

# **System Design Guidelines for Full-Color RGB LED Matrix Based on LP50xx Device**

---



---

Charles Chen

## **ABSTRACT**

The LED-based matrix displays are bringing new dimensions of versatility and eye-pleasing visual effects to a growing number of outdoor and indoor applications. This application note discusses the detailed steps to build a full-color RGB LED matrix based on LP5009, LP5012, LP5018, LP5024, LP5030, and LP5036 devices. Detailed configurations and system structure guidelines are included in this report.

## **Contents**

1	Introduction .....	2
2	Step-by-Step Design Process .....	2
3	Testing and Results .....	7
4	Summary .....	9
5	References .....	9

## **List of Figures**

1	Typical Application Circuit .....	2
2	Typical Timing Sequence of LED Matrix.....	3
3	Line Control Circuit #1 .....	4
4	Line Control Circuit #2 .....	4
5	Line Control Circuit #3 .....	4
6	Ghost Cancelling Method #1 .....	5
7	Ghost Cancelling Method #2 .....	5
8	Ghost Cancelling Method #3 .....	6
9	Detailed Timing Sequence .....	6
10	Ghost Cancelling Effect of Diagonal Line Image .....	7
11	Rainbow Pattern .....	8
12	Experimental Waveform .....	8

## **List of Tables**

1	LED Maximum Average Current Under Different Number of Common Lines .....	3
---	--	---

## Trademarks

LaunchPad is a trademark of Texas Instruments.  
All other trademarks are the property of their respective owners.

## 1 Introduction

The LP50xx device is a multi-channel constant current sink RGB-LED driver with integrated color mixing and brightness control. The integrated 12-bit, 29-kHz PWM generators for each channel enable smooth, vivid color for LEDs, and eliminate audible noise. [Figure 1](#) shows how this application note uses the LP5024 device as an example to drive an 8 × 8 full-color RGB LED matrix with a 1/8 multiplexing rate, which enables us to drive up to 64 RGB LEDs with only one LP5024 LED driver and one multi-channel power switch or several external MOSFETs instead. This cost-effective solution provides flexible PWM resolution from 9-bit to 12-bit with standard I2C interface, ensuring a fine and smooth display effect thanks to the excellent performance provided by the LP50xx device.

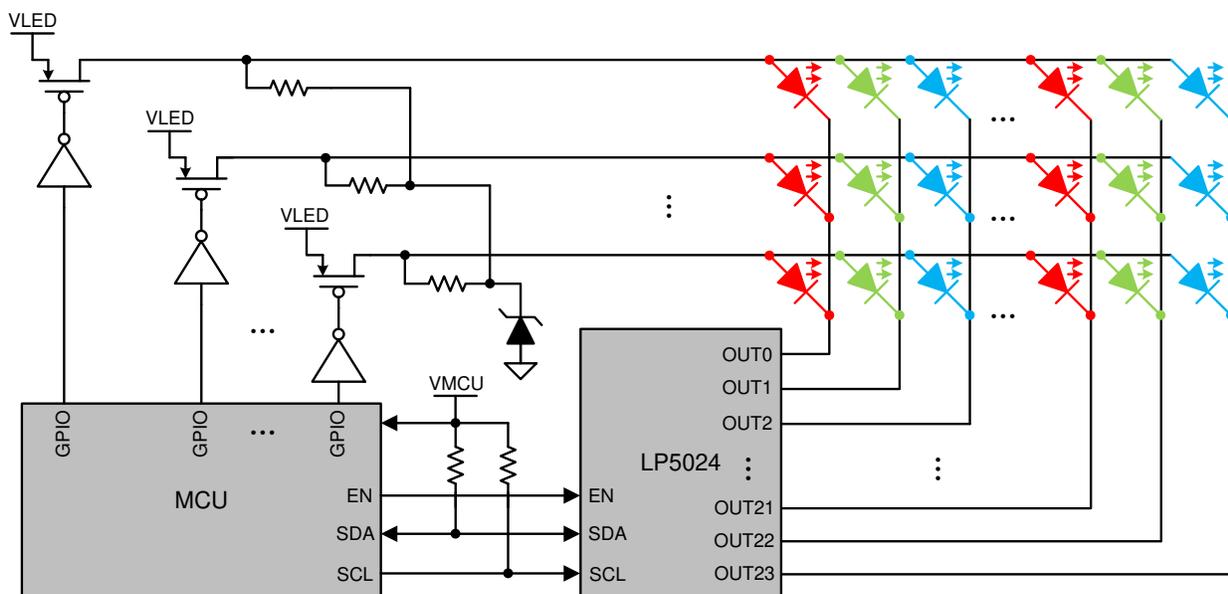
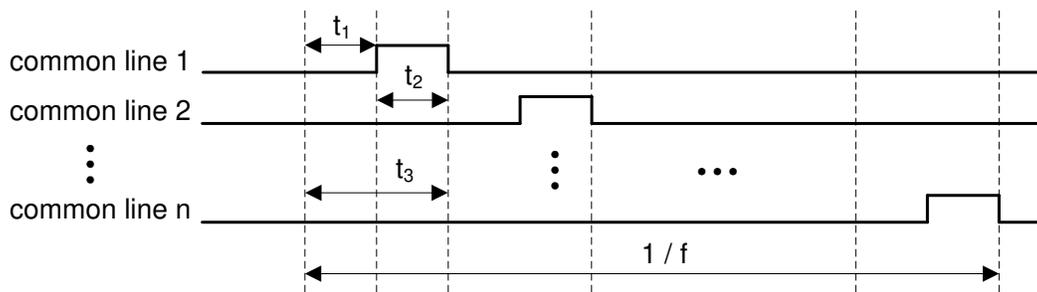


