

Thermal sharing Based on NSL21912

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ABSTRACT

LED is often driven by constant current. Power supply voltage for a linear LED driver is determined by the maximum forward voltage of LED strings to achieve the constant current driving capability. High power supply voltage and high driving current can lead to power loss and heating problems. The thermal analysis is necessary to ensure that the operation junction temperature of device is well managed.

NSL21912 is a 12-channel, 20V high-side LED driver that integrates thermal sharing function. The function adjusts the chip power by an external shunt resistance, which effectively alleviates thermal problems of chips.

This application note first explains the basic operating principle of thermal sharing. Then the test method and results of NSL21912 thermal sharing are provided, and effects of the function is verified. Eventually, a design example is given to help the user better deal with the thermal sharing design based on NSL21912.

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1.Function Description of Thermal Sharing

When using the linear LED driver, such as NSL21912, thermal performance is one of the most important considerations. It limits the maximum output current of the device. The power dissipation of the device can be estimated by Equation (1). The power consumption caused by the device quiescent current is relatively low thus neglected here.

$$P_D = V_{VS} \times \sum_{x=0}^{11} I_{OUTx} - \sum_{x=0}^{11} V_{OUTx} I_{OUTx} \quad (1)$$

LED forward voltage mainly depends on the forward current, temperature, aging and bin code for a selected LED type. The higher the current flowing into the LED is, the higher the forward voltage across the junction is. The lower operating temperature of LED is, the higher the forward voltage across the junction is. The data collected from the LED LR G6SP datasheet is shown in Figure 1-1 as an example.

$I_F = f(V_F); T_S = 25^\circ\text{C}$

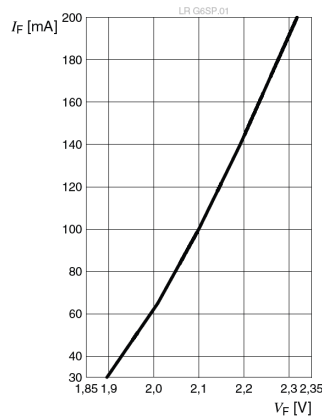


Figure 1-1(a) Forward Current vs Forward Voltage

$\Delta V_F = V_F - V_F(25^\circ\text{C}) = f(T_J); I_F = 140\text{ mA}$

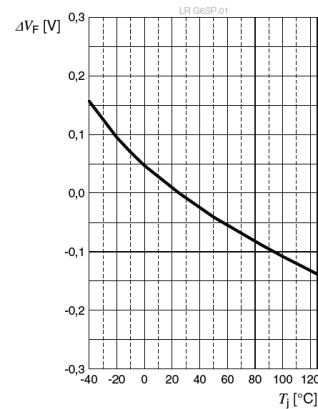


Figure1-1(b) Relative Forward Voltage vs Junction Temperature

For linear LED-driver applications, the supply voltage of device shall be higher than the sum of LED strings forward voltage plus the device headroom to ensure constant current regulation. So the supply voltage of NSL21912 should be determined following Equation (2).

$$V_{VS_min} > V_{OUT_max} + V_{OUT_dropout_max} \quad (2)$$

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where V_{VS_min} is the minimum power supply voltage, V_{OUT_max} is maximum LED string voltage of different output channels and $V_{OUT_dropout_max}$ is maximum dropout voltage of a single channel with the maximum channel output current.

According to Equation (2), enough voltage drop between input and output should be guaranteed. However, high voltage drop leads to high power dissipation according to Equation (1). Due to variation of the input and output voltage, thermal problems faced by NSL21912 have become more severe. Thermal sharing can effectively alleviate thermal problems of NSL21912 caused by high power supply and low forward voltage of LED strings. The functional diagram is shown in Figure 1-2.

