Application Note

ROHM Switching Regulator Solutions

Evaluation Board for ROHM's BD95841MUV Synchronous Buck Converter with Integrated 4A MOSFET

BD95841MUVEVK-101 (3.3V | 4A Output) USAP58-A-0005

● Introduction

This application note will explain the steps necessary to operate and evaluate ROHM's BD95841MUV synchronous buck DC/DC converter using the BD95841MUVEVK-101 evaluation board. Component selection, board layout recommendations, operation procedures and application data are included.

● Description

This evaluation board has been specifically developed to evaluate the BD95841MUV synchronous buck DC/DC converter with integrated 65mΩ high-side and 45mΩ low-side Nch MOSFETs. Features include wide input voltage (7.5V to 15V), output voltage (0.8V to 5.5V), and switching frequency (500kHz to 800kHz) ranges. Multiple protection functions are also built in, including a fixed soft start circuit that prevents inrush current during startup, UVLO (Under Voltage Lock Out), TSD (Thermal Shutdown), OCP (Over Current Protection), SCP (Short-Circuit Protection), and OVP (Over Voltage Protection). An EN pin allows for simple ON/OFF control to reduce standby current consumption while an open-drain Power Good function is incorporated for operation monitoring.

● Applications

LCD TVs
Set Top Boxes (STB)
DVD/Blu-ray Players/Recorders
Broadband and Communication I/F
Gaming and Entertainment

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

Parameter		Symbol	Limit			Unit	Conditions
			MIN	TYP	MAX		
Supply Voltage							
	BD95841MUV	V_{CC}	7.5	-	15	V	
Output Voltage / Current							
	BD95841MUV	V_{OUT}	0.8	-	5.5	V	* Set by R2,R3 and R4
		I_{OUT}	-	-	4	A	

● Evaluation Board

Below is an image of the BD95841MUVEVK-101 evaluation board.

