ROHM Switching Regulator Solutions

Evaluation Board for ROHM's BD9C601EFJ Synchronous Buck DC/DC Converter with Integrated FET

BD9C601EFJEVK-101 (3.3V | 6A Output) USAP58-A-0002

- **Introduction**

This application note will explain the steps necessary to operate and evaluate ROHM's BD9C601EFJ synchronous buck DC/DC converter using the BD9C601EFJEVK-101 evaluation board. Component selection, board layout recommendations, operating procedures, and application data are included.

- **Description**

This evaluation board has been specifically developed to evaluate the BD9C601EFJ synchronous buck DC/DC converter with integrated 50mΩ Pch high-side and 35mΩ low-side Nch power MOSFETs. Features include a wide input voltage range (4.5V to 18.0V), high output current (6A max.), and 500kHz switching frequency. 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), and SCP (Short-Circuit Protection). An EN pin allows for simple ON/OFF control to reduce standby current consumption.

- **Applications**

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

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

Parameter		Symbol	Limit			Unit	Conditions
			MIN	TYP	MAX		
Supply Voltage							
	BD9C601EFJ	V_{CC}	4.5	-	18	V	
Output Voltage / Current							
	BD9C601EFJ	V_{OUT}	-	3.3	-	V	
		I_{OUT}	-	-	6	A	

- **Evaluation Board**

Below is an image of the BD9C601EFJEVK-01 evaluation board.

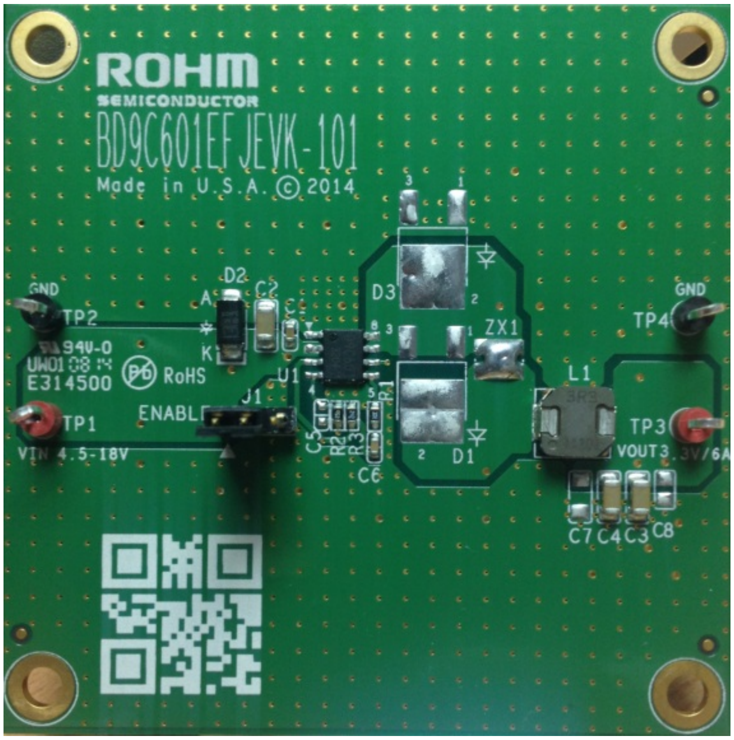
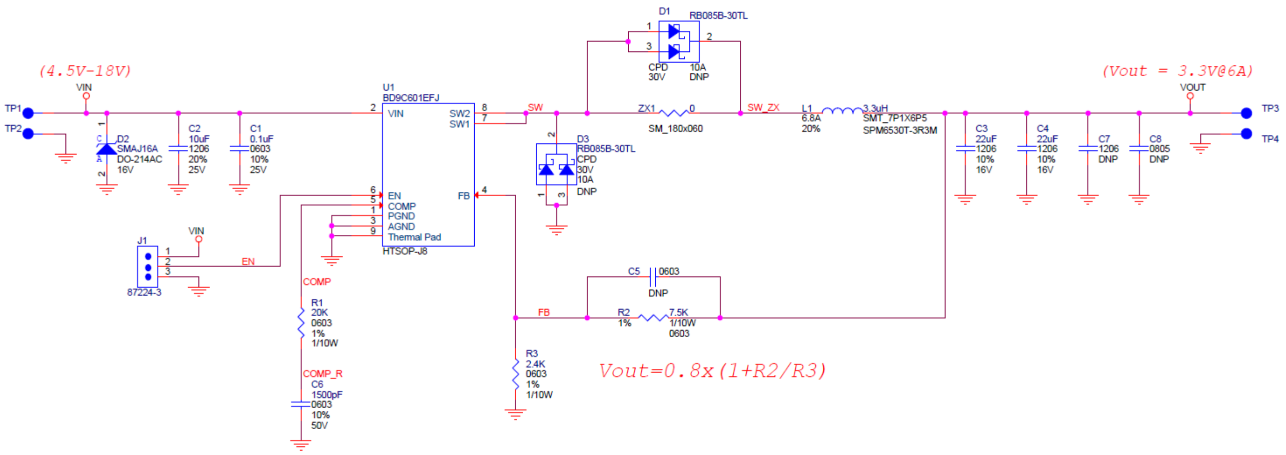


