How to use LM3627x to Design DPU in Smartphones

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ABSTRACT

In smartphone applications, the PCB size is always one of the biggest concerns for a designer: discrete solutions for dedicated functions usually bring better performance, but take up extra space. Higher integration and equal or even better performance in a smaller solution size is the best solution. Texas Instruments released the LM3627x (LM36272, LM36273 and LM36274) family which integrates both backlight driver and LCD bias unit in only 2.44 × 1.67 BGA package which can support up to 4-channel LED strings with a total of 32 LEDs and support LCD screen bias; total system level efficiency is up to 92%. The LM3627x family can help designers to implement Display Power Unit (DPU) design easily with better performance. Besides the advantage of a super compact solution, the LM3627x family can also be configured using *Front-Screen Lighting* (FSL) mode for the most effective selfie possible.

Contents

List of Figures

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1 Introduction

1.1 LM3627x Key Specifications

The LM3627x family has the following specifications:

- 2.7-V to 5-V input voltage range
- Drives up to two, three, or four parallel white LED strings (29-V maximum V_{OUT})
- Backlight and LCD bias driver efficiency up to 92%
- 11-bit exponential and linear dimming control via PWM, I2C brightness control, or both
- Backlight operation with 4.7-µH to 15-µH inductor
- Programmable LCD bias voltages (±4 V to ±6.5 V with 50-mV resolution) with up to 80-mA per output
- 0.2% Matched LED current from 60 µA to 30 mA
- 1% Accurate LED current from 60 µA to 30 mA