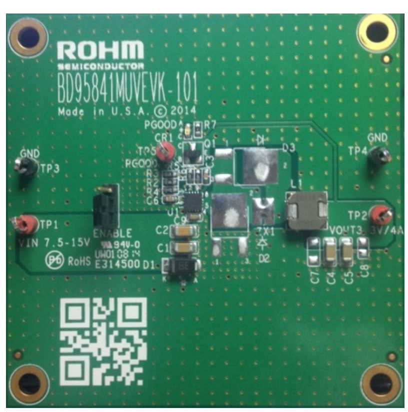


Fig 1: BD95841MUVEVK-101 Evaluation Board

• Board Schematic

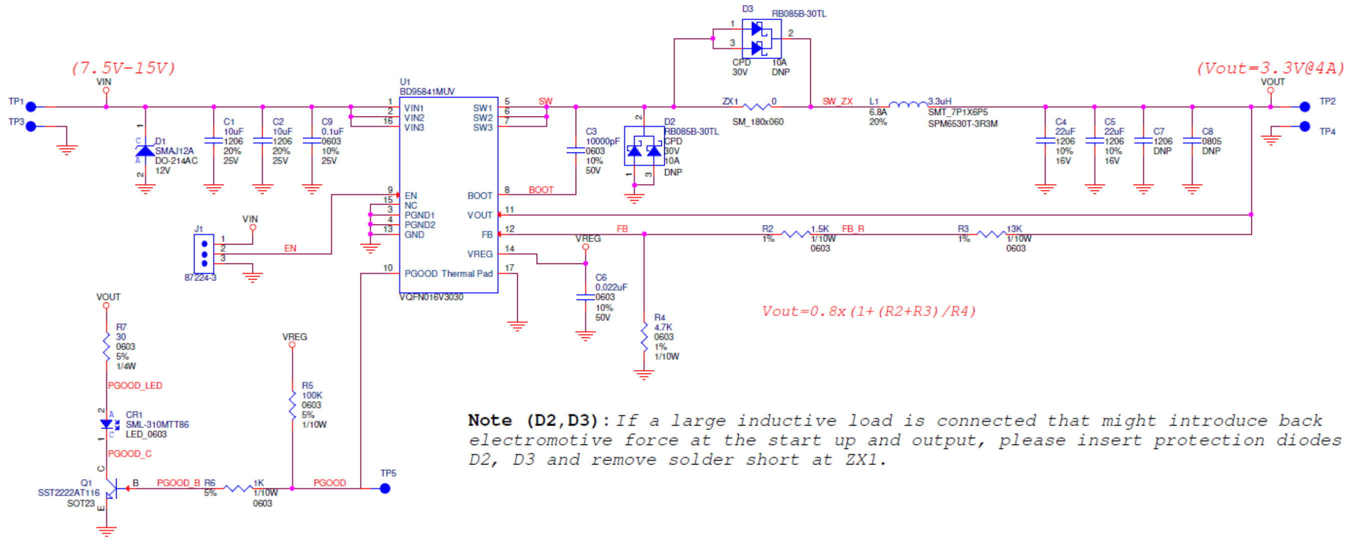


Fig 2: BD95841MUVEVK-101 Evaluation Board Schematic

• Board I/O

Below is a reference application circuit showing the inputs V_{IN} and EN and outputs V_{OUT} and PGOOD.

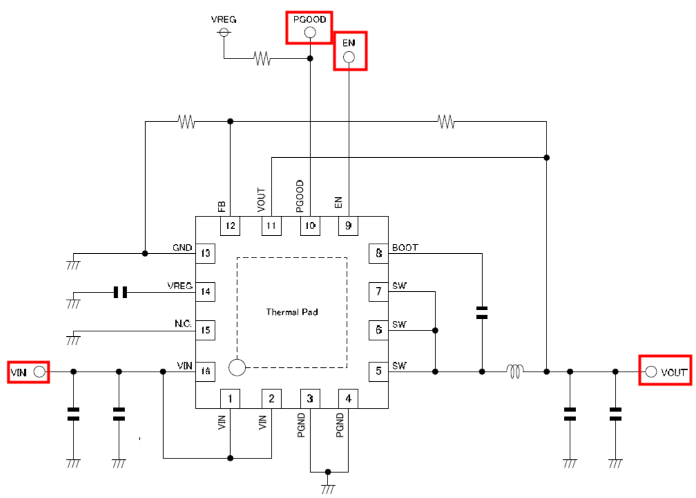


Fig 3: Evaluation Board I/O

• Operating Procedures

1. Connect the power supply's GND terminal to GND test point TP3 on the evaluation board.
2. Connect the power supply's VCC terminal to VIN test point TP1 on the evaluation board. This will provide VIN to the IC U1. Please note that V_{CC} should be in the range from 7.5V to 15V.
3. Check that the shunt jumper J1 is in the ON position (connect Pin 2 to Pin 1, the EN pin of IC U1 is pulled high).
4. Now the output voltage V_{OUT} (+3.3V) can be measured at test point TP2 on the evaluation board with a load attached. The load can be increased up to 4A MAX.

- **Reference Application Data**

  The following are graphs showing the hot plugging test, quiescent current, efficiency, load response, and output voltage ripple response of the BD95841MUVEVK-101 evaluation board.

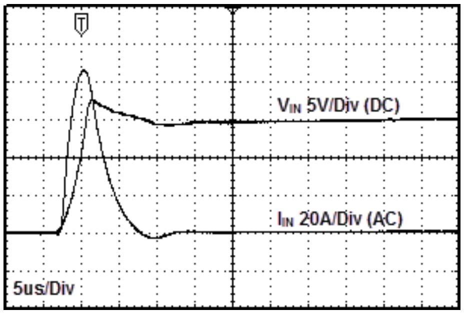


Fig 4: Hot Plug-in Test with Zener Diode SMAJ12A, V_{IN}=15V, V_{OUT}=3.3V, I_{OUT}=4A

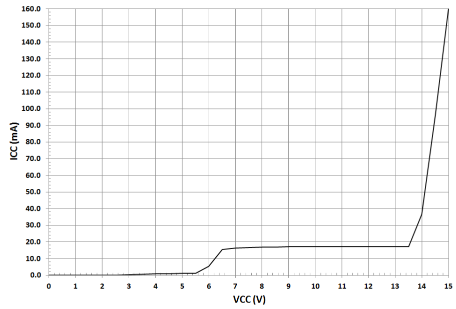


Fig 5: Circuit Current vs. Power Supply Voltage (Temp=25^{o}C)

