



LED dimming implemented on STM32™ microcontroller

1 Introduction

This application note deals with the general principles of LED dimming. This note also focuses on the use of pulse width modulation (PWM) for digital dimming. Its implementation on the STM32™ microcontroller in combination with the STP24DP05 LED driver is described in detail and the most common design approaches are compared.

The conclusion helps developers choose the best approach for their LED dimming application.

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2 Description of LED dimming

There are two categories of LED dimming:

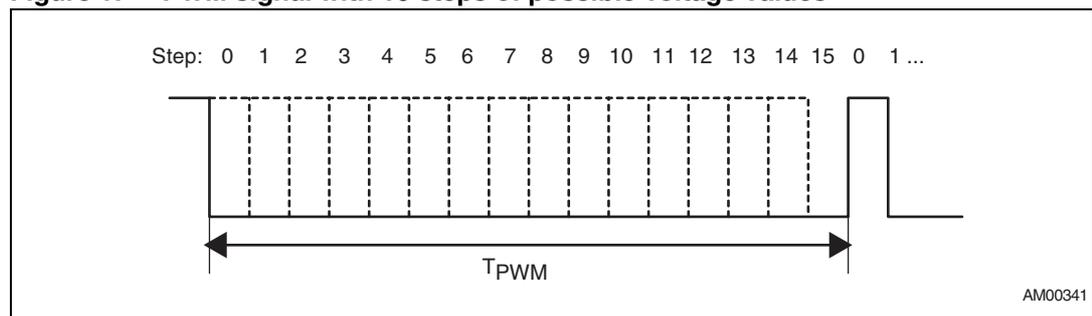
- **Analog:** Uses a linear device to set the current flow through the LED.
Advantages: Absence of digital noise; a simple implementation.
Limitations: Color shift, low dynamics.
- **Digital:** Uses a switch to set nominal or zero current flow through the LED.
Advantages: Accurate and fast color control.
Limitations: The presence of digital noise and necessity to use a frequency high enough to prevent flickering; a complex implementation.

This document focuses on digital dimming and the use of PWM (pulse width modulation) in common applications.

When using PWM for lighting applications, the following rules must be kept in mind:

- For the LED light to be seen as non-flickering by the human eye, in most cases the PWM frequency must be higher than 100 Hz.
- The LED light brightness depends on the PWM duty cycle. The brightness depends on the resolution of the PWM duty cycle.

Figure 1. PWM signal with 16 steps of possible voltage values



Using a 4-bit PWM resolution, there can be 16 different light intensity (energy) values.

Concerning color applications, 16 million ($256 \times 256 \times 256$) colors can be reached using tricolor LEDs with an 8-bit dimming resolution for each single color LED.

2.1 Driving multiple LED applications

Displays, indicators and panels increasingly use more and more LEDs. There are three approaches for driving higher numbers of LEDs:

1. **Dedicated pin**
Each LED is driven by dedicated system (microcontroller, FPGA) pin.
Advantages: Simple implementation of dimming algorithm. No conversion.
Disadvantages: Unusable for high LED counts. Consumes pins of microcontroller.
2. **Serial-parallel conversion**
Multiple LEDs are driven by a single system pin.
Advantages: Reduced number of system pins required. High LED count systems can be developed.
Disadvantages: Additional components and external buffers are needed. The data rate on a single pin must be n times greater than that for the single LED out of n , where n is the number of LEDs.
3. **Matrix**
LEDs are arranged in a square matrix and driven by a complex and sophisticated algorithm that combines serial-parallel conversion with additional decomposition of the serial data stream into the rows and columns by another active component.

This document focuses on serial-parallel conversion applications.

2.2 Multi-channel dimming using serial-parallel conversion

The serial-parallel conversion approach is in fact a parallel-serial-parallel conversion since the data is stored in the system memory in parallel format and then is converted to serial format before its transfer over the serial interface. The serial stream is then reconverted to parallel format by the LED driver used to drive each LED. The serial data transfer speed must be n times faster than driving a single LED, where n is the number of parallel driver outputs.

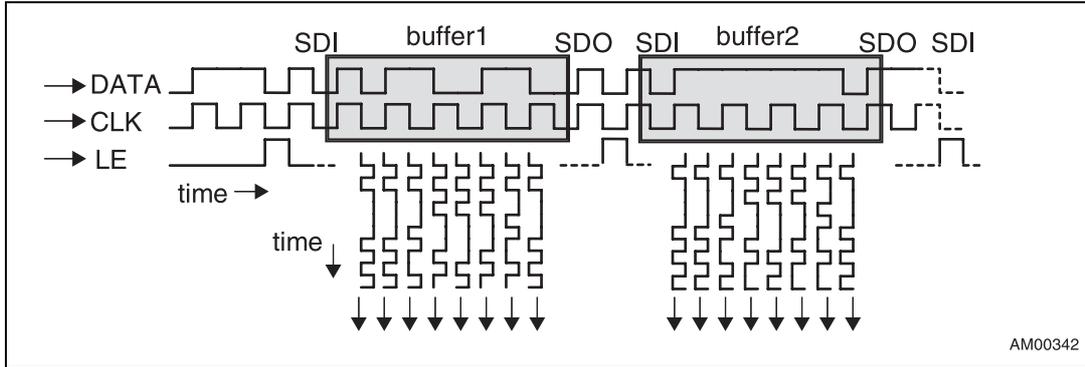
Buffers (LED drivers) used for serial-parallel conversion come generally with the four most important signals:

- SDI: Serial data in
- SDO: Serial data out
- CLK: Clock signal used for loading data in the driver buffer via the SDI (input) and sending data from the buffer via the SDO (output). It also shifts all data actually present (previously loaded) in the driver.
- LE: Copies (latch enable) the actual values loaded in the driver into its output cells. The output cells drive parallel outputs.

The standard serial peripheral interface (SPI) contains SDO, SDI and CLK signals.

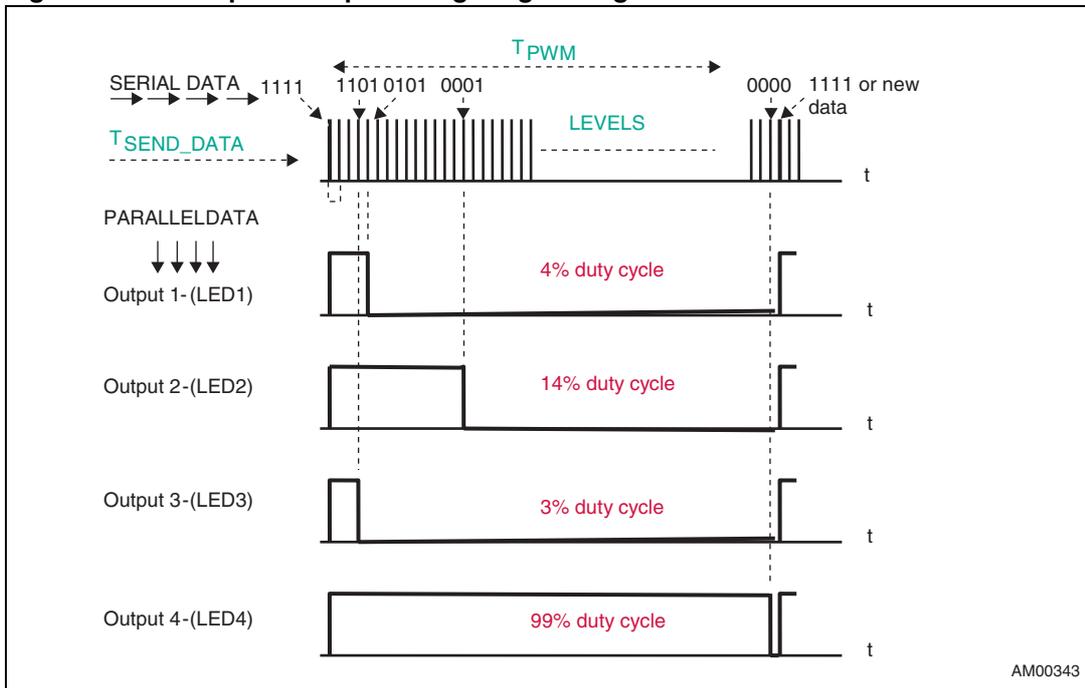
It is necessary to latch (LE signal pulse) internal driver data once per n CLK cycles, where n is the total LED count. This latching rule ensures the correct mapping of the serialized PWM data coming on SDI to the corresponding parallel output. Refer to [Figure 2](#), [Figure 3](#) and [Figure 4](#).

