ISL85403

Tips for Using the ISL85403 in Boost-Buck Mode

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Abstract

This document illustrates some issues that you might encounter when using the ISL85403 in two-stage Boost-Buck mode in applications with input voltages as low as 3V and output voltages about four times greater than the lowest input voltage.

This document is not a step-by-step design example, but explains issues that may be encountered in some designs and shows how to overcome these issues. The ISL85403EVAL1Z evaluation board is used and modified to demonstrate the design considerations.

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Related Literature

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- ISL85403 device page

1. ISL85403 Boost-Buck Mode

The ISL85403 is capable of regulating output voltages in which the input voltage to the circuit is either less than or greater than the output voltage. To achieve these voltages, configure the device in Boost-Buck mode as shown in Figure 1.

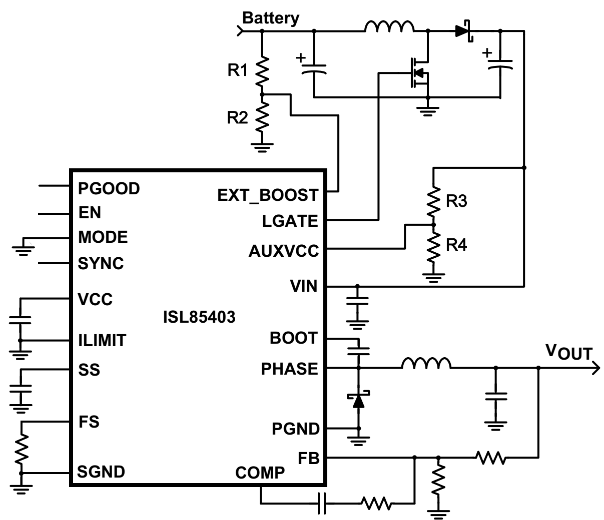


Figure 1. Typical Application Schematic - Two-Stage Boost Buck Converter [1]

Note: The ISL85403 datasheet and evaluation board user guides use the term V_{BAT} or Battery as the input voltage to the boost-buck circuit and use the term V_{IN} as the input voltage to the buck converter where this V_{IN} voltage is generated by the boost stage (see Figure 1). Be aware of this terminology when reading the datasheet and user guides versus this guide.

Note: The red markings in some of the figures in this document are specific to this guide and are not part of the original figures from their respective sources.

2. Design Considerations

This document uses an example circuit with the following specifications:

- V_{IN} = 3V to 24V

Note: As specified in the ISL85403 datasheet, the device may not actually start up until the voltage into VIN is greater than 3V due to the worst case Power-On Reset Threshold specification and the fact that the current to the VIN pin must flow through the Schottky diode from the VBAT input.

- V_{OUT} = 12V at 1A

2.1 Selecting the MOSFET When Operating at 3V V_{BAT} Input

Carefully choose the boost stage switching transistor. The boost stage switching transistor is the FET driven by the LGATE signal in Figure 1. Many FETs, including the BSZ100N06LS3 G used on the ISL85403EVAL1Z evaluation board, are not optimal for being driven with a 3V gate drive signal. The charge curve (Figure 2) for the BSZ100N06LS3 G device shows that the plateau of the charge curve is at a voltage greater than 3V.

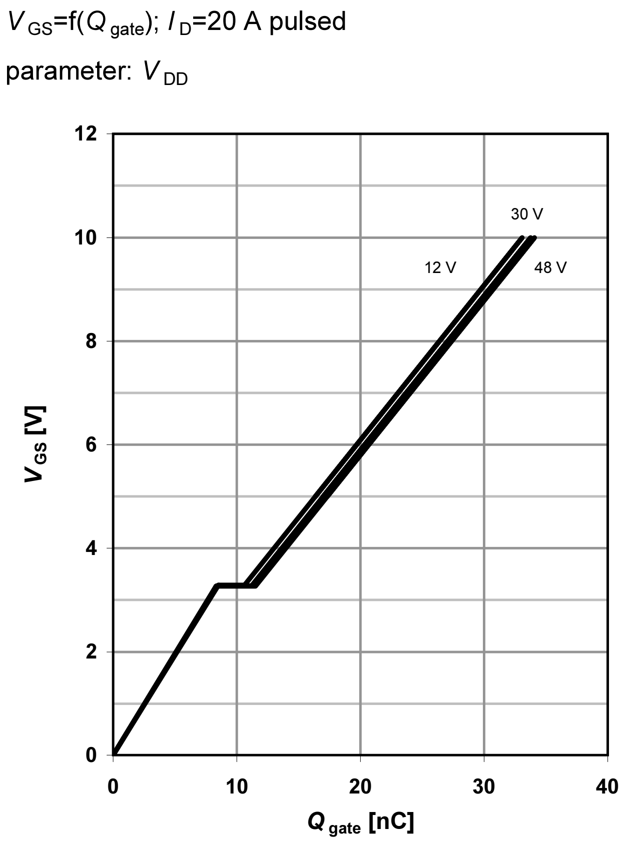


Figure 2. BSZ100N06LS3 G Gate Charge Waveforms [2]

