ROHM Switching Regulator Solutions

Evaluation Board:
7.5V to 15V, 4A Integrated MOSFET
1ch Synchronous Buck DC/DC Converter

BD95841MUVEVK-101 (3.3V | 4A Output)

No.000000000

DRAFT

● **Introduction**

This application note will provide the steps necessary to operate and evaluate ROHM's synchronous buck DC/DC converter using the BD95841MUV 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 BD95841MUV. While accepting a wide power supply of 7.5-15V, an output of 0.8V to 5.5V can be produced. The IC has internal 65mΩ high-side Nch MOSFET and 45mΩ 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 feature for operation indication, OCP, SCP and 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 (TA=25ºC)**

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 evaluation board with the BD95841MUV.

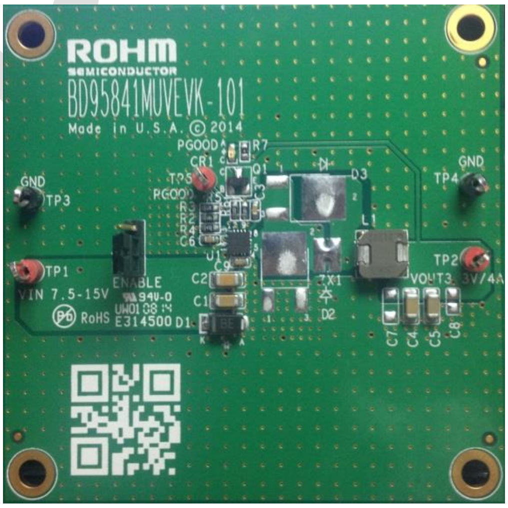


Fig 1: BD95841MUV Evaluation Board

- **Evaluation Board Schematic**

Below is evaluation board schematic for BD95841MUV.

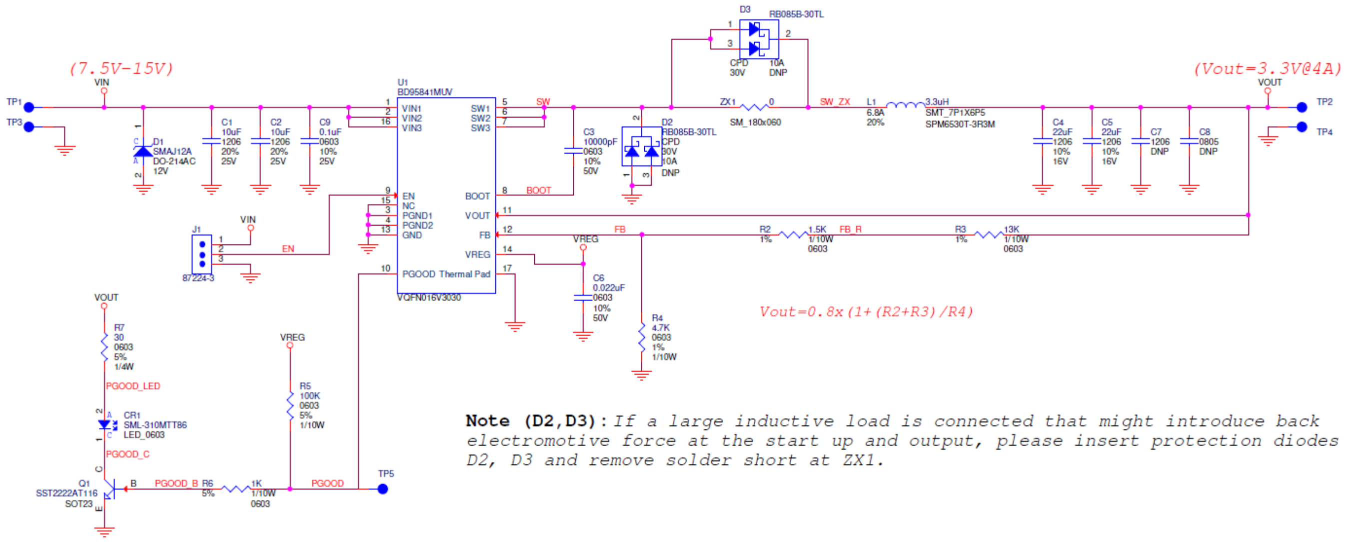


Fig 2: BD95841MUV Evaluation Board Schematic

- **Evaluation Board I/O**

Below is reference application circuit that shows the inputs (V_{IN}, EN) and the output ($V_{OUT,}$ PGOOD).

