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ROHM Switching Regulator Solutions

Evaluation Board: 7.5V to 18V, 6A Integrated MOSFET 1ch Synchronous Buck DC/DC Converter

BD95861MUVEVK-101 (5V | 6A Output)

No.000000000

● Introduction

This application note will provide the steps necessary to operate and evaluate ROHM's synchronous buck DC/DC converter using the BD95861MUV evaluation boards. Component selection, board layout recommendations, operation procedures and application data is provided.

● Description

This evaluation board has been developed for ROHM's synchronous buck DC/DC converter customers evaluating BD95861MUV. While accepting a wide power supply of 7.5-18V, an output of 0.8V to 5.5V can be produced. The IC has internal 50mohm high-side Nch MOSFET and 30mohm low-side Nch MOSFET and a synchronization frequency range of 500 kHz to 800 kHz. A fixed Soft Start circuit prevents in-rush current during startup along with UVLO (low voltage error prevention circuit) and TSD (thermal shutdown detection) protection circuits. An EN pin allows for simple ON/OFF control of the IC to reduce standby current consumption. Include open-drain PGOOD_LED feature for operation indication, OCP, SCP, OVP.

● Applications

- LCD TVs
- Set Top Boxes (STB)
- DVD/Blu-ray players/recorders
- Broadband Network and Communication Interface
- Amusement, other

● Evaluation Board Operating Limits and Absolute Maximum Ratings (T_A=25°C)

Parameter	Symbol	Limit			Unit	Conditions	
		MIN	TYP	MAX			
Supply Voltage							
	BD95861MUV	V _{CC}	7.5	-	18	V	
Output Voltage / Current							
	BD95861MUV	V _{OUT}	0.8	-	5.5	V	* Set by R ₂ ,R ₃ and R ₄
		I _{OUT}	-	-	6	A	

● Evaluation Board

Below is the evaluation board with the BD95861MUV.

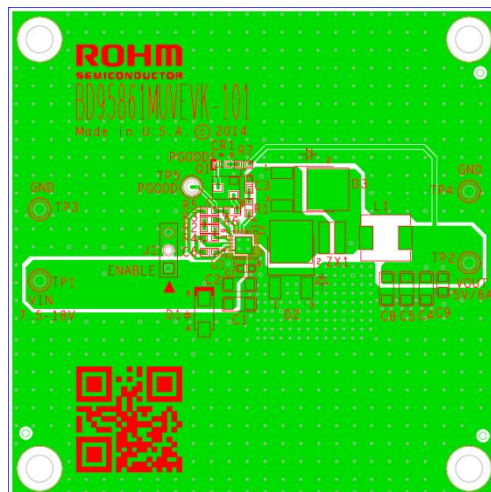


Fig 1: BD95861MUV Evaluation Board

● Evaluation Board Schematic

Below is the evaluation board schematic for BD95861MUV.

