AN191
How to Adjust the MPQ7200's LED Current Derating with an NTC

By Ralf Ohmberger

January 2023

TABLE OF CONTENTS

ABSTRACT

The MPQ7200 is a 42V, 1.2A buck-boost or 3A buck, synchronous LED driver, which is AEC-Q100 qualified. The MPQ7200 supports applications including automotive front lamps, daytime running lights (DRLs), turn indicator lights, and rear lights. A front lamp typically has 10W to 15W of electrical LED power. In some designs, the LEDs and MPQ7200 share a common PCB, which is cost-effective. However, the LED power warms up the PCB, which increases the MPQ7200's die temperature.

The goals of this application note are to increase the MPQ7200's maximum operating temperature at full light intensity and prevent a thermal shutdown due to high die temperature. If the MPQ7200 exceeds a certain ambient temperature ($T_{AMBIENT}$), the LED current and visible light power are automatically reduced. The MPQ7200 uses an external negative temperature coefficient (NTC) resistor to measure the PCB temperature.

This application note discusses how to use an automotive front lamp to reduce the LED current when $T_{AMBIENT}$ exceeds 50°C.

INTRODUCTION

The MPQ7200 is a high-frequency, constant-current, buck-boost LED driver with integrated power MOSFETs. It offers a very compact solution to achieve up to 1.2A of continuous output current (I_{OUT}), with excellent load and line regulation across a wide input supply range. The MPQ7200 can also be configured for buck mode to provide up to 3A of constant load current.

Constant frequency hysteretic control provides extremely fast transient response without loop compensation. The switching frequency (f_{SW}) can be fixed up to 2.3MHz in buck mode to reduce the current ripple and improve EMI. It can also be configured to as low as 1.15MHz for optimized efficiency and thermal performance in buck-boost mode.

Full protection features include over-current protection (OCP), output over-voltage protection (OVP), output under-voltage protection (UVP), thermal derating (TD), and thermal shutdown (TSD). The fault indicator outputs an active logic low signal if a fault condition occurs.

The MPQ7200 requires a minimal number of readily available, standard external components, and is available in a space-saving QFN-19 (3mmx4mm) package.

Applications include automotive front lamps, turns indicator lights, fog lights, rear lights, daytime running lights (DRLs), battery-powered flashlights, and vehicle lamps.

EVALUATION BOARDS

The EVQ7200-L-00A and EVQ7200-L-00B are evaluation boards designed to demonstrate the capabilities of the MPQ7200 for buck mode and buck-boost mode, respectively.

This application note discusses the MPQ7200's negative temperature coefficient (NTC) thermal derating. The MPQ7200 operates in buck-boost mode with a 1.15MHz f_{SW}. The MPQ7200 also has a variant (MPQ7200A) with lower f_{SW} values (410kHz for buck-boost mode and boost mode) and different NTC thermal derating levels. Refer to the MPQ7200 or MPQ7200A datasheets for more details on selecting the NTC thermal derating.

Figure 1 shows the EVQ7200-L-00A evaluation board. Figure 1 and Figure 2 on page 5 show the layout differences between buck mode and buck-boost mode. In particular, buck mode requires fewer passive components.

Figure 1: EVQ7200-L-00A Evaluation Board (Buck Mode)

Board Number	MPS IC Number
EVQ7200-L-00A	MPQ7200GLE-AEC1

Figure 2 shows the EVQ7200-L-00B evaluation board.

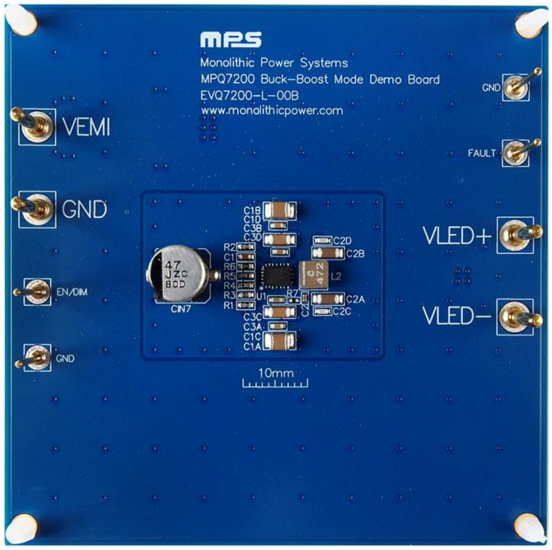

Figure 2: EVQ7200-L-00B Evaluation Board (Buck-Boost Mode)

Board Number	MPS IC Number
EVQ7200-L-00B	MPQ7200GLE-AEC1

MEASUREMENT SET-UP

Figure 3 shows the measurement set-up to adjust the NTC thermal dimming derating.

