



## LED array reference design board

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### Introduction

New high brightness LED (HB LED) applications such as displays, information panels, signs, traffic signals, automotive lighting and advertising are becoming more and more popular. For these applications new HB LED drivers with constant current outputs have been designed. The constant LED current guarantees the same brightness for all LEDs and provides a cost advantage in lighting system solutions, as there is no need for external resistors for each individual LED. This document describes a simple design solution to drive an array of high brightness LEDs, using the STP16CP05 and the STP16CPS05 LED drivers.

Two reference design (one with 80 LEDs and another with 32 LEDs) are proposed to provide a solution for driving high brightness LED arrays. The first has an array of 80 blue HB LEDs arranged in a 5 x 16 matrix. This matrix of LEDs is driven by five 16-channel STP16CPS05 drivers, with which it is possible to implement short, moving text. Also, all of the LEDs in the display can be turned on simultaneously using a switch, in order to demonstrate the uniformity in the brightness of the LEDs, which is achieved by applying the same sink current to all channels. The second reference design is a smaller 4 x 8 LED matrix driven by the STP16CP05 and the STP16CPS05, and includes a DC-DC converter for supply voltages varying from 5 V up to 35 V. For this new 32 LED array reference design, an evaluation board using OSRAM LEDs is available through order code STEVAL-ILL003V2.

The new STP16CP05, STP08CP05 and STP16CPS05 LED drivers are monolithic, low voltage 8-bit or 16-bit shift registers designed for driving LED and LED panel displays. Thanks to these drivers the output LED current is constant and can be very precisely set using just one external resistor to control the light intensity of the LEDs. The STPxxCx05 guarantees up to 20 V output driving capability, allowing designers to connect more LEDs in series. The high 30 MHz clock frequency also satisfies the system requirement of high volume data transmission. Both designs are controlled by the ST7Lite09 microcontroller, which provides full text motion control, brightness regulation through PWM and control of text speed. A 3.3 V supply voltage for the microcontroller and the drivers is provided by a linear voltage regulator (the LE33 or L78L33).

The STP16CPS05 LED driver employs auto power saving to reduce power consumption.

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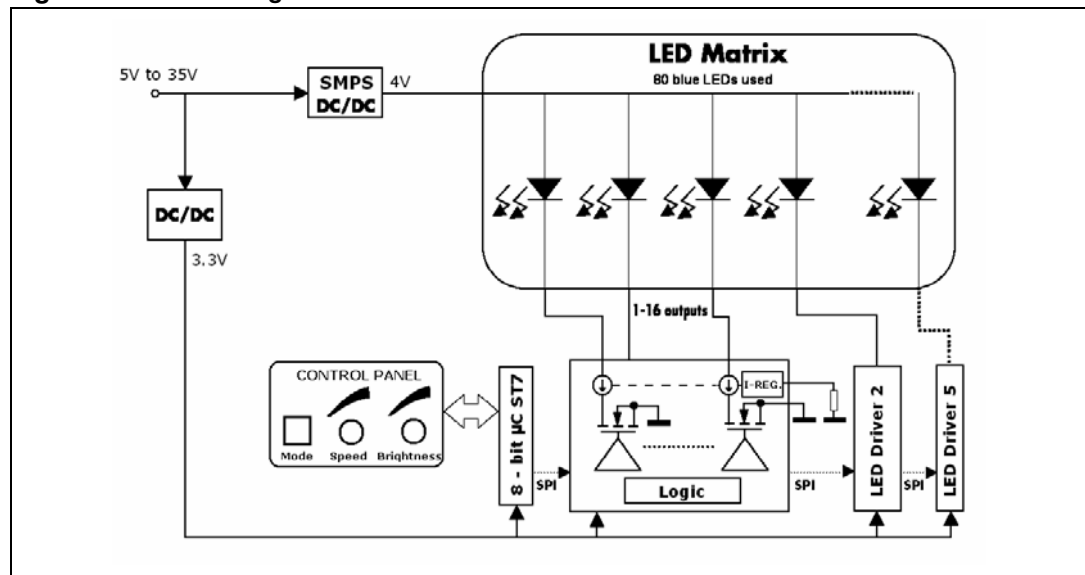
# 1 Block diagram