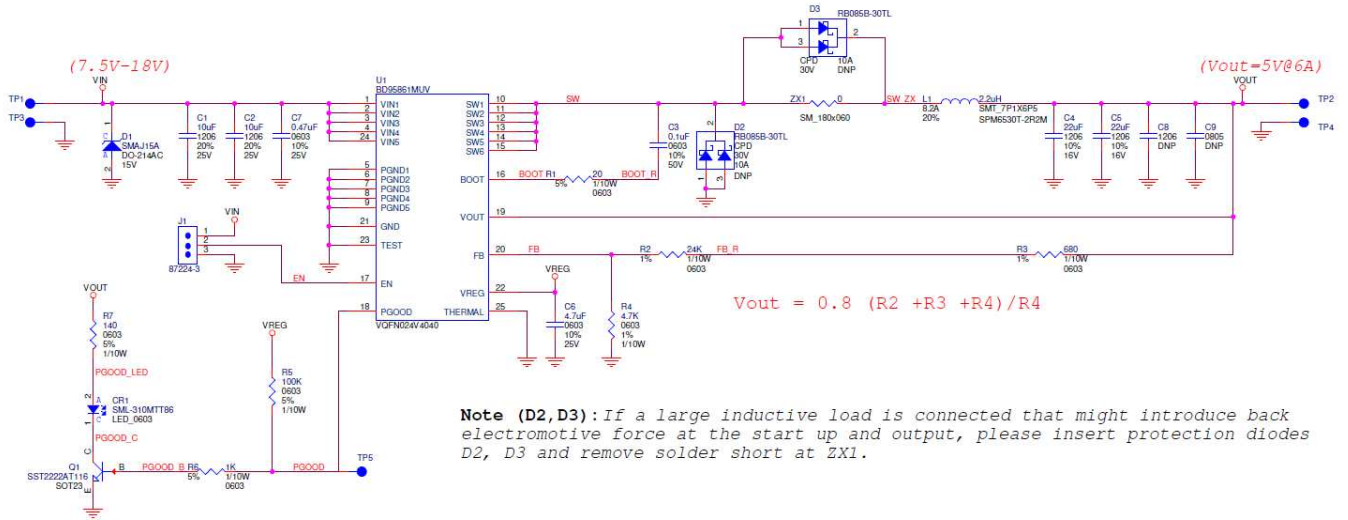


Fig 2: BD95861MUV Evaluation Board Schematic

● Evaluation Board I/O

Below is the reference application circuit that shows the inputs (V_{IN} and EN) and the outputs (V_{OUT} and PGOOD)

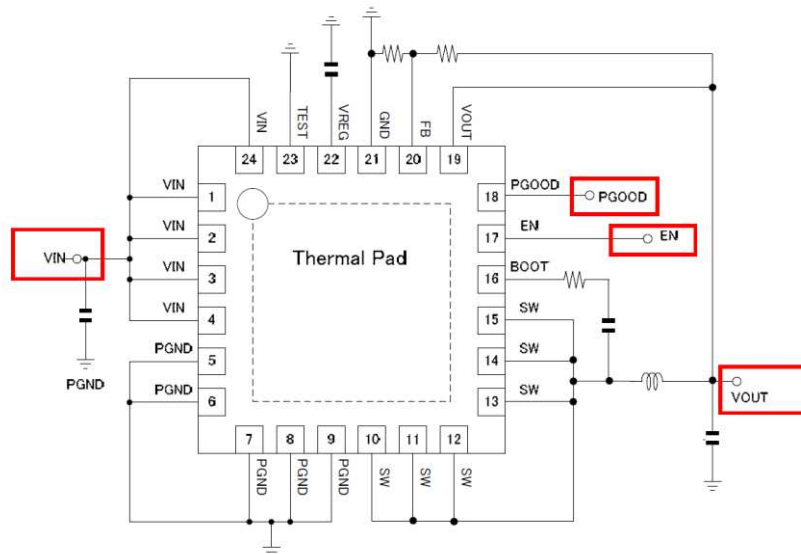


Fig 3: BD95861MUV Evaluation Board I/O

● Evaluation Board Operation Procedures

Below is the procedure to operate the evaluation board

1. Connect power supply's GND terminal to GND test point TP3 on the evaluation board.
2. Connect power supply's V_{CC} terminal to V_{IN} test point TP1 on the evaluation board. This will provide V_{IN} to the IC U1. Please note that the V_{CC} should be in range of 7.5V to 18V.
3. Check if shunt jumper of J1 is at position ON (Pin2 connect to Pin1, EN pin of IC U1 is pulled high as default).
4. Now the output voltage V_{OUT} (+5V) can be measured at the test point TP2 on the evaluation board with a load attached. The load can be increased up to 6A MAX.

● **Reference Application Data for BD95861MUVEVK-101**

The following graphs show hot plugging test, circuit quiescent current, efficiency, load response, output voltage ripple response of the BD95861MUV evaluation board.

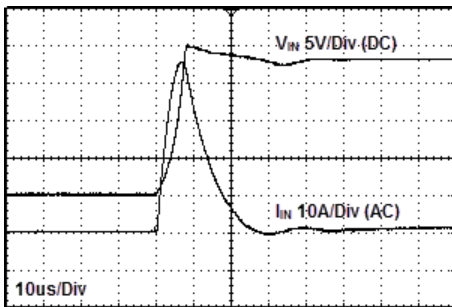


Fig 4: Hot Plug-in Test with Zener Diode SMAJ15A, $V_{IN}=18V$, $V_{OUT}=5V$, $I_{OUT}=6A$

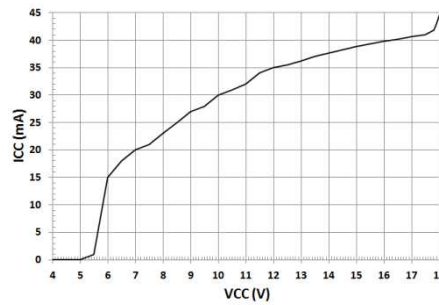


Fig 5: Circuit Current vs. Power supply Voltage Characteristics (Temp=25°C)

