High-brightness RGB LED control using the B-G474E-DPOW1 Discovery kit

Introduction

This application note illustrates the high-brightness RGB LED feature embedded within the B-G474E-DPOW1 Discovery kit .

This demonstration application is built with the STM32G474RE Arm® Cortex®-M4 core-based microcontroller, designed for digital power conversion applications. This application demonstrates how to use some on-chip peripherals: the high-resolution timer (HRTIM), the digital-to-analog converter (DAC) and the comparator (COMP). This demonstration project is included in the STM32CubeG4.

This high level of integration inside the microcontroller reduces 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, or HRTIM and DAC, decrease the CPU load and eliminate any latency in the system.

This document only describes the RGB LED, not the other parts of the B-G474E-DPOW1 demonstration. No additional hardware or software is required. Once B-G474E-DPOW1 is powered up through a Micro-B USB cable connected to the host PC, the user has access to the high-brightness RGB LED demonstration software.

This example comes preloaded with the B-G474E-DPOW1 Discovery kit.

Reference documents

- data brief *Discovery kit with STM32G474RE MCU* for the B-G474E-DPOW1 Discovery kit (DB3835)
- User manual *Discovery kit with STM32G474RE MCU* (UM2577)

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1 Application description

This document applies to the B-G474E-DPOW1 Discovery kit including the STM32G474RE Arm® Cortex®-M4 core-based microcontroller.

Note: *Arm is a registered trademark of Arm Limited (or its subsidiaries) in the US and/or elsewhere.*

1.1 Hardware required

This application uses the high-brightness RGB LED (LD1), four signal LEDs (LD2 to LD5) and the joystick B2 on the B-G474E-DPOW1 Discovery kit. No additional components are required.

Note: *This example and its hardware are totally independent of buck-boost DC/DC converter (that is not described in this document).*

1.2 B-G747E-DPOW1 hardware settings

The IDD jumper JP4 must be fitted and all SBx solder bridges set in their initial factory configuration (see the user manual *B-G474E-DPOW1 Discovery Kit demonstration firmware* (UM2577) for further information related to hardware.

1.3 Application schematics

The figure below describes the B-G474E-DPOW1 Discovery kit hardware.

Figure 1. B-G474E-DPOW1 Discovery kit hardware
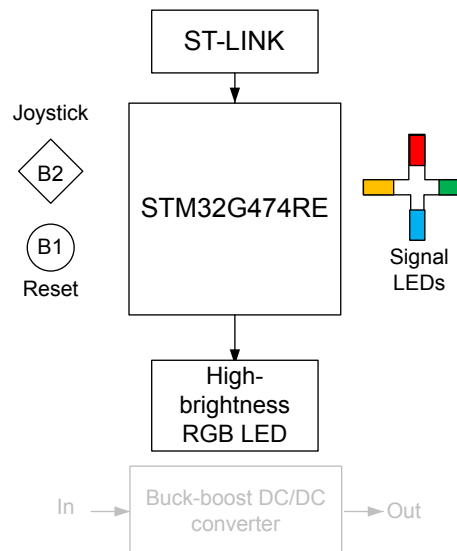
Note: the buck-boost part in gray is not covered in this document.

1.4 Application principles

1.4.1 Overview

The B-G474E-DPOW1 Discovery kit embeds the minimum components required to implement the RGB LED color spectrum scanning function and white dimming. All the other needed functions are managed by the STM32G474RE microcontroller thanks to its embedded features: the LED current sense measurement and comparison with the target current done with the internal comparator. The PWM generation to drive the power MOSFET and the current mode control is managed by the internal high-resolution timer.

The high-brightness LED driving can be done in the following modes:

- RGB LED: This mode scans the entire color spectrum.
- White LED mode: This mode scans the entire white-brightness range. The same RGB LED is used, but red, green and blue colors are mixed to obtain white.

