

How to use the LM3697 Device to Design a Backlight Unit in a Smartphone



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Power Switches, Interface and Lighting

ABSTRACT

In a smartphone application, the backlight unit plays a very important role in different working patterns, such as movie mode, game mode, or reading mode. Higher backlight-unit performance improves the user experience. The Texas Instruments LM369xx (LM3697, LM36923, and LM36922) family are backlight drivers with a BGA package of less than 1.75 × 1.35 that can support up to a 3-channel LED string with a total of 36 LEDs (LM3697). The total system-level efficiency is up to 90%. The LM369xx family helps designers easily implement backlight unit designs with better performance.

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1 Introduction

1.1 LM3697 Key Specifications

The following features are available with the LM3697 device:

- 2.7-V to 5.5-V input voltage range
- Drives up to three parallel white LED strings (40-V maximum V_{OUT})
- Backlight efficiency up to 90%
- Up to 30 mA per current sink
- 11-bit exponential and linear dimming control via PWM, or I2C brightness control, or both
- Supports CABC function
- Backlight operation with 4.7- μ H to 22- μ H inductor
- Selectable 500-kHz and 1-MHz switching frequency
- Four configurable overvoltage protection thresholds (16 V, 24 V, 32 V, and 40 V)
- $\pm 2.5\%$ matched LED current, up to 30 mA
- $\pm 2\%$ accurate LED current at exponential mode

1.2 LM3697 Simplified Block Diagram

The LM3697 device supports most hero LCD panel backlight units in the market so as to simplify backlight design. It supports up to 3 strings with 12 LEDs in series for each string: a total of 36 LEDs (depending on the LED forward-drop voltage, 40 V V_{OUT_MAX}). The device also supports exponential and linear dimming mode so as to erase panel twinkling during extreme low-brightness conditions. The LM3697 also supports CABC function to get better backlight performance in video or movie mode. The flexible 500-kHz and 1-MHz switching frequency selections help designers easily use different inductors. [Figure 1-1](#) illustrates the LM3697 LED backlight driver.

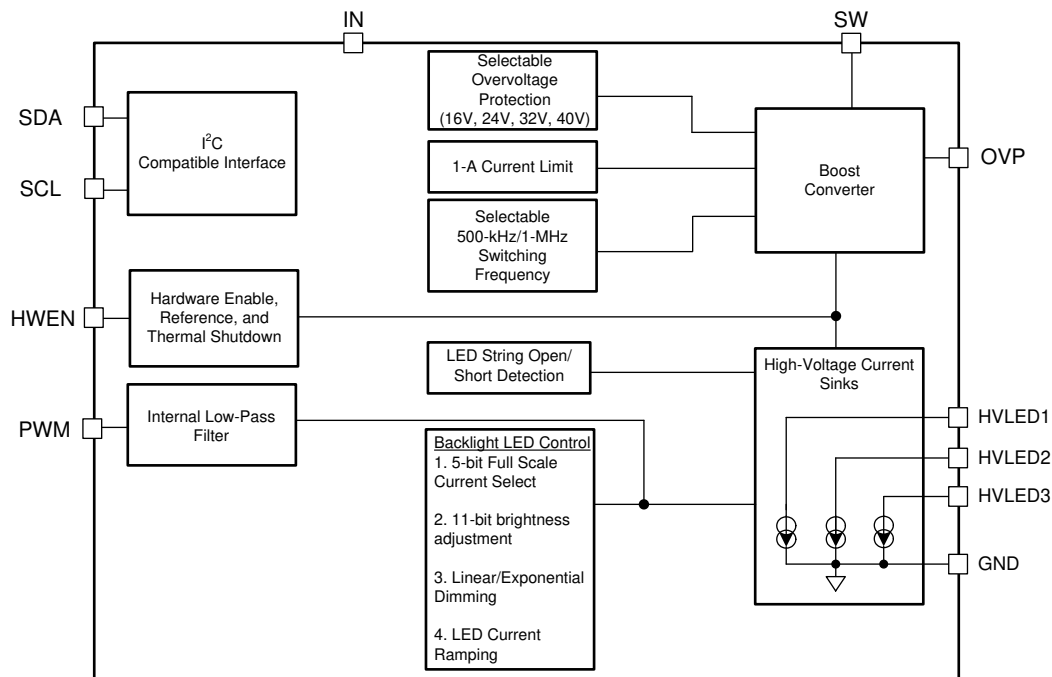


Figure 1-1. LM3697 LED Backlight Driver

2 How to map Exponential Data to the Linear Dimming Lookup Table

2.1 Why use Exponential Data for Dimming?

Exponential brightness data is a kind of special data used to match the experience of the human eye. Since human eyes are similar to a logarithm translator, if the raw data of brightness is referenced in exponential mode, then it would be expressed with linear mode by human eyes. Furthermore, exponential data has a higher resolution than linear data in 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 linear dimming unit. In practice, a designer may face this 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