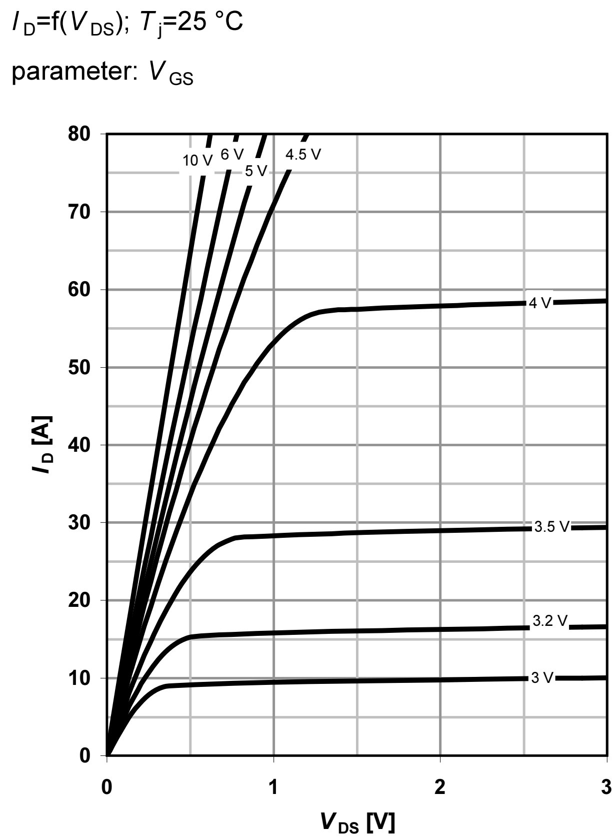


Figure 3. BSZ100N06LS3 G Typical Output Characteristics [2]

Driving a 3V signal to the FET's gate does not fully drive the FET on. See Figure 3 for additional performance details. In the circuit example illustrated in this technical brief, the load is 12V at 1A, which is 12W. If this load is reflected to the input of the boost stage and the system is considered 85% efficient, about 4.7A input current is required when the input voltage to the boost stage is 3V. Figure 4 shows that the ON-resistance for this transistor is about 24mΩ when being driven by 3V to produce 4.7A of drain current. The losses in just the transistor when operating at a 3V gate drive are $(4.7)^2$ x 0.024 = 486mW.

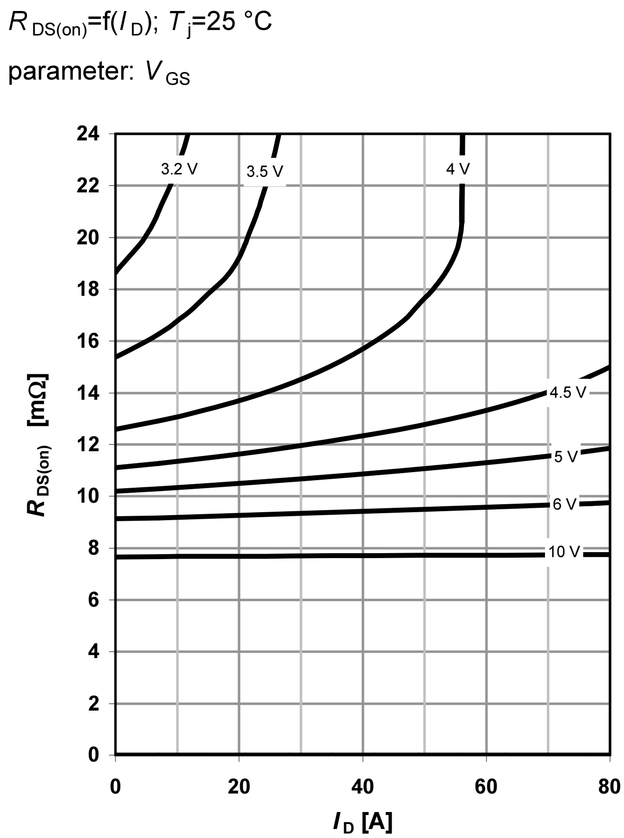
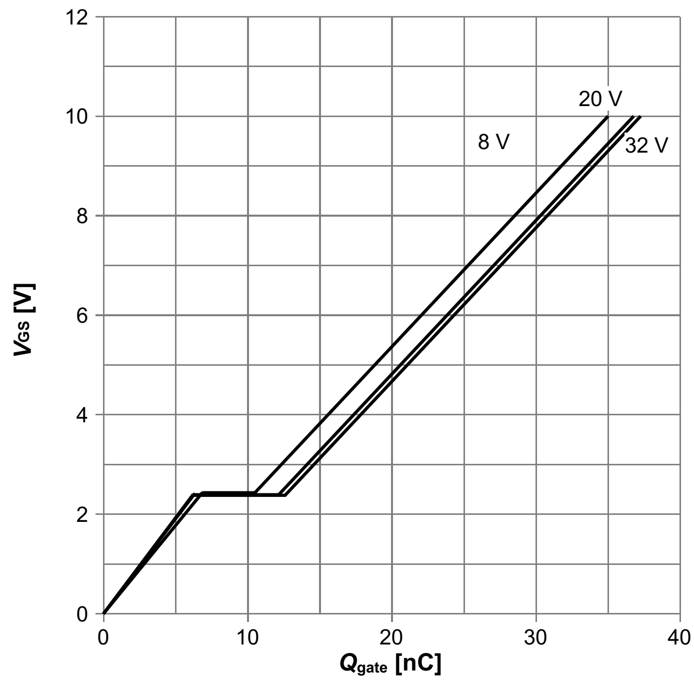


