Application Brief

Improving Accuracy of Shunt-Less Short Circuit Protection in Wide Temperature Range Using LM74912-Q1

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Introduction

In automotive applications, robust reverse polarity protection is essential to safeguard downstream electronics from potential damage. Systems such as Advanced Driver Assistance Systems (ADAS), which are directly connected to the vehicle's battery bus, are particularly susceptible to such faults. To address this, ideal diode controllers are employed at the power input, emulating a low forward-voltage (V_F) diode by driving an external N-channel MOSFET.

As system power demands continue to rise, traditional Schottky diodes become thermally inefficient and inadequate, prompting the replacement with ideal diode designs that offer lower power dissipation and enhanced thermal performance. Furthermore, with increased load currents, it becomes critical to implement overcurrent and short-circuit protection mechanisms.

To meet these requirements, modern ideal diode controllers integrate precision current-sense amplifiers, enabling real-time current monitoring and fault protection. This integration reduces BOM count, PCB area, and design complexity by offering a compact, single-chip protection design.

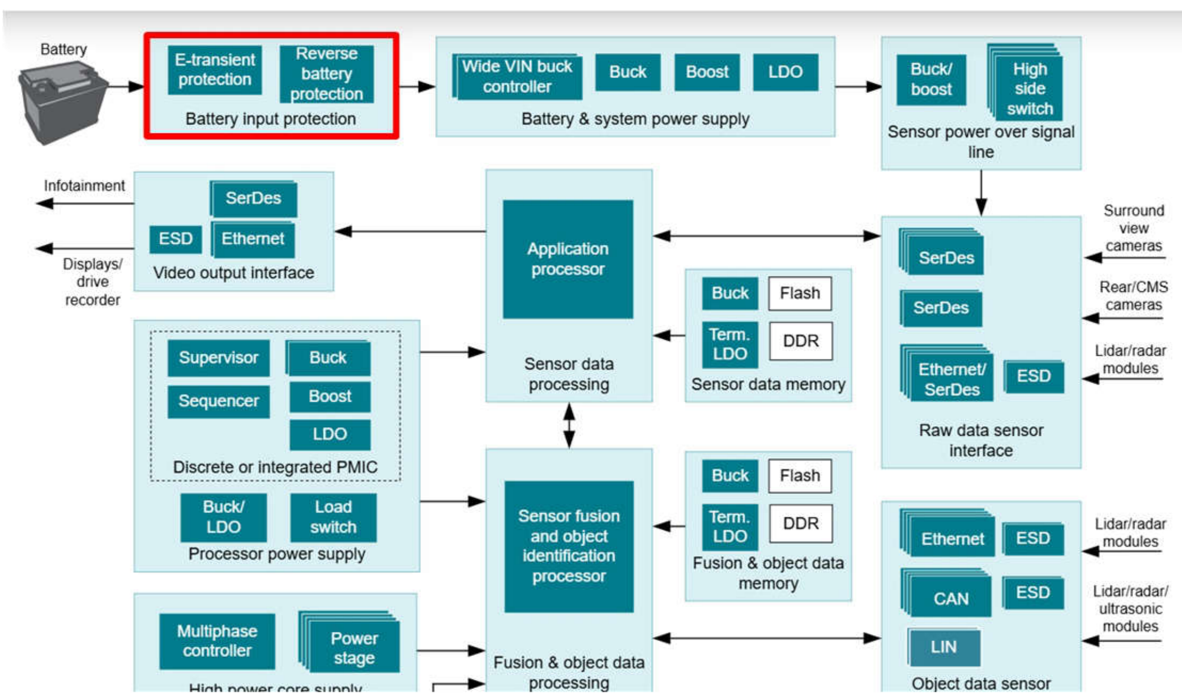

Figure 1. ADAS Domain Controller

LM749xx-Q1 Ideal Diode Controller Overview

The LM749xx-Q1 family of Ideal Diode controller drives back-to-back external N-Channel MOSFETs to realize low loss power path protection with circuit breaker, under and over voltage protection functionality. The wide input supply of 3V to 65V allows protection and control of 12V and 24-V automotive battery powered ECUs. The device can withstand and protect the loads from negative supply voltages down to –65 V. An integrated ideal diode controller (DGATE) drives the first MOSFET to replace a Schottky diode for reverse input protection and output voltage holdup. With a second MOSFET in the power path the device allows load disconnect (ON/OFF control) and overvoltage protection using HGATE control. The device features an adjustable overvoltage cut-off protection feature. With Common Drain configuration of the power MOSFETs, the mid-point can be used for OR-ing designs using another ideal diode. The LM749xx-Q1 has a maximum voltage rating of 65V. This family has two major devices, LM74900-Q1 and LM74912-Q1. The devices differ in how the devices protect from short circuit protection.