Fig 1: BD9C601EFJEVK-101 Evaluation Board

- **Board Schematic**



Note (D1,D3): *If a large inductive load is connected that might introduce back electromotive force at the start up and output, please insert protection diodes D1, D3 and remove solder short at ZX1.*

Fig 2: BD9C601EFJEVK-01 Evaluation Board Schematic

- **Board I/O**

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

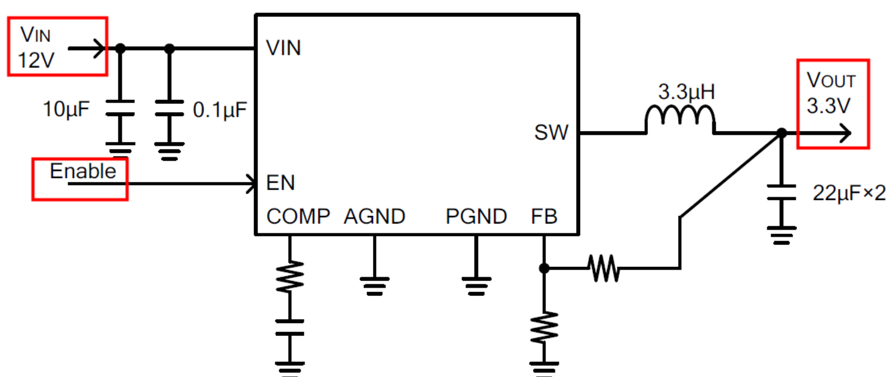


Fig 3: Evaluation Board I/O

- **Operating Procedures**

1. Connect the power supply's GND terminal to GND test point TP2 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 IC U1. Please note that V_{CC} should be in the range from 4.5V to 18V.
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 as a default).
4. Now the output voltage V_{OUT} (+3.3V) can be measured at test point TP3 on the evaluation board with a load attached. The load can be increased up to 6A MAX.

Notes:

Do not perform hot plugging on this board as the peak voltage transition could exceed the maximum voltage input of 20V which may cause damage to the IC. Please refer to Figure 4

- **Reference Application Data**

The following are graphs of the hot plugging test, quiescent current, efficiency, load response, and output voltage ripple response of the BD9C601EFJEVK-01 evaluation board.