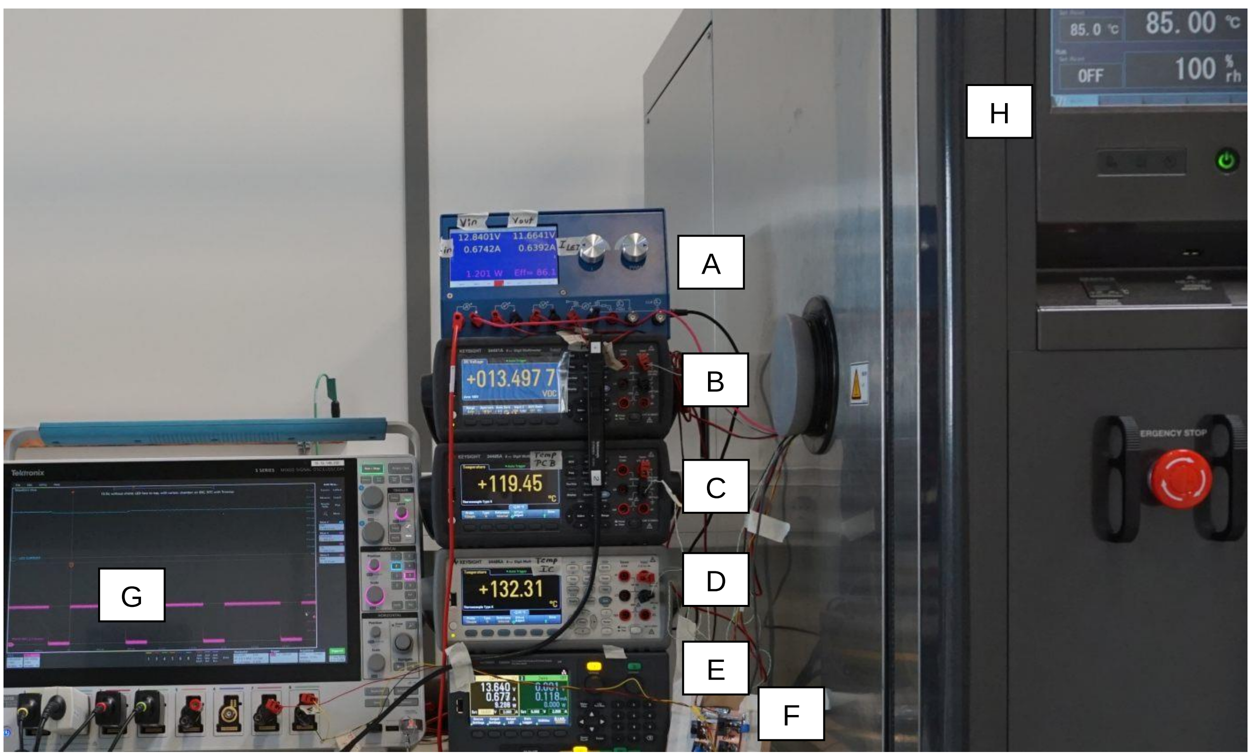

Figure 3: MPQ7200 Measurement Set-Up for NTC Thermal Dimming Derating

The test equipment in Figure 3 on page 5 is described in further detail below:

- MPS efficiency meter (A): The efficiency meter was created by MPS to provide accurate power loss and efficiency measurements for the MPQ7200 using four-wire voltage and current measurements for the IC input voltage (V_{IN_IC}), PCB input current (I_{IN}), LED voltage (V_{LED}), and LED current (I_{LED}).
- Voltmeter (B): The voltmeter measures the input voltage on the PCB input terminals (V_{IN_PCB}). In this instance, V_{IN_PCB} = 13.5V.
- Thermocouple thermometer for the PCB (C): The PCB's on-board NTC resistor (R_{NTC}) measures the PCB temperature and is the temperature signal of the MPQ7200's LED current derating. An external NTC resistor glued on top of R_{NTC} measures the R_{NTC} temperature. The external NTC resistor's temperature (T_{NTC}) is read out by the multimeter.
- Thermocouple thermometer for the IC (D): The IC's thermocouple measures the temperature on top of the MPQ7200 package (T_{IC}). A silicon die temperature cannot be measured with full accuracy using an external thermocouple. However, the measurement error is negligible when using small-sized thermocouples. The package's top side consists of a thin plastic layer, which makes the temperature difference between the silicon and the thermocouple only a few Kelvin.

  Figures 4 shows two different Type K thermocouples. The thermocouple shown on the left is a Keysight TCK-401301-SE with thin wires and is recommended for gluing on small objects onto a PCB using a thermally conductive glue. The thermocouple shown on the right is a general-purpose type with thick wires and is not recommended for gluing on small objects.

  The thermocouple wires are made of metal to transfer heat from the point of interest to the internal and external environments of the climate chamber. This heat transfer results in a measurement error, which specifically results in a measured temperature that is below the object's real temperature. To reduce the measurement error, use thin-wired thermocouples, and place long, thermally insulated wires inside the heated chamber.

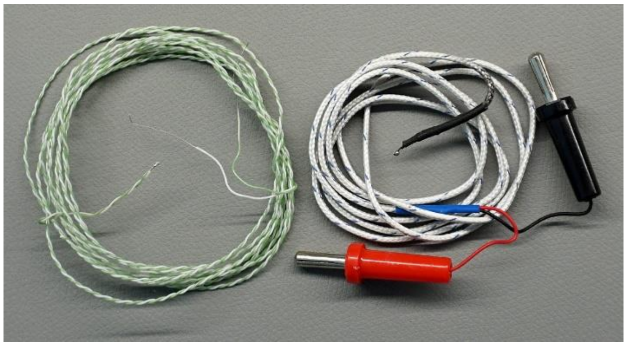

Figure 4: Type K Thermocouples

- Power supply (E): The power supply supplies the power for V_{IN_PCB}. The device under test (DUT) PCB has an on-board EMC filter, followed by a Schottky diode for reverse polarity protection. V_{IN_PCB} is measured on the EMC filter's input, and V_{IN_IC} is measured on the Schottky diode's output.
- External trimmer potentiometer ($R_{PARALLEL}$) (F): When placed outside of the climate chamber, $R_{PARALLEL}$ replaces the PCB surface mount technology (SMT) resistor and sets the NTC thermal dimming derating start point to the desired ambient temperature ($T_{AMBIENT}$, about 50°C).

  Figure 5 on page 7 shows the experimental set-up for $R_{PARALLEL}$. Through experimentation, it is possible to find the correct $R_{PARALLEL}$ resistor to place in parallel with R_{NTC}.

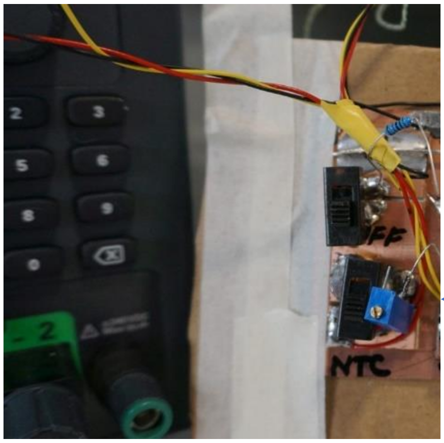

Figure 5: $R_{PARALLEL}$ Adjusts the Starting NTC Thermal Derating to $T_{AMBIENT}$ = 50°C

- Oscilloscope (G) (I_{LED} and pin 19's V_{NTC} (V_{NTC2})): G precisely measures the top square-wave amplitude for V_{NTC2}. The top amplitude provides temperature-related information for the analog NTC thermal derating. The oscilloscope measures I_{LED} with a current probe and displays the calculated RMS value. The I_{LED} waveform characteristics are monitored on the oscilloscope. It should be noted that the efficiency meter can measure the RMS value with higher accuracy.
- Climate chamber for the DUT (H): The climate chamber controls $T_{AMBIENT}$. It also controls the air temperature using a sensor mounted a few centimeters above the cardboard box.

