NCV78902/NCV78964 Booster Current Sensing over MOSFET

AND90357/D

Introduction

NCV78902 and NCV78964 devices incorporate current mode voltage booster. In traditional approach, booster inductor current is sensed by means of shunt resistor (Figure 1). Generation 4+ LED drivers NCV78902 (2 phase Booster and SEPIC controller) and NCV78964 (2 phase Booster controller and 2 channel Buck) support, besides traditional approach, also booster inductor current sensing over MOSFET's RDS_{ON} (Figure 2). This provides the possibility to avoid booster sensing resistor in the application and save its cost and area for each of the phases and thus gain advantage over traditional system. By omitting the shunt resistor, the switching loop also becomes smaller and EMC performance is improved.

To support this feature, positive current sensing pins IBSTSNSxP had been made capable of handling high voltage. Newly, SPI settings programmability must reflect higher variation of MOSFET's RDS_{ON} value. The range of the current limit register BSTx_VLIM_THR[7:0] is significantly extended and can be set in fine steps. Also the voltage from COMP pin can be internally divided in a few fine steps with help of BST_COMP_DIV[2:0] register.

MOSFET's RDS_{ON} has by nature strong temperature dependency (Figure 5), directly affecting booster current limitation level and stability/reaction of the whole system, and it is desirable to compensate this effect in the application. This is possible thanks to the above-mentioned parameters and registers.

This application note further provides guideline on how to handle this compensation with specific NTMFS6H858NL MOSFET which is by default used on evaluation kit boards for generation 4+ LED drivers.