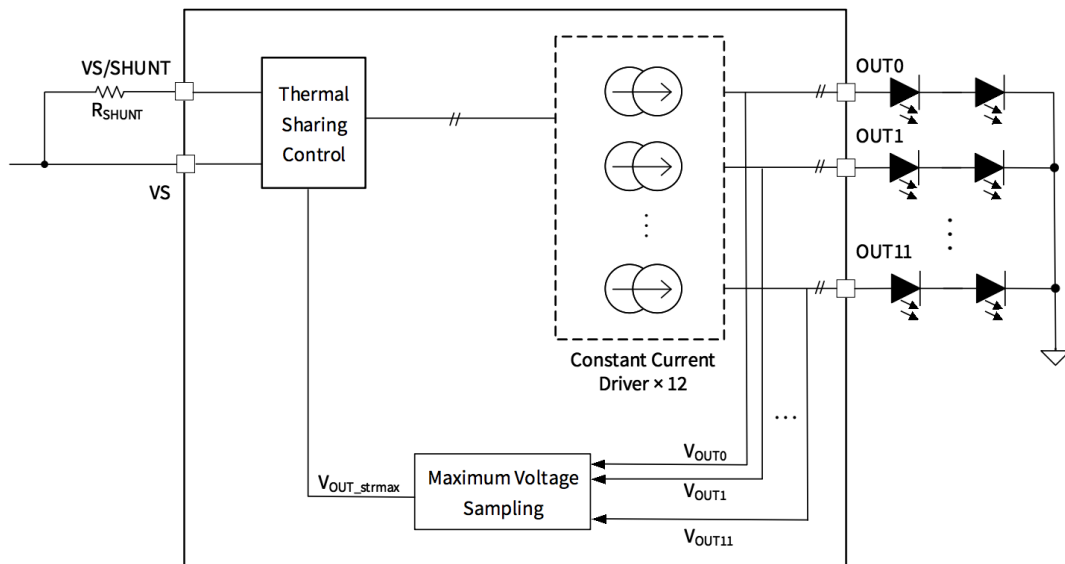


Figure 1-2 Thermal Sharing Function Block Diagram

The thermal sharing feature of NSL21912 is achieved by an external shunt resistor R_{SHUNT} combined with an internal MOSFET. NSL21912 regulates the difference voltage between the VS/SHUNT pin and the maximum output voltage of the 12 channels to V_{SHUNT_ctl} (Typ. 0.94V). The current flowing out from the power supply side has two paths: one is to flow into the VS pin, and the other is to flow through the shunt resistor. When the device dropout is low, current mainly flows through the VS pin. When the device dropout is high, more current flows through the shunt resistor. The power consumption on the device is shared by the resistor. Therefore, junction temperature of NSL21912 reduces. In addition, there's a clamp voltage V_{SHUNT_clamp} (Typ. 6.5V) between VS and VS/SHUNT pin, so the maximum current through the VS/SHUNT path is clamped at $V_{SHUNT_clamp}/R_{SHUNT}$. The typical curve of current and power distribution as a function of $(V_{VS}-V_{OUT_strmax})$ are shown in Figure 1-3(a). Figure 1-3(b) is an example when voltage clamp V_{SHUNT_clamp} between VS and VS/SHUNT pin is triggered.

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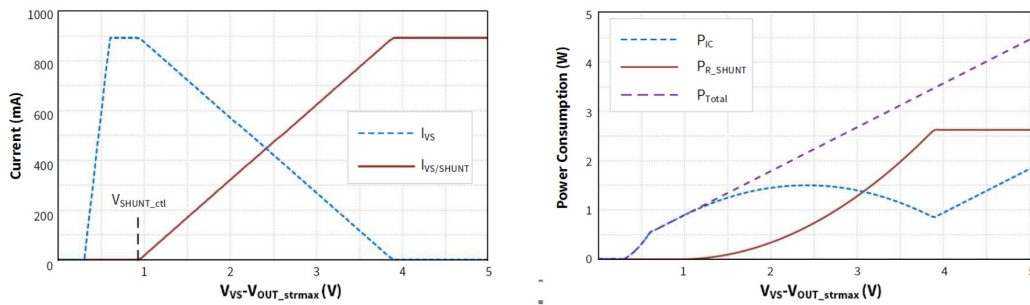