The following data is obtained using the LM369xx according to the 11-bit exponential dimming formula in [Equation 1](#) and [Equation 2](#):

[Equation 1](#) shows the *LM3697 Dimming Equation*:

$$I_{LED} = I_{LED_FULLSCALE} \times 0.85 \left(44 - \frac{\frac{Code}{8} + 1}{5.8181818} \right) \times D_{PWM} \tag{1}$$

[Equation 2](#) shows the *LM36922_3 Dimming Equation*:

$$I_{LED} = 50 \mu A \times 1.003040572^{Code} \tag{2}$$

Where:

- Code is the 11-bit backlight code in the Control Brightness MSB and LSB registers, or 11-bit brightness dimming data
- $I_{LED_FULLSCALE}$ is the full-scale LED current setting
- D_{PWM} is the PWM Duty Cycle; 50 μA is the minimum LED current that the LM36922_3 can handle

Code Configuration sample: Control Brightness MSB and LSB registers. Full format of 11-bit brightness dimming code: 8-bit MSB(10:3) + 3Bit LSB(2:0) = 11 bit, in an actual design, the 11-bit value should be translated to decimal format .

LM3697 Brightness LSB Bit[2:0]

Bits [7:3] Not Used	Bits [2:0] Control A Brightness [2:0]
Reserved	Brightness LSB

LM3697 Brightness MSB Bit[7:0]

Bits [7:0] Control A Brightness [11:3]
Brightness MSB (LED current ramping does not start until the MSB is written, LSB must always be written before MSB)

Figure 2-1. LM3697 LSB+MSB 11Bit Brightness Dimming Code Format

LM36922_3 Brightness Register LSBs Bit[2:0]

Bits [7:3]	I ² C Brightness Code (LSB) Bits [2:0]
R	This is the lower 3 bits of the 11-bit brightness code (default = 111).

LM36922_3 Brightness Register MSBs Bit[7:0]

I ² C Brightness Code (MSB) Bits [7:0]
This is the upper 8 bits of the 11-bit brightness code (default = 11111111).

Figure 2-2. LM36922_3 LSB+MSB 11Bit Brightness Dimming Code Format

Assumes target full brightness LED current of 30 mA, total 2048 step, or 11 bit:

Each step of the LED current in linear format is $I_{LED_Step} = 30 \text{ mA} / 2048 = 14.6 \mu\text{A}$.

- For a design using the LM3697:

$$\begin{aligned}
 I_{LED_Step\ 1} &= 14.6 \mu\text{A} \\
 I_{LED_Step\ 2} &= 29.2 \mu\text{A} \\
 I_{LED_Step\ 3} &= 43.8 \mu\text{A} \\
 I_{LED_Step\ 4} &= 58.4 \mu\text{A} \\
 I_{LED_Step\ 5} &= 73.0 \mu\text{A} \\
 &\dots \\
 I_{LED_Step\ 2048} &= 30 \text{ mA}
 \end{aligned}$$

Changing Equation 1 to $I_{LED_FullScale} = 30 \text{ mA}$, assumes $D_{PWM} = 1$.

$$\text{Code}_{\text{Decimal}} = 8 \times \left[5.818181 \times \left(44 - \frac{\log_{10} \frac{I_{LED_Step}}{I_{LED_FullScale}}}{\log_{10} 85} + \log_{10} D_{PWM} \right) - 1 \right] \quad (3)$$

Then, it translates it from decimal code to Hex code.