Figure 2. PWM serial-parallel conversion for multiple LED applications



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Figure 3. Example of a specific lighting setting



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The following equation is used to determine how many LEDs can be used in an application with specific maximum SPI speed and PWM resolution requirements:

Equation 1

$$N = \frac{f_{SPI}}{2^n f_{PWM}}$$

where;

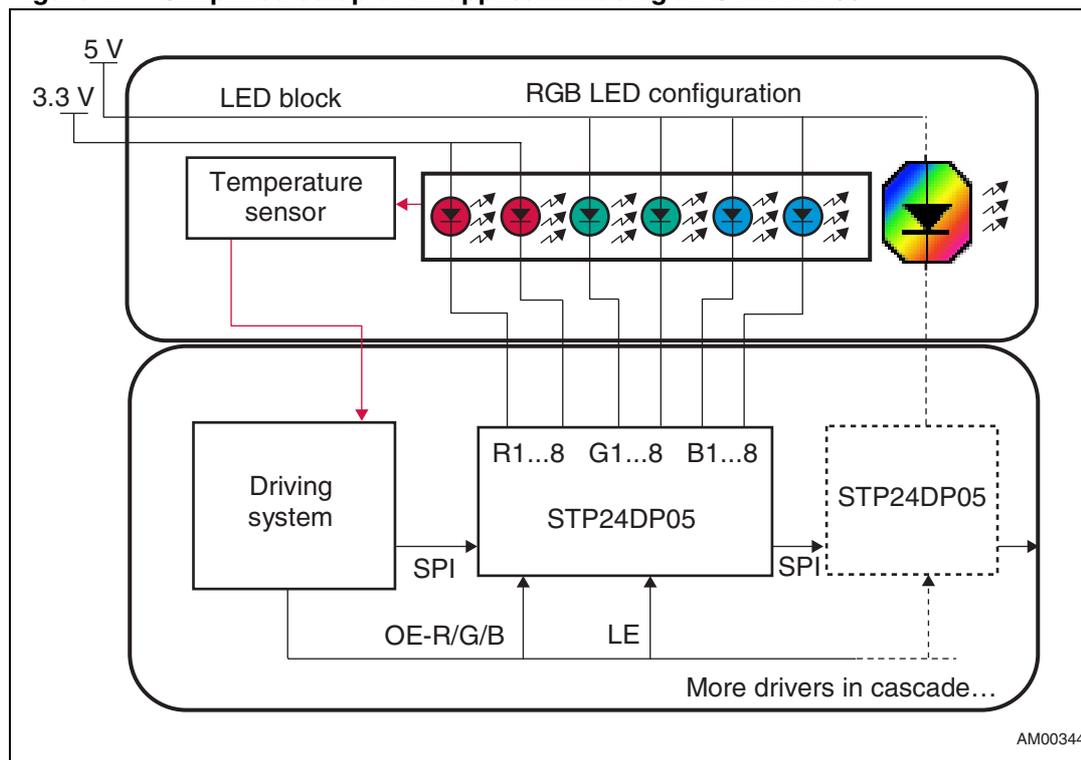
- N is the maximum number of LEDs
- f_{SPI} is the SPI communication speed
- n is the PWM resolution
- f_{PWM} is the dimming frequency

The outcome of *Equation 1* is valid only for the best-case scenario when the data are sent to the LED driver without any delay between blocks of data. This example, of course, is not a real one. The values for a real application can only get close to the value determined above.

2.3 Specific dimming application using an STP24DP05

Figure 4 illustrates a simple dimming application using an STP24DP05 24-bit constant current LED sink driver with output error detection.

Figure 4. Simplified setup of an application using an STP24DP05



3 Dimming application using an STM32 microcontroller

This section describes a dimming application that uses an STM32 microcontroller (MCU). All the computations, results and tests were performed on an evaluation board (reference: STEVAL-ILL015V1) containing an STM32 MCU running at a clock frequency of 48 MHz.

For more information about the use of this evaluation board and dimming applications, please refer to user manuals UM0588 and UM0574 listed in [Section 5: References documents](#).

[Figure 5](#) and [Figure 6](#) provide a brief overview of the STM32 evaluation board.

Figure 5. STM32 evaluation board setup

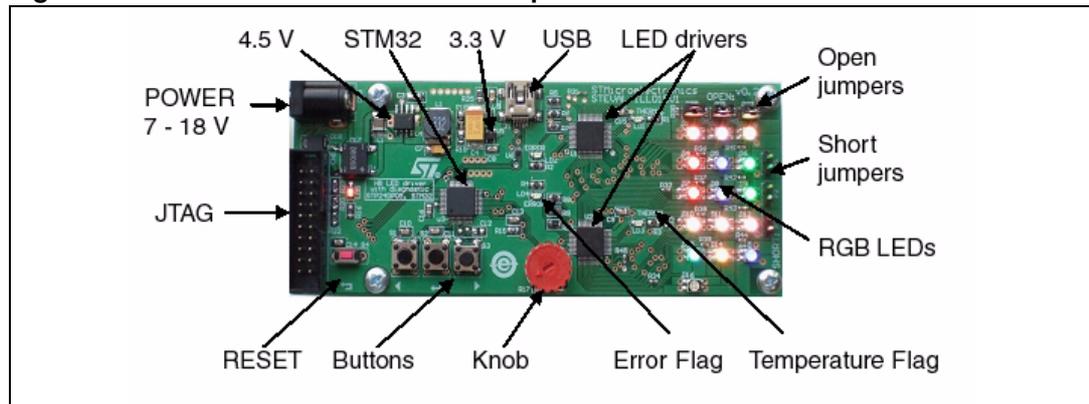
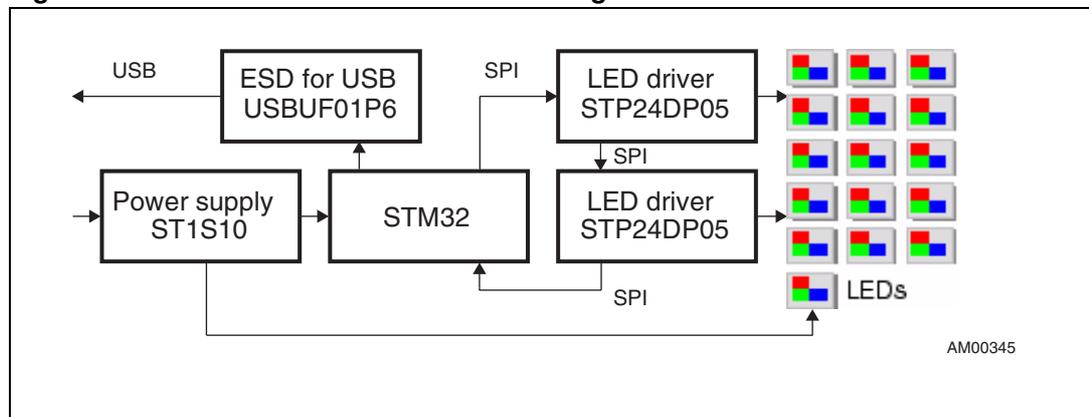


Figure 6. STM32 evaluation board block diagram



3.1 Data transfers and timing

This section describes the two approaches used to transfer data (dynamic and static) as well as timing considerations.

3.1.1 Dynamic data transfer

When using a dynamic data approach, all data is computed just before being transferred to the LED drivers.

The LED brightness value is defined by the user in the LEDmap array. The LEDmap is an array of 8-bit numbers (when using an 8-bit dimming resolution). Each value is dedicated to one single LED (Figure 7).

The dimming algorithm converts the LEDmap array into a serial stream. The serial stream in combination with the LE signal generates requested PWM outputs on the LED drivers as shown in Figure 8.

