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Datasheet

4.5 V to 36 V Input, 3.0 A Integrated MOSFET Single Synchronous Buck DC/DC Converter

BD9E304FP4-LBZ

General Description

This is the product guarantees long time support in Industrial market.

BD9E304FP4-LBZ is a single synchronous buck DC/DC converter with built-in low on-resistance power MOSFETs. The Light Load Mode control provides excellent efficiency characteristics in light-load conditions which make the product ideal for equipment, and devices that demand minimal standby power consumption. BD9E304FP4-LBZ is a current mode control and features good transient response. Phase compensation can also be set easily. It achieves the high power density and offers a small footprint on the PCB by employing small package.

Features

- Long Time Support Product for Industrial Applications
- Single Synchronous Buck DC/DC Converter
- Light Load Mode Control
- Efficiency = 80 % (@I_{OUT} = 10 mA,V_{IN} = 32 V, V_{OUT} = 5 V)
- Output Capacitor Discharge Function
- Over Voltage Protection (OVP)
- Over Current Protection (OCP)
- Short Circuit Protection (SCP)
- Thermal Shutdown Protection (TSD)
- Under Voltage Lockout Protection (UVLO)
- TSOT23-8L Package

Applications

- Industrial Equipment
- Secondary Power Supply and Adapter Equipment
- Telecommunication Devices

Key Specifications

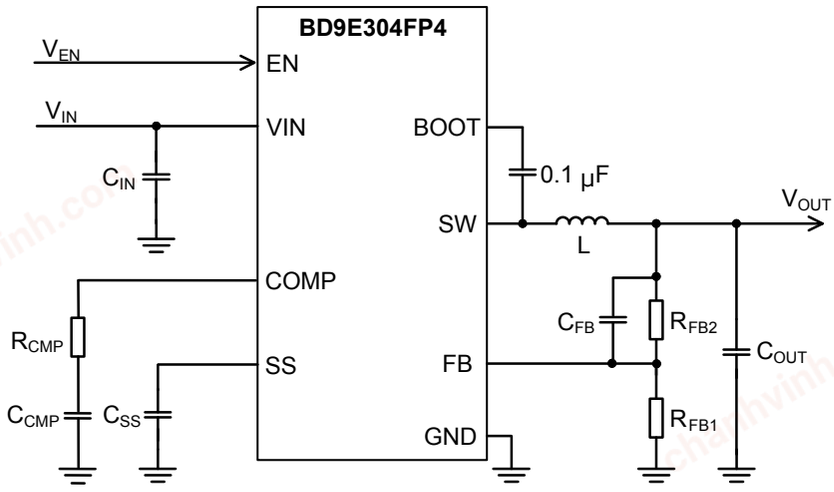
- Input Voltage Range: 4.5 V to 36.0 V
- Output Voltage Range: V_{IN}x0.1 or 0.7 V to V_{IN}x0.8 V
- Output Current: 3 A (Max)
- Switching Frequency: 300 kHz (Typ)
- High Side FET ON Resistance: 100 mΩ (Typ)
- Low Side FET ON Resistance: 60 mΩ (Typ)
- Shutdown Current: 3 μA (Typ)
- Operating Quiescent Current: 45 μA (Typ)

Package	W (Typ) x D (Typ) x H (Max)
TSOT23-8L	2.8 mm x 2.92 mm x 0.95 mm



TSOT23-8L

Typical Application Circuit

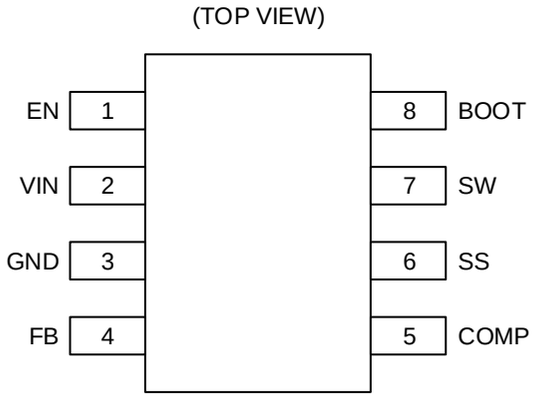


○Product structure : Silicon integrated circuit ○This product has no designed protection against radioactive rays.

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Pin Configuration



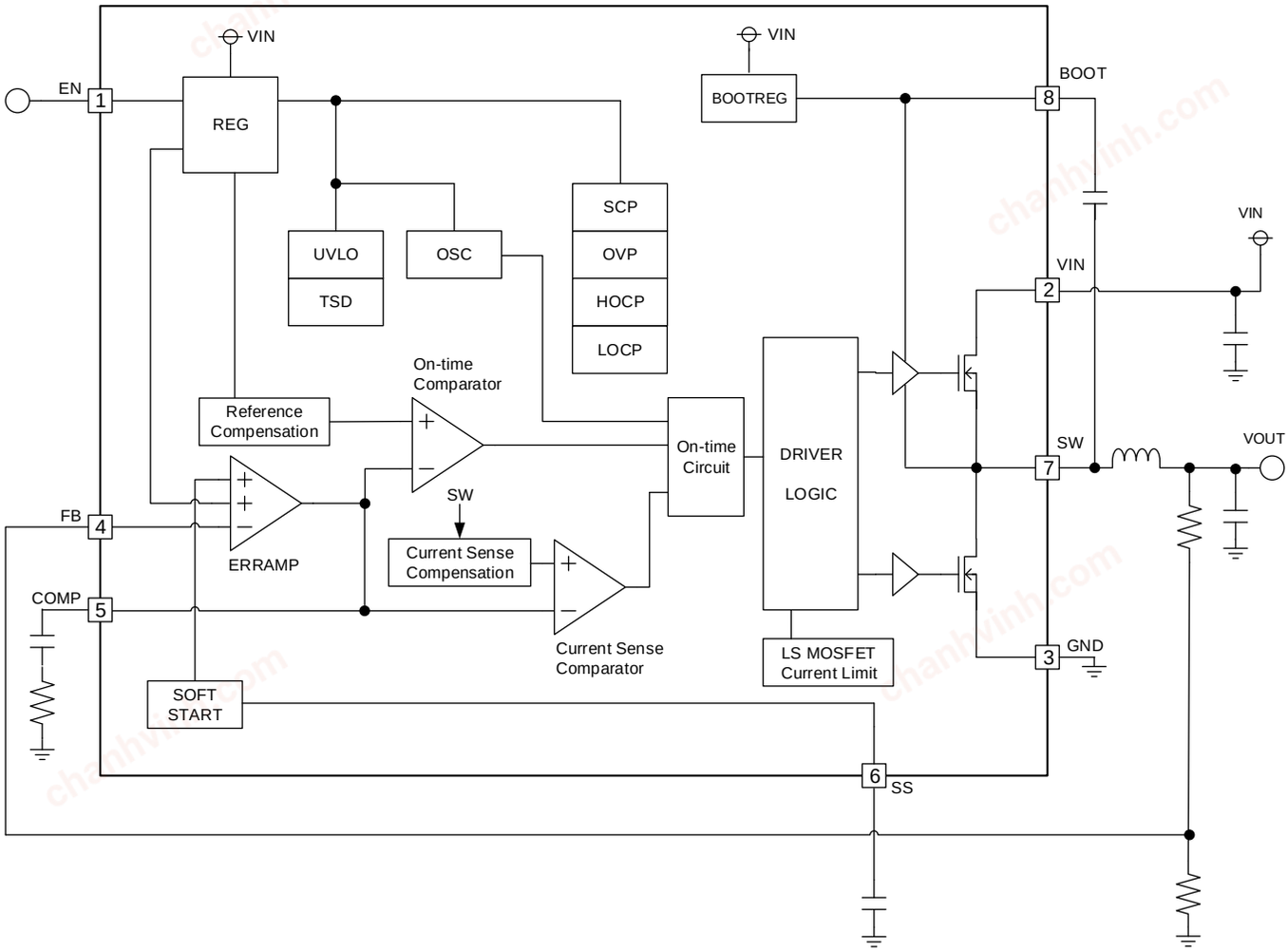
Pin Description

Pin No.	Pin Name	Function
1	EN	Enable pin. The device starts up with setting V_{ENH} to 1.2 V (Typ) or more. The device enters the shutdown mode with setting V_{ENL} to 1.1 V (Typ) or less. This pin must be terminated.
2	VIN	Power supply pin. Connecting 0.1 µF (Typ) and 10 µF (Typ) ceramic capacitors is recommended. The detail of a selection is described in Selection of Components Externally Connected 1. Input Capacitor.
3	GND	Ground pin.
4	FB	Output voltage feedback pin. See Selection of Components Externally Connected 3. Output Voltage Setting, FB Capacitor for the output voltage setting.
5	COMP	Output pin for the error amplifier and input pin for PWM comparator. See Selection of Components Externally Connected 4. Phase Compensation for how to calculate phase compensation components.
6	SS	Pin for setting the soft start time of output voltage. The soft start time is 2.5 ms (Typ) when the SS pin is open. A ceramic capacitor connected to the SS pin makes the soft start time more than 2.5 ms. See Selection of Components Externally Connected 5. Soft Start Capacitor for how to calculate the capacitance.
7	SW	Switch pin. This pin is connected to the source of the High Side FET and the drain of the Low Side FET. Connect a bootstrap capacitor of 0.1 µF between this pin and the BOOT pin. In addition, connect an inductor considering the direct current superimposition characteristic.
8	BOOT	Pin for bootstrap. Connect a bootstrap capacitor of 0.1 µF between this pin and the SW pin. The voltage of this pin is the gate drive voltage of the High Side FET.

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Block Diagram



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Description of Blocks

1. REG
   This block generates the internal regulator voltage.

2. SOFT START
   The Soft Start circuit slows down the rise of output voltage during start-up and controls the current, which allows the prevention of output voltage overshoot and inrush current. The internal soft start time is 2.5 ms (Typ) when the SS pin is open. A capacitor connected to the SS pin makes the rising time more than 2.5 ms.

3. ERRAMP
   This is the error amplifier. This block compares the FB voltage and the internal reference voltage. The COMP pin controls the switching duty and requires phase compensation components. The output voltage is set by the FB external resistors.

4. On-time Comparator
   The On-time Comparator compares the Error Amplifier output voltage and the reference voltage compensated by On-time. When the Error Amplifier output voltage becomes higher than the reference voltage compensated, the output turns low and reports to the On-time Circuit that the output voltage has dropped below the control voltage.

5. On-time Circuit
   This block generates the High Side FET on-time signal. Generates an on-time signal determined by the On-time comparator output, OSC signal, and Current Sense Comparator output.

6. Current Sense Comparator
   This is a comparator that compares the ERRAMP signal with the current sense signal compensated by ramp signal.

7. UVLO
   The UVLO block is for under voltage lockout protection. The device is shutdown when input voltage (V_{IN}) falls to 3.9 V (Typ) or less. The threshold voltage has the 350 mV (Typ) hysteresis.

8. TSD
   The TSD block is for thermal protection. The device is shutdown when the junction temperature Tj reaches to 175 °C (Typ) or more. The device is automatically restored to normal operation with a hysteresis of 25 °C (Typ) when the Tj goes down.

9. OVP
   The OVP block is for over voltage protection. When the FB voltage (V_{FB}) exceeds 120 % (Typ) or more of FB threshold voltage V_{FBTH}, the SW pin is pulled down with 400 Ω (Typ). After V_{FB} falls 115 % (Typ) or less of V_{FBTH}, the device is returned to normal operation condition.

10. HOCP
    This block is for over current protection of the High Side FET. When the current that flows through the High Side FET reaches the value of over current limit, it turns off the High Side FET and turns on the Low Side FET.

11. LOCP
    This block is for over current protection of the Low Side FET. While the current that flows through the Low Side FET over the value of over current limit, the condition that being turned on the Low Side FET is continued.

12. SCP
    This block is for short circuit protection. After soft start is completed and in condition where V_{FB} is 70 % (Typ) of 0.6 V or less and remained there for 0.9 ms (Typ), the device is shutdown for 100 ms (Typ) and subsequently initiates a restart.

13. LS MOSFET Current Limit
    This circuit is a comparator that monitors the inductor current. When inductor current falls below 0 A (Typ) while the Low Side FET is on, it turns off the Low Side FET.

14. Driver Logic
    The Driver Logic controls the switching operation and protection function operation.

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Absolute Maximum Ratings (Ta = 25 °C)

Parameter	Symbol	Rating	Unit
Input Voltage	V_{IN}	-0.3 to +39	V
SW Voltage	V_{SW}	-0.3 to V_{IN}+0.3	V
SW Voltage (30 ns pulse width)	V_{SWAC}	-3	V
Voltage from GND to BOOT	V_{BOOT}	-0.3 to +45	V
Voltage from SW to BOOT	ΔV_{BOOT}	-0.3 to +7	V
FB Voltage	V_{FB}	-0.3 to +3	V
COMP Voltage	V_{COMP}	-0.3 to +3	V
EN Voltage	V_{EN}	-0.3 to +39	V
SS Voltage	V_{SS}	-0.3 to +3	V
Output Current	I_{OUT}	3	A
Maximum Junction Temperature	Tjmax	150	°C
Storage Temperature Range	Tstg	-55 to +150	°C

Caution 1: *Operating the IC over the absolute maximum ratings may damage the IC. The damage can either be a short circuit between pins or an open circuit between pins and the internal circuitry. Therefore, it is important to consider circuit protection measures, such as adding a fuse, in case the IC is operated over the absolute maximum ratings.*

Caution 2: *Should by any chance the maximum junction temperature rating be exceeded the rise in temperature of the chip may result in deterioration of the properties of the chip. In case of exceeding this absolute maximum rating, design a PCB with thermal resistance taken into consideration by increasing board size and copper area so as not to exceed the maximum junction temperature rating.*

Thermal Resistance*(Note 1)*

Parameter	Symbol	Thermal Resistance (Typ)		Unit
		1s*(Note 3)*	2s2p*(Note 4)*	
TSOT23-8L				
Junction to Ambient	θ_{JA}	182.4	82.8	°C/W
Junction to Top Characterization Parameter*(Note 2)*	Ψ_{JT}	25	22	°C/W

(Note 1) Based on JESD51-2A (Still-Air). The chip of BD9E304 has been measured.
(Note 2) The thermal characterization parameter to report the difference between junction temperature and the temperature at the top center of the outside surface of the component package.
(Note 3) Using a PCB board based on JESD51-3.

Layer Number of Measurement Board	Material	Board Size
Single	FR-4	114.3 mm x 76.2 mm x 1.57 mmt

Top	
Copper Pattern	Thickness
Footprints and Traces	70 µm

(Note 4) Using a PCB board based on JESD51-7.

Layer Number of Measurement Board	Material	Board Size
4 Layers	FR-4	114.3 mm x 76.2 mm x 1.6 mmt

Top		2 Internal Layers		Bottom	
Copper Pattern	Thickness	Copper Pattern	Thickness	Copper Pattern	Thickness
Footprints and Traces	70 µm	74.2 mm x 74.2 mm	35 µm	74.2 mm x 74.2 mm	70 µm

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Recommended Operating Conditions

Parameter	Symbol	Min	Typ	Max	Unit
Input Voltage	V_{IN}	4.5	-	36.0	V
Operating Temperature *(Note 1)*	Topr	-40	-	+85	°C
Output Current *(Note 1)*	I_{OUT}	0	-	3	A
Output Voltage Setting *(Note 2)*	V_{OUT}	0.7	-	V_{IN}x0.8	V

(Note 1) Tj must be 125 °C or less under the actual operating environment. Lifetime is derated at junction temperature greater than 125 °C.
(Note 2) Please use within the range of $V_{OUT} \geq V_{IN} \times 0.1$ [V].

Electrical Characteristics (Unless otherwise specified Ta = 25 °C, V_{IN} = 12 V, V_{EN} = 3 V)

Parameter	Symbol	Min	Typ	Max	Unit	Conditions
Input Supply						
Shutdown Current	I_{SDN}	-	3	15	µA	V_{EN} = 0 V
Operating Quiescent Current	I_Q	-	45	90	µA	I_{OUT} = 0 A, No switching
UVLO Detection Threshold Voltage	V_{UVLO1}	3.7	3.9	4.1	V	V_{IN} falling
UVLO Release Threshold Voltage	V_{UVLO2}	4.05	4.25	4.45	V	V_{IN} rising
UVLO Hysteresis Voltage	$V_{UVLOHYS}$	300	350	400	mV	
Enable						
EN Threshold Voltage High	V_{ENH}	1.1	1.2	1.3	V	V_{EN} rising
EN Threshold Voltage Low	V_{ENL}	1.0	1.1	1.2	V	V_{EN} falling
EN Hysteresis Voltage	V_{ENHYS}	50	100	200	mV	
EN Input Current	I_{EN}	-	0	3	µA	V_{EN} = 3 V
Reference Voltage, Error Amplifier, Soft Start						
FB Threshold Voltage	V_{FBTH}	0.591	0.600	0.609	V	
FB Input Current	I_{FB}	-	-	100	nA	V_{FB} = 0.6 V
COMP Source Current	I_{COMPSO}	5	10	15	µA	
COMP Sink Current	I_{COMPSI}	5	10	15	µA	
Soft Start Time	t_{SS}	1.75	2.50	3.25	ms	The SS pin is open.
Soft Start Charge Current	I_{SS}	2.0	2.5	3.0	µA	
SW (MOSFET)						
Switching Frequency	f_{SW}	255	300	345	kHz	
Maximum Duty Ratio	D_{MAX}	80	-	-	%	
High Side FET ON Resistance	R_{ONH}	50	100	150	mΩ	V_{BOOT} - V_{SW} = 5 V
Low Side FET ON Resistance	R_{ONL}	30	60	90	mΩ	
Protection						
High Side Over Current Limit *(Note 3)*	I_{HOCP}	4.5	5.0	5.5	A	
Low Side Over Current Limit *(Note 3)*	I_{LOCP}	3.0	3.5	4.0	A	

(Note 3) No tested on outgoing inspection.

