Brightness and Color Control Unit (BCCU)

XMC1000

About this document

Scope and purpose

This document provides a brief introduction to the key features of the Brightness and Color Control Unit (BCCU) for the XMC1000 Microcontroller family. The document includes some typical LED lighting application examples and hints on how to best use the BCCU.

Intended audience

This document is intended for engineers who wish to develop an LED lighting application with the XMC1000 microcontroller.

Applicable products

- XMC1200
- XMC1202
- XMC1302
- XMC1402
- XMC1404
- DAVE ™
- LED lighting application kit

References

Infineon: DAVE™, http://www.infineon.com/DAVE

Infineon: XMC™ Family, http://www.infineon.com/XMC

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1 Brightness and Color Control Unit basics

This section provides an overview of the key concepts for using the Brightness and Color Control Unit (BCCU).

1.1 Introduction to modulation dimming

Modulation dimming of an LED channel is done by an on-off signal that toggles at a high rate, rapidly turning the LEDs on and off. The average on-off time of this signal determines the brightness of the LED lamp (Figure 1).

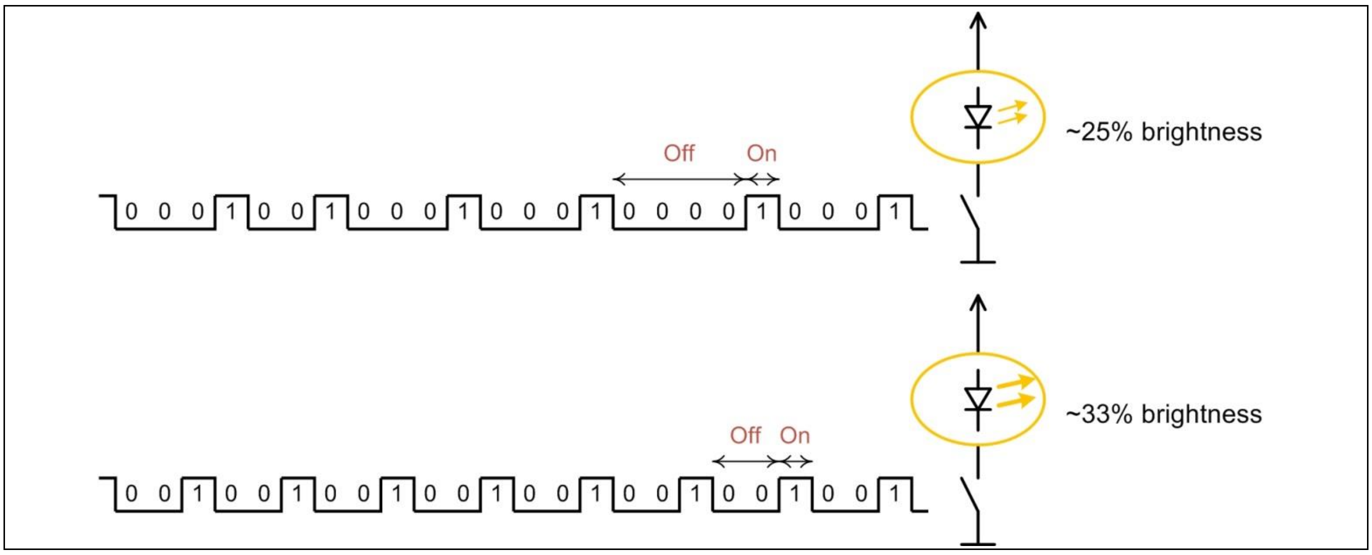


Figure 1 Modulation dimming

In addition, LED lamps often have multiple channels (Figure 2).

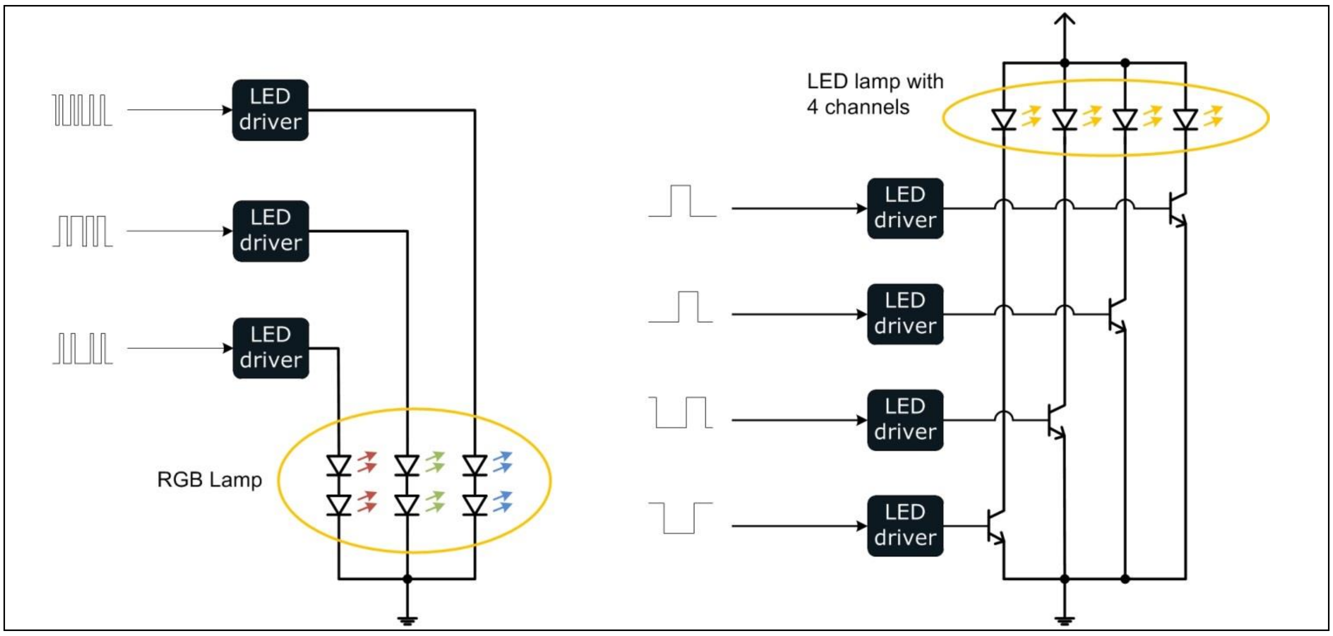


Figure 2 LED lamp examples

The BCCU is a dedicated peripheral for dimming LED lamps and changing their color using modulation dimming. A BCCU can dim up to 9 independent LED channels, depending on pin availability on the microcontroller variant. The brightness of a channel can be changed exponentially so the transition appears to be even to the human eye. A BCCU contains 9 channels, 3 dimming engines (DE) and a connection matrix that links them to each other (Figure 3).

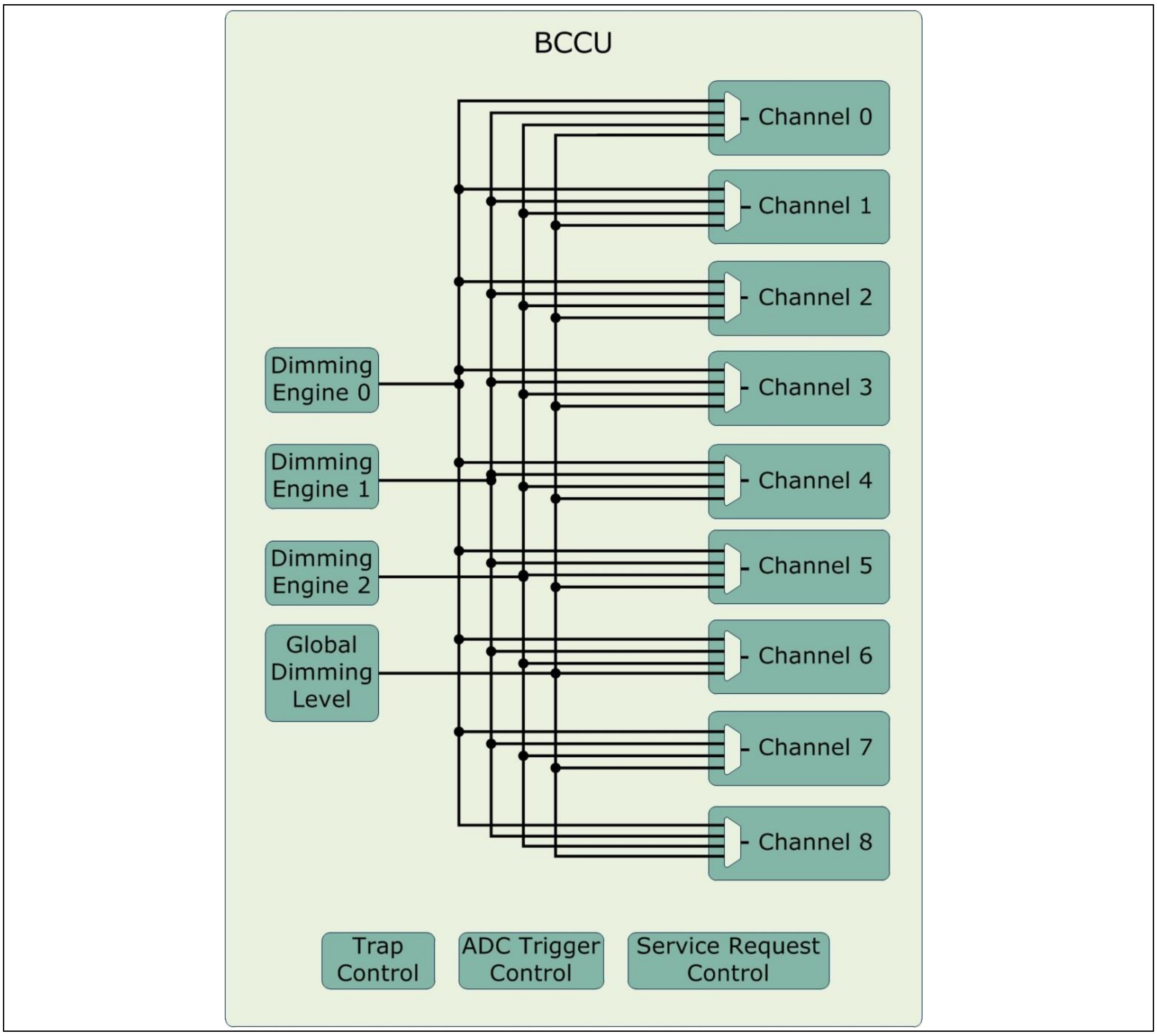


Figure 3 BCCU block diagram

The DEs generate the dimming levels. The channels generate the intensity levels. These two levels, each with a 12-bit resolution, are combined in the channels and then pulse-density modulated. The purpose and difference between these two levels is elaborated in the coming chapters.

1.2 Channels

Every BCCU channel generates an on-off signal that can dim one LED or one string of LEDs (also known as an LED channel). The average on-time of the on-off signal is proportional to the 12-bit “channel brightness” level. This level is the product of a “dimming level” value and a “channel intensity” value (Figure 4), truncated to 12 bits.

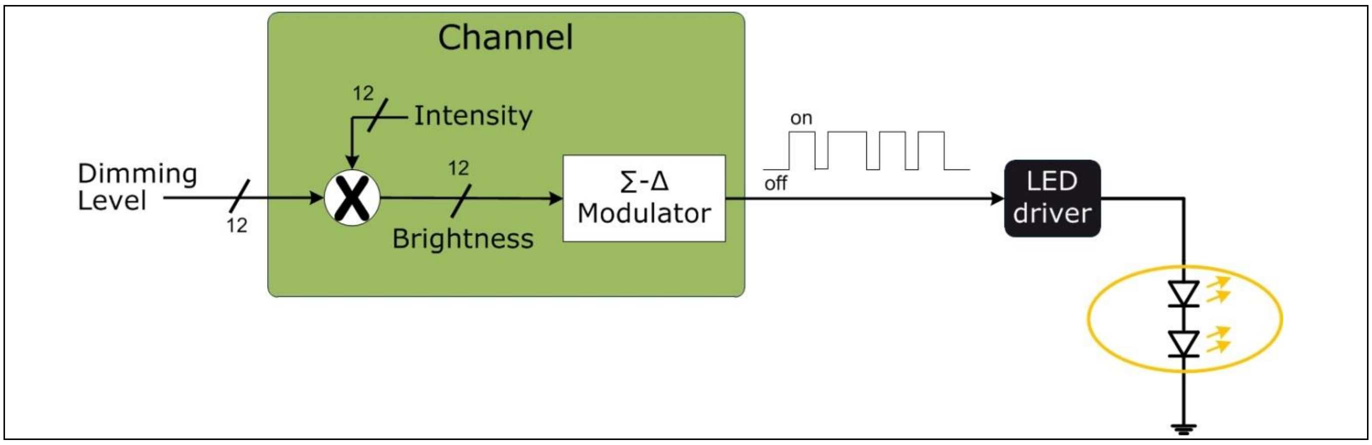


Figure 4 Channel block diagram

The dimming level is either generated by the dimming engines or the global dimming register. The global dimming level register has a bit field value manually controlled by the user. This value is used to control how bright the light appears without affecting the color of the light. The channel intensity is used to control a lamp color component. For example, an RGB lamp is made up of a red chromaticity, a green chromaticity and a blue chromaticity that can be controlled with 3 BCCU channels (Figure 5). The overall color of the lamp is the result of the relative channel intensities. The color of the RGB lamp changes when the channel intensity of any of the three channels changes relative to the other channels. If the sum of the color components remains constant, the brightness of the lamp is unchanged.

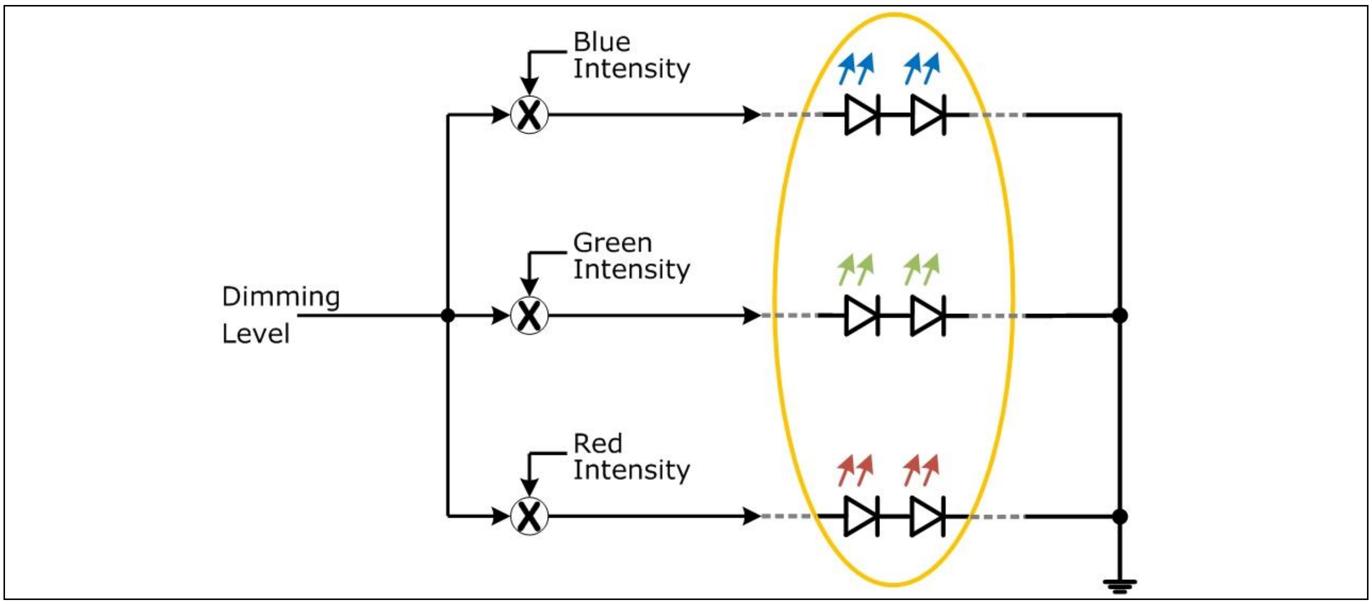


Figure 5 RGB lamp

1.2.1 Linear walker

A smooth color transition can be achieved with the linear walker. A linear walk is simply a straight walk in the orthogonal color space, such as the RGB color space (Figure 6).

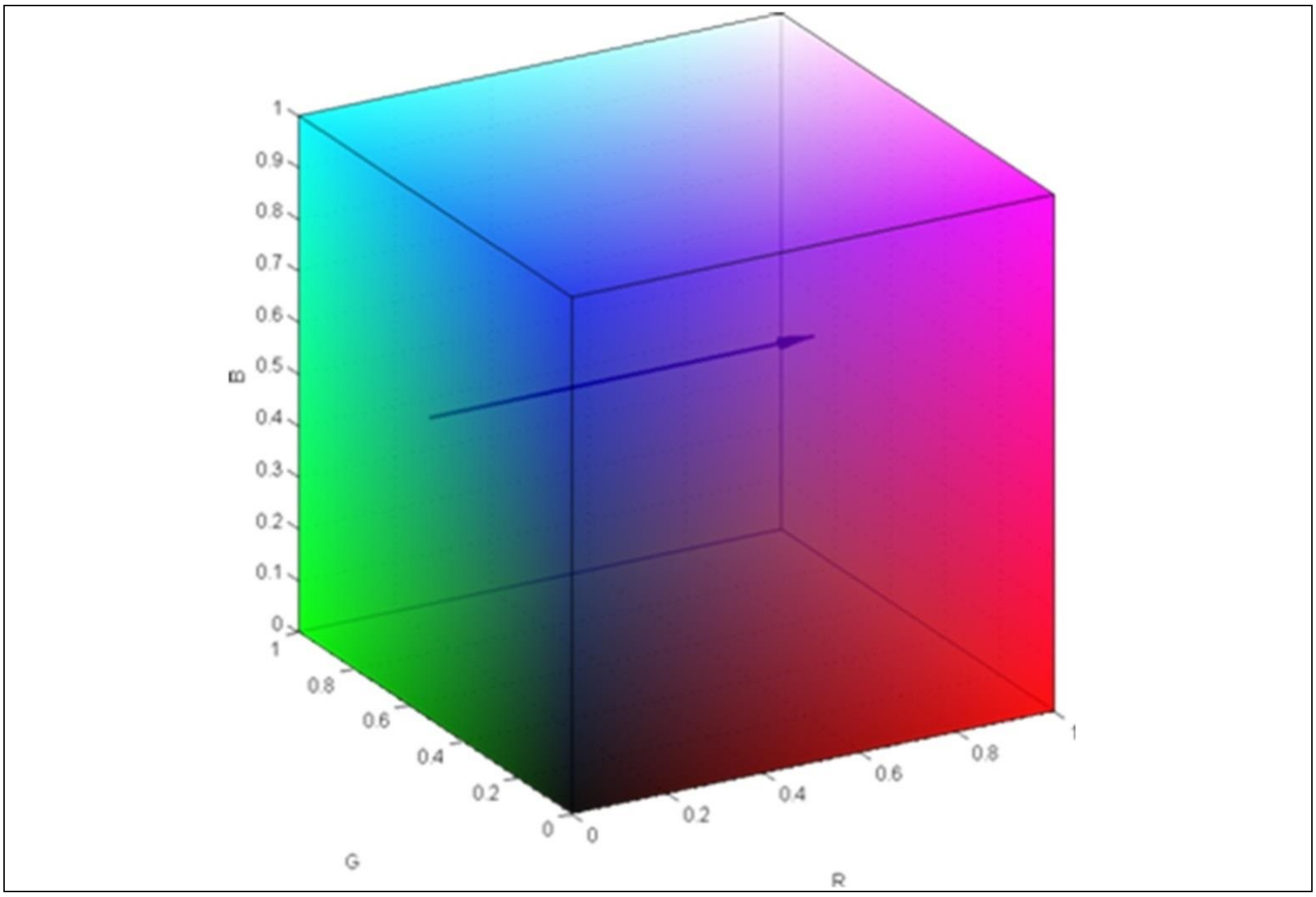


Figure 6 RGB color space

The channel intensities can be programmed to change linearly over time by setting the target intensity level in the BCCU register bit field (**INTSy.TCHINT**) and initiating the walk by setting bit **CHSTRCON.CHyS**. The linear walk time or transition time can be controlled via the BCCU register bit field **CHCONFIGy.LINPRES** (Figure 7).