Caution: For safety reasons, the maximum high-brightness LED forward current is limited by software to 100 mA (for each LED) and an optical cube-shaped protection is 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 the eyes to direct light.
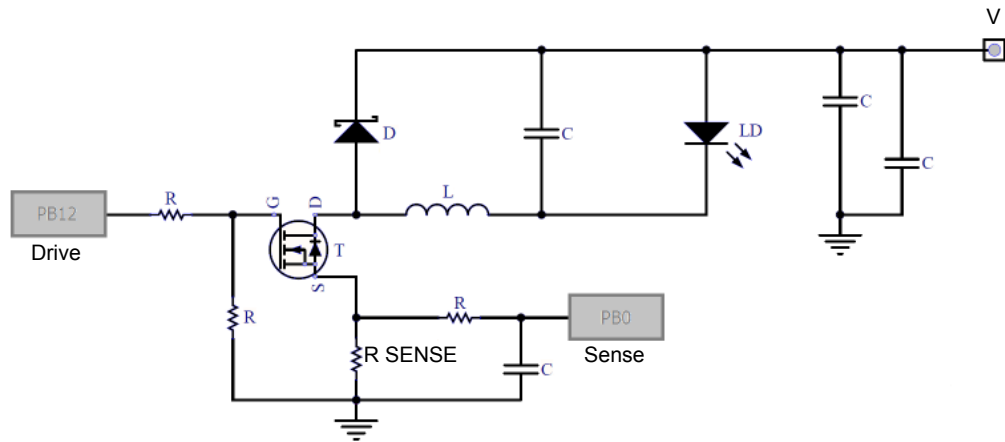
1.4.2 High-brightness LED control

The RGB LED is composed of three independent LEDs: red, green, and blue. Each one is controlled independently.

The figure below shows the high-brightness red LED dimming block diagram and the different microcontroller resources used in this application.

Figure 2. Red LED control function block diagram
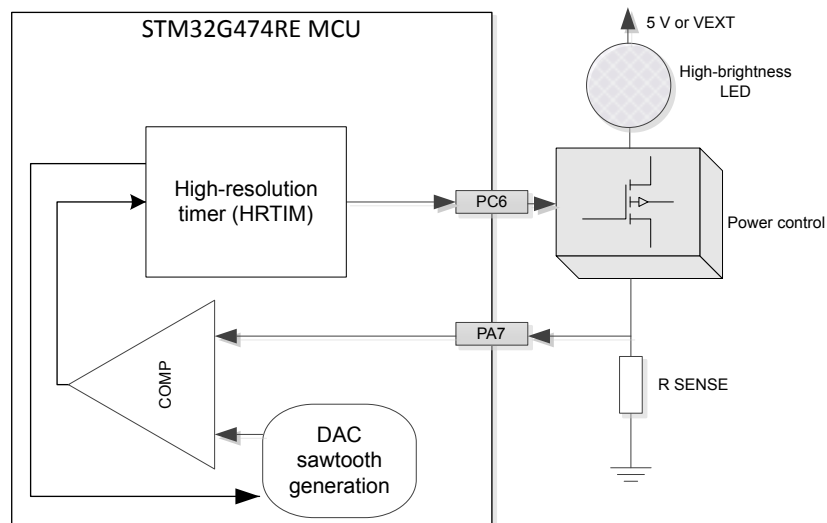
One of the high-resolution timer outputs is connected to the power control MOSFET driving the high-brightness LED. This unit uses an inverter buck converter topology and includes an inductor connected serially between the MOSFET drain pin and the high-brightness LED. A sense resistor (R SENSE) is connected to the MOSFET source pin and this voltage level is fed back to the internal comparator COMP2 (PA7). The electrical scheme is shown in the figure below.

Figure 3. **High-brightness red LED buck converter**

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

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

The capability of the STM32G474RE HRTIM to drive the DAC sawtooth signal generation is used (see Section 1.4.4 Slope compensation).