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Typical Performance Curves

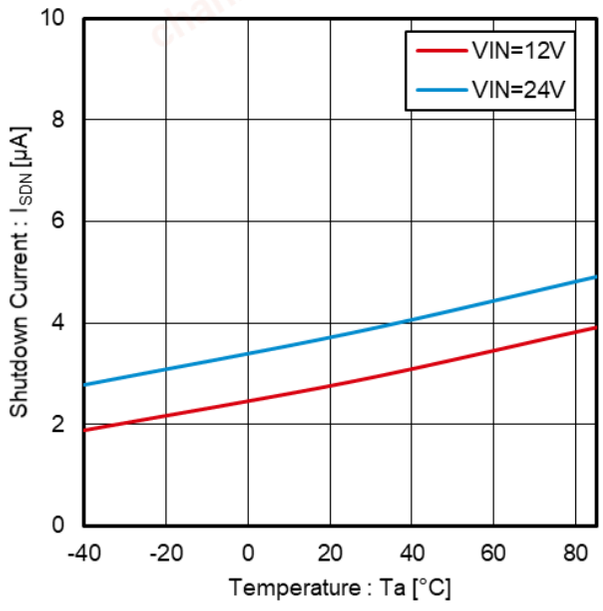


Figure 1. Shutdown Current vs Temperature

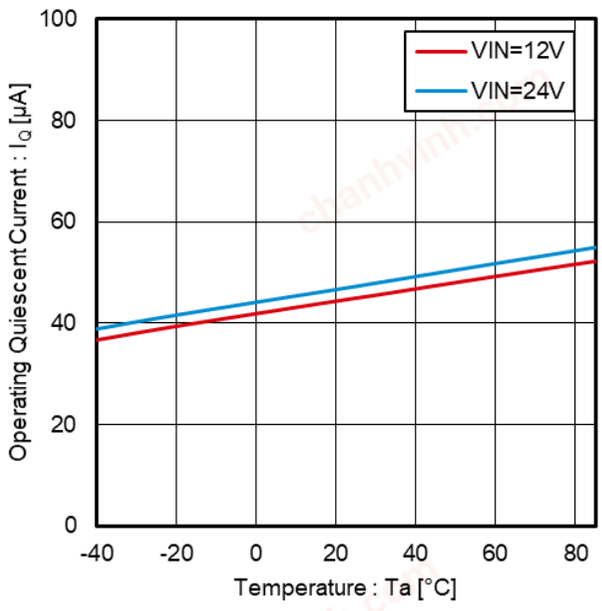


Figure 2. Operating Quiescent Current vs Temperature

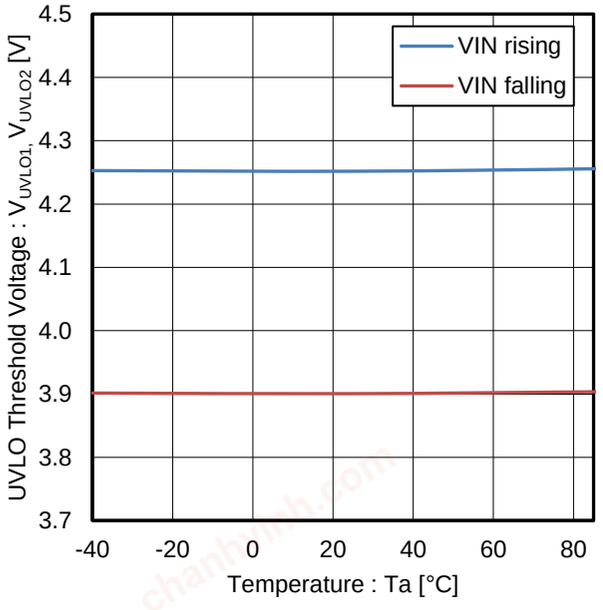


Figure 3. UVLO Threshold Voltage vs Temperature

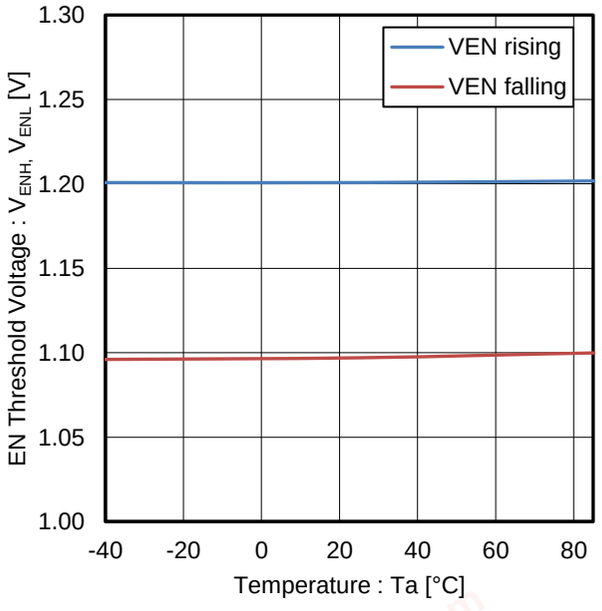


Figure 4. EN Threshold Voltage vs Temperature

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Typical Performance Curves – continued

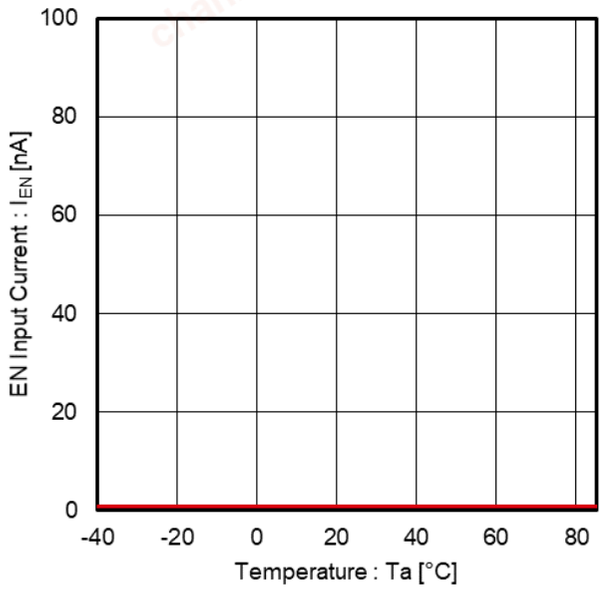


Figure 5. EN Input Current vs Temperature

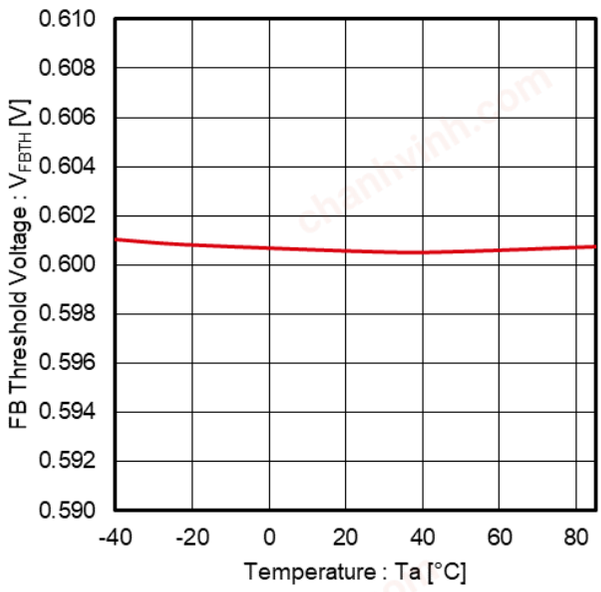


Figure 6. FB Threshold Voltage vs Temperature

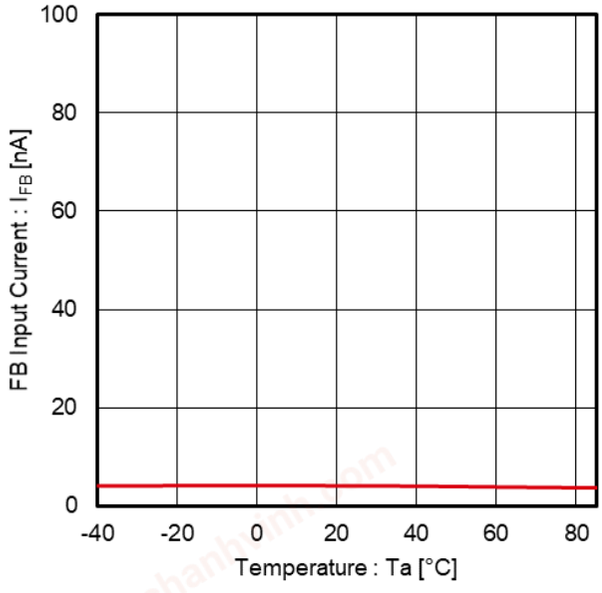


Figure 7. FB Input Current vs Temperature

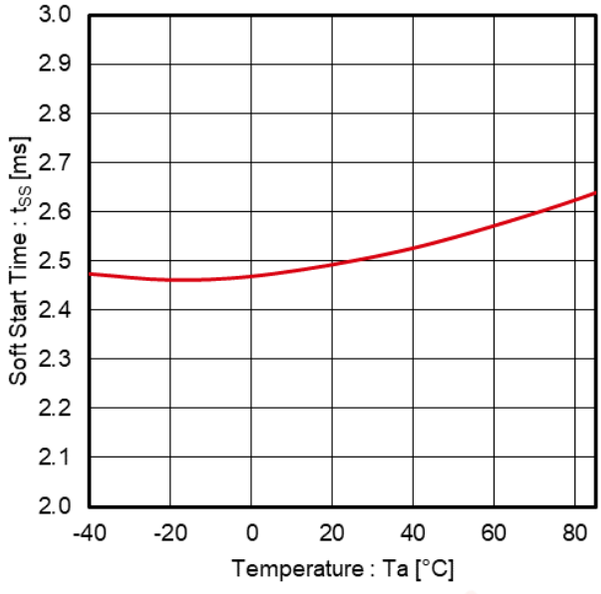


Figure 8. Soft Start Time vs Temperature

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Typical Performance Curves – continued

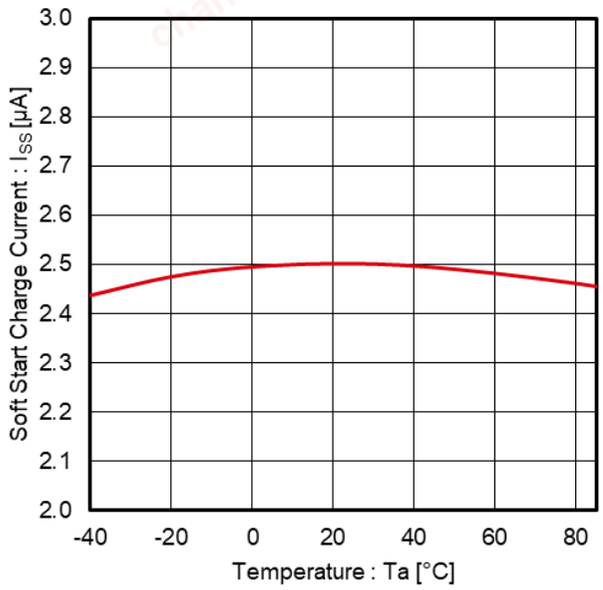


Figure 9. Soft Start Charge Current vs Temperature

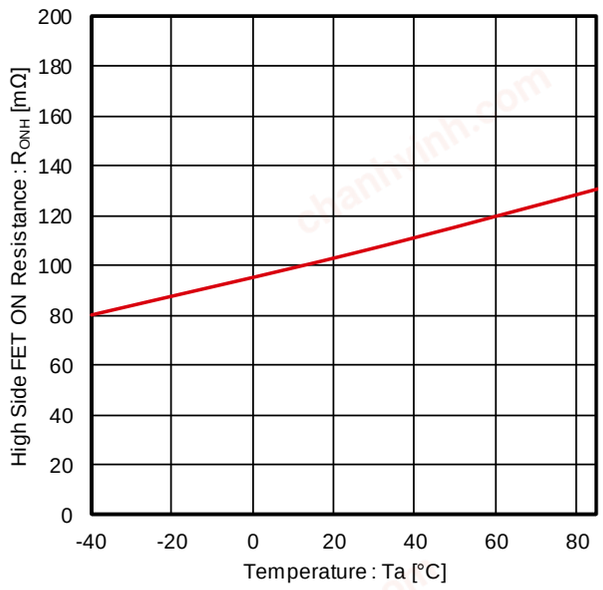


Figure 10. High Side FET ON Resistance vs Temperature

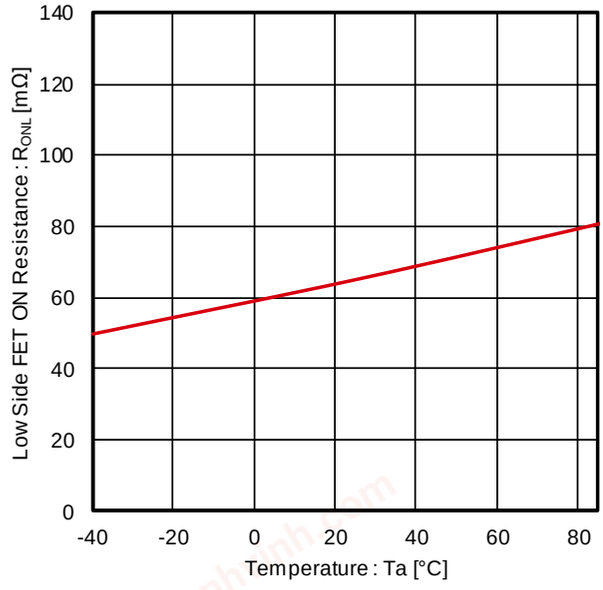


Figure 11. Low Side FET ON Resistance vs Temperature

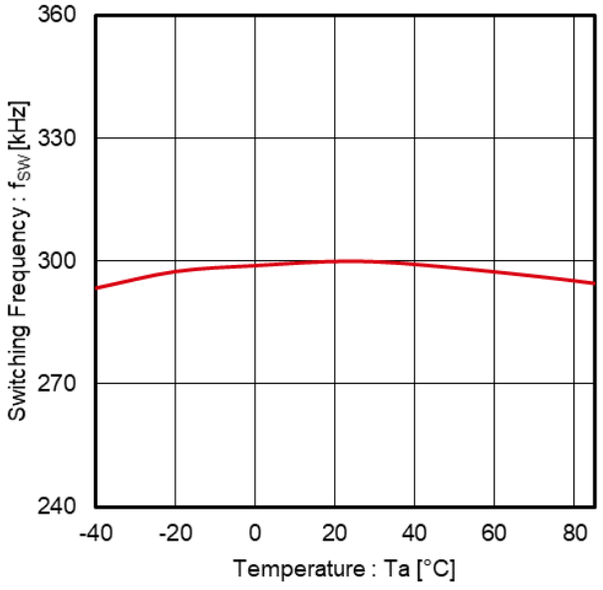


Figure 12. Switching Frequency vs Temperature

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Typical Performance Curves – continued

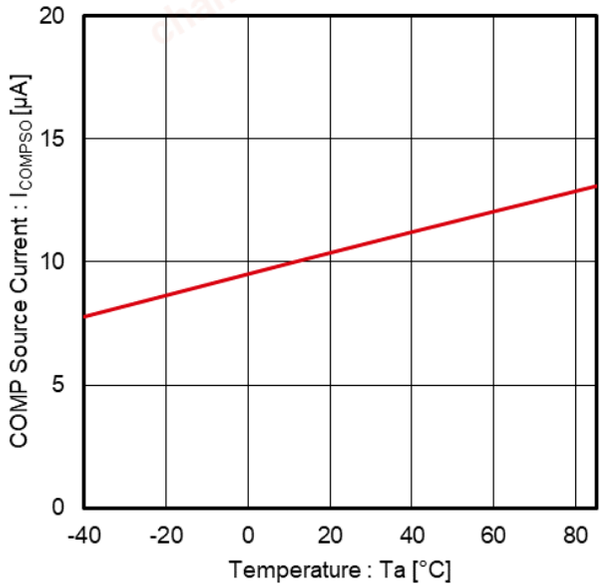


Figure 13. COMP Source Current vs Temperature

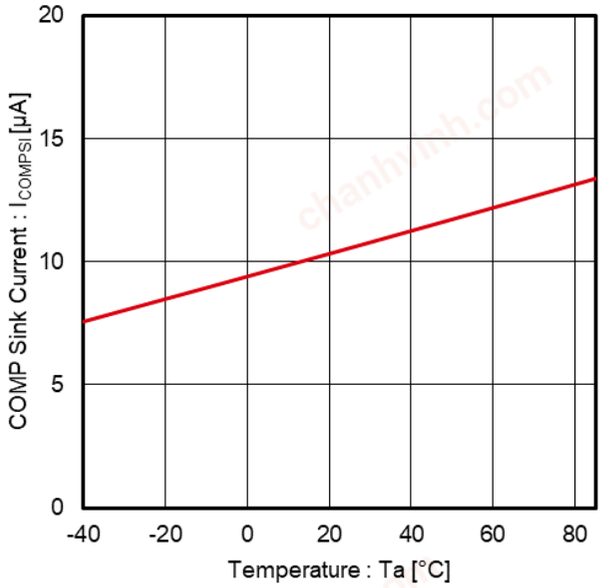


Figure 14. COMP Sink Current vs Temperature

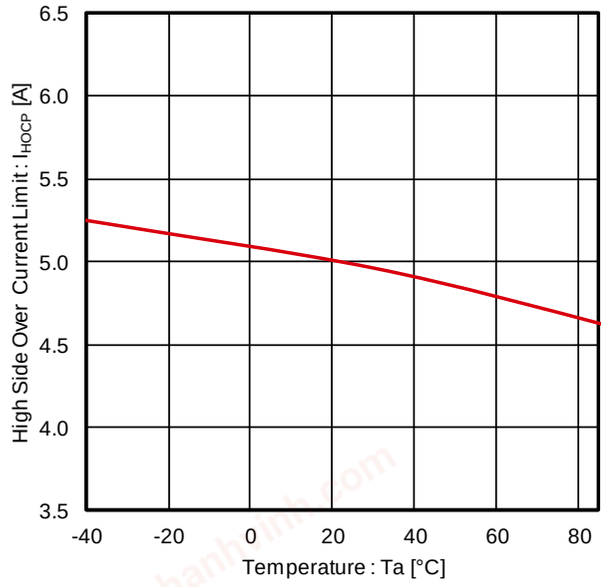


Figure 15. High Side Over Current Limit vs Temperature

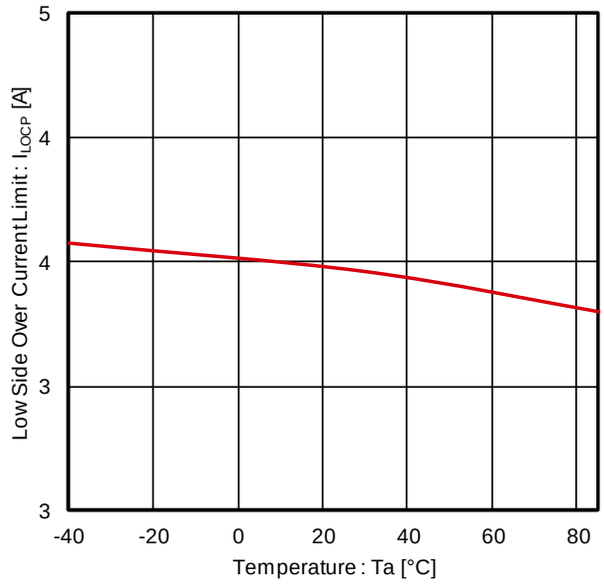


Figure 16. Low Side Over Current Limit vs Temperature

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Typical Performance Curves – continued