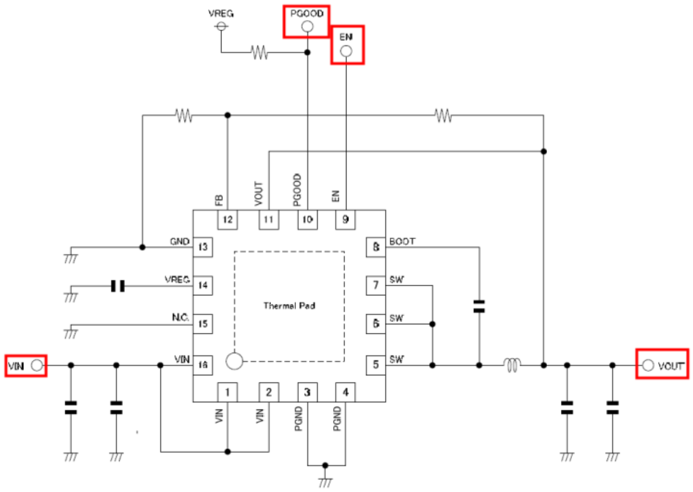


Fig 3: BD95841MUV Evaluation Board I/O

- **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 VCC terminal to VIN test point TP1 on the evaluation board. This will provide VIN to the IC U1. Please note that the V_{CC} should be in range of 7.5V to 15V.
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} (+3.3V) can be measured at the test point TP2 on the evaluation board with a load attached. The load can be increased up to 4A MAX.

- **Reference Application Data for BD95841MUVEVK-101**

  Following graphs show hot plugging test, quiescent current, efficiency, load response, output voltage ripple response of the BD95841MUV evaluation board.

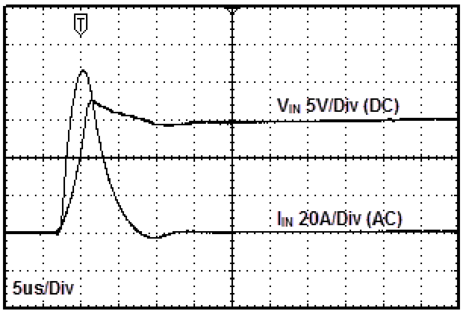


Fig 4: Hot Plug-in Test with Zener Diode SMAJ12A, V_{IN}=15V, V_{OUT}=3.3V, I_{OUT}=4A

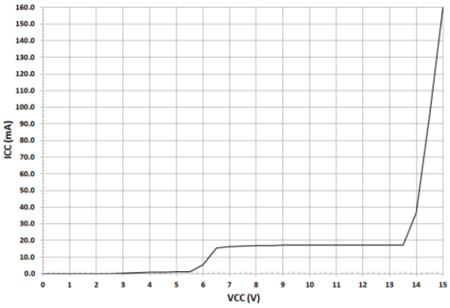


Fig 5: Circuit Current vs. Power supply Voltage Characteristics (Temp=25^{o}C)

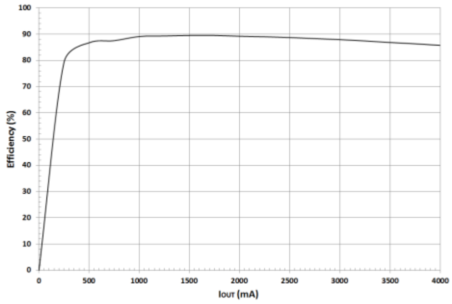


Fig 6: Electric Power Conversion Rate (V_{IN}=12V, V_{OUT}=3.3V)