Finally, the comparator output is 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.

The high-resolution timer is set to have a PWM frequency of 250 kHz, then the high-brightness LED is driven for a maximum period of 4 µs. At the LED ignition, this time may be lengthened for the first pulse as the current starts flowing (due to multiple consecutive periods with 100 % duty cycle).

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 100 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 100 mA current controlled (250 kHz PWM), and sequences with no current (the MOSFET is no more driven). To prevent any flickering effect that the human eye may detect, the driven pulses are repeated in a burst mode at a frequency equal to 400 Hz.

The figure below shows the waveforms output by the high-resolution timer and the R SENSE voltage feedback to the microcontroller.

Figure 4. LED control signals generation
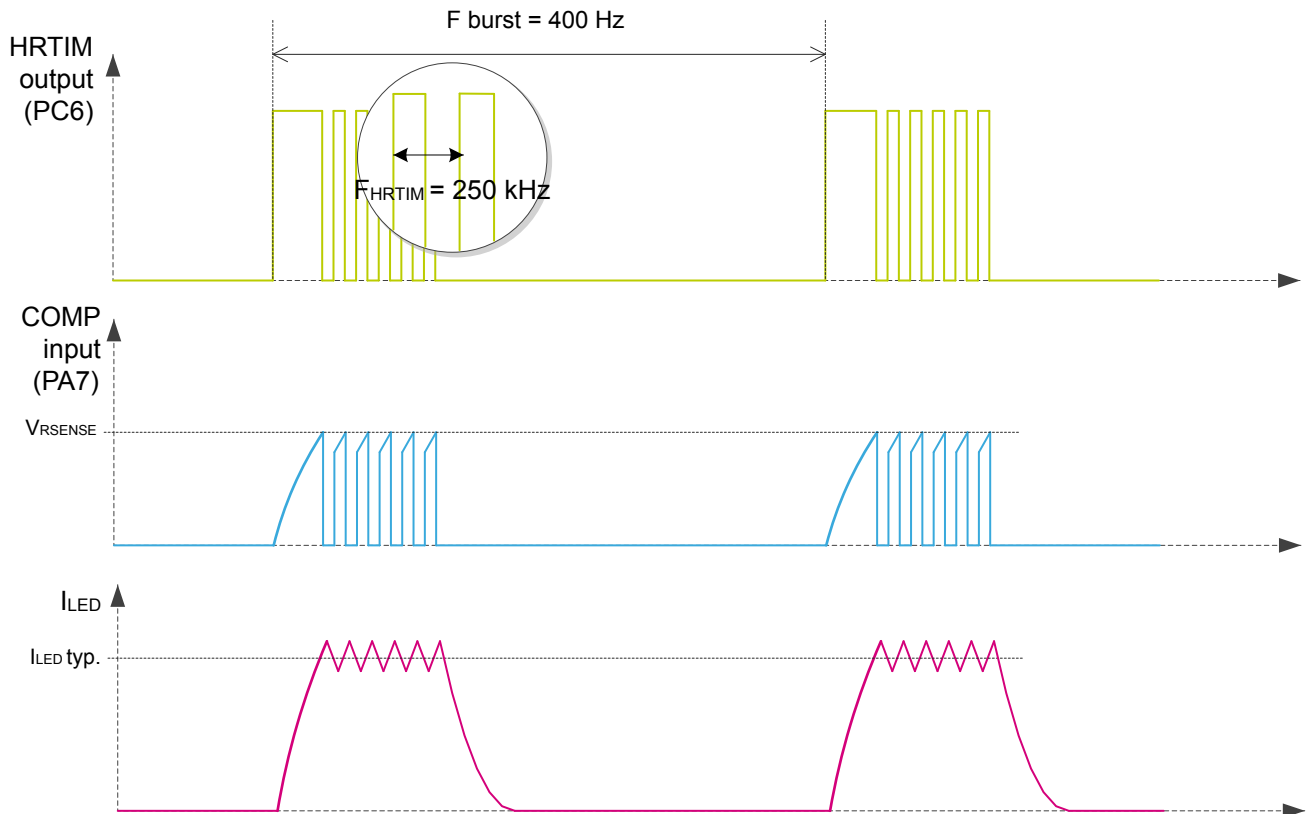
The current across the high-brightness LED is also represented. The brightness of the LED is proportional with the increase in forward conduction current. As soon as the comparator threshold is reached, the high-brightness LED current is regulated at the average value corresponding to ILED typical value. The dimming is performed at constant current (CC), also called peak current mode (PCM) 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.