Figure 4. BSZ100N06LS3 G Drain-Source On-Resistance [2]

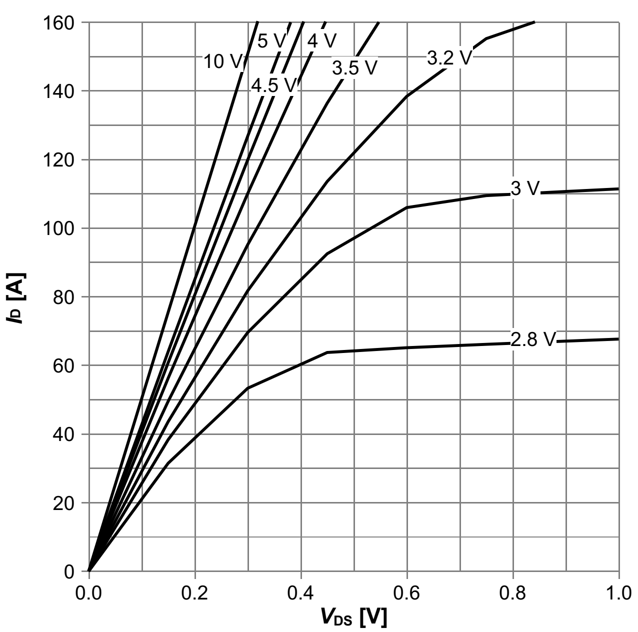
When operating at 3V, choose a FET that operates more efficiently. Renesas recommends the BSZ025N04LS for the supply circuit example in this technical brief.

The BSZ025N04LS's charge curve plateau is at about 2.4V (Figure 5). This FET is fully on when driven with a 3V gate signal; this is confirmed by the other characteristic curves shown in Figures 6 and 7.



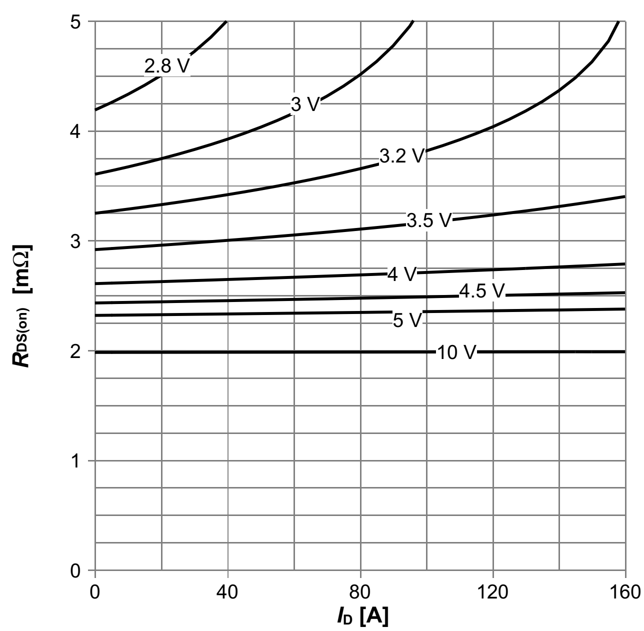
V_{GS}=f(Q_{gate}); I_D=20 A pulsed; parameter: V_{DD}

Figure 5. BSZ025N04LS Typical Gate Charge Waveforms [3]



I_D=f(V_{DS}); T_j=25 °C; parameter: V_{GS}

Figure 6. BSZ025N04LS Typical Output Characteristics [3]



$R_{DS(on)}$=f(I_D); T_j=25 °C; parameter: V_{GS}

Figure 7. BSZ025N04LS Typical Drain-Source On-Resistance [3]

The ON-resistance of the BSZ025N04LS when driven at 3V gate drive is about 3.6mΩ at 25 ºC. The power dissipated in the FET when operating at 3V and full load on the 12V output is much lower at about 80mW.

2.2 Setting the Threshold Voltage on the EXT_BOOST Pin

The voltage input into the EXT_BOOST pin determines whether the boost portion of the circuit is active. When power is first applied to the circuit, the voltage into the EXT_BOOST pin must be greater than 200mV for the boost converter to start up. If the voltage into the EXT_BOOST pin is greater than 800 mV, the boost converter shuts off and the circuit operates in Buck mode.

For the power supply specifications listed in "Design Considerations" on page 2, the signal into the EXT_BOOST pin must be modified to make the boost converter function. On the ISL85403EVAL1Z evaluation board, the voltage into the EXT_BOOST pin is usually derived using a resistor divider that monitors the input voltage to the circuit. However, if the resistors yield a voltage greater than 200mV into the EXT_BOOST pin when the input voltage is 3V, an input voltage of about 12V shuts off the boost stage because 12V divided down by the same resistors yields a voltage exceeding the 800mV threshold for shutting off the boost stage. An input voltage of 12V does not allow enough voltage into the buck converter to yield a regulated 12V output.

The network used to generate the control voltage into the EXT_BOOST pin on the ISL85403EVAL1Z evaluation board needs to be modified.