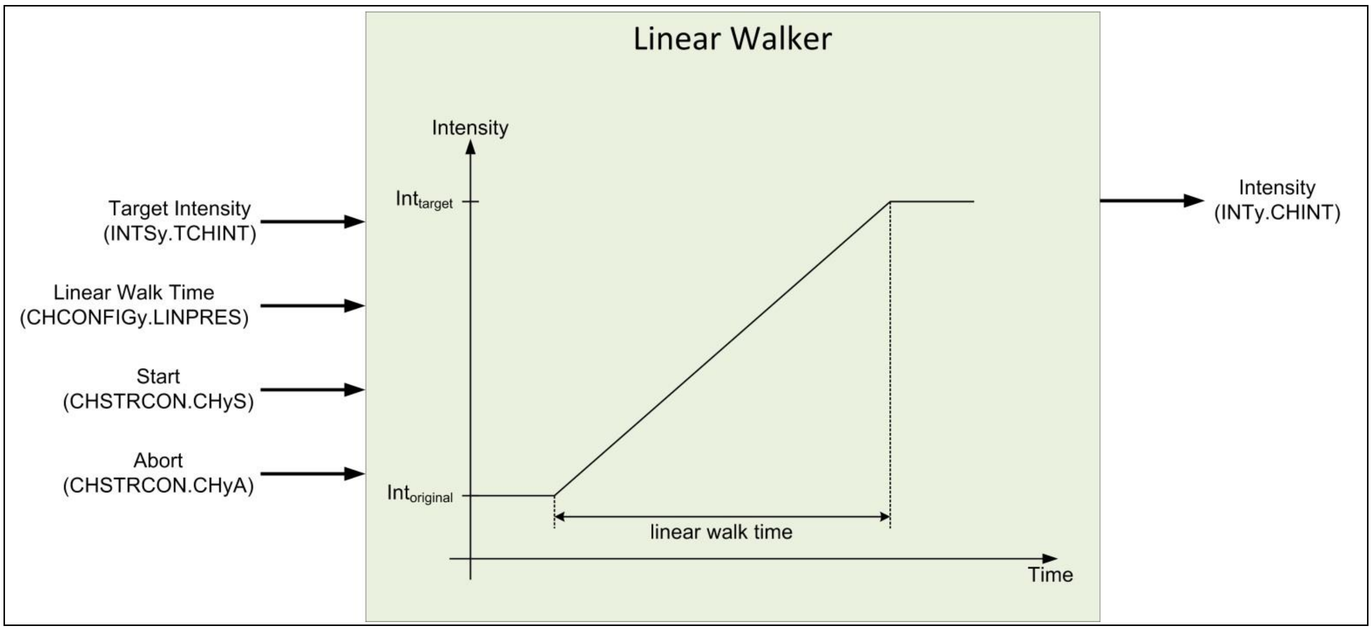


Figure 7 Linear walker

For a multichannel lamp, such as the RGB lamp, linear walks in multiple channels can be started simultaneously by writing to the respective **CHSTRCON.CHyS** bits in a single write. This results in a smooth color change (Figure 8).

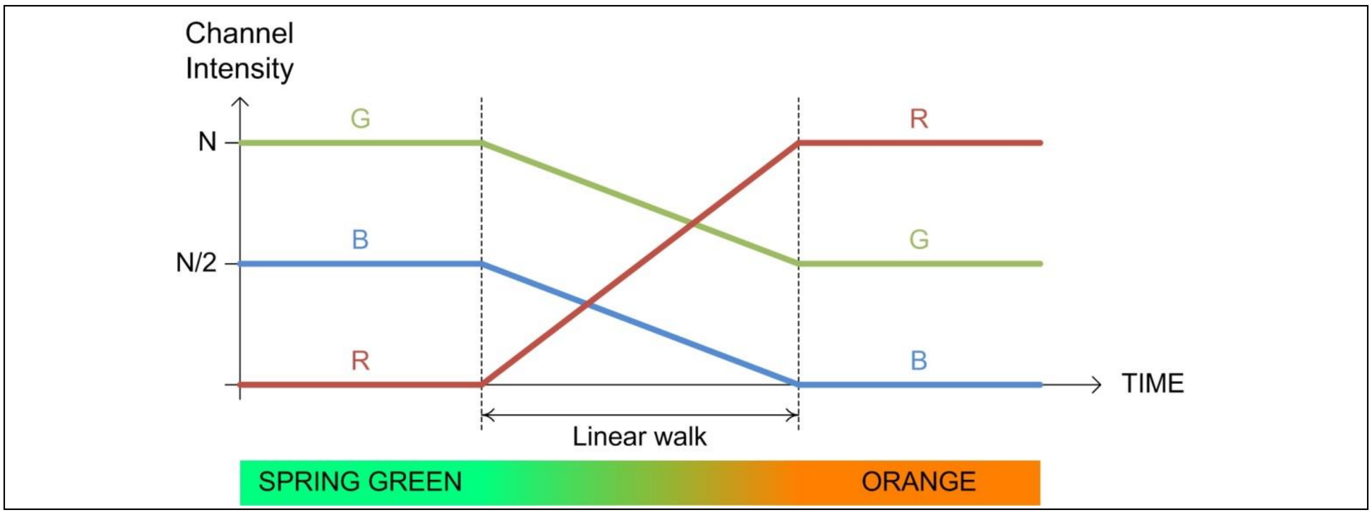


Figure 8 Smooth color change with linear walk

The actual channel intensity can be read from the register bit field **INTy.CHINT** (Figure 9). A linear walk on any channel can be aborted at any time by writing to the respective **CHSTRCON.CHyA** bit. The channel intensity (**INTy.CHINT**) then remains at the level at which the linear walk is aborted (Figure 10).

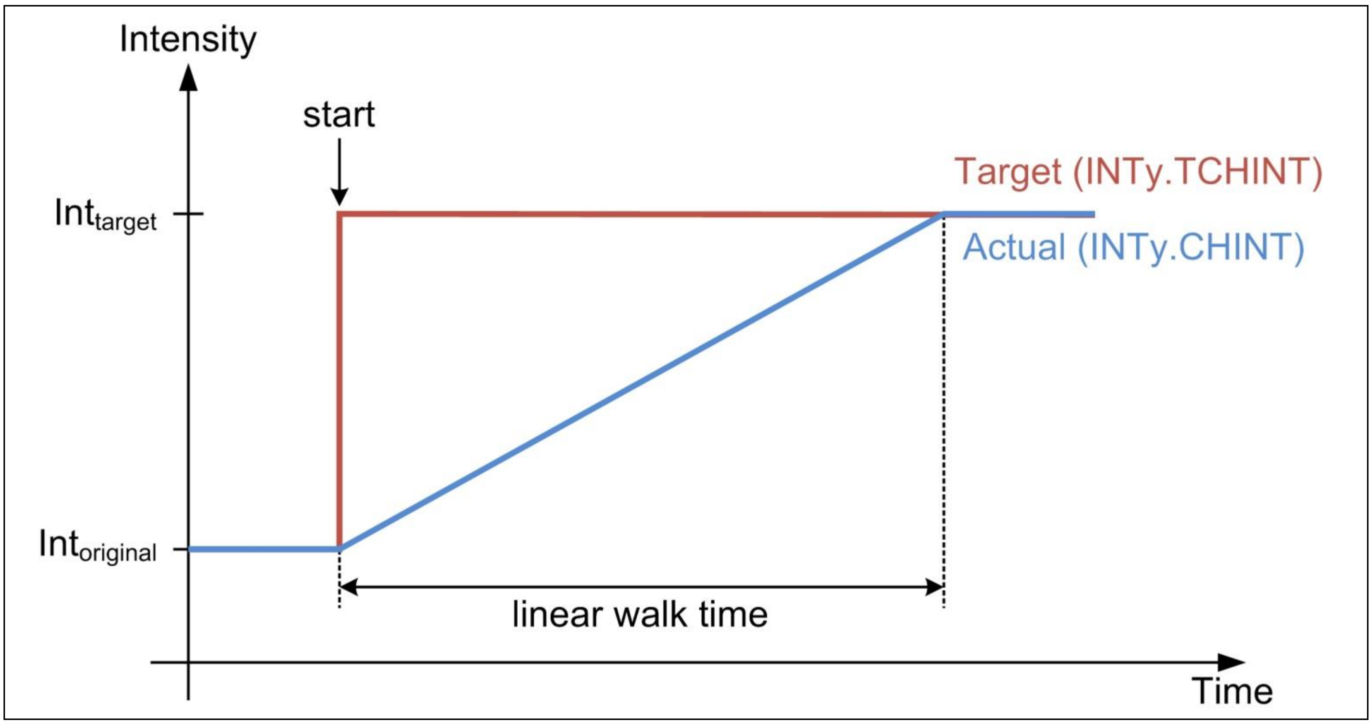


Figure 9 A complete linear walk

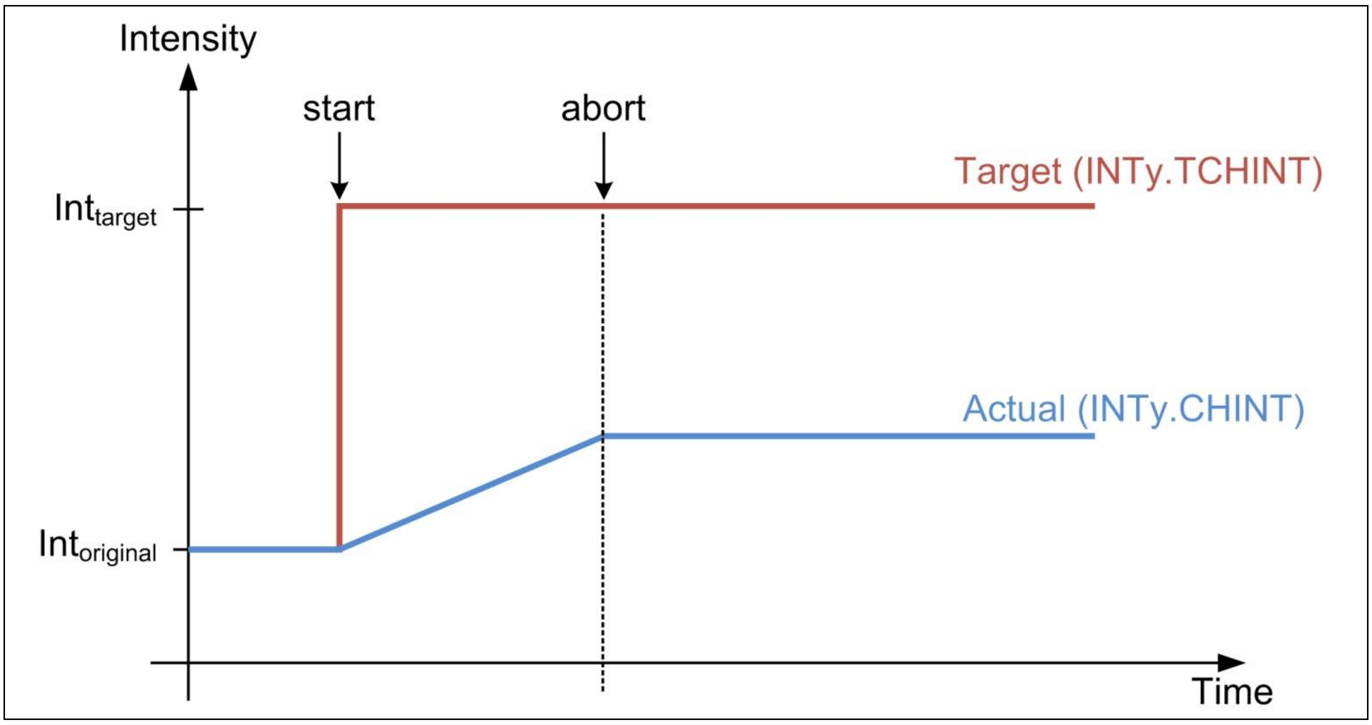


Figure 10 Aborting linear walk

1.2.2 Sigma-delta modulator

The 12-bit channel brightness is converted into an on-off signal by a sigma-delta modulator. The on-off signal that is used to rapidly turn LEDs on and off is a pulse-density modulated (PDM) signal (Figure 11). A PDM frame contains 4096 bits. The brightness value determines the number of on-bits in the frame, while off-bits complete the frame. The sigma-delta modulator includes a quantizer that randomizes the output PDM signal. This slightly affects the stability of PDM signal in terms of its average value within a frame. The average value may be x, x+1 or x-1. However, a stable average value can still be obtained by considering a longer frame of 20480 bits which is 5 frames of 4096 bits. In this case, the average value is then $\frac{x}{4096}$, where x is the input brightness value[1].

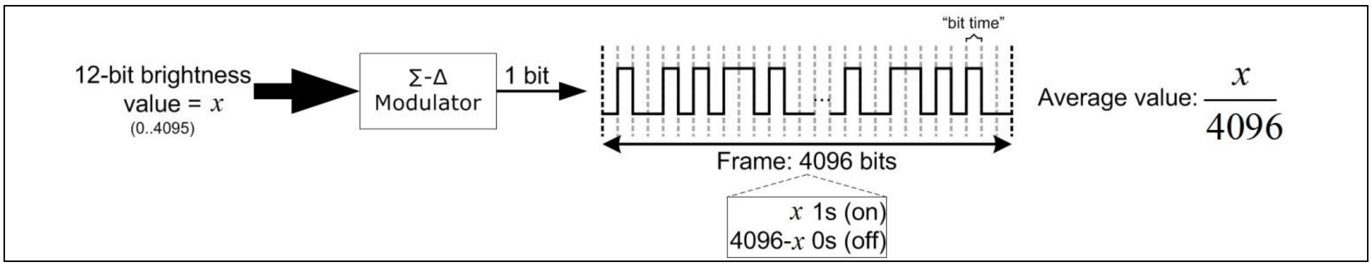


Figure 11 Sigma-delta modulator

1.2.3 Packer

When driving LEDs using an LED driver, the LED current requires time to stabilize. This timing is also known as the LED driver hold time. This is notably longer in switched-mode and high-power systems. Due to the inherent high switching rate of the PDM signal, the period of the generated on-bit may be shorter than the hold time.

[1] x should also be constant across the frame of 20480 bits.

Each BCCU channel contains a packer which can be enabled to control the switching rate. The switching rate refers to the frequency of toggling between on and off bits within a PDM frame. The packer can slow down the rate of switching by grouping on or off bits (Figure 12). The average value of the signal remains unchanged, meaning no effect on the brightness. The number of bits to be grouped can be programmed via the BCCU register **PKCMP**.

This feature allows the BCCU to be easily compatible with a wide range of LED drivers in the market.

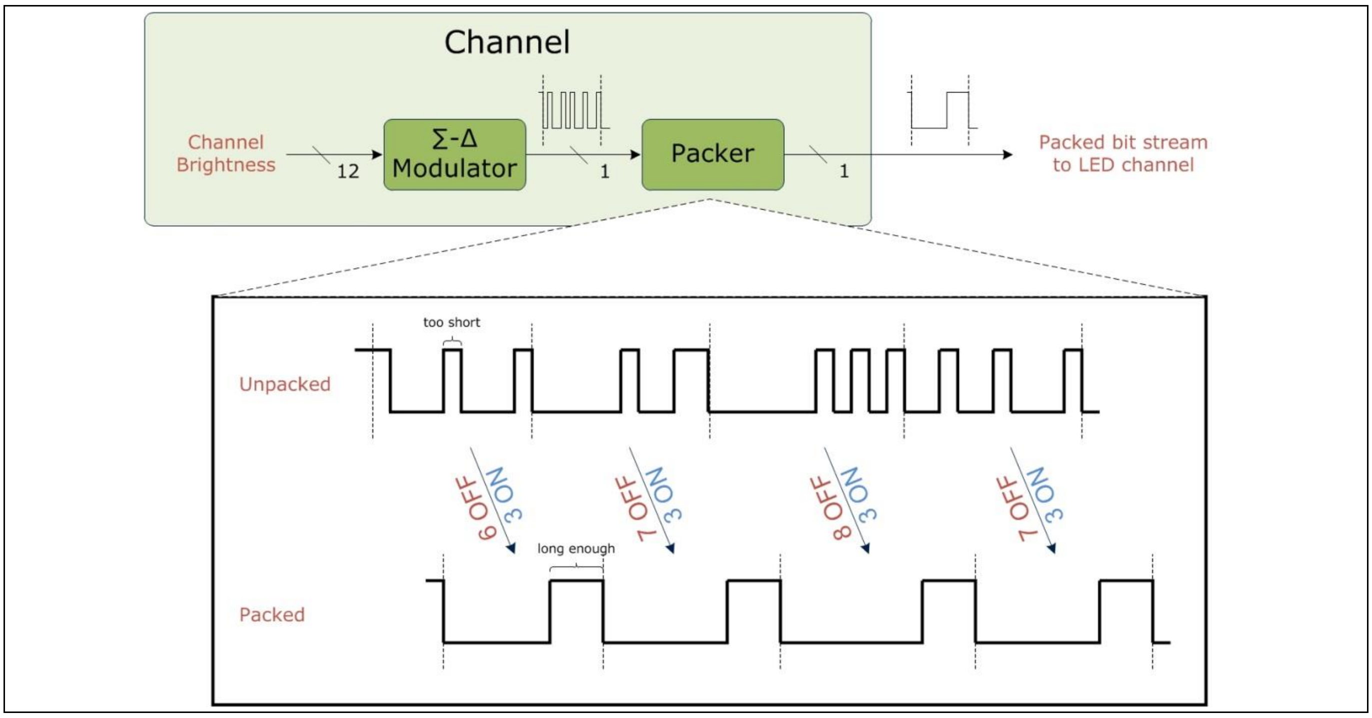


Figure 12 Packer

1.3 Dimming engines

The dimming levels can either be generated by one of the three independent dimming engines or by a global dimming level. The global dimming level can be programmed via the register GLOBDIM and this changes the dimming level to the programmed value immediately. However, the focus for this section is on the dimming engines.

1.3.1 Exponential dimming

The human eye perceives brightness levels logarithmically. To make dimming appear to be even to the human eye, the dimming engines change the dimming levels in an exponential manner over time. The dimming engines perform this automatically without requiring any complex user software (Figure 13). The target dimming level can be programmed via the register bit field **DLSz.TDLEV**. The dimming transition time is controlled by programming the register bit field **DTTz.DIMDIV**. Dimming is started by writing to the respective **DESTRCON.DEzS** bit. The dimming level can be read from the register bit field **DLz.DLEV** (Figure 14). The dimming process can be aborted by setting the respective **DESTRCON.DEzA** bit. The dimming level remains at the level at which dimming is aborted (Figure 15).