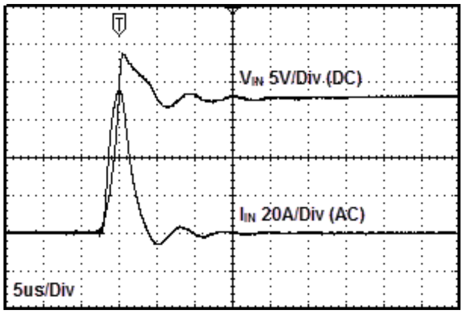


Fig 4: Hot Plug-in Test with TVS Diode SMAJ16A, V_{IN}=18V, V_{OUT}=3.3V, I_{OUT}=6A

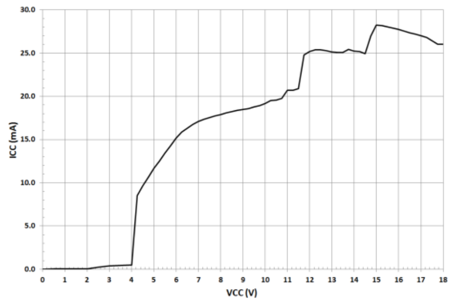


Fig 5: Circuit Current vs. Power Supply Voltage (Temp=25°C)

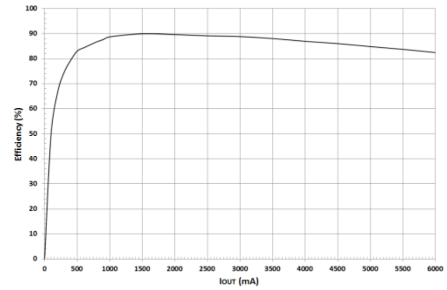


Fig 6: Electric Power Conversion Rate (V_{IN}=12V, V_{OUT}=3.3V)

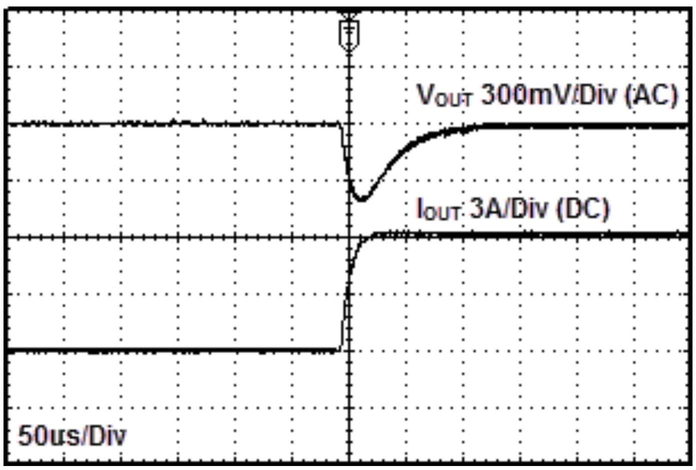


Fig 7: Load Response Characteristics (V_{IN}=12V, V_{OUT}=3.3V, L=3.3uH, C_{OUT}=22uF[x2], I_{OUT}=0A→6A)

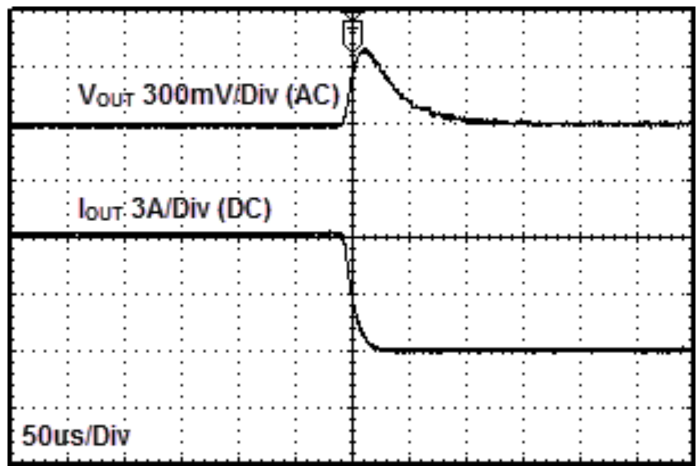


Fig 8: Load Response Characteristics (V_{IN}=12V, V_{OUT}=3.3V, L=3.3uH, C_{OUT}=22uF[x2], I_{OUT}=6A→0A)