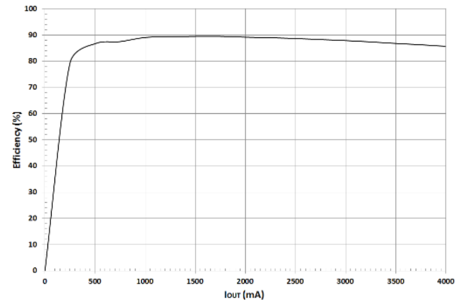


Fig 6: Electric Power Conversion Rate (V_{IN}=12V, V_{OUT}=3.3V)

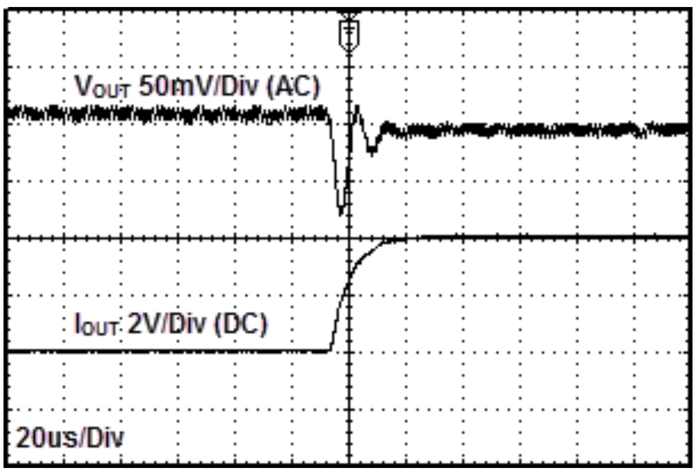


Fig 7: Load Response Characteristics
(V_{IN}=12V, V_{OUT}=3.3V, L=3.3uH, C_{OUT}=22uFx2, I_{OUT}=0A→4A)

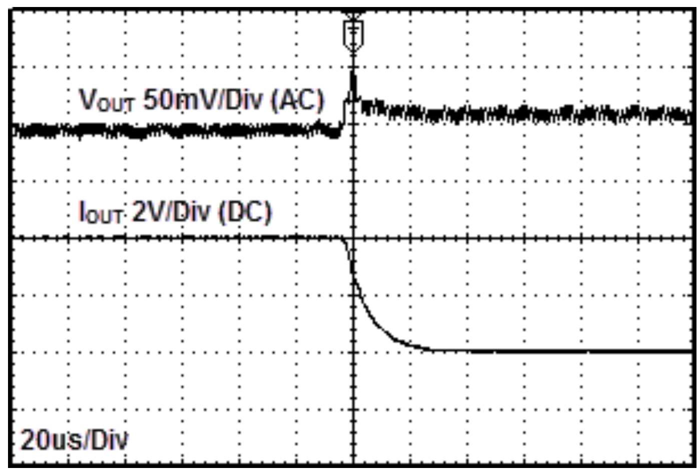


Fig 8: Load Response Characteristics
(V_{IN}=12V, V_{OUT}=3.3V, L=3.3uH, C_{OUT}=22uFx2, I_{OUT}=4A→0A)

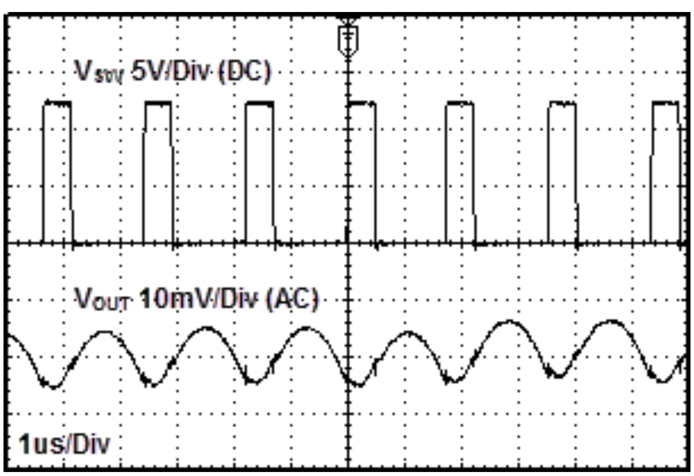


Fig 9: Output Voltage Ripple Response Characteristics
(V_{IN}=12V, V_{OUT}=3.3V, L=3.3uH, C_{OUT}=22uFx2, I_{OUT}=0A)