Figure 7. Computation of LEDdriverDATAbuffer variable

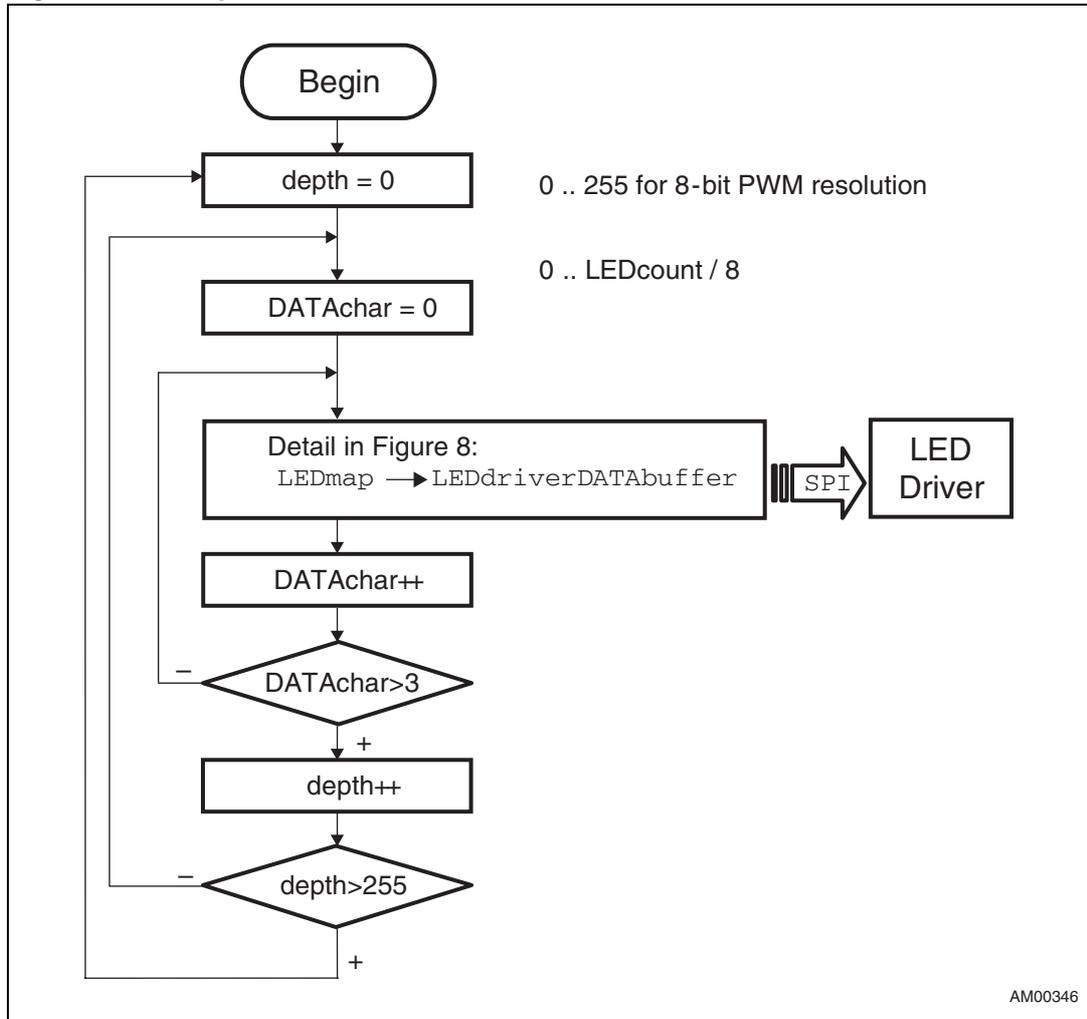
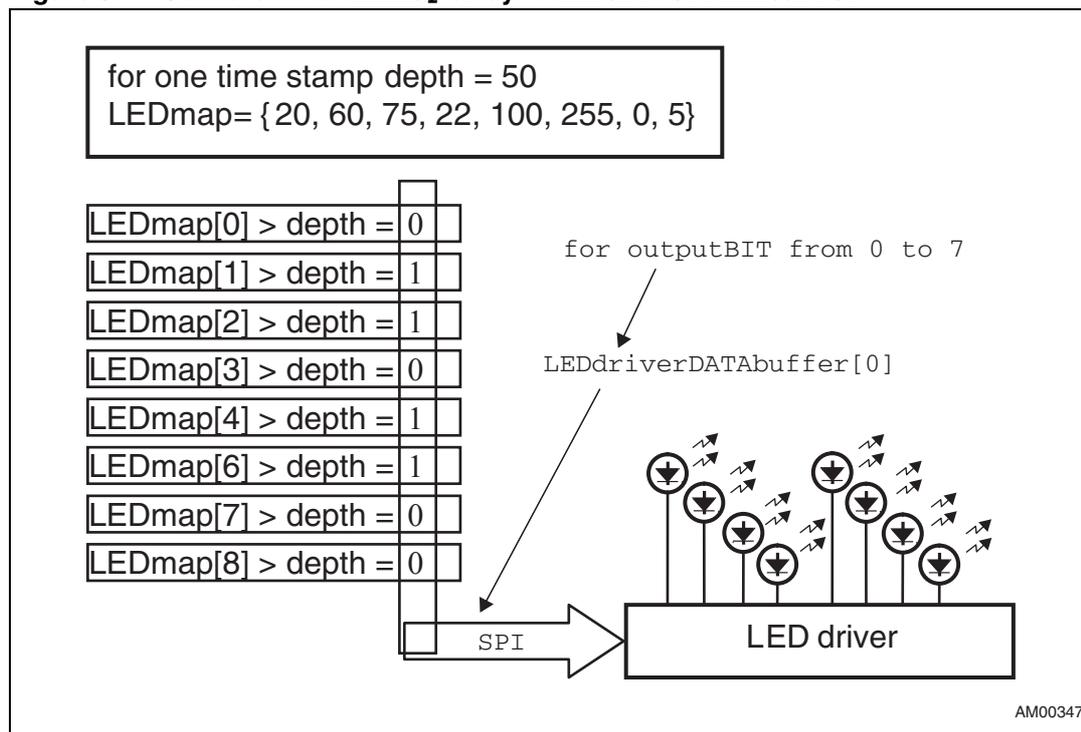


Figure 8. Conversion of LEDmap array to LEDdriverDATAbuffer



Example using a 4x8 LED matrix with an 8-bit PWM resolution

```

while(1)
  for(depth = 1; depth<=0xff; depth++){
    for(DATAchar = 0; DATAchar < 4; DATAchar++){
      for(outputBIT = 0; outputBIT < 8; outputBIT++){
        LEDdriverDATAbuffer[DATAchar] <<= 1;
        if(LEDmap[(DATAchar*8) + outputBIT] > depth)
          LEDdriverDATAbuffer[DATAchar] |= 0x0001;
        else
          LEDdriverDATAbuffer[DATAchar] &= 0xFFFE;
      }
      SPI_SendData(SPI1, LEDdriverDATAbuffer[DATAchar]);
    }
    LE_LOW();
    LE_HIGH();
    LE_LOW();
  }

```

Even though the dynamic data preparation consumes a minimum of system memory, it takes a lot of computational time. This approach is only recommended for low LED count applications. A dynamic data preparation approach can reach 100 Hz for 32 LEDs (with maximum code optimization in C compiler on the STM32 evaluation board).