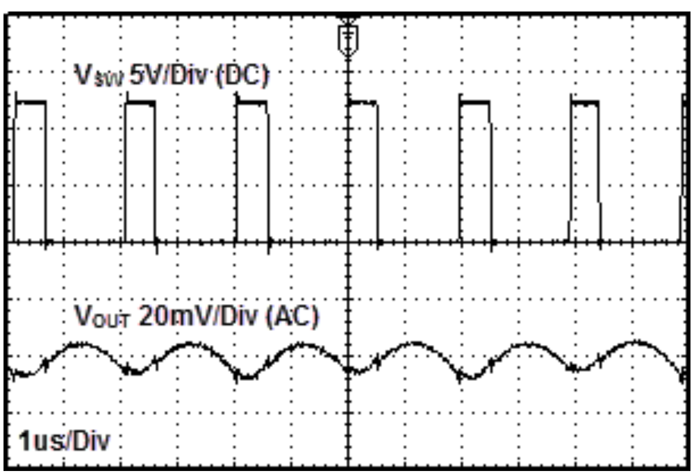


Fig 9: Output Voltage Ripple Response Characteristics (V_{IN}=12V, V_{OUT}=3.3V, L=3.3uH, C_{OUT}=22uF[x2], I_{OUT}=0A)

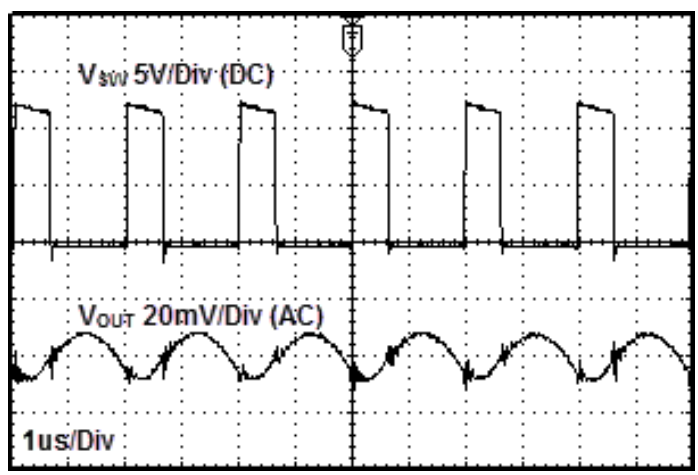


Fig 10: Output Voltage Ripple Response Characteristics (V_{IN}=12V, V_{OUT}=3.3V, L=3.3uH, C_{OUT}=22uF[x2], I_{OUT}=6A)

• Evaluation Board Layout Guidelines

In a step-down DC/DC converter, a large pulse current flows through two loops. The first loop is the one into which current flows when the High-Side FET is turned ON. The flow starts from the input capacitor C_{IN}, runs through the FET, inductor L and output capacitor C_{OUT}, then back to the GND of C_{IN} via the GND of C_{OUT}. In the second loop current flows when the Low-Side FET is turned ON. The flow starts from the Low-Side FET, runs through the inductor L and output capacitor C_{OUT}, then back to GND of the Low-Side FET via the GND of C_{OUT}. We recommend routing these two loops as thick and as short as possible to minimize noise and improve efficiency. The input and output capacitors should be connected directly to the GND plane. Please note that the PCB layout has a large influence on the DC/DC converter in terms of heat generation, noise, and efficiency.