1.2 LM36273 Simplified Block Diagram

- LED Backlight Driver Unit

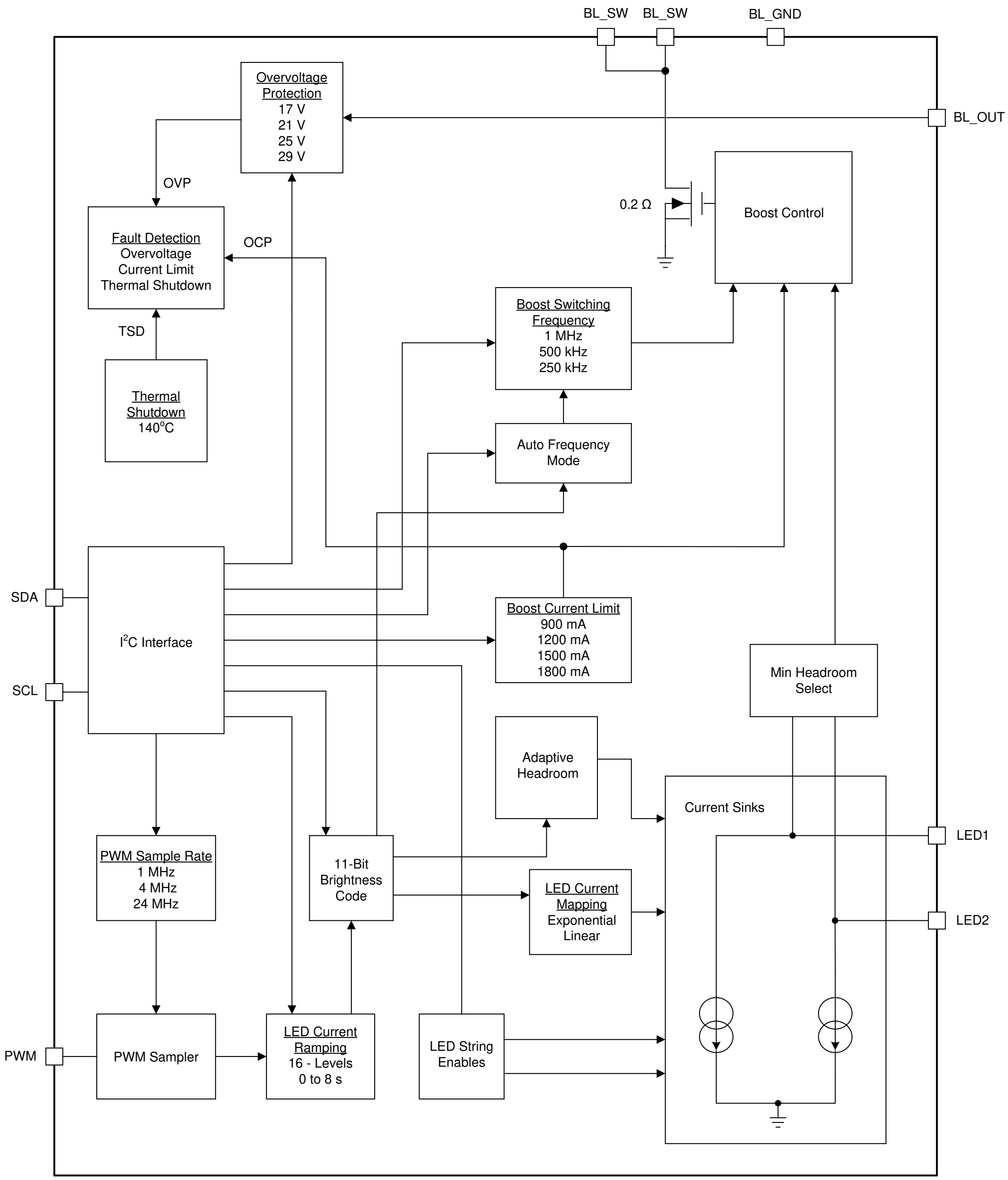

Figure 1. LM36273 LED Backlight Driver Unit

The LED driver can support up to 29 V and with 2 to 4 channels, the maximum LED current for each channel is 30 mA, so the LM36274 device can support *Front-Screen Lighting* (FSL) for better selfies in dark circumstances by configuring every channel of LED current at the maximum value. Eleven-bit resolution can make LED current smoother and avoid flicker at very low LED current conditions, such as the μA level. Exponential dimming strategy meets human eye ability and makes backlight look more linear.

