

ISL85403

Achieving a Regulated Supply (5V or 12V) from an Input Range of 3V to 40V

Abstract

In voltage regulation applications, where input voltage can fluctuate or drop to a voltage lower than the required output voltage (such as a battery powered system), for a buck converter to provide a well-regulated output voltage, it is critical to detect the change in the input voltage and respond to it fast. Respond by either boosting up the input voltage first when it is too low, or running in buck-only mode when input is high enough for regular buck conversion. A conventional 2-stage boost buck converter can implement this functionality, but it typically requires two controller ICs. This application note introduces using a single ISL85403 to output most of the commonly seen voltage rails while accommodating, at a reasonable BOM cost, a wide range of operating input voltage from 3V to 40V. Two 12W evaluation boards for 5V and 12V outputs are also demonstrated.

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Related Literature

For a full list of related documents, visit our website:

- [ISL85403](#) device page

1. Theory of Operation

When the input voltage for a power supply varies or decreases significantly, it is necessary to boost it up whenever needed by turning on a boost converter, so that output regulation can be maintained. However, when the input voltage is adequate or resumes back to normal, the boost is not needed and therefore should be disabled. This can be achieved with a single control IC in the ISL85403. The ISL85403 is a synchronous buck controller integrated with a high-side MOSFET and both high-side and low-side drivers. However, it can be configured to control a boost buck converter as well. The low-side driver can drive a boost converter preceding a buck stage controlled by the same IC. This allows the IC to control a 2-stage boost buck converter. When the system input voltage drops to a level too low for the second stage buck converter to maintain regulation, the first stage boost converter can boost the input voltage up to keep the output voltage in regulation. This provides a reliable converter solution in applications that warrant support for a very wide input voltage range.

[Figure 1](#) shows a typical application circuit of a 2-stage boost buck converter. The EXT_BOOST pin is connected to the system input (oftentimes a battery) through a resistor divider. The EXT_BOOST pin monitors the boost input voltage to turn on and off the boost stage. When the input is high enough for the buck stage to regulate the output voltage, either at startup, or after the input recovers to normal from a decline, the boost stage is disabled. Select the threshold voltage to turn on the boost PWM (from low-side gate drive LGATE) with enough margin to cover the voltage drop of the boost inductor and diode, and the buck's maximum duty cycle and conduction drop, so that the buck converter is still in regulation before the boost kicks in and input voltage can be boosted up. The values of R1 and R2 set the boost turn-on threshold and hysteresis. The AUX VCC pin monitors the boost output voltage in a similar way. More detailed information can be found in the [ISL85403](#) datasheet.

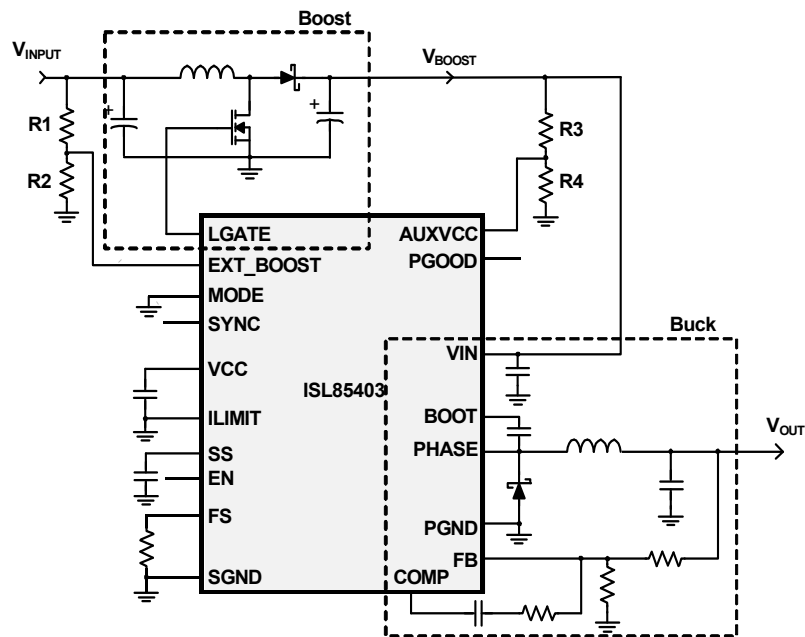


Figure 1. Boost Buck Converter using ISL85403

The steady stage DC transfer functions for the output voltage of the boost stage (V_{BOOST}) and the output of the buck stage (V_{OUT}) are:

$$\text{(EQ. 1)} \quad V_{\text{BOOST}} = \frac{1}{1-D} V_{\text{INPUT}}$$

$$\text{(EQ. 2)} \quad V_{\text{OUT}} = D V_{\text{BOOST}} = \frac{D}{1-D} V_{\text{INPUT}}$$

where V_{INPUT} is the system, or boost, input voltage.