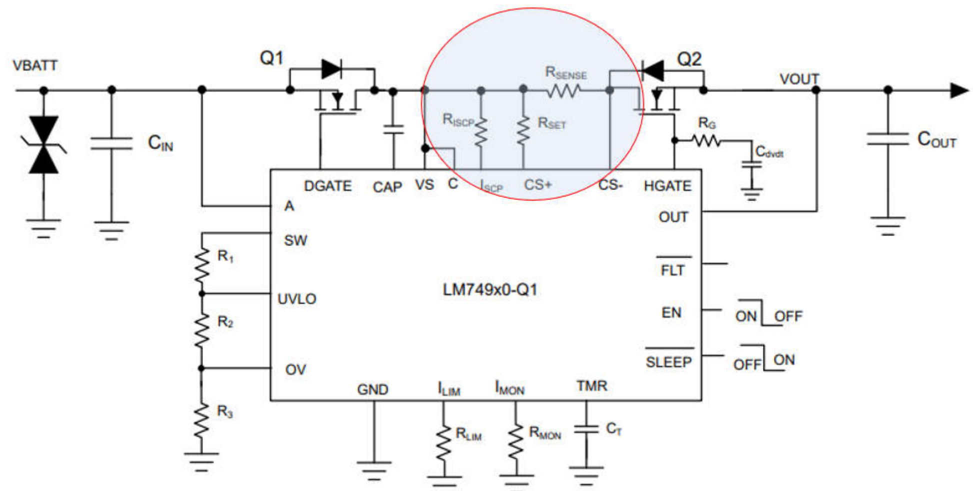

Figure 2. Typical Application Diagram of LM749x0-Q1

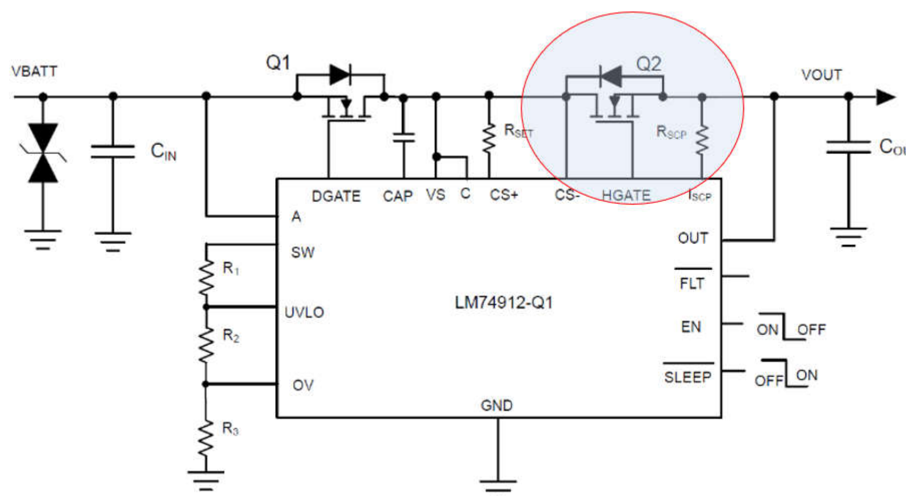

Figure 3. Typical Application Diagram of LM74912-Q1

As shown in Figure 2 and Figure 3 LM749x0-Q1 uses a shunt resistor to feed information to the internal current sense amplifier whereas LM74912-Q1 uses MOSET V_{DS} for the same function.

Although the shunt provides high accuracy but also increases solution size and cost of the design whereas LM74912-Q1 resolves this but can have wide accuracy at different temperature due to the MOSFET.

