ROHM SEMICONDUCTOR

Application Note

ROHM Switching Regulator Solutions

Evaluation Board: Synchronous Buck Converter Integrated FET

BD9D321EFJ-E2EVK-101(1.8V | 3A 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 BD9D321EFJ 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 BD9D321EFJ. While accepting a power supply of 4.5-18.0V, an output of 1.8V can be produced. The IC has internal 100mΩ high-side P-channel MOSFET and 70mΩ low-side N-channel MOSFET and a synchronization frequency 700 kHz. A fixed Soft Start circuit prevents inrush 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.

● Applications

Step-down Power Supply for DSPs, FPGAs,
Microprocessors, etc.
Set-top Box
LCD TVs
DVD / Blu-ray Player / Recorder
Entertainment Devices

● Evaluation Board Operating Limits and Absolute Maximum Ratings

Parameter		Symbol	Limit			Unit	Conditions
			MIN	TYP	MAX		
Supply Voltage							
	BD9D321EFJ	V_{CC}	4.5	-	18.0	V	
Output Voltage / Current							
	BD9D321EFJ	V_{OUT}	-	1.8	-	V	
		I_{OUT}	-	-	3	A	

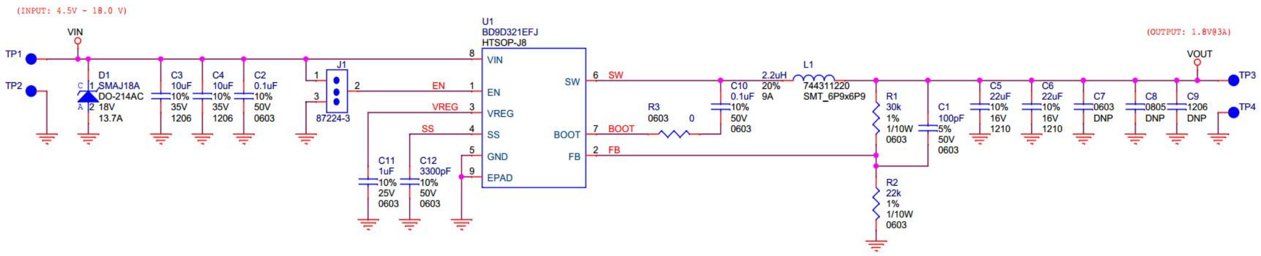
● Evaluation Board

Below is evaluation board with the BD9D321EFJ.

Fig 1: BD9D321EFJ Evaluation Board

- **Evaluation Board Schematic**

Below is evaluation board schematic for BD9D321EFJ.



BD9D321EFJ EVM Jumper Positions

Reference Designator	Position	Description
J1	2 - 1	Enable U1
	2 - 3	Disable U1

VOUT = 0.765*(R1+R2)/R2

Note:

1. 0.07xVIN =< VOUT =< 0.65xVIN

Fig 2: BD9D321EFJ Evaluation Board Schematic

- **Evaluation Board I/O**

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

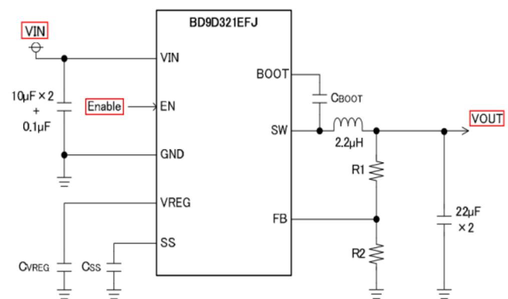


Fig 3: BD9D321EFJ Evaluation Board I/O

- **Evaluation Board Operation Procedures**

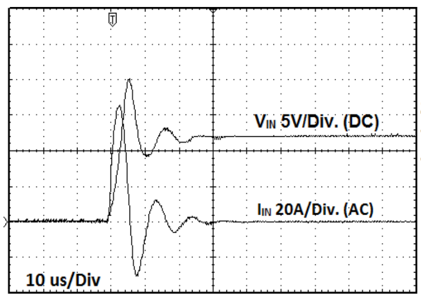
Below is the procedure to operate the evaluation board.