The block diagram of the LED array reference design board is shown in *Figure 1*. The diagram shows a universal STMicroelectronics system solution for driving an LED array. The number of LEDs can be increased by adding additional drivers in cascade. The input voltage is connected to the anodes of all of the HB LEDs. The input voltage value is very important due to the power dissipation in the drivers. A detailed explanation is described in *Section 3: Reducing power dissipation on the chip*. The LED cathodes are connected to ground through constant current sinks. The value of the constant current is set by only one external resistor. The DC-DC converter is represented by a simple linear controller (LE33 or L78L33) and provides 3.3 V supply voltage to the microcontroller and the LED drivers. The DC-DC SMPS (switch mode power supply), using the L5970D step-down converter, is designed to increase the efficiency, performance and supply voltage range (5 V up to 35 V). A detailed description of the SMPS design can be found in the L5970D device datasheet.

The control unit in this application is a microcontroller which sends data through the serial peripheral interface (SPI) to the shift registers. The data are shifted bit by bit to the next driver with the falling edge of the clock frequency (the maximum communication frequency for this driver is 30 MHz).

The control panel consists of the switch and two potentiometers. The switch changes the modes and the potentiometers allow the changing of the brightness and the text speed (blinking speed).

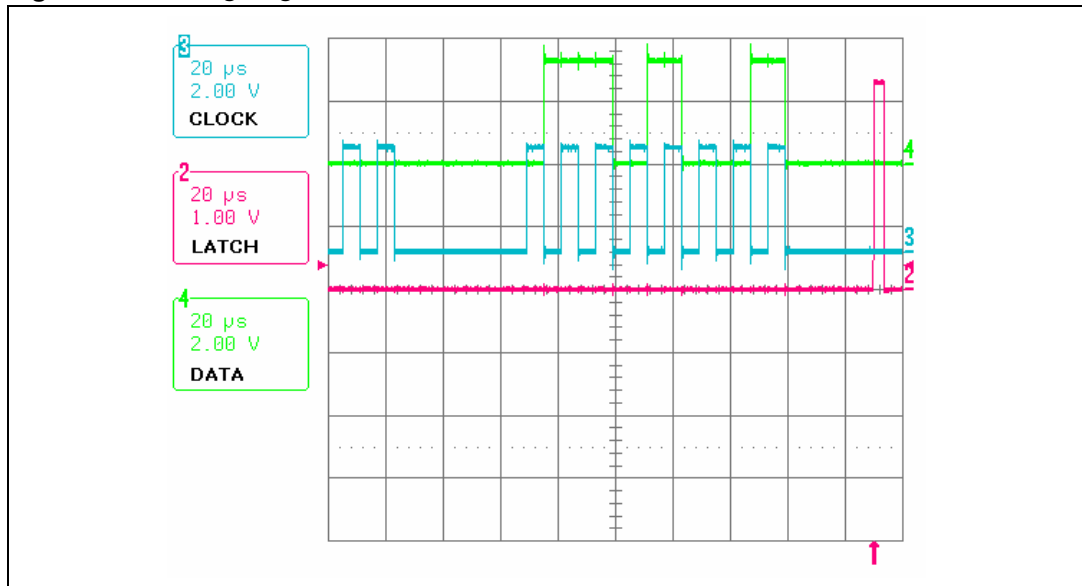
**Figure 1. Block diagram**



## 2 Timing diagram

The typical timing diagram is shown in [Figure 2](#). The DATA, CLOCK and LATCH waveforms are shown. The data are changed with the falling edge of the clock frequency. For example, in [Figure 2](#) one byte (01101001) can be seen. When all data are written to the drivers through the SPI, the microcontroller sets the latch input terminal (LE) pin to "log 1" and rewrites the data to the storage registers. In the next step the LE pin is grounded and thus the following data can be transmitted to the shift registers without changes in the output stage. The data in the storage registers are converted to the output constant current stages by the output enable (EO) pin. Thanks to the output enable pin, the brightness can be regulated through the PWM signal. Both LED array reference designs have adjustable delay time via potentiometer after implementation of the "latch signal". Thanks to this feature the blinking speed can be regulated (time between sending data packets is changed).