Figure 1. Typical Application Circuit

## 2 Step-by-Step Design Process

### 2.1 Step 1 - Calculation of the Maximum Average Current

The maximum average current of each LED in this solution has a close relationship with the communication rate, the number of instruction bytes, the frame rate, and the current range of the LP50xx device. [Figure 2](#) shows the typical timing sequence of LED matrix with a 1/n multiplexing rate.



$t_1$  : instruction sending time       $t_2$  : LED ON time  
 $t_3$  : time allocated to a specific line       $f$  : frame rate

**Figure 2. Typical Timing Sequence of LED Matrix**

The maximum average current of each LED can be derived as Equation 2 from Equation 1 according to Figure 2, where  $n_c$  represents the number of instruction bytes,  $n$  represents the number of common lines,  $f$  represents the frame rate, and  $I_{out}$  represents the current range of the LP50xx device. The value of  $n_c$  should be 34, to update all the LEDx\_BRIGHTNESS and OUTx\_COLOR registers of the LP5024 device. The data in Table 1 can be obtained using Equation 1 and Equation 2, where  $I_{out} = 35$  mA,  $f_{12C} = 400$  kHz and  $f = 60$  Hz. A trade off should be made between the thermal and multiplexing rate for a specific maximum average current since the LED luminous efficiency decreases with the increasing of LED DC forward current.

$$t_1 = \frac{9n_c}{f_{12C}} \tag{1}$$

$$i_{ave} = \left[ \frac{1}{f \times n} - t_1 \right] \times f \times I_{OUT} \tag{2}$$

**Table 1. LED Maximum Average Current Under Different Number of Common Lines**

Number of Common Lines n	Average Current (mA)
2	15.8935
3	10.0602
4	7.1435
5	5.3935
6	4.2268
7	3.3935
8	2.7685
9	2.2824

## 2.2 Step 2 – Selection of Common Line Control Circuits

Several external circuits shown in [Figure 3](#), [Figure 4](#), and [Figure 5](#) are available to achieve common line control.

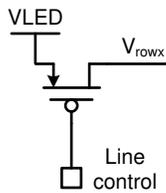


Figure 3. Line Control Circuit #1

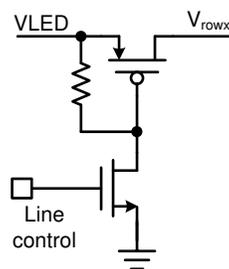


Figure 4. Line Control Circuit #2

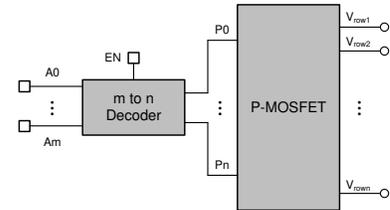


Figure 5. Line Control Circuit #3

The maximum input voltage which can be applied to the MOSFET in circuit #1 is the VOH voltage of the MCU GPIO added to the Vth voltage of the P-MOSFET. Another disadvantage is that the GPIO signal from the microprocessor must always be present to prevent the PMOS from turning on. Those disadvantages can be overcome by circuit #2 as [Figure 4](#) shows. However, one disadvantage with this circuit is a VIN leakage path that is present when the PMOS is turned on. Besides, a number of GPIO resources are still needed in circuit #2. The number of the MCU GPIO can be reduced by using an integrated multi-channel power switch as [Figure 5](#) shows. Overall, the common line control circuits should be selected according to the specific system requirements. Therefore, circuit #3 is adopted in this solution.