Figure 6 shows the cardboard box enclosing the tested PCB, which prevents the airflow caused by the chamber. The entire PCB operates within these measurements without air convention, similar to the serial product.

Figure 6: DUT PCB Under a Closed Carton in the Climate Chamber

HOW TO ADJUST THE THERMAL DERATING

Set DUT to the desired $T_{AMBIENT}$ (50°C) and adjust $R_{PARALLEL}$ until the maximum I_{LED} (I_{LED_MAX}) begins decreasing from 100% of its typical value to a lower value. The NTC dimming derating can be expressed as a ratio (DIM_{RATIO}) or a percentage. See Figure 7 and Figure 8, and Figure 9 on page 9, for details on the schematic and components.

The percentage for DIM_{RATIO} can be calculated with Equation (1):

$$DIM_{RATIO}[\%] = 100 \times \frac{I_{LED\ MAX}}{I_{LED}} \quad (1)$$

Based on I_{LED_MAX}, the maximum RMS I_{LED} is below the derating start point at a 50°C $T_{AMBIENT}$, and I_{LED} is measured at $T_{AMBIENT}$.

THERMOCOUPLES AND RESISTORS

This section will describe several resistors – including R_{NTC} and $R_{PARALLEL}$ – and the thermocouples on the PCB. To detect T_{NTC} on the PCB, this application uses a 47kΩ R_{NTC} (at T_{NTC}= 25°C) and a negative temperature coefficient. Place R_{NTC} a few centimeters from the MPQ7200. R_{NTC} sets DIM_{RATIO}. This is an analog-based I_{LED} current derating, and it is not based on pulse-width modulation (PWM).

A Type K thermocouple is glued on top of R_{NTC}. The thermocouple signal is measured with a digital multimeter using a temperature scale. A second Type K thermocouple measures the MPQ7200's top package temperature. Figure 7 shows the placement for the two Type K thermocouples on the IC package and R_{NTC}.

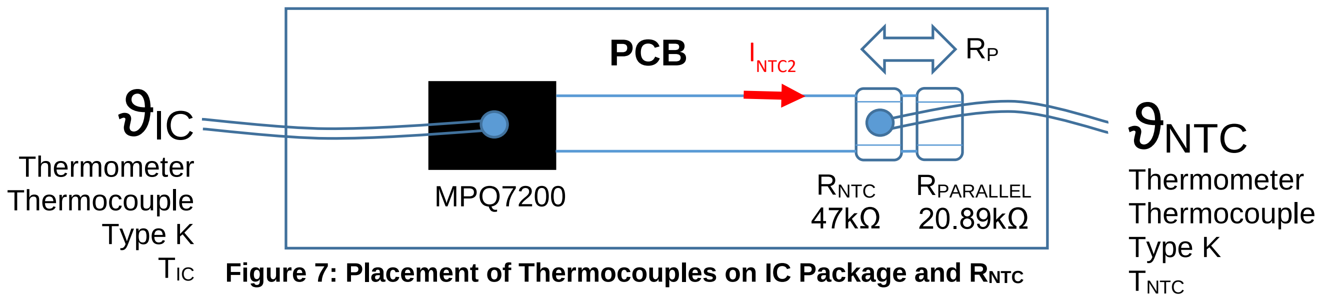

Figure 7: Placement of Thermocouples on IC Package and R_{NTC}

Where R_P is defined as the parallel resistance of $R_{PARALLEL}$ (20.89kΩ) and R_{NTC} (47kΩ) at T_{NTC} = 25°C. The aim of these measurements is to find the experimental $R_{PARALLEL}$. During the measurements, $R_{PARALLEL}$ is set by an external trimmer. For the later series PCB, $R_{PARALLEL}$ acts as a SMT resistor.

Figure 8 shows the relationship between resistance and T_{NTC}.

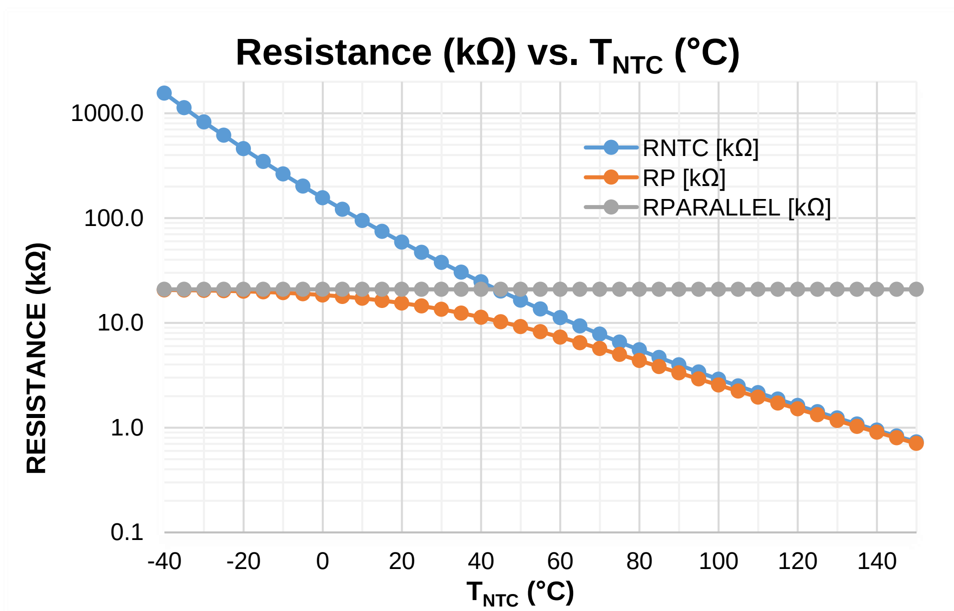

Figure 8: Curve Characteristics (R_{NTC}, R_{NTC}||20.89kΩ, and $R_{PARALLEL}$ vs. T_{NTC})

R_{NTC} covers a wide, non-linear resistance range. $R_{PARALLEL}$ improves linearization when $T_A \geq 50°C$ and sets the desired dimming derating starting point at $T_{AMBIENT} = 50°C$. Note that T_{NTC} exceeds T_A because the PCB is heated by 11W of electrical LED power.

SCHEMATIC THERMAL DERATING

Figure 9 show the resistors that are required to adjust the MPQ7200's analog NTC I_{LED} derating.