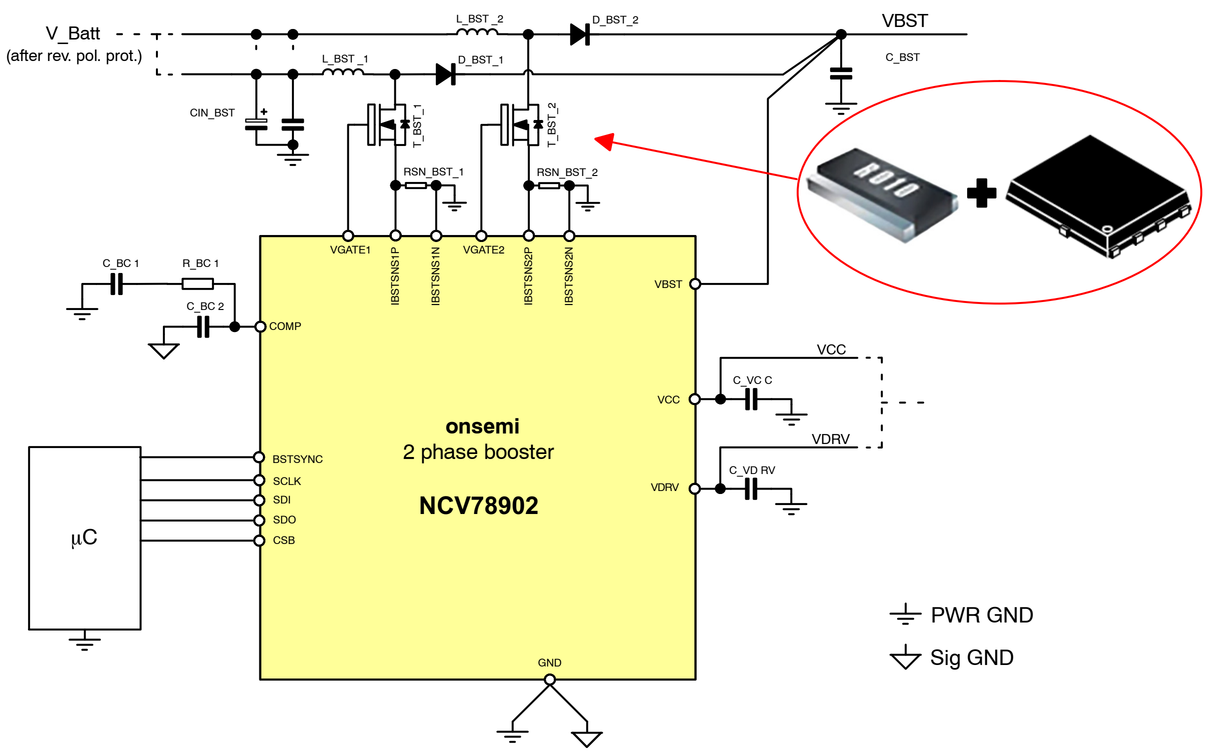

Figure 1. Typical Application Schematic with Booster Shunt Resistor

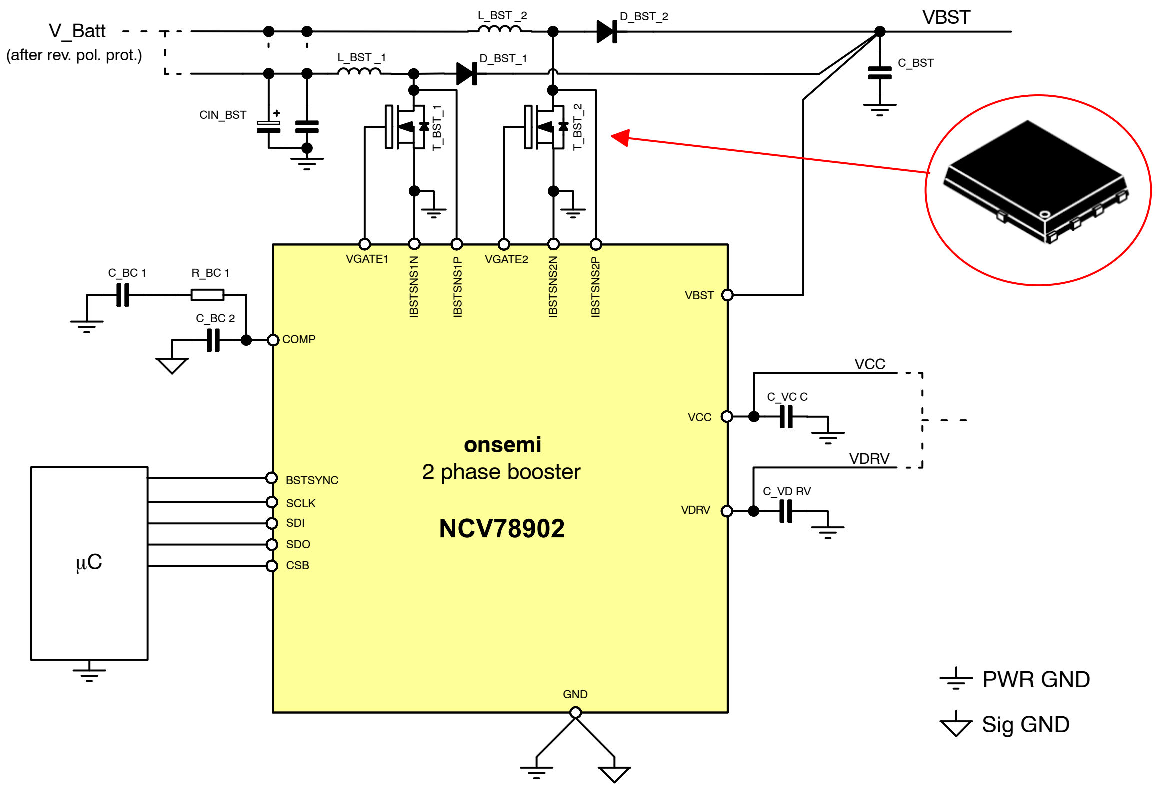

Figure 2. Typical Application Schematic with Current Sensing on Booster MOSFETs

Booster MOSFET Selection and Parameters

For generation 4+ LED drivers the logic level N-channel MOSFETs must be selected as the maximum available voltage for Gate switching on these devices is 5 V.