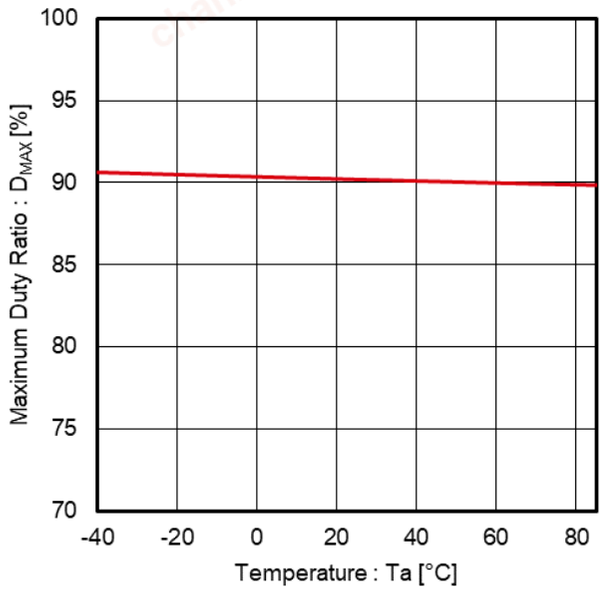


Figure 17. Maximum Duty Ratio vs Temperature

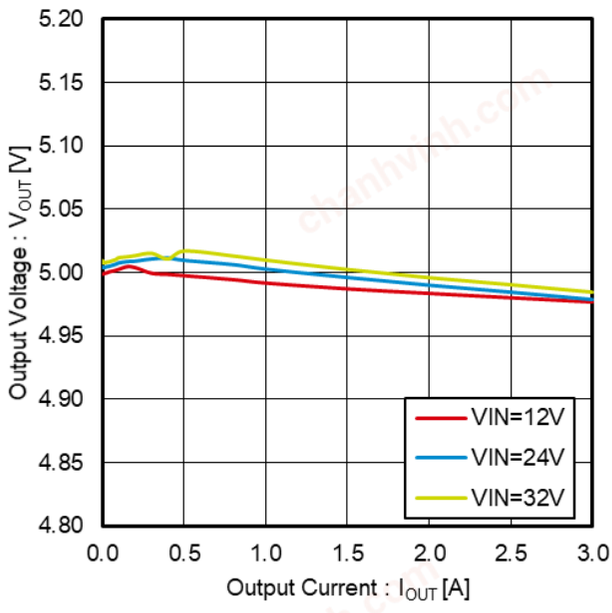


Figure 18. Output Voltage vs Output Current

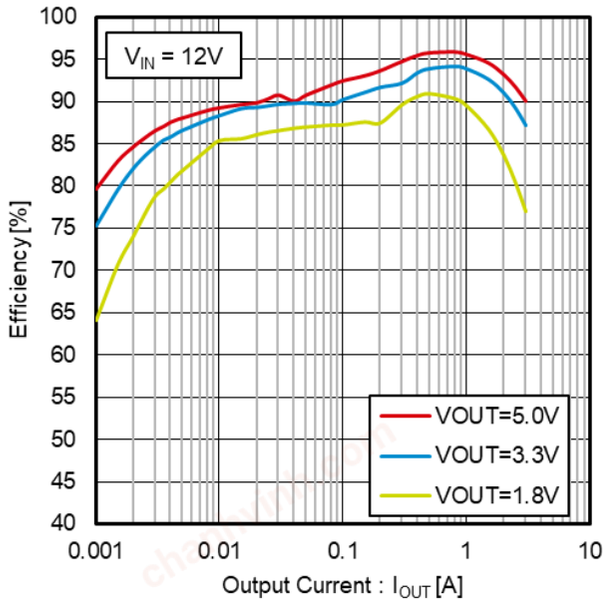


Figure 19. Efficiency vs Output Current 1

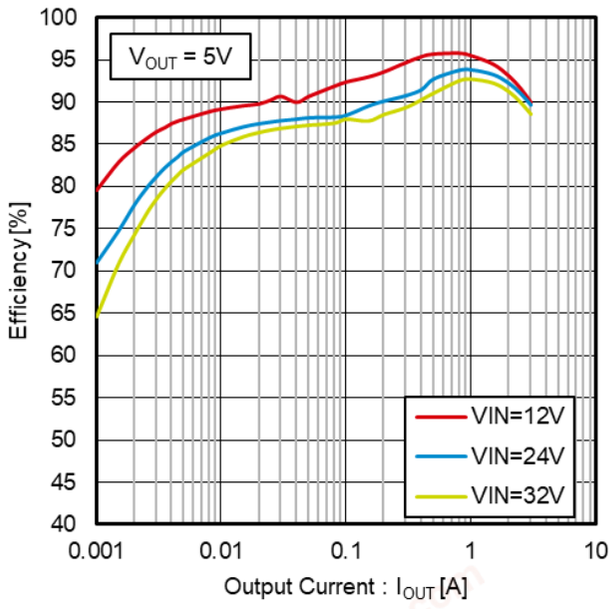


Figure 20. Efficiency vs Output Current 2

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Typical Performance Curves – continued

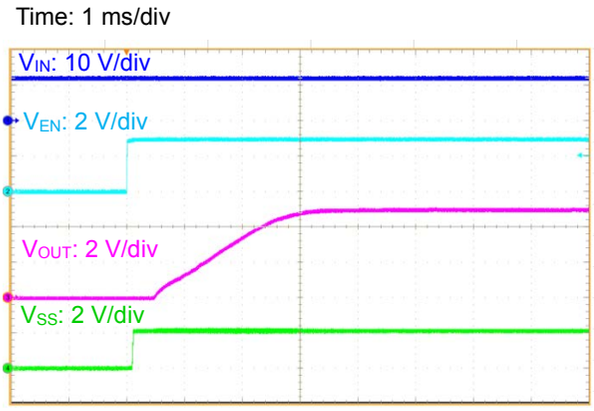


Figure 21. Start-up at No load: V_{EN} = 0 V to 3 V
(V_{IN} = 12 V, V_{OUT} = 5 V, C_{SS} = OPEN)

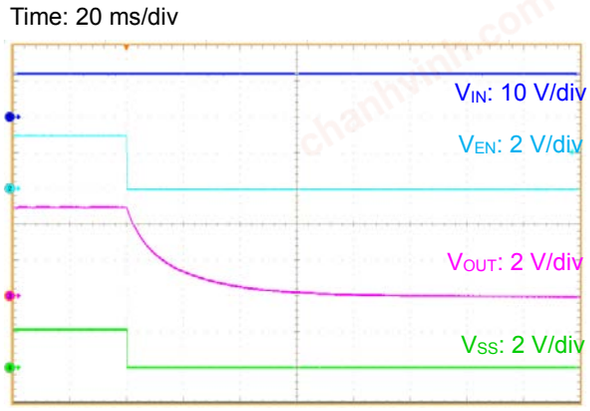


Figure 22. Shutdown at No Load V_{EN} = 3 V to 0 V
(V_{IN} = 12 V, V_{OUT} = 5 V, C_{SS} = OPEN)

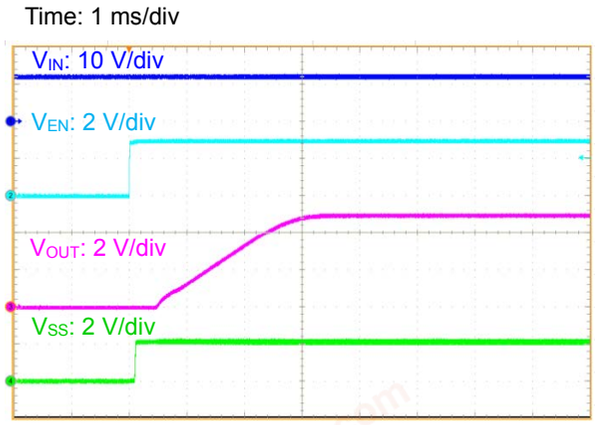


Figure 23. Start-up at R_{LOAD} = 1.66 Ω: V_{EN} = 0 V to 3 V
(V_{IN} = 12 V, V_{OUT} = 5 V, C_{SS} = OPEN)

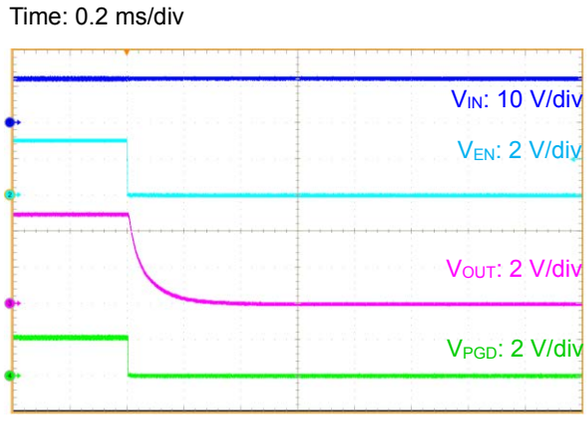


Figure 24. Shutdown at R_{LOAD} = 1.66 Ω: V_{EN} = 3 V to 0 V
(V_{IN} = 12 V, V_{OUT} = 5 V, C_{SS} = OPEN)

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Typical Performance Curves – continued

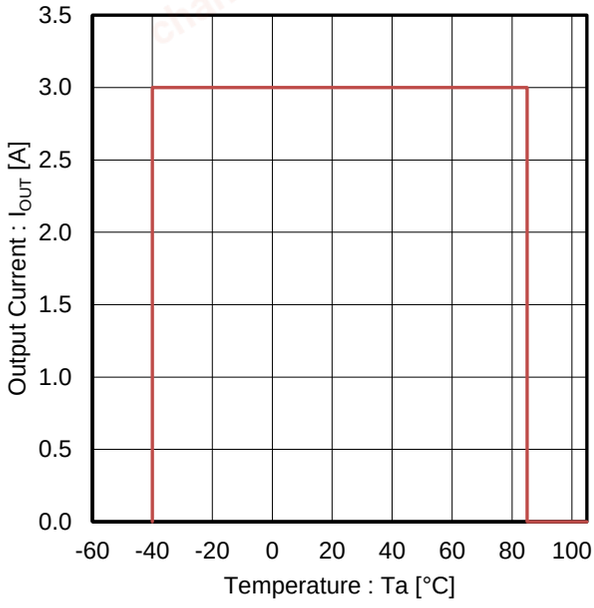


Figure 25. Output Current vs Temperature*(Note 1)*
Operating Range: Tj < 125 °C (V_{IN} = 7 V, V_{OUT} = 0.7 V)

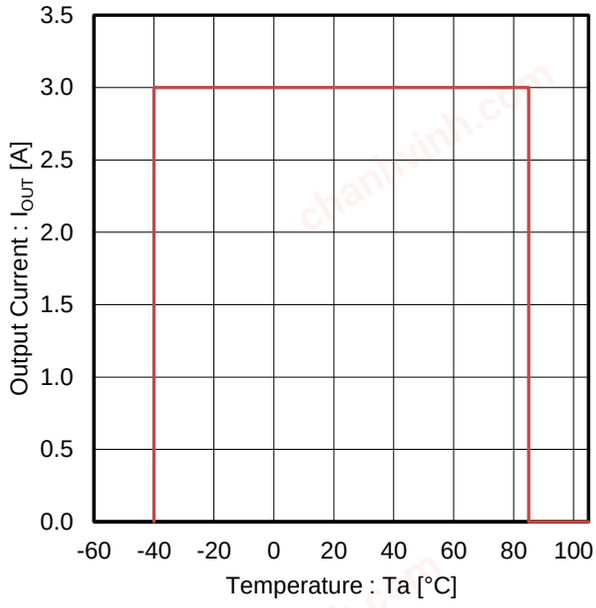


Figure 26. Output Current vs Temperature*(Note 1)*
Operating Range: Tj < 125 °C (V_{IN} = 12 V, V_{OUT} = 1.2 V)

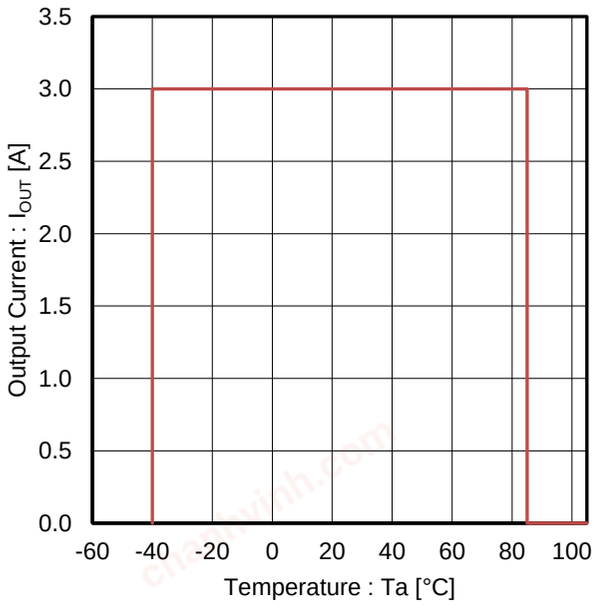


Figure 27. Output Current vs Temperature*(Note 1)*
Operating Range: Tj < 125 °C (V_{IN} = 18 V, V_{OUT} = 1.8 V)

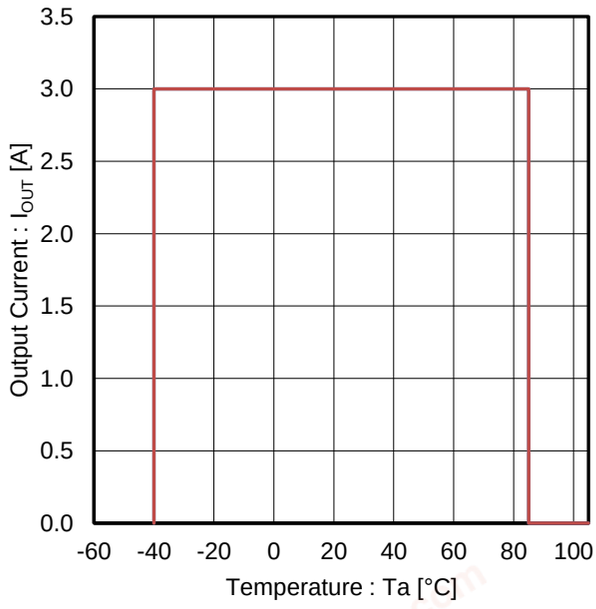


Figure 28. Output Current vs Temperature*(Note 1)*
Operating Range: Tj < 125 °C (V_{IN} = 32 V, V_{OUT} = 3.3 V)

(Note 1) Measured on FR-4 board 85 mm x 85 mm, Copper Thickness: Top and Bottom 70 µm, 2 Internal Layers 35 µm.

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Typical Performance Curves – continued

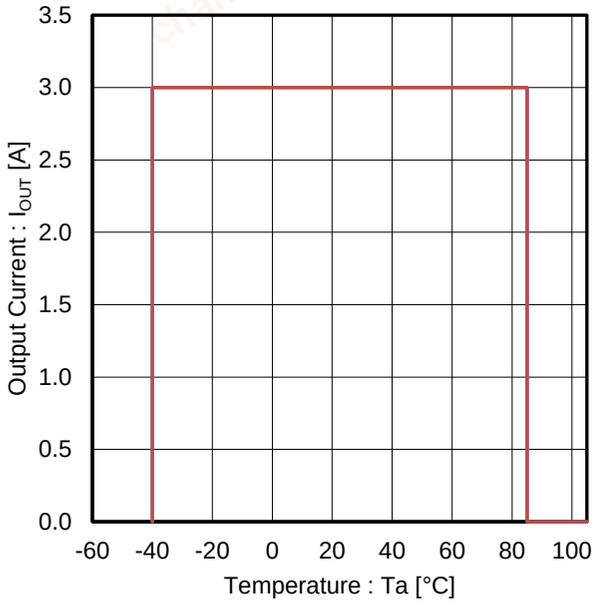


Figure 29. Output Current vs Temperature*(Note 1)*
Operating Range: Tj < 125 °C (V_{IN} = 36 V, V_{OUT} = 5 V)

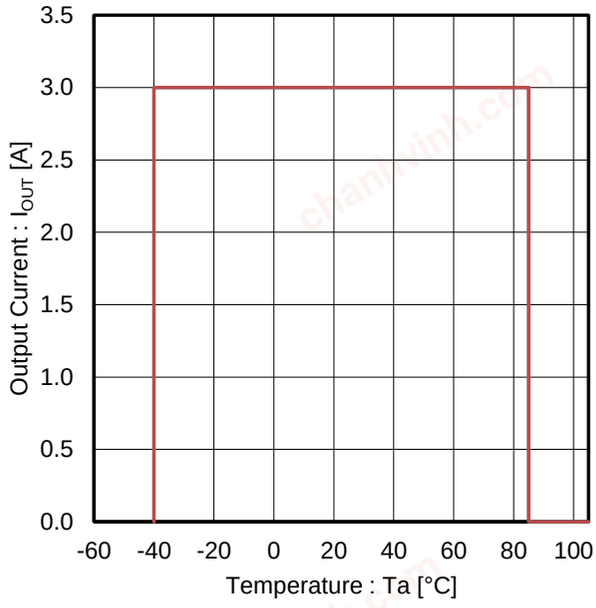


Figure 30. Output Current vs Temperature*(Note 1)*
Operating Range: Tj < 125 °C (V_{IN} = 36 V, V_{OUT} = 12 V)

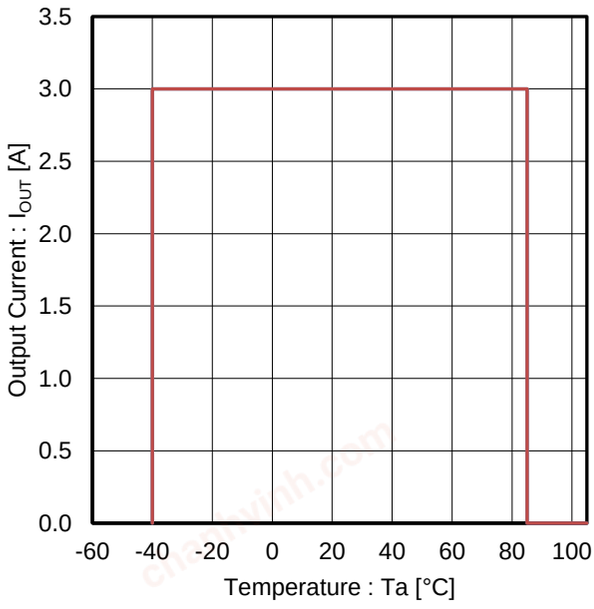


Figure 31. Output Current vs Temperature*(Note 1)*
Operating Range: Tj < 125 °C (V_{IN} = 36 V, V_{OUT} = 24 V)

(Note 1) Measured on FR-4 board 85 mm x 85 mm, Copper Thickness: Top and Bottom 70 µm, 2 Internal Layers 35 µm.

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Function Explanation

1. Basic Operation

(1) DC/DC Converter Operation

BD9E304FP4-LBZ is a synchronous rectifying step-down switching regulator that achieves faster transient response by employing current mode PWM control system. It utilizes switching operation in PWM (Pulse Width Modulation) mode for heavier load, while it utilizes Light Load Mode control for lighter load to improve efficiency.

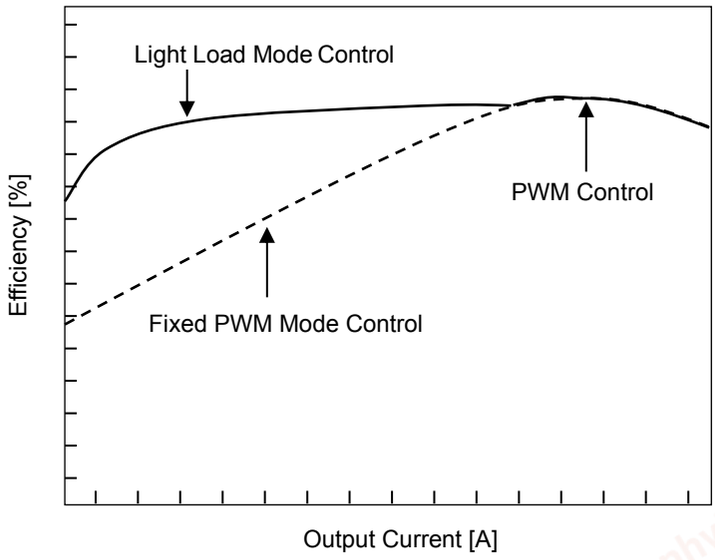


Figure 32. Efficiency Image between Light Load Mode Control and PWM Mode Control

(2) Enable Control

The startup and shutdown can be controlled by the EN voltage (V_{EN}). When V_{EN} becomes 1.2 V (Typ) or more, the internal circuit is activated and the device starts up. When V_{EN} becomes 1.1 V (Typ) or less, the device is shutdown. In this shutdown mode, the High Side FET and the Low Side FET are turned off and the SW pin is connected to GND through an internal resistor 400 Ω (Typ) to discharge the output. The startup with V_{EN} must be at the same time of the input voltage V_{IN} (V_{IN} = V_{EN}) or after supplying V_{IN}.