The same principle applies to the three RGB LEDs:

- Red:
    – Drive : PC6 -> HRTIM F CH1
    – Sense : PA7 -> COMP2 and DAC 3 channel2
- Green:
    – Drive : PC8 -> HRTIM E CH1
    – Sense : PA0 -> COMP3 and DAC 3 channel1
- Blue:
    – Drive : PA8 -> HRTIM A CH1
    – Sense : PB0 -> COMP4 and DAC 1 channel1

Note: DAC3 (red and green) is a fast DAC, supporting up to 15 Msamples/s -> 15 MHz/250 kHz = 60 steps.

DAC1 (blue) is a slow DAC, supporting up to 1 Msamples/s. Nevertheless it is possible to have better performances under certain conditions (see the application note Extending the DAC performance of STM32 microcontrollers (AN4566)). For RGB LED demo, due to low load on DAC, 3 Msamples/s is used -> 3 MHz/ 250 kHz = 12 steps

1.4.3 Gamma correction

The LED brightness is not a linear function of LED forward current:

- At low forward current, any small increase of this current has a visible effect on the LED brightness.
- At high forward current, the increase must be substantial to have a visible effect on the LED brightness.

To compensate the non linearity of the LED brightness, a software gamma correction is implemented. This gamma correction is applied on the global brightness that is represented by the number of pulse in HRTIM burst. Knowing that HRTIM burst is common to all RGB LEDs, the gamma correction applies to all RGB LEDs and thus to the global brightness.

Gamma correction used = 2.2 (see the figure below).

Figure 5. Gamma correction 2.2
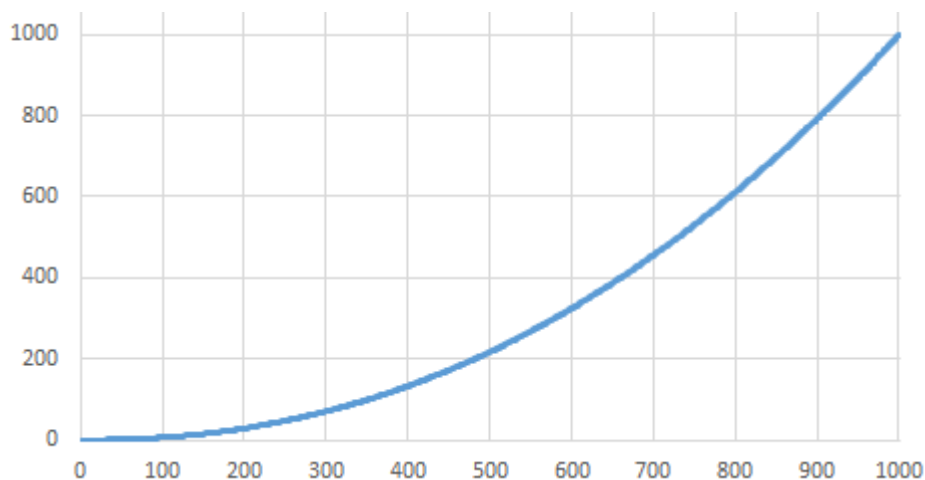

1.4.4 Slope compensation

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, able to deliver a linear ramp that 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 %. 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 %. A way to limit subharmonic oscillation is then to introduce a slope compensation using the DAC peripheral, here dedicated to this task.