Suitable MOSFET should have voltage rating with some margin above the used booster voltage in the application. As generation 4+ LED drivers allow to operate at booster voltage maximum 62 – 65 V, the 80 V MOSFET could be considered as universal choice.

MOSFET's power rating should support the worst-case application conditions (maximum power, low battery voltage, ripple over the Booster inductor).

Another point to consider is selection of the MOSFET with good tradeoff between RDS_{ON} (affects conduction losses) and total gate charge (affects switching losses) depending on the operating conditions (frequency).

NTMFS6H858NL

Considering the above-mentioned selection criteria, the NTMFS6H858NL has been selected as default MOSFET for evaluation kit boards for generation 4+ LED drivers. Its parameters, specifically RDS_{ON} and its dependency on temperature, are illustrated on Figure 3 and Figure 4.

$V_{(BR)DSS}$	$R_{DS(ON)}$ MAX	I_D MAX
80 V	25 mΩ @ 4.5 V	30 A

Figure 3. NTMFS6H858NL MOSFET's PARAMETERS

Drain-to-Source Resistance		$R_{DS(ON)}$			
Test Condition		Min	Typ	Max	Unit
V_{GS} = 4.5 V	I_D = 5 A	–	20	25	mΩ

Figure 4. NTMFS6H858NL MOSFET's ON-RESISTANCE

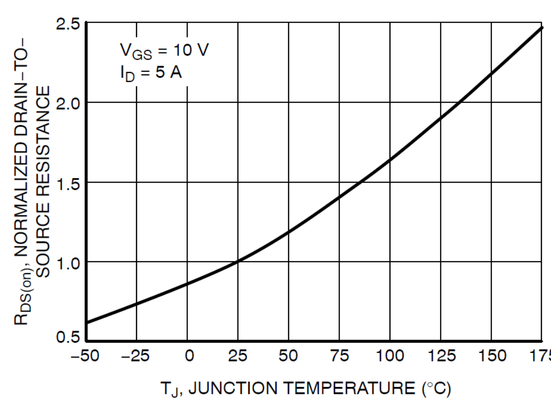

Figure 5. On-Resistance Variation with Temperature

From Figure 5 it is evident that RDS_{ON} changes over temperature range more than factor 2. When current sensing over MOSFET's RDS_{ON} is used, this variation directly affects the current limitation level and stability loop of the booster regulation, and it is desirable to compensate for these effects.

Booster Current Limitation Protection

Overcurrent protection clamps the maximum physical current that can flow in the booster input circuit while the MOSFET is driven. Overcurrent protection is active each PWM cycle and switches off the MOSFET's gate when voltage sensed on positive current sensing pin IBSTSNSxP reaches its maximum threshold defined by the BSTx_VLIM_THR[7:0] register. Therefore, the maximum allowed peak current will be defined, in case of sensing over booster MOSFET, by the ratio:

$$IPEAK\_MAX = \frac{V(BSTx\_VLIM\_THR[7:0])}{RDSon} \quad \text{(eq. 1)}$$

Table 1. SETTING FOR OVER-CURRENT COMPARATOR

Conditions	Min	Typ	Max	Unit
BST_VLIM_THR[7:0] = 255	570	600	630	mV
BST_VLIM_THR[7:0] = 0	–3	2	7	mV
Linear increase, 8 bits	–	2.35	–	mV

Current Limitation Measurement

The impact of varying MOSFET's RDSON on current limitation without any compensation in temperature range 25 °C to 125 °C is depicted on Figure 6. With the temperature increase of 100 °C, the current limit drops by more than 30%. In the application it is necessary to compensate for this effect.