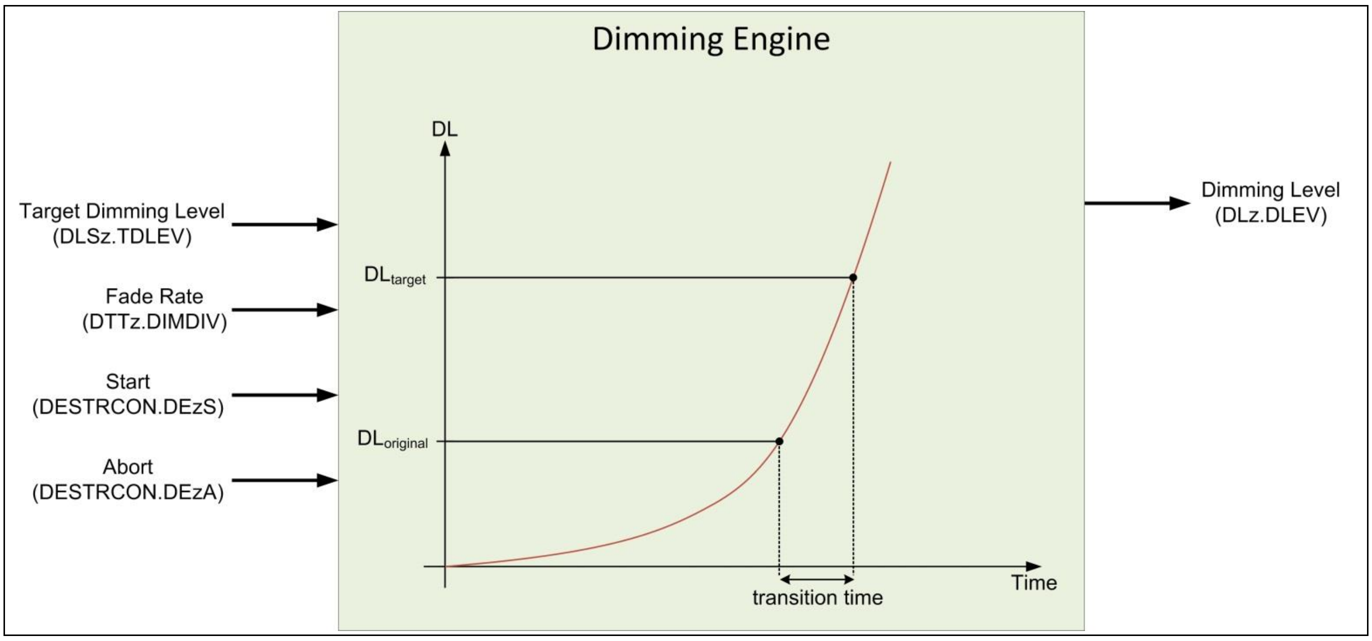


Figure 13 Dimming engine

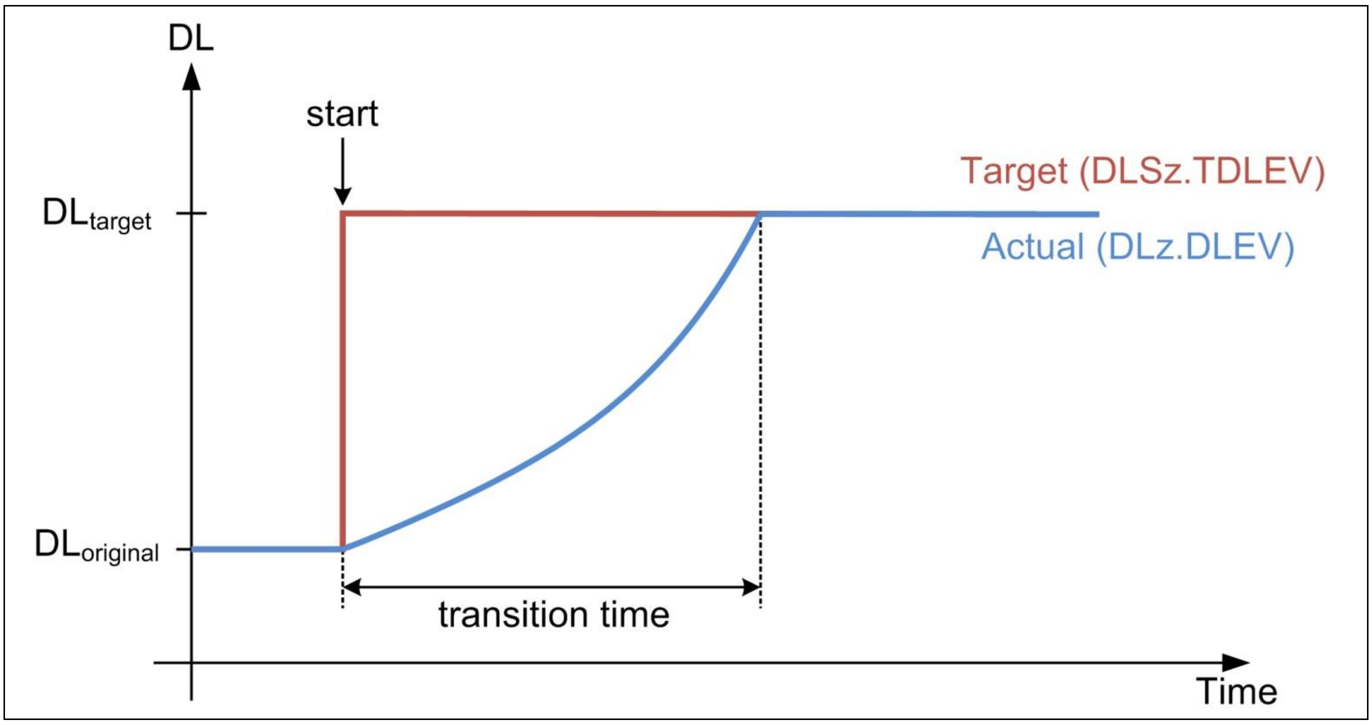


Figure 14 A complete dimming process

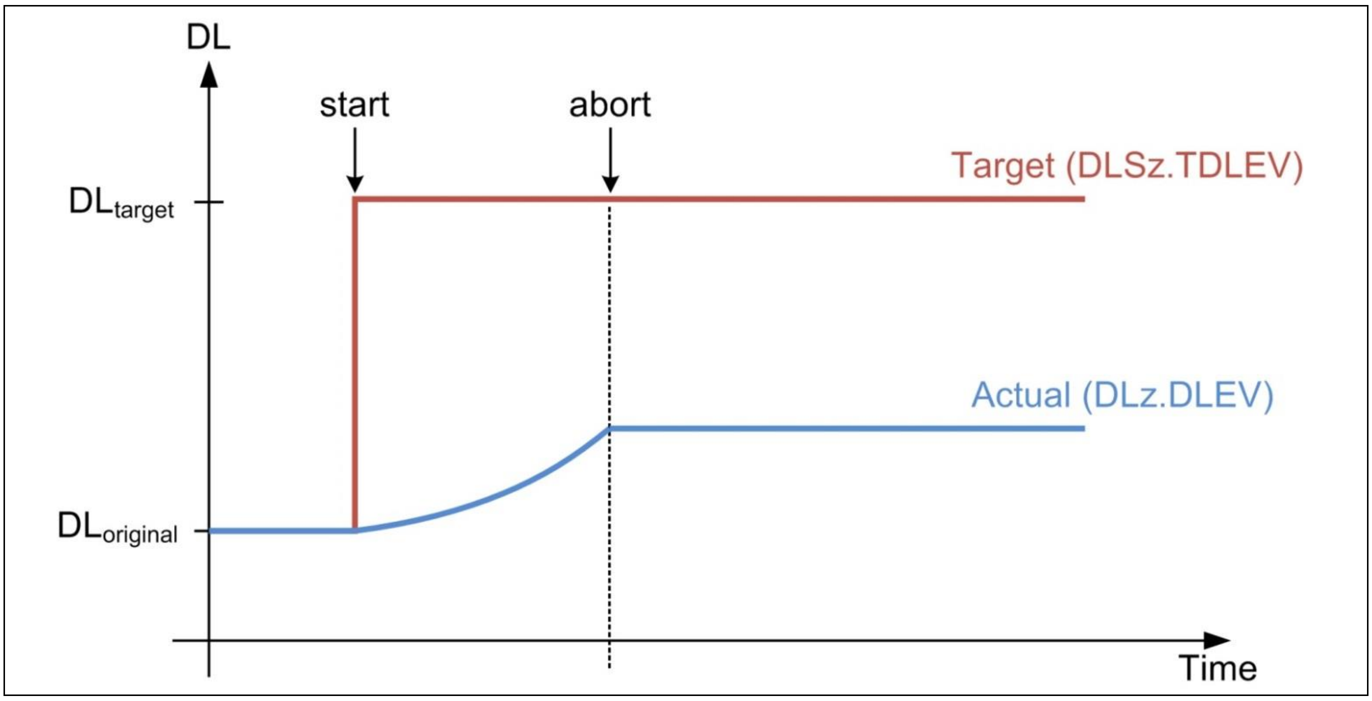


Figure 15 Aborting a dimming process

1.3.2 Dither function

At low brightness levels, the human eye is much more sensitive to changes in illumination. For example, when dimming up from dimming level 0 to dimming level 18, the change in brightness may appear “steppy” and unnatural to the eye (Figure 16). To make the experience even smoother, dithering can be applied at low dimming levels (Figure 17). This function can be enabled by setting the register bit **DTTz.DTEN**.

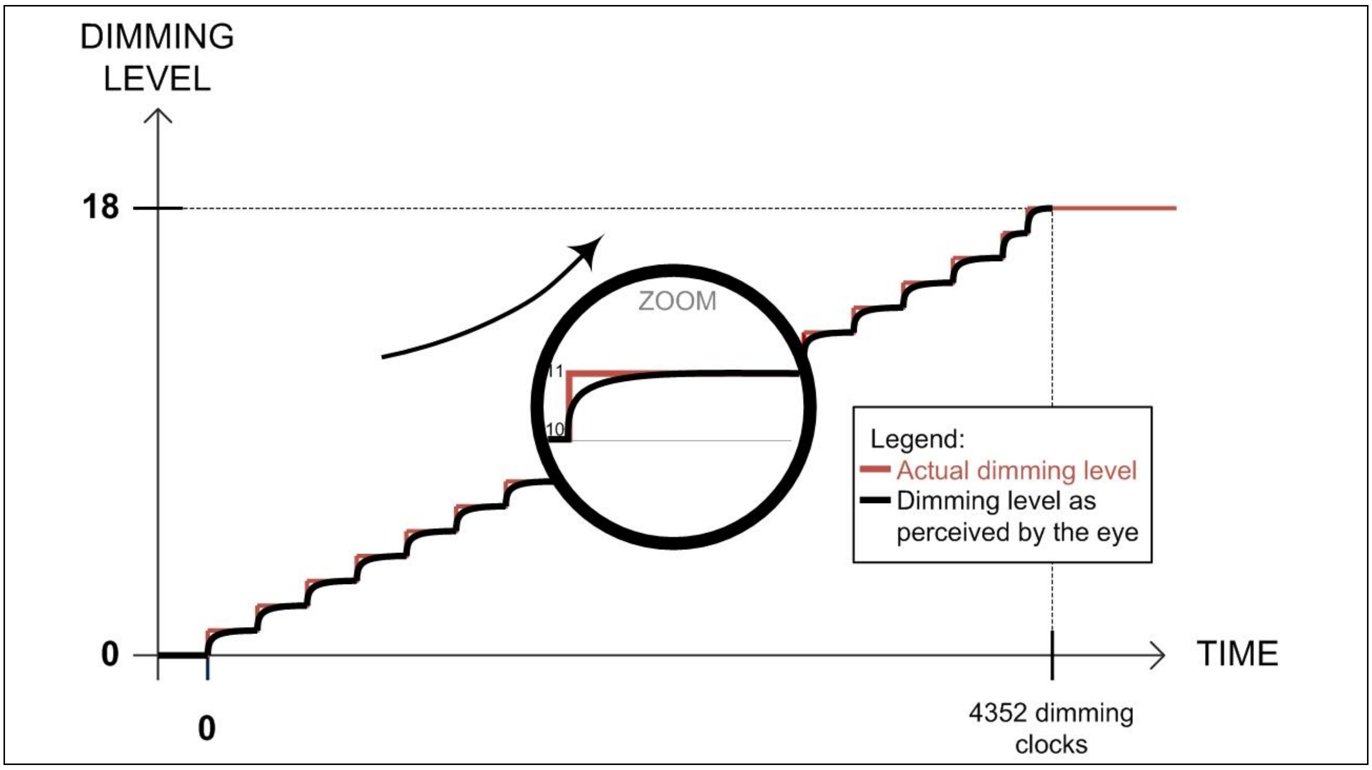


Figure 16 Dimming without dither enabled

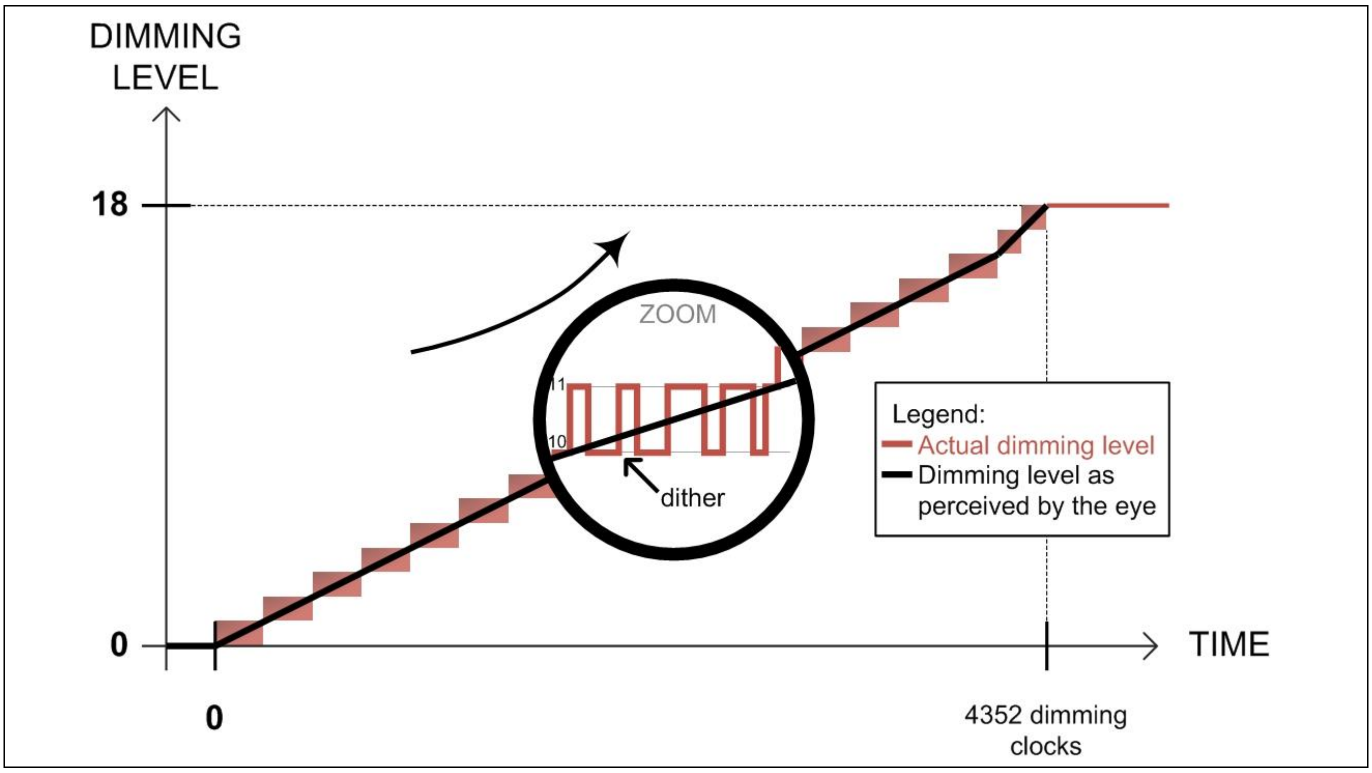


Figure 17 Dimming with dither enabled

1.4 Typical application examples

This chapter briefly describes some typical applications for the BCCU. More details are available in other chapters and in other application notes.

1.4.1 Multichannel lamps

The main target applications are automatic dimming and color control of multichannel LED lamps; and dimming control of multichannel white lamps with a controlled switching rate (Figure 18).

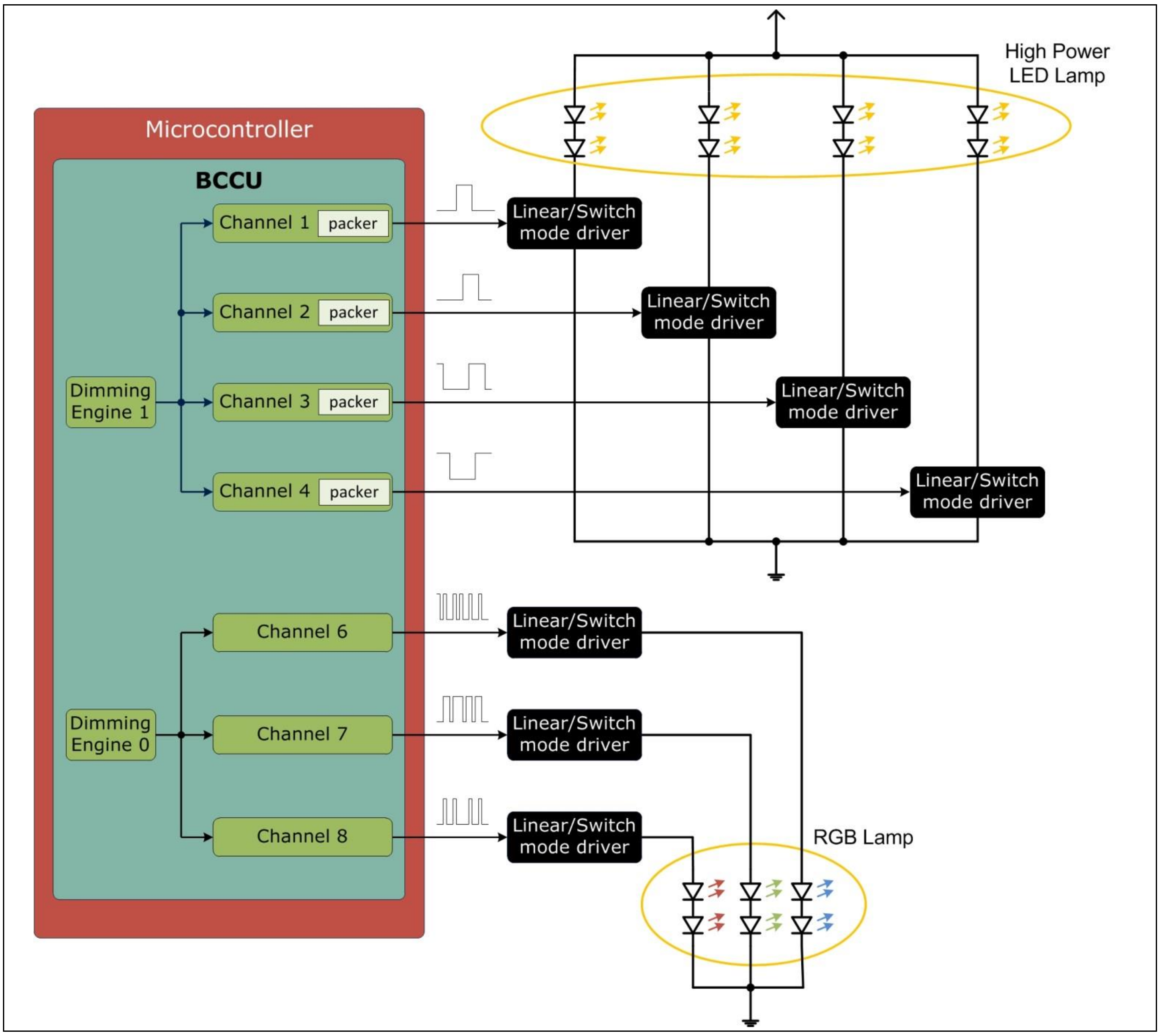


Figure 18 **Multichannel LED Lamps**

The BCCU is directly interconnected to the analog-digital converter (ADC) module via its trigger signals. This makes it convenient for fast, time-triggered lamp signal measurements, such as the LED string current, with minimum CPU load (Figure 19). These measurements can be used for various purposes such as open circuit detection, short circuit detection and variable bus voltage feedback.