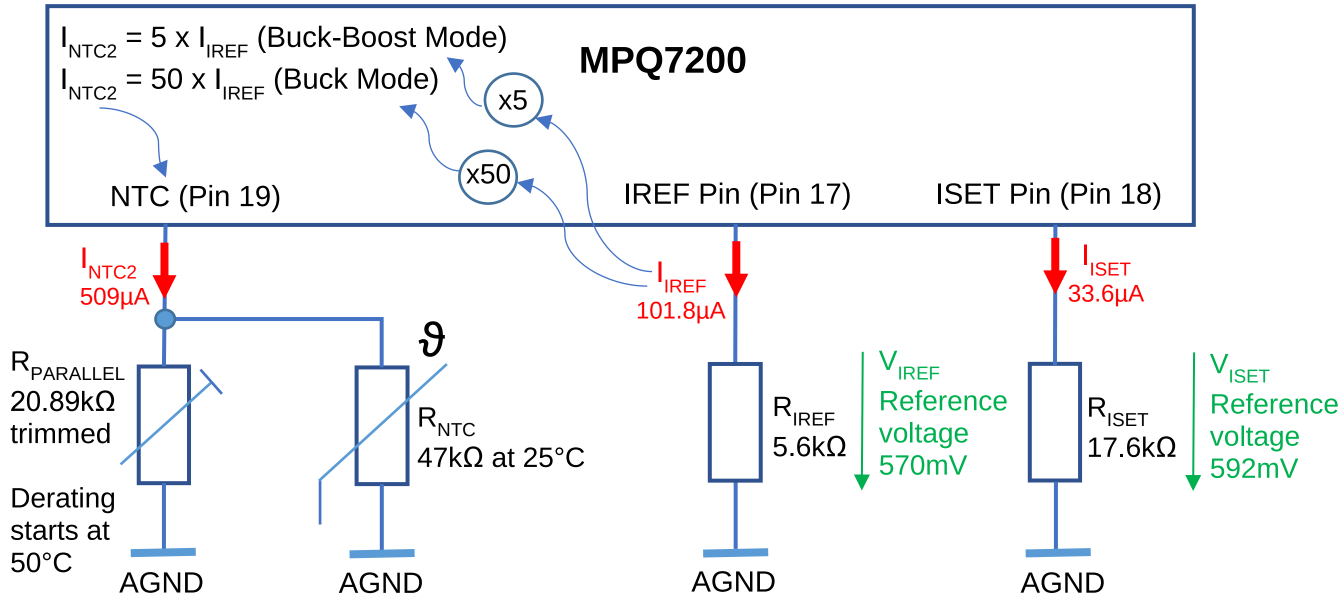

Figure 9: NTC Thermal Derating Adjustment

The key components for NTC thermal derating adjustments are described below.

Setting I_{LED} with the ISET Resistor (R_{ISET})

Connect a resistor to the ISET pin (R_{ISET}) to configure the constant average I_{LED}, which is controlled by the MPQ7200 control loop and DIM_{RATIO}.

I_{LED_MAX} can be estimated with Equation (2):

$$I_{LED\_MAX}[A] = \frac{16}{R_{ISET}\ [k\Omega]} \quad (2)$$

The nominal reference voltage of the ISET pin (V_{ISET}) is 0.592V. In the event of power derating or thermal derating, V_{ISET} can be set below 0.592V to decrease I_{LED_MAX}. Refer to the MPQ7200 datasheet for more details on the ISET current (I_{ISET}) selection. In this application note, I_{LED_MAX} is 0.909A and DIM_{RATIO} = 100% for full light intensity.

Setting I_{IREF} and I_{NTC2} with the IREF Resistor (R_{IREF})

The IREF pin's current (I_{IREF}) can be calculated with Equation (3):

$$I_{IREF} = \frac{V_{IREF}}{R_{IREF}} \quad (3)$$

If the reference voltage at the IREF pin (V_{IREF}) is set to 570mV, I_{IREF} is 101.8µA.

I_{NTC2} is a current sourced from the NTC pin. In buck-boost mode, I_{NCT2} can be estimated with Equation (4):

$$I_{NTC2} = 5 \times I_{IREF} \quad (4)$$

This value is automatically detected and latched.

In buck mode, I_{NCT2} can be calculated with Equation (5):

$$I_{NTC2} = 50 \times I_{IREF} \quad (5)$$

This value is automatically detected and latched.

Mode Detection

Mode detection begins when the VCC pin reaches its under-voltage lockout (UVLO) threshold (about 4.7V). Once detection finishes, the mode latches and I_{IREF} is equal to 0.57V / R_{IREF}. This I_{IREF} value is the reference for I_{NTC2}. The latched mode signal is reset by returning to the V_{CC} UVLO threshold, but it cannot be reset by pulling the EN/DIM pin low.

Selecting the Mode with the IREF Resistor (R_{IREF})

For buck-boost mode, set R_{IREF} between 1.05kΩ and 9.09kΩ. For buck mode, set R_{IREF} between 14.7kΩ and 80.6kΩ. Maintain R_{IREF} within the specified range based on the mode to ensure safe mode selection when the IC starts up.

Refer to the MPQ7200 datasheet for more details on NTC current selection, open detection, and short detection.

In this application note, R_{IREF} is set to 5.6kΩ for buck-boost mode. This means that I_{IREF} = 101.8µA, and I_{NTC2} = 5 x 101.8µA = 509µA.

Analog NTC Thermal Derating

The analog NTC thermal derating requires a three-step timing diagram for I_{NTC}. Figure 10 shows the timing to active I_{NTC} at approximately 1100Hz. I_{NTC2} updates to a new value every 900µs.