First, determine the V_{BAT} voltage needed to ensure the buck regulator properly regulates the output voltage at 12V.

The ISL85403 datasheet specifies the following parameters for the buck PWM:

Table 1. ISL85403 PWM Specifications [1]

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Oscillator						
PWM Frequency	F_{OSC}	R_T = 665kΩ	**160**	200	**240**	kHz
		R_T = 51.1kΩ	**1870**	2200	**2530**	kHz
		FS pin connected to VCC or floating or GND	**450**	500	**550**	kHz
Minimum ON-Time	t_{MIN_ON}			130	**225**	ns
Minimum OFF-Time	t_{MIN_OFF}			210	**330**	ns

The ISL85403 example circuit is operated at 500kHz (2µs period). The ISL85403 datasheet specifies a worst case minimum OFF-time of 330ns, which means the buck converter maximum duty ratio is (2000 - 330)/2000 = 0.835. This result indicates that due to duty ratio limits, the voltage into the buck regulator must be at least 12/0.835 = 14.37V. For margin, add an additional 0.5V to account for voltage losses across the inductor resistance and the FET switch ON-resistance. For the buck regulator to regulate the 12V output, its input voltage should be about 14.9V minimum. However, this voltage is the voltage value needed at the input of the buck converter.

The current used by the buck converter has to flow from the battery source through the boost inductor and through the boost diode as shown in Figure 8 on page 7.

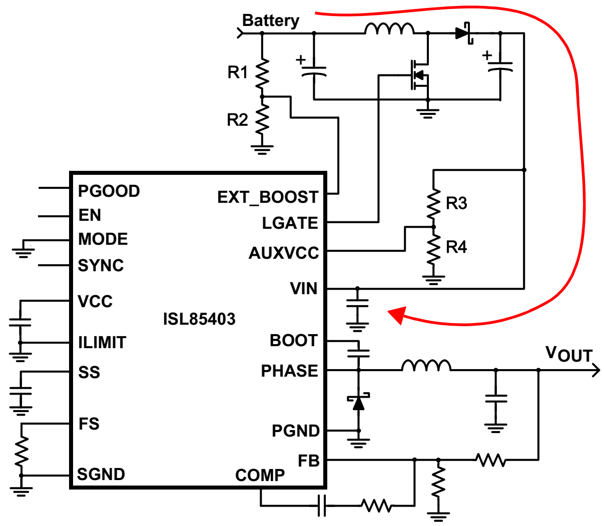


Figure 8. Input Current Path, Two-Stage Boost Buck Converter in Buck Mode [1]

These components introduce some voltage drop between the V_{BAT} input and the buck converter input point (VIN pin). See the diode datasheet for its forward voltage information. The forward voltage for the new diode is approximately 0.42V. The boost inductor resistance for the inductor is about 12mΩ. Therefore, allot another 0.5V for the voltage drop across these two components. The V_{BAT} voltage required for the buck regulator to properly regulate the 12V output would then be 15.4V. The EXT_BOOST network is designed to keep the boost converter active until the V_{BAT} voltage is greater than 15.5V.

Therefore, to modify the voltage signal going to the EXT_BOOST pin, the following component network is used:

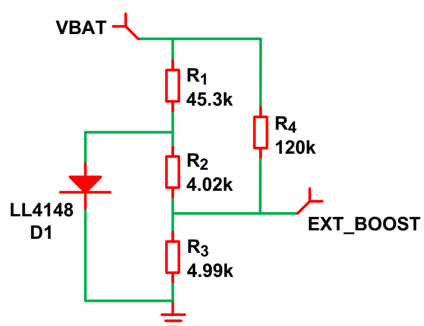


Figure 9. Proposed Component Network to Ensure Proper EXT_BOOST Pin Behavior

When the V_{BAT} voltage is 3V, current flows down the resistor divider, forward biases the diode, and sets the voltage on EXT_BOOST to be about 286mV at 25 ºC or about 260mV at 65 ºC. This data is based on simulation using the diode parameters given in the ON Semiconductors LL4148 diode datasheet (see Figures 17 and 18). As long as the voltage on EXT_BOOST pin is above the required 200mV threshold, the circuit starts up with the boost converter operating when V_{BAT} is 3.0V.

Table 2. EXT_BOOST and VBAT Thresholds

	VBAT (V)	EXT_BOOST (mV)
25ºC	3	285.5
	16.44	800
65ºC	3	259.8
	16.18	800

As the V_{BAT} voltage to the component network on the EXT_BOOST pin increases from 3V, the boost converter shuts off when the V_{BAT} voltage rises to about 16.44V at 25 ºC or about 16.18V at 65 ºC. This data is based on simulation using the diode characteristics from the plots of the diode behavior.

See “Appendix: Using the iSim PE Simulator Software to Help Design the EXT_BOOST Network” for more information about diode simulation.

3. Changing the ISL85403EVAL1Z Schematic to Support the Required Specifications

The boost-buck requirements are defined as V_{IN} (V_{BAT}) = 3Vto 24V, V_{OUT} = 12V, 1 A.

The ISL85403EVAL1Z evaluation board was modified to implement this design.

The ISL85403EVAL1Z User Guide has a component part listing.