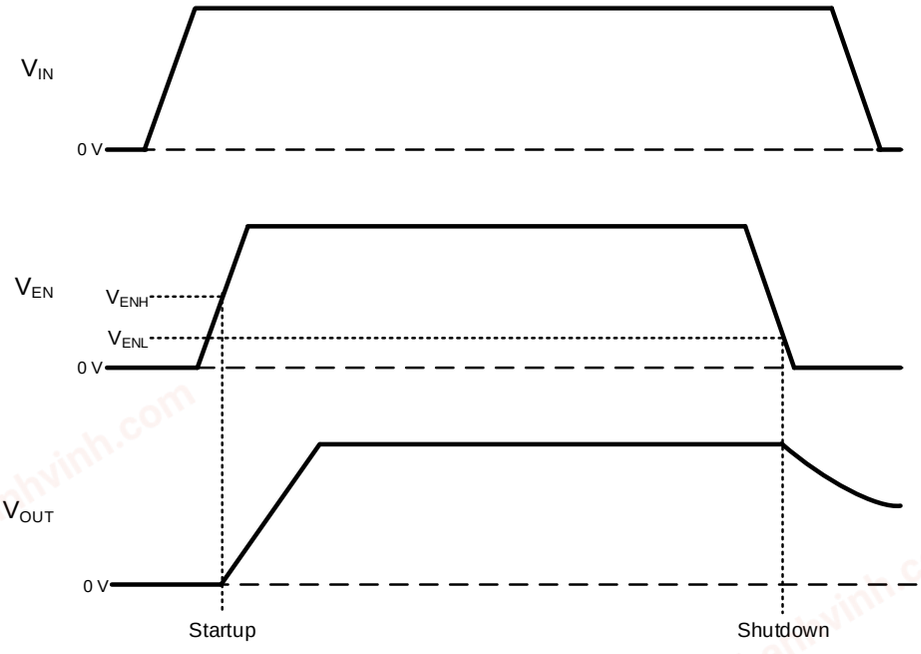


Figure 33. Startup and Shutdown with Enable Control Timing Chart

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1. Basic Operation – continued

(3) Soft Start

When V_{EN} goes high, soft start function operates and output voltage gradually rises. This soft start function can prevent overshoot of the output voltage and excessive inrush current. The soft start time t_{SS} is 2.5 ms (Typ) when the SS pin is left floating. A capacitor connected to the SS pin makes t_{SS} more than 2.5 ms. See Selection of Components Externally Connected 4. Soft Start Capacitor for how to set the soft start time.

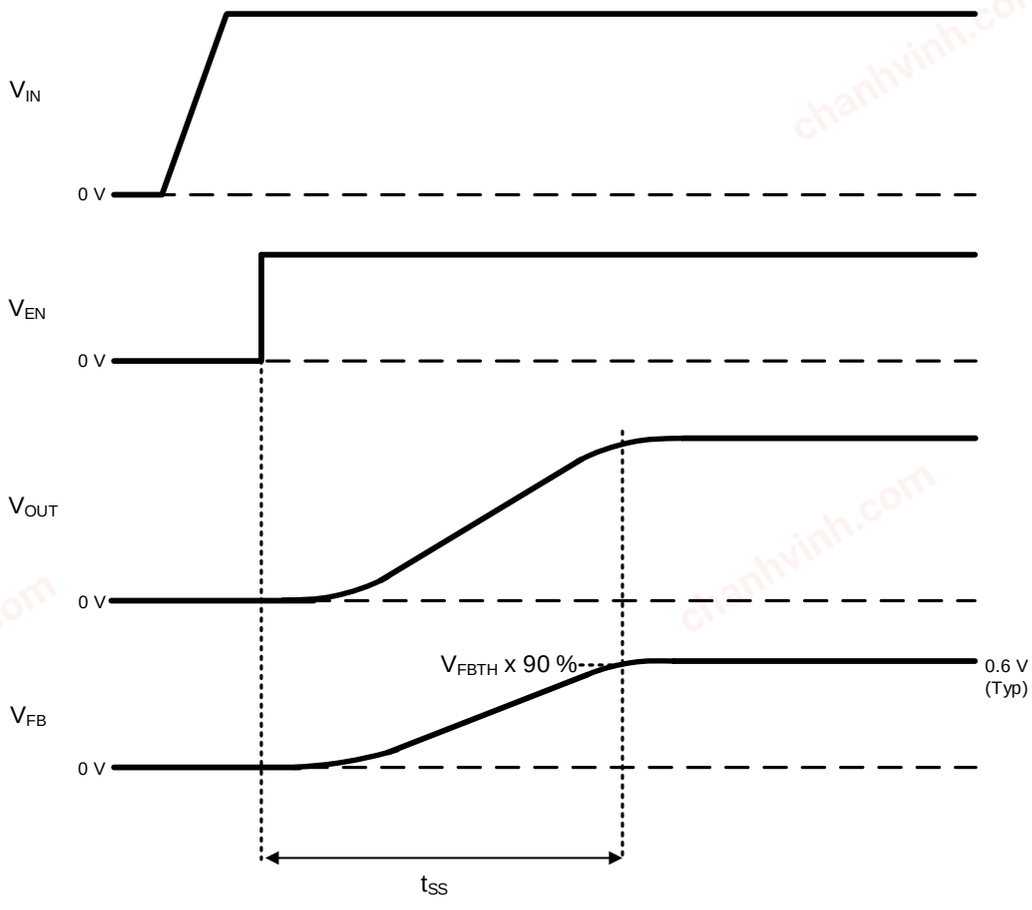


Figure 34. Soft Start Timing Chart

(4) Output Capacitor Discharge Function

When even one of the following conditions is satisfied, output is discharged with 400 Ω (Typ) internal resistor through the SW pin.

- Shutdown: $V_{EN} \leq 1.1$ V (Typ)
- UVLO: $V_{IN} \leq 3.9$ V (Typ)
- TSD: Tj ≥ 175 °C (Typ)
- OVP: $V_{FB} / V_{FBTH} \geq 120$ % (Typ)

When all of the above conditions are released, output discharge is stopped.

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Function Explanation – continued

2. Protection

The protection circuits are intended for prevention of damage caused by unexpected accidents. Do not use the continuous protection.

(1) Over Current Protection (OCP) / Short Circuit Protection (SCP)

Over Current Protection (OCP) restricts the flowing current through the Low Side FET and the High Side FET for every switching period. If the inductor current exceeds the Low Side OCP I_{LOCP} = 3.5 A (Typ) while the Low Side FET is on, the Low Side FET remains on even with FB voltage V_{FB} falls to V_{FBTH} = 0.6 V (Typ) or less. If the inductor current becomes less than I_{LOCP}, the High Side FET is able to be turned on. When the inductor current becomes the High Side OCP I_{HOCP} = 5 A (Typ) or more, while the High Side FET is on, the High Side FET is turned off. Output voltage may decrease by changing frequency and duty due to the OCP operation.

Short Circuit Protection (SCP) function is a Hiccup mode. When Low Side OCP remains at 0.9ms duration while V_{FB} is V_{FBTH} x 70 % or less, the device stops the switching operation for 100ms. After that, the device restarts. SCP does not operate during the soft start even if the device is in the SCP conditions. Do not exceed the maximum junction temperature (Tjmax = 150 °C) during OCP and SCP operation.

V_{EN}	V_{FB}	Start-up	OCP	SCP
≥ 1.2 V (Typ)	≤ V_{FBTH} x 70 % (Typ)	During Soft Start	Enable	Disable
	> V_{FBTH} x 70 % (Typ)	Complete Soft Start	Enable	Disable
	≤ V_{FBTH} x 70 % (Typ)		Enable	Enable
≤ 1.1 V (Typ)	-	Shutdown	Disable	Disable

Table 1. The Operating Condition of OCP and SCP

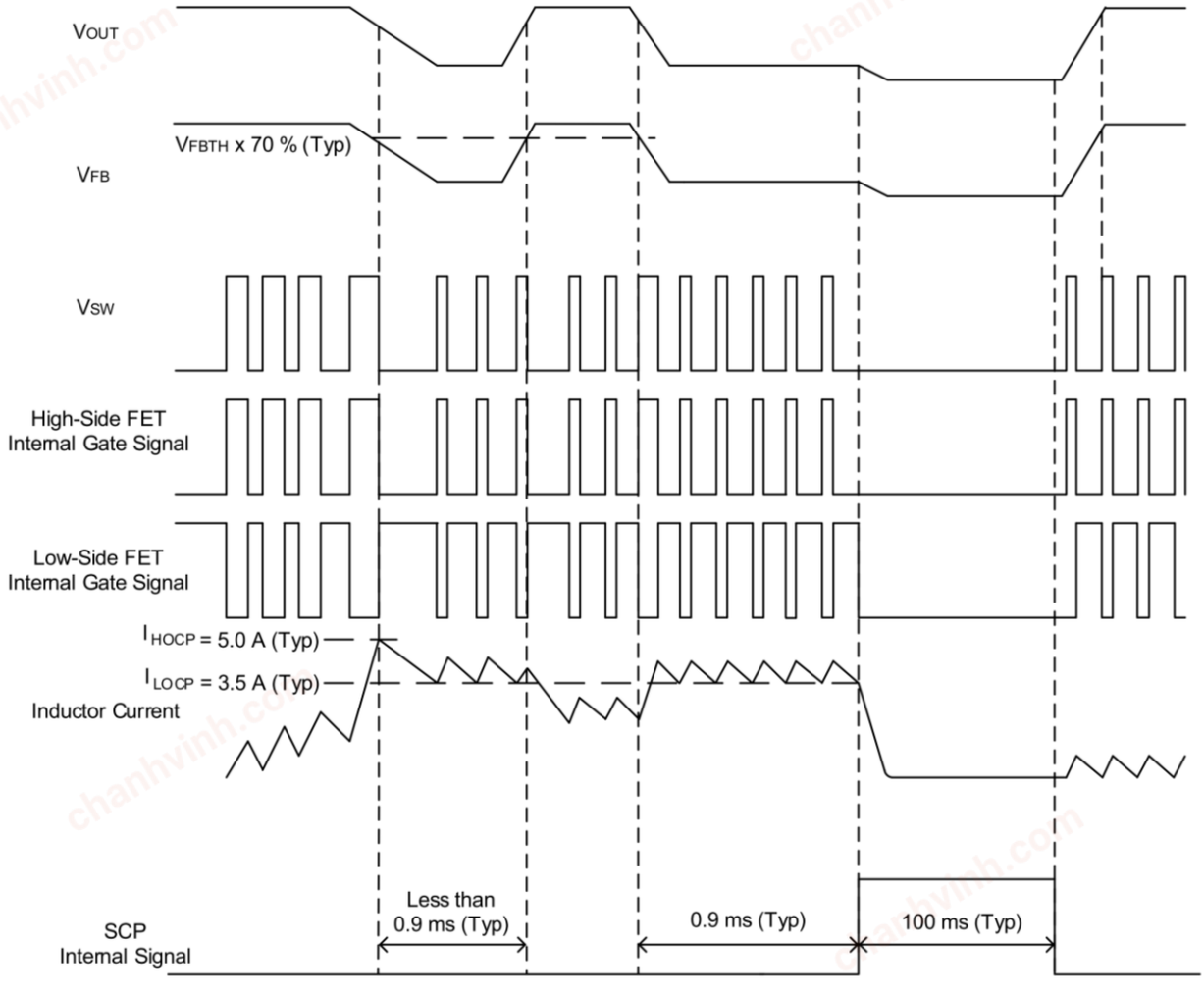


Figure 35. OCP and SCP Timing Chart

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2. Protection – continued

(2) Under Voltage Lockout Protection (UVLO)

When input voltage V_{IN} falls to 3.9 V (Typ) or less, the device is shutdown. When V_{IN} becomes 4.25 V (Typ) or more, the device starts up. The hysteresis is 350 mV (Typ).

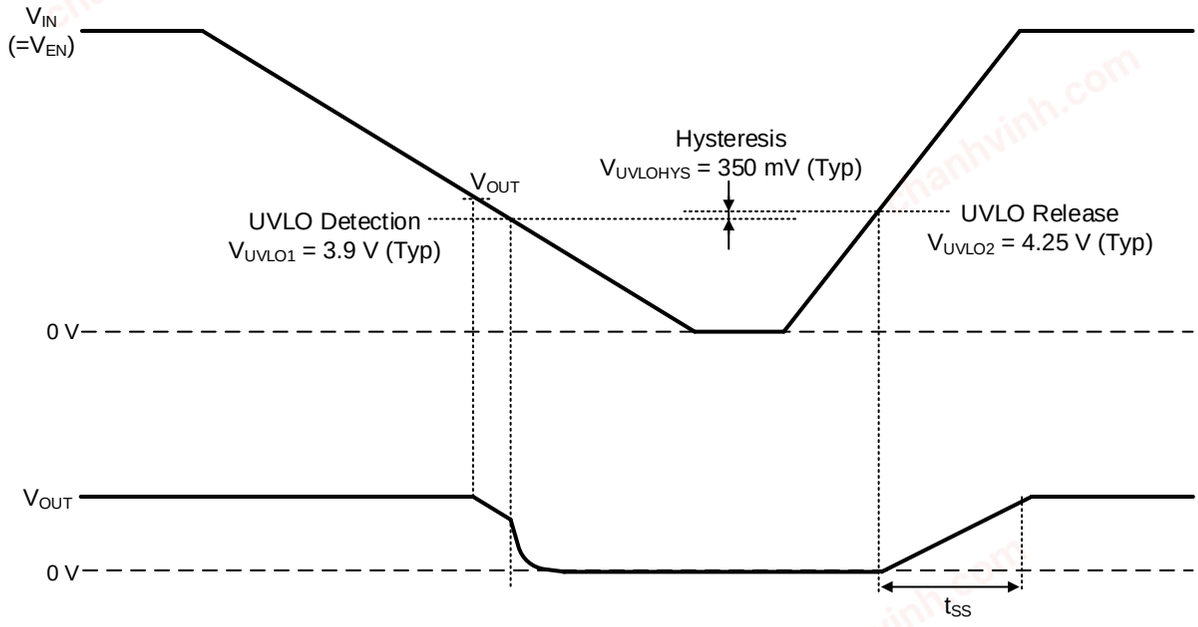


Figure 36. UVLO Timing Chart

(3) Thermal Shutdown Protection (TSD)

Thermal shutdown circuit prevents heat damage to the IC. The device should always operate within the IC's maximum junction temperature rating (Tjmax = 150 °C). However, if it continues exceeding the rating and the junction temperature Tj rises to 175 °C (Typ), the TSD circuit is activated and it turns the output MOSFETs off. When the Tj falls below the TSD threshold, the circuits are automatically restored to normal operation. The TSD threshold has a hysteresis of 25 °C (Typ). Note that the TSD circuit operates in a situation that exceeds the absolute maximum ratings. Therefore, under no circumstances, should the TSD circuit be used in a set design or for any purpose other than protecting the IC from heat damage.

(4) Over Voltage Protection (OVP)

When the FB voltage V_{FB} exceeds V_{FBTH} x 120 % (Typ) or more, output is discharged with 400 Ω (Typ) resister through the SW pin to prevent the increase in the output voltage. After the V_{FB} falls V_{FBTH} x 115 % (Typ) or less, the output MOSFETs are returned to normal operation condition. Switching operation restarts after V_{FB} falls below V_{FBTH} (Typ).

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Application Examples

1. V_{IN} = 5 V to 12 V, V_{OUT} = 1.2 V

Table 2. Specification of Application

Parameter	Symbol	Specification Value
Input Voltage	V_{IN}	5 V to 12 V (Typ)
Output Voltage	V_{OUT}	1.2 V (Typ)
Maximum Output Current	I_{OUTMAX}	3 A
Temperature	Ta	25 °C

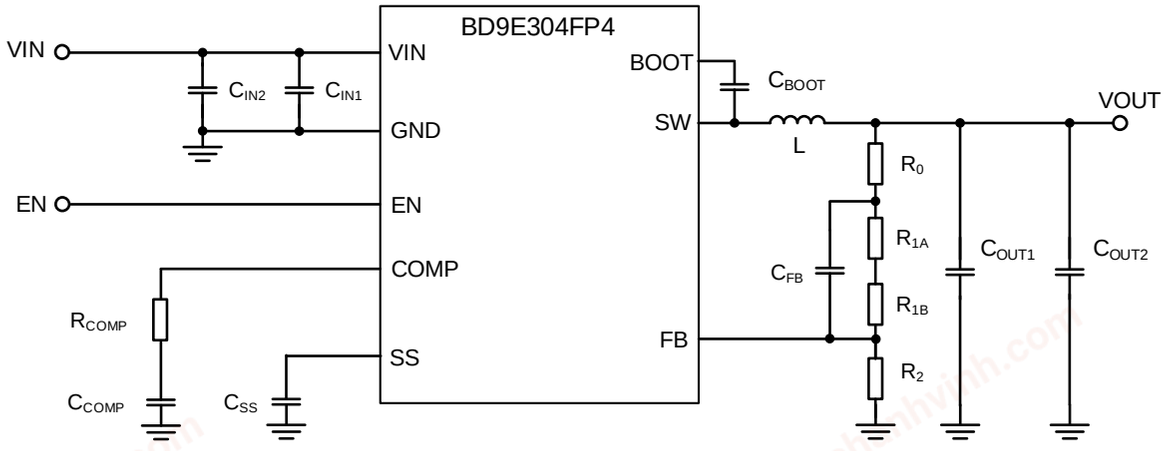


Figure 37. Application Circuit

Table 3. Recommended Component Values

Part No.	Value	Part Name	Size Code (mm)	Manufacturer
L	3.3 µH	DEM8045C	8080	Murata
C_{IN1} *(Note 1)*	0.1 µF (50 V, X5R, ±15 %)	GRM155R61H104KE14	1005	Murata
C_{IN2} *(Note 2)*	10 µF (100 V, X7S, ±22 %)	GRM32EC72A106KE05	3225	Murata
C_{BOOT} *(Note 3)*	0.1 µF (50 V, X5R, ±15 %)	GRM155R61H104KE14	1005	Murata
C_{OUT1} *(Note 4)*	47 µF (16 V, X5R, ±15 %)	GRM31CR61C476ME44	3216	Murata
C_{OUT2} *(Note 4)*	47 µF (16 V, X5R, ±15 %)	GRM31CR61C476ME44	3216	Murata
C_{FB}	120 pF (50 V, C0G, ±5 %)	GRM0335C1H121JA01	0603	Murata
C_{COMP} *(Note 5)*	680 pF (25 V, C0G, ±5 %)	GRM0335C1E681JA01	0603	Murata
C_{SS}	-	-	-	-
R_{COMP} *(Note 5)*	51 kΩ (1 %, 1/16 W)	MCR01MZPF5102	1005	ROHM
R_{1A}	Short	-	-	-
R_{1B}	100 kΩ (1 %, 1/16 W)	MCR01MZPF1003	1005	ROHM
R_2	100 kΩ (1 %, 1/16 W)	MCR01MZPF1003	1005	ROHM
R_0 *(Note 6)*	Short	-	-	-

(Note 1) In order to reduce the influence of high frequency noise, connect a 0.1 µF ceramic capacitor C_{IN1} as close as possible to the VIN pin and the GND pin.
(Note 2) For the input capacitor C_{IN2}, take temperature characteristics, DC bias characteristics, etc. into consideration to set to the actual capacitance of no less than 3.0 µF.
(Note 3) For the bootstrap capacitor C_{BOOT}, take temperature characteristics, DC bias characteristics, etc. into consideration to set to the actual capacitance of no less than 0.022 µF.
(Note 4) In case of changing the actual capacitance value due to temperature characteristics, DC bias characteristics, etc. of the output capacitor C_{OUT1} and C_{OUT2}, the loop response characteristics may change. Confirm the actual application.
(Note 5) See Selection of Components Externally Connected 4. Phase Compensation for how to calculate phase compensation components.
(Note 6) R_0 is an option, used for feedback's frequency response measurement. By inserting a resistor at R_0, it is possible to measure the frequency response (phase margin) using a FRA and so on. However, the resistor is not used in actual application, use this resistor pattern in short-circuit mode.