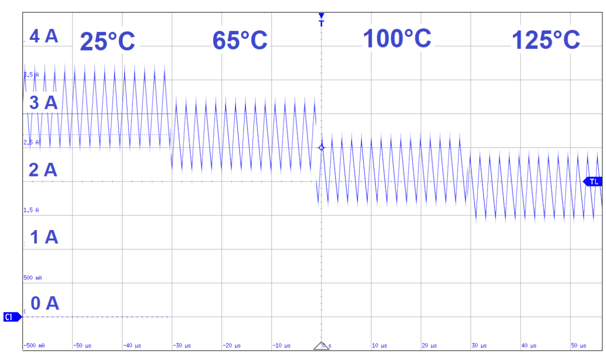

Figure 6. Current Limitation Variation with Temperature

Stability Considerations

COMP pin reference voltage is fed to the current comparator via a divider (ratio of which can be set by register BSTx_COMP_DIV[2:0] for each phase independently). The comparator compares this reference voltage with voltage VSENSE sensed on sensing pins IBSTSNSxP and IBSTSNSxN.

Table 2. DIVISION FACTOR OF VCOMP VOLTAGE TOWARDS THE CURRENT COMPARATOR INPUT

Conditions	Min	Typ	Max	Unit
BST_COMP_DIV[2:0] = 0	1.95	2	2.03	–
BST_COMP_DIV[2:0] = 1	2.76	2.8	2.87	–
BST_COMP_DIV[2:0] = 2	3.90	4	4.06	–
BST_COMP_DIV[2:0] = 3	5.50	5.7	5.74	–
BST_COMP_DIV[2:0] = 4	7.80	8	8.12	–
BST_COMP_DIV[2:0] = 5	11.04	11.3	11.48	–
BST_COMP_DIV[2:0] = 6	15.58	16	16.22	–
BST_COMP_DIV[2:0] = 7	21.07	22.6	22.98	–

Please note that for the selection of the COMP_DIV factor in the application, besides the stability, also available regulation voltage room on COMP pin should be considered. In other words, if too high COMP_DIV factor is selected and together with other application demands (high current from the booster phase e.g. at lower battery conditions, high slope control settings), it could happen that voltage at COMP pin becomes clamped and available current through the booster phase becomes limited by this mechanism.

Stability Simulation and Measurement

For Stability considerations the following typical Booster setup was selected:
VIN = 13 V; Vboost = 50 V; Load = 50 W; Fsw = 400 kHz; LBoost = 10 μH; Rsense = NTMFS6H858NL; Ccer = 22 μF; GM = 30 μS; Se = 360 k; COMP pin division factor = 4 (BST_COMP_DIV[2:0] = 2); COMP network = {R = 3.3 kΩ; C1 = 47 nF; C2 = 470 pF;}

Table 3. IMPACT ON THE STABILITY WITHOUT COMPENSATION OF NTMFS6H858NL RDSon

Temp. [°C]	NTMFS6H858NL RDS_{ON} Typ [mΩ]	Cross over Frequency [Hz]	Phase Margin [°]
–50	12	3924	63
–25	14	3429	66
0	16	3040	68
25	20	2488	69
50	24	2123	68
85	30	1763	65
125	38	1466	61
150	44	1315	59
175	50	1200	56

In this specific system setting, the phase margin is acceptable over full temperature range even without application of any compensation. Only dynamic performance is slightly affected. It is inversely proportional to RDS_{ON} and can be compensated by COMP pin division factor.

MOSFET Temperature Measurement

Ideally, NTC thermistor should be placed on the PCB close to the MOSFET to ensure reliable information about its temperature. If temperature sensor position is far from MOSFET, some temperature offset can be introduced and its compensation in SW should be considered.

In fact, NCV78902/NCV78964 device junction temperature (T_J) is continuously available through VTEMP ADC measurement, however it needs to be taken into account that in case of NCV78964 there are Buck channels inside dissipating big power and in case of NCV78902 there is no exposed pad connection to the PCB, so temperatures may be very different from that of MOSFETs.

Compensation Guideline

Based on the fact that the temperature in the system changes slowly and considering that the temperature of the MOSFETs can be only roughly estimated, general approach for compensation should be such that exaggerated reaction and oscillations are not induced. Our proposal is to perform register adjustment e.g. each 100 ms or slower.