Figure 1-3(a) Current and Power Distribution-Example 1

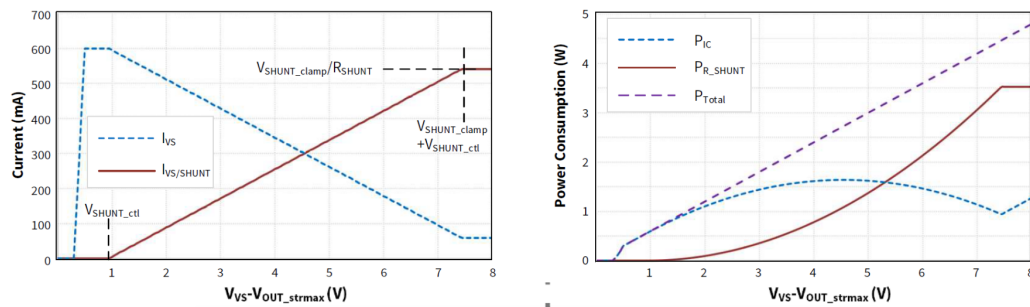
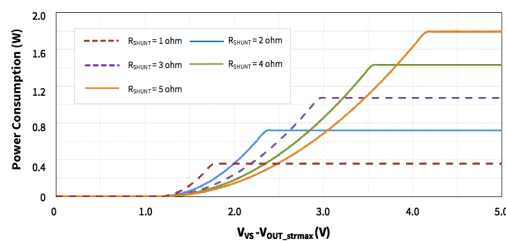
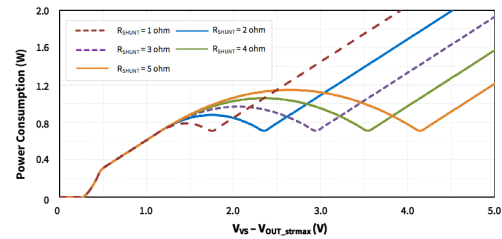


Figure 1-3(b) Current and Power Distribution-Example 2

The selection of shunt resistor is crucial for utilizing thermal sharing. The relationship of the power consumption of the shunt resistor versus $(V_{VS}-V_{OUT_strmax})$ voltage at different shunt resistance value is shown in Figure 1-4(b). Different shunt resistance value can lead to different power distribution. Users can choose the appropriate shunt resistance value to make the power consumption of both the device and the shunt resistor acceptable.

Figure 1-4(a) Shunt Resistors power Consumption vs $(V_{VS}-V_{OUT_strmax})$ Figure 1-4(b) Device Power Consumption vs $(V_{VS}-V_{OUT_strmax})$

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2. Thermal Performance

In the following examples based on the NSL21912 EVM board, the board uses a two-layer design with a copper thickness of 1 ounce. The junction temperature of the NSL21912 device is approximately estimated based on the Junction-to-top characterization thermal metric and the top case temperature measured. The equation is as follows. Though the PCB parameters do not exactly follow the JEDEC specification, the estimated result is used for reference.

$$T_J = T_c + \Psi_{JC} \times P_D \quad (3)$$

where, T_J is the junction temperature of the device, T_c is the case temperature on the top, Ψ_{JC} is the thermal characterization parameter from junction to case and P_D is the total dissipation power of the device.

Under the condition of constant room temperature, by applying a certain voltage and load to the device, the power consumption can be increased from 0W to nearly thermal shutdown. At various output current settings, keep working stable for a certain time and use the thermal imager to measure the top case temperature of the chip. The junction temperature of the device on the evaluation board is estimated by Equation (3). The results at one typical condition are shown in Table 2-1. As can be seen, at this condition, thermal sharing could decrease the junction temperature by 17.9% compared with not turning on thermal sharing. It proves the effectiveness of thermal sharing.

Table 2-1 Thermal information of NSL21912

$V_{VS}-V_{OUT}$ (V)	$I_{out}/channel$ (mA)	P_D (W)	T_a (°C)	Ψ_{JC} (°C/W)	R_{shunt} (ohm)	T_c (°C)	T_J (°C)
2.5	100	3.0	24.5	0.8	/	124.6	127.0
2.5	100	1.86			2	102.7	104.2

Another group of comparison results are shown in Figure 2-1. The case temperatures are provided directly with the thermal imager. The test conditions are $I_{outx} = 50mA/channel$, $R_{shunt} = 6.8\Omega$ and one red LED is connected at each OUT pin. It can be seen that the case temperature of the device is significantly reduced with thermal sharing, especially at high V_{VS} voltage.