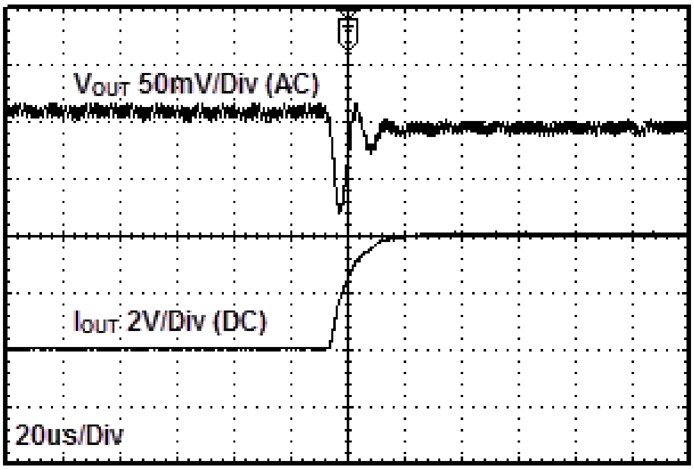


Fig 7: Load Response Characteristics
(V_{IN}=12V, V_{OUT}=3.3V, L=3.3uH, C_{OUT}=22uFx2, I_{OUT}=0A$\rightarrow$4A)

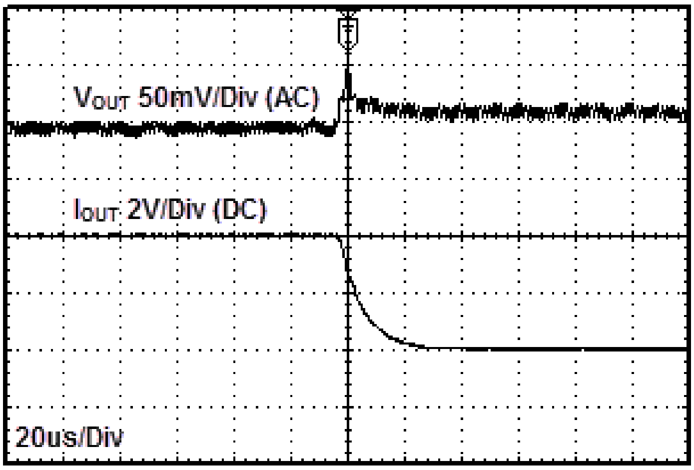


Fig 8: Load Response Characteristics
(V_{IN}=12V, V_{OUT}=3.3V, L=3.3uH, C_{OUT}=22uFx2, I_{OUT}=4A$\rightarrow$0A)

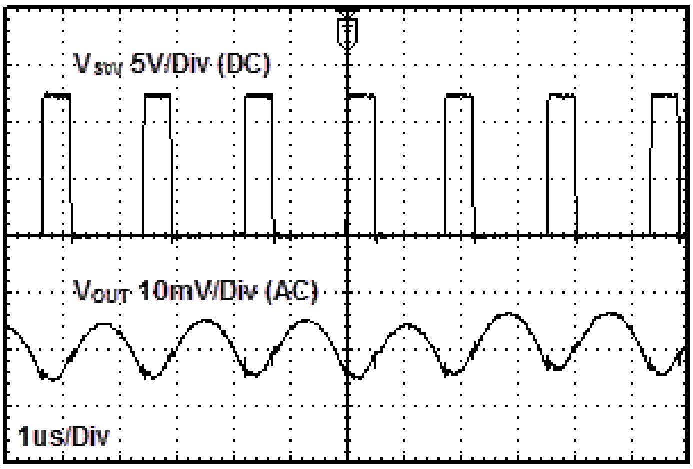


Fig 9: Output Voltage Ripple Response Characteristics
(V_{IN}=12V, V_{OUT}=3.3V, L=3.3uH, C_{OUT}=22uFx2, I_{OUT}=0A)