Protection Against Short Circuit using LM74912-Q1

The LM74912-Q1 integrates a fast-acting short-circuit protection mechanism to safeguard the external high-side FET and the downstream loads. The internal short-circuit comparator is activated once the HGATE-OUT voltage exceeds 6.4V (typ), ensuring the FET is fully enhanced and avoiding false detection during power-up. Upon detecting a short-circuit event—defined by the differential voltage between CS+ and ISCP exceeding 50 mV (typ)—the device pulls HGATE to OUT within 2 µs, quickly turning off the HFET to limit stress. Concurrently, the FLT pin asserts low to flag the fault condition. The device enters a latched-off state, keeping Q2 off until a low-to-high transition is applied to the EN, SLEEP, or VS pins.

Short circuit protection threshold can be increased or decreased from the default 50mV threshold by using an external series resistor R_{SET} from CS+ pin or R_{ISCP} from I_{SCP} pin as shown in Figure 4. The R_{SET} resistor shifts the threshold in positive direction while R_{ISCP} resistor shifts the threshold in negative direction. The shift in the short circuit protection threshold can be calculated using Equation 1.

$$\mathrm{VDS\_SNS} = 50\mathrm{mV} + (11\mu\mathrm{A} \times \mathrm{RSET}) - (11\mu\mathrm{A} \times \mathrm{RISCP}) \tag{1}$$

Here, once V_{DS_SNS} is decided, the short-circuit current threshold also depends on the R_{DSon} of the FET.

$$\mathrm{ISCP} = \frac{V_{DS\_SNS}}{R_{DSon}} \tag{2}$$

Equation 2 states the short-circuit current threshold.

Since Equation 2 is dependent on the R_{DSon} of the FET, the MOSFET characteristics are important.

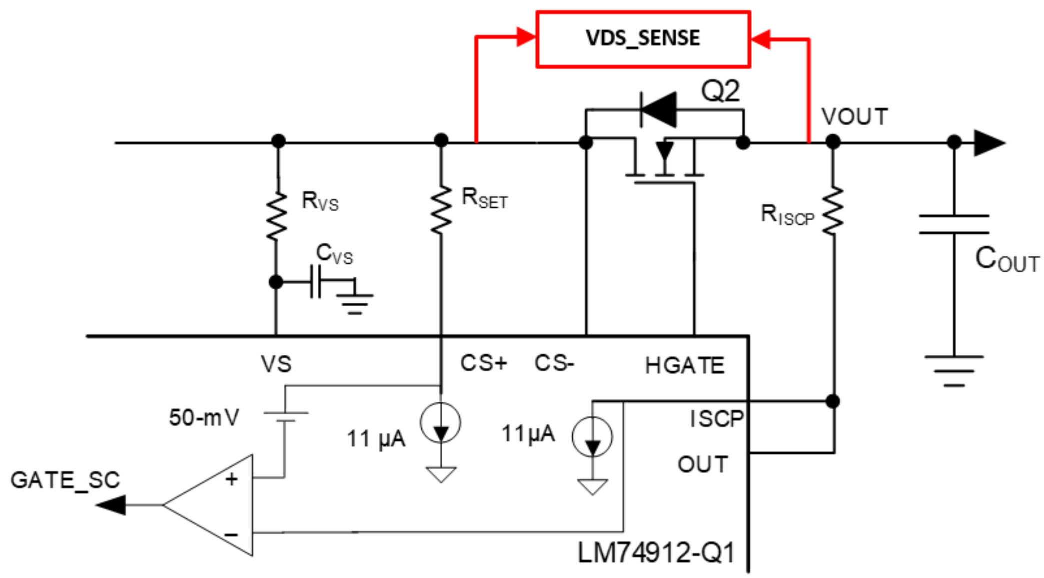

Figure 4. Short Circuit Protection Comparator

MOSFET Dependency

Power MOSFET datasheets have a specification called temperature coefficient 'α' that is used to describe the relationship between Rdson and junction temperature Tj. The drain-source on-state resistance Rdson of MOSFET mostly has a positive temperature coefficient in the normal operation condition, that contributes to the balanced current distribution over the complete area of the die. With a positive coefficient, the hottest spot at a die shows a higher resistance and would tend to conduct less currents, leading to lower temperature in that area. This mechanism creates an effective negative feedback and finally lead to the current balance of the MOSFET.

$$R_{DSon(TJ)} = R_{DSon(25C)} x \left[1 + \alpha \times \left(T_J - 25°C\right)\right] \quad (3)$$

From the data sheet of BUK7Y4R8-60E, the temperature coefficient a has been given to describe the relationship between R_{DSon} and junction temperature T_J. It indicates the R_{DSon} temperature stability, i.e. the degree to which the R_{DSon} is affected by T_J. The greater the α, the greater the R_{DSon} is affected by temperature. The resistance of the MOSFET changes according to Equation 3.