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1. V_{IN} = 5 V to 12 V, V_{OUT} = 1.2 V – continued

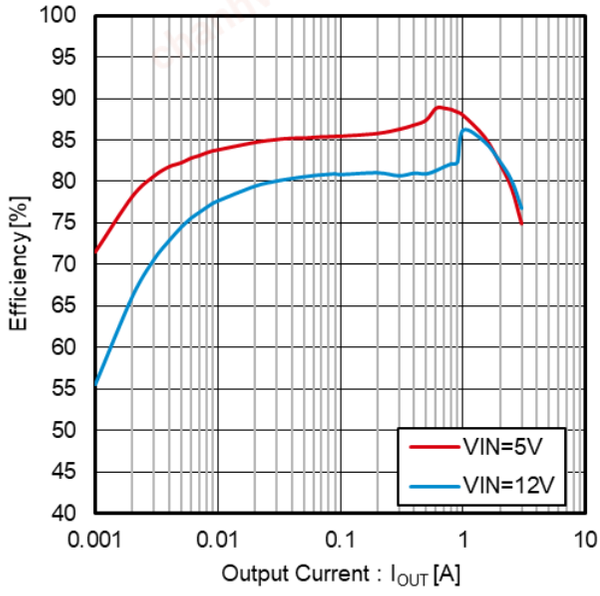


Figure 38. Efficiency vs Output Current

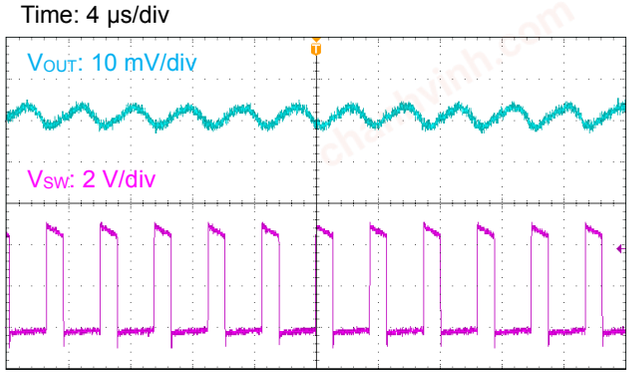


Figure 39. Output Ripple Voltage (V_{IN} = 5 V, I_{OUT} = 3 A)

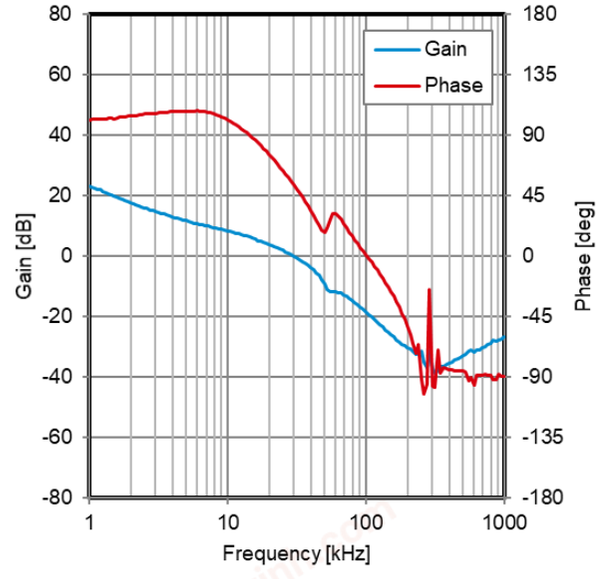


Figure 40. Frequency Characteristics (V_{IN} = 5 V, I_{OUT} = 3 A)

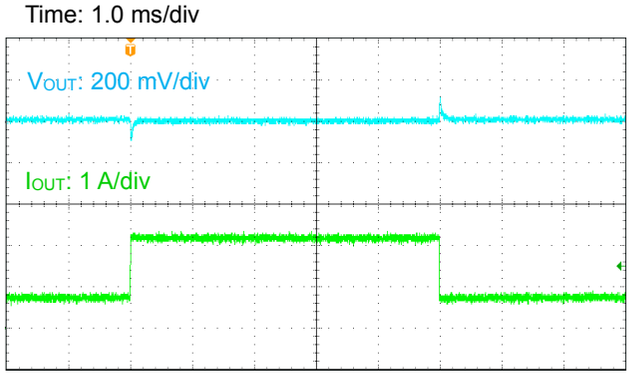


Figure 41. Load Transient Response (V_{IN} = 5 V, I_{OUT} = 0.75 A to 2.25 A)

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Application Examples – continued

2. V_{IN} = 5 V to 18 V, V_{OUT} = 1.8 V

Table 4. Specification of Application

Parameter	Symbol	Specification Value
Input Voltage	V_{IN}	5 V to 18 V (Typ)
Output Voltage	V_{OUT}	1.8 V (Typ)
Maximum Output Current	I_{OUTMAX}	3 A
Temperature	Ta	25 °C

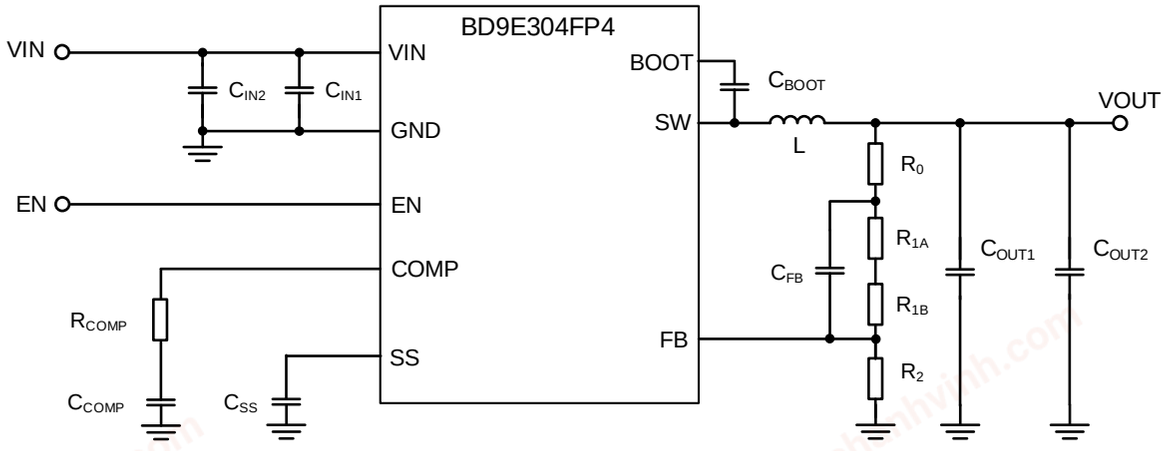


Figure 42. Application Circuit

Table 5. Recommended Component Values

Part No.	Value	Part Name	Size Code (mm)	Manufacturer
L	10 µH	DEM8045C	8080	Murata
C_{IN1} *(Note 1)*	0.1 µF (50 V, X5R, ±15 %)	GRM155R61H104KE14	1005	Murata
C_{IN2} *(Note 2)*	10 µF (100 V, X7S, ±22 %)	GRM32EC72A106KE05	3225	Murata
C_{BOOT} *(Note 3)*	0.1 µF (50 V, X5R, ±15 %)	GRM155R61H104KE14	1005	Murata
C_{OUT1} *(Note 4)*	47 µF (16 V, X5R, ±15 %)	GRM31CR61C476ME44	3216	Murata
C_{OUT2} *(Note 4)*	47 µF (16 V, X5R, ±15 %)	GRM31CR61C476ME44	3216	Murata
C_{FB}	120 pF (50 V, C0G, ±5 %)	GRM0335C1H121JA01	0603	Murata
C_{COMP} *(Note 5)*	680 pF (25 V, C0G, ±5 %)	GRM0335C1E681JA01	0603	Murata
C_{SS}	-	-	-	-
R_{COMP} *(Note 5)*	91 kΩ (1 %, 1/16 W)	MCR01MZPF9102	1005	ROHM
R_{1A}	43 kΩ (1 %, 1/16 W)	MCR01MZPF4302	1005	ROHM
R_{1B}	43 kΩ (1 %, 1/16 W)	MCR01MZPF4302	1005	ROHM
R_2	43 kΩ (1 %, 1/16 W)	MCR01MZPF4302	1005	ROHM
R_0 *(Note 6)*	Short	-	-	-

(Note 1) In order to reduce the influence of high frequency noise, connect a 0.1 µF ceramic capacitor C_{IN1} as close as possible to the VIN pin and the GND pin.
(Note 2) For the input capacitor C_{IN2}, take temperature characteristics, DC bias characteristics, etc. into consideration to set to the actual capacitance of no less than 3.0 µF.
(Note 3) For the bootstrap capacitor C_{BOOT}, take temperature characteristics, DC bias characteristics, etc. into consideration to set to the actual capacitance of no less than 0.022 µF.
(Note 4) In case of changing the actual capacitance value due to temperature characteristics, DC bias characteristics, etc. of the output capacitor C_{OUT1} and C_{OUT2}, the loop response characteristics may change. Confirm the actual application.
(Note 5) See Selection of Components Externally Connected 4. Phase Compensation for how to calculate phase compensation components.
(Note 6) R_0 is an option, used for feedback's frequency response measurement. By inserting a resistor at R_0, it is possible to measure the frequency response (phase margin) using a FRA and so on. However, the resistor is not used in actual application, use this resistor pattern in short-circuit mode.

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2. V_{IN} = 5 V to 18 V, V_{OUT} = 1.8 V – continued

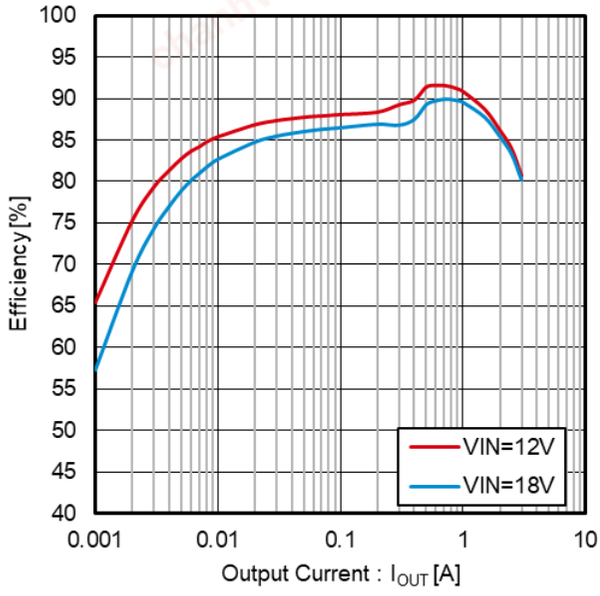


Figure 43. Efficiency vs Output Current

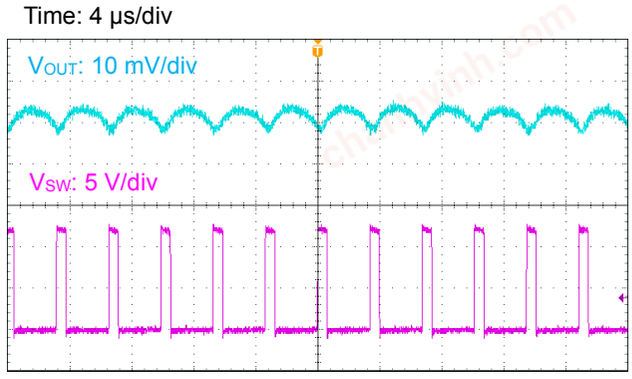


Figure 44. Output Ripple Voltage (V_{IN} = 12 V, I_{OUT} = 3 A)

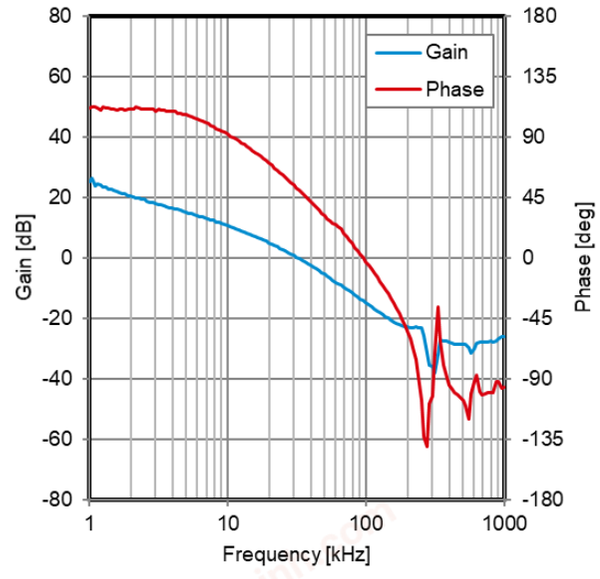


Figure 45. Frequency Characteristics (V_{IN} = 12 V, I_{OUT} = 3 A)

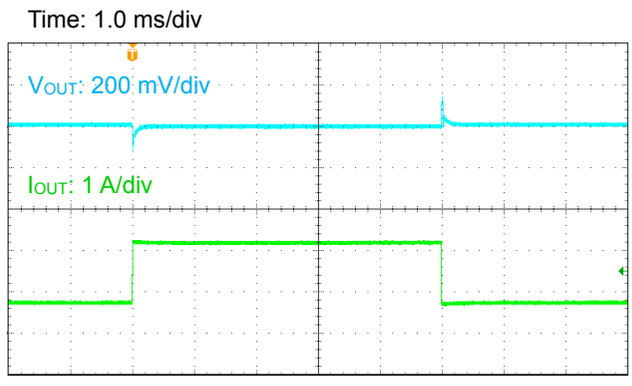


Figure 46. Load Transient Response (V_{IN} = 12 V, I_{OUT} = 0.75 A to 2.25 A)

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Application Examples – continued

3. V_{IN} = 12 V to 24 V, V_{OUT} = 3.3 V

Table 6. Specification of Application

Parameter	Symbol	Specification Value
Input Voltage	V_{IN}	12 V to 24 V (Typ)
Output Voltage	V_{OUT}	3.3 V (Typ)
Maximum Output Current	I_{OUTMAX}	3 A
Temperature	Ta	25 °C

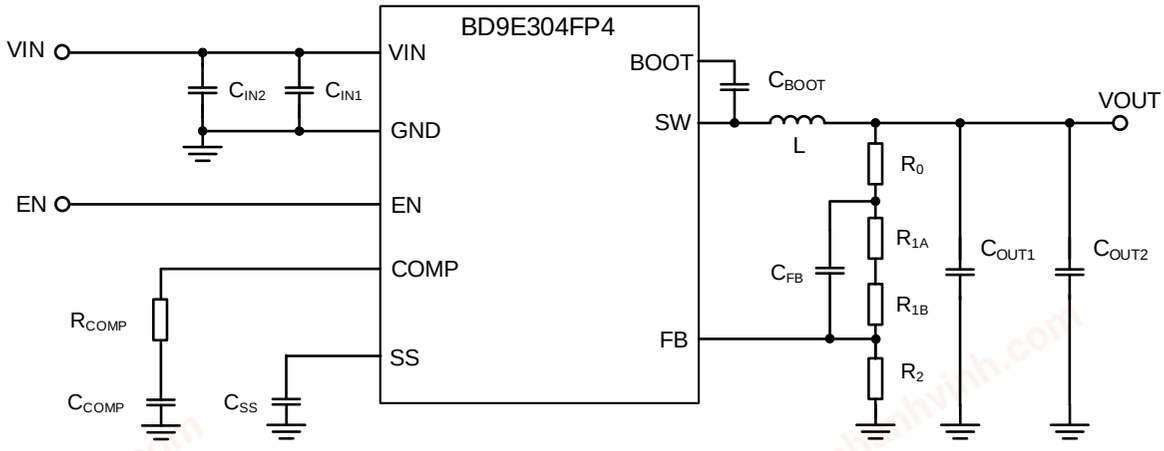


Figure 47. Application Circuit

Table 7. Recommended Component Values

Part No.	Value	Part Name	Size Code (mm)	Manufacturer
L	10 µH	DEM8045C	8080	Murata
C_{IN1} *(Note 1)*	0.1 µF (50 V, X5R, ±15 %)	GRM155R61H104KE14	1005	Murata
C_{IN2} *(Note 2)*	10 µF (100 V, X7S, ±22 %)	GRM32EC72A106KE05	3225	Murata
C_{BOOT} *(Note 3)*	0.1 µF (50 V, X5R, ±15 %)	GRM155R61H104KE14	1005	Murata
C_{OUT1} *(Note 4)*	47 µF (16 V, X5R, ±15 %)	GRM31CR61C476ME44	3216	Murata
C_{OUT2} *(Note 4)*	47 µF (16 V, X5R, ±15 %)	GRM31CR61C476ME44	3216	Murata
C_{FB}	120 pF (50 V, C0G, ±5 %)	GRM0335C1H121JA01	0603	Murata
C_{COMP} *(Note 5)*	680 pF (25 V, C0G, ±5 %)	GRM0335C1E681JA01	0603	Murata
C_{SS}	-	-	-	-
R_{COMP} *(Note 5)*	47 kΩ (1 %, 1/16 W)	MCR01MZPF4702	1005	ROHM
R_{1A}	13 kΩ (1 %, 1/16 W)	MCR01MZPF1302	1005	ROHM
R_{1B}	180 kΩ (1 %, 1/16 W)	MCR01MZPF1803	1005	ROHM
R_2	43 kΩ (1 %, 1/16 W)	MCR01MZPF4302	1005	ROHM
R_0 *(Note 6)*	Short	-	-	-

(Note 1) In order to reduce the influence of high frequency noise, connect a 0.1 µF ceramic capacitor C_{IN1} as close as possible to the VIN pin and the GND pin.
(Note 2) For the input capacitor C_{IN2}, take temperature characteristics, DC bias characteristics, etc. into consideration to set to the actual capacitance of no less than 3.0 µF.
(Note 3) For the bootstrap capacitor C_{BOOT}, take temperature characteristics, DC bias characteristics, etc. into consideration to set to the actual capacitance of no less than 0.022 µF.
(Note 4) In case of changing the actual capacitance value due to temperature characteristics, DC bias characteristics, etc. of the output capacitor C_{OUT1} and C_{OUT2}, the loop response characteristics may change. Confirm the actual application.
(Note 5) See Selection of Components Externally Connected 4. Phase Compensation for how to calculate phase compensation components.
(Note 6) R_0 is an option, used for feedback's frequency response measurement. By inserting a resistor at R_0, it is possible to measure the frequency response (phase margin) using a FRA and so on. However, the resistor is not used in actual application, use this resistor pattern in short-circuit mode.