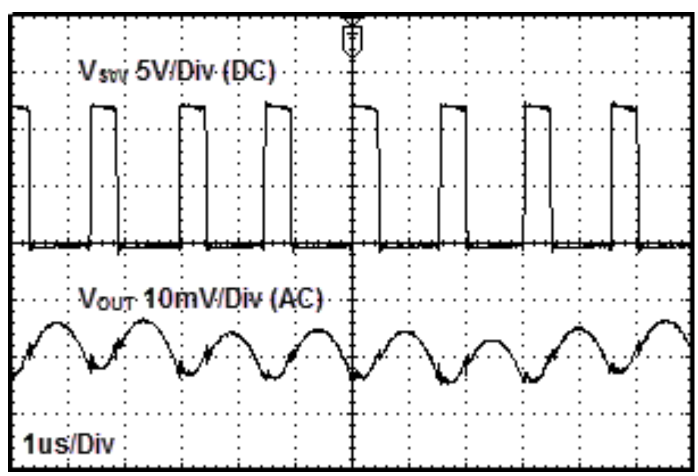


Fig 10: Output Voltage Ripple Response Characteristics
(V_{IN}=12V, V_{OUT}=3.3V, L=3.3uH, C_{OUT}=22uFx2, I_{OUT}=4A)

- **Evaluation Board Layout Guidelines**

Two high pulsing current flowing loops exist in the buck regulator system.
The first loop, when FET is ON, starts from the input capacitor, travels to the VIN terminal, then the SW terminal and through the inductor to the output capacitor, then returns to the input capacitor through GND.
The second loop, when FET is OFF, begins from the low-side FET, passes through the inductor to the output capacitor, then returns to the low FET through GND.
To reduce noise and improve efficiency, please minimize the areas of the two loops.
In particular, the input and output capacitors should be connected to the GND (PGND) planes.
The PCB layout has a major effect on the thermal performance, noise, and efficiency of the entire system. Therefore, please take extra care when designing the PCB patterns.

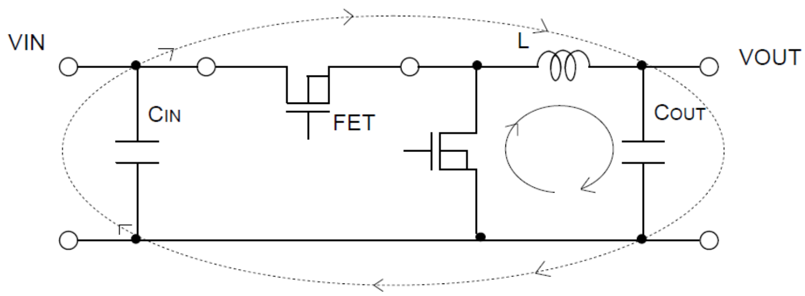


Fig 11: Current loop Buck regulator system

- The thermal pad on the backside of the IC has excellent thermal conduction to the chip, so making the GND plain as broad and wide as possible can help thermal dissipation. And using a large amount of thermal vias to facilitate 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 V_{IN} terminal.
- The inductor and output capacitor should be placed as close to the SW pin as possible.