- LCD Bias Driver Unit

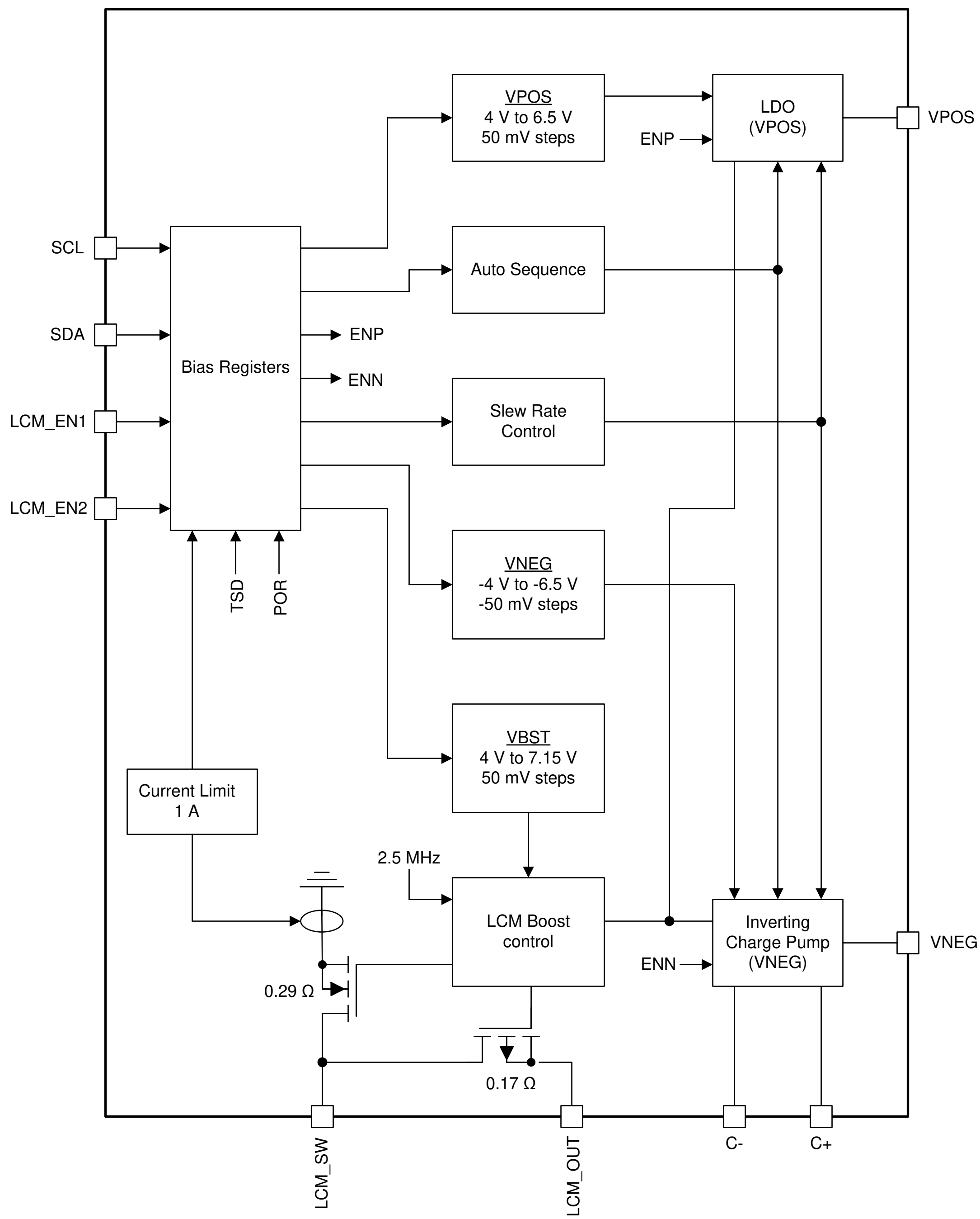

Figure 2. LM36273 LCD Bias Driver

The LCD bias driver can support most of the best *Liquid Crystal Modules* (LCMs) in the market so as to make LCM design more easily. Both of 2 rails (Positive and Negative) can be adjusted continually with 50-mV steps, the maximum output current for these 2 rails is up to 80 mA. The designer can get multiple power up or power down sequences between positive and negative rails by controlling LCM_EN1 and LCM_EN2 freely to meet any LCMs power sequence request.

2 How to map Exponential Data to Linear Dimming Lookup Table

2.1 Why use Exponential Data for Dimming?

Exponential brightness data is a special kind of data to emulate the human eye's actual feeling because human eyes are just like a logarithm translator. If the raw data of brightness is an exponential mode, then it would be expressed with linear mode by human eyes. Furthermore, exponential data has higher resolution than linear data at low dimming levels, so in an actual case, to decrease the software design difficulty of brightness adjustment, the designer prefers to map exponential data to a linear dimming unit. The designer may meet an obstacle: How to map exponential data to a linear system to get more accurate dimming?

2.2 Design Sample: Map Exponential Data to Linear Brightness Dimming Lookup Table

This section uses a sample with the LM36273 device :

According to the formula of exponential dimming as shown in this section, the "code" here is 11-bit brightness dimming data; 60 µA is the minimum LED current that the LM3627x device can handle. The full format of the 11-bit brightness dimming code: 8-bit MSB(10:3) + 3-bit LSB(2:0) = 11 bit, in actual design, should translate an 11-bit value to decimal format.

Backlight Brightness MSB Register (Address = 0x05)[Reset = 0xFF]

Backlight Brightness MSB Register

7	6	5	4	3	2	1	0
BRT[10]	BRT[9]	BRT[8]	BRT[7]	BRT[6]	BRT[5]	BRT[4]	BRT[3]
R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1

Backlight Brightness LSB Register (Address = 0x04)[Reset = 0x07]

Backlight Brightness LSB Register

7	6	5	4	3	2	1	0
NOT USED					BRT[2]	BRT[1]	BRT[0]
					R/W-1	R/W-1	R/W-1

Figure 3. 11-Bit Brightness Code

Assume that the target full brightness of an LED current is 30 mA, with a total of 2048 steps, or 11 bits.

So each step of the LED current in linear format is:

I_{LED_Step} = 30 mA / 2048 = 14.6 µA

Step 1 = 14.6 µA
Step 2 = 29.2 µA
Step 3 = 43.8 µA
Step 4 = 58.4 µA
} Manually set Step 1 to Step 4 at 60 µA

Step 5 = 73 µA

….

Step 2048 = 30 mA

Because the minimum LED current that the LM3627x device can support is 60 µA in exponential mode, keep all of the value that is less than 60 µA to 60 µA. Change Equation 1.:

Then, translate the decimal code to Hex code.