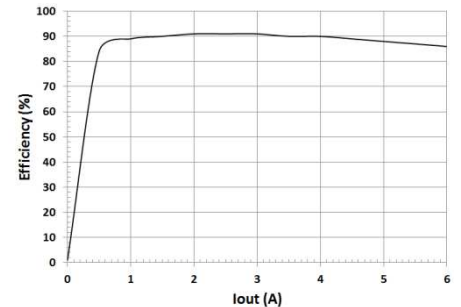


Fig 6: Electric Power Conversion Rate $V_{IN}=12V$, $V_{OUT}=5V$

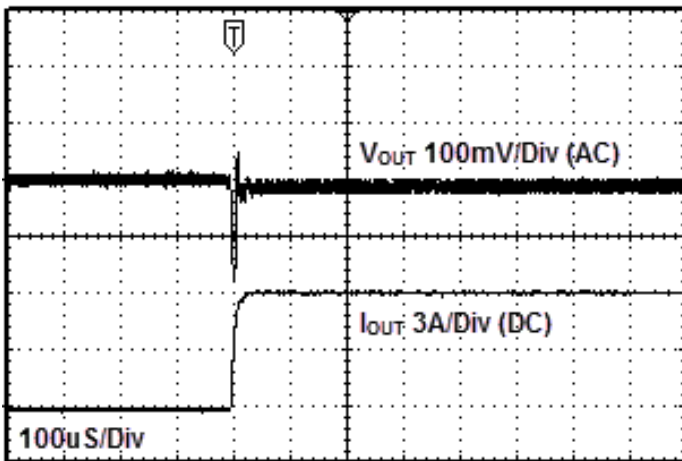


Fig 7: Load Response Characteristics ($V_{IN}=12V$, $V_{OUT}=5V$, $L=2.2\mu H$, $C_{OUT}=44\mu F$, $I_{OUT}=0A \rightarrow 6A$)

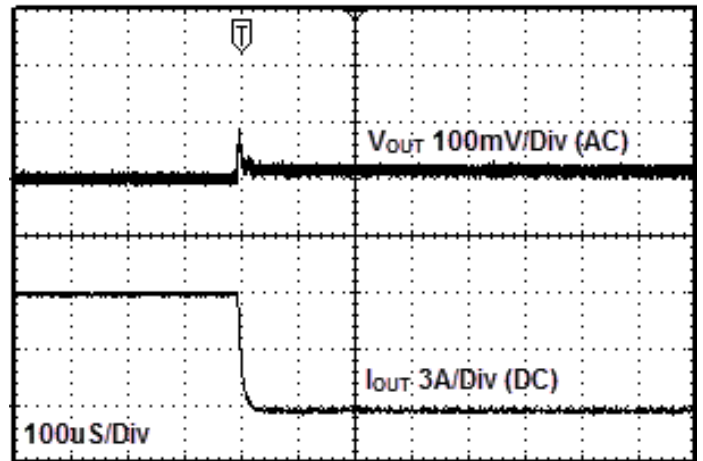


Fig 8: Load Response Characteristics ($V_{IN}=12V$, $V_{OUT}=5V$, $L=2.2\mu H$, $C_{OUT}=44\mu F$, $I_{OUT}=6A \rightarrow 0A$)

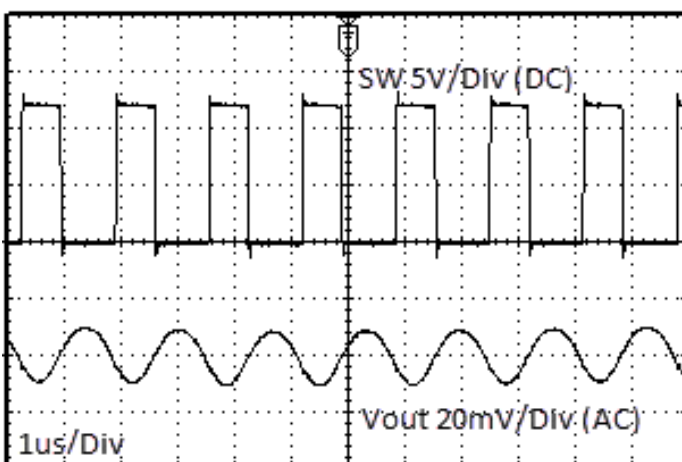


Fig 9: Output Voltage Ripple Response Characteristics ($V_{IN}=12V$, $V_{OUT}=5V$, $L=2.2\mu H$, $C_{OUT}=44\mu F$, $I_{OUT}=0A$)