Figure 9. Dynamic data preparation - time consumption - block diagram

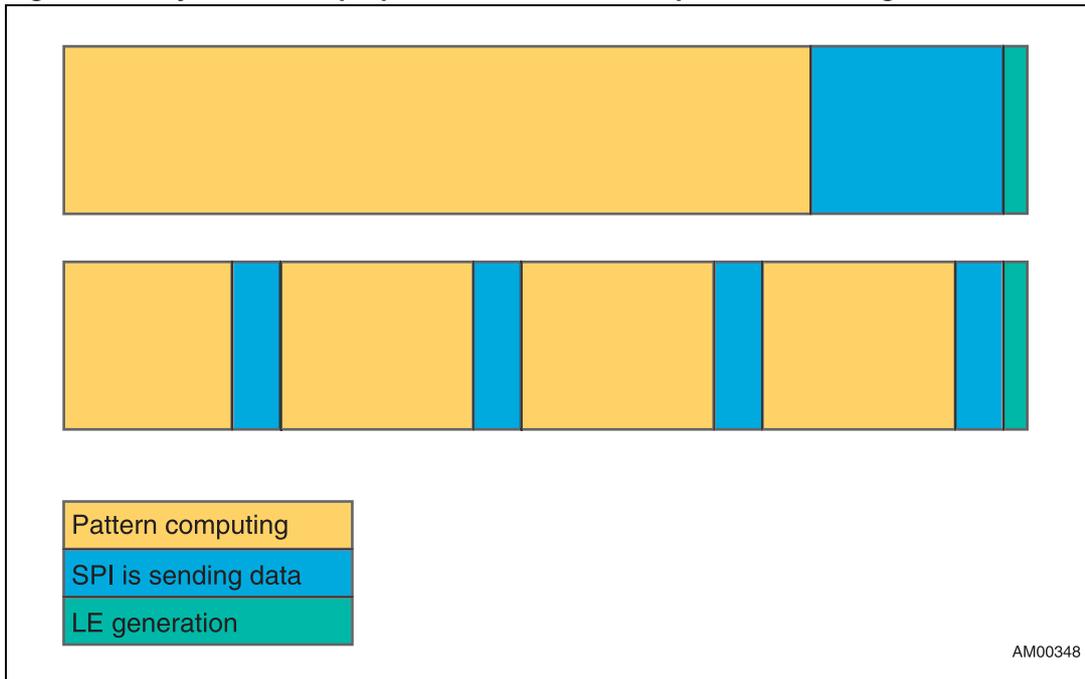
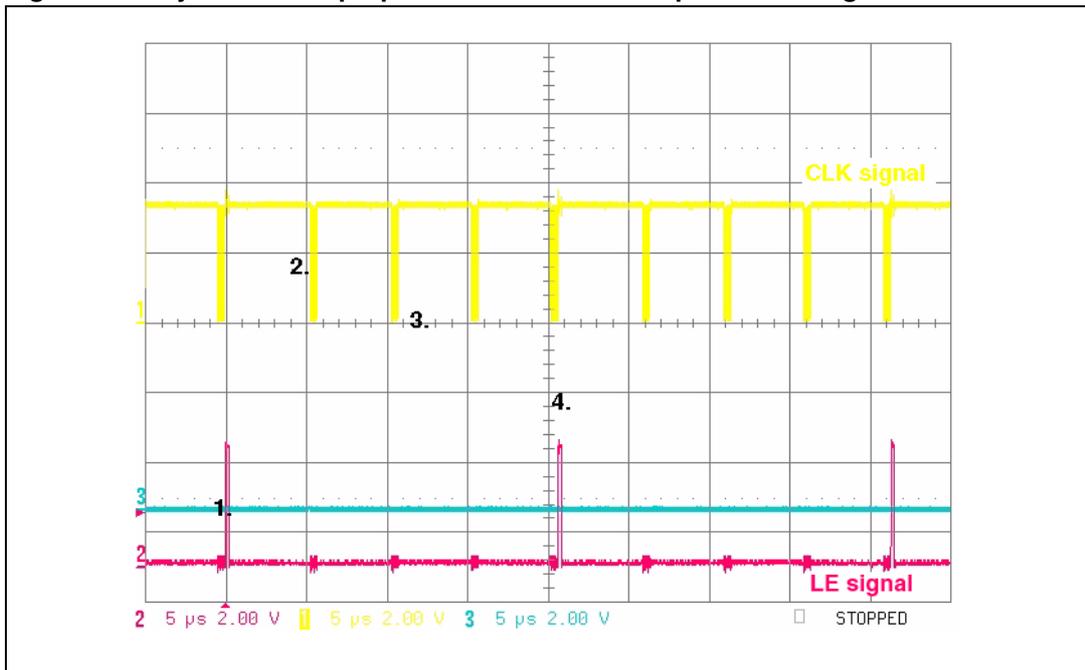


Figure 10. Dynamic data preparation - time consumption - real signals



3.1.2 Static data transfer using lookup tables

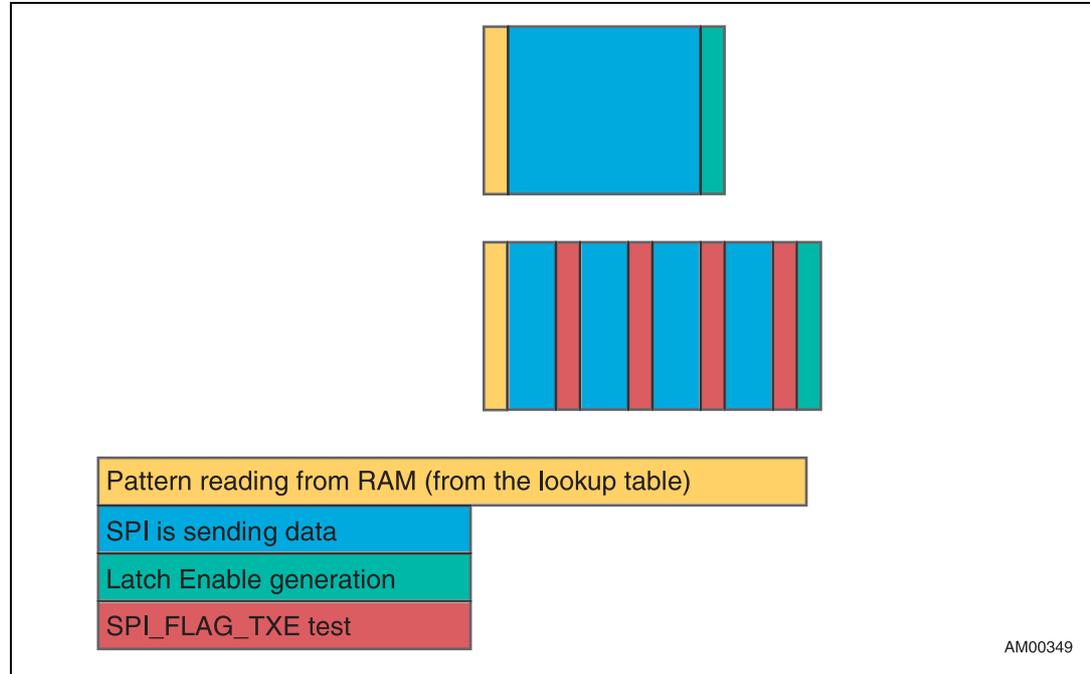
When using static lookup tables, all data is computed before being sent to the LED drivers.

Static lookup tables are used to convert the brightness value from an 8-, 9-, 10-, 11- or 12-bit representation from the `LEDmap` array into the serial stream representing the PWM of the LED driver outputs.

Once the brightness data is determined, the repetitive dimming procedure needs only to take the prepared data and send it to the LED driver.

Figure 11 shows the calculation time of the algorithm.

Figure 11. Static lookup table time consumption with 166 kHz - 333 kHz LE signal



Accurate LE timing and the dimming part running in the application background are necessary requirements for a successful application. These targets can be achieved using the following methods:

- Single interrupt
- Single interrupt with DMA
- Interrupt + DMA + interrupt

3.1.3 Single interrupt

The simplest approach is to use a timer interrupt approach where only a timer interrupt is required for the data transfer timing. This approach which does not require direct memory access (DMA) is designed for microcontrollers without DMA capability.

Except for pattern loading, SPI data transfer and Latch Enable generation, the code must also contain the TX buffer Empty Flag test. This test must be taken into account if you compute the total time necessary for all dimming operations.

Figure 12 shows a timing diagram for a dimming application using this method.