Make a linear format excel table (*Exponential Data to Linear Format Dimming Lookup Table*) with for quick calculation:

Full Brightness Current, mA	Linear Format Dimming Step	Linear Format Dimming Current mA	Exponential Dimming Code base on Linear Format, Decimal	Exponential Dimming Current in Linear Format mA
30	1	0.014648438	0	0.06
	2	0.029296875	0	0.06
	3	0.043945313	0	0.06
	4	0.05859375	0	0.06
	5	0.073242188	6	0.06110296
	6	0.087890625	7	0.061288748
	7	0.102539063	177	0.102689438
	8	0.1171875	221	0.11736532
	9	0.131835938	259	0.131717291

. . .

Full Brightness Current, mA	Linear Format Dimming Step	Linear Format Dimming Current mA	Exponential Dimming Code base on Linear Format, Decimal	Exponential Dimming Current in Linear Format mA
	2040	29.8828125	2046	29.90904694
	2041	29.89746094	2046	29.90904694
	2042	29.91210938	2046	29.90904694
	2043	29.92675781	2046	29.90904694
	2044	29.94140625	2046	29.90904694
	2045	29.95605469	2047	29.99998755
	2046	29.97070313	2047	29.99998755
	2047	29.98535156	2047	29.99998755
	2048	30	2047	29.99998755

Figure 4. Exponential-Linear Dimming Lookup Table

When dimming starts , the application processor (AP) can lookup this table according to the linear dimming step to get the target exponential mode brightness code easily. An example follows to show its working process:

1. Software Dimming Module in Smartphone OS sends out orders which are linearity from 1 to 2048, as the “Linear Format Dimming Step” column in Figure 4 shows to the AP.
2. The AP will map linearity dimming orders to exponential dimming code that has been preset in the “Exponential Dimming Code base on Linear Format” column in Figure 4.
3. Then, the AP gets this exponential code from Figure 4 and sends it to the DPU.
4. The DPU will execute commands from the AP and output target brightness.

In some user cases, the AP can not handle exponential dimming process directly due to Software Dimming Module limits, so this method helps designers keep the AP dimming code linearity and make use of smoother dimming performance in exponential dimming. Furthermore, Figure 4 can be integrated into a software platform, or used as a general tool in all projects in which the LM3627x family is designed-in. The solution is effective on multiple levels: easy dimming compatibility and better performance.