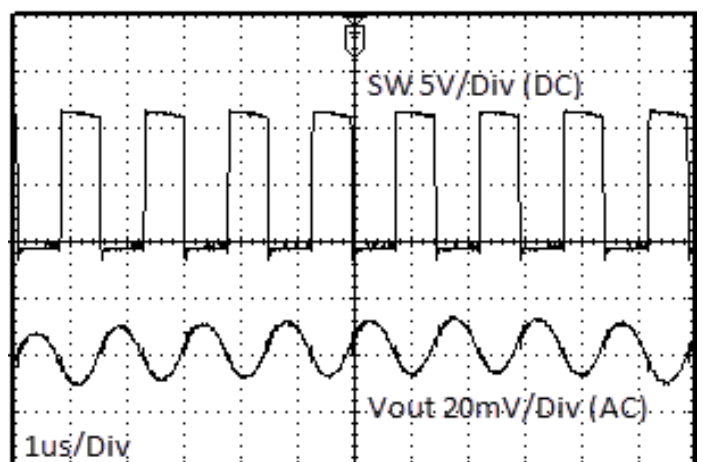


Fig 10: Output Voltage Ripple Response Characteristics ($V_{IN}=12V$, $V_{OUT}=5V$, $L=2.2\mu H$, $C_{OUT}=44\mu F$, $I_{OUT}=6A$)

● Evaluation Board Layout Guidelines

Below are the guidelines that have been followed and recommended for BD95861MUV designs

Layout is a critical portion of good power supply design. There are several signals path that conduct fast changing currents or voltage that can interact with stray inductance or parasitic capacitance to generate noise or degrade the power supplies performance. To help eliminate these problems, the VCC pin should be bypassed to ground with a low ESR ceramic bypass capacitor with B dielectric.

Two high pulsing current flowing loops exist in the buck regulator system:

1. The first loop, when FET is ON, starts from the input capacitors, to the V_{IN} terminal, to the SW terminal, to the inductor, to the output capacitors, and then returns to the input capacitor through GND.
2. The second loop, when FET is OFF, starts from the low FET, to the inductor, to the output capacitor, and then returns to the low FET through GND.

To reduce the noise and improve the efficiency, please minimize the areas of the two loops. The input and output capacitors should be connected to the GND (PGND) planes.

The PCB layout design will affect the thermal performance, noise and efficiency of the system. So please take extra care when designing PCB Layout patterns.