Figure 12. Timing diagram: Single interrupt method

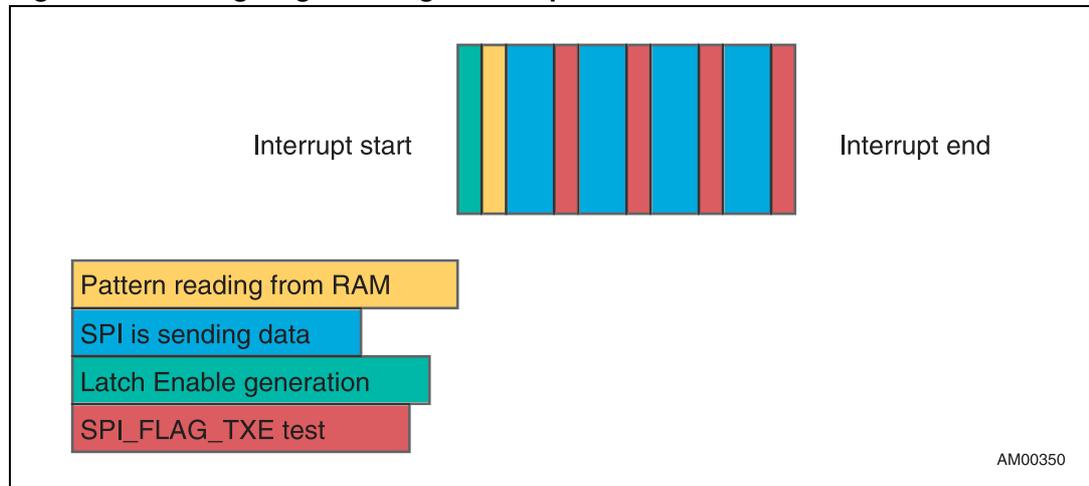
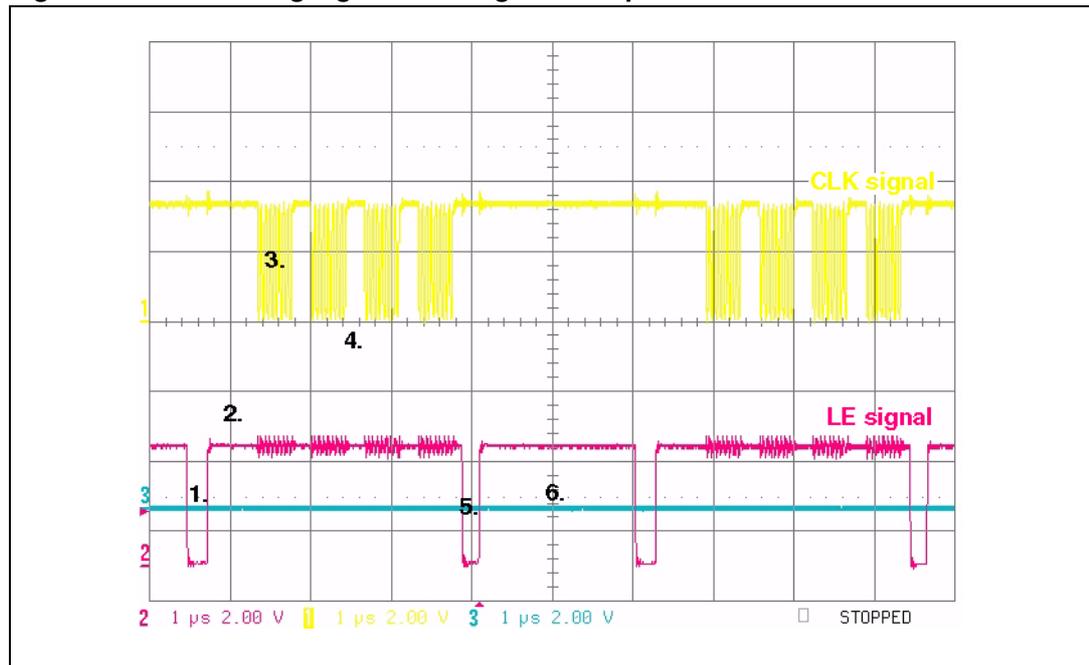


Figure 13 shows the waveforms of the signals output by the MCUs controlling the LED drivers.

Figure 13. Real timing signals for single interrupt method



Example of C code implementation of the timer interrupt routine

```
void SysTickHandler(void)
{
    LE_LOW(); (Step 1)
    LE_HIGH();

    depth+=4;

    if(depth > 0x400) (Step 2)
        depth = 0;

    SPI_SendData(SPI1, LookUp[depth+0]); (Step 3)
    while(!SPI_GetFlagStatus(SPI1, SPI_FLAG_TXE));
    SPI_SendData(SPI1, LookUp[depth+1]);
    while(!SPI_GetFlagStatus(SPI1, SPI_FLAG_TXE)); (Step 4)
    SPI_SendData(SPI1, LookUp[depth+2]);
    while(!SPI_GetFlagStatus(SPI1, SPI_FLAG_TXE));
    SPI_SendData(SPI1, LookUp[depth+3]);
    while(!SPI_GetFlagStatus(SPI1, SPI_FLAG_TXE));
    LE_LOW(); (Step 5)
    LE_HIGH();
}
```

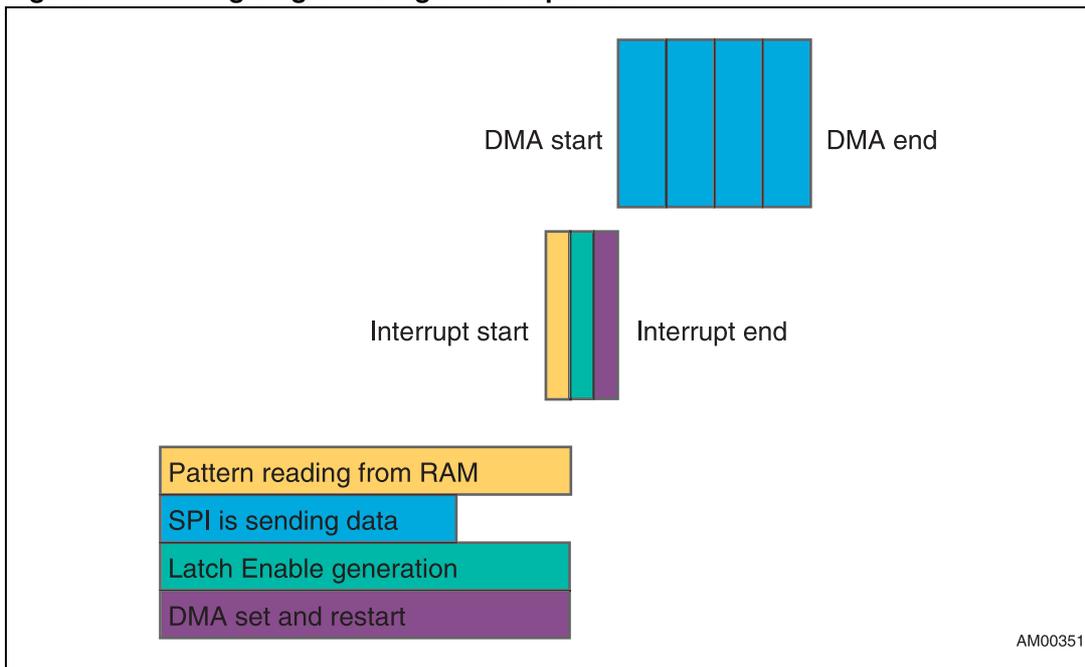
In the above example, the waveform and program code are described in the following steps:

1. The generation of the LE after entering the interrupt.
2. Increment of the lookup table pointer.
3. The transfer of the first 8 bits.
4. Test of TX buffer Empty Flag.
5. An additional edge on LE. This is for measurement purposes only.
6. The time between the end of the current interrupt and the next one. This time can be used for calculating certain foreground tasks in the application.

3.1.4 Single interrupt with DMA

The data is transferred from the microcontroller RAM into the LED driver using a single interrupt with DMA approach. You cannot use a DMA approach without a timer, because you cannot change the speed of the DMA and thus you cannot change PWM parameters and the refresh rate in required steps. The benefit of using DMA is that the SPI buffer can be automatically filled. The time saved is nearly in the range of the time needed for the DMA to restart and re-configure itself for the next transfer (in comparison to previous approach). An example of a timing diagram for this programming model is shown in *Figure 14*. The timing can be compared in *Figure 12* and *Figure 14*.