Modify the following components in addition to the FET and EXT_BOOST components to enable the evaluation board to support the regulator specifications:

- Replace D_3 with a Schottky diode with higher current rating (6A or higher).
- Change C_5 and C_{60} to capacitors with higher voltage ratings so they can support the 12V output.

Table 3 is a listing of component changes:

Table 3. Recommended Component Replacements

Original Component	Replacement Component
Q_2	BSZ025N04LS
D_3	FSV15100V
L_1	22µH 7443551221
R_3	140k
C_{57}	47µF EEE-FK1K470P
C_5	100µF EMK325ABJ107MM-T
C_{60}	100µF T543D107K016ATE035

Figure 10 on page 10 shows the schematic of the evaluation board with the component changes noted in green.

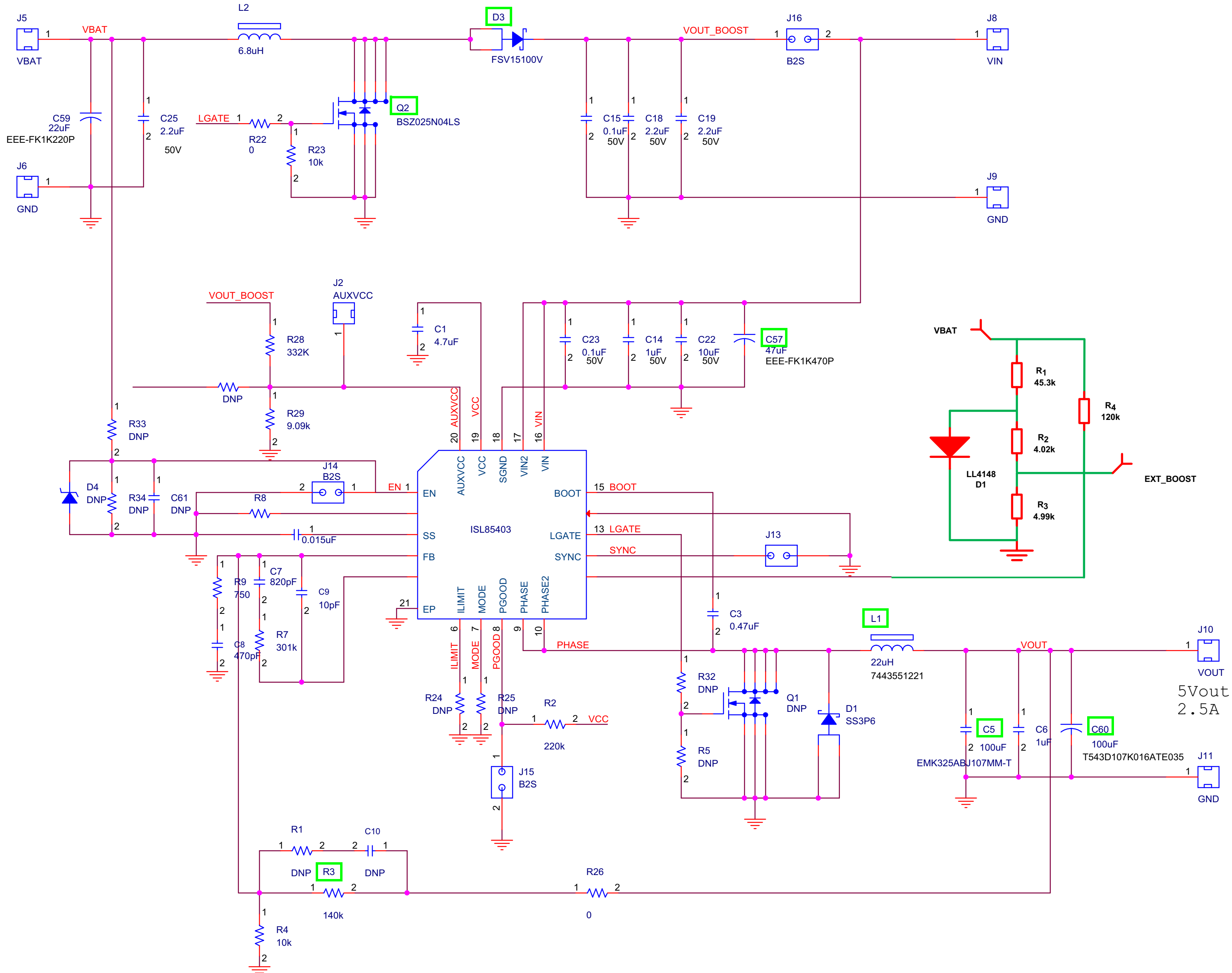


Figure 10. Modified Schematic of the ISL85403EVAL1Z for 12V, 1A Output

4. Measurement Results at 12V, 1A Output

This power circuit is specified to operate over an input voltage range of 3V to 24V. Based on testing, the circuit required 3.1V to start up but remained operating until the input voltage was reduced to 2.0V.