Make a linear format excel table ([Exponential Data to Linear Format Dimming Lookup Table](#)) with the previous equations for quick calculation:

Table 2-1. LM3697 Exponential to Linear Dimming

Full Brightness Current (mA)	Linear Format Dimming Step	Linear Format Dimming Current (mA)	Exponential Dimming Code Based on Linear Format, Decimal	Exponential Dimming Current in Linear Format (mA)
30	1	0.014648	0	0.024193
	2	0.029297	55	0.029315
	3	0.043945	171	0.043953
	4	0.058594	253	0.058524
	5	0.073242	317	0.073178
	6	0.087891	369	0.087747
		...		
	2034	29.79492	2038	29.79123
	2035	29.80957	2038	29.79123
	2036	29.82422	2038	29.79123
	2037	29.83887	2038	29.79123
	2038	29.85352	2039	29.89543
	2039	29.86816	2039	29.89543
	2040	29.88281	2039	29.89543
	2041	29.89746	2039	29.89543
	2042	29.91211	2039	29.89543
	2043	29.92676	2039	29.89543
	2044	29.94141	2039	29.89543
	2045	29.95605	2040	30
	2046	29.9707	2040	30
2047	29.98535	2040	30	
2048	30	2040	30	

- For a design with the LM36922 and LM36923

$$\left. \begin{aligned}
 I_{\text{LED_Step 1}} &= 14.6 \mu\text{A} \\
 I_{\text{LED_Step 2}} &= 29.2 \mu\text{A} \\
 I_{\text{LED_Step 3}} &= 43.8 \mu\text{A} \\
 I_{\text{LED_Step 4}} &= 58.4 \mu\text{A} \\
 I_{\text{LED_Step 5}} &= 73.0 \mu\text{A} \\
 &\dots \\
 I_{\text{LED_Step 2048}} &= 30 \mu\text{A}
 \end{aligned} \right\} \text{Manually set step 1 thru step 3 to } 50 \mu\text{A}$$

Because the minimum LED current that the LM3692x can support is 50 μA in exponential mode, keep all of the value that is less than 50 μA to 50 μA , then make the following change to [Equation 2](#):

$$\text{Code}_{\text{Decimal}} = \frac{\text{Log}_{10} I_{\text{LED_Step}} - \text{Log}_{10} 50 \mu\text{A}}{\text{Log}_{10} 1.003040572} = \frac{\text{Log}_{10} \frac{I_{\text{LED_Step}}}{0.05 \text{ mA}}}{\text{Log}_{10} 1.003040572} \quad (4)$$

Then, translate decimal code to Hex code.

Make a linear format excel table ([Exponential Data to Linear Format Dimming Lookup Table](#)) with the previous equations for quick calculation:

Table 2-2. LM3692x Exponential to Linear Dimming

Full Brightness Current (mA)	Linear Format Dimming Step	Linear Format Dimming Current (mA)	Exponential Dimming Code Based on Linear Format, Decimal	Exponential Dimming Current in Linear Format (mA)
30	1	0.014648	0	0.05
	2	0.029297	0	0.05
	3	0.043945	0	0.05
	4	0.058594	52	0.058551
	5	0.073242	126	0.0733
	6	0.087891	186	0.087945

	2037	29.83887	2105	29.81349
	2038	29.85352	2105	29.81349
	2039	29.86816	2106	29.90414
	2040	29.88281	2106	29.90414
	2041	29.89746	2106	29.90414
	2042	29.91211	2106	29.90414
	2043	29.92676	2106	29.90414
	2044	29.94141	2106	29.90414
	2045	29.95605	2107	29.99507
	2046	29.9707	2107	29.99507
	2047	29.98535	2107	29.99507
	2048	30	2107	29.99507

When dimming begins, the AP(Application Processor) can lookup this table according to linear dimming steps to easily get the target exponential mode brightness code. An example is made to show its working process:

1. The Software Dimming Module in a smartphone OS sends out linear orders from 1 to 2048 as the *Linear Format Dimming Step* column of [Table 2-1](#) and [Table 2-2](#) show to AP.
2. The AP will map linearity dimming orders to exponential dimming code that has been preset in the *Exponential Dimming Code Based on Linear Format, Decimal* column in [Table 2-1](#) and [Table 2-2](#).
3. Next, the AP gets this exponential code from [Table 2-1](#) and [Table 2-2](#) sends it to the DPU.
4. The DPU executes commands from the AP and outputs the target brightness.

In some user cases, the AP cannot handle exponential dimming processes directly for *Software Dimming Module* limits, so this method helps designers keep the AP dimming code linearity and take the use of smoother dimming performance in expo dimming. Furthermore, this Lookup Table could be integrated into software platform, it could be used as a general tool in all projects in which LM369xx family is designed-in. This solution is acceptable from all sides: easy dimming compatibility and better performance.