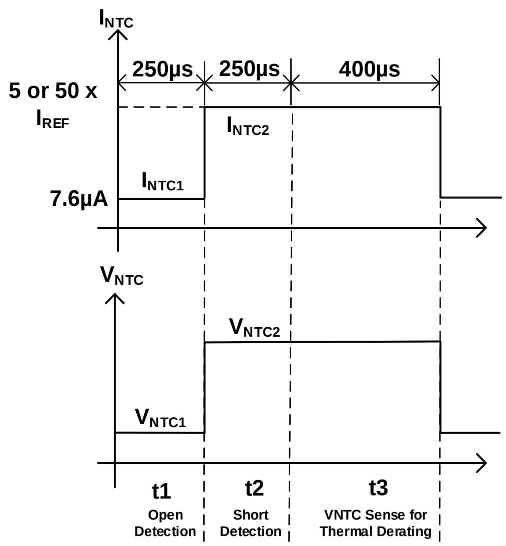

Figure 10: Timing Diagram for Activating I_{NTC} and I_{LED} DIM_{RATIO} Using a Three-Step V_{NTC} Detection

Three-Step V_{NTC} Detection

Table 1, Table 2, and Table 3 show V_{NTC} based on Figure 10 on page 10, DIM_{RATIO}, and $R_P = R_{NTC}||R_{PARALLEL}$.

NTC Open Detection (t_1)

During t1, the detection current (I_{NTC1}) is a constant 7.6µA (R_P open detection) to measure V_{NTC1}. Table 1 shows two scenarios during t1.

Table 1: V_{NTC1} during NTC Open Detection

Case	V_{NTC1}	Condition	NTC Thermal Derating	Assert FAULT Pin	If I_{NTC1} = 7.6µA
A	V_{NTC1} > 2V	R_P open detected	Disabled	No	R_P > 263kΩ
B	0V < V_{NTC1} < 2V	R_P detected	Enabled	No	R_P < 263kΩ

NTC Short Detection (t_2)

During t2, the MPQ7200 sets I_{NTC2} based on R_P and R_{IREF} (R_P short detection) to measure V_{NTC2}. Table 2 shows four scenarios during t2.

Table 2: V_{NTC2} during NTC Short Detection

Case	V_{NTC2}	Condition	NTC Thermal Derating	Assert FAULT Pin	If I_{NTC2} = 509µA
C	V_{NTC2} > 0.5V	50% to 100% DIM_{RATIO}	Enabled	No	R_P > 982Ω
D	0.38V < V_{NTC2} <0.5V	50% DIM_{RATIO}	Enabled	No	747Ω < R_P < 982Ω
E	0.18V < V_{NTC2} < 0.38V	Latch-off	Disabled	Yes	354Ω < R_P < 747Ω
F	0V < V_{NTC2} <0.18V	R_P short detected	Disabled	No	R_P < 354Ω

Case E depicts a latch-off condition where I_{LED} = 0A due to R_{NTC} thermal shutdown. To restart the MPQ7200 from this latch-off condition, T_{NTC} must decrease first. If V_{NTC2} > 0.5V, the device restarts after its power is recycled, or after the EN pin is reset.

V_{NTC} Sensing for Thermal Derating (t_3)

During t3, the MPQ7200 sets I_{NTC2} based on R_P and R_{IREF} (R_P temperature detection) and continues to measure V_{NTC2}. DIM_{RATIO} is generated at the end of t_3. Table 3 shows two scenarios during t3.

Table 3: V_{NTC2} during V_{NTC} Sensing for Thermal Derating

Case	V_{NTC2}	Condition	NTC Thermal Derating	Assert FAULT Pin	If I_{NTC2} = 509µA
G	V_{NTC2} > 1.25V	100% DIM_{RATIO}	Enabled	No	R_P > 2456Ω
H	0.5V < V_{NTC2} < 1.25V	50% to 100% DIM_{RATIO}	Enabled	No	982Ω < R_P < 2456Ω

Case H depicts when DIM_{RATIO} linearly decreases from 100% to 50%. DIM_{RATIO} can be estimated with Equation (6):

$$DIM_{RATIO} = 100\% - \left[(1.25V - V_{NTC2}) x \frac{2\%}{30mV}\right] \quad (6)$$

To decrease in relationship to $T_{AMBIENT}$, DIM_{RATIO} drops by a constant device scale factor of -2%/30mV. If V_{NTC2} = 1.25V, DIM_{RATIO} is 100%; if V_{NTC2} = 0.5V V_{NTC2} DIM_{RATIO} is 50%.

OSCILLOSCOPE PLOTS

The I_{LED} and V_{NTC} oscilloscope waveforms are measured for 100% and 71.4% DIM_{RATIO} levels. Figure 11 shows V_{NTC2} measured at T_A = 45°C, I_{LED} = 907.7mA, and DIM_{RATIO} = 100%. Channel 1 (denoted by the blue trace) measures the RMS I_{LED} using a current probe. Channel 2 (denoted by the pink trace) measures the square wave's top amplitude (V_{NTC2}).

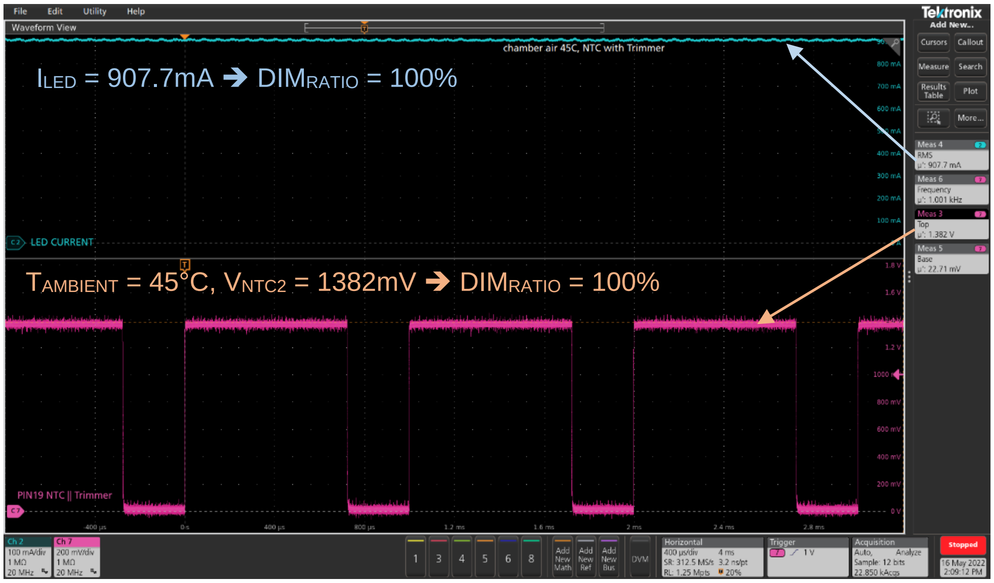

Figure 11: Measured V_{NTC2} at the NTC Pin (V_{NTC2} = 1382mV, I_{LED} = 907.7mA, $T_{AMBIENT}$ = 45°C)

Figure 12 shows V_{NTC2} measured at T_A = 85°C, I_{LED} = 648.8mA, DIM_{RATIO} = 71.4%.