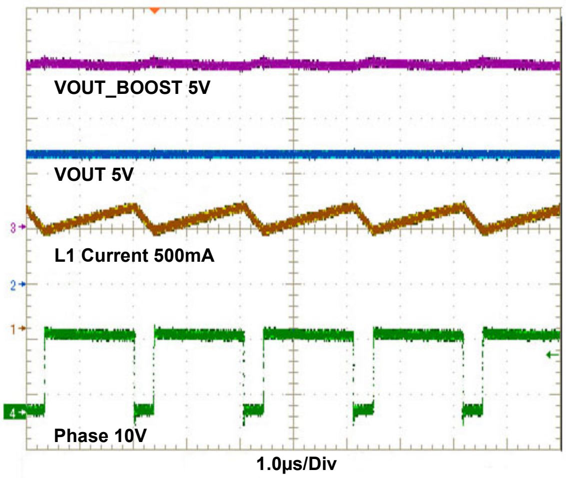


Figure 11. Steady State Waveforms (V_{IN} = 3V)

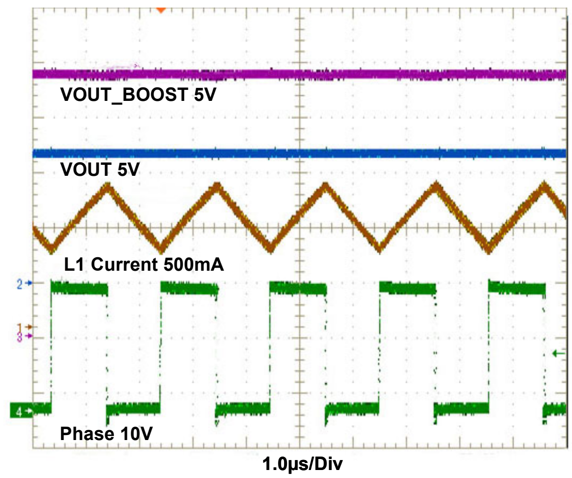


Figure 12. Steady State Waveforms (V_{IN} = 24V)

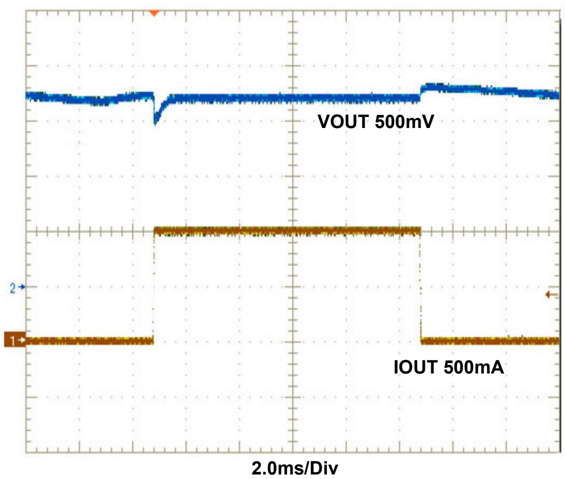


Figure 13. Load Transient (V_{IN} = 3V)

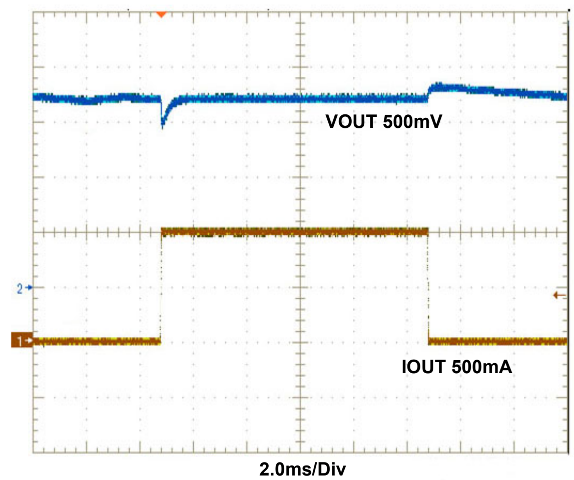


Figure 14. Load Transient (V_{IN} = 24V)

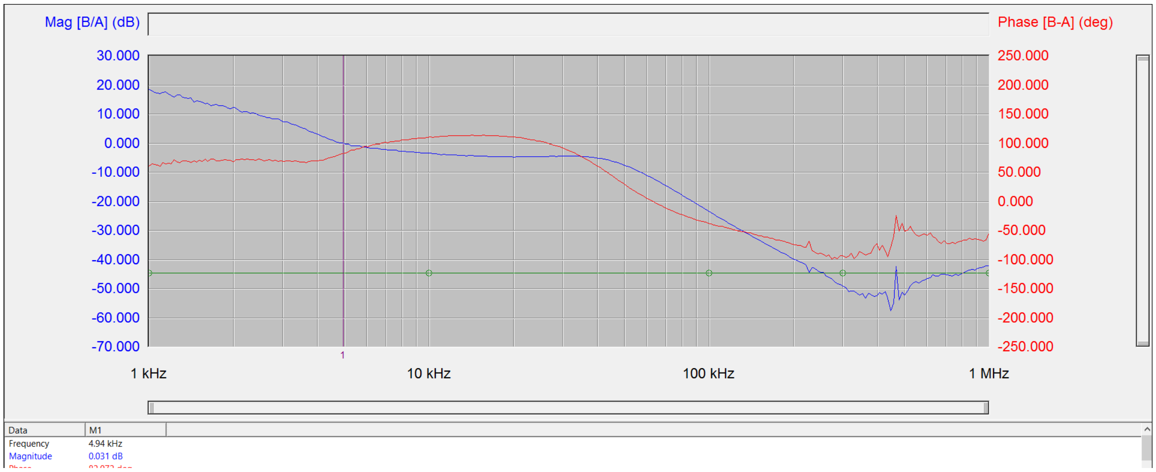


Figure 15. Loop Bode Plot (V_{IN} = 3V)