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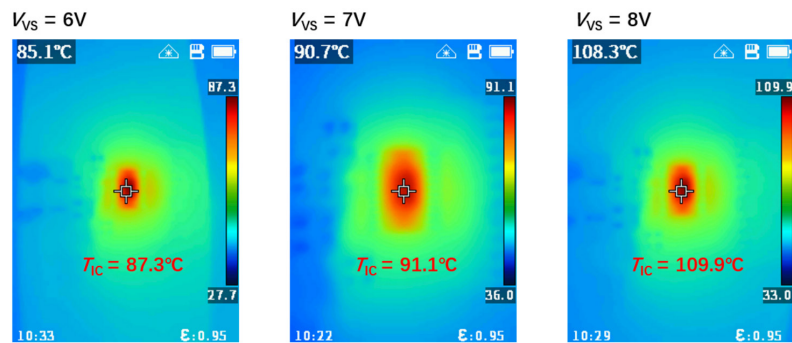


Figure 2-1(a) Case temperature measurement results without thermal sharing

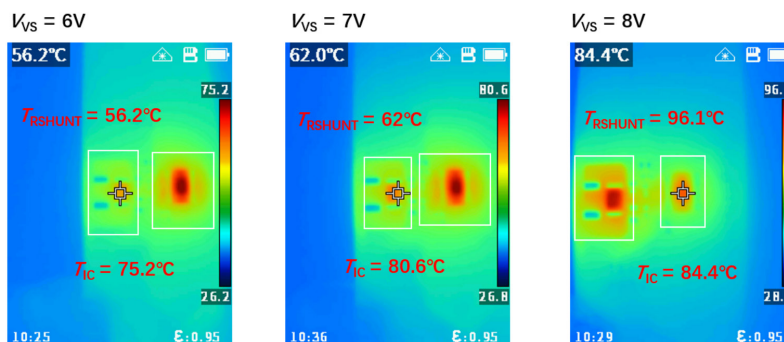


Figure 2-1(b) Case temperature measurement results with thermal sharing

The maximum supported output current of the device under a certain condition is also evaluated. It is tested under 85 °C ambient temperature. The NSL21912_EVM board is placed in an incubator set to 85 °C and the junction temperature of the chip is obtained by the internal ADC. All channels are enabled. The current configuration and output voltage of each output channel is almost equal. Output current of the device is increased until the junction temperature of the device reaches up to 150 °C. It should be noted that the device maximum power consumption is closely related to the PCB layout. Therefore, the test is for reference only. The maximum output current per channel under different ($V_{VS}-V_{OUT}$) are shown in Table 2-2 and Table 2-3.

Table 2-2 Maximum output current per channel vs ($V_{VS}-V_{OUT}$) without thermal sharing

$V_{VS}-V_{OUT}$ (V)	1.53	2.01	2.57	3.06
R_{shunt} (Ω)	0	0	0	0
$I_{out}/channel_{max}$ (mA)	87.5	65.6	48.4	39.1

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Table 2-2 Maximum output current per channel vs ($V_{VS}-V_{OUT}$) without thermal sharing

$V_{VS}-V_{OUT}$ (V)	1.54	2.05	2.57	3.02
R_{shunt} (Ω)	1.13	2.7	5.38	8.81
$I_{out/channel_max}$ (mA)	93.8	76.6	64.1	57.8

It can be seen that thermal sharing can significantly improve the maximum output current at the same working condition. When $V_{VS}-V_{OUT} = 3V$, the device total output current can be increased by 47.8% compared to $R_{shunt} = 0$.

In summary, thermal sharing can effectively avoid high chip power dissipation caused by variation of power supply voltage and LED forward voltage. Therefore, NOVOSENSE recommends using thermal sharing to reduce the junction temperature in high power dissipation applications.

3.Design Sequence and Design Example

The current and power distribution is determined by the shunt resistor. To determine the shunt resistance value, Novosense recommends setting the initial resistance value to make the resistor and the device both consume half of the total power dissipation at the worst-case condition. The initial value of the shunt resistor can be preliminarily determined by the following equation.

$$R_{SHUNT_init} = \frac{(V_{VS_max} - V_{OUT_strmax_min} - V_{SHUNT_ctl})^2}{P_{Total_max}/2} \quad (4)$$

where, V_{VS_max} is the maximum device input voltage, $V_{OUT_strmax_min}$ is the minimum output voltage of the LED string with the highest total voltage, V_{SHUNT_ctl} uses the typical thermal sharing control voltage value here for simplicity, and P_{Total_max} is the maximum total device power consumption without thermal sharing.

After getting the initial resistance, the maximum power dissipation of the device should be calculated and evaluated. If the power dissipation is not acceptable, adjust the shunt resistance and recalculate the power dissipation until the power dissipation is reduced to an acceptable level.