3 Key LM369xx Design Tips

3.1 Simplified Schematic

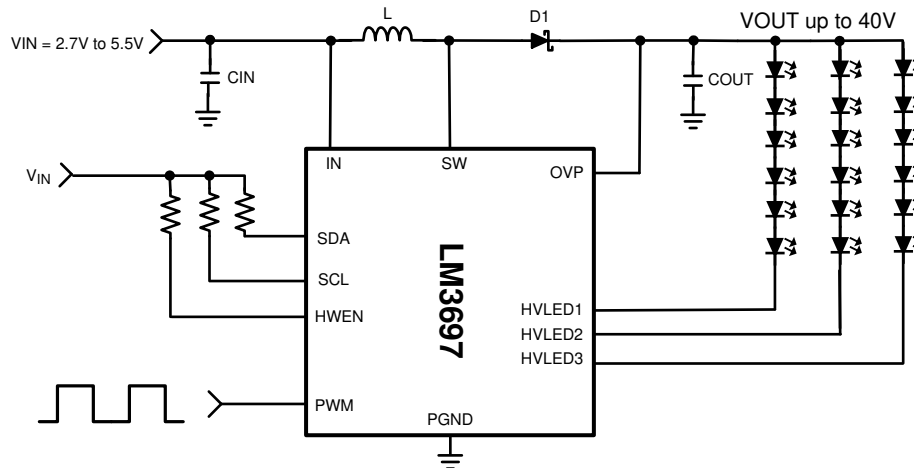


Figure 3-1. LM3697 Typical Schematic

- C_{OUT} is output filter capacitor, the maximum resistant voltage has to be higher than V_{OUT} .
- Schottky Diode D1 is used to rectify and generate high voltage to drive the LED string, the maximum reversed voltage has to be higher than V_{OUT} .
- Power inductor L is used to store power energy to drive the LED string.
- For the unused channel pin, float it.

3.2 How to Choose Key Components: Inductor and Capacitor, Schottky Diode D1

This section provides instructions for choosing key components:

- Power Capacitor: C_{IN} , C_{OUT}

In general, all LM369xx power capacitor applications should be MLCC (**M**ultiple **L**ayer **C**eramic **C**apacitor) because of smaller package and lower ESR, and lower power dissipation. The biggest shortage of MLCC is because the effective capacitance is derated due to DC biased voltage on the capacitor, when the DC biased voltage on MLCC increases, the effective capacitance of MLCC will decrease accordingly. It is necessary to keep enough capacitance, in actual design, the curve about DC biased voltage versus capacitance in MLCC data sheet is a useful tool to find suitable power capacitor. As [Figure 3-2](#) shows, when DC biased voltage increases, effective capacitance will decrease quickly. Of course, the designer must consider whether the maximum voltage that power capacitor supports can meet the actual request, for example, if the power rail is 29 V, then the designer should choose 35-V MLCC to avoid any failure issues. Meanwhile the designer must consider the impact of temperature to effective capacitance, different ambient working temperatures will lead to the change of effective capacitance.