From stability point of view, also taking into account granularity of BST_COMP_DIV register, it makes sense to compensate the effect of the changing RDS_{ON} only in a few discrete steps, our proposal would be to use 4 ranges as indicated in Table 4, where COMP pin division factor is compensating RDS_{ON} in inversely proportional way.

In the contrary, the current limitation can be compensated by means of BST_VLIM_THR[7:0] register in finer steps. The following table brings specific examples for both compensations.

Table 4. EXAMPLE OF CURRENT LIMITATION AND STABILITY COMPENSATION

Temperature Range [°C] for Stability Compensation	–50 – 0			0 – 50			50 – 125			125 – 150		
Temperature [°C] for Current Limitation Settings	–50	–25	0	0	25	50	50	85	125	125	150	175
NTMFS6H858NL RDSon Typ [mΩ] Read from Graph	12	14	16	16	20	24	24	30	38	38	44	50
BSTx_VLIM_THR [mV] for Ipeak = 10 A	120	140	160	160	200	240	240	300	380	380	440	500
BST_VLIM_THR[7:0] Reg.	50	58	67	67	84	101	101	127	161	161	186	212
Current Limitation Ipeak [A] after Compensation	10	10	10	10	10	10	10	10	10	10	10	10
COMP Pin Division Factor [–]* Applied	5.7			4			2.8			2		
BSTx_COMP_DIV[2:0] Reg.	3			2			1			0		
Cross over Frequency [kHz] after Compensation	2862	2496	2224	3040	2490	2129	2909	2387	1954	2606	2293	2058
Phase Margin [°] after Compensation	69	67	65	70	67	64	69	66	62	67	65	63

* Cannot be set in finer steps.

The example of equation for current limit compensation is shown below. Please note that the equation for MOSFET's RDS_{ON} dependency on temperature should be adjusted to the specific MOSFET, intended temperature range of use and another application requirements.

In most cases the quadratic equation can provide the best possible approximation in exchange for a need of more computing power:

$$\text{BSTx\_VLIM\_THR[7 : 0] register} = \frac{255}{600 - 2} \cdot \left(\left(I_{PEAK} \cdot \left(0.0004 \cdot t^2 + 0.12 \cdot t + 16.71 \right) \right) - 2 \right) \quad \text{(eq. 2)}$$

where

I_{PEAK} is requested booster current limitation level,

T is actual temperature of the MOSFET.

Quadratic equation coefficients are estimated from the NTMFS6H858NL RDS_{ON} figure.

Another approach can be simple linear approximation in certain temperature range. For the specific MOSFET NTMFS6H858NL, the MOSFET's RDS_{ON} can be linearly interpolated between 25 °C and 175 °C, providing good precision for temperatures above 25 °C. For temperatures below 25 °C the level can be kept constant, not introducing excessive error.

$$\text{BST\_VLIM\_THR[7 : 0] register} = \frac{255}{600 - 2} \cdot \left(\left(\left(I_{PEAK} \cdot \left(RDS_{ON25} + (t - 25\ ^\circ C) \frac{RDS_{ON175} - RDS_{ON25}}{175 - 25} \right) \right) \right) - 2 \right) \quad \text{(eq. 3)}$$

where

I_{PEAK} is requested booster current limitation level,

T is actual temperature of the MOSFET,

RDS_{ON25} is MOSFET's RDS_{ON} at 25 °C,

RDS_{ON175} is MOSFET's RDS_{ON} at 175 °C.