Figure 3-1 illustrated the detailed sequence of the thermal sharing design.

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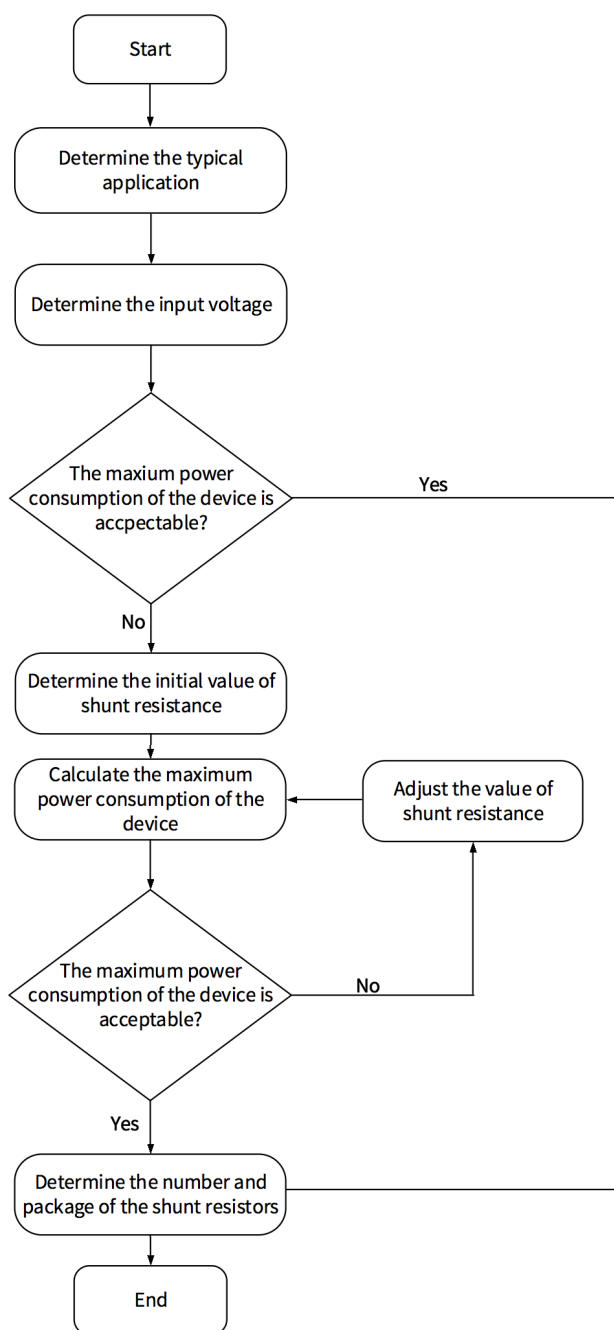


Figure 3-1 Thermal sharing design sequence

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A design example following the design sequence is shown below.

STEP 1: Determine the typical application

Three LEDs in series is connected at each output pin. The maximum forward voltage of a single LED $V_{F_MAX} = 2.15V$, minimum forward voltage $V_{F_MIN} = 1.75V$, and each string current $I_{LED} = 50mA$. Output current error is not considered. For simplicity, the output voltages of all channels are assumed to be equal at the same time, therefore V_{OUT_strmax} is considered equal to V_{OUTx} ($x=0$ to 11).

STEP 2: Determine the input voltage for NSL21912

Input voltage design is necessary for linear LED driver applications to ensure the normal operation of the device. It can be calculated by using the following equation. The voltage needs to have a certain margin. Therefore, the typical input voltage is set to 7.6V. Then the voltage range can be from 7.22V to 7.98V when $\pm 5\%$ variation is considered.

$$\begin{aligned} V_{VS_min} &> V_{OUT_max} + V_{OUT_dropout_max} \\ &= 2.15 \times 3 + 0.7 \\ &= 7.15V \end{aligned} \quad (5)$$

STEP 3: Thermal analysis for the worst-case application conditions

Thermal analysis is necessary to make sure the operation junction temperature of NSL21912 is well managed. The maximum allowable junction temperature should be limited below $150^{\circ}C$. Customers can evaluate the maximum allowable power consumption of the chip under the worst-case condition based on the thermal metrics. If the device maximum power consumption is acceptable, there's no need to use the shunt resistors. Otherwise, execute STEP 4.