The STM32G474RE DACs are able to generate a sawtooth signal controlled by HRTIM. The slope reset and steps are triggered by HRTIM to generate a linear ramp. These points are represented on the figure below as repetition period event REP and steps. By injecting a 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 may interfere with LED current regulation.

This is applied to all RGB LEDs.

Figure 6. DAC slope compensation
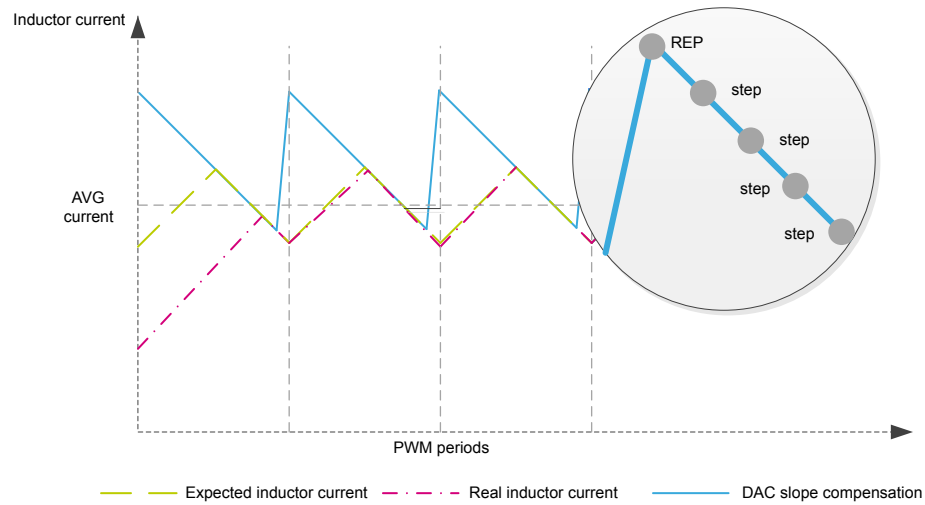
Expected inductor current — · — · Real inductor current —— DAC slope compensation

Note: *DAC3 (red and green) is a fast DAC, supporting up to 15 Msamples/s -> 15 MHz/250 kHz = 60 steps.*

DAC1 (blue) is a slow DAC, supporting up to 1 Msamples/s. Nevertheless it is possible to have better performances under certain conditions (see the application note Extending the DAC performance of STM32 microcontrollers (AN4566)). For RGB LED demo, due to low load on DAC, 3 Msamples/s is used -> 3 MHz/ 250 kHz = 12 steps

1.4.5 High-brightness LED current regulation soft start

Another technique implemented in this RGB LED demonstration is to start and stop the LED with a progressive current threshold adjustment in the regulation control loop.

This allows the LED control 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.

If the LED is driven with only one single pulse, it is 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 (see the figure below).

Figure 7. Soft start current regulation
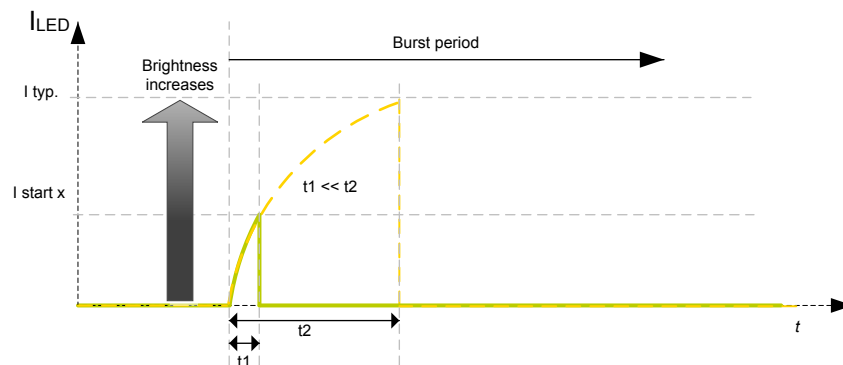
## 1.4.6 RGB color spectrum scanning

As explain previously, the number of pulse in HRTIM burst is common to all three RGB LEDs and determines the global brightness. But the user must be able to differentiate each RGB LED brightness separately, to be able to change the color .