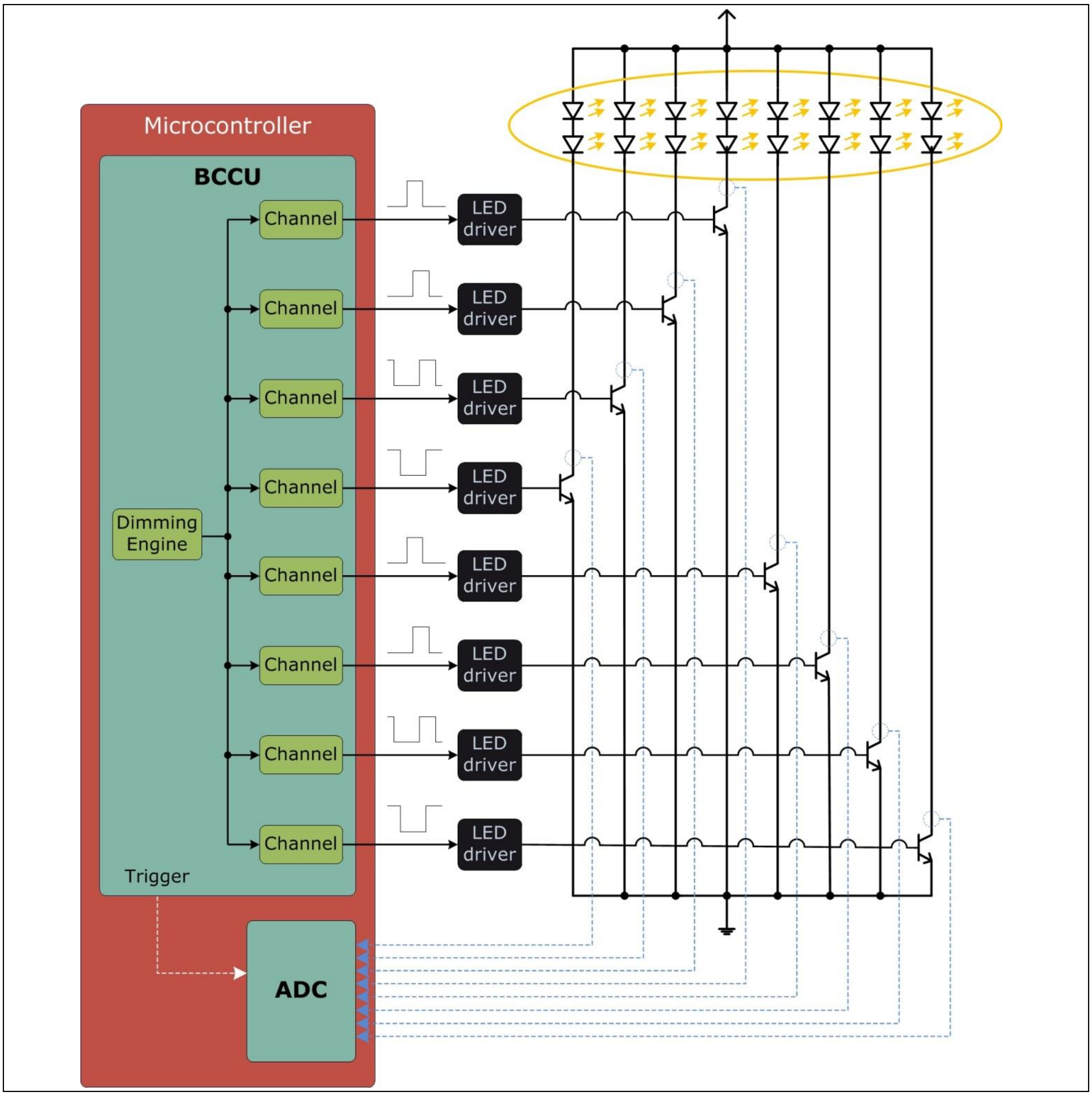


Figure 19 8-channel street lamp with ADC for signal measurement

The BCCU is also directly interconnected to capture and compare units, CCU4 and CCU8. This enables lamps to be controlled directly by the microcontroller without any switch-mode drivers (Figure 20).

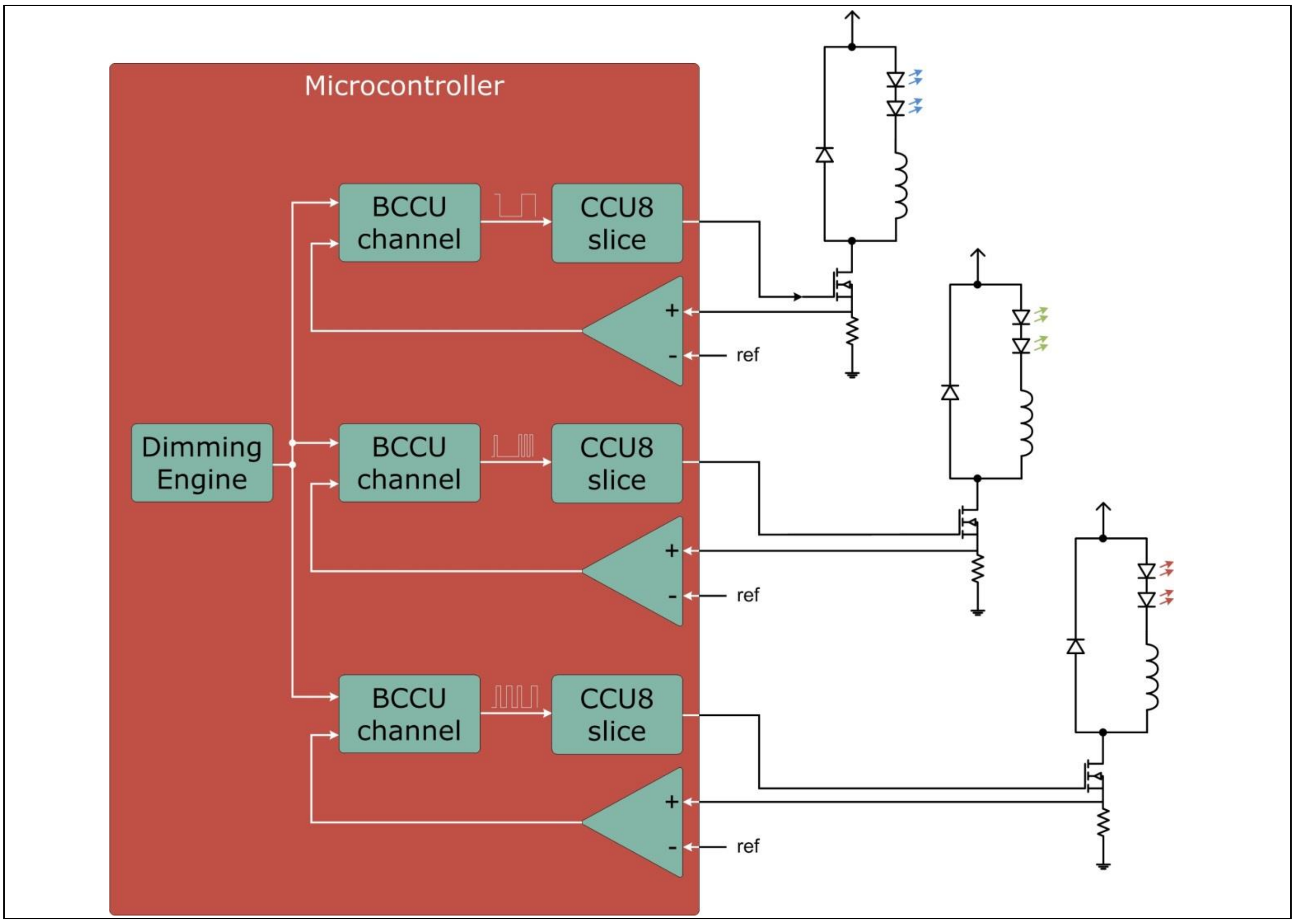


Figure 20 BCCU-CCU8 control of an RGB lamp without drivers

1.4.2 Simple digital-to-analog converter (DAC)

The BCCU can also be used as a simple DAC with one external resistor and one external capacitor as a filter (Figure 21).

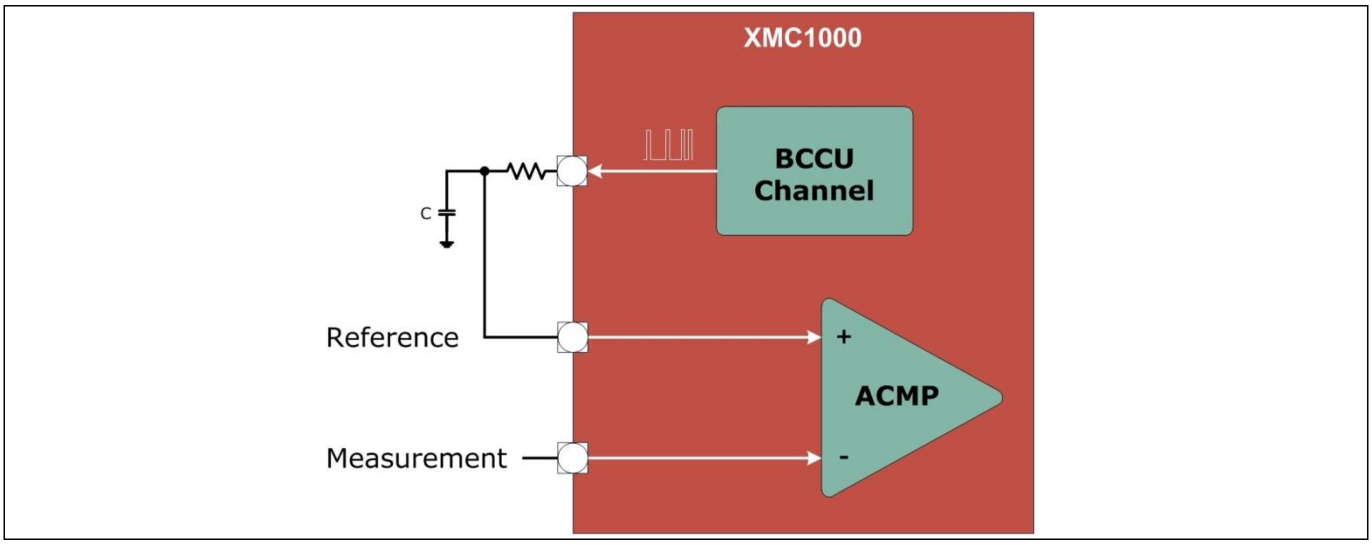


Figure 21 Simple DAC with BCCU

2 Color LED lamp control with BCCU

This section intends to highlight the merits of using the BCCU to control color LED lamps, backed with a DAVE^{TM} example project.

2.1 Color LED lamp

A color LED lamp has at least two LED channels, each with a different chromaticity. A common example is an RGB lamp that has 3 channels to represent red, green and blue chromaticities (Figure 2). This arrangement suits human color vision well because the human eye perceives color by cones most sensitive to red, green and blue wavelengths. The combination of the channel intensities gives rise to the perception of a certain color by the human eye.

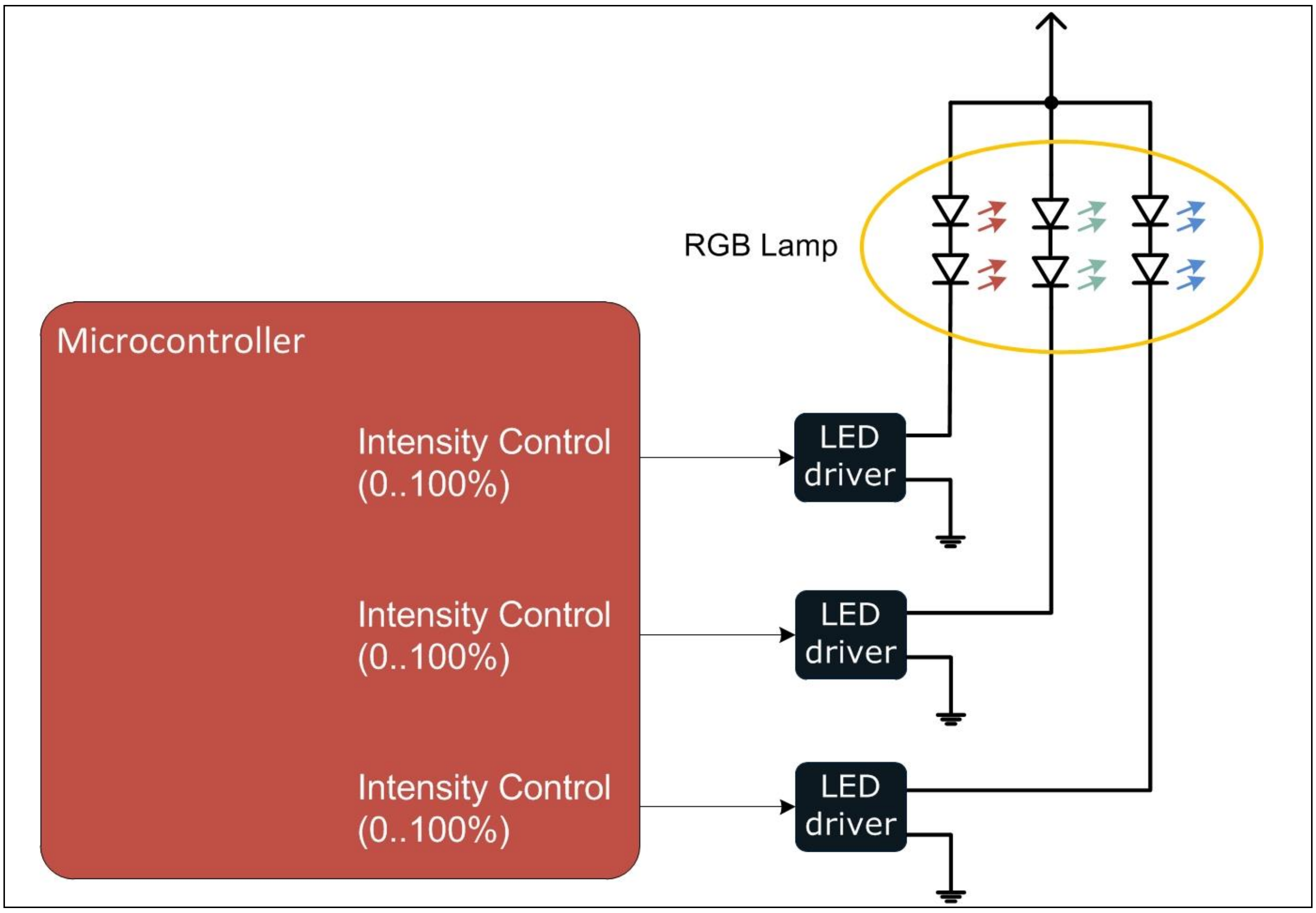

RGB Lamp
Microcontroller
Intensity Control (0..100%)
Intensity Control (0..100%)
Intensity Control (0..100%)
LED driver
LED driver
LED driver

Figure 22 RGB lamp example

2.2 BCCU for color LED lamps

The BCCU natively supports this arrangement.The BCCU channels provide intensity control to the respective chromaticities of the color LED lamp. From the perspective of hardware, the BCCU channels are selected based on the microcontroller pins used, and can be in any order.

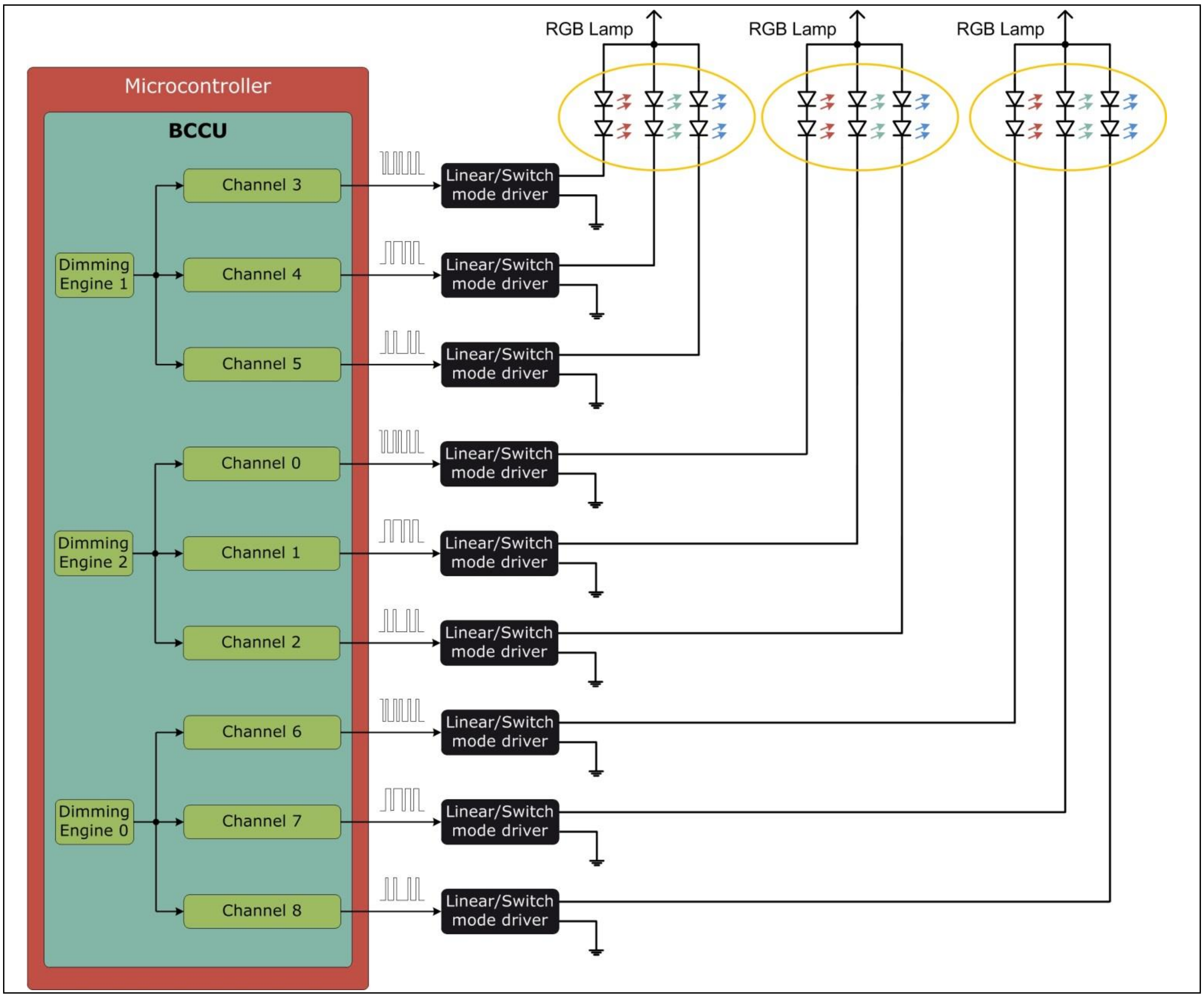


Figure 23 Controlling color lamps with BCCU

The channels and dimming engines (DEs) can be freely connected to each other by programming the register bit fields **CHCONFIGy.DSEL**.

Each DE generates a 12-bit number to represent the dimming level. This number can be read from the register bit field **DLz.DLEV**. The dimming level determines how dim or bright the lamp is, without affecting its color. This number can be changed gradually in an exponential manner over time automatically by the DE to match the human eye's logarithmic brightness perception.

To start this dimming process automatically:

1. Select the fade rate via register bit field **DTTz.DIMDIV**.
2. Program the target dimming level via register bit field **DLSz.TDLEV**.
3. Start fading via register bit **DESTRCON.DEzS**.

More details on exponential dimming are covered in Exponential dimming with BCCU.

2.2.1 Controlling lamp color

Each channel generates a 12-bit number to represent the channel intensity. This number can be read from the register bit field **INTy.CHINT**. In a multi-channel lamp, these channel intensities determine the color of the lamp. In every channel, the dimming level is multiplied by the channel intensity. After truncating, the resulting 12-bit value determines the brightness of the LEDs in the given color channel of the lamp.

The channel brightness is modulated by a sigma-delta (ΣΔ) modulator into a pulse-density modulated (PDM) signal that controls the lamp channel (Figure 24). The average value of the signal is proportional to the channel brightness. As an example, if *red brightness* is 2048, then the red LEDs are turned on 50% of the time. If *blue brightness* is 4095, then the blue LEDs are always turned on.