Implementation in Code for MOSFET NTMFS6H858NL

```
#include <stdint.h>
#include <math.h>

// Returns MOSFET's temperature in degrees Celcius, it is typically sensed by NTC thermistor and converted by ADC
float readMOSFETtemperature() {
    // ...
}

// Calculates NTMFS6H858NL MOSFET's RDSon for given temperature
float calcMOSFETResistance(float temperature) {
    return (0.0004*pow(temperature, 2) + 0.12*temperature + 16.708);
}

// Calculates and sets BST1_VLIM_THR[7:0] and BST2_VLIM_THR[7:0] registers according to actual MOSFET temperature
void setBoostCurrentLimitThr() {
    regVal = (int)round((Ipeak*calcMOSFETResistance(MOSFETtemp)-2)/2.35);

    setNCV78902register("[BST1_VLIM_THR]", regVal); // Saves calculated value into the register map
    setNCV78902register("[BST2_VLIM_THR]", regVal); // Saves calculated value into the register map
}

// Sets the default COMP pin division factor at 25 degC with room for its temperature compensation
void setMidpointCOMPDiv() {
    float MOSFETResistance25 = calcMOSFETResistance(25); // Calculates MOSFET's RDSon at 25 degC

    midpCompDiv = (int)round(4.0/(MOSFETResistance25/10.0)); // Sets midpoint according to specific application needs
    // This example considers default settings of midpCompDiv = 4 for 10 mOhm sensing resistor
    // and scales it according to the selected MOSFET's RDSon

    if(midpCompDiv > 6) { // Checks midpoint value and sets its high value limit
        midpCompDiv = 6;
    }

    if(midpCompDiv < 2) { // Checks midpoint value and sets its low value limit
        midpCompDiv = 2;
    }
}

// Calculates and sets BST1_COMP_DIV[2:0] and BST2_COMP_DIV[2:0] registers according to actual MOSFET temperature
void setCOMPDivisionFactor() {
    quint8 regVal;

    if(MOSFETtemp > 125.0) { // Checks MOSFET's temperature to set BSTx_COMP_DIV value
        regVal = midpCompDiv-2;
    }
    else if(MOSFETtemp > 50.0 && MOSFETtemp <= 125.0){ // Checks MOSFET's temperature to set BSTx_COMP_DIV value
        regVal = midpCompDiv-1;
    }
    else if(MOSFETtemp > 0.0 && MOSFETtemp <= 50.0) { // Checks MOSFET's temperature to set BSTx_COMP_DIV value
        regVal = midpCompDiv;
    }
    else {
        regVal = midpCompDiv+1;
    }

    setNCV78902register("[BST1_COMP_DIV]", regVal); // Saves calculated value into the register map
    setNCV78902register("[BST2_COMP_DIV]", regVal); // Saves calculated value into the register map
}

//************************************************************************************//
// Example of compensation of Booster current limitation and COMP pin division factor
// ...
float Ipeak = 10.0; //Requested booster current limitation level = 10 A
float MOSFETtemp;

setMidpointCOMPDiv();

// ISR for interrupt (100ms timer)
ISR(AUTOTUNE_INT_vect) {
    MOSFETtemp = readMOSFETtemperature();

    setBoostCurrentLimitThr();
    setCOMPDivisionFactor();
}
// ...
```

Conclusion

Sensing of the current on MOSFET's RDS_{ON}, compared to traditional approach with dedicated sensing resistor, brings besides many advantages also new challenges. Strong dependency of MOSFET's RDS_{ON} on temperature directly affects booster current limitation level and stability/reaction of the whole system. So it is necessary to measure and estimate the temperature and compensate the behavior of the system accordingly. This application note summarizes all related aspects and introduces a suitable approach for such compensation and its effect on the system's behavior.

Without compensation, the system would be naturally stable with negative feedback because with increasing temperature the maximum input current decreases and in this way the overheating of the system is prevented. But the impact is also that total available power can be limited and requested output voltage and current not reached when regulated input current hits the decreased limitation threshold. So this guideline shows how to work with current limitation threshold depending on the temperature. For a correctly designed system from a stability point of view, the effect of the temperature is almost negligible, and only dynamic performance would be slightly affected as presented in this application note.

REVISION HISTORY

Revision	Description of Changes	Date
0	Initial Document released.	7/8/2025

ADDITIONAL INFORMATION

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