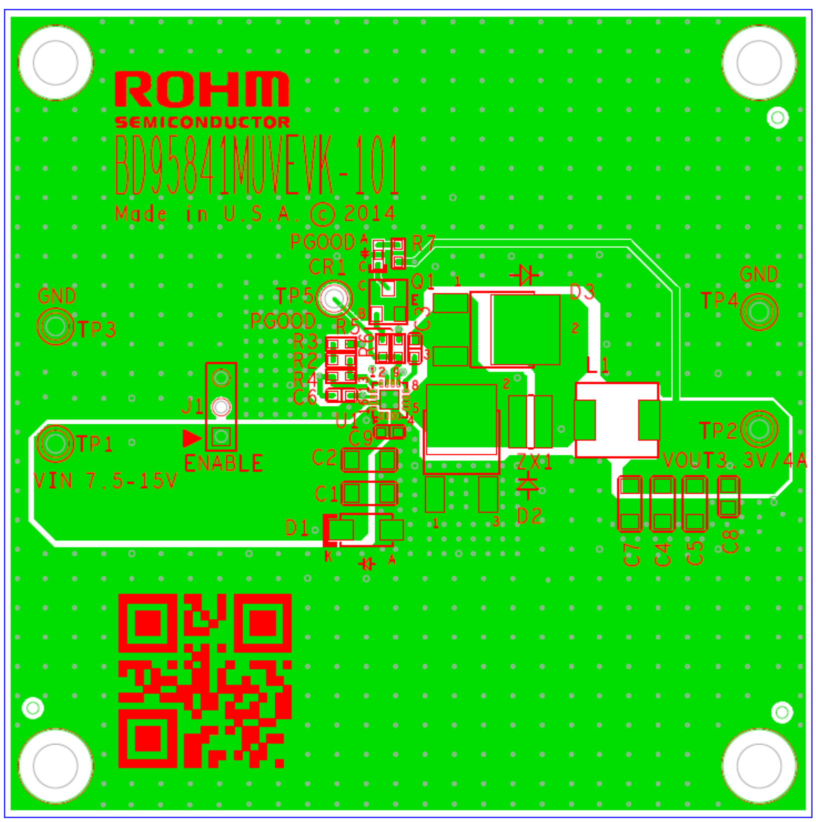
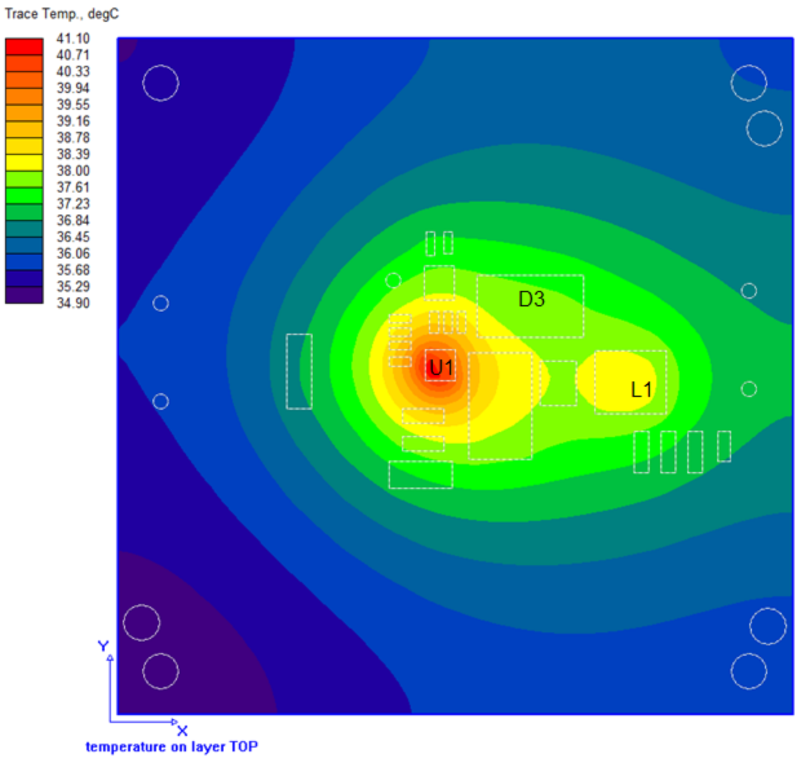


Fig 12: BD95841MUVEVK-101 Board layout



U1: BD95841MUV
- Max. power dissipation: 1.7216 W @VIN=7.5V
- Component temperature = 57.9 ^{0}C

L1: SPM6530T-3R3M
- Max. power dissipation: 0.4752 W
- Component temperature = 38.6 ^{0}C

D3:RB085B-30TL
- Component temperature = 37.8 ^{0}C

Fig 13: BD95841MUVEVK-101 Thermal Characteristics at Ta=25°C, no air flow, V_{IN}=7.5V, V_{OUT}=3.3V, I_{OUT}=4A, and D3 not installed

Additional layout notes:

- 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 drops. For final designs operating near these conditions, we recommend using one of the below PCB options for better heat dissipation of the IC.
  1) 4-layer PCB with internal GND planes connected to the IC GND pins.
  2) 2-layer PCB with a heat sink attached to the IC package.
  3) 2-layer PCB with a copper plane (>1oz) attached to the IC.