**Figure 2.** Timing diagram



### 3 Reducing power dissipation on the chip

One of the most important considerations in this application is the calculation of the maximum power dissipation on the driver chip. The maximum power consumption can be calculated with the ambient temperature and the thermal resistance of the chip. The thermal resistance depends on the type of package and can be found together with the maximum allowed junction temperature in the datasheet for the device. The maximum allowable power consumption of this device is calculated as follows:

#### Equation 1

$$P_{dmax} = \frac{T_{jmax} - T_a}{R_{thja}}$$

- $P_{dmax}$  - maximum power dissipation [W]
- $T_a$  - ambient temperature [°C]
- $T_{jmax}$  - maximum junction temperature [°C]
- $R_{thja}$  - thermal resistance junction to ambient [°C/W]

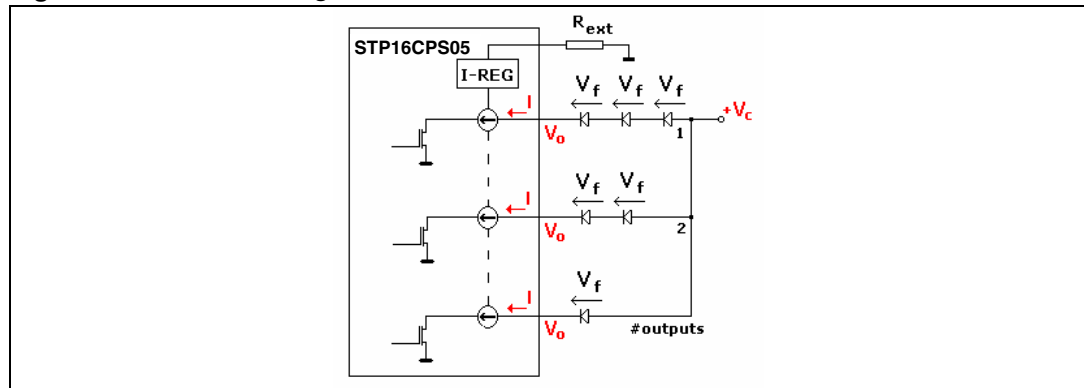
The maximum forward current for each type of LED is provided in the datasheet and must not be exceeded. Each output channel of the driver operates as a linear current sink. As the sink current for each output of LED driver is set as constant by an external resistor, the power dissipation of the chip depends on the value of LED supply voltage ( $V_c$ ) minus the forward voltage drop of the LEDs. To optimize the power dissipation of the chip, it is recommended to use the lowest possible supply voltage for the LEDs. An example of how to calculate the power dissipation of the chip is shown in [Figure 3](#). The equation for this basic connection is:

#### Equation 2

$$P_{tot} = I_c \cdot U_c + I \sum_{i=1}^{\#outputs} (V_c - n_i V_F)$$

- $P_{tot}$  - power dissipation of chip [W]
- $I_c$  - supply current for driver [A]
- $U_c$  - supply voltage for driver [V]
- $I$  - constant LED current set by external resistor [A]
- #outputs - number of outputs
- $V_c$  - LED supply voltage [V]
- $n_i$  - number of serial connected LED for each output
- $V_F$  - LED forward voltage [V]

**Figure 3. General configuration**



When only one LED is connected to each output (the most common configuration used in LED array reference boards) the equation can be simplified as follows:

**Equation 3**

$$P_{tot} = I_c \cdot U_c - \#outputs \cdot I \cdot (V_c - V_F)$$

As previously stated, only the LED supply voltage  $V_c$  is variable. Thus the correct choice is an LED supply voltage  $V_c$  about 0.5 V higher than  $V_F$  or  $n \cdot V_F$  for  $n$  LEDs connected in series.

If a PWM signal controls the brightness of the LEDs, the total power dissipation on the chip is calculated as:

**Equation 4**

$$P_{tot} = I_c \cdot U_c - \#outputs \cdot I \cdot (V_c - V_F) \cdot D$$

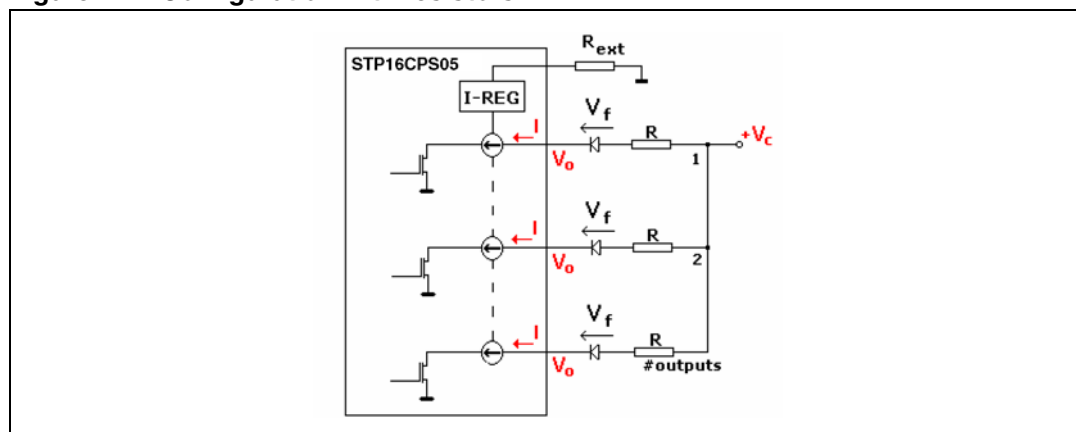
where  $D$  is the duty cycle.

If there is no possibility to obtain the proper value of the LED supply voltage in an application, an external resistor  $R$  in series with each LED must be connected to limit the power dissipation on the chip as shown in [Figure 4](#). The power dissipation on the chip is consequently decreased as follows:

**Equation 5**

$$P_{tot} = I_c \cdot U_c - \#outputs \cdot I \cdot (V_c - (V_F + I \cdot R))$$

Figure 4. Configuration with resistors



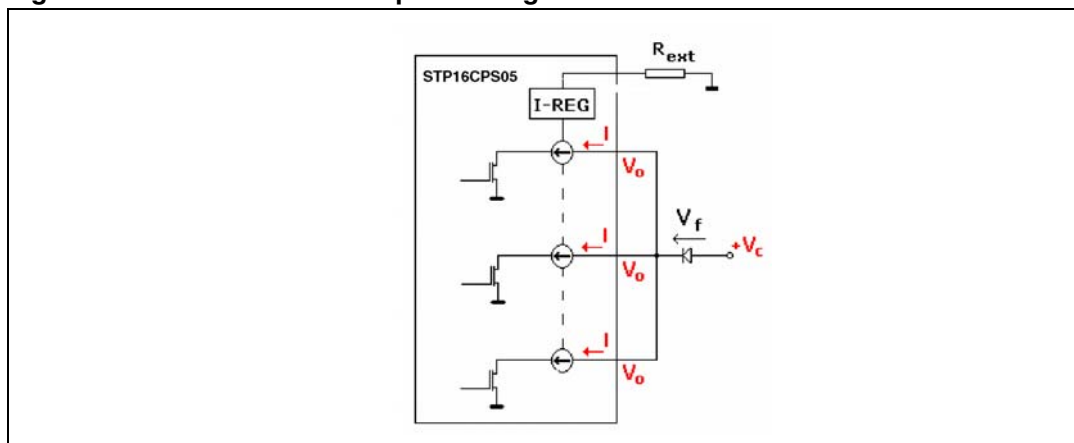


## 4 Common drain outputs configuration

As mentioned above, the STPxxCx05 is focused on driving high brightness LEDs. The maximum forward current of HB LEDs can vary from 20 mA to several hundred mA.

A typical current value for super HB LEDs is 350 mA. Thanks to the common drain configuration the outputs can be connected together as shown in [Figure 5](#). This increases the performance and current capability of the driver. This configuration enables the driving of several types of HB LEDs even with the limited current-per-output.

**Figure 5. Common drain outputs configuration**



## 5 LED array reference designs

Two LED array reference designs have been developed: one with 80 LEDs using the STP16CPS05 LED driver, and another with 32 LEDs using the STP16CP05 and STP16CPS05 LED drivers. In the following sections these two designs and their differences are briefly described.

### 5.1 80 LED array reference design

An example of the 80 LED array reference design proposal (no evaluation board is currently available for this design) is shown in [Figure 6](#). Its block schematic description is provided in [Section 1: Block diagram](#). The only simplification in this reference design is that it does not include an SMPS DC-DC converter. Therefore the supply voltage should be in the range of 4 V to 5 V.