Resistance at different temperatures can be found out using Equation 3 and information from data sheets for alpha. An example relation is shown in Figure 5.

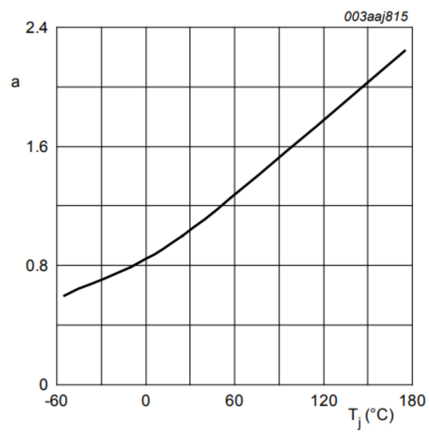

Figure 5. Temperature Coefficient Variation of BUK7Y4R8-60E MOSFET with Temperature

Figure 5 shows that the FET R_{DSon} varies approximately by a factor of 2.5 from -40C to 125°C, which affects the desired response of the controller when used in stringent conditions which is very likely in automotive use cases. With this, the short circuit protection can vary widely as listed in Table 2. This leads to over-scaling the design in terms of connector sizes, denser copper boards and higher current capability layouts to accommodate the higher current flow and hence increasing the design cost and size.

Reducing Threshold Variability for Safer Short Circuit Protection

Since the temperature change causes high variation in R_{DSon} and causes deviation in short circuit current threshold, a negative temperature coefficient resistor is added close to the FET such that similar temperature variation is seen on NTC (negative temperature coefficient) and FET. This R_{NTC} must be connected parallel to the R_{ISCP} resistor as shown in Figure 6 to create an offset voltage when paired with the internal current source of the controller to the varied R_{DSon}. Based on temperature of the MOSFET, variable offset voltage gets added to SCP comparator reference which linearizes the SCP threshold.

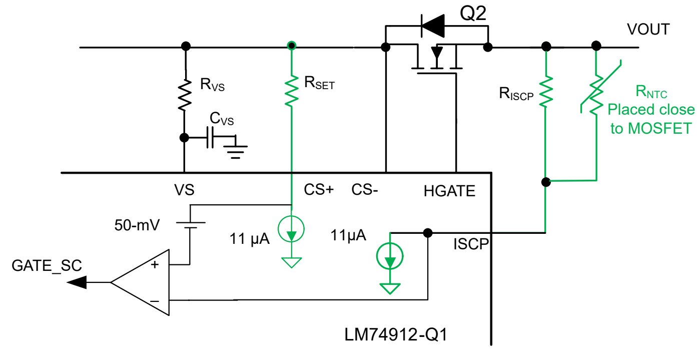

Figure 6. Typical Application Diagram with NTC Addition

Working Principle

The short-circuit current threshold is as shown in Equation 6.

$$\frac{V_{DS_{SNS}}}{R_{DSon}} = \frac{[50mV + (11\mu A \times RSET) - (11\mu A \times RISCP||RNTC)]}{R_{DSon}} \quad (4)$$

At high temperature (125C), R_{NTC} is low impedance compared to R_{ISCP} and approximately shorts the R_{ISCP} resistor. Hence the current source does not create an offset. Only parameter to decide the short-circuit current threshold is RSET.

$$ISCP@125C = 50mV + 11\mu A \times \frac{RSET}{R_{DSon@125C}} \quad (5)$$

$$ISCP@-40C = 50mV + 11\mu A \times \frac{RSET - RISCP}{R_{DSon@-40C}} \quad (6)$$

At low temperature (-40C), R_{NTC} is high impedance compared to R_{RISCP} and has very minor effect on the system thresholds and the offset is primarily decided by R_{SET} and R_{ISCP}.