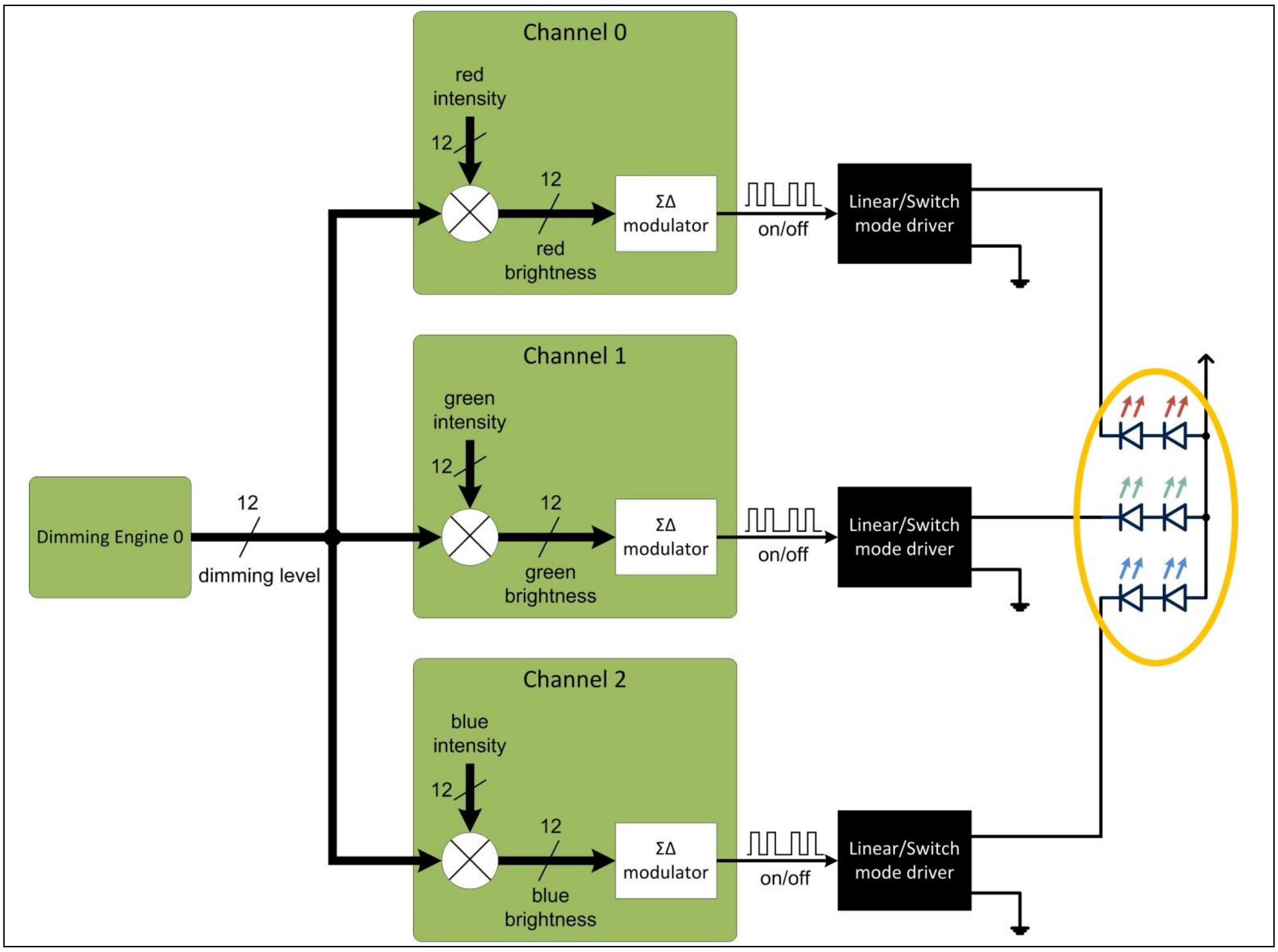


Figure 24 Multi-channel lamp control with BCCU

The color of the lamp can be controlled by programming the channel intensities via register bit field **INTSy.TCHINT**. If *red intensity* is 4095, *green intensity* is 4095 and *blue intensity* is 0, then the lamp appears yellow regardless of the dimming level. This is in accordance with the behavior of an additive RGB color space. This color also depends on the dominant wavelength and relative output power of the red, green and blue LEDs as RGB is a device-dependent color space.

The color of the lamp can be changed in a linear, gradual manner in a process called linear walk (Figure 25). Alternatively, the lamp color can be changed immediately.

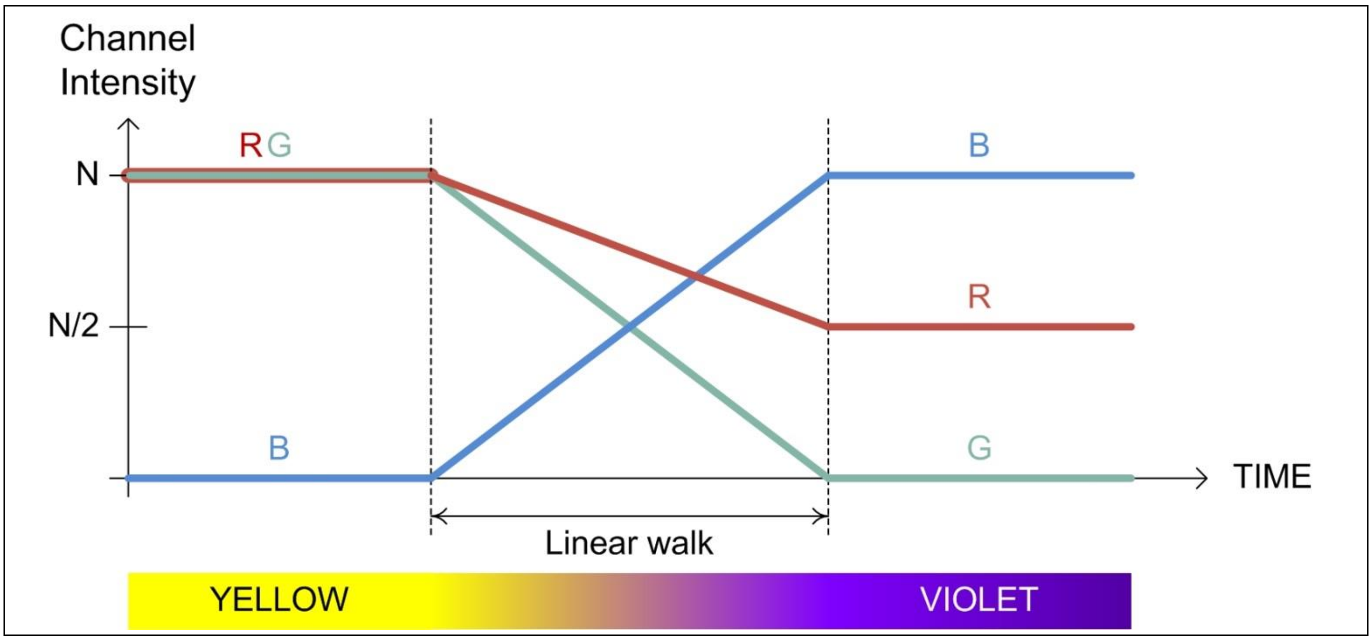


Figure 25 Linear walk for a 3-channel lamp

To change the lamp color:

1. Set target intensity for each channel via register bit fields **INTSy.TCHINT**.
2. Set the transition time or linear walk time via register bit field **CHCONFIGy.LINPRES**. Set this parameter to 0 for an immediate change.
3. Start the linear walk via bit **CHSTRCON.CHyS**.

*Note: For a smooth color change, the transition time has to be the same in all channels and the linear walks have to be started the same time by setting the respective **CHSTRCON.CHyS** bits in a single write.*

Bit **CHSTRCON.CHyS** resets automatically upon completion of the linear walk (Figure 26). A linear walk on any channel can be aborted at any time by writing to the respective **CHSTRCON.CHyA** bit. The channel intensity (**INTy.CHINT**) then remains at the level at which the linear walk is aborted (Figure 27).

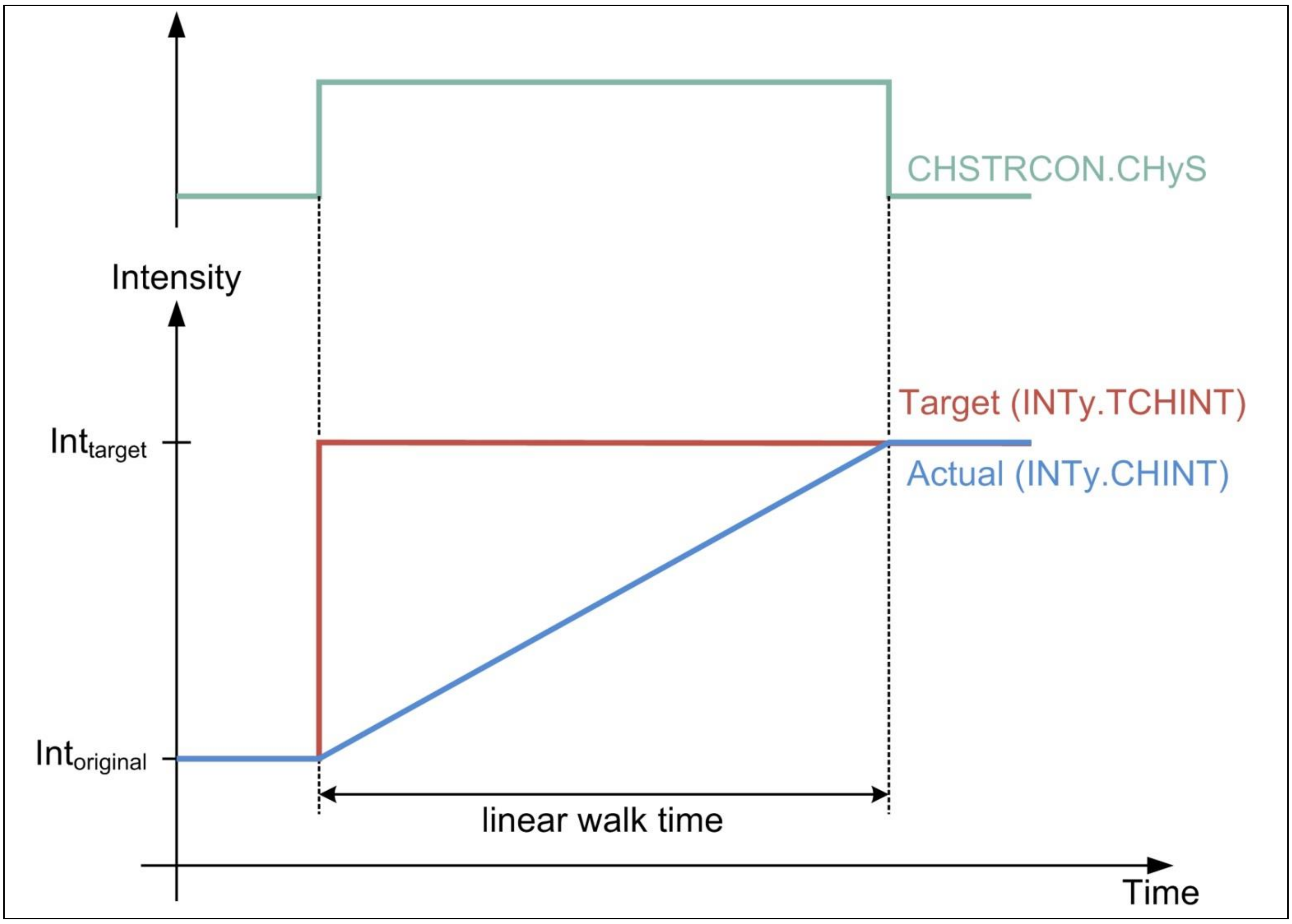


Figure 26 A complete linear walk

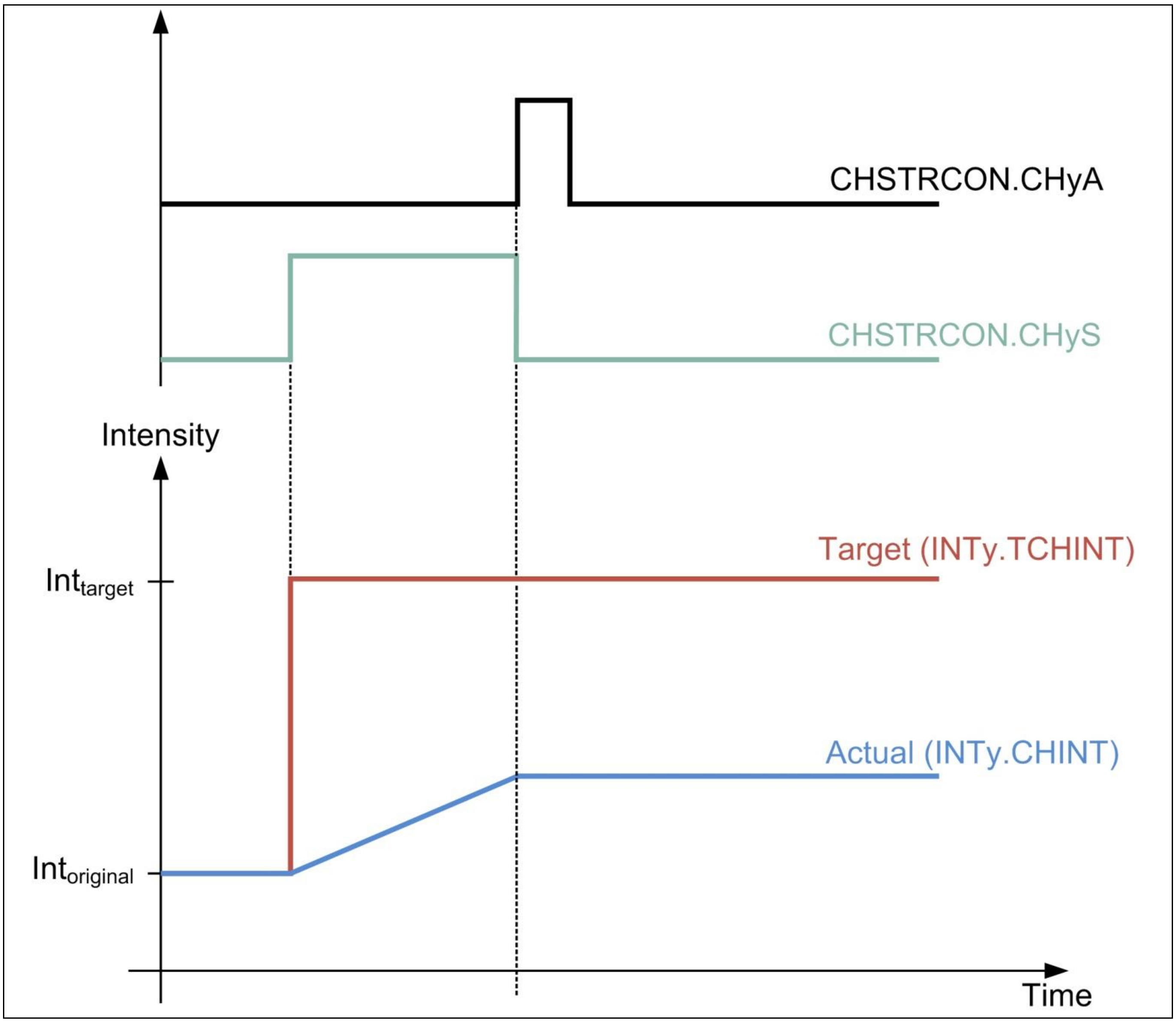


Figure 27 An aborted linear walk

2.3 RGB LED example

This section provides a guide to set up a basic project to control an RGB LED. This example demonstrates the linear walk feature of the BCCU.

The hardware required is:

- XMC1200 Boot Kit
- Color LED Card (Figure 28)

DAVE^{TM} is used as the development environment (Figure 29).

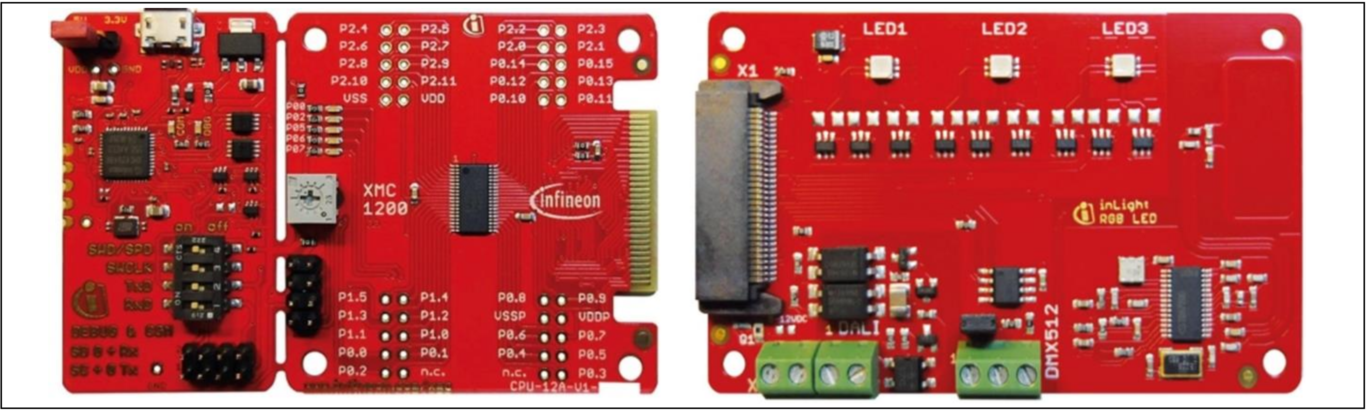


Figure 28 XMC1200 boot kit (left) and color LED card

Figure 29 DAVE^{TM} Integrated Development Environment by Infineon

Only one of the RGB LEDs on the Color LED Card, LED1, is controlled in this example. The PDM output from three BCCU channels drives the LED drivers (BCR421) on each channel (Figure 30). The drivers in turn control the current flow through the Red, Green and Blue LEDs of the LED module.

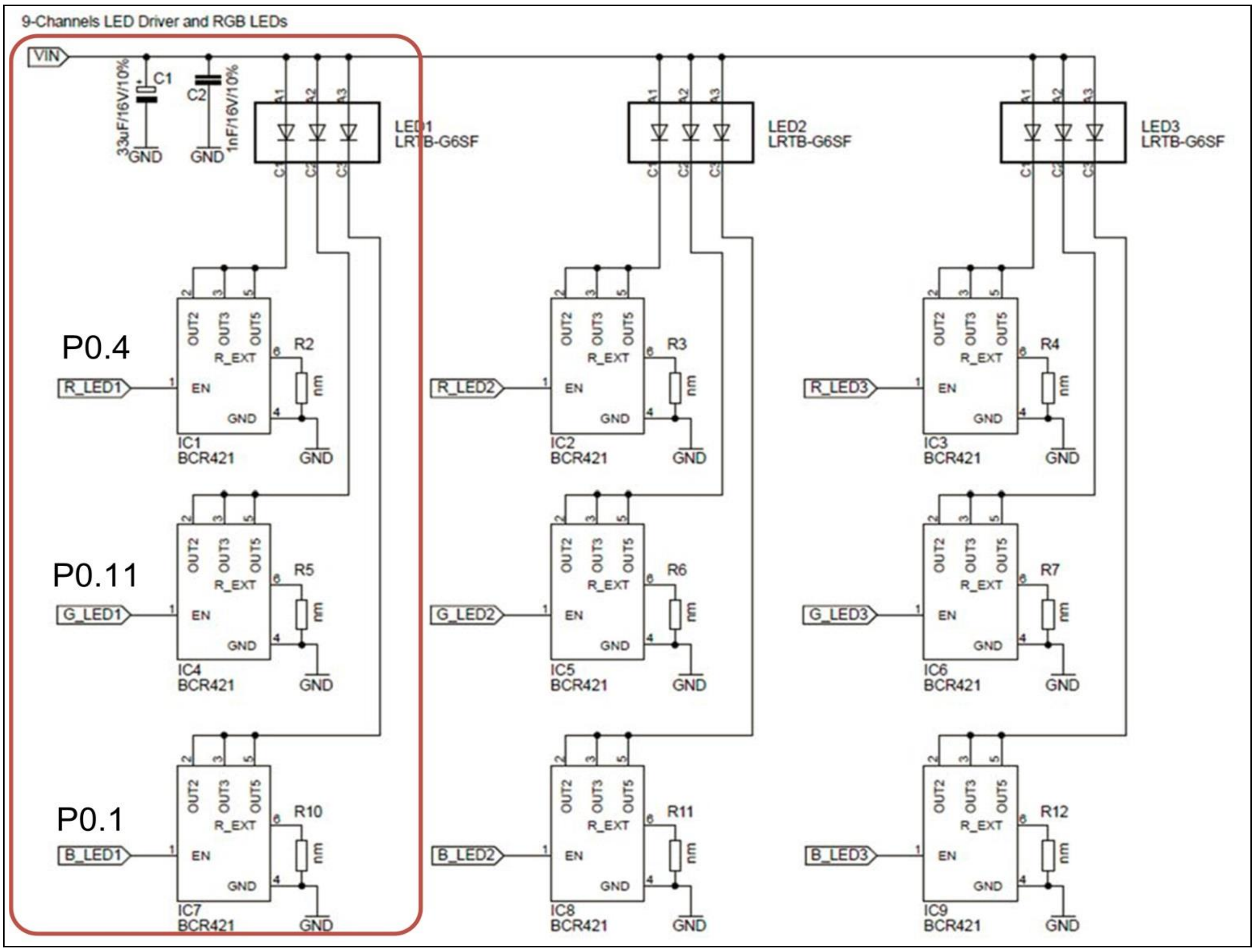


Figure 30 Schematic of LED1

2.3.1 Implementation with XMC™ Lib

This section describes how the Infineon XMC Lib can be used to implement the RGB LED example.