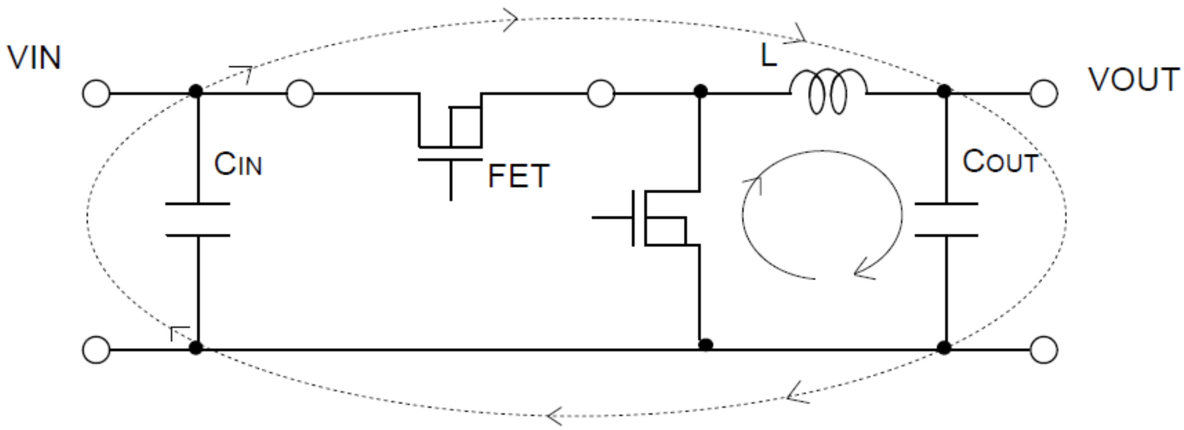


Fig 11: Current Loops of a Buck Converter

Accordingly, when designing the PCB layout please consider the following points.

- Connect an input capacitor as close as possible to the IC VIN pin on the same plane as the IC.
- If there is any unused area on the PCB, provide a copper foil plane for the GND node to assist heat dissipation from the IC and the surrounding components.
- Switching nodes such as SW are susceptible to noise due to AC coupling with other nodes. Therefore, route the coil pattern as thick and as short as possible.
- Ensure that the lines connected to FB and COMP are far from the SW nodes.
- Place the output capacitor away from the input capacitor in order to avoid the effects of harmonic noise from the input.