To achieve this, the current threshold for each LED is adjusted separately. The sawtooth threshold of each LED determines the individual LED brightness.

With the pattern shown in the figure below:

- Only two LEDs are enable at a time.
- The global brightness is constant at any time.

Figure 8. R, G, B brightness pattern generating color spectrum scanning
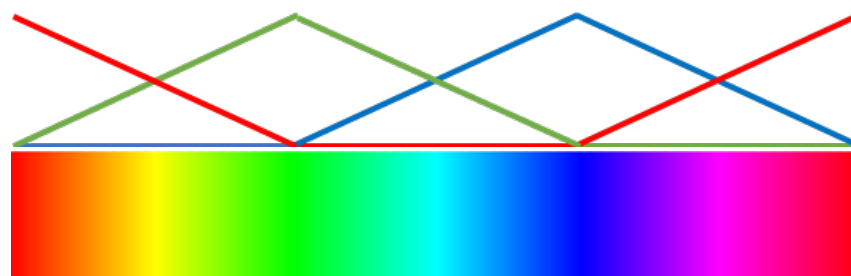
1.4.7 Triangle waveform generation

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

If the demonstration software remains in STATE_4LED, a triangular waveform is generated on TP4 'RC Sinus'. The difference between the positive slope and the negative slope of the triangle shows 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 around 20 Hz and an amplitude of around 600 mV (from Vmin = 400 mV to Vmax = 1 V).

The HRTIM channel F2 is programmed to output a 2 MHz PWM on the STM32G474RE PC7 port. This PWM is filtered externally, through a RC filter (R97 and C41), to get the 20 Hz 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 can be achieved with the TIM1 timer for example), while the negative slope is generated using the high-resolution.

The HRTIM is fed with a 170 MHz clock, but the analog delays embedded in the HRTIM allow the application to reach an equivalent clock frequency of 170 MHz x 32 = 5.440 GHz.

Considering a PWM at 2 MHz with a duty cycle range from 0 to 100 %, this gives 85 levels without the high-resolution (equivalent to a 6-bit resolution digital-to-analog converter), and 2720 levels with the high-resolution (equivalent to a 11-bit digital-to-analog converter).

Note: *In this example, as the power supply is 3.3 V (full duty cycle range of the PWM), the ramp from 400 mV to 1 V is generated from 16 steps without the high-resolution, and 494 steps with the high-resolution.*

Figure 9. Triangle waveform
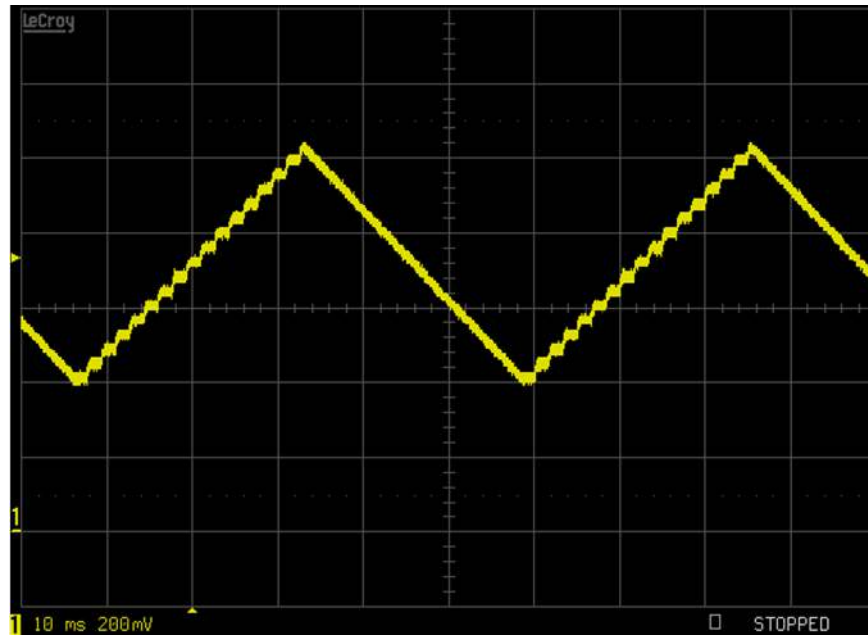
1.4.8 Getting started with the application