Configuration

The configuration section can be broken down to three parts:

1. Global configuration:

   This constitutes the configuration of BCCU clocks. The BCCU fast clock (FCLK) prescaler is configured with a value of 0x50. Assuming that the peripheral clock frequency is configured to 64 MHz, the resulting frequency value is 800 kHz. A BCCU bit-clock (BCLK) frequency that is a quarter of the BCCU FLCK is desired (200 kHz). Therefore XMC_BCCU_BCLK_MODE_NORMAL is configured for the bit-clock selector. The BCCU dimmer clock (DCLK) prescaler is configured with a value of 0xDB to get a frequency value of 292.237 kHz.

```
XMC_BCCU_GLOBAL_CONFIG_t bccu_global_config =
{
  .fclk_ps = 0x50, //800kHz @PCLK=64MHz
  .dclk_ps = 0xdb, //292.237KHz @PCLK=64MHz
  .bclk_sel = XMC_BCCU_BCLK_MODE_NORMAL //200KHz @PCLK=64MHz
};
```

2. Dimming engine configuration:
   Configuration of the dimming engine is still required, even though the dimming engine is not actively used in this example. This is mainly to initialize the dimming level of the RGB LED. The dimming clock divider is configured with a value of 0. With this setting, the dimming level immediately becomes the same as the target dimming value.

```
XMC_BCCU_DIM_CONFIG_t bccu_dim_config =
{
  .dim_div = 0x0 // immediate dimming
};
```

3. Channel configuration:
   This constitutes the selection of the dimming input source for each of the three BCCU channels. As the three channels form a single RGB LED, the same dimming engine is selected for all of them. XMC_BCCU_CH_DIMMING_SOURCE_DE0 is used to select dimming engine 0.

```
XMC_BCCU_CH_CONFIG_t r_pdm_config =
{
  .dim_sel = XMC_BCCU_CH_DIMMING_SOURCE_DE0 // DE0
};
XMC_BCCU_CH_CONFIG_t g_pdm_config =
{
  .dim_sel = XMC_BCCU_CH_DIMMING_SOURCE_DE0 // DE0
};
XMC_BCCU_CH_CONFIG_t b_pdm_config =
{
  .dim_sel = XMC_BCCU_CH_DIMMING_SOURCE_DE0 // DE0
};
```

Initialization

Similarly, the initialization can be broken down to three parts:

1. Global initialization:
   It is essential that the BCCU global functions are initialized first. This also ungates the peripheral clock to the BCCU kernel.

```
/* BCCU Global Initialization */

XMC_BCCU_GlobalInit(BCCU0, &bccu_global_config);
```

2. Dimming engine intialization:

```
/* init dimming engine */
XMC_BCCU_DIM_Init(BCCU0_DE0, &bccu_dim_config);
/* enable dimming engine */

XMC_BCCU_EnableDimmingEngine(BCCU0, XMC_BCCU_CH_DIMMING_SOURCE_DE0);
```

Although the objective of this example is to demonstrate the linear walk feature in the BCCU channels rather than the exponential dimming feature in the dimming engines, it is still important that the dimming engine is initialized, with the dimming level initialized to a non-zero value. This is because the channel brightness value is a product of the dimming level and the intensity value. If the dimming level is left at the default value of 0, the channel brightness has a value of 0 regardless of the intensity value.

```
/* set target dimming level to max */
XMC_BCCU_DIM_SetTargetDimmingLevel(BCCU0_DE0, 4095);
```

After the target dimming level is set, the change in dimming level can be effected by starting the dimming process.

```
/* effect the change in dimming level */
XMC_BCCU_StartDimming(BCCU0, XMC_BCCU_CH_DIMMING_SOURCE_DE0);
```

3. Channel initialization:
   The three BCCU channels that are used are BCCU0_CH0, BCCU0_CH7 and BCCU0_CH8 for the red, green and blue LED channels respectively.

```
/* init channels */
XMC_BCCU_CH_Init(BCCU0_CH0, &r_pdm_config);
XMC_BCCU_CH_Init(BCCU0_CH7, &g_pdm_config);
XMC_BCCU_CH_Init(BCCU0_CH8, &b_pdm_config);
```

The linear walk time is set to an initial value of 7 seconds, by setting the prescaler to a value of 0x2AC. The prescaler can be calculated using this formula:

*Linear presclar = (Linear walk * FCLK) / 2^13*

```
/* Set linear walk time for PDMs*/
XMC_BCCU_CH_SetLinearWalkPrescaler(BCCU0_CH0, 0x2AC);
XMC_BCCU_CH_SetLinearWalkPrescaler(BCCU0_CH7, 0x2AC);
XMC_BCCU_CH_SetLinearWalkPrescaler(BCCU0_CH8, 0x2AC);
```

The channels are then enabled concurrently. The mask required to enable channels 0, 7 and 8 is 0x181.

```
/* Enable PDM channels*/
XMC_BCCU_ConcurrentEnableChannels(BCCU0, 0x181);
```

The color of the RGB LED can then be initialized by setting the target channel intensities. To set the LED color to white, set each target channel intensity with the same value.

```
/* set initial color to white */
XMC_BCCU_CH_SetTargetIntensity(BCCU0_CH0, 1365);
XMC_BCCU_CH_SetTargetIntensity(BCCU0_CH7, 1365);
XMC_BCCU_CH_SetTargetIntensity(BCCU0_CH8, 1365);
```

To effect the color change, start the linear walk. For a smooth color transition, start the linear walk concurrently in all three channels. The same mask can be used.

```
XMC_BCCU_ConcurrentStartLinearWalk(BCCU0, 0x181);
```

Function implementation

The color of the RGB LED can be changed in two steps:

1. Set the target channel intensities. The combination of the channel intensities results in a color. One simple color scheme that can be suggested here is as follows (Table 1), whereby the respective channel intensities sum up to a maximum intensity value of 4095 or 4096.

Table 1 Simple color scheme

Desired color	RED channel intensity	GREEN channel intensity	BLUE channel intensity
Red	4095	0	0
Green	0	4095	0
Blue	0	0	4095
White	1365	1365	1365
Yellow	2048	2048	0
Magenta	2048	0	2048
Cyan	0	2048	2048

   For example, to change the color of the LED to red:

```
XMC_BCCU_CH_SetTargetIntensity(BCCU0_CH0, 4095);
XMC_BCCU_CH_SetTargetIntensity(BCCU0_CH7, 0);
XMC_BCCU_CH_SetTargetIntensity(BCCU0_CH8, 0);
```

2. Start the linear walk concurrently in all channels.

```
XMC_BCCU_ConcurrentStartLinearWalk(BCCU0, 0x181);
```

The status of the linear walk can be checked:

```
XMC_BCCU_IsLinearWalkComplete(BCCU0, BCCU0_CH0); // returns 0 if complete
```

Note: It is sufficient to check the status of 1 channel if the start of linear walk is synchronized for all channels of a lamp.

The linear walk can be aborted as follows:

```
XMC_BCCU_ConcurrentAbortDimming(BCCU0, 0x181);
```

The respective channel intensities can then be read:

```
XMC_BCCU_CH_ReadIntensity(BCCU0_CH0);
XMC_BCCU_CH_ReadIntensity(BCCU0_CH7);
XMC_BCCU_CH_ReadIntensity(BCCU0_CH8);
```

2.3.2 Implementation with DAVE™ APPs

PDM_DIMMED_LED_LAMP APP (Figure 31) allows for the configuration of up to nine channels in a lamp. In this example, select 3 LED channels (Figure 32).

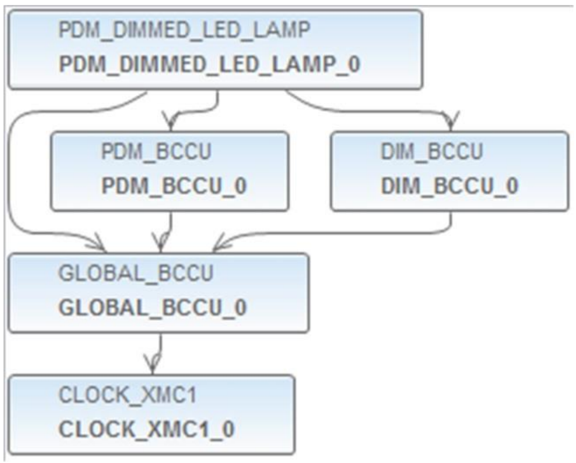
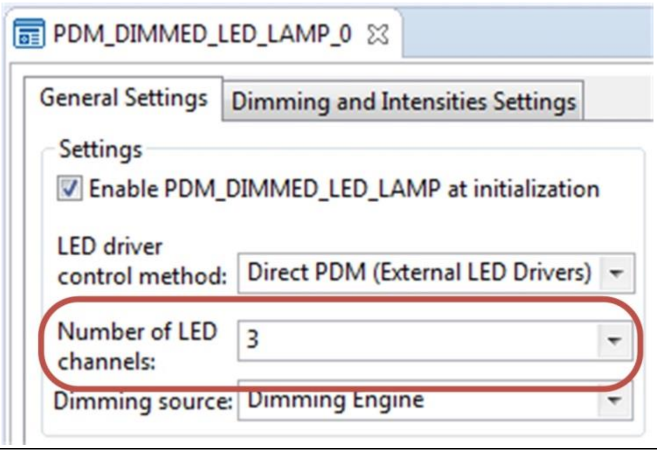


Figure 31 PDM_DIMMED_LED_LAMP APP in DAVE™



☑ Enable PDM_DIMMED_LED_LAMP at initialization

LED driver control method: Direct PDM (External LED Drivers)

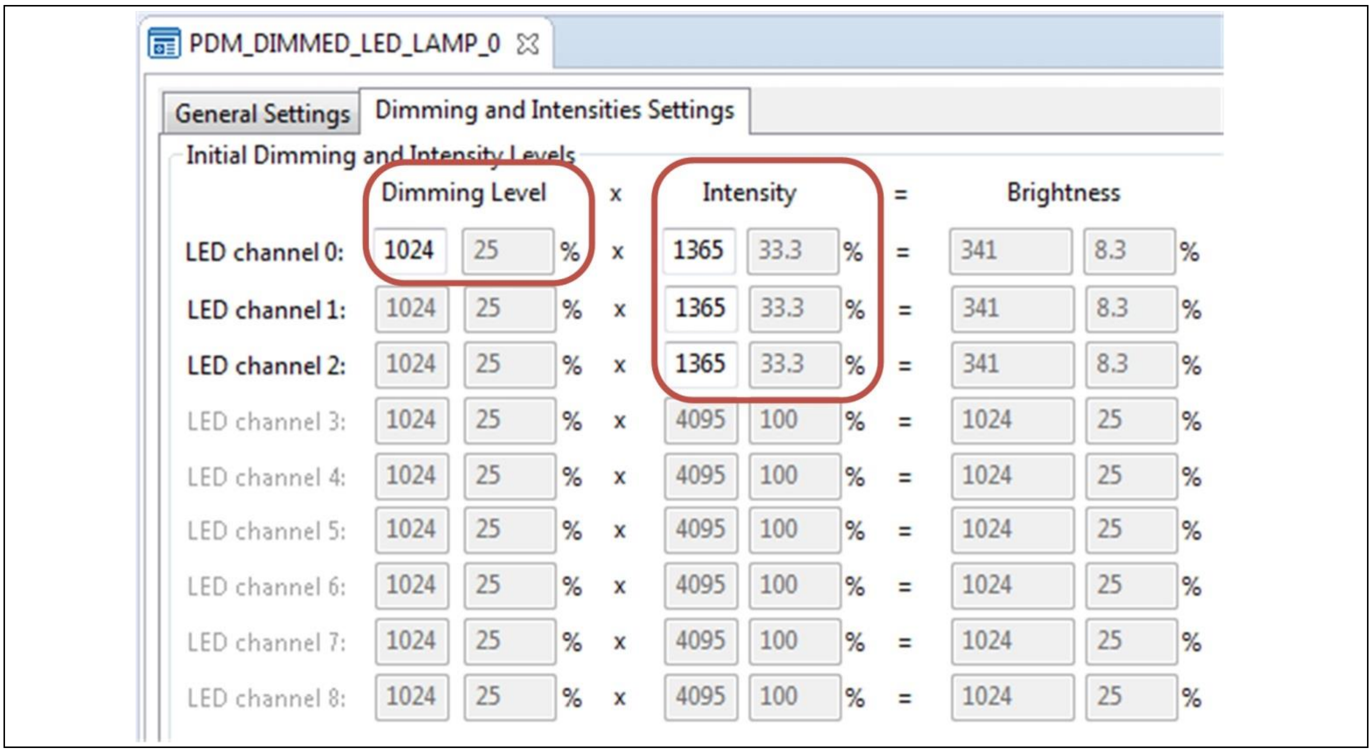
Number of LED channels: 3

Dimming source: Dimming Engine

Figure 32 Select number of LED channels in PDM_DIMMED_LED_LAMP APP UI

The dimming level and channel intensities can be configured in the PDM_DIMMED_LED_LAMP APP under the “Dimming and Intensities Settings” tab (Figure 33). For this example, the dimming level is kept constant. Only the channel intensities are changed in-application.

The linear walk time can also be configured under the same tab (Figure 34).

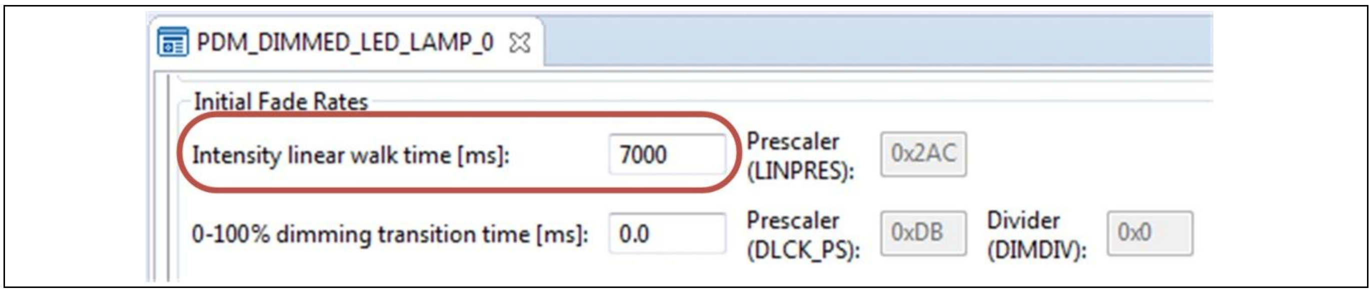

PDM_DIMMED_LED_LAMP_0

General Settings | Dimming and Intensities Settings

Initial Dimming and Intensity Levels

	Dimming Level			x	Intensity			=	Brightness		
LED channel 0:	1024	25	%	x	1365	33.3	%	=	341	8.3	%
LED channel 1:	1024	25	%	x	1365	33.3	%	=	341	8.3	%
LED channel 2:	1024	25	%	x	1365	33.3	%	=	341	8.3	%
LED channel 3:	1024	25	%	x	4095	100	%	=	1024	25	%
LED channel 4:	1024	25	%	x	4095	100	%	=	1024	25	%
LED channel 5:	1024	25	%	x	4095	100	%	=	1024	25	%
LED channel 6:	1024	25	%	x	4095	100	%	=	1024	25	%
LED channel 7:	1024	25	%	x	4095	100	%	=	1024	25	%
LED channel 8:	1024	25	%	x	4095	100	%	=	1024	25	%

Figure 33 Configuring dimming level and channel intensities


PDM_DIMMED_LED_LAMP_0

Initial Fade Rates

Intensity linear walk time [ms]:	7000	Prescaler (LINPRES):	0x2AC		
0-100% dimming transition time [ms]:	0.0	Prescaler (DLCK_PS):	0xDB	Divider (DIMDIV):	0x0

Figure 34 Configuring linear walk time

Pin assignment

Ideally, for an RGB LED, the RED, GREEN and BLUE LEDs are assigned to BCCU channels in a sequential manner to facilitate in-application control. To make a sequential channel assignment:

1. Hover mouse cursor over the **connecting arrow** to a PDM_BCCU APP. A label appears momentarily showing the LED number, for example: LED0 (Figure 35).

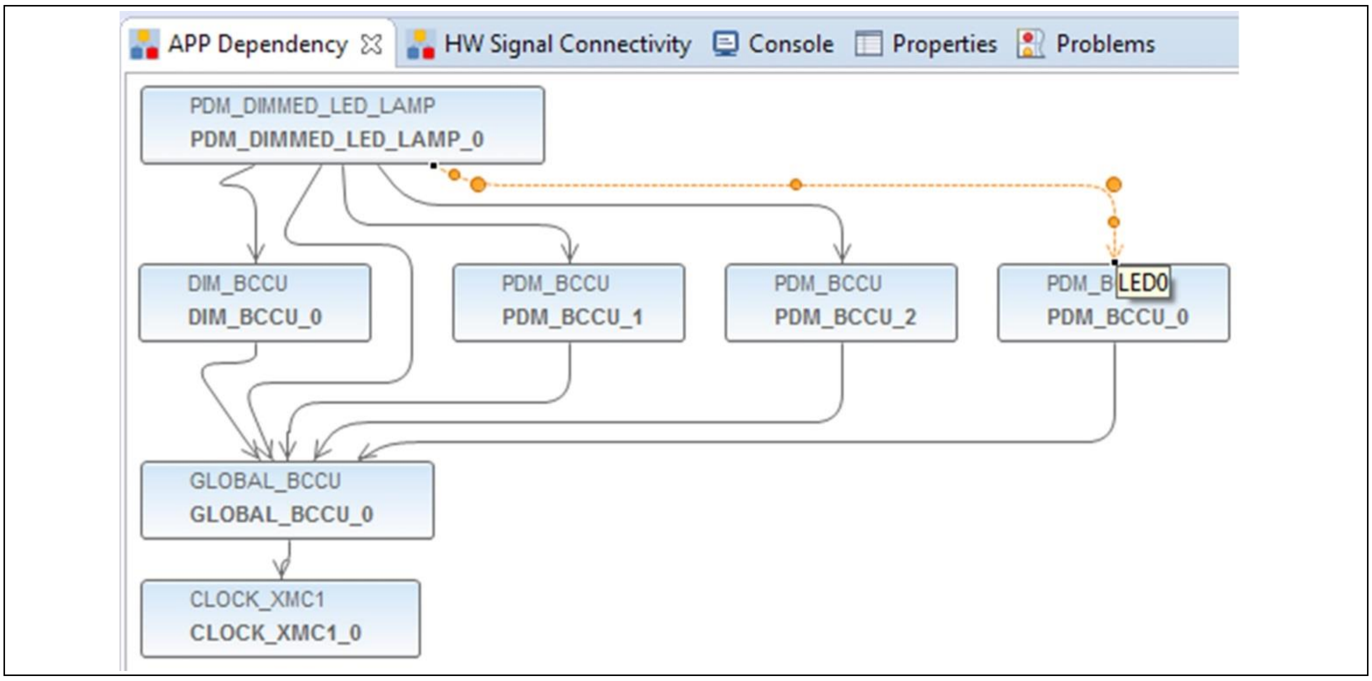
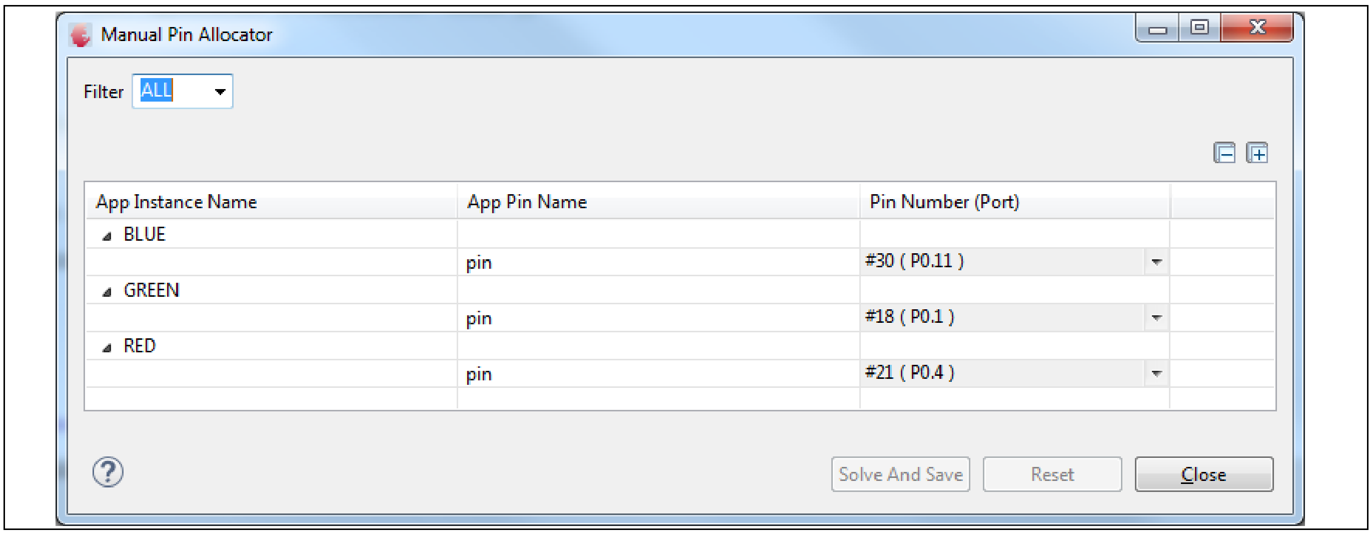


Figure 35 Renaming PDM_BCCU instance label

2. Right-click the PDM_BCCU APP.
3. Select "Rename instance label".
4. Type in new instance label. Replace the label of the instance "LED0" with "RED".
5. Repeat steps 1 to 4 for the other PDM_BCCU APP instances. Replace "LED1" with "GREEN" and "LED2" with "BLUE".
6. Manually assign pins to the renamed PDM_BCCU APP instances (Figure 36).