The steady state boost output voltage can be derived using [Equations 1](#) and [2](#) as follows:

$$(EQ. 3) \quad V_{\text{BOOST}} = (1 - D)V_{\text{BOOST}} + DV_{\text{BOOST}} = V_{\text{INPUT}} + V_{\text{OUT}}$$

V_{OUTBST} is connected to the VIN pin of the IC, which is internally connected to a bias LDO to generate VCC; therefore, the IC can keep operating even when V_{INPUT} drops to a very low level.

Although a 2-stage configuration, this boost buck converter only requires one controller IC and one external MOSFET. Therefore, compared with the conventional ones, this configuration has lower BOM cost while supporting an equally wide input voltage range.

2. Design Considerations for Low Input Operation

The ISL85403 supports a 2-stage boost buck converter with an input voltage as low as 3V. However, there are some issues associated with this operating condition that need to be addressed.

2.1 2.1 Selecting the Boost MOSFET

When starting up at 3V, it is critical that the switching MOSFET of the boost stage can be fully turned on. Therefore, the gate charge waveforms and the output characteristics charts of a MOSFET need to be examined carefully when selecting the MOSFET. It is preferred to choose one with a gate charge chart where the plateau occurs at a voltage lower than 3V, although MOSFETs that meet this specification are limited. As a recommendation, the BSZ025N04LS by Infineon is a good choice. Not only can it switch on at 3V, it also has a low ON-resistance when fully turned on, which helps improve system efficiency in steady-state operation.

2.2 2.2 Setting the On/OFF Threshold for the Boost Stage

Another issue that needs to be considered is that, depending on the output voltage, the simple resistor divider on the EXT_BOOST pin may not be adequate to ensure proper turn-on and turn-off of the boost converter.

When powering up at a low input voltage, the voltage into the EXT_BOOST pin must be greater than 200mV for the boost converter to start up. When the input is high enough and the voltage into EXT_BOOST is greater than 800mV, the boost converter is disabled and only the buck stage operates.

If the boost converter needs to start at an input voltage of 3V, the lowest voltage the EXT_BOOST pin needs to see is 200mV. Then an 800mV voltage (4 times of the 200mV threshold) into this pin would mean an input voltage of 12V (4 times of 3V), which means only the buck stage can switch at 12V. However, if the targeted output voltage is 12V (or 9V to 10V considering all the overhead), regulation cannot be maintained. Therefore, a resistor divider is not sufficient for this kind of specification.

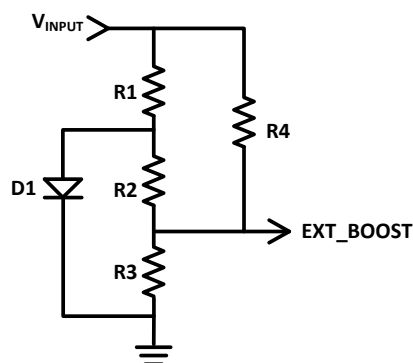


Figure 2. Component Network to Adjust Threshold Voltages for EXT_BOOST

[Figure 2](#) shows a component network that can be adjusted to ensure proper thresholds to turn on or turn off the boost converter. It replaces the resistor divider R1 and R2 in [Figure 1 on page 2](#). At power-up from the input, current flows through the resistor divider and forward biases the diode, which sets the voltage on the EXT_BOOST pin. Choose values for R1, R2, and R3 to ensure a greater than 200mV voltage on EXT_BOOST at

the low end of the input voltage range. R4 is a large value resistor that pulls minimum current when the input voltage is low. As input goes up, R4 pulls more current and voltage on EXT_BOOST increases. Therefore, R4 can be adjusted to set the input voltage where EXT_BOOST sees 800mV and the boost converter is disabled.