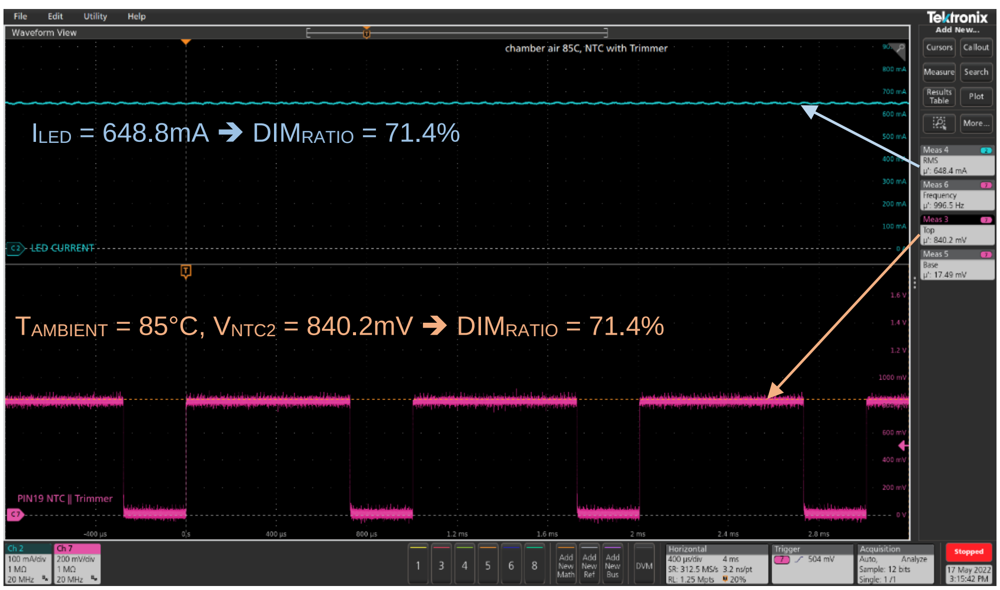

Figure 12: Measured V_{NTC2} at the NTC Pin (V_{NTC2} = 840.2mV, I_{LED} = 648.4mA, $T_{AMBIENT}$ = 85°C)

For both Figure 11 and Figure 12, T_{NTC} exceeds T_A, meaning the PCB is warmer than $T_{AMBIENT}$.

It is recommended to use a precision oscilloscope to measure the V_{NTC2} and I_{LED}. NTC thermal derating starts at V_{NTC2} < 1250mV with a -2%/30mV derating scale factor.

GRAPHS VS. TEMPERATURE

The measurement results below have a DIM_{RATIO} that starts at T_A = 50°C. For all the following graphs, V_{IN_PCB} = 13.5V, R_P = R_{NTC}||20.89kΩ, and there are four white LEDs connected in series.

Figure 13 shows V_{NTC2}, as measured with the oscilloscope, in which DIM_{RATIO} starts when V_{NTC2} < 1250mV and T_A > 50°C. Decreasing or increasing $R_{PARALLEL}$ moves the V_{NTC2} vs. T_A trace to another DIM_{RATIO} starting point.

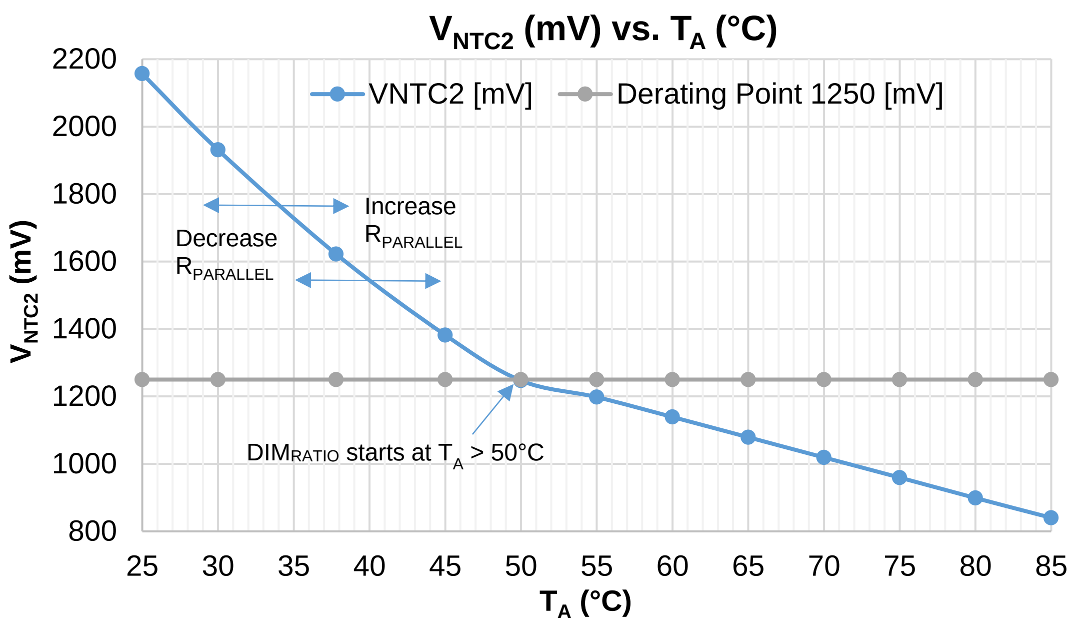

Figure 13: Measured V_{NTC2} at the NTC Pin with a Dimming Derating Starting at T_A = 50°C