3 Key Design Tips for LM3627x

3.1 Simplified Schematic

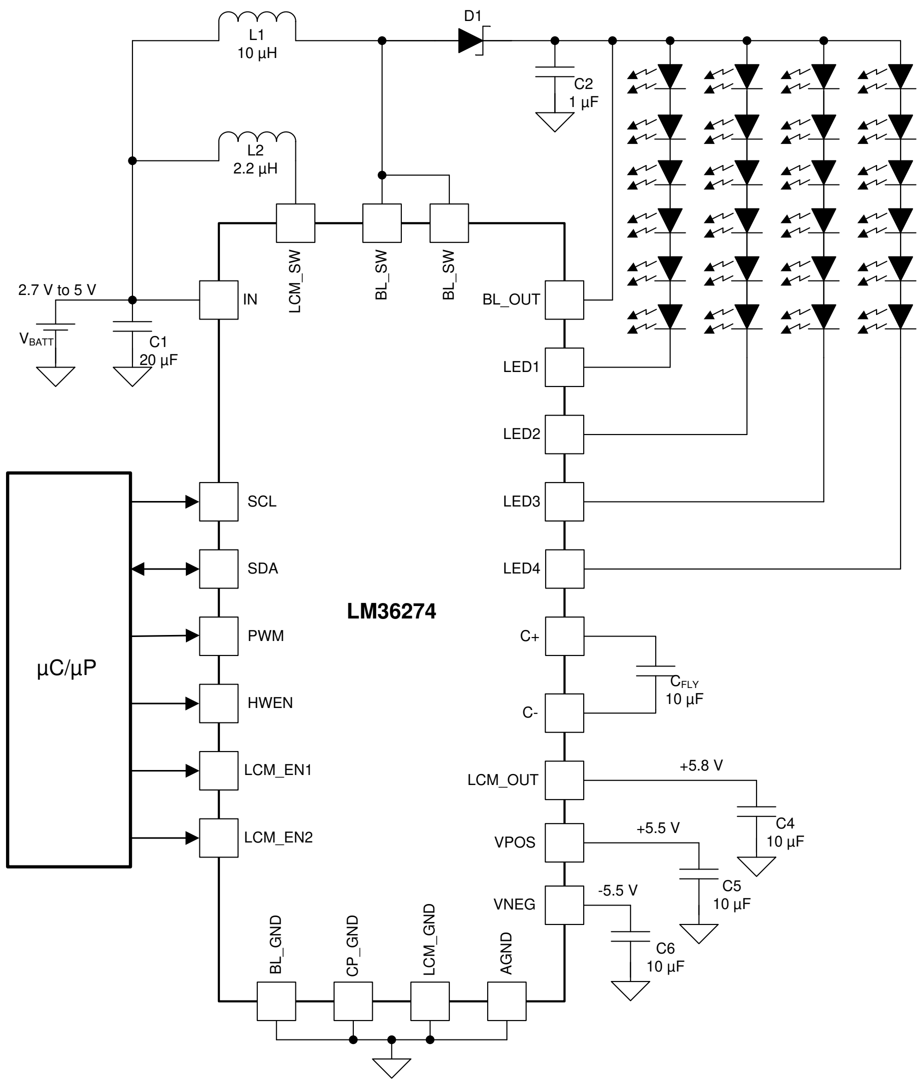

Figure 5. LM36274 Typical Schematic

- C_{FLY} is the charge pump capacitor, it is the power storage component, and is used to generate the negative rail of LCM.
- A Schottky Diode D_{SCH} is used to rectify and generate high voltage to drive the LED string.
- The ower inductors, L_{BL} and L_{LCM} are used to store energy to drive the LED string and LCD screen.

3.2 How to Choose Key Components: Inductor and Capacitor, Schottky Diode D_{SCH}

- Power Capacitor: C_{IN_BL},C_{IN_LCM},C_{IN},C_{OUT_BL}, C_{FLY}, C_{OUT_LCM}, C_{POS}, C_{NEG}

In general, all power capacitors for LM3627x applications should be MLCC (Multiple Layer Ceramic Capacitor) because of their smaller package, lower ESR, and lower power dissipation. The biggest shortfall of MLCC is that the effective capacitance is derated due to DC biased voltage on capacitor. When DC biased voltage on the MLCC increases, the effective capacitance of the MLCC will decrease accordingly. It is necessary to keep enough capacitance, in an actual design, the curve about DC biased voltage vs capacitance in the MLCC data sheet is a useful tool to find suitable power capacitor. As Figure 6 shows, when DC biased voltage increases, effective capacitance decreases quickly. Of course, the designer has to consider whether the maximum voltage that power capacitor supports can meet actual request. For example, if the power rail is 29 V, then designer should choose 35-V MLCC to avoid any failures. Meanwhile, the designer has to consider the impact of temperature to effective capacitance because different ambient working temperatures will lead to the change of effective capacitance.