Note: The forward voltage of the diode changes across temperature; therefore, the resistor values need to yield proper threshold voltages over the entire operating temperature range specified for the application, based on the characteristics of the diode. Detailed instruction about how to design such a network can be seen in the [R16ZZ0001](#) *Tips for Using the ISL85403 in Boost-Buck Mode*.

3. Application Examples

As examples, two evaluation boards using the ISL85403 in the 2-stage boost buck configuration are provided, one for a 5.0V output voltage (ISL85403EVAL1Z) and the other for a 12V output voltage (ISL85403EVAL3Z). Both examples support an input range from 3V to 40V and an output power up to 12W.

Pictures for the two evaluation boards, ISL85403EVAL1Z and ISL85403EVAL3Z, can be seen in [Figures 3](#) and [4](#). They are designed for the specifications listed below:

Specification	ISL85403EVAL1Z	ISL85403EVAL3Z
Input Voltage (V _{IN})	3V to 40V	3V to 40V
Output Voltage (V _{OUT})	5.0V	12.0V
Maximum Output Current (I _{OUT_MAX})	2.5A	1A

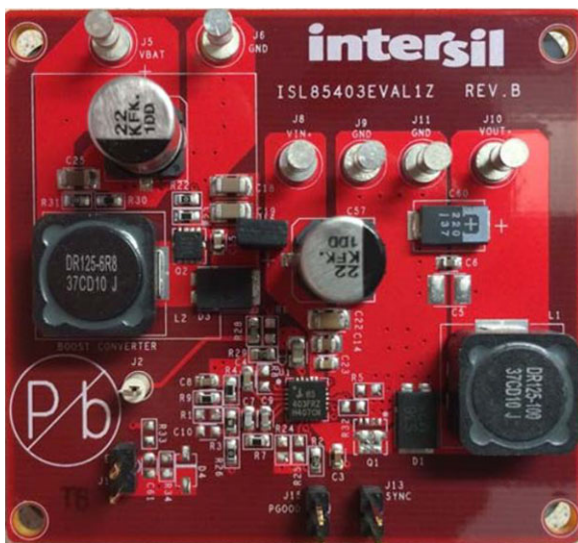


Figure 3. ISL85403EVAL1Z Board

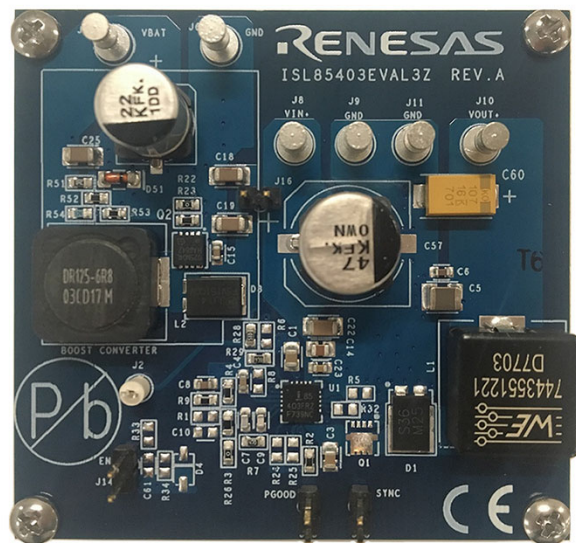


Figure 4. ISL85403EVAL3Z Board

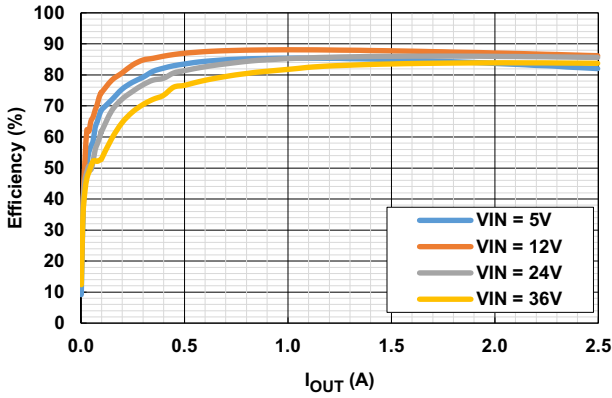


Figure 5. ISL85403EVAL1Z Efficiency vs Load

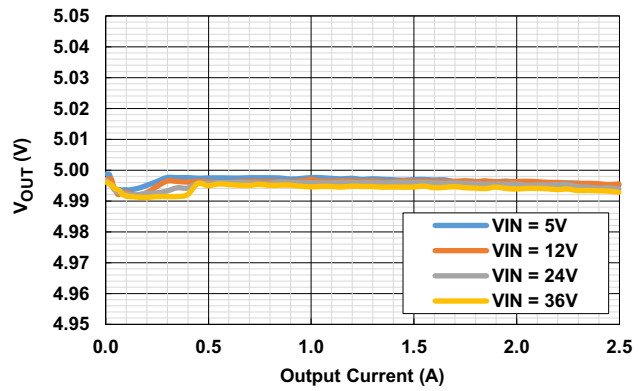


