 per cent. Indeed, the waveform expected for the steady state of the inductor current is perfectly triangular. Actually, the necessary duty cycle controlled by the PWM to energize the inductor can exceed 50 per cent. A way to limit subharmonic oscillation is then to introduce slope compensation using the DAC peripheral, here dedicated to this task. The DAC output signal delivers a linear ramp set synchronously with the high-resolution timer events at different scheduled times. These points are represented on the figure below as repetition period event REP and compare events CMP1 to CMP4. By injecting slope compensation in the current loop, the stability is recovered for all values of the duty cycles. The subharmonic oscillation may result in a PWM switching frequency degradation that can reach one half of the initial switching frequency and would interfere with LED current regulation.

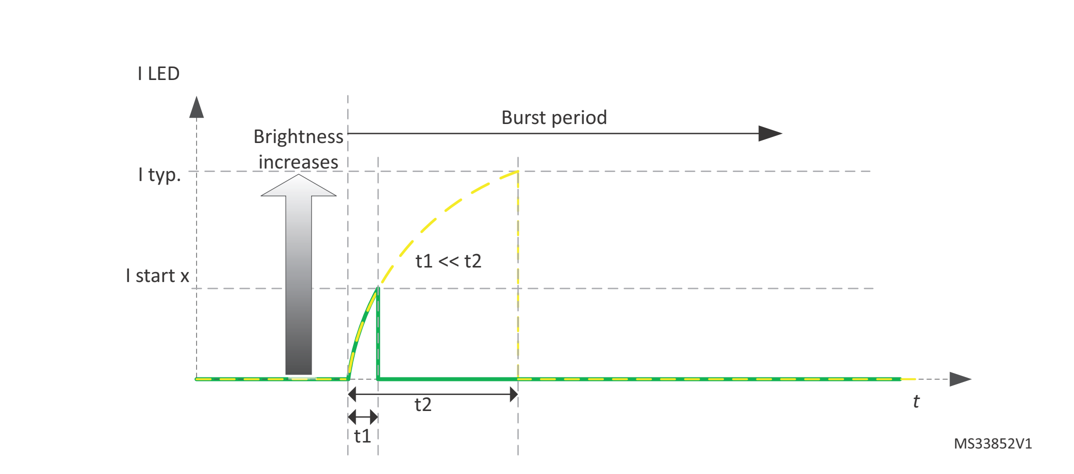
Figure 6. DAC slope compensation



1.4.5 High brightness LED current regulation soft start

Another technique implemented in this automatic dimmer demonstration is to start and stop the LED with a progressive current threshold adjustment in the regulation control loop. This allows control of the LED with the very minimum forward current, thereby dimming the LED much more efficiently. By looking at the yellow first pulse emitted during a single burst period, it takes some time (t2) for the high brightness LED current to achieve its target value as it first starts from zero. This time t2 is relatively longer than the high-resolution timer base time, and can be evaluated approximately to 2 or 3 timer periods maximum. This means that if the LED has to be driven with only one single pulse, it’s necessary to wait until the current rises up to the regulation value corresponding to t2 time. The soft start current regulation shortens the time required to establish the current regulation by progressively setting the current thresholds with the DAC peripheral across the period and triggering the PWM off at I start x value. For instance, for the first 250 burst periods, the current threshold values may start from zero and increment until they reach the typical current value. The result is a lower amount of global light energy during the start of the LED ON sequence until the thresholds achieve their nominal values corresponding to I typical for the high brightness LED forward current. This is explained on the figure below.

Figure 7. Soft start current regulation



1.4.6 Getting started with the application

The application needs to be connected to a PC thanks to a mini-B USB connector on the STM32F334 Discovery kit side.

As soon as the application is power supplied, all signal LEDs (LD3 to LD6) are lit one by one and the high brightness LED is not controlled (OFF state). In that state, the triangle waveform generation is performed (see the description below).