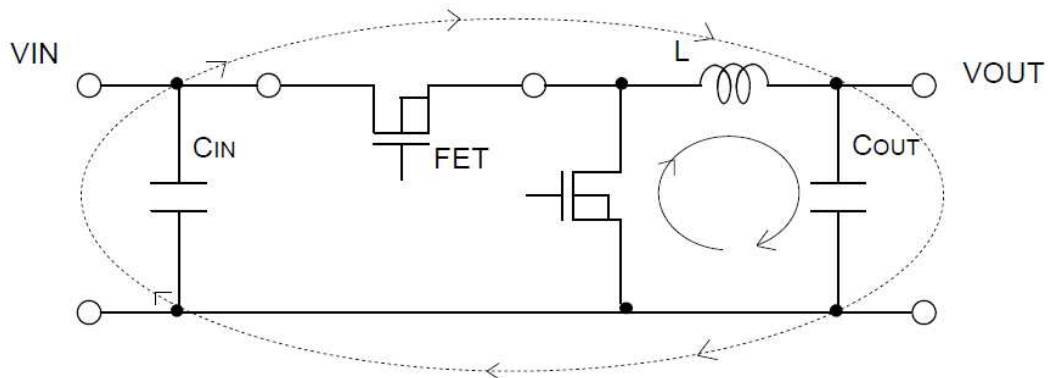


Fig 11: Current loop Buck regulator system

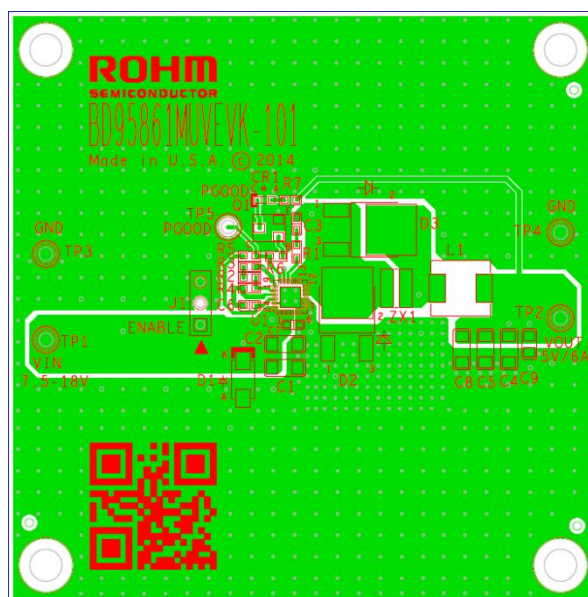


Fig 12: BD95861MUVEVK-101 PCB layout

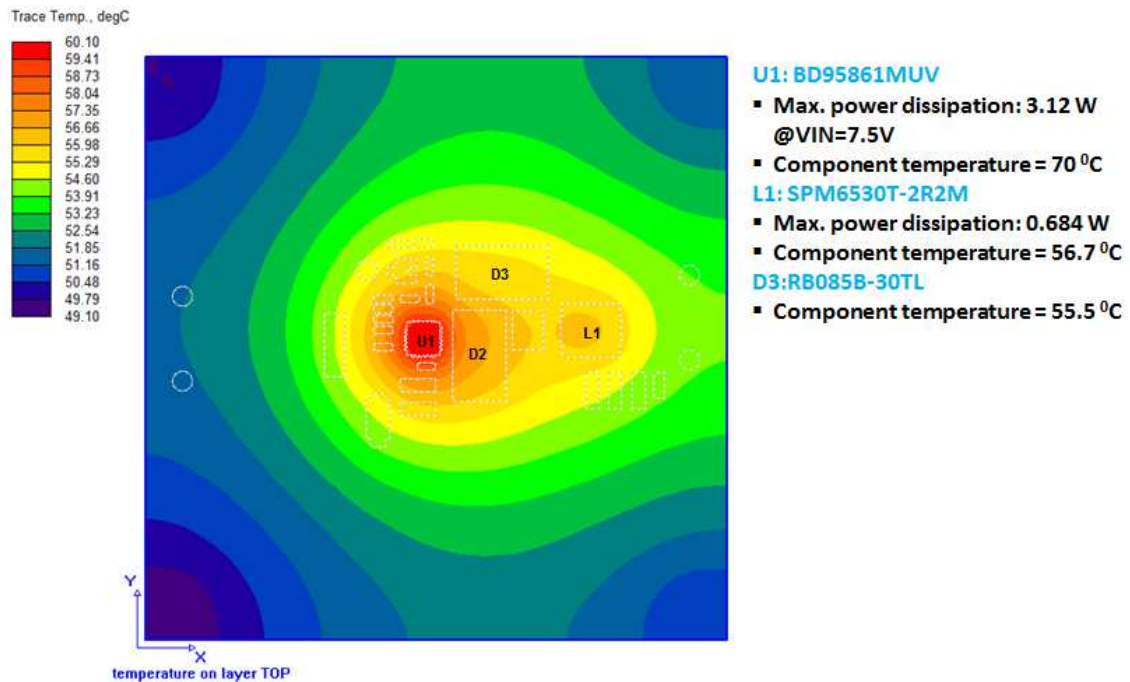


Fig 13: BD95861MUVEVK-101 Thermal Characteristics at Temp=25°C, no air flow, $V_{IN}=7.5V$, $V_{OUT}=5V$, $I_{OUT}=6A$ and D2&D3 not installed

Thermal note: If the board is operated above room temperature ($T > 25^{\circ}C$) OR with 2 DNP diodes D2&D3 installed, an active cooling source (fan) or heat sink (soldered to bottom of PCB) need to be added.

Additional layout notes:

- The thermal Pad on the back side of IC has the great thermal conduction to the chip. So using the GND plane as broad and wide as possible can help thermal dissipation. And a lot of thermal via for helping the spread of heat to the different layer is also effective.
- The input capacitors should be connected to PGND as close as possible to the VIN terminal.
- The inductor and the output capacitors should be placed close to SW pin as much as possible.
- For applications operating at or near maximum voltage conditions (18V max), additional precautions regarding heat dissipation need to be considered during board layout. The provided evaluation board is a 4-layer board meant for evaluation purposes only. At maximum conditions, the IC's internal thermal shutdown detection circuit will be potentially initiated and the output disabled until the junction temperature falls. For final designs operating near these conditions, we recommend using one of the below PCB options for better heat dissipation of the IC.
 - 1) Use of a 4-layer PCB with internal GND planes connected to the IC GND pins
 - 2) Use of a 2-layer PCB with a heat sink attached to the IC package
 - 3) Use of a 2-layer PCB with a copper plane (>1oz) attached to the IC

● Calculation of Application Circuit Components

1. Output LC Filter Selection (Buck Converter)

1-1. Inductor (L) Selection

The Output LC filter is required to supply constant current to the output load. A larger value inductance at this filter results in less inductor ripple current (ΔI_L) and less output ripple voltage. However, the larger value inductors tend to have a slower load transient-response, a larger physical size, a lower saturation current and higher series resistance. A smaller value inductance has almost opposite characteristics above.