Figure 6. ISL85403EVAL1Z Output Voltage vs Load

Figures 5 and 6 show efficiency and regulation performance of the 5V converter on ISL85403EVAL1Z. Figures 7 and 8 show efficiency and regulation performance of the 12V converter on ISL85403EVAL3Z.

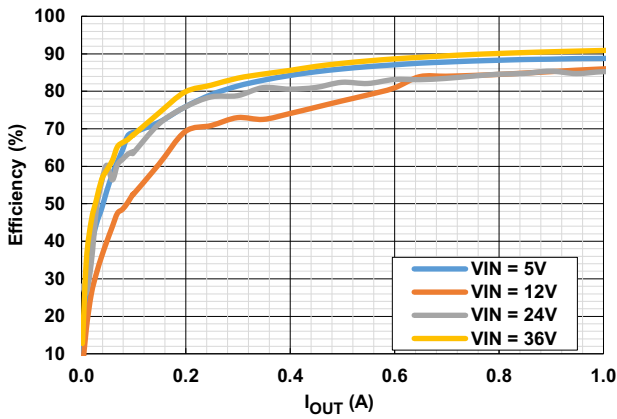


Figure 7. ISL85403EVAL3Z Efficiency vs Load

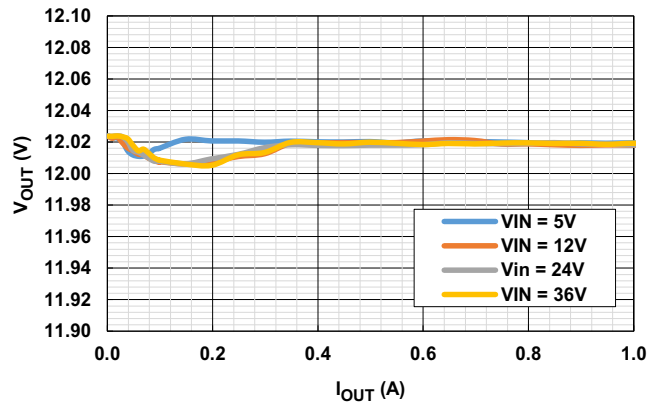


Figure 8. ISL85403EVAL3Z Output Voltage vs Load

Figure 9 shows the schematic of the ISL85403EVAL1Z, and Figure 10 shows the schematic of ISL85403EVAL3Z.

In ISL85403EVAL1Z, it can be seen that a simple resistor divider sets the voltage on the EXT_BOOST pin. This is sufficient in this application where the output voltage is 5V and the minimum input voltage is 3V. At 3V input, EXT_BOOST sees 293mV, which is well above the required 200mV to start up the boost stage. When the voltage at EXT_BOOST is 800mV, the corresponding input voltage is 8.2V, where enough headroom is present to allow the converter to run in Buck mode only.

In the ISL85403EVAL3Z where the output voltage is 12V, the component network illustrated in Figure 2 on page 3 needs to be included in this application. The LL4148 by On Semiconductors is used as the diode in the network, and based on its characteristics, the resistor values are chosen as follows:

R1	R2	R3	R4
45.3k	4.02k	4.99k	120k

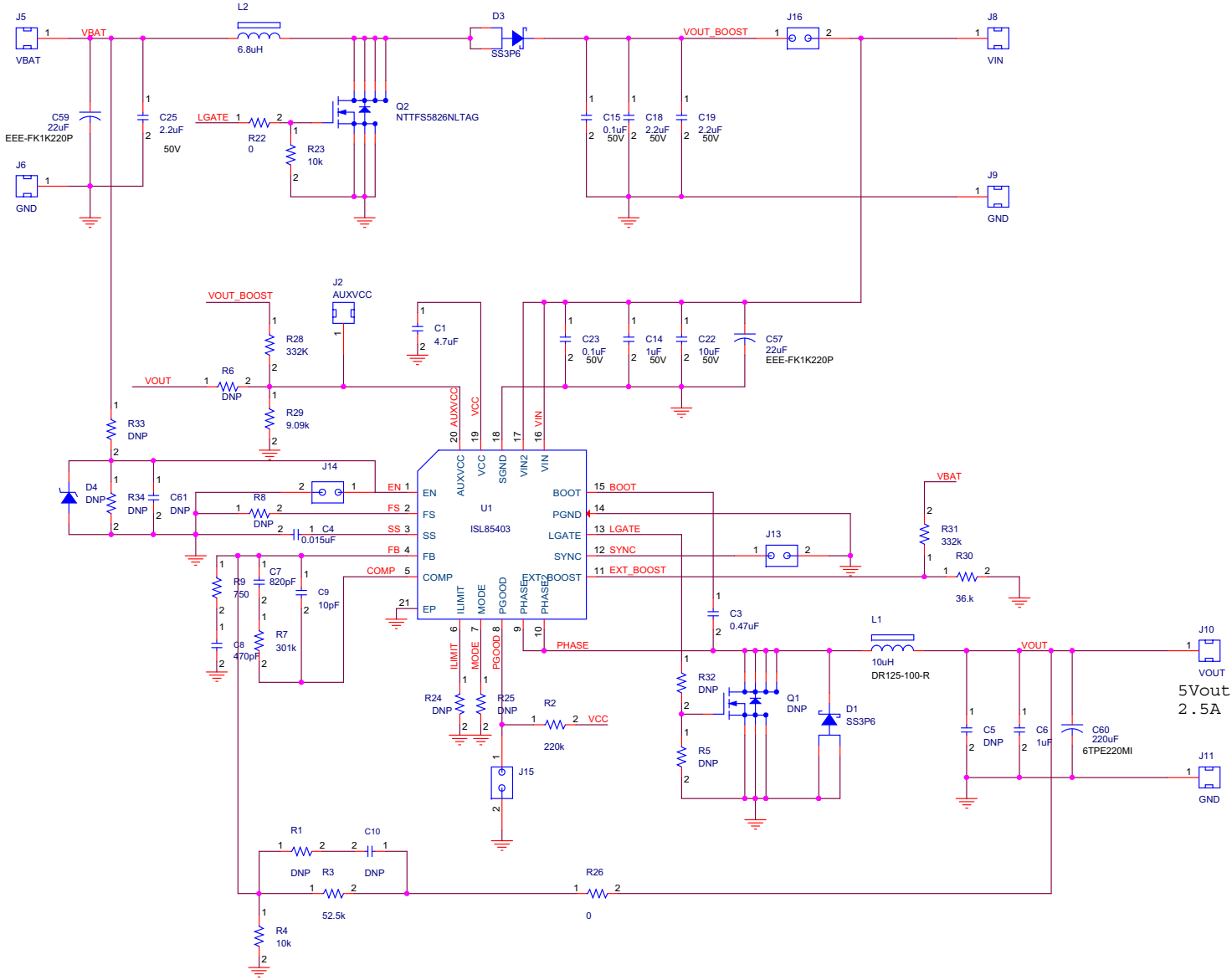


Figure 9. ISL85403EVAL1Z Schematic

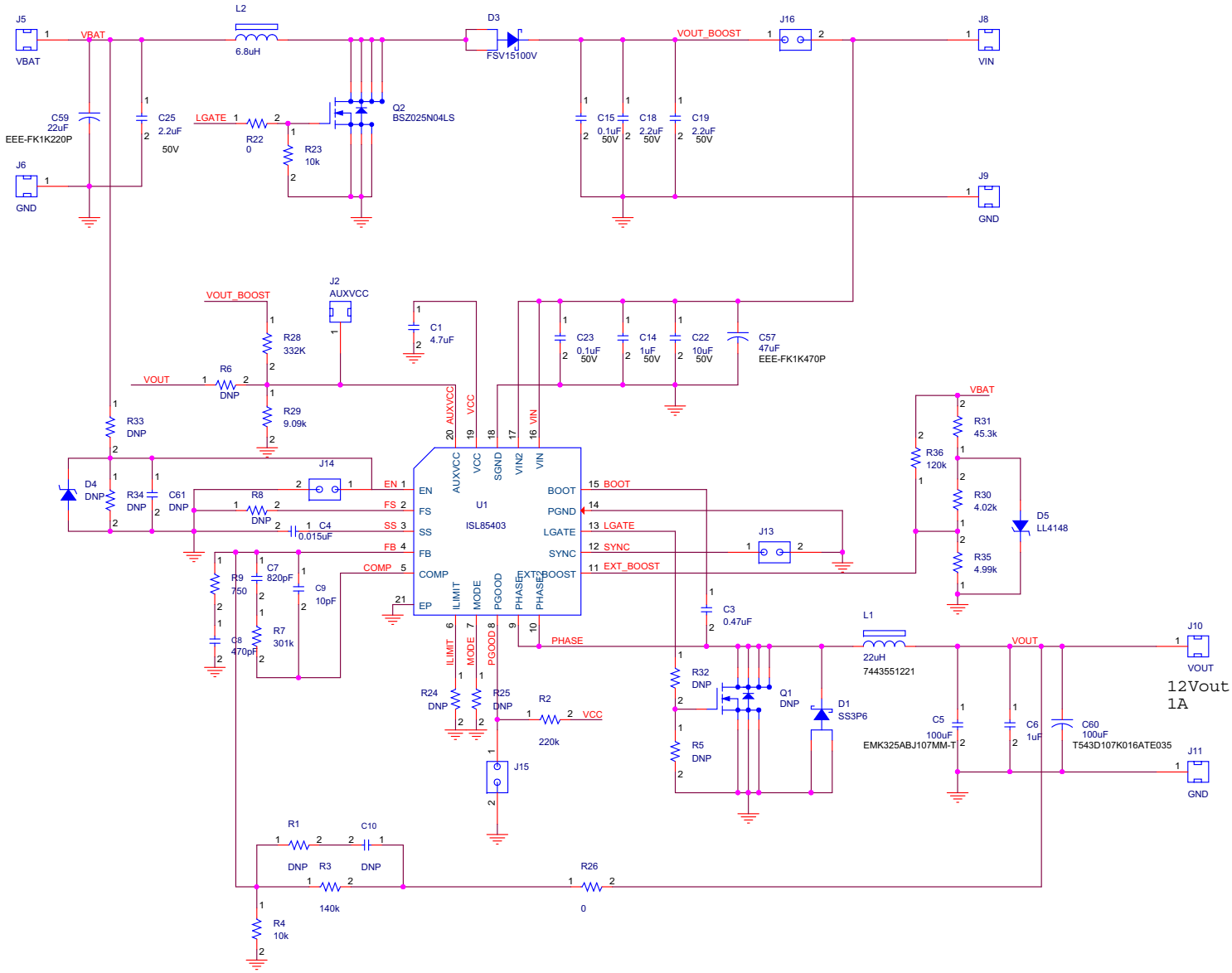


Figure 10. ISL85403EVAL3Z Schematic

As a result, the voltage thresholds to turn on and off the boost stage are set as the following:

Temperature	V _{Battery} (V)	EXT_BOOST (mV)
25°C	3	286
	16.38	800
65°C	3	260
	16.125	800

Note: The input voltage at which the boost converter is disabled is set above 16V to account for the maximum duty cycle of the buck converter and to cover voltage drop from components such as the boost diode and inductor.

The following are the bill of materials for these two boards.