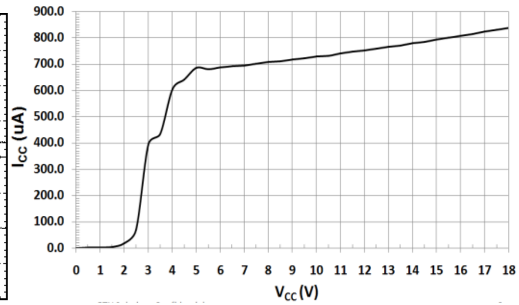
1. Connect power supply's GND terminal to GND test point TP2 on the evaluation board.
2. Connect power supply's V_{CC} terminal to V_{IN} test point TP1 on the evaluation board. This will provide V_{IN} to the IC U1. Please note that the V_{CC} should be in range of 4.5V to 18V.
3. Check if shunt jumper of J1 is at position ON (Pin2 connect to Pin1, EN pin of IC U1 is pulled high).
4. Connect electronic load to TP3 and TP4. Do not turn on load (electronic load is off power).
5. Turn on power supply. The output voltage V_{OUT}(+1.8V) can be measured at the test point TP3. Now turn on the load. The load can be increased up to 3A MAX.

Notes:

Do not perform hot plugging on this board, the inrush current is so high (I_{IN_MAX} >=65A) which exceed the clamping range of SMAJ series (I_{PP}=20A@V_C=20V). The SMAJ diode can not suppress the voltage glitch over the maximum voltage input rating 20V of BD9D321EFJ, so IC is not protected when doing hot plug test. Please refer figure 4.

- **Reference Application Data for BD9D321EFJ-E2EVK-101**
  Following graphs show hot plugging test, quiescent current, efficiency, load response, output voltage ripple response of the BD9D321EFJ evaluation board.





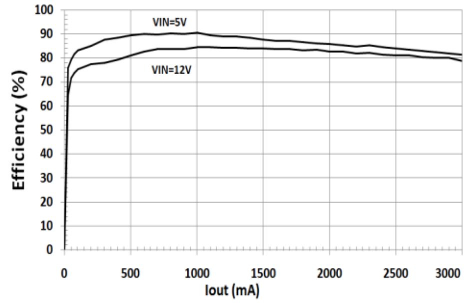


Fig 4: Hot Plug-in Test with Zener Diode SMAJ18A, V_{IN}=12V, V_{OUT}=1.8V, I_{OUT}=3A,

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

Fig 6: Electric Power Conversion Rate (V_{OUT}=1.8V)

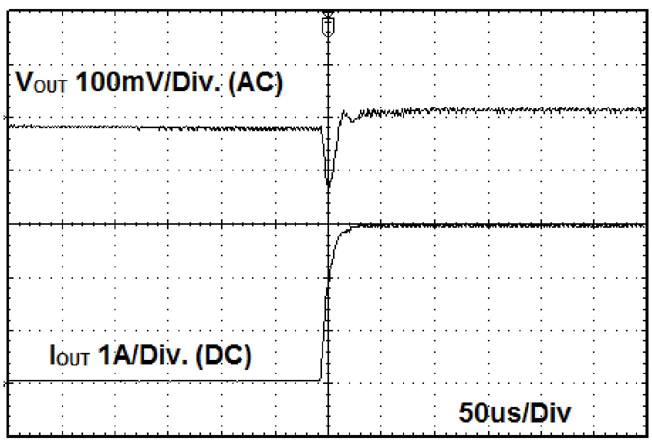


Fig 7: Load Response Characteristics (V_{IN}=5V, V_{OUT}=1.8V, I_{OUT}=0→3A)

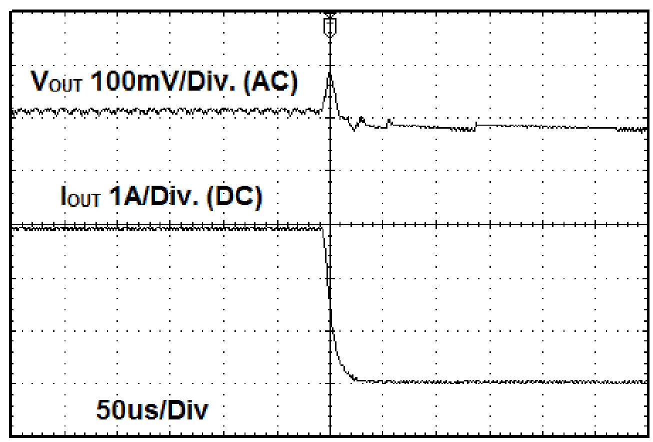


Fig 8: Load Response Characteristics (V_{IN}=5V, V_{OUT}=1.8V, I_{OUT}=3A→0A)