The value of ΔI_L is shown as formula below.

$$\Delta I_L = \frac{(V_{IN} - V_{OUT}) \times V_{OUT}}{L \times f \times V_{IN}} \quad [A]$$

The inductor saturation current must be larger than the sum of the maximum output current (I_{OUTMAX}) and 1/2 of the inductor ripple current ($\Delta I_L / 2$). A larger current than the inductor's saturation current will cause magnetic saturation in the inductor, and decrease efficiency. When selecting an inductor, be sure to allow enough margins to assure that peak current does not exceed the inductor's saturation current value.

※ To minimize loss of inductor and improve efficiency, choose an inductor with a low resistance (DCR, ACR).

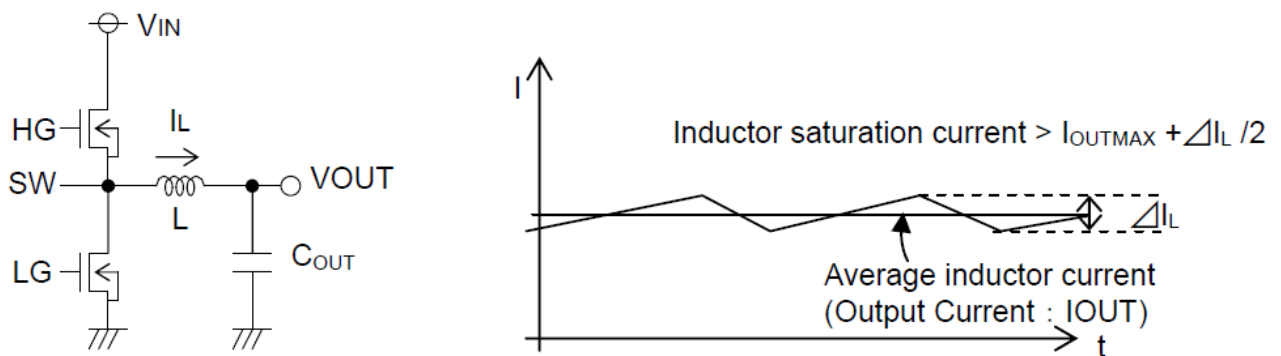


Fig 14: Inductor Ripple Current

1-2. Output Capacitor (C_{OUT}) Selection

Output Capacitor (C_{OUT}) has a considerable influence on output voltage regulation due to a rapid load change and smoothing output ripple voltage. Determine the capacitor by considering the value of capacity, the equivalent series resistance, and equivalent series inductance. Also, make sure the capacitor's voltage rating is high enough for the set output voltage (including ripple).

Output ripple voltage is determined as in formula below.

$$\Delta V_{OUT} = \Delta I_L / (8 \times C_{OUT} \times f) + ESR \times \Delta I_L + ESL \times \Delta I_L / T_{on} \quad [V]$$

(ΔI_L : Output ripple current, ESR: Equivalent series resistance, ESL: Equivalent series inductance)

Also, give consideration to the conditions in the formula below for output capacitance, bearing in mind that output rise time must be established within the fixed soft start time. As output capacitance, bypass capacitor will be also connected to output load side (C_{EXT} , Fig 15). Please set the over current detection value with regards to these capacitance.

$$C_{OUT} \leq \frac{1\text{msec} \times (I_{OCP} - I_{OUT})}{V_{OUT}} \quad [F]$$

(I_{OCP} : OCP Current Limit, I_{OUT} : Output Current)

Note: an improper output capacitor may cause startup malfunctions.

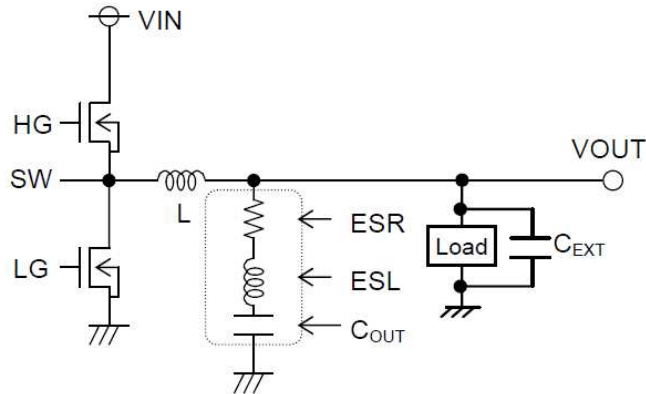


Fig 15: Output Capacitor

2. Input Capacitor (C_{IN}) Selection

In order to prevent transient spikes in voltage, the input capacitor should have a low enough ESR resistance to fully support a large ripple current. The formula for ripple current I_{RMS} is given in equation as below.