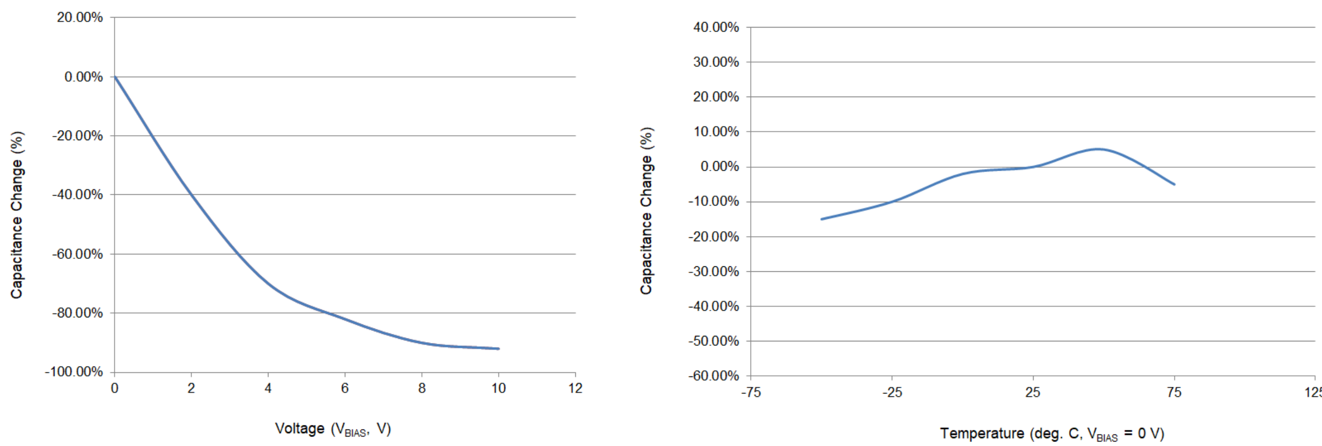

Figure 6. MLCC Effective Capacitance vs DC Biased Voltage and Temperature

- Power Inductor: $L_{\_BL}$, $L_{\_LCM}$

The power inductor is the key component to store energy, so the designer must pay more attention to calculate it. To the LM3627x family, a 10-µH inductor may meet most application needs for a backlight driver and 2.2 µH for an LCD bias driver. But the designer must carefully calculate the peak current that flows through the power inductor to keep inductor always running in safe status. Use formulas as in Equation 1 to Equation 3 to choose the correct power inductor. Additionally, pay attention to the curve of the effective inductance versus temperature and load current in the inductor data sheet. Generally, when load current is increased more than the saturation threshold that the inductor can handle, effective inductance of the power inductor will decrease greatly as Figure 7 shows, it will cause the inductor to be destroyed. Choose the correct inductor according to calculated I_{PEAK} value and the curve of Figure 7 to avoid any saturation occurring. The inductor should be magnetic shielded to get better EMC performance at the system level.

$$I_{LED} = 60\ \mu A \times 1.003040572^{Code} \quad (1)$$

$$Code_{Decimal} = \frac{Log_{10} I_{LED} - Log_{10} 60\ \mu A}{Log_{10} 1.003040572} = \frac{Log_{10} \frac{I_{LED}}{0.06\ mA}}{Log_{10} 1.003040572} \quad (2)$$

$$I_{PEAK} = \frac{I_{LOAD}}{Efficiency} \times \frac{V_{OUT}}{V_{IN\_MIN}} + \Delta I_{LOAD} \quad (3)$$

$$\Delta I_{LOAD} = \frac{V_{IN} \times (V_{OUT} - V_{IN} \times Efficiency)}{2 \times f_{SW} \times L \times V_{OUT}} \quad (4)$$

$$I_{PEAK} = \frac{I_{LOAD}}{Efficiency} \times \frac{V_{OUT}}{V_{IN\_MIN}} + \frac{V_{IN} \times (V_{OUT} - V_{IN} \times Efficiency)}{2 \times f_{SW} \times L \times V_{OUT}} \quad (5)$$

In these equations,

1. Efficiency means the total efficiency of the LM3627x device, at the worst case (such as the DCR of the inductor is more than 100 mΩ), its minimum is 80%.
2. F_{SW} means switching frequency of the converter: Select 1 MHz for a backlight driver default as the switching frequency; 2.5 MHz for LCD bias driver default as a switching frequency.
3. L means target inductance of the power inductor, such as 10 µH or 2.2 µH depending on the target applied driver unit, such as backlight driver 10 µH and LCD bias driver 2.2 µH.
4. V_{OUT} means the maximum output voltage of the converter, for a backlight driver unit, the designer can figure it out using a simple method.
5. It is assumed that the configuration of LED string 3P7S (3-channel parallel with 7 LEDs in series) and the forwarded voltage for each LED is 3.5 V, so the V_{OUT} should be (7 + 1) × 3.5 V = 26 V. For LCD bias driver, V_{OUT} is the higher voltage between V_{POS} and V_{NEG}.