Figure 14 shows DIM_{RATIO} with a starting point at T_A = 50°C

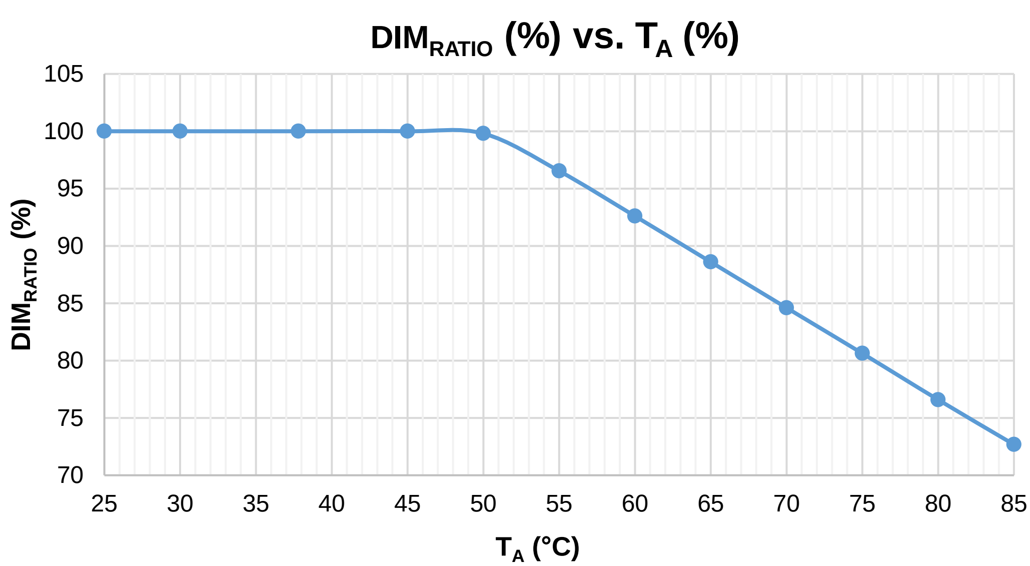

Figure 14: Measured DIM_{RATIO} with Starting Point at T_A = 50°C

Figure 15 shows I_{LED} and I_{IN}, as measured by the efficiency meter. Both currents are their average values. In this scenario, I_{LED_MAX} = 909mA.

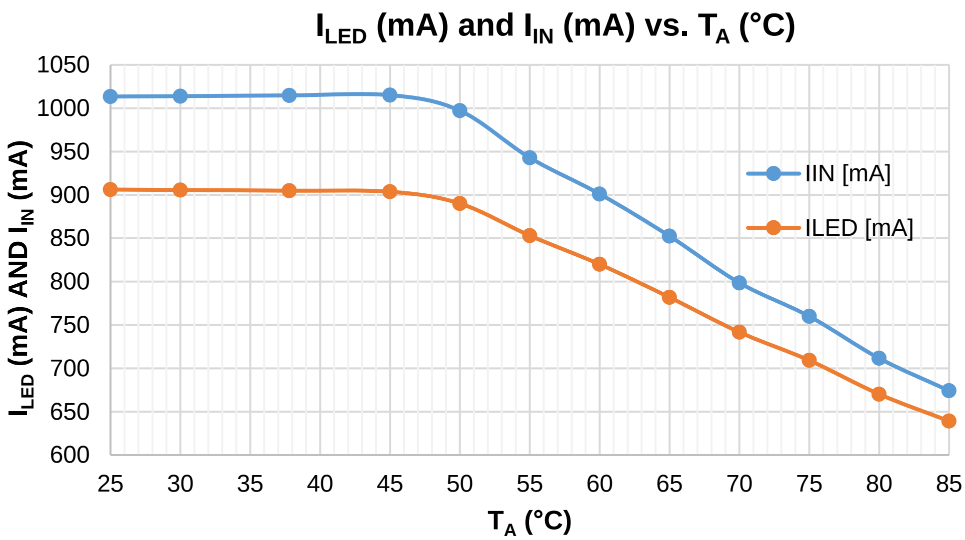

Figure 15: Measured I_{LED} and I_{IN} Using the Efficiency Meter

Figure 16 shows the average V_{IN_IC} measured at the two VIN pins (pin 4 and pin 13), as well as the average differential voltage (V_{LED}) measured at the four white LEDs in series (at the LED+ and LED- pins). The PCB has an on-board input EMC filter and a Schottky diode placed in series. The diode provides reverse polarity protection. Both the filter and diode reduce V_{IN_PCB} from 13.5V to approximately 12.6V at V_{IN_IC}, which is measured directly on the VIN pins. Both the EMC filter and Schottky diode experience a voltage drop that reduces the overall efficiency and increase power losses.

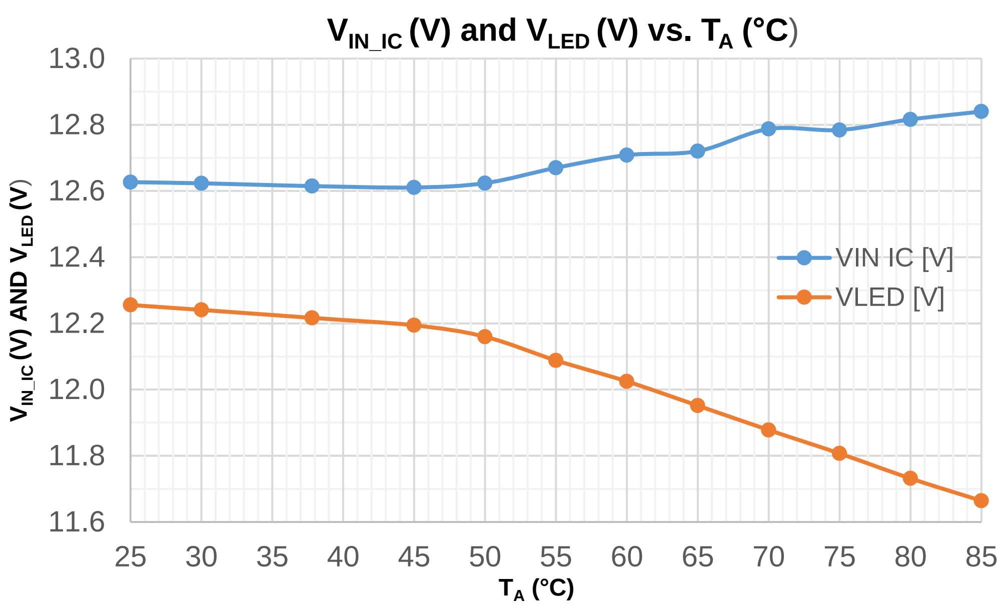

Figure 16: Measured V_{IN_IC} and V_{LED}

The 300mV to 700mV Schottky diode voltage drop can be reduced to only 20mV by using the MPQ5850-AEC1, a smart diode controller.