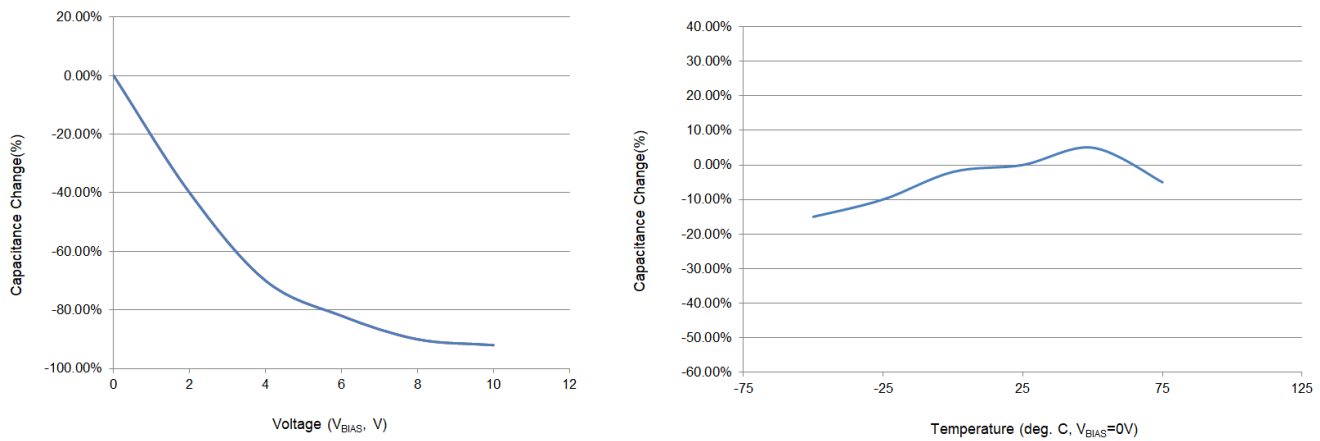


Figure 3-2. MLCC Effective Capacitance vs DC Biased Voltage and Temperature

- Power Inductor: L

The power inductor is the key component to store energy. To the LM369xx family, a 10- μ H inductor may work for most applications for a backlight driver. The designer must carefully calculate the peak current that flows through the power inductor to keep the inductor running in safe status. Use the formulas in Equation 5 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. In general, when the load current is increased more than the saturation threshold that the inductor can handle, the effective inductance of the power inductor will decrease greatly, as Figure 3-3 shows. This leads to a destroyed inductor. Therefore, choose the correct inductor according to calculated I_{PEAK} value and the curve of Figure 3-3 to avoid any saturation occurring. The inductor should be magnetic shielded to get better EMC performance at the system level.

$$I_{PEAK} = \frac{I_{LOAD}}{\text{Efficiency}} \times \frac{V_{OUT}}{V_{IN_MIN}} + \Delta I_{LOAD}$$

$$\Delta I_{LOAD} = \frac{V_{IN} \times (V_{OUT} - V_{IN} \times \text{Eff})}{2 \times f_{sw} \times L \times V_{OUT}}$$

$$I_{PEAK} = \frac{I_{LOAD}}{\text{Eff}} \times \frac{V_{OUT}}{V_{IN_MIN}} + \frac{V_{IN} \times (V_{OUT} - V_{IN} \times \text{Eff})}{2 \times f_{sw} \times L \times V_{OUT}} \quad (5)$$

Where:

1. Efficiency means the total efficiency of LM369xx, at worst case (such as the DCR of inductor is more than 100 m Ω), its minimum is 80%.
2. f_{sw} means switching frequency of converter: 1 MHz / 500KHz for *Backlight Driver* default as switching frequency.
3. L is the target inductance of the power inductor, typical 10 μ H with 1 MHz switch frequency.
4. V_{OUT} means the maximum output voltage of the converter.

For a simple method to calculate the backlight driver unit, assume the configuration of the LED string 3P7S (3 channel parallel with 7LED in series) and the forwarded voltage for each LED is 3.5 V, so the V_{OUT} should be $(7 + 1) \times 3.5 \text{ V} = 26 \text{ V}$.