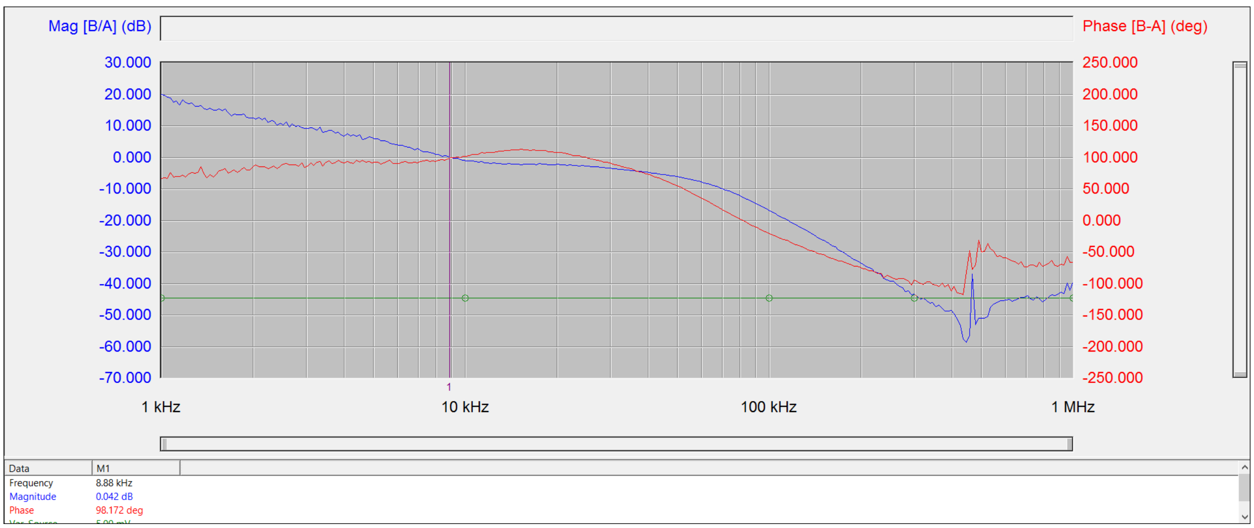


Figure 16. Loop Bode Plot (V_{IN} = 24V)

Table 4. Efficiency

Input Voltage (V)	Efficiency (%)
3	87.1
24	92.7

Note: The efficiency measurements were taken using the original FET on the ISL85403EVAL1Z evaluation board, not the new recommended FET with the lower gate charge threshold and lower ON-resistance.

5. Appendix: Using the iSim PE Simulator Software to Help Design the EXT_BOOST Network

In “Setting the Threshold Voltage on the EXT_BOOST Pin”, the components in Figure 9 on page 7 were used in the network on the EXT_BOOST pin.

The iSim PE simulator can provide a good estimate of the network behavior by means of simulation.

The LL4148 diode (ON Semiconductor) was used in the network. Its characteristics impact the behavior, especially over temperature.

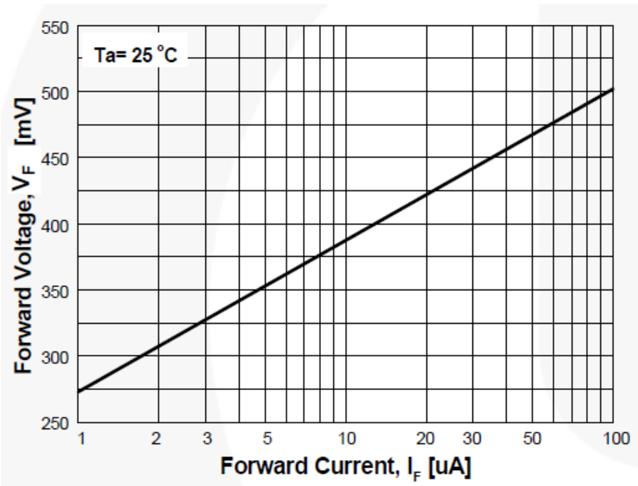


Figure 17. Forward Voltage vs Forward Current [5]

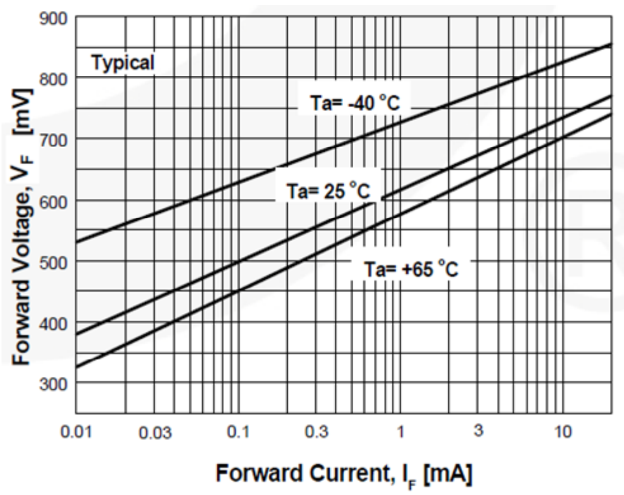


Figure 18. Forward Voltage vs Ambient Temperature [5]

The simulator software does not include a model for this diode but it is easy to make a simulator element to represent the diode because the ON Semiconductor LL4148 datasheet includes curves about the diode behavior.