Table 1. ISL85403EVAL1Z Bill of Materials

Ref Des	Part Number	Qty	Description	Manufacturer
C6	C1608X7R1C105K	1	CAP, SMD, 0603, 1.0µF, 16V, 10%, X7R, ROHS	TDK
C57, 59	EEE-FK1K220P	2	CAP, SMD, 8X10.2, 22µF, 80V, 20%, ALUM.ELEC., ROHS	Panasonic
C9	Various	1	CAP, SMD, 0603, 10pF, 50V, 5%, C0G, ROHS	Various
C15, C23	Various	1	CAP, SMD, 0603, 0.1µF, 50V, 10%, X7R, ROHS	Various
C4	Various	1	CAP, SMD, 0603, 0.015µF, 50V, 10%, X7R, ROHS	Various
C8	Various	1	CAP, SMD, 0603, 470pF, 50V, 5%, NP0, ROHS	Various
C3	C1608X7R1H474K	1	CAP, SMD, 0603, 0.47µF, 50V, 10%, X7R, ROHS	TDK
C7	Various	1	CAP, SMD, 0603, 820pF, 50V, 5%, C0G, ROHS	Various
C14	Various	1	CAP, SMD, 0805, 1.0µF, 50V, 10%, X7R, ROHS	Various
C1	0805ZD475KAT2A	1	CAP, SMD, 0805, 4.7µF, 10V, 10%, X5R, ROHS	AVX
C22	Various	1	CAP, SMD, 1206, 10µF, 50V, 10%, X5R, ROHS	Various
C18, C19, C25	GRM31CR71H225KA88L	3	CAP, SMD, 1206, 2.2µF, 50V, 10%, X7R, ROHS	Murata
C60	6TPE220MI	1	CAP-POSCAP, SMD, 7.3x4.3x1.8, 220µF, 6.3V, 20%, 18mΩ, ROHS	Sanyo
L1	DR125-100-R	1	COIL-PWR INDUCTOR, SMD, 12.5mm, 10µH, 20%, 5.35A, ROHS	Coiltronics
L2	DR125-6R8-R	1	COIL-PWR INDUCTOR, SMD, 12.5mm, 6.8µH, 20%, 6.64A, ROHS	Coiltronics
D1, D3	SS6P3LHM3/86A	2	DIODE-SCHOTTKY RECTIFIER, SMD, SMPC, 60V, 3A, ROHS	Vishay
U1	ISL85403IRZ	1	IC-SWITCHING REGULATOR, 20P, QFN, 4X4, ROHS	Renesas
Q2	BSZ100N06LS3G	1	TRANSIST-MOS, N-CHANNEL, 8P, PG-TSDSON-8, 60V, 20A, ROHS	Infineon
R2	Various	1	RES, SMD, 0603, 220k, 1/10W, 1%, TF, ROHS	Various
R3	Various	1	RES, SMD, 0603, 52.3k, 1/10W, 1%, TF, ROHS	Various
R4, R23	Various	2	RES, SMD, 0603, 10k, 1/10W, 1%, TF, ROHS	Various
R7	Various	1	RES, SMD, 0603, 301k, 1/10W, 1%, TF, ROHS	Various
R9	Various	1	RES, SMD, 0603, 750Ω, 1/10W, 1%, TF, ROHS	Various
R22, R26	Various	2	RES, SMD, 0603, 0Ω, 1/10W, TF, ROHS	Various
R28, R31	Various	2	RES, SMD, 0603, 332k, 1/10W, 1%, TF, ROHS	Various
R29	Various	1	RES, SMD, 0603, 9.09k, 1/10W, 1%, TF, ROHS	Various
R30	Various	1	RES, SMD, 0603, 36k, 1/10W, 1%, TF, ROHS	Various

Table 1. ISL85403EVAL1Z Bill of Materials (Continued)

Ref Des	Part Number	Qty	Description	Manufacturer
R1, R5, R6, R8, R24, R25, R32, R33, R34, C5, C10, C61, D4, Q1	N/A	0	Do not populate	N/A