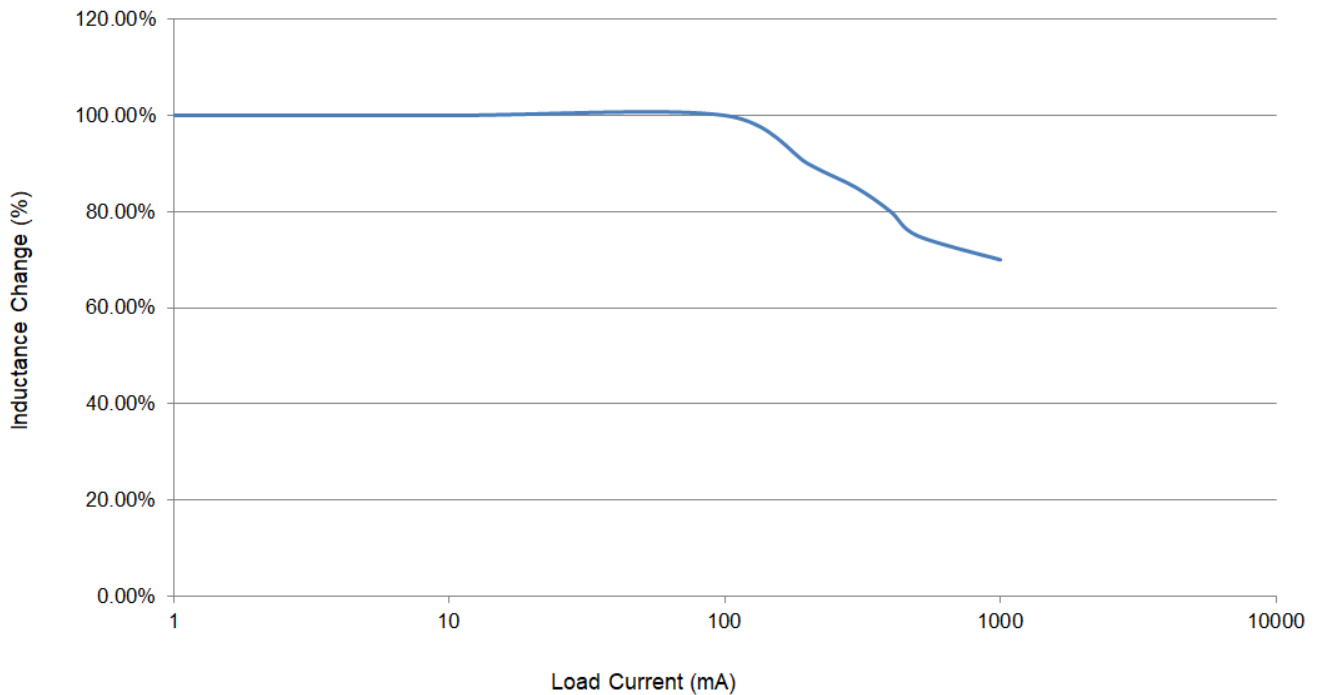


Figure 3-3. Inductance vs Load Current

- Schottky Diode

A diode is used to rectify the output voltage on the backlight driver unit. In the discharge period of power inductor L, the diode is forward biased and outputs high voltage, while during the charging stage of L, this diode will be reverse-biased by V_{OUT} . The maximum rating voltage that the diode can resist must be higher than target maximum V_{OUT} . The type of diode should be Schottky for higher efficiency and good thermal performance in actual applications.

4 LM369xx PCB Layout Tips

Good PCB layout ensures superb performance. Figure 4-1 shows an effective layout using the LM3697 device.

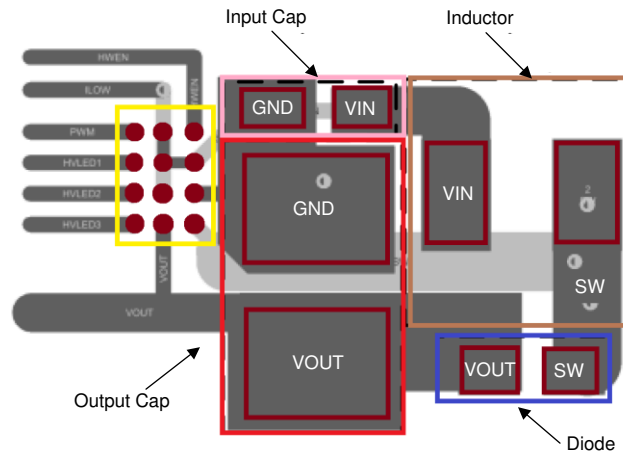


Figure 4-1. LM3697 PCB Layout

- Place the C_{IN} and C_{OUT} capacitors and the Schottky diode close to the LM3697, the power trace should be short and wide to decrease power loss on the PCB trace.
- Place the L inductor close to the LM3697.
- The width of the power trace between the inductor and LM3697 should be 10 mil or more to decrease the noise and power dissipation on the power trace, and meanwhile optimize EMI performance.
- The width of the SW trace **must** be more than 10 mil especially for the inner layer or bottom layer, for the quantity of vias connected to the inductor is **no less** than 3 to decrease dv/dt and improve EMI performance.
- The width of the power trace between C_{IN} and C_{OUT} and the LM3697 should be more than 10 mil to decrease the noise and power dissipation on the power trace, meanwhile this optimizes EMI performance.
- The GND pin should be connected to main ground plane (Brown color layer) directly to get better thermal sink and better EMI performance.

5 References

1. Texas Instruments, [LM3697 High-Efficiency Three-String White LED Driver Data Sheet](#)
2. Texas Instruments, [LM36922 Highly Efficient Dual-String White LED Driver Data Sheet](#)
3. Texas Instruments, [LM36923 Highly Efficient Triple-String White LED Driver Data Sheet](#)

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