Figure 14. Timing diagram: Single interrupt with DMA



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3.1.5 Interrupt + DMA + interrupt

Figure 14 shows that data from the previous transfer is latched during the current timer interrupt which causes several problems. The algorithm is more complicated in this case. A slightly different approach that has no impact on the system can be used: it is obtained by generating the LE pulse when the DMA transfer is complete instead of generating it on a timer interrupt. The LE pulse is generated at the DMA transfer complete interrupt as shown in Figure 15.

Figure 15. Timer interrupt + DMA transfer + DMA interrupt

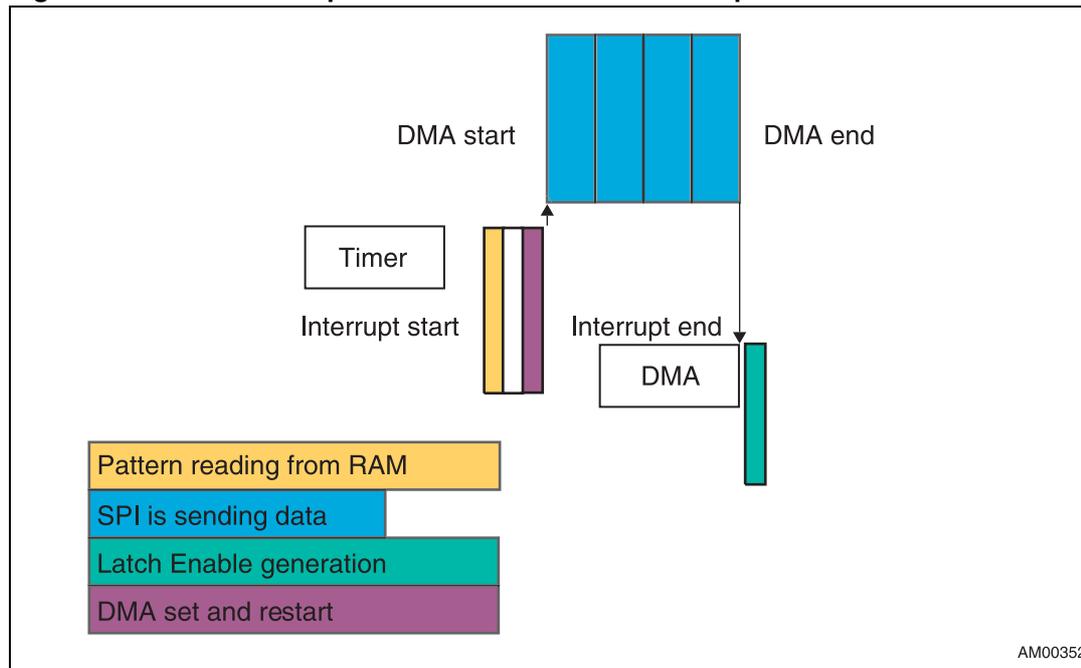
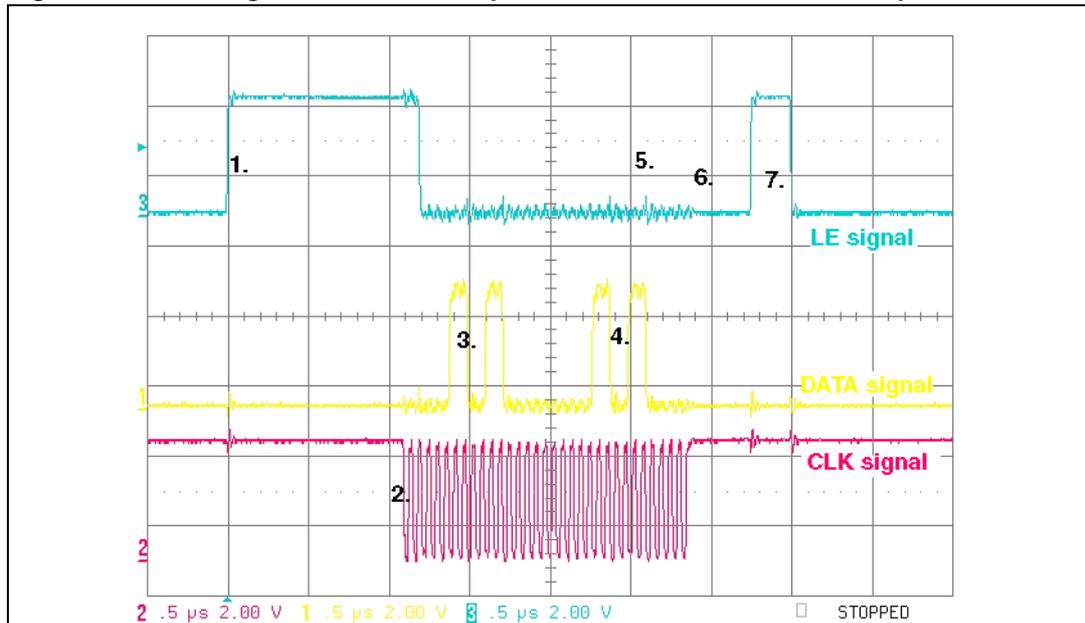


Figure 16 shows the waveform of the outbound signals from the microcontrollers controlling the LED drivers. An example of the C code implementation of the timer routine is given below. A detailed description follows the example.

Figure 16. Real signals: timer interrupt + DMA transfer + DMA interrupt model



Step "1" in [Figure 16](#) is not necessary, but it is used for a better visualization of the tracking of signals on the oscilloscope.

Example of C code of DMA and timer interrupt routine: interrupt + DMA + interrupt approach

```
void SysTickHandler(void)
{
    LE_LOW(); (Step 1)
    LE_HIGH();

    depth+=4;
    if(depth > 0x400)
        depth = 0;

    DMA_Channel3->CCR &= CCR_ENABLE_Reset;
    DMA_Channel3->CNDTR = 0x04;
    DMA_Channel3->CMAR = ((u32) (LookUp))+depth;
    DMA_Channel3->CCR |= CCR_ENABLE_Set; (Step 2)
    DMA_Channel3->CCR |= DMA_IT_TC;

    LE_LOW();
}

void DMAChannel3_IRQHandler(void) (Step 5)
{
    while(!SPI_GetFlagStatus(SPI1, SPI_FLAG_TXE)); (Step 6)

    LE_HIGH(); (Step 7)
    LE_LOW();
    DMA_ClearITPendingBit(DMA_IT_GL3);
}

```

In the above example, the waveform and program code are described in the following steps:

1. The generation of the LE after entering the interrupt.
2. Setting the DMA: source address, data length, and Start flag.
3. Data is sent automatically by DMA.
4. Data is sent automatically by DMA.
5. DMA interrupt routine is called when the last byte is sent by DMA.
6. Wait until the data from the SPI TX buffer is delivered to the driver.
(Step 6 can be exchanged with calculations that take the amount of time necessary for the SPI transfer to be finished).
7. LE generation.

3.2 Data preparation: redundant and non redundant use of memory

3.2.1 Full lookup table (redundant)

The static lookup table generation is mentioned in [Section 3.1.2](#). The lookup table generation procedure is described in more detail in this section.

The lookup table row is computed for every PWM step (8-bit PWM means 256 rows for 256 steps). The C code of the full lookup table generation is given in the example below.

Example using a 4x8 LED matrix with an 8-bit PWM resolution

```
void generateLookUpTable(unsigned char *LEDmapIN){
    unsigned int tmpdepth;

    for(tmpdepth = 0; tmpdepth < 0xff; tmpdepth++){
        for(DATAchar = 0; DATAchar < 4; DATAchar++){
            for(outputBIT = 0; outputBIT < 8; outputBIT++){
                LookUp[tmpdepth*4 + DATAchar] <<= 1;
                if(LEDmapIN[(DATAchar*8) + outputBIT] > tmpdepth)
                    LookUp[tmpdepth*4 + DATAchar] |= 0x01;
                else
                    LookUp[tmpdepth*4 + DATAchar] &= 0xFE;
            }
        }
    }
}
```

Table 1. LEDmap - requested LED brightness configuration

Output	LED 1	LED 2	LED 3	...	...	LED <i>i</i>
Duty cycle (brightness)	$2 / 2^n$	$6 / 2^n$	$4 / 2^n$			100%

Table 2. Full lookup table

Step	Output					
	LED 1	LED 2	LED 3	...	...	LED <i>i</i>
0	1	1	1			1
1	1	1	1			1
2	1	1	1			1
3	0	1	1			1
4	0	1	1			1
5	0	1	0			1
6	0	1	0			1
...	0	0	0			1
...	0	0	0			1
2 ^{<i>n</i>}	0	0	0			1

3.2.2 Reduced lookup table (non redundant)

Only the data that changes the LED driver output state is generated. A LED can change the state only once per complete PWM cycle: from one to zero. If there are *i* number of LEDs, there are *i* new data items for the LED drivers. For example, if *i* = 32 LEDs when using an 8-bit PWM, you need a cycle with $i \times i = 32 \times 32 = 1024$ loops.