App Instance Name	App Pin Name	Pin Number (Port)
BLUE		
	pin	#30 (P0.11)
GREEN		
	pin	#18 (P0.1)
RED		
	pin	#21 (P0.4)

Figure 36 Manual pin assignment for PDM_BCCU APPs

2.3.2.1 Controlling lamp color

DAVE^{TM} generates a configuration data structure for the PDM_DIMMED_LED_LAMP_0 APP instance, *PDM_DIMMED_LED_LAMP_0.config*. This data structure holds the intensity values of the respective BCCU channels used in the lamp and also acts like a shadow register for the respective register bit fields **INTSy.TCHINT.**

As an example, to change the light color to red:

```
PDM_DIMMED_LED_LAMP_0.config->led_intensity[0] = 4095;
PDM_DIMMED_LED_LAMP_0.config->led_intensity[1] = 0;
PDM_DIMMED_LED_LAMP_0.config->led_intensity[2] = 0;
```

The lines above set the respective channel intensities for the desired color. To effect the color change, the linear walk has to be started:

```
PDM_DIMMED_LED_LAMP_SetColor(&PDM_DIMMED_LED_LAMP_0);
```

This function programs the BCCU register bit fields with the requested intensity values and then synchronizes the start of the linear walk for all channels of the lamp, to ensure a smooth and natural color transition. The linear walk time is configured the same as previously in the UI of the PDM_DIMMED_LED_LAMP APP.

The combination of the channel intensities results in a color. One simple color scheme that can be followed is as suggested in Table 1.

To use a different linear walk time for changing lamp color:

```
PDM_DIMMED_LED_LAMP_SetColorAdv(&PDM_DIMMED_LED_LAMP_0, 0x125); // walk time = 3s
```

The PDM_DIMMED_LED_LAMP APP UI can be used to easily calculate the prescaler for the desired walk time (Figure 37).

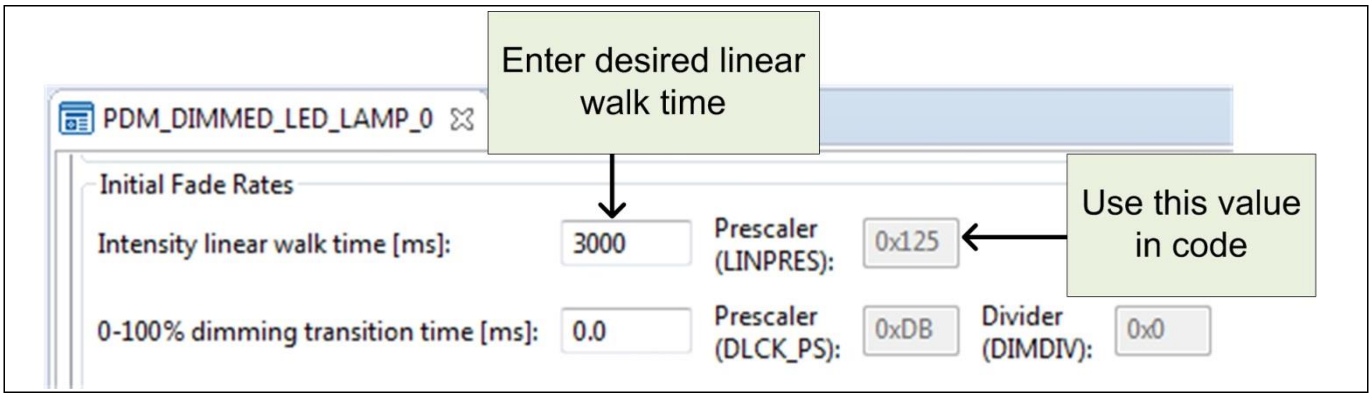

PDM_DIMMED_LED_LAMP_0
Initial Fade Rates
Intensity linear walk time [ms]: 3000
Prescaler (LINPRES): 0x125
0-100% dimming transition time [ms]: 0.0
Prescaler (DLCK_PS): 0xDB
Divider (DIMDIV): 0x0

Figure 37 Use PDM_DIMMED_LED_LAMP APP to calculate linear walk time prescaler

To get the status of the linear walk:

```
PDM_BCCU_LinearWalkStatus(&RED); // returns 0 if completed, else 1
```

Note: It is sufficient to check the status of 1 channel if the start of linear walk is synchronized for all channels of a lamp.

Alternatively, the application can wait indefinitely for the end of linear walk:

```
PDM_BCCU_AwaitEndOfLinearWalk(&RED); // wait till linear walk is complete
```

The linear walk can be aborted as follows:

```
PDM_DIMMED_LED_LAMP_AbortColorChange(&PDM_DIMMED_LED_LAMP_0);
```

To get the respective channel intensities after a linear walk abort:

```
PDM_BCCU_GetIntensity(&RED); // intensity value of Red channel
PDM_BCCU_GetIntensity(&GREEN); // intensity value of Green channel
PDM_BCCU_GetIntensity(&BLUE); // intensity value of Blue channel
```

3 Exponential dimming with BCCU

This section provides hints on using the dimming engine to achieve smooth and natural LED light dimming.

3.1 Dimming engine

At the heart of the dimming functionality in the BCCU are its dimming engines. A dimming engine can be simply viewed as a number generator. It always holds a certain number, which is the current dimming level. Based on the configuration and the request (target dimming level) that it received, the BCCU periodically increments or decrements its number towards the requested number, which then becomes the current dimming level.

Studies have shown that the human eye perceives light according to a logarithmic pattern. To compensate for this, in order for the transition to look even to the human eye, the dimming engine attempts to change its number in an exponential fashion. To achieve this, straight lines of differing gradient are pieced together to form a pseudo-exponential curve (Figure 38).

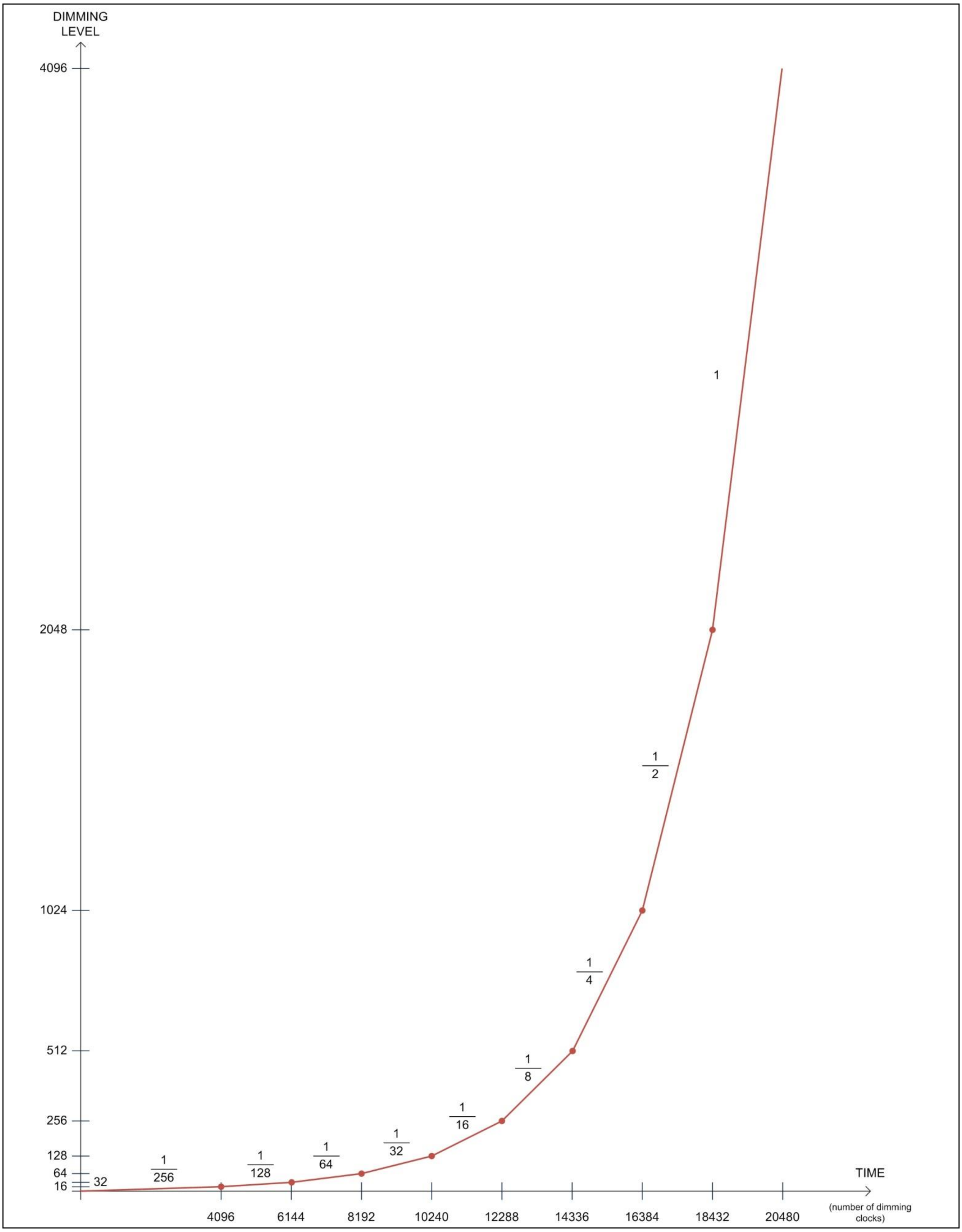


Figure 38 Pseudo-exponential curve

The BCCU offers two options for this pseudo-exponential curve – coarse and fine. The fine pseudo-exponential curve is made up of more pieces of straight lines of differing gradient. This option can be configured via the register bit **DTTz.CSEL**.

The dimming engines perform dimming following the selected exponential curve automatically without requiring any complex user software. To change the dim level of a lamp:

1. Program target dim level via the register bit field **DLSz.TDLEV**.
2. Program dimming transition time via the register bit field **DTTz.DIMDIV**.
3. Start dimming process by writing to the respective **DESTRCON.DEzS** bit.

Note: This same register bit can also be used to check if the dimming process is complete as it is cleared by hardware upon completion.

The dimming level can be read from the register bit field **DLz.DLEV**. A dimming process can be aborted by setting the respective **DESTRCON.DEzA** bit. The dimming level remains at the level at which dimming is aborted.

The dimming engine allows the BCCU to control the dim level of a lamp independently from the lamp's color component (Figure 39). This is especially beneficial in the case of color lamps, where the BCCU is able to maintain the lamp color while changing its dim level (Figure 40).

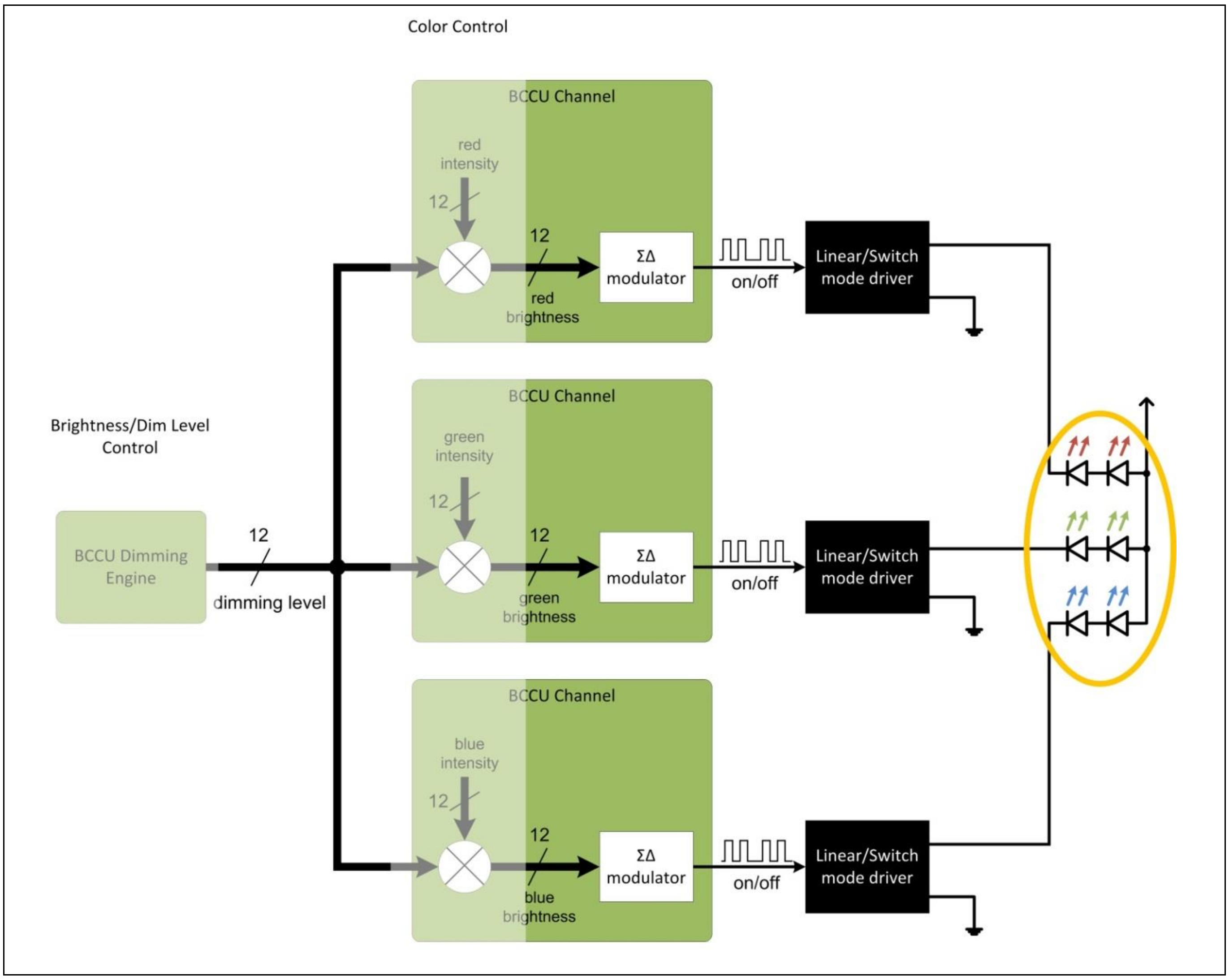


Figure 39 Separate control of dim level and color

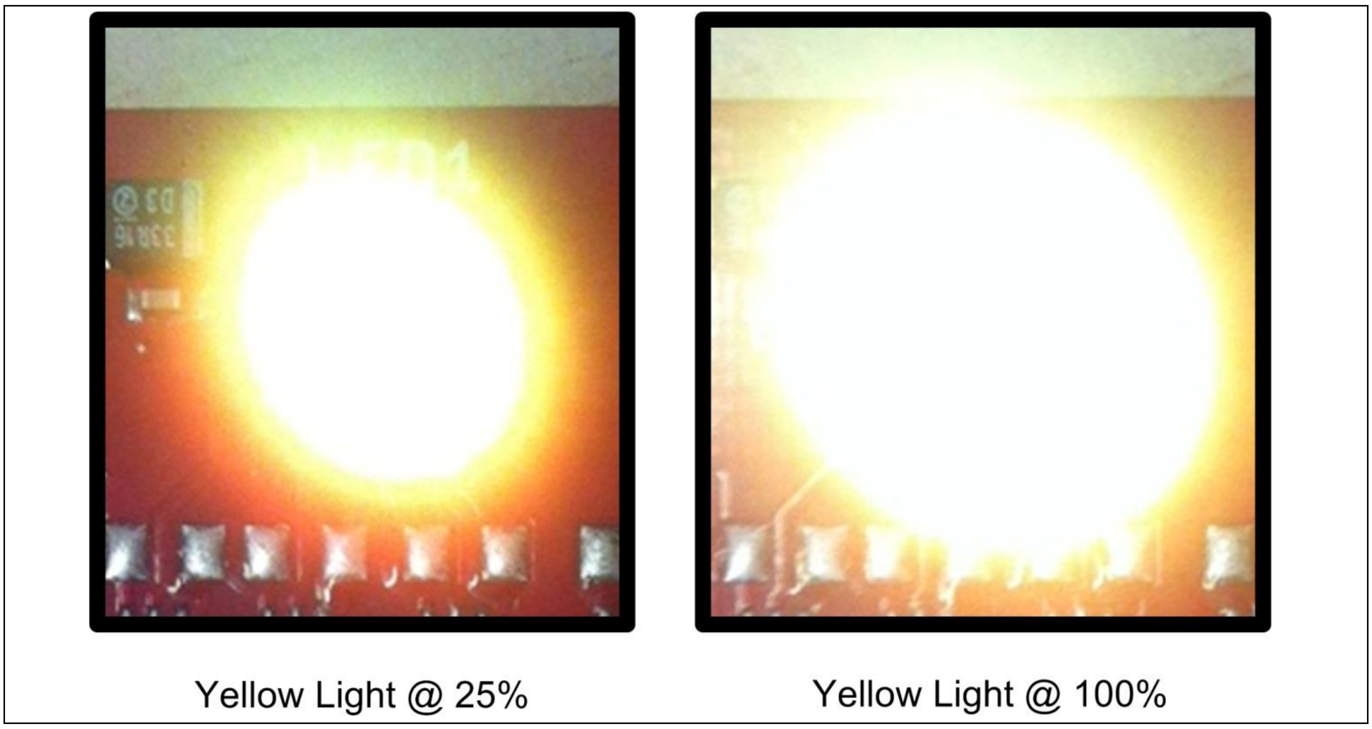


Figure 40 Changing dim level without changing lamp color

The human eye can be sensitive to changes in brightness, more notably in low dim levels. To avoid visible discrete steps in brightness, dimming engine comes with a dither function which can be configured via register bit **DTTz.DTEN**.

Note: The dither function can only be used with the coarse exponential curve.

When the dither function is enabled, a dither pattern is automatically superimposed each time the dimming level is supposed to change by a single dimming step (Figure 41). This makes the transition appear smoother to the human eye.