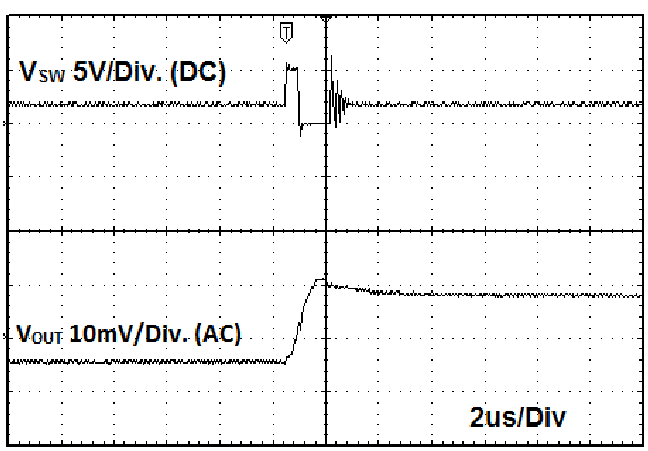


Fig 9: Output Voltage Ripple Response Characteristics (V_{IN}=5V, V_{OUT}=1.8V, I_{OUT}=0A)

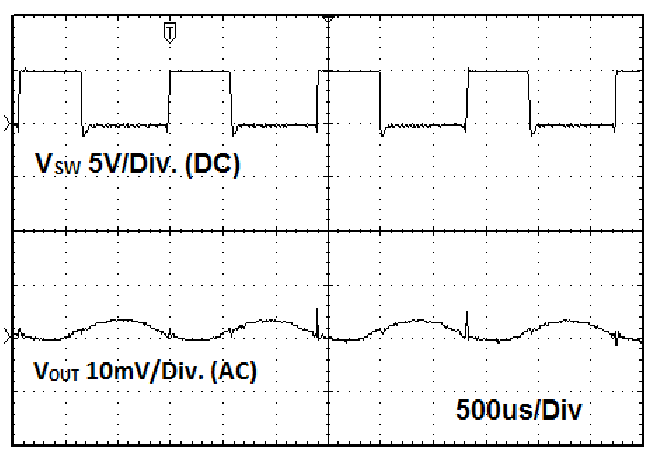


Fig 10: Output Voltage Ripple Response Characteristics (V_{IN}=5V, V_{OUT}=1.8V, I_{OUT}=3A)

- **Evaluation Board Layout Guidelines**

In the step-down DC/DC converter, a large pulse current flows into two loops. The first loop is the one into which the 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} and back to ground of CIN via ground of C_{OUT}. The second loop is the one into which the 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} and back to ground of the low side FET via ground of C_{OUT}. Route these two loops as thick and as short as possible to allow noise to be reduced for improved efficiency. It is recommended to connect the input and output capacitors directly to the ground plane. The PCB layout has a great influence on the DC/DC converter in terms of all of the heat generation, noise and efficiency characteristics.

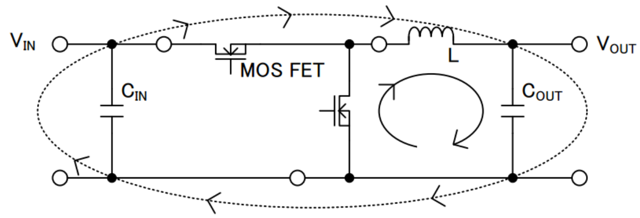


Fig 11: Current Loop of Buck Converter

Accordingly, design the PCB layout considering the following points.

- Connect an input capacitor as close as possible to the IC V_{IN} terminal on the same plane as the IC.
- If there is any unused area on the PCB, provide a copper foil plane for the ground 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. Route the coil pattern as thick and as short as possible.
- Provide lines connected to FB and SS far from the SW nodes.
- Place the output capacitor away from the input capacitor in order to avoid the effect of harmonic noise from the input.