**Figure 6. 80 LED array reference design**



#### 5.1.1 Application schematic

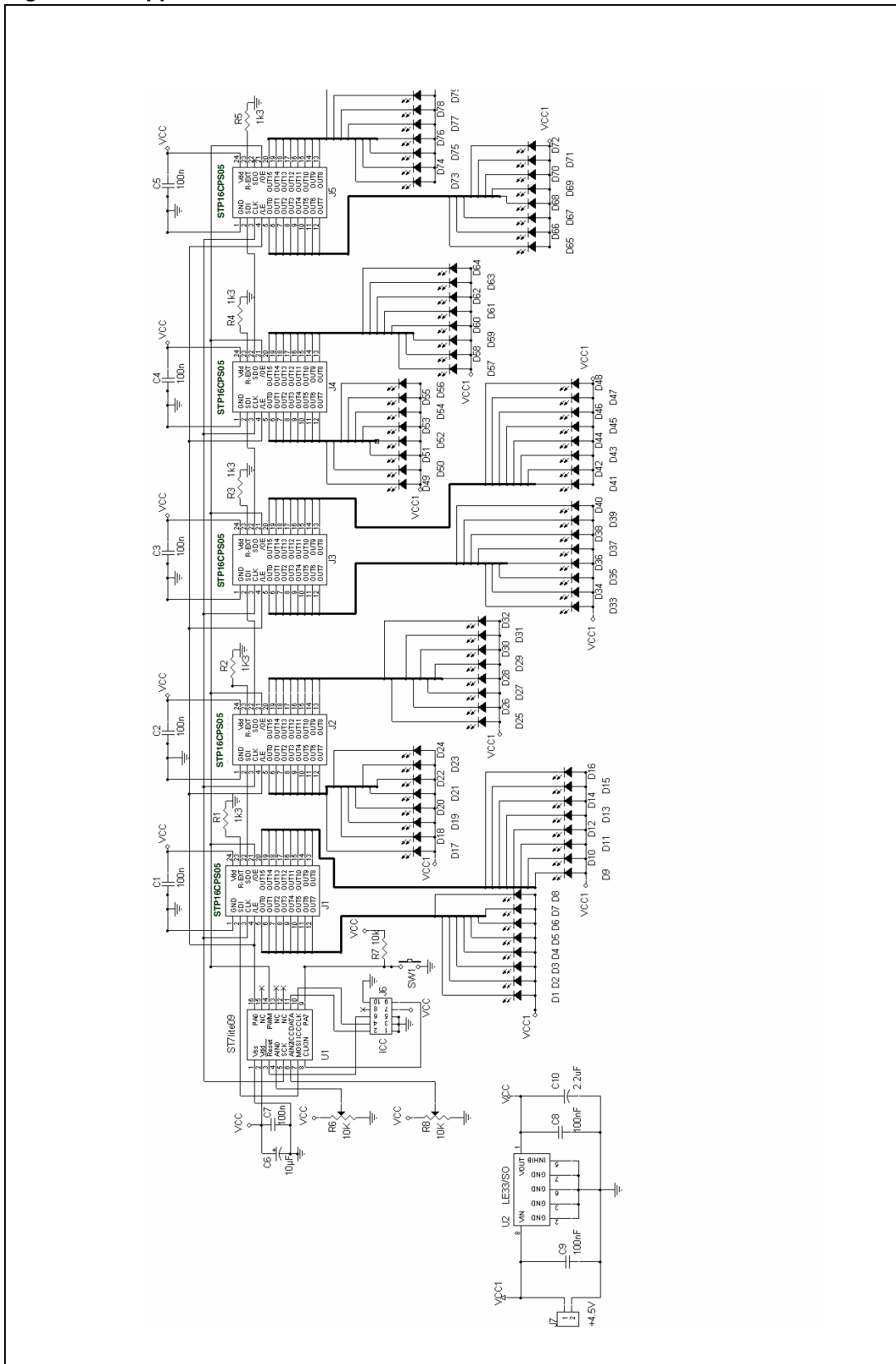
A detailed application schematic of this design is shown in [Figure 7](#). Five STP16CPS05 LED drivers with 16 outputs are controlled by the ST7Lite09 microcontroller. The microcontroller provides the clock frequency (SCK pin), the serial data (MOSI pin), the PWM signal (PWM pin) and the latch signal (PA0 pin). The clock frequency in this application is 633 KHz and the PWM signal for brightness regulation is 619 Hz. Resistors R1 to R5 (one for each driver) set the constant current for all outputs. Their value is 1.3 k $\Omega$  and they set the constant sink current to approximately 10 mA (for more information, please refer to the STP16CP05 and STP16CPS05 datasheets). The analog voltage values from the trimmers R6 and R8 are measured and converted by the microcontroller's ADC to the digital reference signal. The microcontroller sets the PWM signal for brightness and the data time delay for text speed control accordingly.