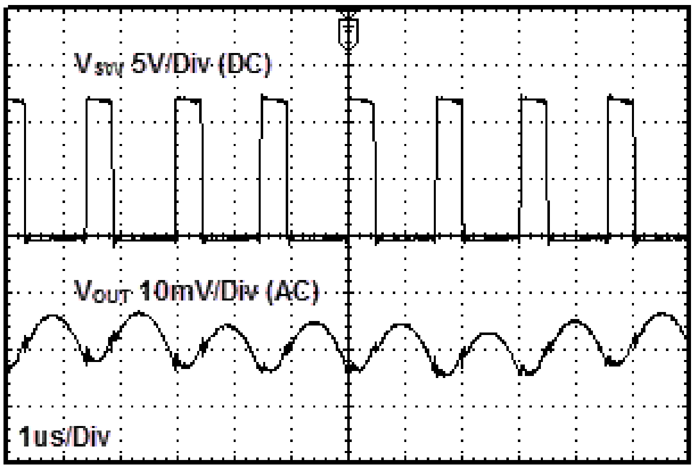


Fig 10: Output Voltage Ripple Response Characteristics
(V_{IN}=12V, V_{OUT}=3.3V, L=3.3uH, C_{OUT}=22uFx2, I_{OUT}=4A)

- **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 capacitors, to the VIN terminal, to the SW terminal, to the inductor, to the output capacitors, and then returns to the input capacitor through GND.
  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 these two loop area.
  Especially input capacitor and output capacitor should be connected to GND (PGND) plain.
  PCB Layout may affect the thermal performance, noise and efficiency greatly. So please take extra care when designing PCB Layout patterns.

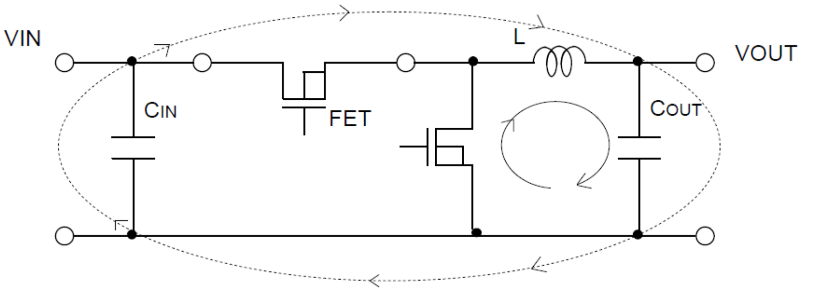


Fig 11: Current loop Buck regulator system

- The thermal Pad on the back side of IC has the great thermal conduction to the chip. So using the GND plain 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 V_{IN} terminal.
- The inductor and the output capacitors should be placed close to SW pin as much as possible.