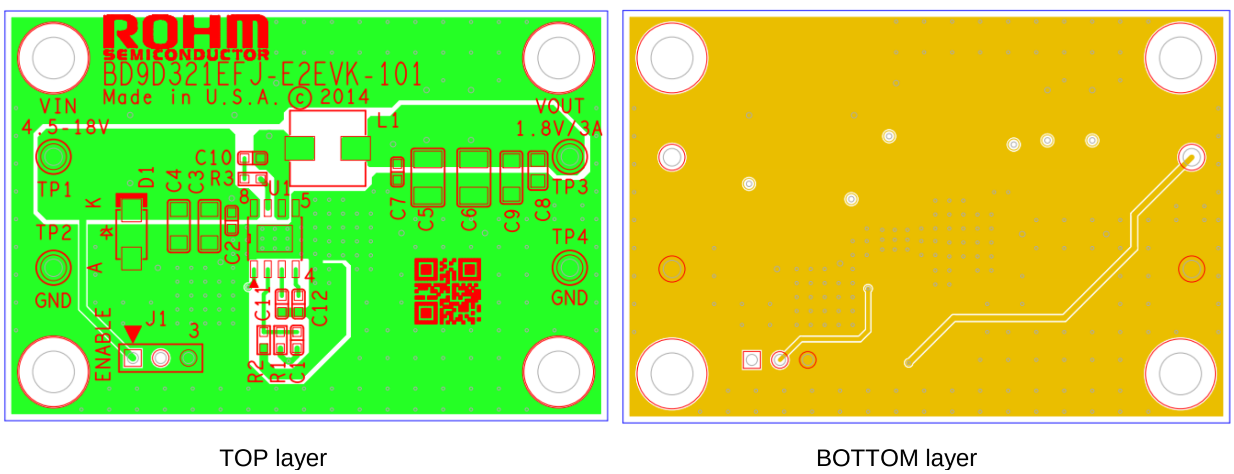
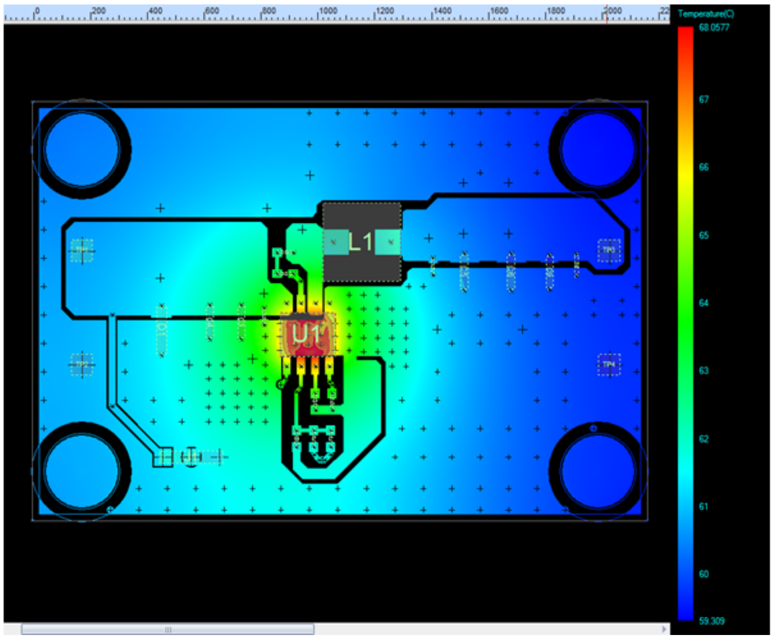


Fig 12: BD9D321EFJ-E2EVK-101 Board PCB layout



U1: BD9D321EFJ
- Max. power dissipation: 1.476 W @VIN=4.5V
- Component temperature = 68.06 ^{0}C

L1: 744311220
- Max. power dissipation: 0.1026 W
- Component temperature = 62.46 ^{0}C

Fig 13: BD9D321EFJ-E2EVK-101 Thermal Characteristics at Temp=25ºC, no air flow, V_{IN}=4.5V, V_{OUT}=1.8V, I_{OUT}=3A

Thermal note: If the board is operated above room temperature (T>25ºC), an active cooling source (fan) or heat sink (soldered to bottom of PCB) need to be added.