## 5.1.2 Bill of material

Table 1. Bill of material

Item	Quantity	Reference	Part
1	8	C1, C2, C3 C4 C5 C7, C8, C9	100 nF
2	1	C6	10 $\mu$ F
3	1	C10	2.2 $\mu$ F
4	80	D1 - D80	LED
5	5	J1, J2, J3, J4, J5	STP16CPS05
6	1	J6	ICP
7	1	J7	Connector
8	5	R1, R2, R3, R4, R5	1k3
9	3	R6, R7, R8	10 k
10	1	SW1	SW push button
11	1	U1	ST7Lite09
12	1	U2	LE33/SO

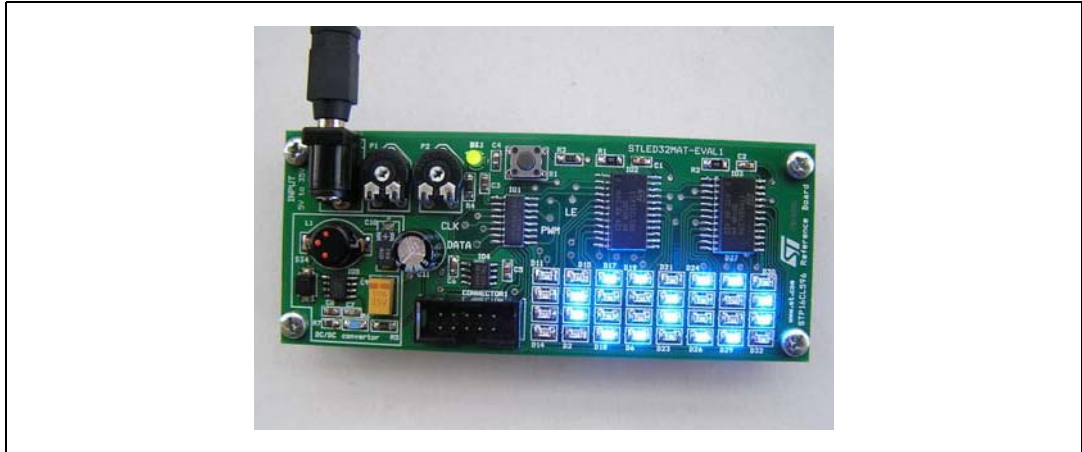
Figure 7. Application schematic



## 5.2 32 LED array reference design

The 32 LED array reference design board is shown in [Figure 8](#) and its block schematic description corresponds to [Section 1: Block diagram](#). All components are placed on the top side of the board. This board includes an SMPS DC-DC converter using the L5970D step-down switching regulator for input voltages from 5 V to 35 V. The order code for this reference design board is STEVAL-ILL003V2.

**Figure 8. 32 LED array reference design board**



### 5.2.1 Application schematic

The detailed application schematic of this design is shown in [Figure 9](#). Two LED drivers (STP16CP05 and STP16CPS05) with 16 outputs each are controlled by one ST7Lite09 microcontroller. Resistors R1 and R2 (one for each driver) set the constant current for all outputs. Their value is 1.2 k $\Omega$  and they set the constant sink current to 16 mA for each output (for more information, please refer to the STP16CP05 and STP16CPS05 datasheets). Six blinking modes are programmed in this application. The first switches the entire display ON/OFF. The second is a "harmonic" lighting effect, as the light is moved from the margin to the center of the display and back. During the third mode the numbers from one to nine are moved on the display. The fourth and fifth modes are implemented to show differences between the STP16CP05 and the STP16CPS05 LED drivers (as described below). Since the constant current LED drivers are used in this design, the brightness for each LED must be the same. Therefore, during the sixth mode, all LEDs are simply turned ON for LED brightness checking. All features and functions (communication, brightness regulation, blinking speed regulation, etc.) are similar to the 80 LED array reference design board, with exception of the addition of an SMPS DC-DC converter. Its output voltage is 4 V and its maximum current is 1 A (L5970D device). For more details on this converter design, please refer to the L5970D datasheet. The clock frequency in this application is 83.6 KHz and the PWM signal for brightness regulation is 654 Hz.