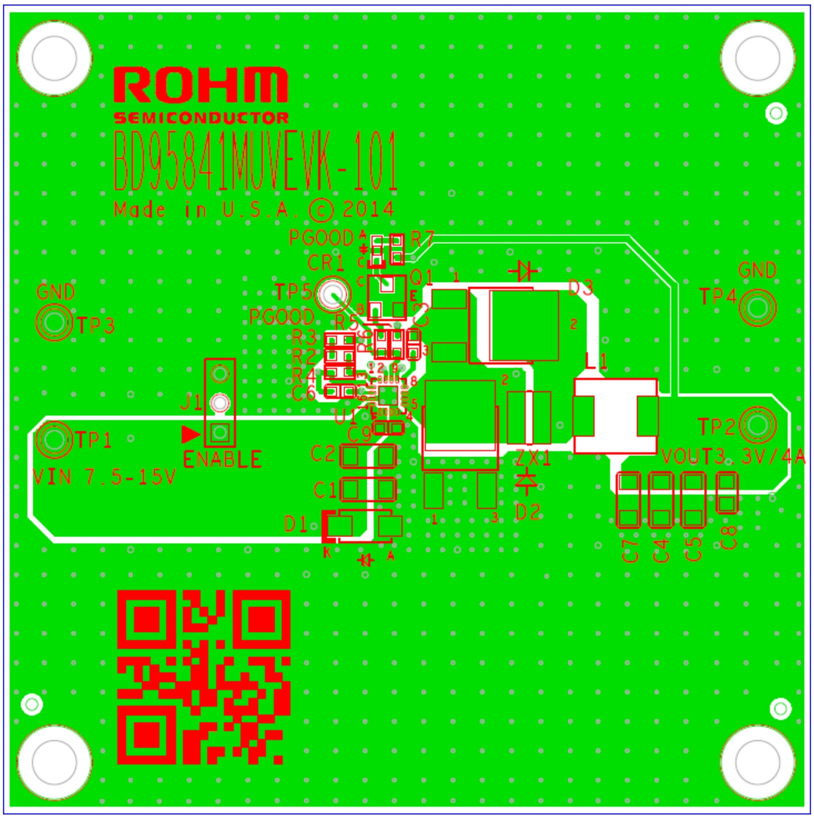
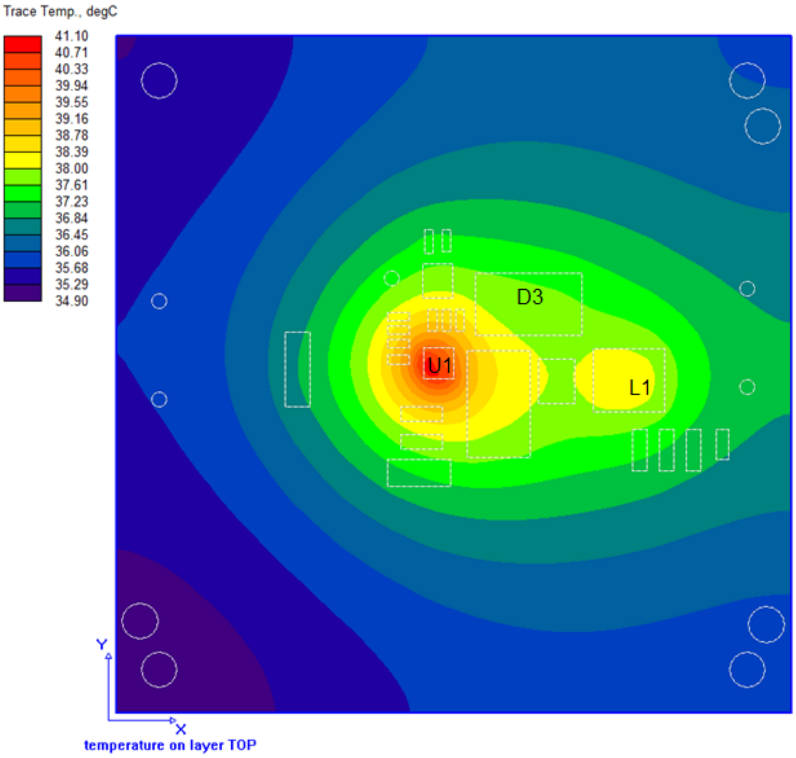


Fig 12: BD95841MUVEVK-101 Board PCB layout



U1: BD95841MUV
- **Max. power dissipation: 1.7216 W @VIN=7.5V**
- **Component temperature = 57.9 °C**

L1: SPM6530T-3R3M
- **Max. power dissipation: 0.4752 W**
- **Component temperature = 38.6 °C**

D3:RB085B-30TL
- **Component temperature = 37.8 °C**

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

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 less fast 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 (1). The larger value of the inductance or the faster switching frequency makes the lower ripple voltage.