Table 2. ISL85403EVAL3Z Bill of Materials

Ref Des	Part Number	Qty	Description	Manufacturer
C5	EMK325ABJ107MM-T	1	CAP, SMD, 1210, 100µF, 16V, 20%, X5R, ROHS	
C6	C1608X7R1C105K	1	CAP, SMD, 0603, 1.0µF, 16V, 10%, X7R, ROHS	TDK
C57	EEE-FK1K470P	1	CAP, SMD, 10X10.2, 47µF, 80V, 20%, ALUM.ELEC., ROHS	Panasonic
C59	EEE-FK1K220P	1	CAP, SMD, 8X10.2, 22µF, 80V, 20%, ALUM.ELEC., ROHS	Panasonic
C9	Various	1	CAP, SMD, 0603, 10pF, 50V, 5%, C0G, ROHS	Various
C15, C23	Various	1	CAP, SMD, 0603, 0.1µF, 50V, 10%, X7R, ROHS	Various
C4	Various	1	CAP, SMD, 0603, 0.015µF, 50V, 10%, X7R, ROHS	Various
C8	Various	1	CAP, SMD, 0603, 470pF, 50V, 5%, NP0, ROHS	Various
C3	C1608X7R1H474K	1	CAP, SMD, 0603, 0.47µF, 50V, 10%, X7R, ROHS	TDK
C7	Various	1	CAP, SMD, 0603, 820pF, 50V, 5%, C0G, ROHS	Various
C14	Various	1	CAP, SMD, 0805, 1.0µF, 50V, 10%, X7R, ROHS	Various
C1	0805ZD475KAT2A	1	CAP, SMD, 0805, 4.7µF, 10V, 10%, X5R, ROHS	AVX
C22	Various	1	CAP, SMD, 1206, 10µF, 50V, 10%, X5R, ROHS	Various
C18, C19, C25	GRM31CR71H225KA8 8L	3	CAP, SMD, 1206, 2.2µF, 50V, 10%, X7R, ROHS	Murata
C60	T543D107K016ATE035	1	CAP-TANTALUM, SMD, 2917, 100µF, 16V, 10%, 35mΩ, ROHS	Kemet
L1	7443551221	1	22uH SHIELDED WIREWOUND INDUCTOR, 6A,24.7mOhm	Würth
L2	DR125-6R8-R	1	COIL-PWR INDUCTOR, SMD, 12.5mm, 6.8µH, 20%, 6.64A, ROHS	Coiltronics
D1	SS6P3LHM3/86A	1	DIODE-SCHOTTKY RECTIFIER, SMD, SMPC, 60V, 3A, ROHS	Vishay
D3	FSV15100V	1	DIODE-SCHOTTKY, 100V, 15A, TO-277-3	ON Semi
D5	LL4148	1	DIODE, 100V, 200mA, SOD80	ON Semi
U1	ISL85403IRZ	1	IC-SWITCHING REGULATOR, 20P, QFN, 4X4, ROHS	Renesas
Q2	BSZ100N06LS3G	1	TRANSIST-MOS, N-CHANNEL, 8P, PG-TSDSON-8, 60V, 20A, ROHS	Infineon
R2	Various	1	RES, SMD, 0603, 220k, 1/10W, 1%, TF, ROHS	Various
R3	Various	1	RES, SMD, 0603, 140k, 1/10W, 1%, TF, ROHS	Various
R4, R23	Various	2	RES, SMD, 0603, 10k, 1/10W, 1%, TF, ROHS	Various
R7	Various	1	RES, SMD, 0603, 301k, 1/10W, 1%, TF, ROHS	Various
R9	Various	1	RES, SMD, 0603, 750Ω, 1/10W, 1%, TF, ROHS	Various
R22, R26	Various	2	RES, SMD, 0603, 0Ω, 1/10W, TF, ROHS	Various
R28	Various	1	RES, SMD, 0603, 332k, 1/10W, 1%, TF, ROHS	Various
R29	Various	1	RES, SMD, 0603, 9.09k, 1/10W, 1%, TF, ROHS	Various
R30	Various	1	RES, SMD, 0603, 4.02k, 1/10W, 1%, TF, ROHS	Various
R31	Various	1	RES, SMD, 0603, 45.3k, 1/10W, 1%, TF, ROHS	Various
R35	Various	1	RES, SMD, 0603, 4.99k, 1/10W, 1%, TF, ROHS	Various

Table 2. ISL85403EVAL3Z Bill of Materials (Continued)

Ref Des	Part Number	Qty	Description	Manufacturer
R36	Various	1	RES, SMD, 0603, 120k, 1/10W, 1%, TF, ROHS	Various
R1, R5, R6, R8, R24, R25, R32, R33, R34, C10, C61, D4, Q1	N/A	0	Do not populate	N/A

4. Conclusion

The ISL85403 by Renesas is a versatile regulator IC that can be used not only as a conventional buck controller, but also as a boost buck controller, which accommodates a wide range of input voltage while reliably maintaining output regulation. It also has comprehensive protections against various faults including overcurrent, overvoltage and over-temperature, which makes it a robust solution in a large variety of applications.

5. Revision History

Rev.	Date	Description
1.00	Aug.29.19	Initial release

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