The inside of the loop is the same for full lookup table generation as described in [Section 3.2.1](#). The lookup table row is computed only in case you need to change the LED intensity pattern (specific value of a parallel output configuration). [Table 3](#), [Table 4](#) and [Table 5](#) bring better understanding of the lookup table reduction. The C code of the reduced lookup table generation is shown in the example below.

Example of reduced lookup table generation

```

void performGenerateReducedLookUpTable(unsigned char *LEDmapIN,
int LEDcount, int PWMdepth, unsigned char **tableIN, unsigned
char **tableKeyIN, int *table_size){

    int streamSize = LEDcount/8;

    *table_size = differentValuesCount(LEDmapIN, LEDcount);
    *tableKeyIN = SortAndReduce(LEDmapIN, LEDcount, *table_size);

    *tableIN = malloc(streamSize * (*table_size)
        * sizeof(unsigned char));
    for(tmpdepth = 0; tmpdepth < (*table_size); tmpdepth++){
        for(DATAchar = 0; DATAchar < streamSize; DATAchar++){
            for(outputBIT = 0; outputBIT < 8; outputBIT++){
                (*tableIN)[tmpdepth*streamSize + DATAchar] <<= 1;
                if(LEDmapIN[(DATAchar*8) + outputBIT] >
                    (*tableKeyIN)[tmpdepth])
                    (*tableIN)[tmpdepth*streamSize + DATAchar] |= 0x01;
                else
                    (*tableIN)[tmpdepth*streamSize + DATAchar] &= 0xFE;
            }
        }
    }
}

```

Table 3. LEDmap - requested LED brightness configuration

Outputs	LED 1	LED 2	LED 3	...	...	LED <i>i</i>
Duty cycle (brightness)	$2 / 2^n$	$6 / 2^n$	$4 / 2^n$			100%

Table 4. LEDmap - reordered requested LED brightness configuration

	Output					
	LED 1	LED 3	LED 2	...	LED x	LED i
Duty cycle (brightness)	$2 / 2^n$	$4 / 2^n$	$6 / 2^n$		$x / 2^n$	100%
Step of change (time of change)	2	4	6			100%
Table row	1	2	3			i

Table 5. Reduced lookup table

Row	Level	Output					
		LED 1	LED 2	LED 3	...	...	LED i
0	0	1	1	1	1	1	1
1	2	1	1	1	1	1	1
2	4	0	1	1	1	1	1
3	6	0	1	0	1	1	1
...	...	0	0	0	1	1	1
...	...	0	0	0	0	1	1
$m^{(1)}$	$x + 1$	0	0	0	0	0	1

1. "m" is less or equal to number of LEDs = i

3.3 Timing: set up of the main dimming timer

3.3.1 The main system timer, SysTick setting

The approach with interrupt + DMA + interrupt is considered the most effective.

The microcontroller can reach the maximum frame rate based on the minimum time required for the all the necessary operations. A time reserve of 6% was used:

- t_{DMAen} re-enabling the DMA (~ 1.25 μ s)
- t_{oneSPI} time necessary for transfer of the data over SPI (~ LEDs \times 55 ns)
- t_{LEgen} LE generation and new data pointer generation (~ 1 μ s)

The total time needed for correct processing is the sum of the times above:

Equation 2

$$\begin{aligned}
 \text{TotalTime} &= t_{DMAen} + t_{oneSPI} \times \text{LEDs} + t_{LEgen} \\
 &= 1.25 \mu\text{s} + 55 \text{ ns} \times \text{LEDs} + 1 \mu\text{s} \\
 &= 2.25 \mu\text{s} + 55 \text{ ns} \times \text{LEDs}
 \end{aligned}$$

The number of LEDs must be rounded up to nearest number commensurable by the length of an SPI buffer. The SPI buffer length is 8 either or 16 bits in most cases.

More examples of TotalTime for different number of LEDs and PWM resolution can be seen in [Table 6](#).

Table 6. TotalTime necessary for requested dimming parameters

LEDs	PWM	TotalTime	Max. LE frequency
8	8-bit	$2.25 + 0.055 \times 8 = 2.69 \mu\text{s}$	371.7 kHz
8	12-bit	$2.25 + 0.055 \times 8 = 2.69 \mu\text{s}$	371.7 kHz
672	8-bit	$2.25 + 0.055 \times 672 = 39.21 \mu\text{s}$	25.5 kHz

[Table 6](#) shows the time required for processing one PWM step, one buffer load and one buffer latch. With an 8-bit PWM resolution, 256 buffer latches are needed; the maximum LE (Latch Enable) frequency must be divided by 256. These results are shown in [Table 7](#).

Table 7. Maximum refresh rate

LEDs	PWM	Max. LE frequency	Max. refresh rate
8	8-bit	371.7 kHz	1452 Hz
8	12-bit	371.7 kHz	90.7 Hz
672	8-bit	25.5 kHz	99.6 Hz

[Table 7](#) shows the maximum refresh frequencies for controlled LEDs. But the inverse computation must be used to solve our task. [Table 8](#) shows the inversion of the [Table 7](#) values and gives the required refresh frequency. The LE frequency must be derived and the SysTick timer preload value (SysTick-preload-value) set to generate the LE pulse by generating an interrupt at every counter reload event.

Table 8. SysTick-reload-time for 100 Hz

LEDs	PWM	Requested refresh rate	SysTick-reload-time
8	8-bit	100 Hz	39 μs (25.6 kHz)
8	12-bit	90.7 Hz	2.7 μs (371.7 kHz)
672	8-bit	100 Hz	39 μs (25.6 kHz)
32	8-bit	100 Hz	39 μs (25.6 kHz)

[Table 7](#) and [Table 8](#) show that SysTick-reload-frequency will be set between 25.6 kHz and 371.7 kHz according to requested PWM resolution and LED count.

The STM32 SysTick timer uses a reference clock of 72 MHz when set to the maximum value. The interrupt period for this timer is the SysTick-preload-value multiplied by $1 / (72\,000\,000)$.

The reference clock of STM32 evaluation board is set to 48 MHz for the USB to operate correctly. This value should be taken into the account while making measurements on this evaluation board as their computation will influence [Equation 3](#).

The reference clock can be also divided by 8 by using the hardware divider. The divided reference clock is then 9 MHz. In this case, the interrupt period for this timer is equal to a preload value multiplied by $1 / (9\,000\,000)$.

$$\text{Preload value} = \text{requested SysTick interrupt time} / \text{reference period}$$

$$\text{Preload value} = \text{reference frequency} / \text{requested SysTick interrupt frequency.}$$

Table 9. Example of values used in Equations 3 and 4

LEDs	PWM	Requested refresh rate	SysTick-reload-time
32	8-bit	100 Hz	39 μ s (25.6 kHz)

Equation 3

$$\text{SysTick-preload-value} = 72\,000\,000 / 25\,600 = 2812$$

The frequency ranges 25.6 kHz and 371.7 kHz required for all possible applications ranges can be achieved using preload values: 2812 and 194, or with divider by 8: 351 or 24.

SysTick timer setting with no divider on the reference clock:

```
SysTick_CLKSourceConfig(SysTick_CLKSource_HCLK);
SysTick_SetReload(900);
```

generates pulses with the period of 12 μ s.