Example Design

For a design which requires 15A short circuit protection threshold, the flow of components selection must be as follows.

Selected MOSFET: BUK7Y4R8-60E, $R_{NTC:}$ NCU18XH103E60RB

Target short circuit protection threshold: 15A

Table 1 shows the variation of MOSFET and R_{NTC} with temperature which is important to calculate the desired values of the components.

Table 1. FET R_{DSon} and RNTC Variation with Temperature

Temperature (C)	BUK7Y4R8-60E	NCU18XH103E60RB
	R_{Dson} (mΩ)	NTC Resistance, kΩ
-40	1.885	200
0	2.61	28
25	2.9	10
50	3.48	4
100	4.64	1
125	5.365	0.5

Traditional Approach

From Equation 1, it is clear that the threshold depends on two resistors, one of them can be kept constant and equation can be solved for the remaining value. At 25°C, our design example keeps R_{ISCP} constant at 3kΩ and results in R_{SET} = 2.4kΩ.

Proposed Approach

From Equation 5, at high temperature (125C), calculated R_{SET} = 2.77kΩ

From Equation 6 and using calculated R_{SET} value, R_{ISCP} = 4.7kΩ

When LM74912-Q1 is Paired with R_{NTC} NCU18XH103F60RB and FET BUK7Y4R8-60E, the short circuit current threshold can vary as listed in Table 2 based on Table 1 when the system is designed for a 15A short circuit current threshold.

Table 2. Short Circuit Threshold Variation with Temperature

Temperature (°C)	For R_{SET} = 2.4kΩand R_{ISCP} = 3kΩ *(Traditional Approach)*	R_{SET} = 2.77kΩ and R_{ISCP} = 4.7kΩ R_{NTC} = NCU18XH103E60RB *(Proposed Approach)*
	I_{SCP} (A)	I_{SCP} (A)
-40	23	15.89
0	16.6	13.87
25	14.96	15.62
50	12.471	16.35
100	9.35	15.38
125	8.08	14.07

Performance

Figure 7 and Figure 8 shows the overload protection performance of the system when tested at 25°C using the traditional and proposed approach respectively when designed for a 15A limit. Figure 9 and Figure 10 shows the overload protection performance of the system when tested at 100°C. When R_{NTC} is not used, the protection threshold is reduced by 50% due to increased R_{DSon} of the MOSFET which can cause false turn-off of the power path under high load conditions.