Figures 17 and 18 from the ON Semiconductor LL4148 diode datasheet show the resistance of the diode for various current levels. The curves for 25 ºC and 65 ºC are also provided. Using the data in these curves you can construct a Piece Wise Linear (PWL) resistor in the PE simulator to model the diode at 25 ºC and 65 ºC.

The following data is obtained from the curves:

Table 5. PWL Resistor Setup to Model LL4148 Over-Temperature

Diode at 25ºC PWL Resistor	Diode at 65ºC PWL Resistor
0.310V at 2µA	0.325V at 10µA
0.375V at 10µA	0.360V at 20µA
0.420V at 20µA	0.380V at 30µA
0.440V at 30µA	0.400V at 40µA
0.457V at 40µA	-

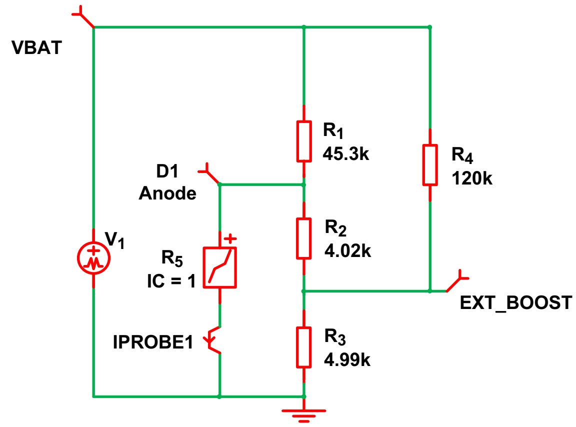


Figure 19. Simulation Schematic for the EXT_BOOST Network

In the simulation schematic of Figure 19, the LL4148 diode is represented by the PWL resistor R_5.

The parameters for the PWL resistor are taken from the LL4148 diode datasheet curves as shown in Table 5 on page 13. R_5 can be set up to first use the data at 25 °C. Voltage source V_1 is a PWL voltage source that can be set for any span of voltage to examine the behavior of the EXT_BOOST voltage at various inputs for the V_{BAT} voltage. Figure 20 shows an example simulation where the V_{BAT} voltage is changed from 1V to 18V.

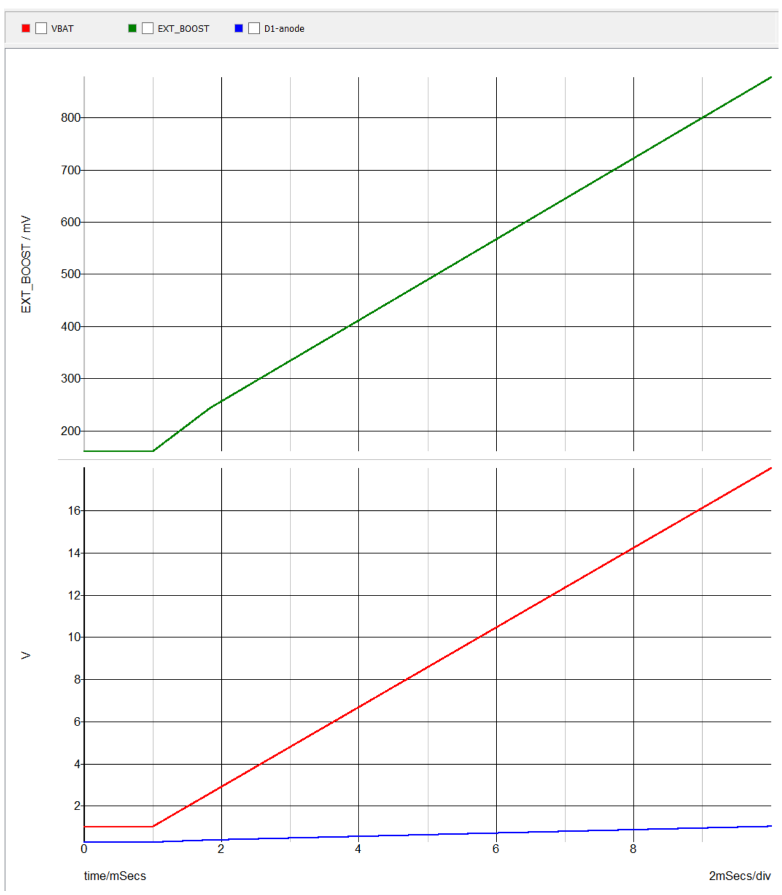


Figure 20. EXT_BOOST Voltage at Various V_{BAT} Voltages

6. References

(1) ISL85403 datasheet
(2) BSZ100N06LS3 G datasheet, Infineon
(3) BSZ025N04LS datasheet, Infineon
(4) ISL85403EVAL1Z User Guide
(5) LL4148 datasheet, ON Semiconductor

7. Revision History

Rev.	Date	Description
01.00	Mar 5, 2019	Initial release

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