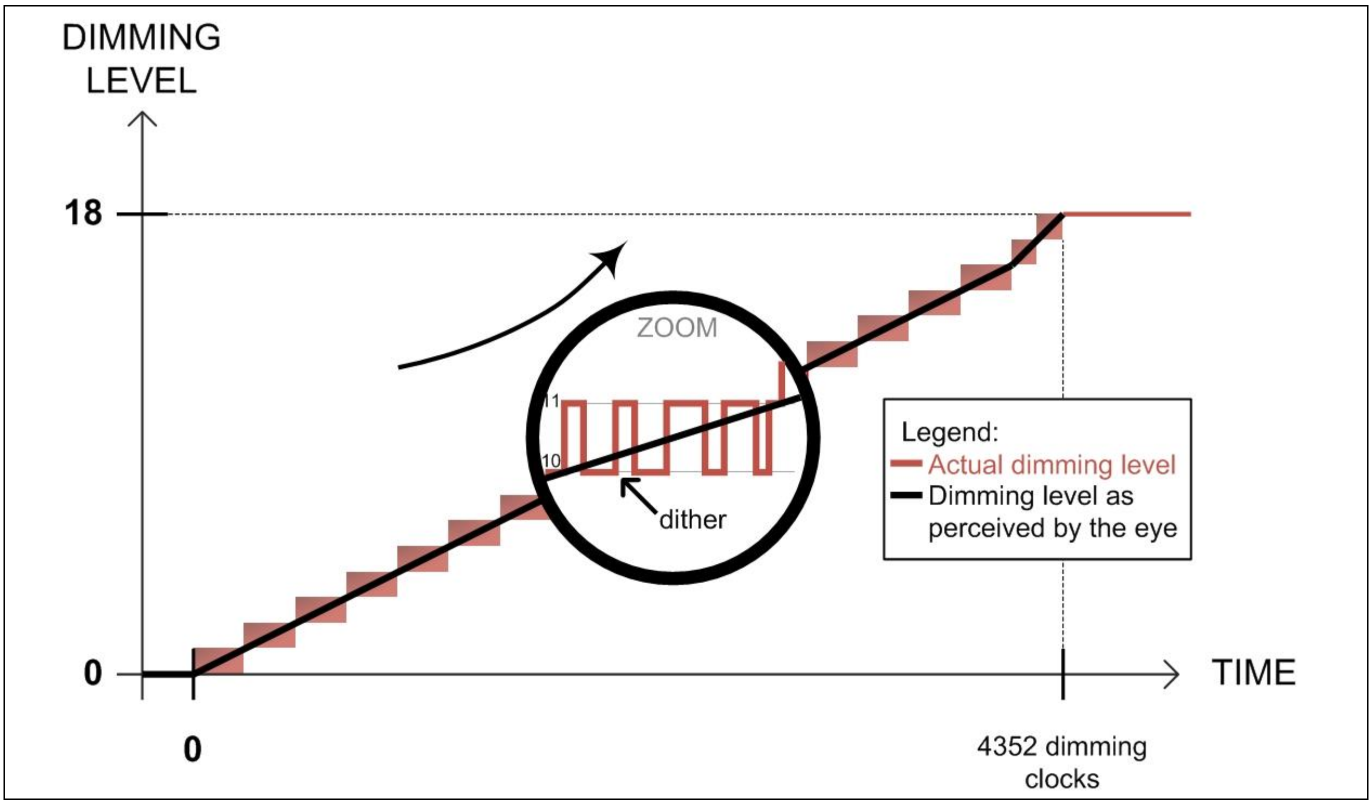


Figure 41 Dither function in action

3.2 RGB LED example revisited

In this section, the RGB LED example is revisited, with the focus turning to the setting up of the dimming engine and controlling the lamp's dim or brightness level.

3.2.1 Implementation with XMC™ Lib

This section demonstrates the usage of XMC Lib. The focus is mainly on the setting up and control of the dimming engine. Refer to 2.3.1 Implementation with for a complete view on the configuration steps for the RGB LED example.

Configuration

The fade time can be configured by programming dim_div with the right value. This fade time refers to dimming from 0% to 100% brightness, and vice versa. The formulae for calculating dim_div are as follows:

$DIMDIV = (Fade\ time * DCLK) / 20479$ for dimming up

$DIMDIV = (Fade\ time * DCLK) / 20734$ for dimming down

As an example, for dimming up with a fade time of 10 seconds:

DIMDIV = (10 * 292237) / 20479 = 143 or 0x8F

The dimming curve can be selected using XMC_BCCU_DIM_CURVE_COARSE or XMC_BCCU_DIM_CURVE_FINE. If the coarse curve is selected, the dither function can additionally be enabled by setting dither_en with a value of 1.

```
XMC_BCCU_DIM_CONFIG_t bccu_dim_config =
{
  .dim_div = 0x8F, // fade time of 10s
  .dither_en = 1, // enable dither
  .cur_sel = XMC_BCCU_DIM_CURVE_COARSE // coarse dimming curve
};
```

Initialization

The example below shows the initialization and enabling of dimming engine 0. For dimming engine 1 and 2, BCCU0_DE1 and BCCU0_DE2 can be used respectively in place of BCCU0_DE0.

```
/* init dimming engine */
XMC_BCCU_DIM_Init(BCCU0_DE0, &bccu_dim_config);
/* enable dimming engine */
XMC_BCCU_EnableDimmingEngine(BCCU0, XMC_BCCU_CH_DIMMING_SOURCE_DE0);
```

Function implementation

To change the lamp brightness, the target dimming level must be set first:

```
/* set target dimming level to max */
XMC_BCCU_DIM_SetTargetDimmingLevel(BCCU0_DE0, 4095);
```

After the target dimming level is set, the change in dimming level can be effected by starting the dimming process:

```
/* start dimming process */
XMC_BCCU_StartDimming(BCCU0, XMC_BCCU_CH_DIMMING_SOURCE_DE0);
```

To change the fade time, use the following function before starting the dimming process:

```
/* set fade time to 3s */
XMC_BCCU_DIM_SetDimDivider(BCCU0_DE0, 0x2B);
```

The dimming status can be checked:

```
/* check dim status: returns 0 if complete */
status = XMC_BCCU_IsDimmingFinished(BCCU0, XMC_BCCU_CH_DIMMING_SOURCE_DE0);
```

The dimming process can be aborted as follows:

```
XMC_BCCU_AbortDimming(BCCU0, XMC_BCCU_CH_DIMMING_SOURCE_DE0);
```

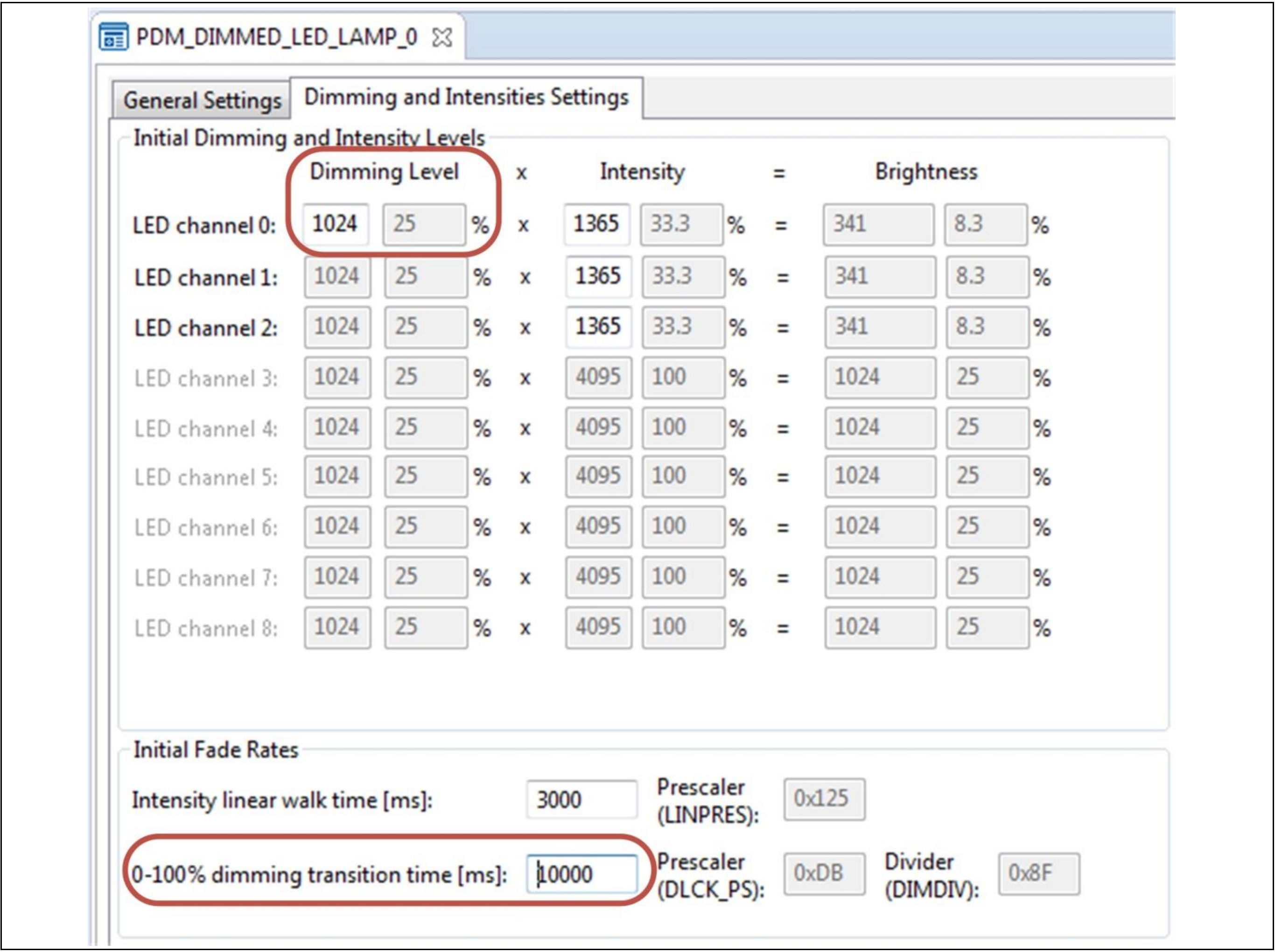
To get the last dim level after a dimming process abort:

```
XMC_BCCU_DIM_ReadDimmingLevel(BCCU0_DE0); // read current dim level
```

3.2.2 Implementation with DAVE™ APPs

This section demonstrates the usage of DAVE™ APPs. The focus is mainly on setting up and controlling the dimming engine. Refer to 2.3.2 Implementation with DAVE™ APPs for a complete view on the configuration steps for the RGB LED.

The lamp's initial dimming level and dimming transition time can be configured in the PDM_DIMMED_LED_LAMP APP under the "Dimming and Intensities Settings" tab (Figure 42).



Initial Dimming and Intensity Levels

	Dimming Level			x	Intensity			=	Brightness		
LED channel 0:	1024	25	%	x	1365	33.3	%	=	341	8.3	%
LED channel 1:	1024	25	%	x	1365	33.3	%	=	341	8.3	%
LED channel 2:	1024	25	%	x	1365	33.3	%	=	341	8.3	%
LED channel 3:	1024	25	%	x	4095	100	%	=	1024	25	%
LED channel 4:	1024	25	%	x	4095	100	%	=	1024	25	%
LED channel 5:	1024	25	%	x	4095	100	%	=	1024	25	%
LED channel 6:	1024	25	%	x	4095	100	%	=	1024	25	%
LED channel 7:	1024	25	%	x	4095	100	%	=	1024	25	%
LED channel 8:	1024	25	%	x	4095	100	%	=	1024	25	%

Initial Fade Rates

Intensity linear walk time [ms]: 3000 Prescaler (LINPRES): 0x125

0-100% dimming transition time [ms]: 10000 Prescaler (DLCK_PS): 0xDB Divider (DIMDIV): 0x8F

Figure 42 Configuring initial dimming level and transition time

Note: The dimming transition time configured here is for a transition from dim level of 0% to 100%. For any smaller transitions, the time taken is scaled according to the exponential curve. For example, referring to Figure 38:

If dimming up from 0% to 100% which takes 20480 dimming clocks is equivalent to 10 seconds, then dimming up from 0% to 50% which takes 18432 dimming clocks is equivalent to 9 seconds.

The dimming curve can be selected in the DIM_BCCU APP via a drop-down box (Figure 43). The dither function can also be enabled by selecting the check-box in the same APP.

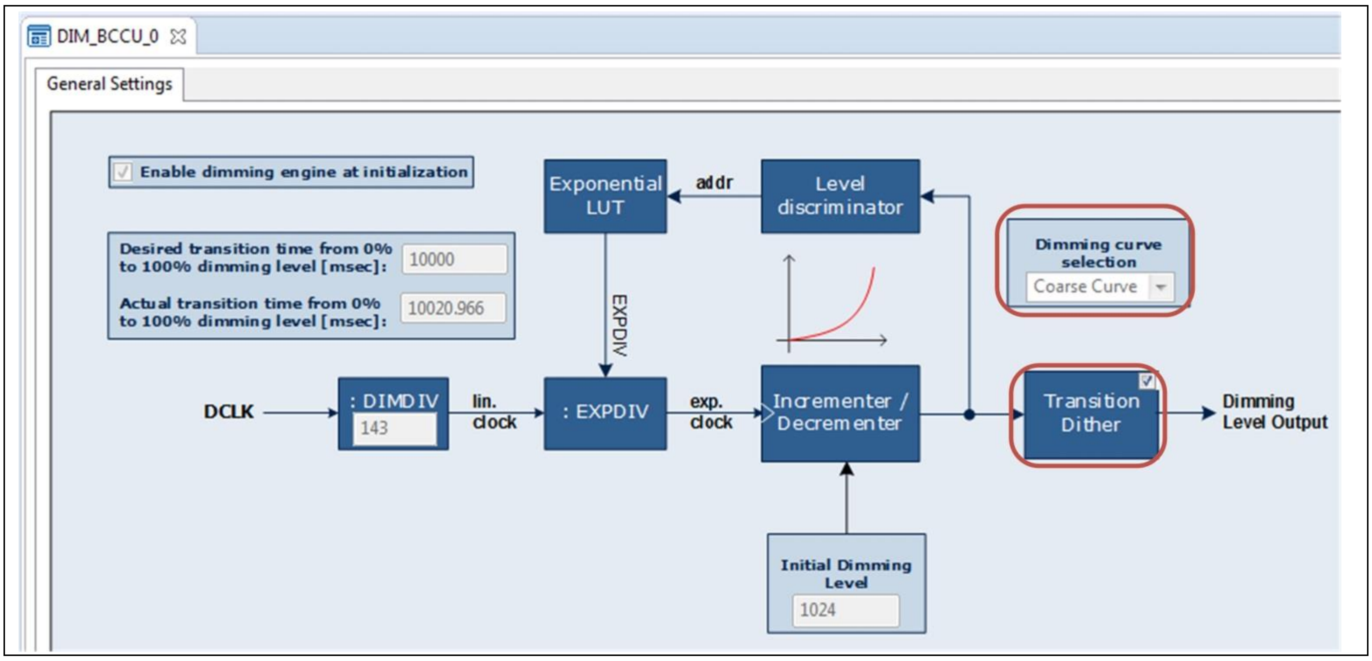

DIM_BCCU_0
General Settings
Enable dimming engine at initialization: ✓
Desired transition time from 0% to 100% dimming level [msec]: 10000
Actual transition time from 0% to 100% dimming level [msec]: 10020.966
Dimming curve selection: Coarse Curve
Transition Dither: ✓
DIMDIV: 143
Initial Dimming Level: 1024

Figure 43 Selecting dimming curve and enabling dither function

3.2.2.1 Controlling lamp brightness

The DAVE^{TM}-generated configuration data structure, *PDM_DIMMED_LED_LAMP_0.config*, for the PDM_DIMMED_LED_LAMP_0 APP instance also holds the dim level value of the dimming engine used in the lamp. It acts like a shadow register for the respective register bit field **DLSz.TDLEV**.

As an example, to change the dim level to 100%:

```
PDM_DIMMED_LED_LAMP_0_config.dim_level = 4095;
```

The line above sets the dimming engine target level for the desired dim level. To effect the brightness change, the dimming process has to be started:

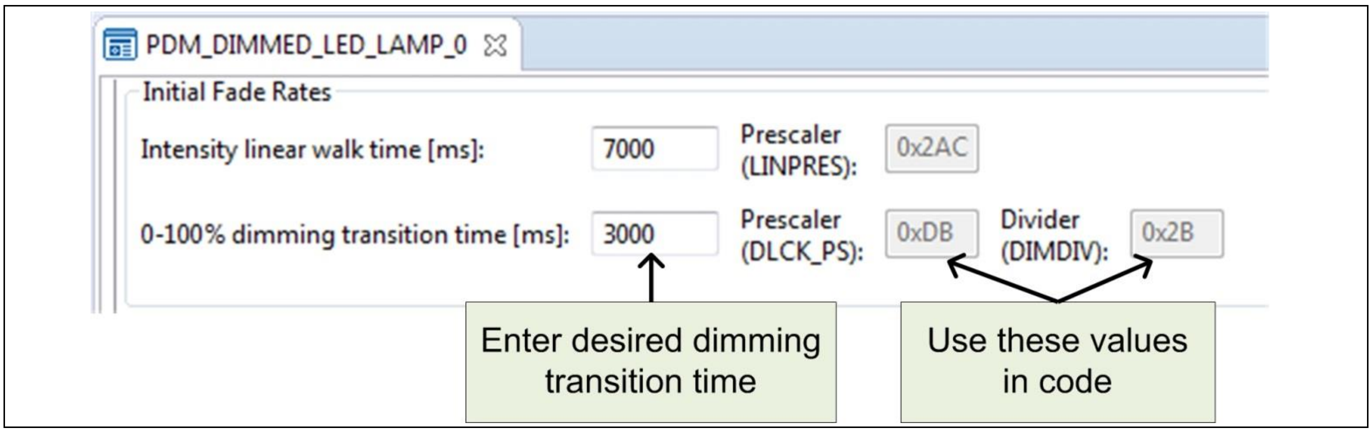
```
PDM_DIMMED_LED_LAMP_SetDimLevelExponential(&PDM_DIMMED_LED_LAMP_0);
```

This function programs the BCCU register bit fields with the configured dimming transition time, the target dimming level and starts the dimming process. The dimming transition time used configured the same way as previously in the UI of the PDM_DIMMED_LED_LAMP APP.

To use a different dimming transition time for changing lamp brightness:

```
/* Configure dimming transition time = 3s, and start dimming process */
PDM_DIMMED_LED_LAMP_SetDimLevelExponentialAdv(&PDM_DIMMED_LED_LAMP_0, 0x2B, 0xDB);
```

The PDM_DIMMED_LED_LAMP APP UI can be used to easily calculate the prescaler and divider values for the desired dimming transition time (Figure 44).


PDM_DIMMED_LED_LAMP_0

Initial Fade Rates

Intensity linear walk time [ms]: 7000 Prescaler (LINPRES): 0x2AC

0-100% dimming transition time [ms]: 3000 Prescaler (DLCK_PS): 0xDB Divider (DIMDIV): 0x2B

Figure 44 Use PDM_DIMMED_LED_LAMP APP to calculate dimming transition time prescaler and divider

To get the status of the dimming process:

```
DIM_BCCU_FadeCompletionStatus(&DIM_BCCU_0); // returns 0 if completed, else 1
```

Alternatively, the application can wait indefinitely for the end of dimming process:

```
DIM_BCCU_AwaitFadeCompletion(&DIM_BCCU_0); // wait till dimming process is complete
```

The dimming process can be aborted as follows:

```
DIM_BCCU_AbortDimming(&DIM_BCCU_0);
```

To get the last dim level after a dimming process abort:

```
DIM_BCCU_GetDimLvl(&DIM_BCCU_0); // read current dim level
```

Revision history

Major changes since the last revision

Page or Reference	Description of change
1.2.3	Enhanced packer description.
Figure 21	Updated figure for using BCCU channel as pseudo-DAC.
2.3.2, 3.2.2	Updated LED_LAMP APP to PDM_DIMMED_LED_LAMP APP due to APP name change in DAVE™.

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