## 2.3 Step 3 – Ghost Cancelling

Ghost is a common phenomenon in time-multiplexed LED-based matrix displays. Since PN junctions of LED lamps have relatively high levels of capacitance, their residual charge can keep triggering capacitive charge transfers between the floating nodes. And every time there is forward electron flow through a PN junction it may cause the LED to light at unwanted times. The worst situation where this phenomenon is most obvious is a diagonal line image. For more details, see the [Build a High-Density, High-Refresh Rate, Multiplexing Panel With the TLC5957 User's Guide](#).

[Figure 6](#), [Figure 7](#), and [Figure 8](#) illustrate methods for solving the upside ghost issue. Those methods are aimed to discharge the residual charge caused by the parasitic capacitance of the common line. However, method #1 shown in [Figure 6](#) will increase too much additional power loss, which can be improved by adding a Zener diode as [Figure 7](#) shows. The power loss and discharge speed should be taken into account when selecting the value of the resistor. The additional discharge control of N-MOSFET is needed in method #3 as shown in [Figure 8](#). For detailed timing sequence of method #3, see the [TLC59283应用于LED Wall的行线多次放电方案 Application Note](#). Therefore, method #3 is adopted in this solution.

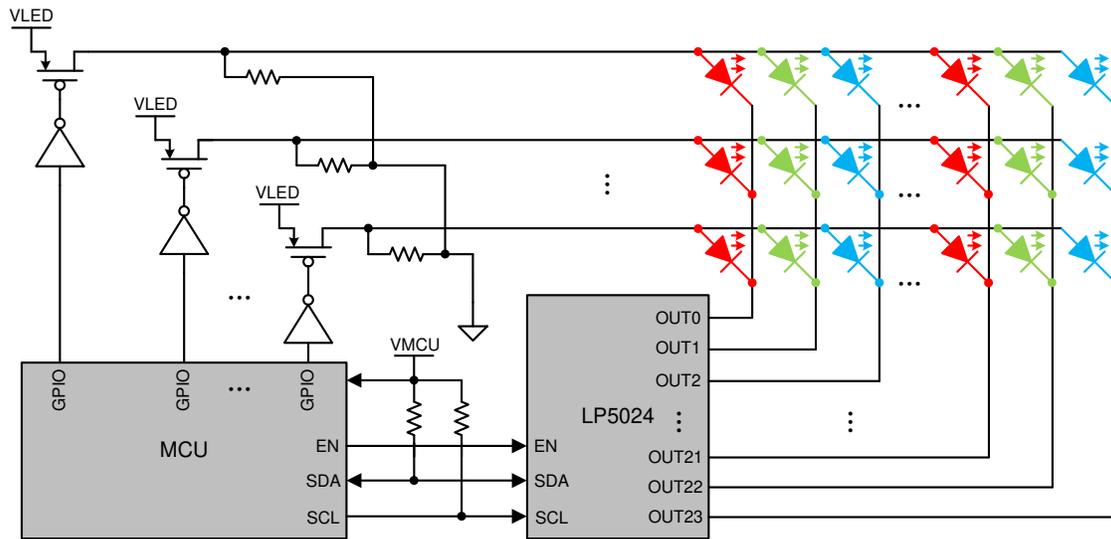


Figure 6. Ghost Cancelling Method #1

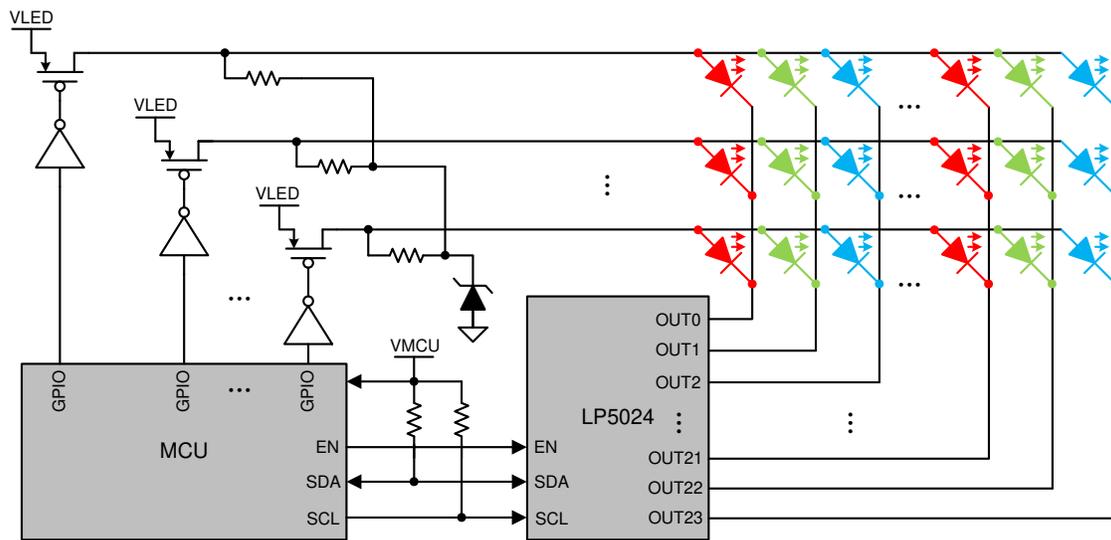


Figure 7. Ghost Cancelling Method #2

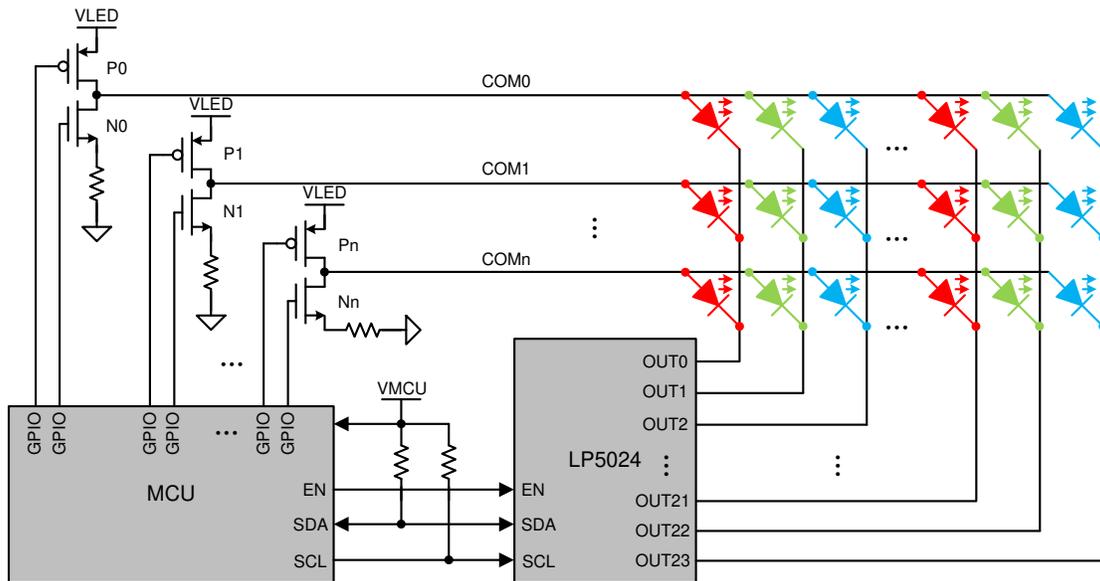
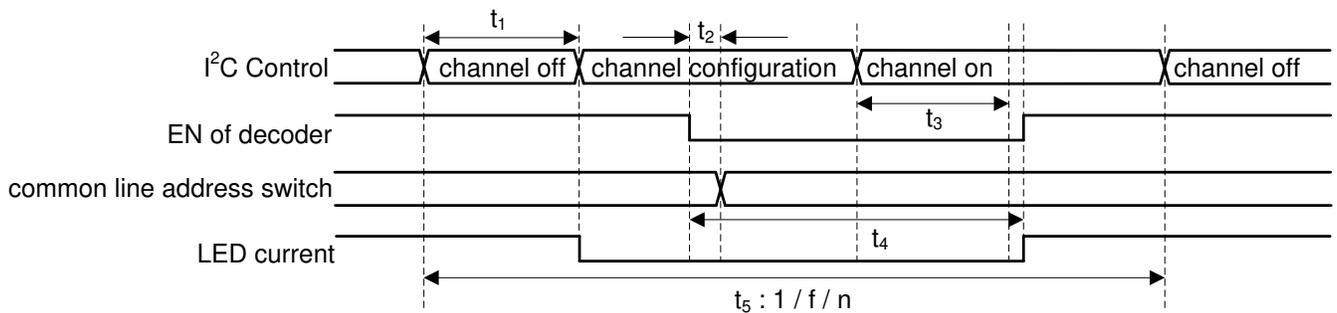