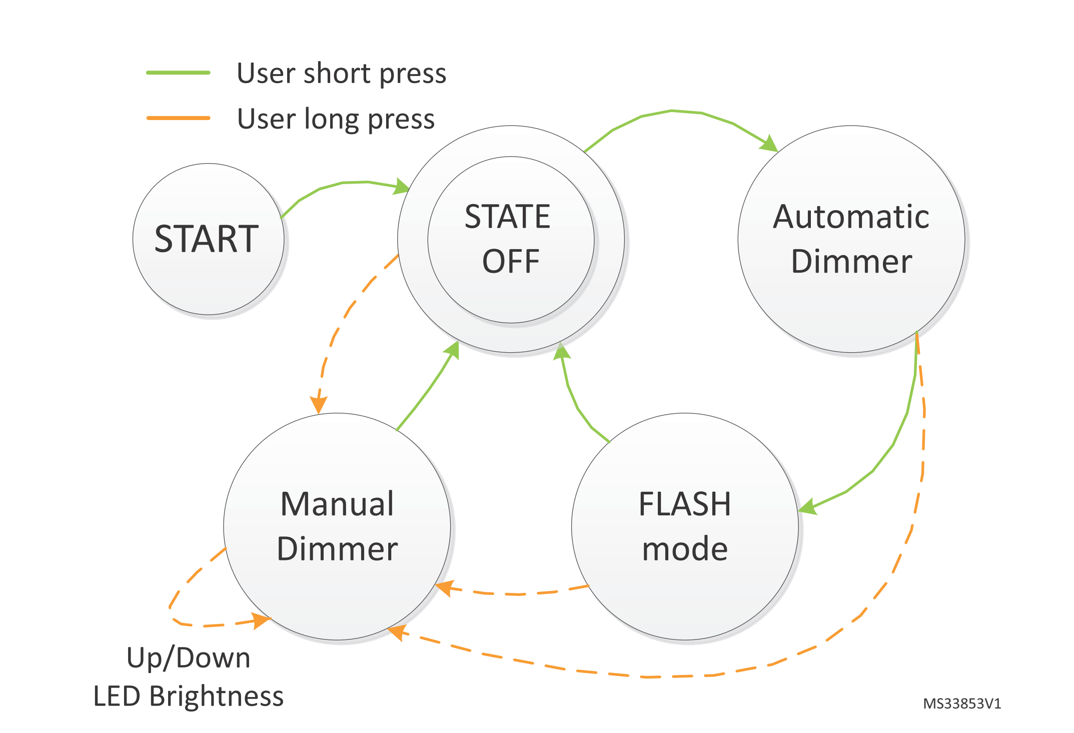
As soon as the user button B1 is pressed, the application enters automatic dimmer mode that covers the entire brightness range with the features explained above. The red LED LD3 is ON when the brightness increases whereas the blue LED LD6 is ON when the brightness decreases.

If the user button B1 is pressed again, then the application enters flash mode. Leds LD4 and LD5 (orange and green) are toggling at the flash rate. The high brightness LED is switched ON and OFF at the frequency of 10Hz and the brightness is set at its maximum.

By pressing again B1, the application comes back to the OFF state with the high brightness LED OFF and LD3 to LD6 periodically lit.

At any time, the user can switch the application into manual dimmer where the LED brightness can be set manually by maintaining the user button pressed for more than one second. The LED brightness first starts to increase from zero to maximum when LD3 (red) is turned ON. When the brightness reaches the maximum value then LD3 toggles to show maximum brightness achieved. If a second and long push onto the user button is performed, then the manual dimmer is active for decreasing the LED brightness and LD6 (blue) is turned ON. When the brightness reaches the minimum value then LD6 toggles to show minimum brightness achieved. To exit the manual dimmer, quickly press the user button and the application returns to high brightness LED OFF state. The figure below describes and summarizes all possible sequences.

Figure 8. Application state diagram



1.4.7 Triangle waveform generation

The triangle waveform generation is an example performed in parallel of the high brightness LED demonstration that uses features of the high-resolution timer. Anyway, there is no interaction between these two examples except that the triangle waveform generation can be observed at a specific state of the execution software.

If the demonstration software remains in STATE OFF, a triangular waveform is generated on TP3. The difference between the positive slope and the negative slope of the triangle aims to show the benefit of the HRTIM high-resolution (refer to *Figure 9*).

In this example, the objective is to generate a triangular waveform, with a frequency of 25Hz and an amplitude of around 600mV (from Vmin=400mV to Vmax=1V).

The HRTIM channel D1 is programmed to output a 2MHz PWM on the STM32F334xx PB14 port. This PWM is filtered externally, through a RC filter (R32 and C23), to get the 25Hz triangular signal.