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3. V_{IN} = 12 V to 24 V, V_{OUT} = 3.3 V – continued

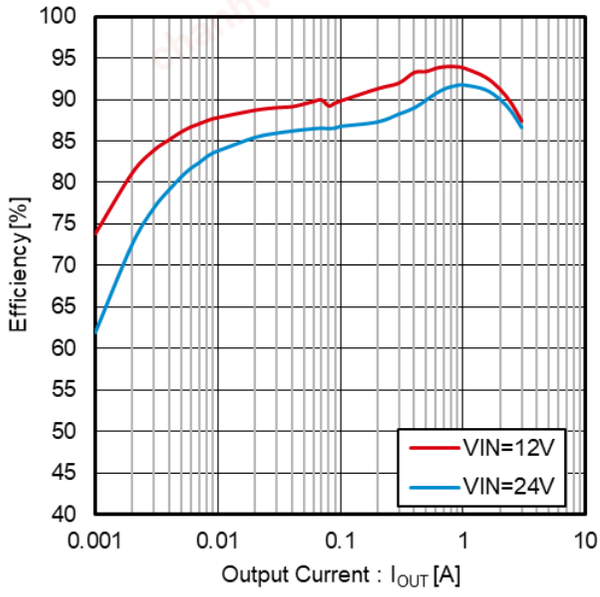


Figure 48. Efficiency vs Output Current

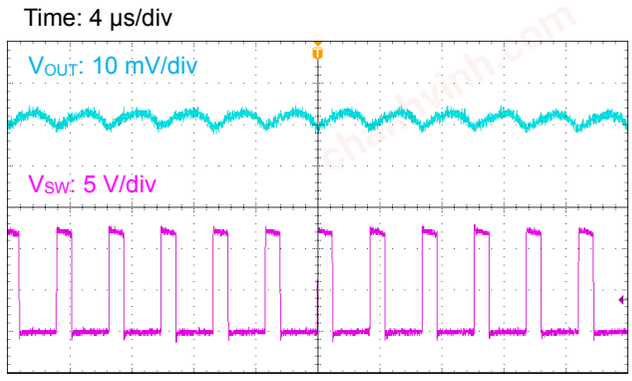


Figure 49. Output Ripple Voltage (V_{IN} = 12 V, I_{OUT} = 3 A)

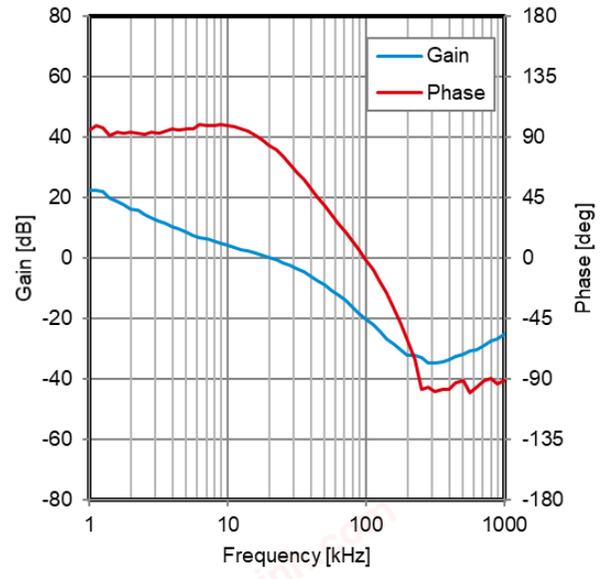


Figure 50. Frequency Characteristics (V_{IN} = 12 V, I_{OUT} = 3 A)

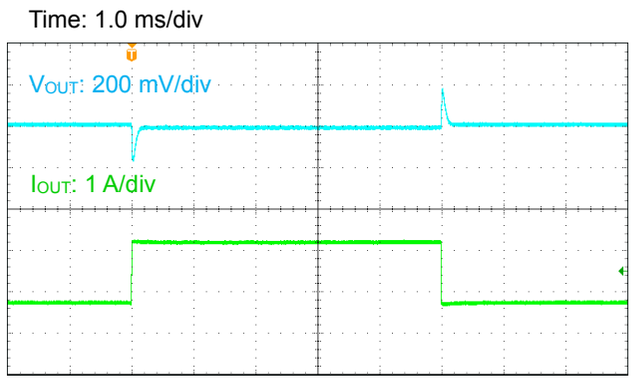


Figure 51. Load Transient Response (V_{IN} = 12 V, I_{OUT} = 0.75 A to 2.25 A)

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Application Examples – continued

4. V_{IN} = 12 V to 24 V, V_{OUT} = 5 V

Table 8. Specification of Application

Parameter	Symbol	Specification Value
Input Voltage	V_{IN}	12 V to 24 V (Typ)
Output Voltage	V_{OUT}	5 V (Typ)
Maximum Output Current	I_{OUTMAX}	3 A
Temperature	Ta	25 °C

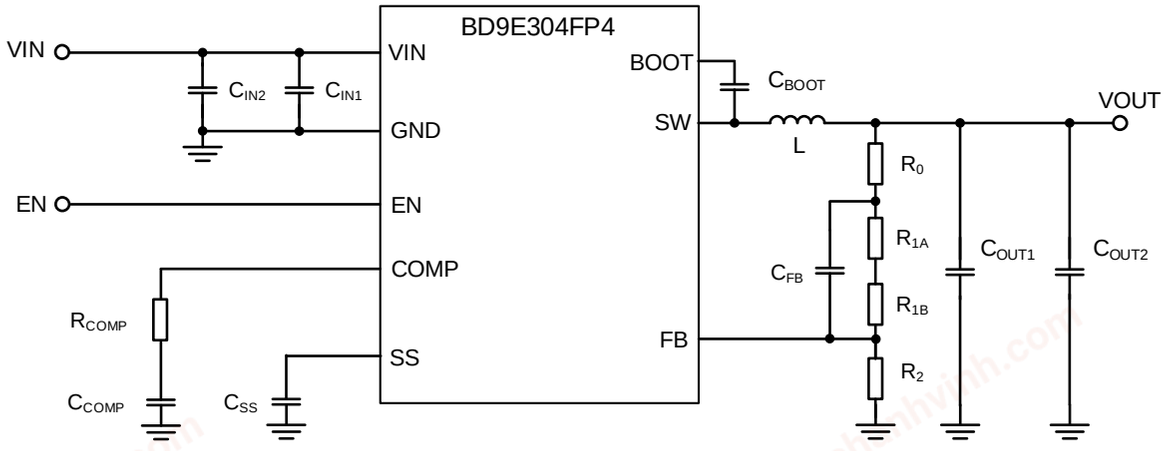


Figure 52. Application Circuit

Table 9. Recommended Component Values

Part No.	Value	Part Name	Size Code (mm)	Manufacturer
L	15 µH	DEM8045C	8080	Murata
C_{IN1} *(Note 1)*	0.1 µF (50 V, X5R, ±15 %)	GRM155R61H104KE14	1005	Murata
C_{IN2} *(Note 2)*	10 µF (100 V, X7S, ±22 %)	GRM32EC72A106KE05	3225	Murata
C_{BOOT} *(Note 3)*	0.1 µF (50 V, X5R, ±15 %)	GRM155R61H104KE14	1005	Murata
C_{OUT1} *(Note 4)*	47 µF (16 V, X5R, ±15 %)	GRM31CR61C476ME44	3216	Murata
C_{OUT2} *(Note 4)*	47 µF (16 V, X5R, ±15 %)	GRM31CR61C476ME44	3216	Murata
C_{FB}	120 pF (50 V, C0G, ±5 %)	GRM0335C1H121JA01	0603	Murata
C_{COMP} *(Note 5)*	680 pF (25 V, C0G, ±5 %)	GRM0335C1E681JA01	0603	Murata
C_{SS}	-	-	-	-
R_{COMP} *(Note 5)*	33 kΩ (1 %, 1/16 W)	MCR01MZPF3302	1005	ROHM
R_{1A}	15 kΩ (1 %, 1/16 W)	MCR01MZPF1502	1005	ROHM
R_{1B}	300 kΩ (1 %, 1/16 W)	MCR01MZPF3003	1005	ROHM
R_2	43 kΩ (1 %, 1/16 W)	MCR01MZPF4302	1005	ROHM
R_0 *(Note 6)*	Short	-	-	-

(Note 1) In order to reduce the influence of high frequency noise, connect a 0.1 µF ceramic capacitor C_{IN1} as close as possible to the VIN pin and the GND pin.
(Note 2) For the input capacitor C_{IN2}, take temperature characteristics, DC bias characteristics, etc. into consideration to set to the actual capacitance of no less than 3.0 µF.
(Note 3) For the bootstrap capacitor C_{BOOT}, take temperature characteristics, DC bias characteristics, etc. into consideration to set to the actual capacitance of no less than 0.022 µF.
(Note 4) In case of changing the actual capacitance value due to temperature characteristics, DC bias characteristics, etc. of the output capacitor C_{OUT1} and C_{OUT2}, the loop response characteristics may change. Confirm the actual application.
(Note 5) See Selection of Components Externally Connected 4. Phase Compensation for how to calculate phase compensation components.
(Note 6) R_0 is an option, used for feedback's frequency response measurement. By inserting a resistor at R_0, it is possible to measure the frequency response (phase margin) using a FRA and so on. However, the resistor is not used in actual application, use this resistor pattern in short-circuit mode.

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4. V_{IN} = 12 V to 24 V, V_{OUT} = 5 V – continued

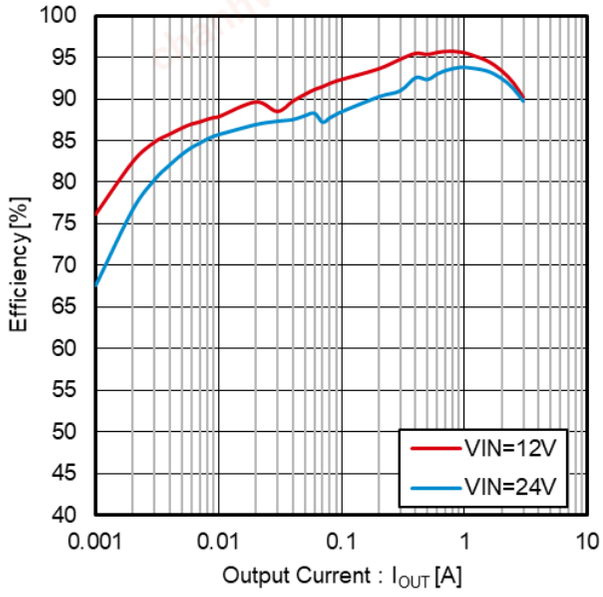


Figure 53. Efficiency vs Output Current

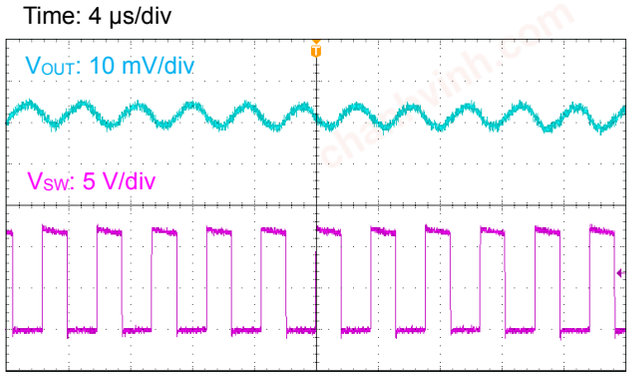


Figure 54. Output Ripple Voltage (V_{IN} = 12 V, I_{OUT} = 3 A)

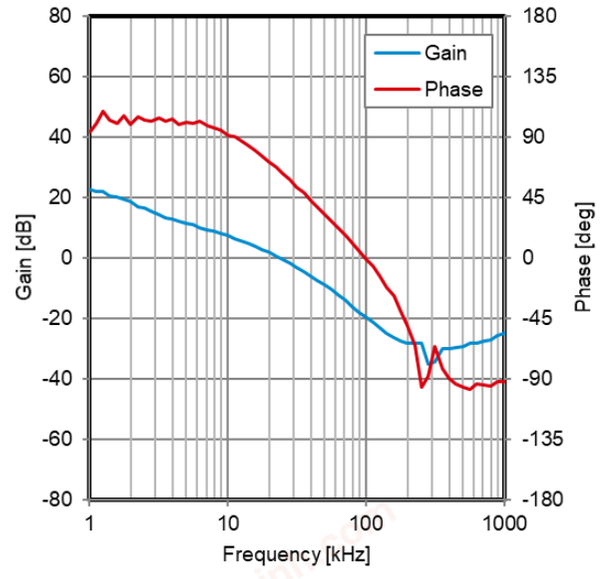


Figure 55. Frequency Characteristics (V_{IN} = 12 V, I_{OUT} = 3 A)

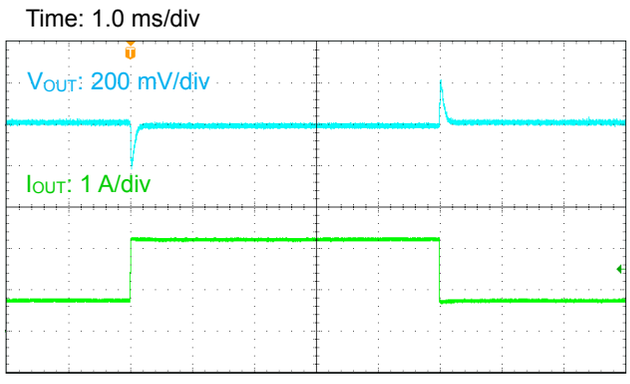


Figure 56. Load Transient Response (V_{IN} = 12 V, I_{OUT} = 0.75 A to 2.25 A)

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Application Examples – continued

5. V_{IN} = 24 V to 36 V, V_{OUT} = 12 V

Table 10. Specification of Application

Parameter	Symbol	Specification Value
Input Voltage	V_{IN}	24 V to 36 V (Typ)
Output Voltage	V_{OUT}	12 V (Typ)
Maximum Output Current	I_{OUTMAX}	3 A
Temperature	Ta	25 °C

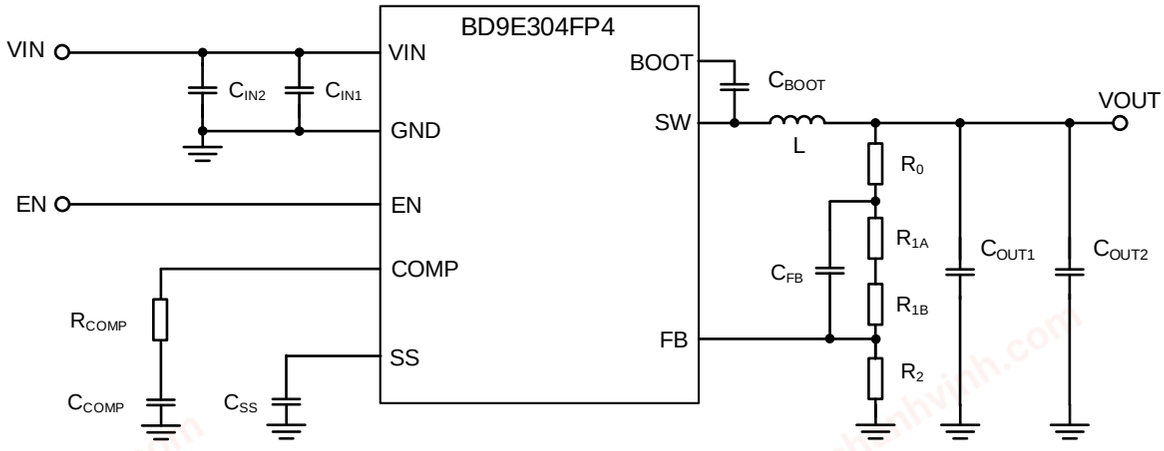


Figure 57. Application Circuit

Table 11. Recommended Component Values

Part No.	Value	Part Name	Size Code (mm)	Manufacturer
L	22 µH	DEM10050C	100100	Murata
C_{IN1} *(Note 1)*	0.1 µF (50 V, X5R, ±15 %)	GRM155R61H104KE14	1005	Murata
C_{IN2} *(Note 2)*	10 µF (100 V, X7S, ±22 %)	GRM32EC72A106KE05	3225	Murata
C_{BOOT} *(Note 3)*	0.1 µF (50 V, X5R, ±15 %)	GRM155R61H104KE14	1005	Murata
C_{OUT1} *(Note 4)*	47 µF (25 V, X5R, ±20 %)	TMK325ABJ476MM-P	3225	TAIYO YUDEN
C_{OUT2} *(Note 4)*	47 µF (25 V, X5R, ±20 %)	TMK325ABJ476MM-P	3225	TAIYO YUDEN
C_{FB}	120 pF (50 V, C0G, ±5 %)	GRM0335C1H121JA01	0603	Murata
C_{COMP} *(Note 5)*	680 pF (25 V, C0G, ±5 %)	GRM0335C1E681JA01	0603	Murata
C_{SS}	-	-	-	-
R_{COMP} *(Note 5)*	30 kΩ (1 %, 1/16 W)	MCR01MZPF3002	1005	ROHM
R_{1A}	43 kΩ (1 %, 1/16 W)	MCR01MZPF4302	1005	ROHM
R_{1B}	470 kΩ (1 %, 1/16 W)	MCR01MZPF4703	1005	ROHM
R_2	27 kΩ (1 %, 1/16 W)	MCR01MZPF2702	1005	ROHM
R_0 *(Note 6)*	Short	-	-	-

(Note 1) In order to reduce the influence of high frequency noise, connect a 0.1 µF ceramic capacitor C_{IN1} as close as possible to the VIN pin and the GND pin.
(Note 2) For the input capacitor C_{IN2}, take temperature characteristics, DC bias characteristics, etc. into consideration to set to the actual capacitance of no less than 3.0 µF.
(Note 3) For the bootstrap capacitor C_{BOOT}, take temperature characteristics, DC bias characteristics, etc. into consideration to set to the actual capacitance of no less than 0.022 µF.
(Note 4) In case of changing the actual capacitance value due to temperature characteristics, DC bias characteristics, etc. of the output capacitor C_{OUT1} and C_{OUT2}, the loop response characteristics may change. Confirm the actual application.
(Note 5) See Selection of Components Externally Connected 4. Phase Compensation for how to calculate phase compensation components.
(Note 6) R_0 is an option, used for feedback's frequency response measurement. By inserting a resistor at R_0, it is possible to measure the frequency response (phase margin) using a FRA and so on. However, the resistor is not used in actual application, use this resistor pattern in short-circuit mode.