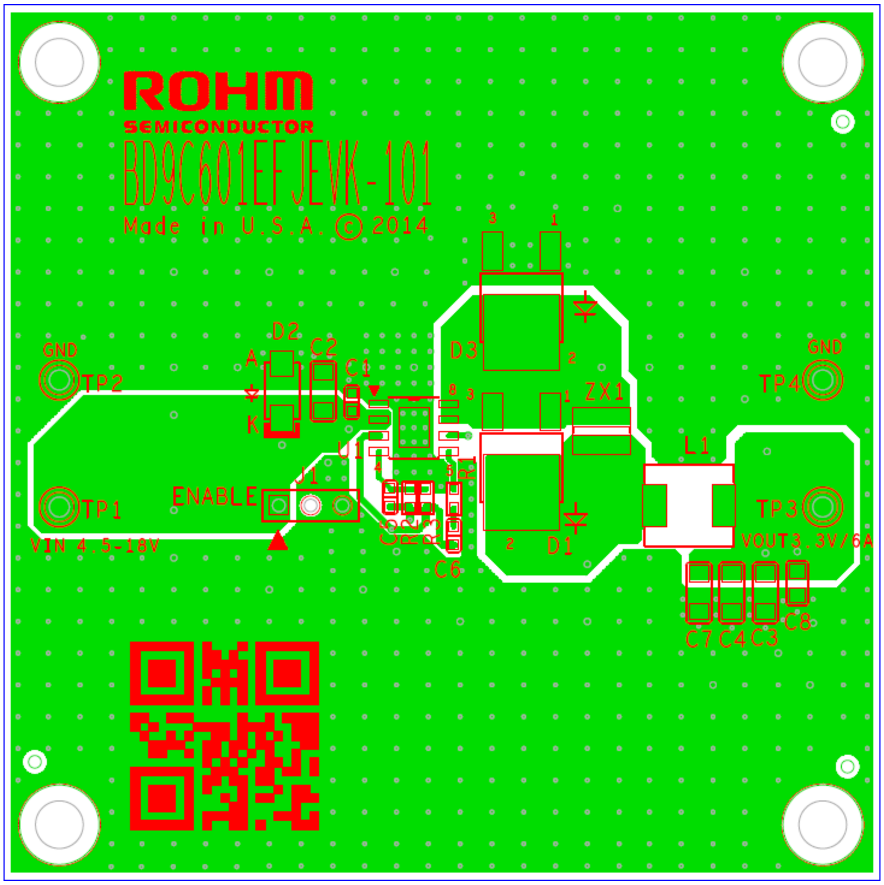


Fig 12: Evaluation Board Layout

- **Application Circuit Component Selection**

1. Output LC Filter Constant

DC/DC converters require an LC filter for smoothing the output voltage in order to supply a continuous current to the load. Selecting an inductor with a large inductance will cause the ripple current ΔIL that flows into the inductor to be small. However, decreasing the ripple voltage generated in the output is not advantageous in terms of the load transient response. An inductor with a small inductance improves transient response but results in a larger inductor ripple current which increases the ripple voltage at the output, exhibiting a trade-off relationship. Therefore, we recommend selecting an inductance such that the size of the ripple current component of the coil will be 20% to 40% of the average output current (average inductor current).

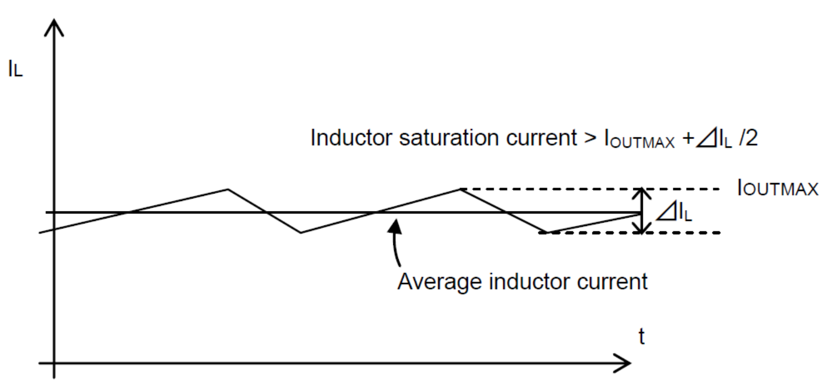


Fig 13: Current Waveform Through Inductor

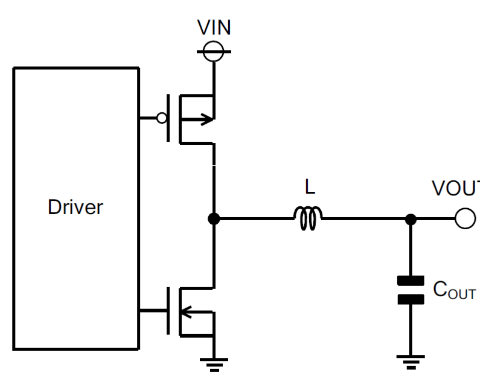


Fig 14: Output LC Filter Circuit

With a V_{IN} of 12V, V_{OUT}=3.3V, switching frequency FOSC=500kHz, and coil ripple current ΔIL=30% x 5A (Ave. Output Current) = 1.5A, the inductance L is calculated as:

$$L = V_{OUT} \times (V_{IN} - V_{OUT}) \times \frac{1}{V_{IN} \times F_{OSC} \times \Delta I_L} = 3.19\mu H \approx 3.3\mu H$$

The saturation current of the inductor must be larger than the sum of the maximum output current and 1/2 of the inductor ripple current ΔI_L.
The output capacitor C_{OUT} affects the output ripple voltage characteristics. Therefore, C_{OUT} must satisfy the following equation for ripple voltage:

$$\Delta V_{RPL} = \Delta I_L \times \left(R_{ESR} + \frac{1}{8 \times C_{OUT} \times F_{OSC}} \right) \ [V]$$

Where R_{ESR} is the Equivalent Series Resistance (ESR) of the output capacitor.