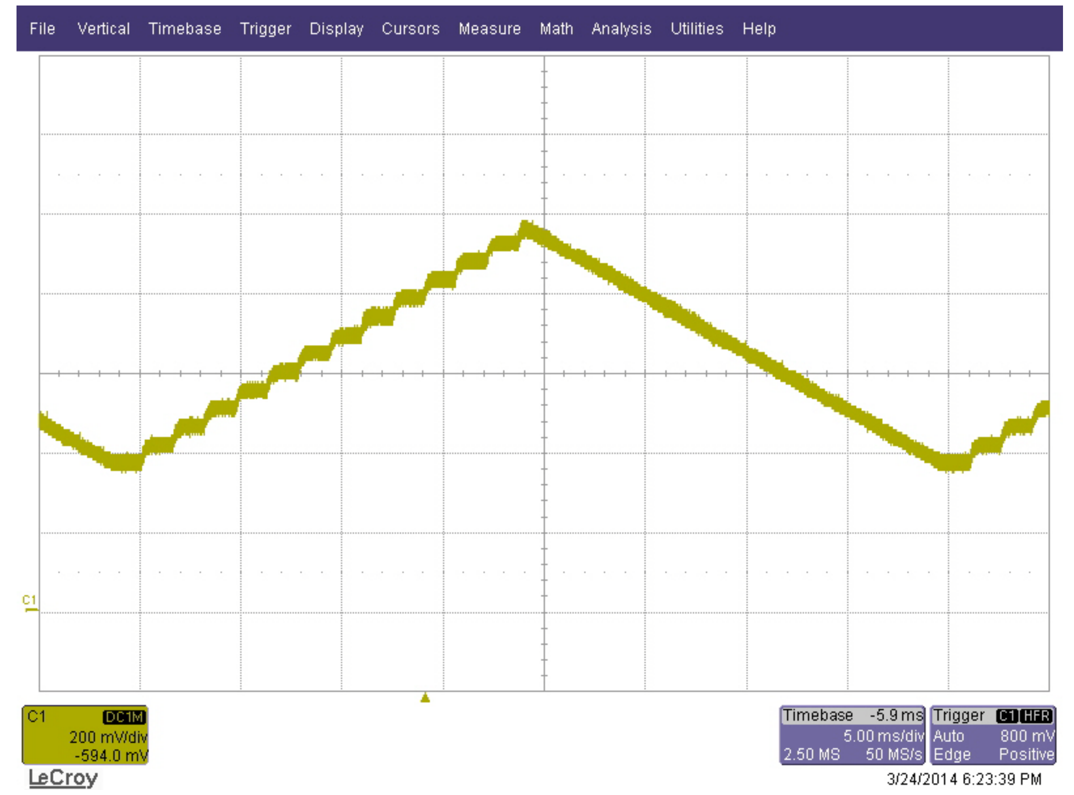
In order to observe the high-resolution benefit, the positive slope of the triangle is generated without using the high-resolution of the HRTIM (this corresponds to what could be achieved with the TIM1 timer for example), while the negative slope is generated using the high-resolution.

The HRTIM is fed with a 144MHz clock, but the analog delays embedded in the HRTIM allow to reach an equivalent clock frequency of 144MHz x 32 = 4.608Ghz.

Considering a PWM at 2MHz with a duty cycle range from 0 to 100%, this gives 72 levels without the high-resolution (equivalent to a 6-bit resolution Digital to Analog converter), and 2304 levels with the high-resolution (equivalent to a 11-bit Digital to Analog converter).

In our example, as the supply is 3.3V (full duty cycle range of the PWM), the ramp from 400mV to 1V is generated from 13 steps without the high-resolution, and 418 steps with the high-resolution.

Figure 9. Triangle waveform



2 Software description

2.1 STM32F334xx peripherals used by the application

This application example uses the following STM32F334xx peripherals with the settings described below:

GPIOs

Some of the GPIOs are needed to connect the User push-button B1 and the 4 signal LEDs used for different features in demonstration modes display.

- PB6 to PB9 set as output GPIOs to drive the signal LEDs
- PA0 set as input GPIO and connected to the User push-button B1

DMA

The STM32F334xx DMA channel 5 is configured to update the DAC output and generate the slope compensation curve on the internal comparator COMP4 minus input, as described in section 1.4.4. The DMA requests are generated by HRTIM following events: REP (repetition period), CMP1 (Compare event 1), CMP2, CMP3 and CMP4. The curve is built from 5 points stored in the CurrentSenseTab[] array in RAM. A DMA transfer from the RAM to the DAC 12-bit right-aligned data holding register is triggered on each HRTIM event.

Note: In order to compensate the DAC output settling time, the top of the curve is synchronized with the CMP4 event instead of the PER event.

DMA Channel 5 is configured to interact with DAC channel 1 peripheral. It provides high-speed transfer between the memory and the DAC peripheral. Base address of the memory is set to CurrentSenseTab[] array. Its buffer size is 5-word long and contains the values of current thresholds that will be used for linear ramp generation (slope compensation). The five DMA parameters are set into HRTIM DMA configuration such as REP (repetition period), CMP1 to CMP4 (Compare events 1 to 4). DMA mode is circular and the values are automatically reloaded.