$$I_{RMS} = I_{OUT} \times \frac{\sqrt{V_{OUT} \times (V_{IN} - V_{OUT})}}{V_{IN}} \quad [A]$$

Where $V_{IN} = 2 \times V_{OUT}$, $I_{RMS} = I_{OUT}/2$

A low ESR capacitor is recommended to reduce ESR loss and improve efficiency

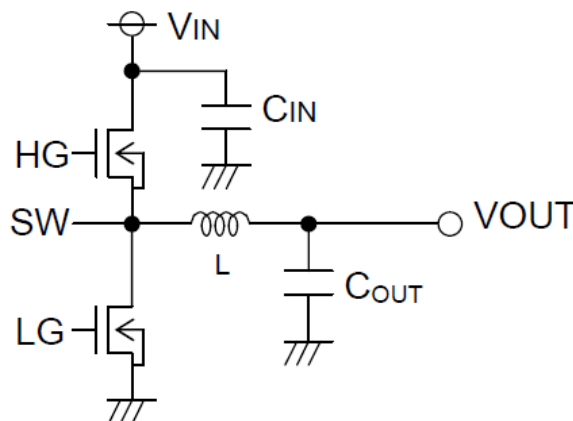


Fig 16: Input Capacitor

3. Output Voltage Setting

The IC controls output voltage as $REF = V_{FB}$.

However, the actual output voltage will also reflect the average ripple voltage value.

The output voltage is set with a resistor divider from the output node to the FB pin. The formula for output voltage is given in below:

$$\text{Output Voltage} = \frac{R1+R2}{R2} \times REF + \Delta V_{OUT} \quad [V]$$

$$REF = V_{FB}(\text{TYP } 0.8V) + 0.02 - (\text{ON DUTY} \times 0.05) \quad [V]$$

$$\text{ON DUTY} = \frac{V_{OUT}}{V_{IN}}$$

4. Relationship between Output Voltage and ON TIME

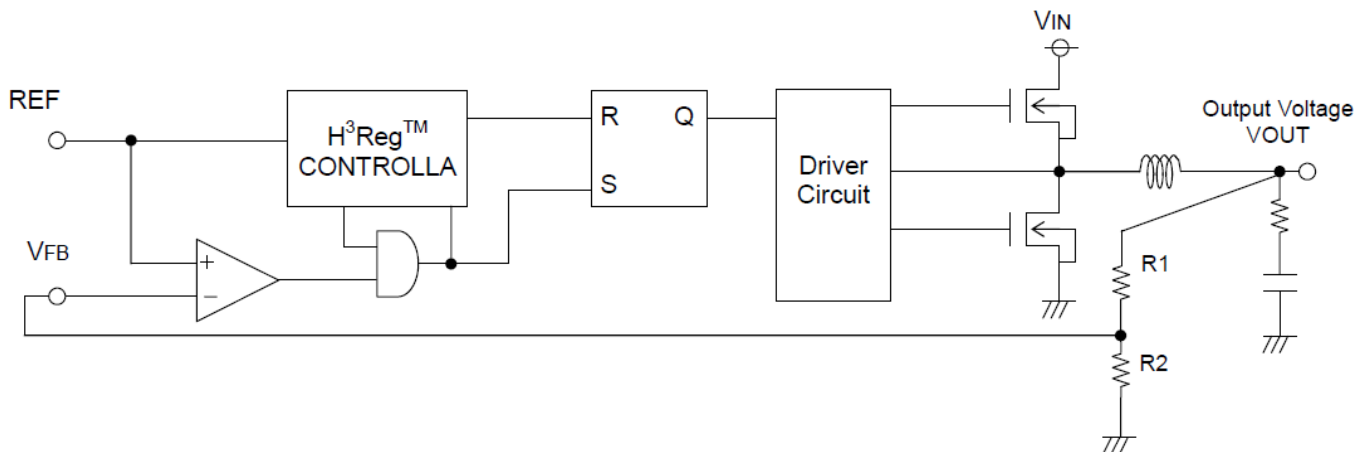


Fig 17: Output Voltage Setting

BD95861MUV is a synchronous buck converter controlling constant ON TIME. The ON TIME (T_{ON}) depends on the output voltage settings, as described by the formula.

$$T_{on} = 1770 \times \frac{V_{OUT}}{V_{IN}} - \frac{610}{V_{IN}} + 55 \quad [\text{nsec}]$$

$$\Delta V_{OUT} = \Delta I_L / (8 \times C_{OUT} \times f) + ESR \times \Delta I_L + ESL \times \Delta I_L / T_{on} \quad [V]$$

The frequency of the application condition is determined by the below formula using the above T_{on} .

$$\text{Frequency} = \frac{V_{OUT}}{V_{IN}} \times \frac{1}{T_{on}}$$

However with actual applications, there exists a rising and falling time of the SW due to the gate capacitance of the integrated MOSFET and the switching speed, which may vary the above parameters. Therefore please also verify those parameters experimentally.