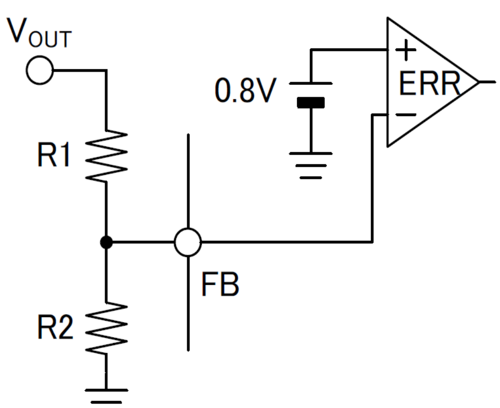
A soft start function is also included to reduce sudden current flow in the output capacitor during startup. However, if the capacitance value of the output capacitor C_{OUT} is too large the correct soft start waveform may not appear in some cases (Ex. V_{OUT} overshoot at soft start).
Therefore, select the output capacitor C_{OUT} fulfilling the following condition (including scattering and margin).

$$C_{OUT} < \frac{I_{OCP} \times T_{SS}}{V_{OUT}} \ [F]$$

Where:
I_{OCP} is the Switch Overcurrent Threshold (6.5A min)
T_{SS} is the Soft Start Time (0.5ms min)

Caution: Note that the C_{OUT} denotes the total capacitance value including every component connected to the output line

2. Output Voltage Setting
The output voltage value can be set by the feedback resistance ratio.



$$\mathbf{V_{OUT}} = \frac{\mathbf{R1 \times R2}}{\mathbf{R2}} \times \mathbf{0.8\ [V]}$$

V_{OUT} is restricted by V_{IN} based on the following equations:
V_{OUTMin} = 0.075 × VIN ≥ 0.8V
V_{OUTMax} = 0.7 × VIN

Fig15: Feedback Resistor Circuit

3. Phase Compensation Component

A current mode control buck DC/DC converter is a two-pole, one-zero system. Two poles are formed by an error amplifier and load and the one-zero point is added by phase compensation. The phase compensation resistor R_{CMP} determines the crossover frequency F_{CRS} where the total loop gain of the DC/DC converter is 0dB. A high value crossover frequency F_{CRS} provides a good load transient response but inferior stability. Conversely, a low value crossover frequency F_{CRS} greatly stabilizes the characteristics, but the load response suffers. Here, select a constant so that the crossover frequency F_{CRS} will be 1/10th of the switching frequency.

(1) Selection of Phase Compensation Resistor R_{CMP}

The Phase Compensation Resistance $\mathbf{R_{CMP}}$ can be determined by using the following equation.

$$\mathbf{R_{CMP}} = \frac{\mathbf{2\pi \times V_{OUT} \times F_{CRS} \times C_{OUT}}}{\mathbf{V_{FB} \times G_{MP} \times G_{MA}}}\ [\boldsymbol{\Omega}]$$

Where:
V_{OUT} is the Output Voltage
F_{CRS} is the Crossover Frequency
C_{OUT} is the Output Capacitance
V_{FB} is the Feedback Reference Voltage (0.8V typ.)
G_{MP} is the Current Sense Gain (6.8A/V typ.)
G_{MA} is the Error Amp Transconductance (400uA/V typ.)

(2) Selection of Phase Compensation Capacitance C_{CMP}

Use the following equation to determine C_{CMP}.

$$\boldsymbol{C_{CMP} = \frac{V_{OUT} \times C_{OUT}}{I_{OUT} \times R_{CMP}}\ [F]}$$

(3) Loop Stability

To guarantee DC/DC converter stability, ensure that sufficient phase margin is provided. A phase margin of at least 45° under worst-case conditions is recommended.