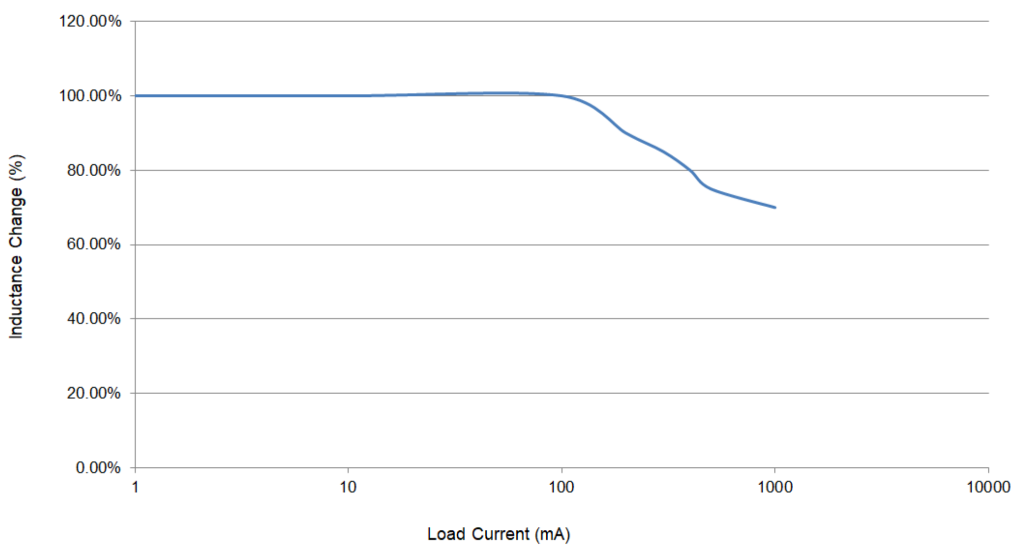

Figure 7. Inductance vs Load Current

- Schottky Diode

A diode is used to rectify output voltage on backlight driver unit, in the discharge period of the power inductor L_{BL}, the diode is forward biased and output high voltage, while during charging stage of $L_{\_BL}$, this diode will be reverse-biased by V_{OUT}. The maximum rating voltage that the diode can resist has to be higher than the target maximum V_{OUT}. Note that the type of diode should be a Schottky for higher efficiency and good thermal performance in an actual application.

4 PCB Layout Tips for LM3627x

Good PCB layout ensures good performance, so pay close attention on PCB layout. Figure 8 shows a good example.

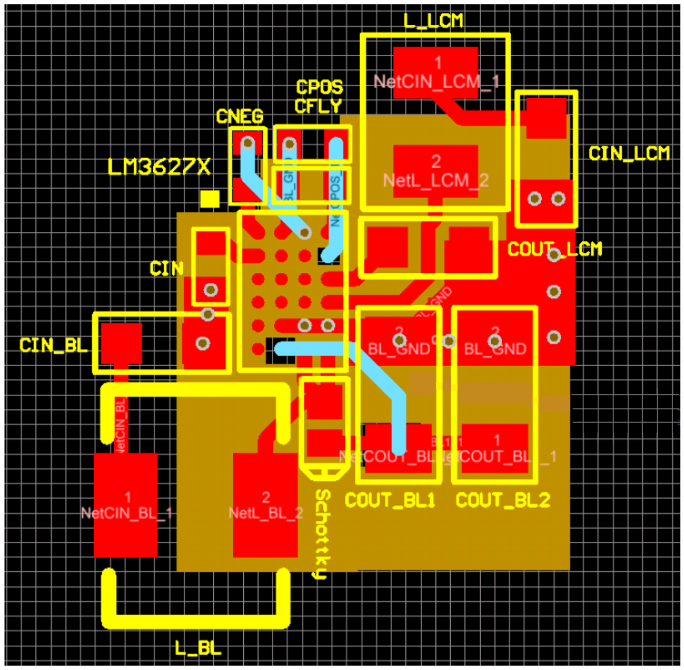

Figure 8. LM36274 PCB Layout

- Place the C_{IN}, C_{IN_BL}, C_{BL_OUT}, C_{FLY}, C_{NEG}, and C_{POS} capacitors and Schottky diode close to the LM3627x device, the power trace should be short and wide to decrease power loss on the PCB trace.
- Place $L_{\_BL}$, $L_{\_LCM}$ inductor close to the LM3627x device.
- The width of the power trace between the inductor and the LM3627x device should be 10 mil or more to decrease the noise and power dissipation on the power trace, meanwhile optimize EMI performance.
- The width of the power trace between C_{IN_BL}, C_{BL_OUT}, C_{FLY}, C_{VNEG}, and C_{VPOS} and the LM3627x device should be more than 10 mil to decrease the noise and power dissipation on power trace, meanwhile optimize EMI performance.
- The GND pin should be connected to the main ground plane (Brown color layer) directly to get better thermal sink and better EMI performance.

5 References

1. Texas Instruments, *LM36273 Three-Channel LCD Backlight Driver With Integrated Bias Power Data Sheet*
2. Texas Instruments, *Four-Channel LCD Backlight Driver With Integrated Bias Power Data Sheet*
3. Texas Instruments, *LM3627x Layout Guidelines Application Report*