- **Application Circuit Component Selection**

1. Output LC Filter (Buck Converter)

1.1. Inductor (L)

The output LC filter is required to supply constant current to the output load. A larger inductance value will result in less inductor ripple current (ΔI_L) and output ripple voltage. However, large value inductors tend to have slower load transient response, a larger physical size, lower saturation current, and higher series resistance, while a smaller inductance value will have the opposite characteristics.

The value of ΔI_L is shown in the formula (1) below. The larger the inductance value and/or faster the switching frequency the lower the ripple voltage.

$$\Delta I_L = \frac{(V_{IN} - V_{OUT}) \times V_{OUT}}{L \times f \times V_{IN}} \ [A] \qquad (1)$$

The recommended output ripple current setting is about 30% of the maximum output current.

$$\Delta I_L = 0.3 \times I_{OUTMAX} \ [A] \qquad (2)$$

$$L = \frac{(V_{IN} - V_{OUT}) \times V_{OUT}}{\Delta I_L \times f \times V_{IN}} \ [A] \qquad (3)$$

(ΔI_L: Output Ripple Current, f: Switching Frequency)

- A current larger than the inductor's rated current will cause magnetic saturation in the inductor, decreasing efficiency. Therefore, when selecting an inductor, be sure to allow sufficient margin to ensure that the peak current does not exceed the inductor's rated current value.
- To minimize inductor loss and improve efficiency, select an inductor with low resistance (DCR, ACR).

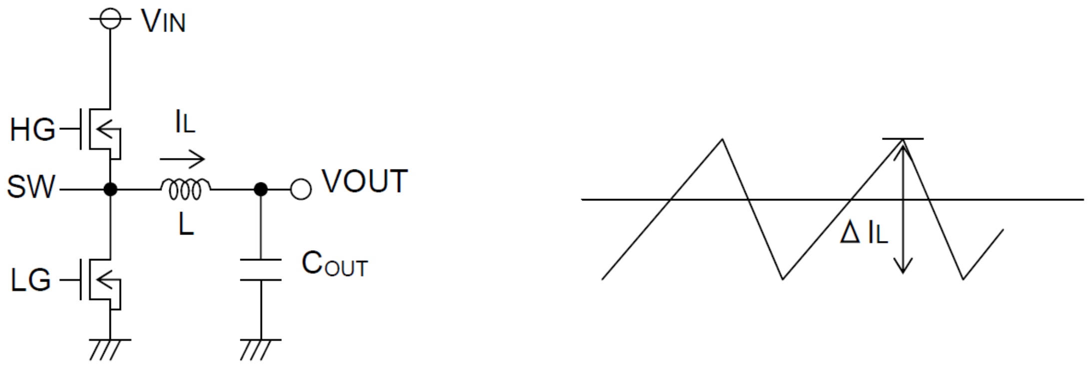


Fig 14: Inductor Ripple Current

1.2. Output Capacitor (C_{OUT})

The output Capacitor (C_{OUT}) has a considerable influence on smoothing the output ripple voltage and output voltage fluctuations. Determine the appropriate capacitor by considering the capacitance, equivalent series resistance, and equivalent series inductance. Also, make sure the capacitor's rating has enough margin for the set output voltage (including ripple).
The output ripple voltage is determined using the formula (4) below.

$$\Delta V_{OUT} = \frac{\Delta I_L}{8 \times C_{OUT} \times f} + ESR \times \Delta I_L + \frac{ESL \times \Delta I_L}{T_{ON}} \ [V] \qquad (4)$$

(ΔI_L: Output Ripple Current, ESR: Equivalent Series Resistance, ESL: Equivalent Series Inductance)

Also, consideration must be given to the conditions in the following formula (5) for output capacitance, since the output rise time must be established within the soft start time. For the output capacitance, the bypass capacitor is also connected to the output load side (C_{EXT}, Fig.14). Please set the over current detection value taking into account these capacitances.

$$C_{OUT} \leq \frac{1ms \times (I_{OCP} - I_{OUT})}{V_{OUT}} \ [F] \qquad (5)$$

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

Note: An improper output capacitor may cause startup malfunctions.