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

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

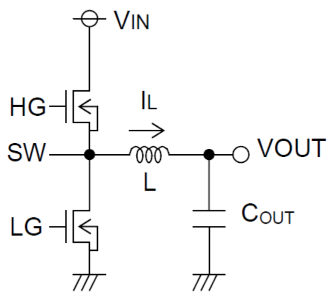
$$\Delta I_L = 0.3 \times I_{OUTMAX} \ [A] \qquad (2)$$

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

(ΔI_L: output ripple current, f: switching frequency)

❖ A larger current than the inductor's rated 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 rated current value.

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



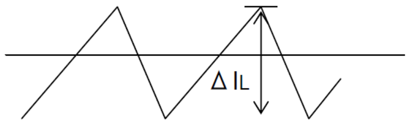


Fig 14: Inductor Ripple Current

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 (4) below.

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

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

Also, give consideration to the conditions in formula (5) 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.14). Please set the over current detection value with regards to these capacitance.

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

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

Note: an improper output capacitor may cause startup malfunctions.

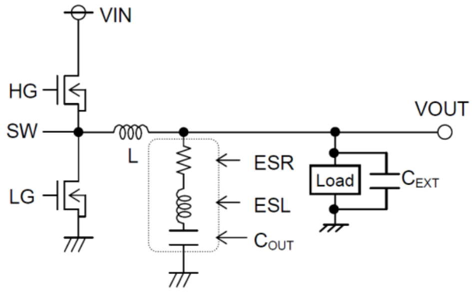


Fig 15: Output Capacitor

2. Input Capacitor (C_{IN}) 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 IRMS is given in formula (6) as below.

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

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

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

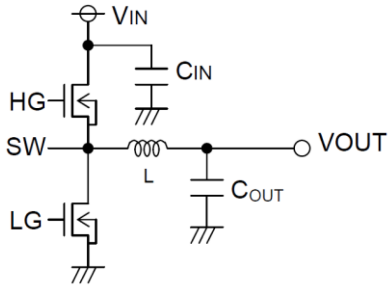


Fig 16: Input Capacitor

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.
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 formula (7) below:

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

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

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

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

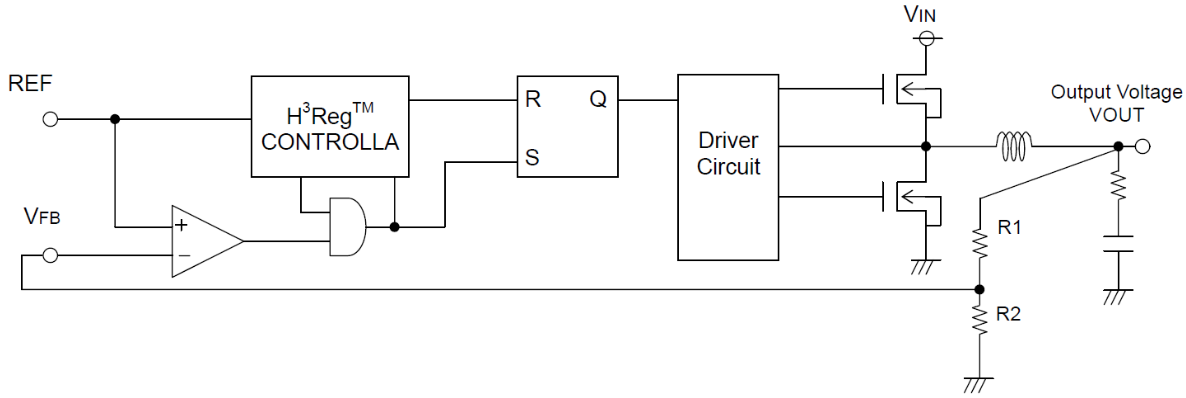


Fig 17: Output Voltage Setting

4. Relationship between Output Voltage and ONTIME

BD95841MUV is a synchronous buck converter controlling constant ON TIME. The ONTIME (T_{ON}) depends on the output voltage settings, as described by the formula (10).

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

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

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

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

BD95841MUV is a constant ontime 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.
The loss of the inductor, MOSFET, and output capacitor is determined as below.

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

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

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

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

(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/Freq) becomes

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

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 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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