Additional layout notes:

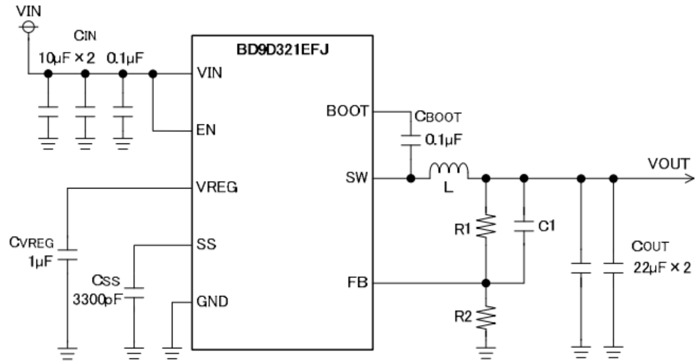
- The thermal Pad on the back side of IC has the great thermal conduction to the chip. So using the GND plane as broad and wide as possible can help thermal dissipation. And a lot of thermal via for helping the spread of heat to the different layer is also effective.
- The input capacitors should be connected to GND 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.
- 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 Constant

The DC/DC converter requires 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 causes the ripple current ΔI_L 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 characteristic. An inductor with a small inductance improves the transient response characteristic but causes the inductor ripple current to be large which increases the ripple voltage in the output voltage, showing a trade-off relationship. The recommended inductor values are shown in Fig 14.



Application Circuit

VOUT [V]	R1 [kΩ]	R2 [kΩ]	C1 [pF]	L [μH] (Note 7)
1.0	6.8	22	- (Note 6)	1.5
1.05	8.2	22	- (Note 6)	1.5
1.2	12+0.51	22	- (Note 6)	1.5
1.8	30	22	- (Note 6)	2.2
3.3	68+5.1	22	- (Note 6)	2.2
5.0	120+1.8	22	- (Note 6)	3.3
7.0	180	22	- (Note 6)	3.3

Fig 14: Recommended Component values

(Note 6) C1 is a feed forward capacitor. The IC can operate normally even if the capacitor is not connected. Additional phase boost can be achieved by adding the 5pF to 100pF capacitor (C1) in parallel with R1.
(Note 7) Recommended Inductor

- ALPS GLMC series
- TDK SPM6530 series

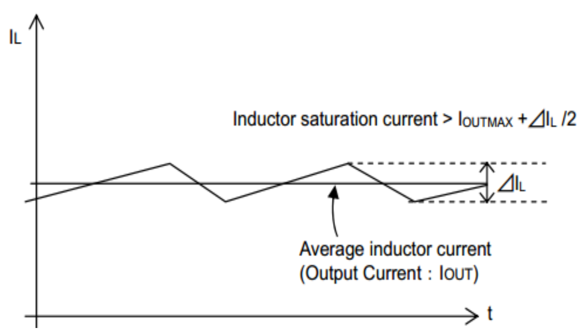


Fig 15: Waveform of current through inductor

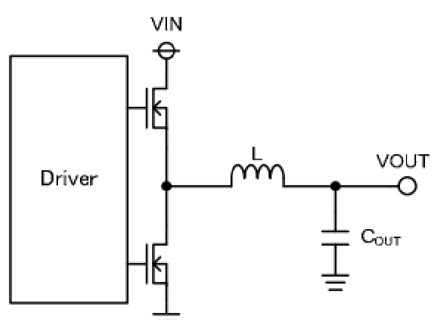


Fig 16: Output LC filter circuit

The inductor peak to peak ripple current ΔI_L is calculated using the following equation.

$$\Delta I_L = \frac{V_{IN} - V_{OUT}}{L} \times \frac{V_{OUT}}{V_{IN}} \times \frac{1}{F_{OSC}} \quad (A)$$

For example, with V_{IN}= 12 V, V_{OUT}= 1.8 V, L = 2.2µH and the switching frequency F_{OSC} = 700 kHz, the calculated peak current ΔI_L is 1.0A.
Then, the inductor saturation current must be larger than the sum of the maximum output current ($I_{OUT\ MAX}$) and 1/2 of the inductor ripple current (ΔI_L / 2).

The output capacitor **C_{OUT}** affects the output ripple voltage characteristics. The output capacitor C_{OUT} must satisfy the required ripple voltage characteristics.

The output ripple voltage can be represented by the following equation.

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

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

- The capacitor rating must allow a sufficient margin with respect to the output voltage.
  The output ripple voltage can be decreased with a smaller ESR.
  A ceramic capacitor of about 22 µF to 100 µF is recommended.