Figure 8. Ghost Cancelling Method #3

## 2.4 Step 4 – Timing Sequence Control

The detailed timing sequence of each frame is shown in Figure 9. The “channel off” of I<sup>2</sup>C control instruction writes “1” to the “LED\_Global Off” register while “channel on” of I<sup>2</sup>C control instruction writes “0” to it. The auto-increment mode of I<sup>2</sup>C communication is selected for the LP5024 device to reduce the time of instruction transmission. It should be noted that when common line control circuit #3 is adopted in the solution, the line address should be switched when all the power switches are off to avoid lighting undesired LEDs owing to the intermediate state during the switching stage of the line address.



$t_1$  : sending time of channel off command by I<sup>2</sup>C  $t_2$  : common line address switch dead time

$t_3$  : sending time of channel on command by I<sup>2</sup>C  $t_4$  : discharge time of row parasitic capacitance

Figure 9. Detailed Timing Sequence

### 3 Testing and Results

#### 3.1 Hardware and Software Setup

The MSP-EXP432P401R LaunchPad™ is used to send instructions by I<sup>2</sup>C to the LP50xx device in this solution. The source code is compiled in Code Composer Studio™ (CCS). To edit the code or design new patterns, install the CCS Integrated Development Environment (IDE) in the PC first. The program of desired patterns are then downloaded to the MSP432P401R LaunchPad.

#### 3.2 Test Results

Figure 10 shows the ghost cancelling effect under scanning pattern. According to the display results, there is no ghost issue when displaying a diagonal line image. Figure 11 shows the capture of the rainbow pattern.

Figure 12 shows the average current of a lighted LED with a 1/8 multiplexing rate when displaying a diagonal line image, which is almost the same as the theoretical analysis results. The green curve (CH4) is the current of the lighted LED. The remaining curves (CH1–CH3) are the bits of common line addresses.