## 5.2.2 Bill of material

**Table 2. Bill of material**

Item	Qty	Reference	Part	Description	Order code
1	1	CONNECTOR1	ICC	Programming connector	
2	5	C1,C2,C3,C5,C6	100 nF	SMD cap. 0805	
3	1	C4	10 nF	SMD cap. 0805	
4	1	C7	220 pF	SMD cap. 0805	
5	1	C8	22 nF	SMD cap. 0805	
6	1	C9	10 $\mu$ F/35 V	SMD tantal. cap.	
7	1	C10	100 $\mu$ F/16 V	SMD tantal. cap.	
8	1	C11	220 $\mu$ F/16 V	Electrolytic cap.	
9	32	D1 - D32	OSRAM SMD blue LED	LB T68C-P2S1-35	OSRAM - Q65110A1978
10	1	D33	SMD green LED	Green SMD LED	
11	1	D34	STPS340U	Schottky diode	STPS340U
12	1	IO1	ST7LITE09	Microcontroller	ST7FLite09Y0M6
13	1	IO2	STP16CP05	LED driver	STP16CP05MTR
14	1	IO3	STP16CPS05	LED driver	STP16CPS05MTR
15	1	IO4	78L33	Voltage regulator	L78L33ACD
16	1	IO5	L5970D	DC-DC converter	L5970D
17	4	J1,J2,J3,J4	CON1	Not connected	
18	1	J5	CON3	Input connector	
19	1	L1	33 $\mu$ H	Inductor	Coilcraft - DO3316P-333
20	2	P1,P2	10 k	Potentiometer	
21	2	R1,R2	1K2	SMD 1206 resistor	
22	1	R3	10 k	SMD 1206 resistor	
23	1	R4	560 $\Omega$	SMD 1206 resistor	
24	1	R5	6k8	SMD 1206 resistor	
25	1	R6	3 k	SMD 1206 resistor	
26	1	R7	4k7	SMD 1206 resistor	
27	1	S1	Switch	Button	



## 6 The STP16CP05 vs. the STP16CPS05

The STP16CPS05 LED driver includes an additional feature called “auto power saving”, which minimizes the quiescent current if no active data is detected on the latches, and automatically powers-up the device at the first active data latched. The fourth and fifth blinking modes are designed on the 32 LED reference design board STEVAL-ILL003V2 to measure the supply current for the STP16CP05 and STP16CPS05, when no active data is detected and when active data is latched.

[Table 3](#) shows that the STP16CPS05 has much lower current (0.067 mA) than the STP16CP05 (3.11 mA) if no active data is detected. Therefore for large panels it is possible to save a significant amount of energy using the STP16CPS05 LED drivers with the auto power saving feature.

**Table 3. Current consumption for the STP16CP05 and STP16CPS05 measured on the STEVAL-ILL003V2**

Data status	STP16CP05	STP16CPS05
Active data is detected (all outputs are turned ON)	3.03 mA	3.07 mA
No active data is detected (all outputs are turned OFF)	3.11 mA	0.067 mA



## 7 References and related materials

1. STP16CP05 and STP16CPS05 datasheets
2. ST7Lite0 datasheet
3. L5970D datasheet

## 8 Revision history

**Table 4. Document revision history**

Date	Revision	Changes
28-Apr-2005	1	Initial release.
17-Nov-2005	2	Added information about new LED driver STP16CP596. Modified <a href="#">Table 2</a> and <a href="#">Figure 9</a> .
22-Jan-2008	3	Document reformatted. Replaced references to part numbers STP16CP596, STP16CL596 and STP08CL596 throughout the document with the new, improved devices STP16CP05, STP16CPS05 and STP08CP05, respectively. Added <a href="#">Section 6: The STP16CP05 vs. the STP16CPS05</a> . Added the order code for the 32 LED reference design board STEVAL-ILL003V2. Clarified that no board is commercially available for the 80 LED reference design in <a href="#">Section 5: LED array reference designs</a>

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