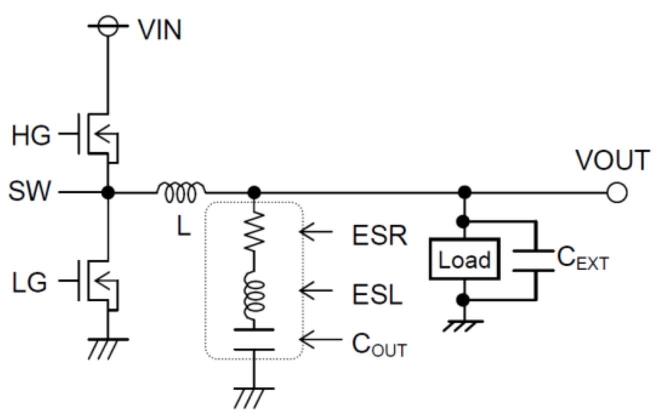


Fig 15: Output Capacitor

2. Input Capacitor (C_{IN})

In order to prevent transient spikes in voltage, the input capacitor should have a low enough ESR resistance to sufficiently handle large ripple current. The formula for ripple current IRMS is given in formula (6) below.

$$I_{RMS} = I_{OUT} \times \frac{\sqrt{V_{OUT} \times (V_{IN} - V_{OUT})}}{V_{IN}} \ [A] \qquad (6)$$

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

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

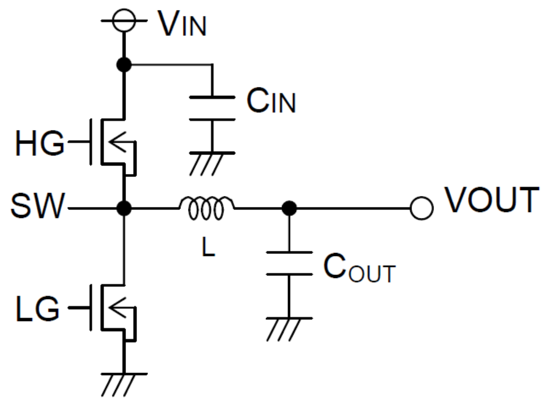


Fig 16: Input Capacitor

3. Output Voltage Setting

The IC controls output voltage as REF≒VFB.
However, the actual output voltage will also reflect the average ripple voltage value.
Output voltage is set using a resistor divider from the output node to the FB pin. The formula for output voltage is given in for the formula (7) below:

$$V_{OUT} = \frac{R1 + R2}{R2} \times REF + \Delta V_{OUT} \ [V] \qquad (7)$$

$$REF = V_{FB}(\text{Typ. } 0.8V) + 0.002 - 0.05 \times \text{ON DUTY} \ [V] \qquad (8)$$

$$\text{ON DUTY} = \frac{V_{OUT}}{V_{IN}} \qquad (9)$$

Please refer to the following formula (4) regarding ΔV_{OUT}.

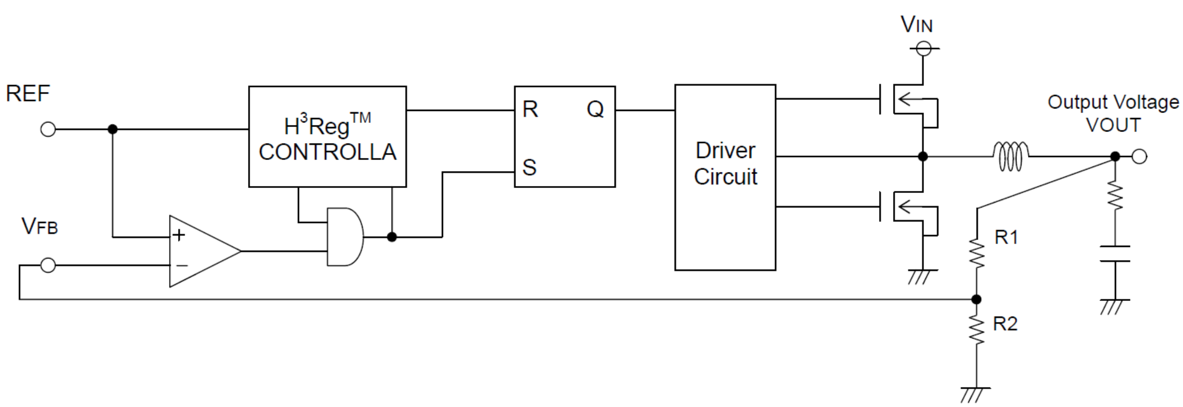


Fig 17: Output Voltage Setting

4. Relationship Between Output Voltage and ON Time Ton

BD95841MUV is a synchronous buck converter with fixed ON Time. However, the ON Time (Ton) depends on the output voltage settings, as described by:

$$\mathbf{T_{ON} = 1770 \times \frac{V_{OUT}}{V_{IN}} - \frac{610}{V_{IN}} + 55\ [ns]} \tag{10}$$