- Pay attention to total capacitance value, when additional capacitor C_{LOAD} is connected in addition to output capacitor C_{OUT}. Then, please determine C_{LOAD} and soft start time Tss (Refer to **(3) Soft Start Setting**) as satisfying the following equation.

$$C_{OUT} + C_{LOAD} \leq \frac{(I_{OCP} - I_{OUT}) \times T_{SS}}{V_{OUT}} \quad (\mu F)$$

I_{OCP} is Over Current Protection Current limit value

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

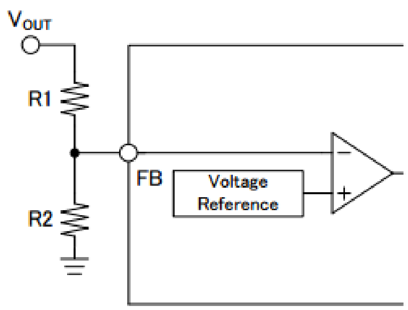


Fig 17: Feedback Resistor Circuit

$$V_{OUT} = \frac{R_1 + R_2}{R_2} \times 0.765\ (V)$$

BD9D321EFJ can operate under the condition which satisfies the following equation.

$$0.07 \leq \frac{V_{OUT}}{V_{IN}} \leq 0.65$$

(3) Soft Start Setting

Turning the EN terminal signal High activates the soft start function. This causes the output voltage to rise gradually while the current at startup is placed under control. This allows the prevention of output voltage overshoot and inrush current. The rise time depends on the value of the capacitor connected to the SS terminal.

$$\mathbf{T_d = \frac{C_{SS} \times V_{TH}}{I_{SS}}}$$

$$\mathbf{T_{SS} = \frac{C_{SS} \times V_{FB} \times 1.15}{I_{SS}}}$$

T_d : Soft Start Delay Time
T_{SS} : Soft Start Time
C_{SS} : Capacitor connected to Soft Start Time Terminal
V_{FB} : FB Terminal Voltage (0.765V Typ)
V_{TH} : Internal MOS threshold voltage (0.7V Typ)
I_{SS} : Soft Start Terminal Source Current (2.0µA Typ)

With C_{SS} = 3300 pF,
T_d = (3300 pF x 0.7 V) / 2.0 µA = 1.16 msec
T_{SS} = (3300 pF x 0.765 V x 1.15) / 2.0 µA = 1.45 msec

- **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	C1	CAP CER 100PF 50V 5% NP0 0603	Murata	GRM1885C1H101JA01D
2	2	C2,C10	CAP CER 0.1UF 50V 10% X7R 0603	Murata	GRM188R71H104KA93D
3	2	C3,C4	CAP CER 10UF 35V 10% X5R 1206	Murata	GRM31CR6YA106KA12L
4	2	C5,C6	CAP CER 22UF 25V 10% X5R 1210	Murata	GRM32ER61E226KE15L
5	1	C11	CAP CER 1UF 25V 10% X7R 0603	Murata	GRM188R71E105KA12D
6	1	C12	CAP CER 3300PF 50V 10% X7R 0603	Murata	GRM188R71H332KA01D
7	1	D1	TVS DIODE 18VWM 29.2VC SMA	Littelfuse Inc	SMAJ18A
8	1	J1	CONN HEADER VERT .100 3POS 15AU	TE Connectivity	87224-3
9	1	L1	INDUCTOR POWER 2.2UH 9A SMD	Wurth	744311220
10	1	R1	RES 30K OHM 1/10W 1% 0603 SMD	Rohm	MCR03ERTF3002
11	1	R2	RES 22K OHM 1/10W 1% 0603 SMD	Rohm	MCR03ERTF2202
12	1	R3	RES 0.0 OHM 1/10W JUMP 0603 SMD	Rohm	MCR03ERTJ000
13	2	TP1,TP3	TEST POINT PC MULTI PURPOSE RED	Keystone Electronics	5010
14	2	TP2,TP4	TEST POINT PC MULTI PURPOSE BLK	Keystone Electronics	5011
15	1	U1	IC REG BUCK SYNC ADJ 3A 8HTSOP	Rohm	BD9D321EFJ-E2
16	1		Shunt jumper for header J1(item #8) CONN SHUNT 2POS GOLD W/HANDLE	TE Connectivity	881545-1