5. Relationship between Output Current and Frequency

BD95861MUV is a constant on time type of switching regulator. When the output current increases, the switching loss of the inductor, MOSFET, and output capacitor also increases. Hence the switching frequency speeds up.

$$\textcircled{1} \text{ Loss of Inductor} = I_{OUT}^2 \times DCR$$

$$\textcircled{2} \text{ Loss of MOSFET (High Side)} = I_{OUT}^2 \times R_{ONH} \times \frac{V_{OUT}}{V_{IN}}$$

$$\textcircled{3} \text{ Loss of MOSFET (Low Side)} = I_{OUT}^2 \times R_{ONL} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

$$\textcircled{4} \text{ Loss of Output Capacitor} = I_{OUT}^2 \times ESR$$

The loss of the inductor, MOSFET, and output capacitor is determined as below.

(DCR: Inductor Equivalent series resistance, R_{ONH} : On resistance of High-side MOSFET, R_{ONL} : On resistance of Low-side MOSFET, ESR: C_{OUT} Equivalent series resistance)

Taking the above losses into the frequency equation, then $T (=1/\text{Freq})$ becomes

$$T (=1/\text{Freq}) = \frac{V_{IN} \times I_{OUT} \times T_{on}}{V_{OUT} \times I_{OUT} + \textcircled{1} + \textcircled{2} + \textcircled{3} + \textcircled{4}} \text{ [nsec]}$$

However since the parasitic resistance of the PCB layout pattern exists in actual applications and affects the parameter, please also verify experimentally.

● Evaluation Board BOM

Below is a table with the build of materials. Part numbers and supplier references are provided.

Item	Qty	Ref	Description	Manufacturer	Part Number
1	1	CR1	LED 570NM GREEN WTR CLR 0603 SMD	Rohm	SML-310MTT86
2	2	C1,C2	CAP CER 10UF 25V 20% X5R 1206	Murata	GRM31CR61E106MA12L
3	1	C3	CAP CER 0.1UF 50V 10% X7R 0603	Murata	GRM188R71H104KA93D
4	2	C4,C5	CAP CER 22UF 16V 10% X5R 1206	Murata	GRM31CR61C226KE15K
5	1	C6	CAP CER 4.7UF 25V 10% X5R 0603	Murata	GRM188R61E475KE11D
6	1	C7	CAP CER 0.47UF 25V 10% X7R 0603	Murata	GRM188R71E474KA12D
7	1	D1	DIODE TVS 15V 400W UNI 5% SMA	Littelfuse Inc	SMAJ15A
8	1	J1	CONN HEADER VERT .100 3POS 15AU	TE Connectivity Div	87224-3
9	1	L1	INDUCTOR 2.2UH 8.2A 20% SMD	TDK Corporation	SPM6530T-2R2M
10	1	Q1	TRANSISTOR NPN 40V 0.6A SOT-23	Rohm	SST2222AT116
11	1	R1	RES 20 OHM 1/10W 5% 0603 SMD	Rohm	MCR03ERTJ200
12	1	R2	RES 24K OHM 1/10W 1% 0603 SMD	Rohm	MCR03ERTF2402
13	1	R3	RES 680 OHM 1/10W 1% 0603 SMD	Rohm	MCR03ERTF6800
14	1	R4	RES 4.7K OHM 1/10W 1% 0603 SMD	Rohm	MCR03ERTF4701
15	1	R5	RES 100K OHM 1/10W 5% 0603 SMD	Rohm	MCR03ERTJ104
16	1	R6	RES 1K OHM 1/10W 5% 0603 SMD	Rohm	MCR03ERTJ102
17	1	R7	RES 140 OHM 1/10W 1% 0603 SMD	Rohm	MCR03ERTF1400
18	3	TP1,TP2,TP5	TEST POINT PC MULTI PURPOSE RED	Keystone Electronics	5010
19	2	TP3,TP4	TEST POINT PC MULTI PURPOSE BLK	Keystone Electronics	5011
20	1	U1	7.5V to 18V, 6A Integrated MOSFET 1ch Synchronous Buck DC/DC Converter	ROHM	BD95861MUV
21	1	ZX1	1806 footprint solder-short during assembly		
22	1		Shunt jumper for header J1 (item #11), CONN SHUNT 2POS GOLD W/HANDLE	TE Connectivity	881545-1

Notes

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