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5. V_{IN} = 24 V to 36 V, V_{OUT} = 12 V – continued

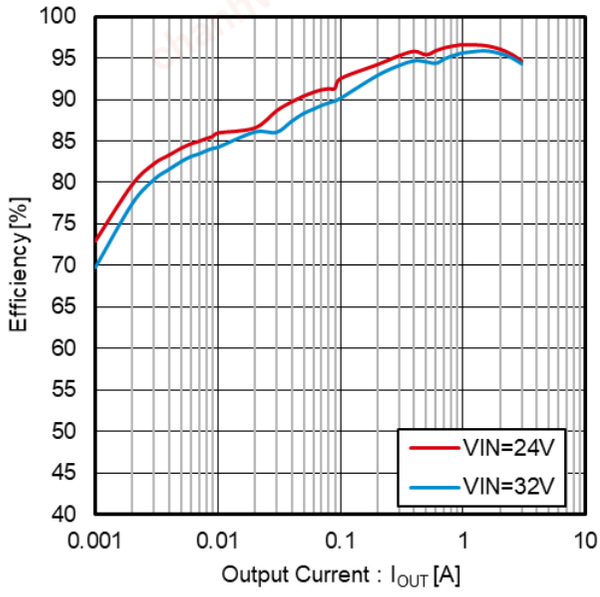


Figure 58. Efficiency vs Output Current

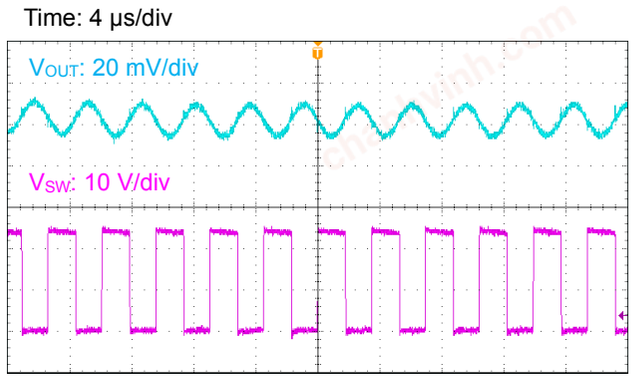


Figure 59. Output Ripple Voltage (V_{IN} = 24 V, I_{OUT} = 3 A)

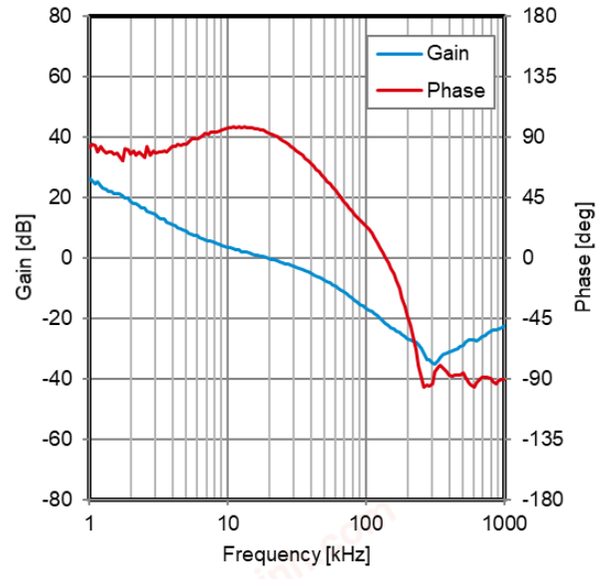


Figure 60. Frequency Characteristics (V_{IN} = 24 V, I_{OUT} = 3 A)

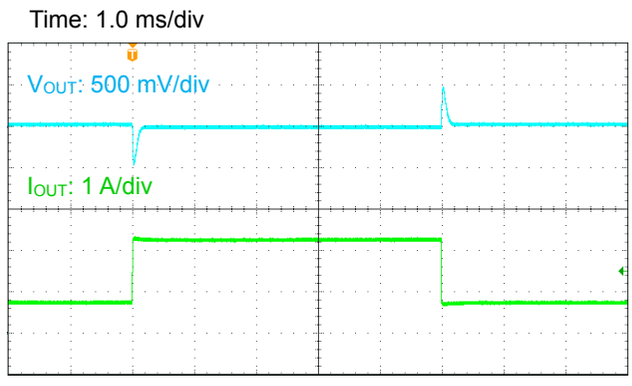


Figure 61. Load Transient Response (V_{IN} = 24 V, I_{OUT} = 0.75 A to 2.25 A)

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Application Examples – continued

6. V_{IN} = 32 V to 36 V, V_{OUT} = 24 V

Table 12. Specification of Application

Parameter	Symbol	Specification Value
Input Voltage	V_{IN}	32 V to 36 V (Typ)
Output Voltage	V_{OUT}	24 V (Typ)
Maximum Output Current	I_{OUTMAX}	3 A
Temperature	Ta	25 °C

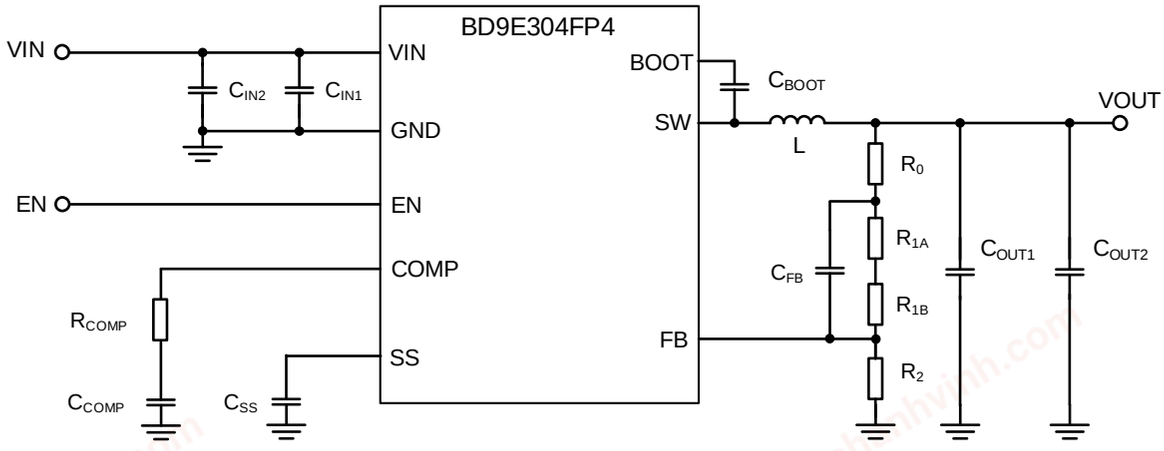


Figure 62. Application Circuit

Table 13. Recommended Component Values

Part No.	Value	Part Name	Size Code (mm)	Manufacturer
L	22 µH	DEM10050C	100100	Murata
C_{IN1} *(Note 1)*	0.1 µF (50 V, X5R, ±15 %)	GRM155R61H104KE14	1005	Murata
C_{IN2} *(Note 2)*	10 µF (100 V, X7S, ±22 %)	GRM32EC72A106KE05	3225	Murata
C_{BOOT} *(Note 3)*	0.1 µF (50 V, X5R, ±15 %)	GRM155R61H104KE14	1005	Murata
C_{OUT1} *(Note 4)*	47 µF (25 V, X5R, ±20 %)	TMK325ABJ476MM-P	3225	TAIYO YUDEN
C_{OUT2} *(Note 4)*	47 µF (25 V, X5R, ±20 %)	TMK325ABJ476MM-P	3225	TAIYO YUDEN
C_{FB}	120 pF (50 V, C0G, ±5 %)	GRM0335C1H121JA01	0603	Murata
C_{COMP} *(Note 5)*	680 pF (25 V, C0G, ±5 %)	GRM0335C1E681JA01	0603	Murata
C_{SS}	-	-	-	-
R_{COMP} *(Note 5)*	27 kΩ (1 %, 1/16 W)	MCR01MZPF2702	1005	ROHM
R_{1A}	Short	-	-	-
R_{1B}	390 kΩ (1 %, 1/16 W)	MCR01MZPF3903	1005	ROHM
R_2	10 kΩ (1 %, 1/16 W)	MCR01MZPF1002	1005	ROHM
R_0 *(Note 6)*	Short	-	-	-

(Note 1) In order to reduce the influence of high frequency noise, connect a 0.1 µF ceramic capacitor C_{IN1} as close as possible to the VIN pin and the GND pin.
(Note 2) For the input capacitor C_{IN2}, take temperature characteristics, DC bias characteristics, etc. into consideration to set to the actual capacitance of no less than 3.0 µF.
(Note 3) For the bootstrap capacitor C_{BOOT}, take temperature characteristics, DC bias characteristics, etc. into consideration to set to the actual capacitance of no less than 0.022 µF.
(Note 4) In case of changing the actual capacitance value due to temperature characteristics, DC bias characteristics, etc. of the output capacitor C_{OUT1} and C_{OUT2}, the loop response characteristics may change. Confirm the actual application.
(Note 5) See Selection of Components Externally Connected 4. Phase Compensation for how to calculate phase compensation components.
(Note 6) R_0 is an option, used for feedback's frequency response measurement. By inserting a resistor at R_0, it is possible to measure the frequency response (phase margin) using a FRA and so on. However, the resistor is not used in actual application, use this resistor pattern in short-circuit mode.

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6. V_{IN} = 32 V to 36 V, V_{OUT} = 24 V – continued

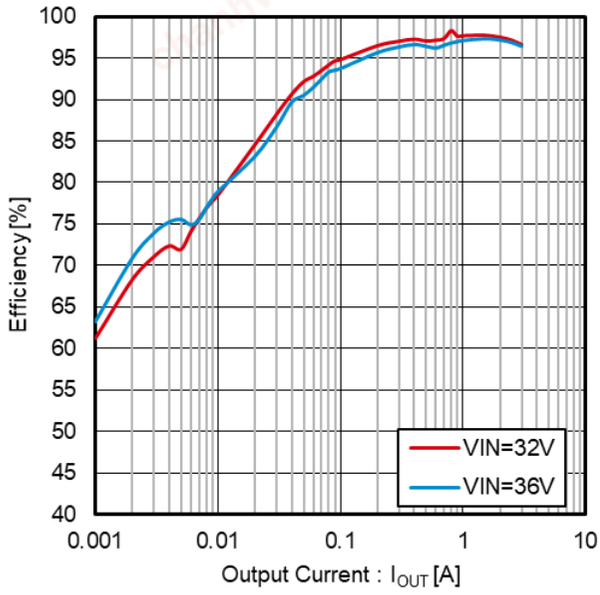


Figure 63. Efficiency vs Output Current

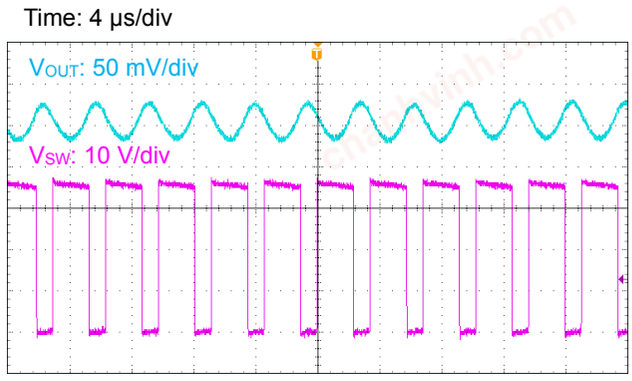


Figure 64. Output Ripple Voltage (V_{IN} = 36 V, I_{OUT} = 3 A)

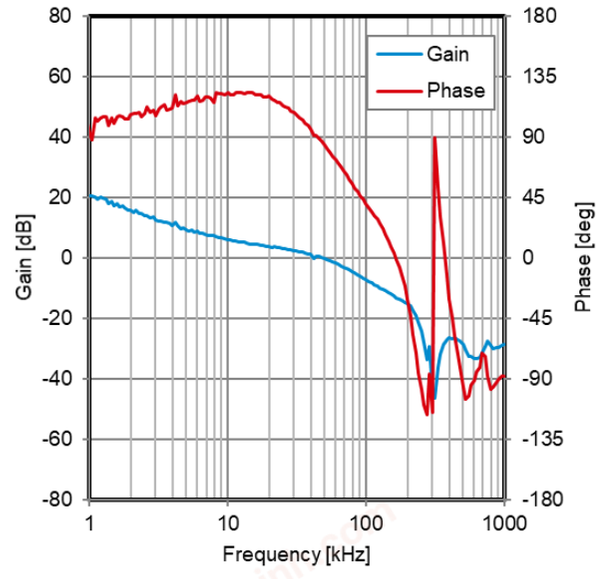


Figure 65. Frequency Characteristics (V_{IN} = 36 V, I_{OUT} = 3 A)

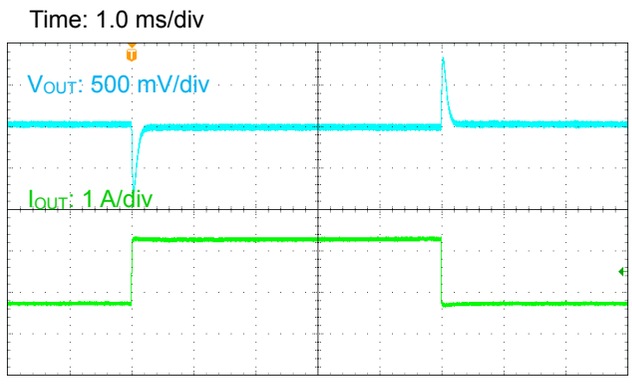


Figure 66. Load Transient Response (V_{IN} = 36 V, I_{OUT} = 0.75 A to 2.25 A)

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Selection of Components Externally Connected

Contact us if not use the recommended component values in Application Examples.

1. Input Capacitor

Use ceramic type capacitor for the input capacitor. The input capacitor is used to reduce the input ripple noise and it is effective by being placed as close as possible to the VIN pin. Set the capacitor value so that it does not fall to 3 µF considering the capacitor value variances, temperature characteristics, DC bias characteristics, aging characteristics, and etc. The PCB layout and the position of the capacitor may lead to IC malfunction. Refer to the notes on the PCB layout on PCB Layout Design when designing PCB layout. In addition, the capacitor with value 0.1 µF can be connected as close as possible to the VIN pin and the GND pin in order to reduce the high frequency noise.

2. Output LC Filter

In order to supply a continuous current to the load, the DC/DC converter requires an LC filter for smoothing the output voltage. For recommended inductance, use the values listed in Table 14.

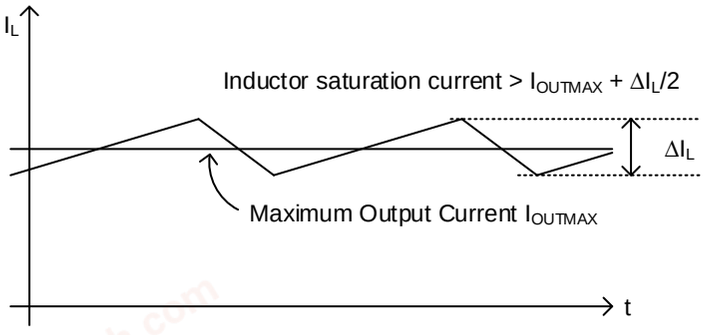


Figure 67. Waveform of Inductor Current

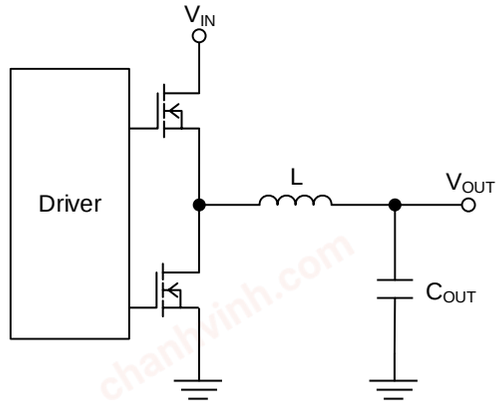


Figure 68. Output LC Filter Circuit

For example, given that V_{IN} = 12 V, V_{OUT} = 5 V, L = 15 µH, and the switching frequency f_{SW} = 300 kHz, Inductor current ΔI_L can be represented by the following equation.

$$\Delta I_L = V_{OUT} \times (V_{IN} - V_{OUT}) \times \frac{1}{V_{IN} \times f_{SW} \times L} = 0.648 \text{ [A]}$$

The rated current of the inductor (Inductor saturation current) must be larger than the sum of the maximum output current I_{OUTMAX} and 1/2 of the inductor ripple current ΔI_L.

Use ceramic type capacitor for the output capacitor C_{OUT}. For recommended actual capacitance, use the values listed in Table 16. C_{OUT} affects the output ripple voltage. Select C_{OUT} so that it must satisfy the required ripple voltage characteristics.

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

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

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

For example, given that C_{OUT} = 44 µF and R_{ESR} = 3 mΩ, ΔV_{RPL} can be calculated as below.

$$\Delta V_{RPL} = 0.648\ A \times \left(3\ m\Omega + \frac{1}{8 \times 44\ \mu F \times 300\ kHz} \right) = 8.1 \text{ [mV]}$$

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2. Output LC Filter – continued

In addition, the total capacitance connected to V_{OUT} needs to satisfy the value obtained by the following equation.

$$C_{OUTMAX} < \frac{t_{SSMIN}}{V_{OUT}} \times \left(I_{OUTMAX} + \frac{\Delta I_L}{2} - I_{OUTSS}\right) \text{ [F]}$$

where:
t_{SSMIN} is the minimum soft start time.
V_{OUT} is the output voltage.
I_{OUTMAX} is the maximum output current.
ΔI_L is the inductor current.
I_{OUTSS} is the maximum output current during soft start.

For example, given that V_{IN} = 12 V, V_{OUT} = 5 V, L = 15 µH, f_{SW} = 300 kHz (Typ), t_{SSMIN} = 1.75 ms (C_{SS} = OPEN), I_{OUTMAX} = 3 A, and I_{OUTSS} = 3 A, C_{OUTMAX} can be calculated as below.

$$C_{OUTMAX} < \frac{1.75\ ms}{5.0\ V} \times \left(3\ A + \frac{0.648\ A}{2} - 3\ A\right) = 113 \text{ [µF]}$$

If the total capacitance connected to V_{OUT} is larger than C_{OUTMAX}, over current protection may be activated by the inrush current at startup and prevented to turn on the output. Confirm this on the actual application.

Table 14. Recommended external parts value

V_{IN} [V]	V_{OUT} [V]	Inductor L[µH]	C_{OUT_EFF} *(Note 1)* [µF]	R_1 [kΩ]	R_2 [kΩ]	C_{FB} [pF]	R_{COMP} [kΩ]	C_{COMP} [pF]
5 to 12	1.2	3.3	44	100	100	120	51	680
5 to 18	1.8	10	44	86	43	120	91	680
12 to 32	3.3	10	44	193	43	120	47	680
12 to 36	5.0	15	44	315	43	120	33	680
24 to 36	12	22	22	513	27	120	30	680
32 to 36	24	22	22	390	10	120	27	680

(Note 1) C_{OUT_EFF} is the sum of actual output capacitance.

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Selection of Components Externally Connected – continued

3. Output Voltage Setting, FB Capacitor

The output voltage can be set by the feedback resistance ratio connected to the FB pin. For recommended R_1, R_2, and C_{FB} use the values listed in Table 14.

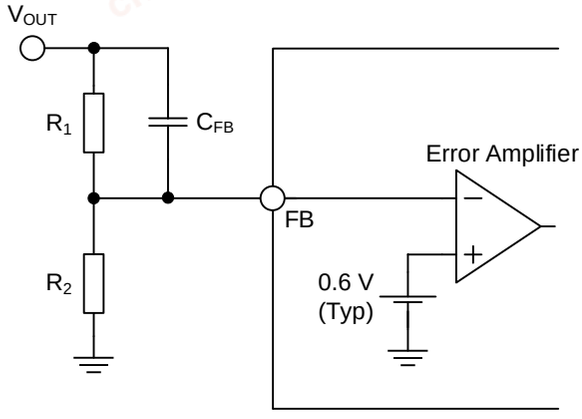


Figure 69. Feedback Resistor Circuit

The output voltage V_{OUT} can be calculated as below.

$$V_{OUT} = \frac{R_1+R_2}{R_2} \times 0.6 \text{ [V]}$$

4. Phase Compensation

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 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 0 dB. High value for this crossover frequency f_{CRS} provides a good load transient response characteristic but inferior stability. Conversely, specifying a low value for the crossover frequency f_{CRS} greatly stabilizes the characteristics but the load transient response characteristic is impaired. the total capacitance connected to V_{OUT} needs to satisfy the value obtained by the following equation.

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

The phase compensation resistance R_{CMP} can be determined by using the following equation.

$$R_{CMP} = \frac{2\pi \times V_{OUT} \times f_{CRS} \times C_{OUT}}{V_{FB} \times G_{MP} \times G_{MA}}$$

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 0.6 V (Typ).
G_{MP} is the current sense gain 11.76 A/V (Typ).
G_{MA} is the error amplifier trans conductance 42 μA/V (Typ).

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

For stable operation of the DC/DC converter, inserting a zero point at 1/6 or less of the zero crossover frequency cancels the phase delay due to the pole formed by the load often provides favorable characteristics.