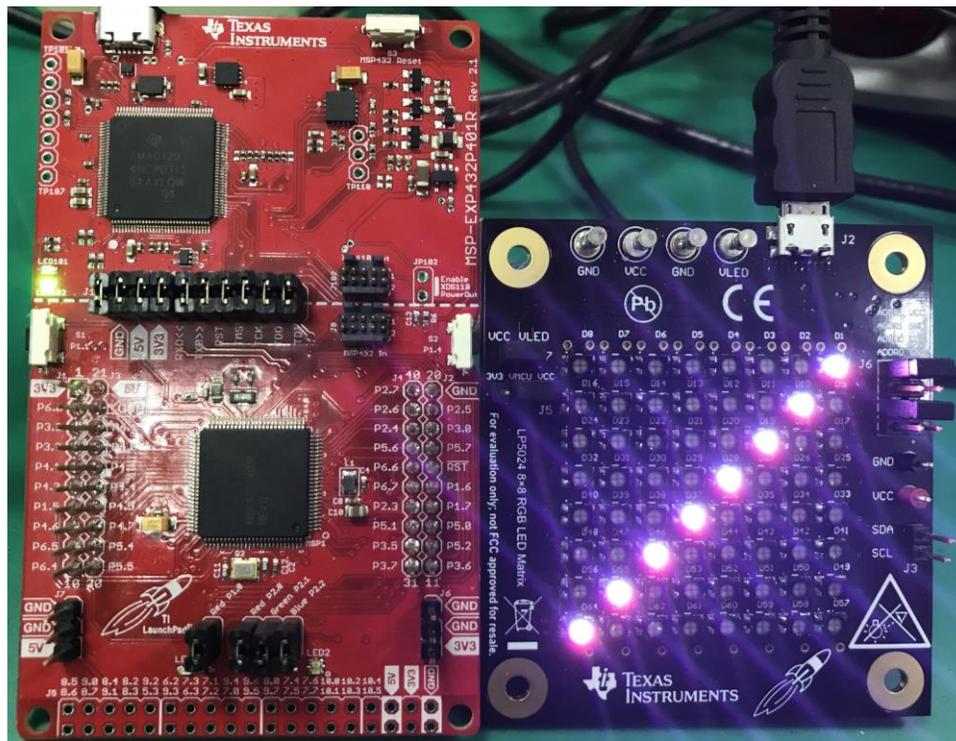


Figure 10. Ghost Cancelling Effect of Diagonal Line Image

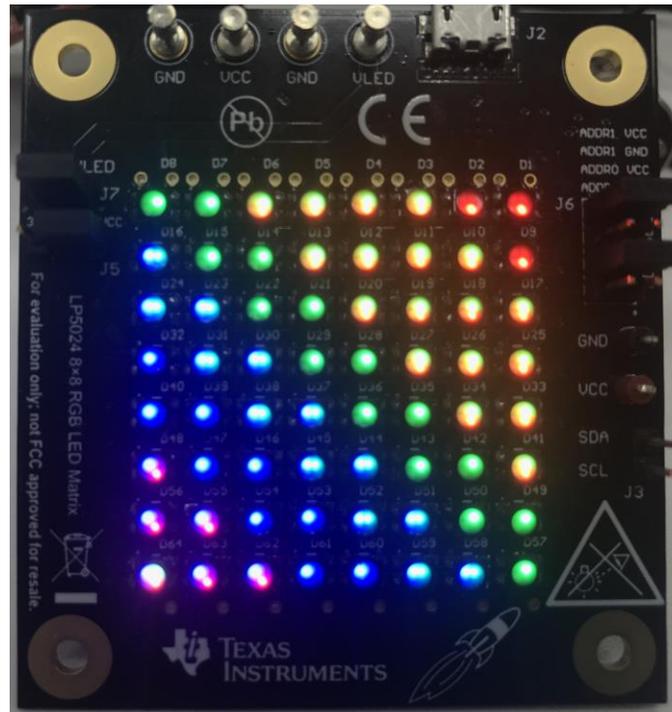


Figure 11. Rainbow Pattern

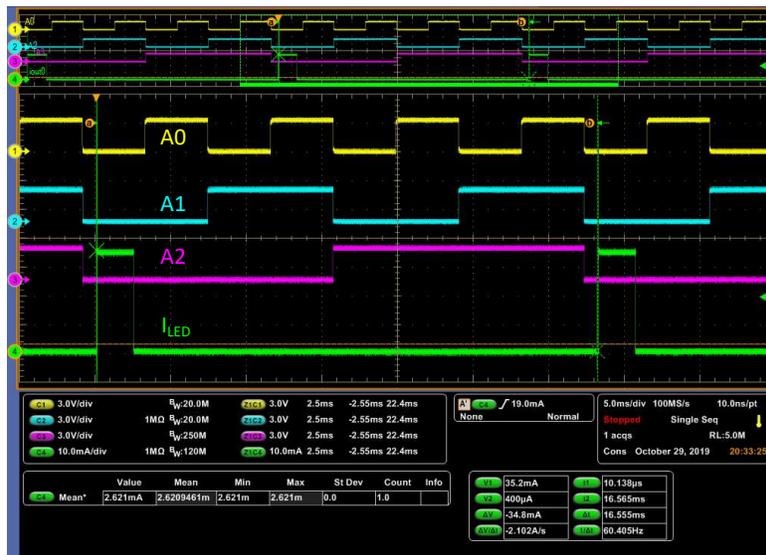


Figure 12. Experimental Waveform

## 4 Summary

This application note describes how to use the LP50xx device to build a full-color RGB LED matrix. This solution provides flexible PWM resolution from 9-bit to 12-bit with standard I2C interface, which is very suitable for the system that is sensitive to the cost.

## 5 References

1. Texas Instruments, [LP50xx 18-, 24-Channel, 12-Bit, PWM Ultralow-Quiescent-Current,  \$\mu\$ C RGB LED Drivers Data Sheet \(Rev. B\)](#)
2. Texas Instruments, [Build a High-Density, High-Refresh Rate, Multiplexing Panel With the TLC5957 User's Guide](#)

## IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to [TI's Terms of Sale](#) or other applicable terms available either on [ti.com](http://ti.com) or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265  
Copyright © 2022, Texas Instruments Incorporated