Figure 17 shows T_{IC} measured on the top of the MPQ7200 package and T_{NTC} measured on the PCB. Both temperatures are measured with thermocouples. The silicon junction temperature (T_J) is approximately only 2°C to 3°C higher than T_{IC}. The plastic covering on the silicon die is thin and does not isolate the thermal too much.

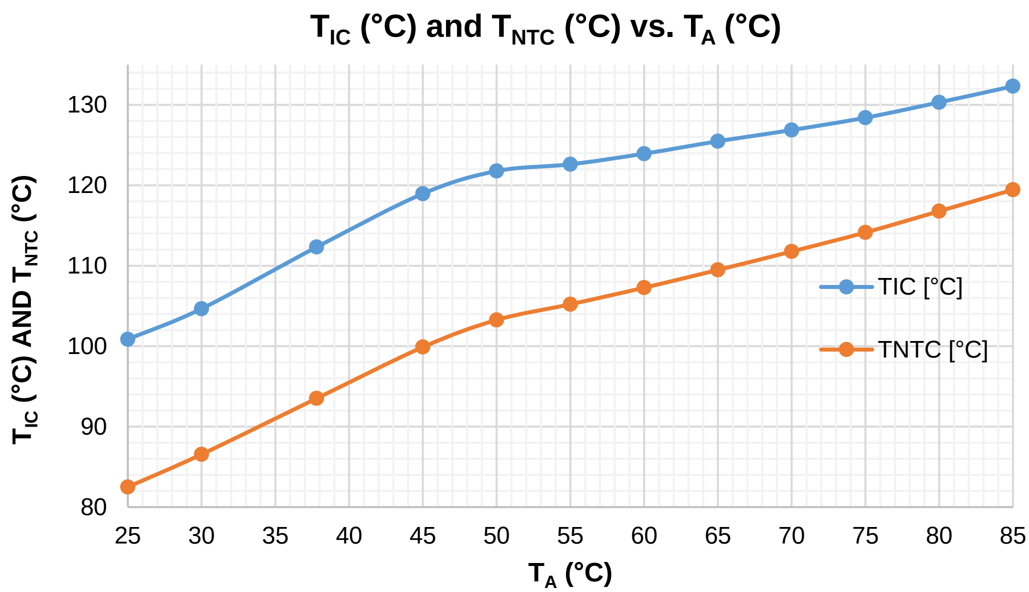

Figure 17: Measured T_{IC} on Top of the MPQ7200 Package and T_{NTC} on the PCB

Where T_{IC} = 122°C at 50°C T_A, 28K below the 150°C maximum operating junction temperature (T_{J_MAX}), which is a safe margin. If T_A exceeds 50°C, T_{IC} increases to 132°C. The NTC thermal derating prevents the die temperature from reaching high levels or thermal shutdown.

Figure 18 shows the measured IC and inductor power loss as well as efficiency. Power loss decreases with the starting DIM_{RATIO}. The switching inductance has 6mmx6mmx5mm operating dimensions at a 1.15MHz f_{SW}.

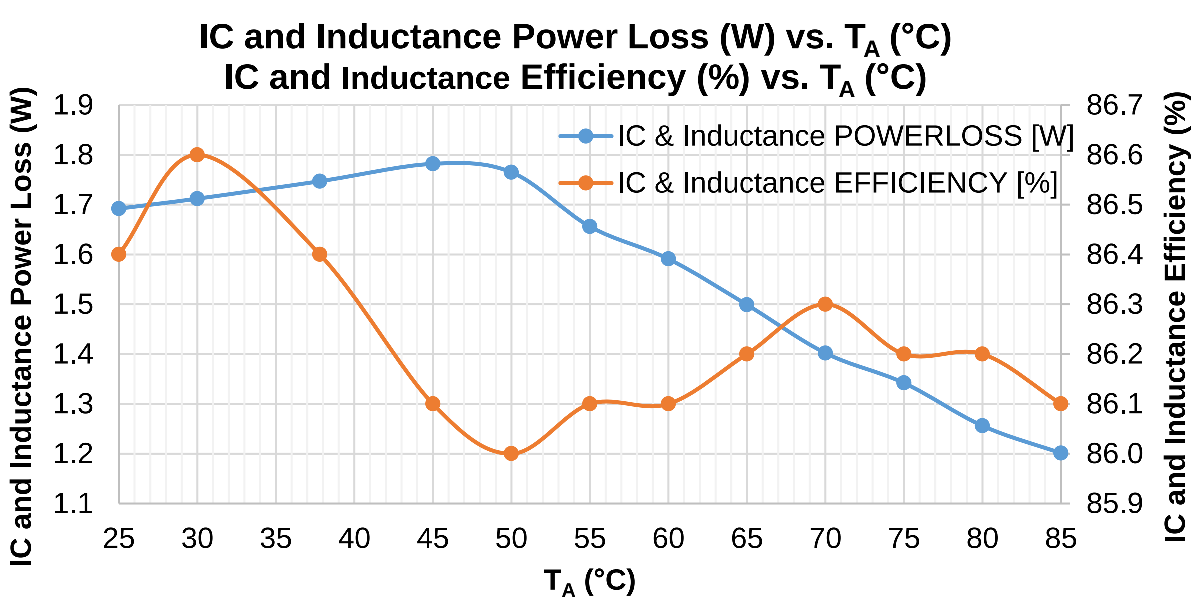

Figure 18: Measured IC and Inductance Power Loss, and Measured IC and Inductance Efficiency

CONCLUSION

The MPQ7200 is a flexible I_{LED} driver designed for applications with a low external part count and low BOM cost. The devices offers numerous built-in features for full flexibility in controlling I_{LED}.

In this application note, NTC I_{LED} derating expands the usable T_A range even under the worst-case scenario. This scenario occurs when the electrical LED power heats up the PCB, which is comprised of four LEDs and the MPQ7200. The power loss for the four LEDs can be calculated with Equation (7):

$$\text{Four-LED Power Loss} = 12.15V \times 0.909A = 11W \tag{7}$$

This means that the IC and inductance power loss is 1.8W.

NTC thermal dimming derating allows for a cost-effective solution where the two heat sources can share the same PCB.

ADDITIONAL READING

For more information about MPS automotive products, contact an MPS FAE or visit the MPS website.

REVISION HISTORY

Revision #	Revision Date	Description	Pages Updated
1.0	1/4/2023	Initial Release	-