SysTick timer setting with the divider by 8 on the reference clock:

```
SysTick_CLKSourceConfig(SysTick_CLKSource_HCLK_Div8);
SysTick_SetReload(900);
```

generates pulses with the period of 100 μ s.

The setup algorithm for the SysTick timer configuration has to check if it is possible to set preload value to keep enough time for processing (TotalTime) together with reaching the requested refresh frequency:

$$\text{TotalTime} = 2.25 + 0.055 \times \text{LEDs}$$

$$\text{SysTick-reload-time} = 1 / \text{SysTick-reload-frequency}$$

TotalTime is the time slot, during which the SPI transfer and all the arbitrations needs to be achieved. The SysTick time is the time slot which must be respected to reach the required refresh rate.

Equation 4

$$\text{SysTick-reload-time} > \text{TotalTime}$$

To reach the requested refresh rate and set up the SysTick timer preload value:

$$\text{SysTick-reload-frequency} = \text{requested-refresh-rate} \times \text{PWMdepth} (100 \text{ Hz} \times 256 \text{ steps}).$$

4 Achieved values

Dynamic computing takes a lot of time and 120 Hz can be reached only for 32 LEDs. In addition, no other foreground or background tasks can be performed during computation. As a consequence, this solution is recommended only for simple applications that use only a few diodes. For other more complicated applications, it is recommended to use the lookup table approach using a single interrupt only or interrupt + DMA (if DMA is available).

The LED brightness resolution is limited by the size of the lookup table ([Table 10](#)). For every level of brightness, you need a single string of zeros and ones for all the LEDs.

Table 10. Lookup table size (full and reduced)

Bit depth	LEDs	Lookup table size: $i \times 2^n$	Reduced table size ⁽¹⁾ : $i \times n$
8	32	$256 \times 4 = 1 \text{ kB}$	$32 \times 4 = 128 \text{ B}$
12	32	$4096 \times 4 = 16 \text{ kB}$	$32 \times 4 = 128 \text{ B}$
8	128	$256 \times 16 = 4 \text{ kB}$	$128 \times 16 = 2 \text{ kB}$
12	128	$4096 \times 16 = 64 \text{ kB}$	$128 \times 16 = 2 \text{ kB}$
8	512	$256 \times 64 = 16 \text{ kB}$	$256 \times 64 = 16 \text{ kB}$
12	512	$4096 \times 64 = 256 \text{ kB}$	$512 \times 64 = 32 \text{ kB}$

1. Values indicates the maximum size.

From [Figure 13](#), the maximum refresh frequency can be computed. The time between two interrupts is 6 μs . This is a refresh rate for one brightness level, for 32 LEDs, 166 kHz. [Table 11](#). shows the possible refresh rates for whole brightness depth and different LED count.

Table 11. Refresh frequencies

LEDs/PWM	8-bit [Hz]	9-bit [Hz]	10-bit [Hz]	11-bit [Hz]	12-bit [Hz]
	256	512	1024	2048	4096
8	1514	757	379	189	95 ⁽¹⁾
16	1293	647	323	162	81
24	1129	564	282	141	71
32	1002	501	250	125	63
40	900	450	225	113	56
48	817	409	204	102	51
56	748	374	187	94	47
64	690	345	173	86	43
72	640	320	160	80	40
80	597	299	149	75	37
88	560	280	140	70	35
96	526	263	132	66	33
104	497	248	124	62	31
112	471	235	118	59	29
120	447	223	112	56	28
128	426	213	106	53	27
136	406	203	102	51	25
144	388	194	97	49	24
152	372	186	93	47	23
160	357	179	89	45	22
168	343	172	86	43	21
176	330	165	83	41	21
184	319	159	80	40	20
192	308	154	77	38	19
7200	297	149	74	37	19
208	288	144	72	36	18
216	279	139	70	35	17
224	270	135	68	34	17
232	262	131	66	33	16
240	255	127	64	32	16
248	248	124	62	31	15
256	241	120	60	30	15
264	234	117	59	29	15

Table 11. Refresh frequencies (continued)

LEDs/PWM	8-bit [Hz]	9-bit [Hz]	10-bit [Hz]	11-bit [Hz]	12-bit [Hz]
	256	512	1024	2048	4096
272	228	114	57	29	14
280	223	111	56	28	14
288	217	109	54	27	14
296	212	106	53	27	13
304	207	104	52	26	13
312	202	101	51	25	13
320	198	99	49	25	12
328	194	97	48	24	12
336	189	95	47	24	12
344	185	93	46	23	12
352	182	91	45	23	11
360	178	89	45	22	11
368	175	87	44	22	11
376	171	86	43	21	11
384	168	84	42	21	10
392	165	82	41	21	10
400	162	81	40	20	10
408	159	79	40	20	10
416	156	78	39	20	10
424	153	77	38	19	10
432	151	75	38	19	9
440	148	74	37	19	9
448	146	73	36	18	9
456	144	72	36	18	9
464	141	71	35	18	9
472	139	70	35	17	9
480	137	68	34	17	9
488	135	67	34	17	8
496	133	66	33	17	8
504	131	65	33	16	8
512	129	64	32	16	8
520	127	64	32	16	8
528	125	63	31	16	8

Table 11. Refresh frequencies (continued)

LEDs/PWM	8-bit [Hz]	9-bit [Hz]	10-bit [Hz]	11-bit [Hz]	12-bit [Hz]
	256	512	1024	2048	4096
536	124	62	31	15	8
544	122	61	30	15	8
552	120	60	30	15	8
560	119	59	30	15	7
568	117	59	29	15	7
576	116	58	29	14	7
584	114	57	29	14	7
592	113	56	28	14	7
600	111	56	28	14	7
608	110	55	27	14	7
616	110	55	27	14	7
624	110	55	27	14	7
632	106	53	26	13	7
640	105	52	26	13	7
648	103	52	26	13	6
656	102	51	26	13	6
664	101	51	25	13	6
672	100	50	25	12	6
680	99	49	25	12	6
688	98	49	24	12	6

1. 100 Hz can be reached with very high level of optimization.

Table 12. Refresh frequencies for better optimized code (8- and 12-bit PWM)

LEDs	8-bit PWM freq. [Hz]	12-bit PWM freq. [Hz]
32	$250\,000 / 256 = 1000$	$250\,000 / 4096 = 61$
128	$(250\,000 / 256) / 4 = 244$	$(250\,000 / 4096) / 4 = 15$
512	$(250\,000 / 256) / 16 = 61$	$(250\,000 / 4096) / 16 = 4$

Table 13. Refresh frequencies for better optimized code (10- and 11-bit PWM)

LEDs	10-bit PWM freq. [Hz]	11-bit PWM freq. [Hz]
32	$250\,000 / 1024 = 244$	$250\,000 / 2048 = 122$
128	$(250\,000 / 1024) / 4 = 64$	$(250\,000 / 2048) / 4 = 30$
512	$(250\,000 / 1024) / 16 = 15$	$(250\,000 / 2048) / 16 = 7$

[Table 12](#) and [Table 13](#) show the results in case you remove the additional LE edge used for the measurement of the interrupt end and optimize time between two interrupts (used for SPI in 16-bit mode).

4.1 Dimming approach comparison and conclusion

4.1.1 Comparison between interrupt and interrupt + DMA approaches

When using the single interrupt approach described in [Figure 12](#) and [Figure 13](#), the time spent by the MCU to drive the LEDs is long and little time is left to execute other tasks.

The combination of the single interrupt + DMA approach frees more computing time for other tasks. This approach does not improve the refresh rate.

4.1.2 Comparison between dynamic preparation, static, and reduced static lookup table

The dynamic data preparation shown in [Figure 9](#) allows to save memory but requires additional computing time.

The static lookup table method saves computing time. However, the computing must be performed at the beginning of the dimming.

The reduced static lookup table offers the same functionalities as a full lookup table, while saving memory space.

5 References documents

1. User manual UM0588 - Multilayer C library for LED dimming used on systems with SPI and DMA capabilities
2. User manual UM0574 - STEVAL-ILL015V1 - LED dimmer demonstration board based on the STP24DP05 and STM32™.

6 Revision history

Table 14. Document revision history

Date	Revision	Changes
10-Nov-2008	1	Initial release.

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