The frequency is determined by the below formula (11) using the above T_{ON}.

$$\mathbf{Frequency = \frac{V_{OUT}}{V_{IN}} \times \frac{1}{T_{ON}}\ [kHz]} \tag{11}$$

However, with actual applications rise and fall times of the SW will occur due to the gate capacitance of the integrated MOSFET and the switching speed, which may vary the above parameters. Therefore, please confirm under actual conditions.

5. Relationship Between Output Current and Frequency

BD95841MUV is a constant ON time type switching regulator. When the output current increases, the switching losses of the inductor, MOSFET, and output capacitor also increase, speeding up the switching frequency.
The switching losses are determined from the following equations.

$$① \mathbf{\ Inductor\ Loss = {I_{OUT}}^2 \times DCR}$$

$$② \mathbf{\ High - Side\ MOSFET\ Loss = {I_{OUT}}^2 \times R_{ONH} \times \frac{V_{OUT}}{V_{IN}}}$$

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

$$④ \mathbf{\ Output\ Capacitor\ Loss = {I_{OUT}}^2 \times ESR}$$

(DCR: Inductor Equivalent Series Resistance, R_{ONH}: High-Side MOSFET ON Resistance, R_{ONL}: Low-Side MOSFET ON Resistance, ESR: C_{OUT} Equivalent Series Resistance)

Taking the above losses into the frequency equation, T (=1/Freq) becomes

$$\mathbf{T = \frac{V_{IN} \times I_{OUT} \times T_{ON}}{V_{OUT} \times I_{OUT} + ① + ② + ③ + ④}\ [\mathit{ns}]} \tag{12}$$

However, since parasitic resistance, etc. of the PCB layout pattern exist in real-world applications and affect various parameters, please verify under actual conditions.

- **Evaluation Board BOM**

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 10000PF 50V 10% X7R 0603	Murata	GRM188R71H103KA01D
4	2	C4,C5	CAP CER 22UF 16V 10% X5R 1206	Murata	GRM31CR61C226KE15K
5	1	C6	CAP CER 0.022UF 50V 10% X7R 0603	Murata	GRM188R71H223KA01D
6	1	C9	CAP CER 0.1UF 25V 10% X7R 0603	Murata	GRM188R71E104KA01D
7	1	D1	TVS DIODE 12VWM 19.9VC SMA	Littelfuse Inc	SMAJ12A
8	1	J1	CONN HEADER VERT .100 3POS 15AU	TE Connectivity Div	87224-3
9	1	L1	INDUCTOR 3.3UH 6.8A 20% SMD	TDK Corporation	SPM6530T-3R3M
10	1	Q1	TRANSISTOR NPN 40V 0.6A SOT-23	Rohm	SST2222AT116
11	1	R2	RES 1.5K OHM 1/10W 1% 0603 SMD	Rohm	RHM1.5KBJTR-ND
12	1	R3	RES 13K OHM 1/10W 1% 0603 SMD	Rohm	MCR03ERTF1302
13	1	R4	RES 4.7K OHM 1/10W 1% 0603 SMD	Rohm	MCR03ERTF4701
14	1	R5	RES 100K OHM 1/10W 5% 0603 SMD	Rohm	MCR03ERTJ104
15	1	R6	RES 1K OHM 1/10W 5% 0603 SMD	Rohm	MCR03ERTJ102
16	1	R7	RES 30 OHM 1/10W 5% 0603 SMD	Rohm	ESR03EZPJ300
17	3	TP1,TP2,TP5	TEST POINT PC MULTI PURPOSE RED	Keystone Electronics	5010
18	2	TP3,TP4	TEST POINT PC MULTI PURPOSE BLK	Keystone Electronics	5011
19	1	U1	7.5V to 15V, 4A 1ch Synchronous Buck Converter	ROHM	BD95841MUV
20	1		Shunt jumper for header J1 (item #8), CONN SHUNT 2POS GOLD W/HANDLE	TE Connectivity	881545-1

Notes

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