The B-G474E-DPOW1 Discovery kit must be supplied with a power source. Several possibilities are available as described the user manual *Discovery kit with STM32G474RE MCU* (UM2577).

For example, B-G474E-DPOW1 can be connected to a PC thanks to a micro-B USB connector (ST-LINK connector) on the board side, with JP5 on STLK.

As soon as the application is power supplied, it enters the four LEDs demonstrations (also called demo). The user can jump from one demo to the other, by pressing the selection key of joystick (SEL):

- 4 LEDs demo

  All signal LEDs (LD2 to LD5) are lit one by one, quicker and quicker. In that state, the triangle waveform generation is performed (see Section 1.4.7 Triangle waveform generation). The high-brightness RGB LED is not controlled (OFF state).

- RGB LED Color demo

  The color spectrum is automatically scanned by the RGB LED (see Section 1.4.6 RGB color spectrum scanning). The user can pause/resume automatic scanning by pressing respectively left/right joystick key. The user can also increase/decrease the global RBG LED brightness by pressing respectively up/down joystick key.

  The LED LD5 is ON when the global RGB LED brightness is increased. LD5 flashes as soon as the RGB LED brightness upper limit is reached.

  The LED LD2 is ON when the global RGB LED brightness is decreased. LD2 flashes as soon as the RGB LED brightness lower limit is reached.

- RGB LED White demo

  This demo corresponds to an automatic dimming of the entire white brightness range. Red, green and blue LED of RGB are mixed to get white. The user can pause/resume automatic dimming by pressing respectively left/right joystick key. The user can also force increase/decrease the global RBG LED White brightness by pressing respectively up/down joystick key.

  The LED LD5 is ON when the global RGB LED brightness is in increasing phase (even if automatic dimming is stopped). LD5 flashes as soon as the global RGB LED White brightness upper limit is reached.

  The LED LD2 is ON when the global RGB LED brightness is in decreasing phase (even if automatic dimming is stopped). LD2 flashes as soon as the global RGB LED White brightness lower limit is reached.

- Buck demo

  This demo corresponds to a buck conversion that is not detailed in this document.

- Buck-boost demo

  This demo corresponds to a buck-boost conversion that is not detailed in this document.

When the last demo is reached, pressing SEL key again loops to first demo.

2   Software description

This application example uses some STM32G474RE peripherals with the settings described below:

GPIOs

Some GPIOs are needed to connect the joystick B2 and the four signal LEDs used for different features in the demonstration modes display:

- PB7, PA15, PB5, PB1 set as output GPIOs to drive the signal LEDs
- PC13, PC4, PC5, PB2, PB10 set as input GPIO and connected to the joystick B2

HRTIM

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

The HRTIM configuration sets the following:

- PC6 as HRTIM timer F channel 1 output (red)
- PC8 as HRTIM timer E channel 1 output (green)
- PA8 as HRTIM timer A channel 1 output (blue)
- PC7 as HRTIM timer F channel 2 output (triangle generation)

Those pins are configured as alternate function.

An HRTIM DLL calibration is performed at the beginning of the HRTIM initialization function (at triangle waveform initialization).