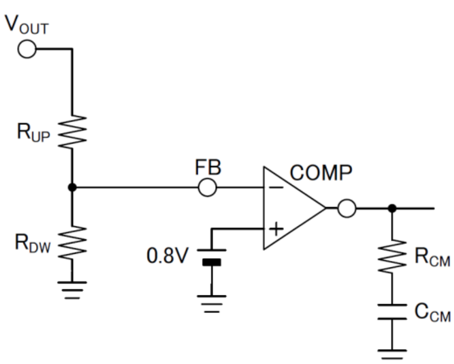


Fig 16: Phase Compensation Circui

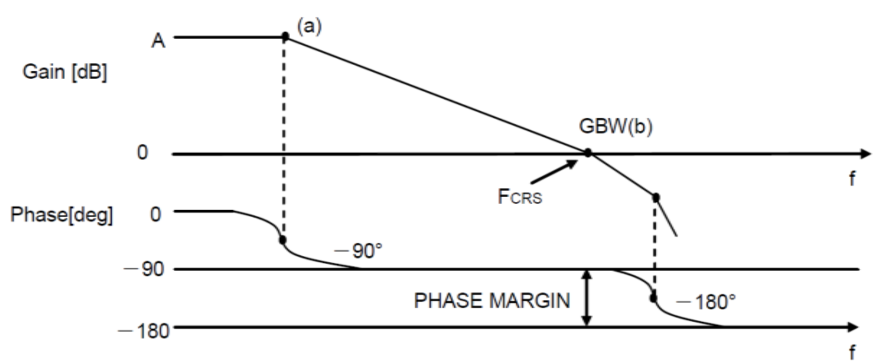


Fig 17: Bode Plot

- **Evaluation Board BOM**

Below is a table showing the bill of materials. Part numbers and supplier references are also provided.

No.	Qty.	Ref	Description	Manufacturer	Part Number
1	1	C1	CAP CER 0.1UF 25V 10% X7R 0603	Murata	GRM188R71E104KA01D
2	1	C2	CAP CER 10UF 25V 20% X5R 1206	Murata	GRM31CR61E106MA12L
3	2	C3,C4	CAP CER 22UF 16V 10% X5R 1206	Murata	GRM31CR61C226KE15K
4	1	C6	CAP CER 1500PF 50V 10% X7R 0603	Murata	GRM188R71H152KA01D
5	1	D2	TVS DIODE 16VWM 26VC SMA	Littelfuse Inc	SMAJ16A
6	1	J1	CONN HEADER VERT .100 3POS 15AU	TE Connectivity Div	87224-3
7	1	L1	INDUCTOR 3.3UH 6.8A 20% SMD	TDK Corporation	SPM6530T-3R3M
8	1	R1	RES 20K OHM 1/10W 1% 0603 SMD	Rohm	TRR03EZPF2002
9	1	R2	RES 7.5K OHM 1/10W 1% 0603 SMD	Rohm	MCR03ERTF7501
10	1	R3	RES 2.4K OHM 1/10W 1% 0603 SMD	Rohm	MCR03ERTF2401
11	2	TP1,TP3	TEST POINT PC MULTI PURPOSE RED	Keystone Electronics	5010
12	2	TP2,TP4	TEST POINT PC MULTI PURPOSE BLK	Keystone Electronics	5011
13	1	U1	4.5V to 18V Input, 6.0A Integrated MOSFET 1ch Synchronous Buck DC/DC Converter	ROHM	BD9C601EFJ
14	1	ZX1	1806 footprint solder-short during assembly		
15	1		Shunt jumper for header J1 (item #6), CONN SHUNT 2POS GOLD W/HANDLE	TE Connectivity	881545-1

Notes

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