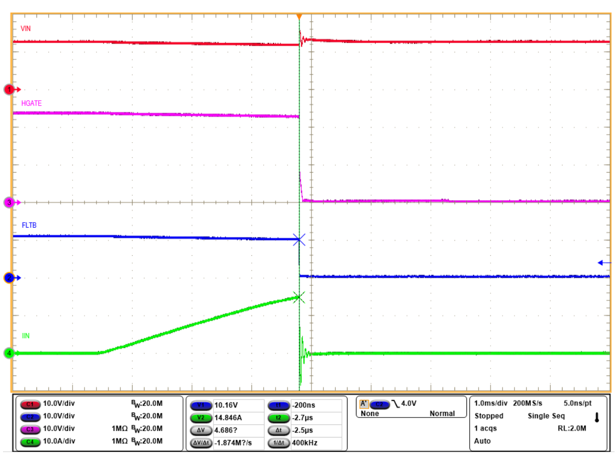

Figure 7. Overload Protection Without RNTC at 25°C

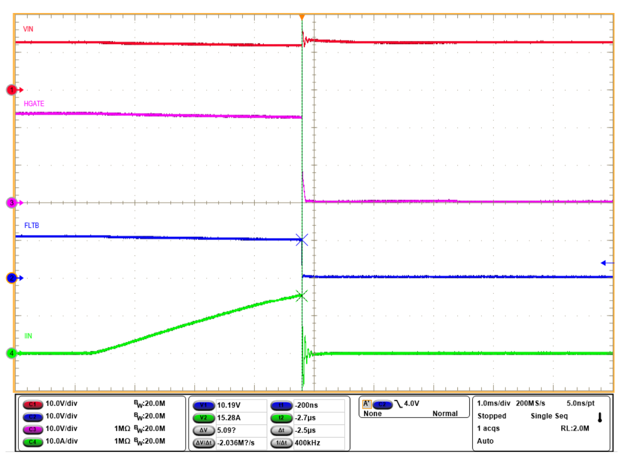

Figure 8. Overload Protection With RNTC at 25°C

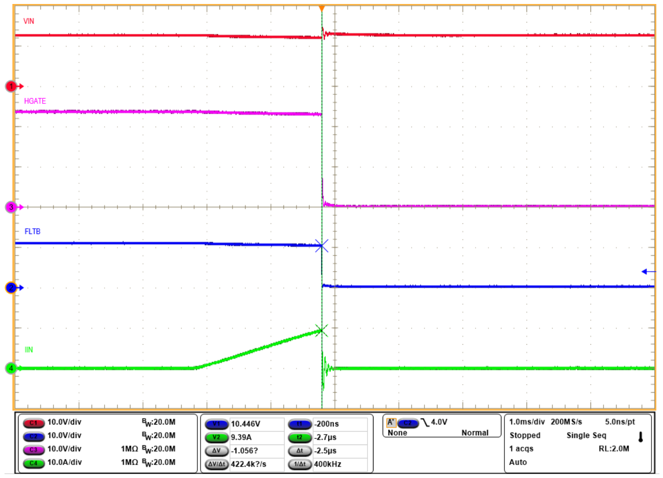

Figure 9. Overload Protection Without RNTC at 100°C

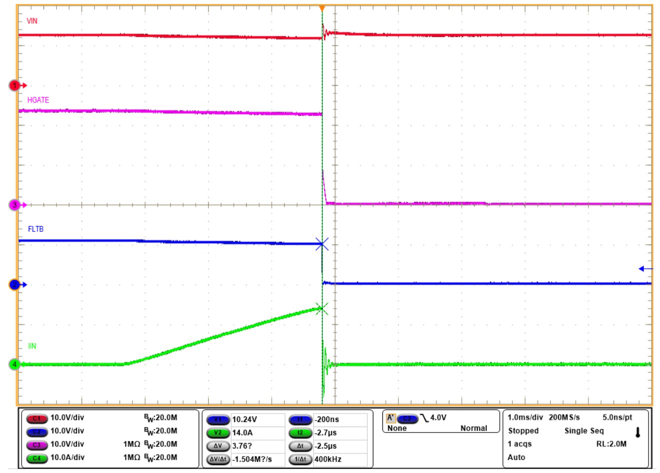

Figure 10. Overload Protection With RNTC at 100°C

Figure 11 shows the theoretical deviation in the thresholds with two different schemes.

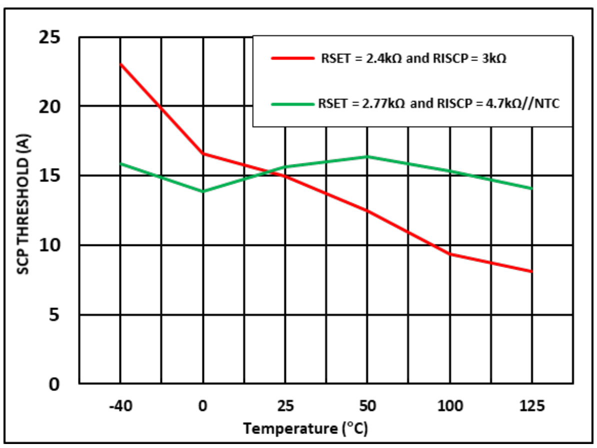

Figure 11. Comparison of SCP Threshold With and Without R_{NTC}

Summary

The R_{DSon} of a MOSFET increases with temperature due to the construction fundamental and impacts system protection when R_{DSon} is used for system level decisions. The positive temperature coefficient of the FET can be compensated with negative temperature coefficient resistor to maintain a stable short circuit current threshold. The proposed approach in this article helps to reduce the variation from approximately 184% to approximately 15.1%.

References

- Texas Instruments, *LM74912-Q1 data sheet, product information and support | TI.com*, product folder.
- Texas Instruments, *LM74900-Q1 data sheet, product information and support | TI.com*, product folder.
- Texas Instruments, *What's not in the power MOSFET data sheet, part 1: temperature dependency*, technical article.