DAC

DAC Channel 1 is configured as a 12-bit digital-to-analog converter. Data from CurrentSenseTab[] array are converted to deliver a variable voltage to the comparator 4 input.

COMP4

The comparator is used to make the comparison between the voltage present on the R SENSE resistor (image of the high brightness LED current) and the current thresholds set by the DAC peripheral in slope compensation. The comparator COMP4 inverting input is connected to DAC1_CH1 while the COMP4 non inverting input is connected to PB0 where R SENSE resistor is present.

The comparator output is not used externally but rerouted as an external event source 2 to the HRTIM high-resolution timer. The output polarity of COMP4 is not inverted.

HRTIM High-resolution timer

The high-resolution timer is at the center of this application example as it has many interactions with other peripherals.

HRTIM configuration sets PB12 as HRTIM Timer C output. This pin is configured as an alternate function.

A HRTIM DLL calibration is performed at the beginning of HRTIM initialization function.

The HRTIM Timer C period is set to 4µs (250kHz). This imposes the switching frequency of the current mode controlled buck converter. The Timer C output 1 is configured to be set on the Timer C counter period event, and to be reset on the HRTIM external event number 2, which is configured to be connected to the comparator COMP4 output.

There are 5 main events used to interact with DMA and DAC that are REP (repetition period) and CMP1 to CMP4 events (compare1 to compare 4). REP event is aligned with Timer C period event and the other CMP1 to CMP4 events are distributed respectively at 20% period, 40% period, 60% period and 80% period. The DMA transactions are then synchronized with high-resolution timer.

The HRTIM operates in continuous burst mode. This means that one or more pulses are output followed by an idle period. The burst mode frequency is set to 400Hz according to the eye flicker detection and the different dimming techniques detailed above.

Interrupts

Some interrupts are managed in this application example as described below:

- Systick_Handler(): Based on the system tick timer, this 1ms interrupt manages the delays used by the software.
- EXTI0_IRQHandler(): This interrupt detects any activity present on the user push-button B1 and determine if this key is pressed for a short or long time. Following the cases statements, the application will access different menus. Each time the interrupt is serviced, the different modes are changed accordingly as described in *Figure 8*.
- HRTIM1_Master_IRQHandler(): Interrupt manages the extra pulses determined by the dither sequences and occurs each burst period (t = 2.5ms). A different set of data included in the dither table is scanned at each interrupt and defines if an extra pulse must be applied to the buck converter or not. The compare value of the HRTIM burst mode controller is updated accordingly. These data are rolling circularly every 8 burst periods to cover one full dither sequence.

For instance, the dither pattern to apply is “10100100”:

Then each data rolls at every interrupt: 1=>0=>1=>0=>0=>1=>0=>0

...and loops back to the first value 1=>0=>1=>......etc...

A pattern duration or dither period is then 20 ms.

3 Ordering and product information

The STM32F334 Discovery kit is a low-cost and easy-to-use development kit to quickly evaluate and start a development with an STM32F3 series microcontroller. Before installing and using the product, please accept the Evaluation Product License Agreement from http://www.st.com/epla. For more information on the STM32F334 Discovery board and for demonstration software, visit www.st.com/stm32f3discovery.

3.1 Order code

To order the STM32F334 Discovery kit, use the user code: STM32F3348-DISCO.

4 Conclusion

LED lighting applications are overtaking classic incandescent or halogen lamp solutions as they require less and less energy with constantly increasing performance. For indoor as well as outdoor lighting solutions, they’re now frequently used with full range dimming capability. There are several existing dimming techniques and especially the PWM dimming based shown here with the STM32F334 Discovery kit. This method prevents any change of the color in the LED during dimming and allows various brightness levels.

This example around the STM32F334xx advanced ARM®-based 32-bit MCUs shows one of the various capabilities that such a microcontroller can offer with a full set of peripherals and plethora of settings. The high-resolution timer is a model of the variety of available high-performance peripherals. It includes many configuration settings that make this application example possible with a minimum of external hardware and enhanced possibilities. These configurations have mainly been anticipated especially for application using power converters topology and their requirements.

This demonstration example is a starting point for other applications and highlights how the high-resolution timer can be configured in combination with other internal product resources. It can be easily reused for further developments and includes all minimum software sets to control the high-resolution timer interacting with associated peripherals.

5 Revision history

Table 1. Document revision history

Date	Revision	Changes
19-Jun-2014	1	Initial release.

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