For triangle generation, HRTIM timer F frequency is set at 2 MHz with a repetition counter of 100, that leads to an interrupt every 50 µs.

For RGB LED (color and white), the period of the three HRTIM timers (F, E and A) is set at 4 µs (250 kHz). This imposes the switching frequency of the current-mode-controlled buck converter. The three timer outputs 1 are configured to be set on the timer counter period event, and to be reset on the following HRTIM external events:

- EEV 1, configured to be connected to the comparator COMP2 output (red)
- EEV 5, configured to be connected to the comparator COMP3 output (green)
- EEV 2, configured to be connected to the comparator COMP4 output (blue)

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

The HRTIM is also configured to generate reset signal and step signal for DAC sawtooth generation. This direct internal connection between HRTIM and DAC is possible thanks to the STM32G474RE feature.

Note: *Compare unit 3 of each HRTIM is used to blank COMP event at the beginning of the period. This is to avoid being reset by spurious glitches.*

DAC

The digital to analog converter includes the following channels, that are configured to generate slope compensation signals.:

- DAC3 channel 2 (red)
- DAC3 channel 1 (green)
- DAC1 channel 1 (blue)

The DAC sawtooth is configured with a 'Decrement' polarity. Reset and Step events are configured to be triggered by HRTIMs as follows:

- TRG6 -> HRTIM F (red)
- TRG5 -> HRTIM E (green)
- TRG1 -> HRTIM A (blue)

Note: *DAC3 (red and green) is a fast DAC, supporting up to 15 Msamples/s -> 15 MHz/250 kHz = 60 steps.*

DAC1 (blue) is a slow DAC, supporting up to 1 Msamples/s. Nevertheless it is possible to have better performances under certain conditions (see the application note Extending the DAC performance of STM32 microcontrollers (AN4566)). For RGB LED demo, due to low load on DAC, 3 Msamples/s is used -> 3 MHz/ 250 kHz = 12 steps

COMP

The comparator is used to compare the voltage present on R SENSE (image of the high-brightness LED current) and the current thresholds set by the DAC peripheral in slope compensation.

The comparators are configured as detailed below:

- The COMP2 inverting input is connected to DAC3_CH2 while the COMP2 non inverting input is connected to PA7 where R SENSE is present (red).
- The COMP3 inverting input is connected to DAC3_CH1 while the COMP3 non inverting input is connected to PA0 where R SENSE is present (green).
- The COMP4 inverting input is connected to DAC1_CH1 while the COMP4 non inverting input is connected to PB0 where R SENSE is present (blue).

The comparator outputs are not used externally but re-routed as external event sources to HRTIM. The COMP output polarities are not inverted.

Interrupts

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

- Systick_Handler(): Based on the SysTick timer, this 1 ms interrupt manages the delays used by the software.
- EXTI2_IRQHandler, EXTI4_IRQHandler, EXTI9_5_IRQHandler and EXTI15_10_IRQHandler: Those interrupts detect any activity present on the joystick B2 and determine which key is pressed. The actions corresponding to pressed key depend on the running demo (see Section 1.4.8 Getting started with the application).

3 Ordering information

The B-G474E-DPOW1 Discovery kit can be ordered with the code: B-G474E-DPOW1.

More information on the B-G474E-DPOW1 Discovery kit and for demonstration software are available on B-G474E-DPOW1.

Note: *Before installing and using the product, the user must accept the evaluation product license agreement.*

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 are now frequently used with full-range dimming capability.

There are several existing dimming techniques and especially the PWM dimming based, shown here with the B-G474E-DPOW1 Discovery kit. This method prevents any change of the color in the LED during dimming and allows various brightness levels.

This example around the STM32G474RE shows one of the various capabilities that such a microcontroller can offer with a full set of peripherals and settings. The high-resolution timer 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.

Revision history

Table 1. Document revision history

Date	Version	Changes
24-July-2019	1	Initial release.

Contents

List of figures