$$\begin{aligned} P_{Total_max} &= (V_{VS_max} - V_{OUT_min}) \times I_{OUT_total} \\ &= (7.98 - 1.75 \times 3) \times 0.05 \times 12 \\ &= 1.638W \end{aligned} \quad (6)$$

STEP 4: Determine the initial value of shunt resistance

A properly designed shunt resistance is helpful to minimize the power consumption on the NSL21912 device. In this design, the initial value of shunt resistance is 3.91Ω as calculated from Equation (4).

$$\begin{aligned} R_{SHUNT_init} &= \frac{(V_{VS_max} - V_{OUT_min} - V_{SHUNT_ctd})^2 \times 2}{P_{Total_max}} \\ &= \frac{(7.98 - 1.75 \times 3 - 0.94)^2 \times 2}{1.638} \\ &= 3.91\Omega \end{aligned} \quad (7)$$

STEP 5: Check the maximum power consumption of the device

The power consumption of the NSL21912 device can be calculated from Equation (8).

$$P_{Device} = P_{Total} - P_{SHUNT} = (V_{VS} - V_{OUT}) \times I_{OUT_total} - \frac{(V_{VS} - V_{OUT} - V_{SHUNT_ctd})^2}{R_{SHUNT}} \quad (8)$$

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With the initial RSHUNT value 3.91Ω, the current and power distribution as a function of V_{VS}-V_{OUT} voltage is shown in Figure 3-2.

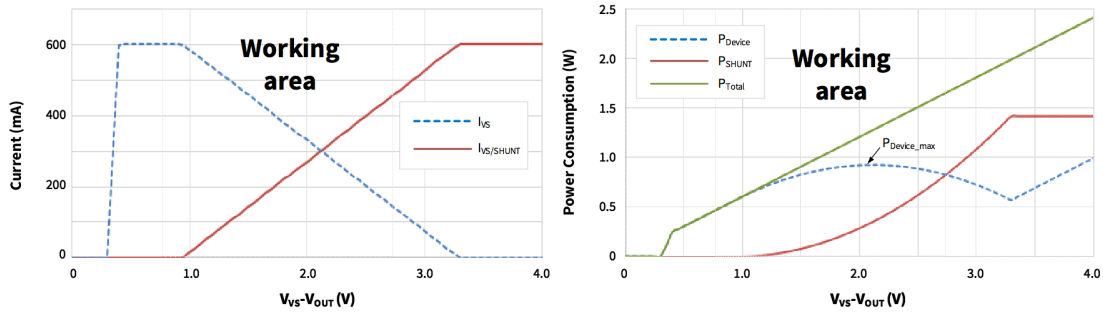


Figure 3-2 Current and Power Distribution vs $V_{VS}-V_{OUT}$

It can be seen from Equation (8) and Figure 3-2 that P_{Device} is a quadratic expression that behaves as a parabola. P_{Device} reaches the peak value when:

$$V_{VS} - V_{OUT} = R_{SHUNT} * I_{OUT_total} / 2 + V_{SHUNT_ctl} = 2.11V \quad (9)$$

Then the maximum device power consumption can be calculated as:

$$P_{Device_max} = 2.11 \times 0.6 - \frac{(2.11 - 0.94)^2}{3.91} = 0.92W \quad (10)$$

For a typical 2-layer PCB design with enough copper area, 0.92W power dissipation for a single NSL21912 device is usually acceptable. But it's still up to the user to do the evaluation based on their PCB design. If the power consumption is acceptable, the initial value of shunt resistance can be selected as the final value. Otherwise, reduce the shunt resistance value and recalculate the device power as shown in Figure 3-1.

STEP 6: Determine the number and package of the shunt resistors

The maximum power consumption of the shunt resistor is $P_{Total_max} / 2 = 0.819W$. Determine the number and package of the shunt resistors to meet the maximum power consumption requirement.

Novosense provides a calculation tool “NSL21912 External Components Calculation Tool.xls” to help with the thermal sharing design. Users can enter the initial shunt resistance value obtained from Equation (4) into the calculation tool as a starting point. Then the power distribution curve can be easily achieved. Adjust the R_{SHUNT} value accordingly to adjust the power distribution.

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4.Revision History

Revision	Description	Author	Date
1.0	Initial version	Lanxin Nie, Jiexiu He, Jian Deng, Sidong Wang	2025/02/13

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