The phase compensation capacitance C_{CMP} can be determined by using the following equation.

$$C_{CMP} = \frac{1}{2\pi \times R_{CMP} \times f_Z}$$

where:
f_Z is Zero point inserted

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4. Phase Compensation – continued

(3) Loop Stability
In order to ensure stability of DC/DC converter, confirm there is enough phase margin on actual equipment. Under the worst condition, it is recommended to ensure phase margin is 45° or more. In fact, the characteristics may be variable due to PCB layout, routing of wiring, types of used components and operating environments (temperature etc.). Use gain-phase analyzer or FRA to confirm frequency characteristics on actual equipment. Please contact each measuring instrument manufacture for the measuring method.

5. Soft Start Capacitor (Soft Start Time Setting)

The soft start time t_{SS} depends on the value of the capacitor connected to the SS pin. The t_{SS} is 2.5 ms (Typ) when the SS pin is left floating. The C_{SS} capacitor connected to the SS pin makes t_{SS} more than 2.5 ms. The t_{SS} and C_{SS} can be calculated using below equation. The C_{SS} should be set in the range between 0.01 µF and 0.1 µF.

$$t_{SS} = \frac{C_{SS} \times 0.6}{I_{SS}} \text{ [s]}$$

where:
I_{SS} is the Soft Start Charge Current 2.5 µA (Typ).

With C_{SS} = 0.022 µF, t_{SS} can be calculated as below.

$$t_{SS} = \frac{0.022\ \mu F \times 0.6}{2.5\ \mu A} = 5.28 \text{ [ms]}$$

6. Bootstrap Capacitor

The bootstrap capacitor 0.1 µF is recommended. Connect the capacitor between the SW pin and the BOOT pin. For the capacitance, take temperature characteristics, DC bias characteristics, and etc. into consideration to set to the actual capacitance of no less than 0.022 µF.

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PCB Layout Design

PCB layout design for DC/DC converter is very important. Appropriate layout can avoid various problems concerning power supply. Figure 70-a to Figure 70-c show the current path in a buck DC/DC converter. The Loop 1 in Figure 70-a is a current path when H-side switch is ON and L-side switch is OFF, the Loop 2 in Figure 70-b is when H-side switch is OFF and L-side switch is ON. The thick line in Figure 70-c shows the difference between Loop1 and Loop2. The current in thick line change sharply each time the switching element H-side and L-side switch change from OFF to ON, and vice versa. These sharp changes induce a waveform with harmonics in this loop. Therefore, the loop area of thick line that is consisted by input capacitor and IC should be as small as possible to minimize noise. For more details, refer to application note of switching regulator series “PCB Layout Techniques of Buck Converter”.

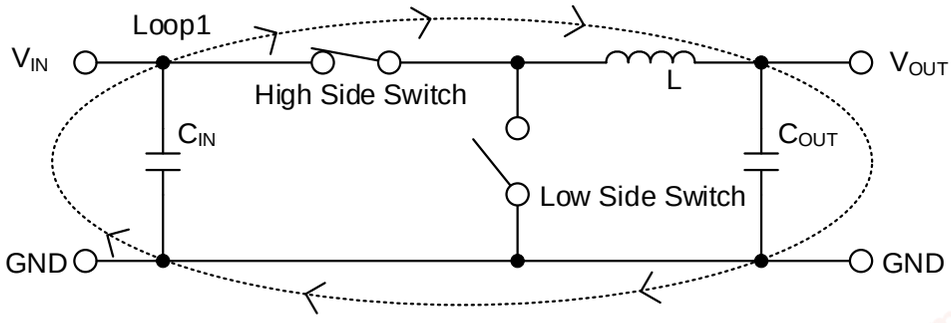


Figure 70-a. Current Path when H-side Switch = ON, L-side Switch = OFF

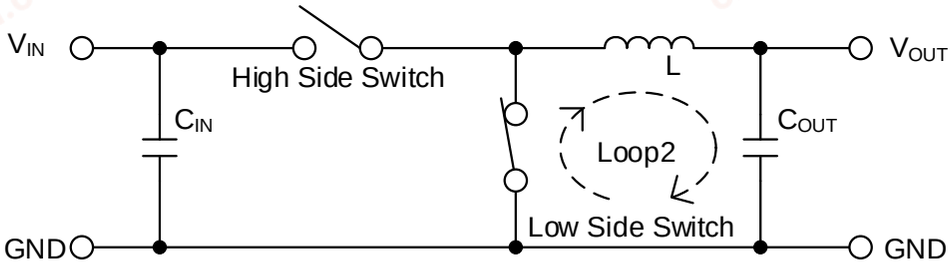


Figure 70-b. Current Path when H-side Switch = OFF, L-side Switch = ON

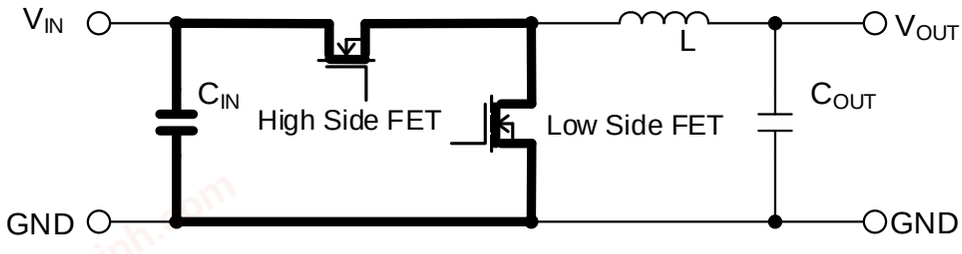


Figure 70-c. Difference of Current and Critical Area in Layout

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PCB Layout Design – continued

When designing the PCB layout, pay attention to the following points:

- Connect the input capacitor C_1 and C_2 as close as possible to the VIN pin and the GND pin on the same plane as the IC.
- Switching nodes such as SW are susceptible to noise due to AC coupling with other nodes. Route the inductor pattern L as thick and as short as possible.
- The feedback line connected to the FB pin should be as far away from the SW nodes as possible.
- Place the output capacitor C_7 and C_8 away from input capacitor C_1 and C_2 to avoid harmonics noise from the input.
- R_0 is provided for the measurement of feedback frequency characteristics (optional). By inserting a resistor into R_0, it is possible to measure the frequency characteristics of feedback (phase margin) using FRA etc. R_0 is short-circuited for normal use.

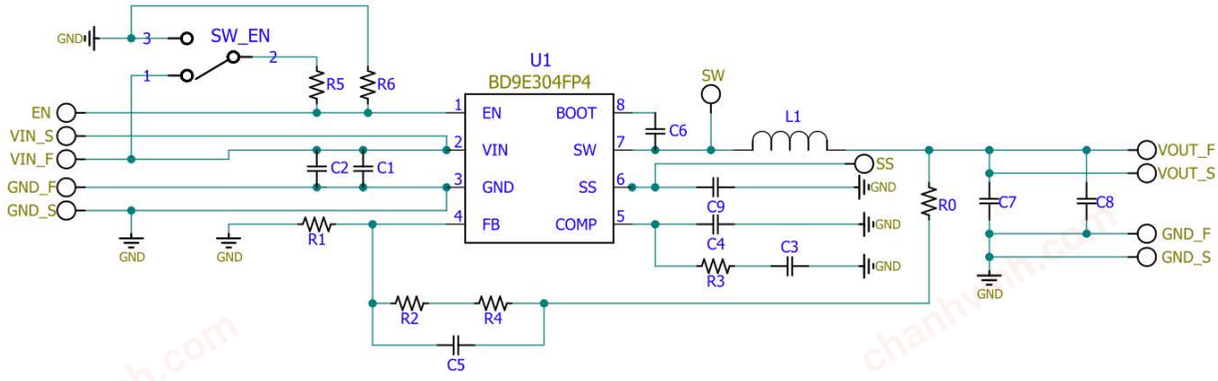


Figure 71. Application Circuit

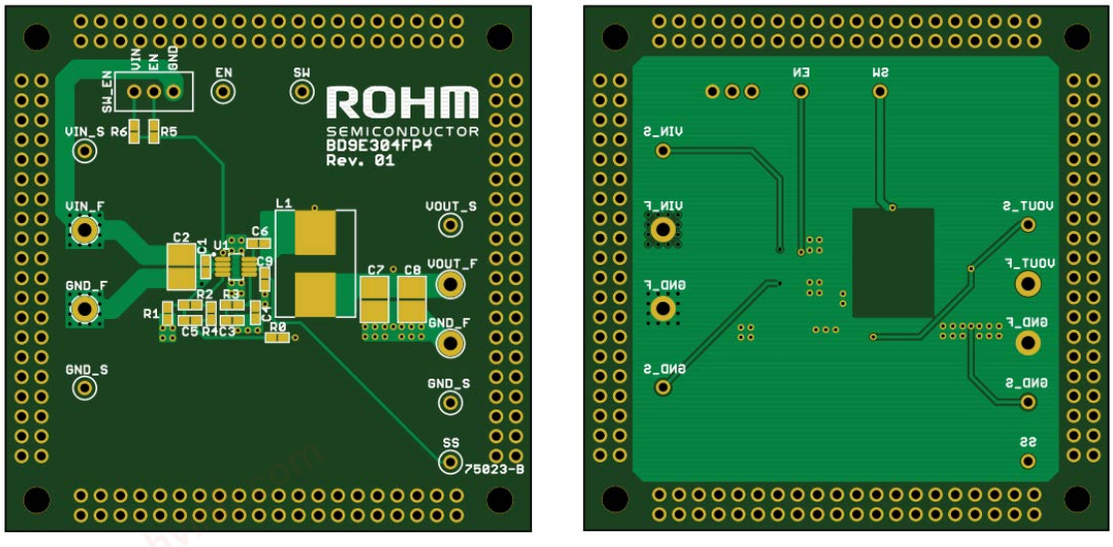


Figure 72. Example of PCB Layout (Silkscreen Overlay)

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PCB Layout Design – continued

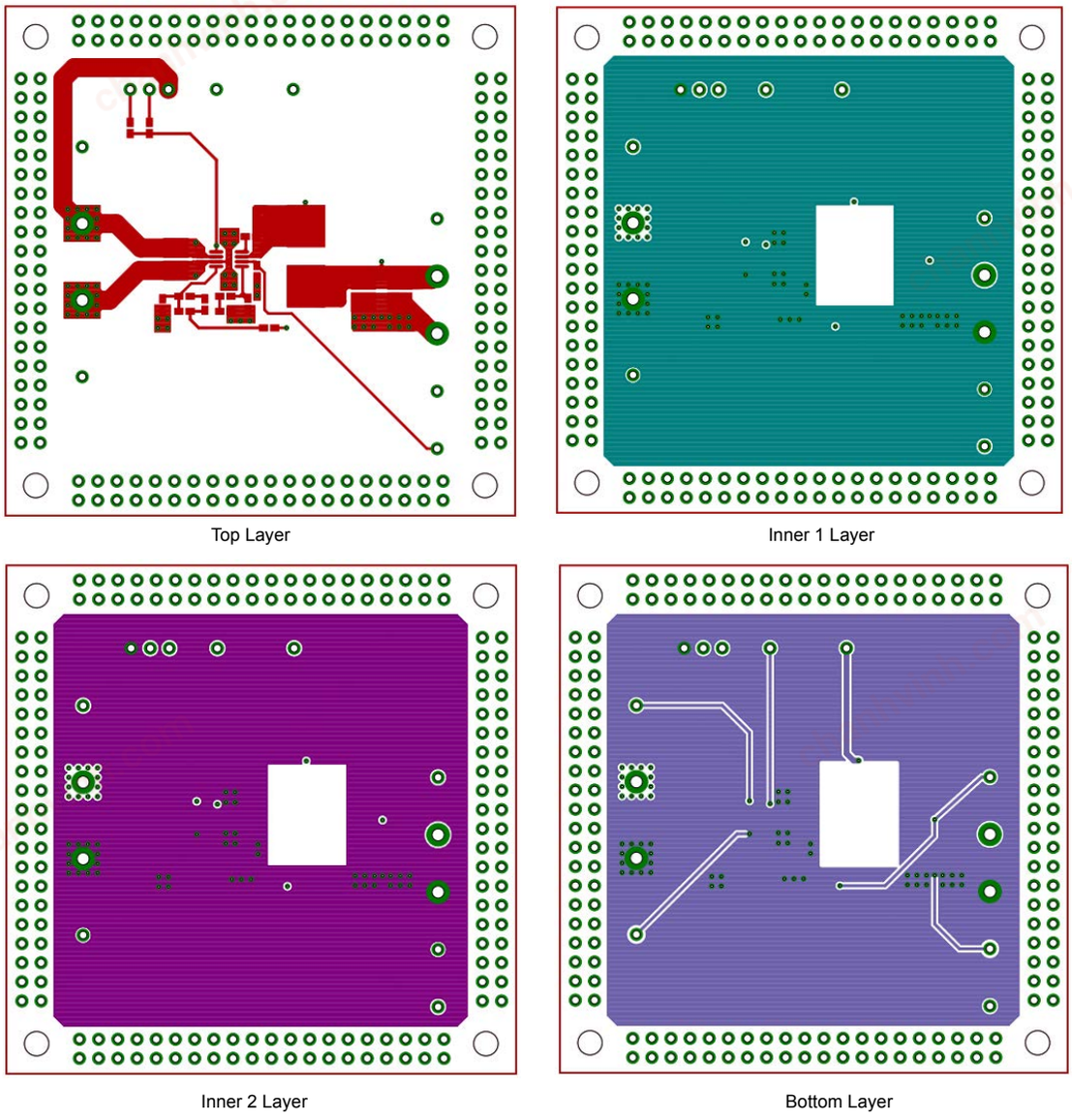
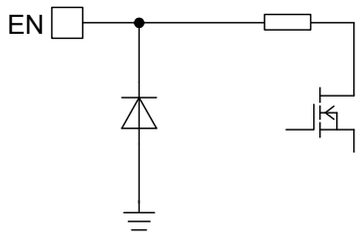
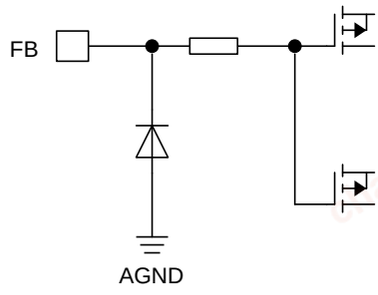
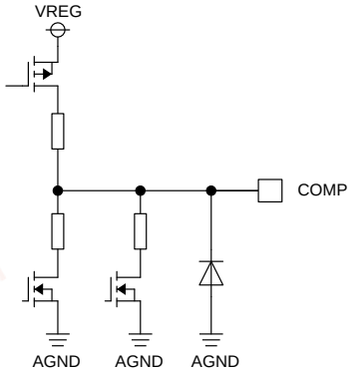
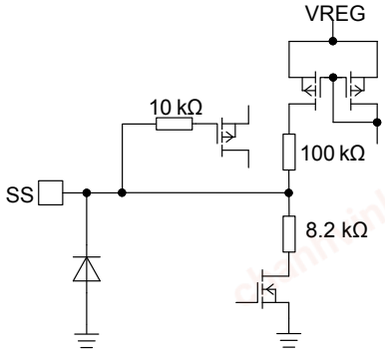
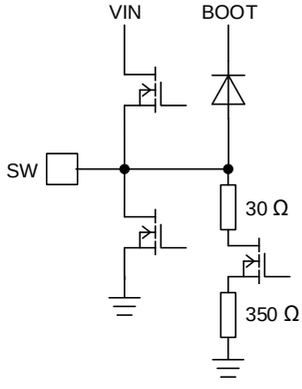
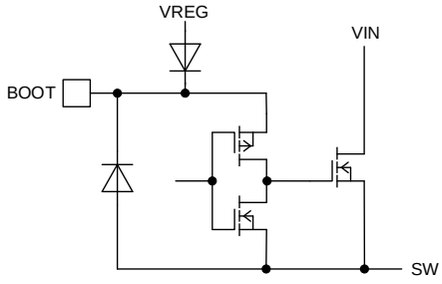


Figure 73. Example of PCB Layout

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I/O Equivalence Circuits

1. EN	4. FB
	
5. COMP	**6. SS**
	
7. SW	**8. BOOT**
	

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Operational Notes

1. **Reverse Connection of Power Supply**
Connecting the power supply in reverse polarity can damage the IC. Take precautions against reverse polarity when connecting the power supply, such as mounting an external diode between the power supply and the IC's power supply pins.

2. **Power Supply Lines**
Design the PCB layout pattern to provide low impedance supply lines. Furthermore, connect a capacitor to ground at all power supply pins. Consider the effect of temperature and aging on the capacitance value when using electrolytic capacitors.

3. **Ground Voltage**
Ensure that no pins are at a voltage below that of the ground pin at any time, even during transient condition. However, pins that drive inductive loads (e.g. motor driver outputs, DC-DC converter outputs) may inevitably go below ground due to back EMF or electromotive force. In such cases, the user should make sure that such voltages going below ground will not cause the IC and the system to malfunction by examining carefully all relevant factors and conditions such as motor characteristics, supply voltage, operating frequency and PCB wiring to name a few.

4. **Ground Wiring Pattern**
When using both small-signal and large-current ground traces, the two ground traces should be routed separately but connected to a single ground at the reference point of the application board to avoid fluctuations in the small-signal ground caused by large currents. Also ensure that the ground traces of external components do not cause variations on the ground voltage. The ground lines must be as short and thick as possible to reduce line impedance.

5. **Recommended Operating Conditions**
The function and operation of the IC are guaranteed within the range specified by the recommended operating conditions. The characteristic values are guaranteed only under the conditions of each item specified by the electrical characteristics.

6. **Inrush Current**
When power is first supplied to the IC, it is possible that the internal logic may be unstable and inrush current may flow instantaneously due to the internal powering sequence and delays, especially if the IC has more than one power supply. Therefore, give special consideration to power coupling capacitance, power wiring, width of ground wiring, and routing of connections.

7. **Testing on Application Boards**
When testing the IC on an application board, connecting a capacitor directly to a low-impedance output pin may subject the IC to stress. Always discharge capacitors completely after each process or step. The IC's power supply should always be turned off completely before connecting or removing it from the test setup during the inspection process. To prevent damage from static discharge, ground the IC during assembly and use similar precautions during transport and storage.

8. **Inter-pin Short and Mounting Errors**
Ensure that the direction and position are correct when mounting the IC on the PCB. Incorrect mounting may result in damaging the IC. Avoid nearby pins being shorted to each other especially to ground, power supply and output pin. Inter-pin shorts could be due to many reasons such as metal particles, water droplets (in very humid environment) and unintentional solder bridge deposited in between pins during assembly to name a few.

9. **Unused Input Pins**
Input pins of an IC are often connected to the gate of a MOS transistor. The gate has extremely high impedance and extremely low capacitance. If left unconnected, the electric field from the outside can easily charge it. The small charge acquired in this way is enough to produce a significant effect on the conduction through the transistor and cause unexpected operation of the IC. So unless otherwise specified, unused input pins should be connected to the power supply or ground line.

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Operational Notes – continued

10. Regarding the Input Pin of the IC

This monolithic IC contains P+ isolation and P substrate layers between adjacent elements in order to keep them isolated. P-N junctions are formed at the intersection of the P layers with the N layers of other elements, creating a parasitic diode or transistor. For example (refer to figure below):

When GND > Pin A and GND > Pin B, the P-N junction operates as a parasitic diode.
When GND > Pin B, the P-N junction operates as a parasitic transistor.

Parasitic diodes inevitably occur in the structure of the IC. The operation of parasitic diodes can result in mutual interference among circuits, operational faults, or physical damage. Therefore, conditions that cause these diodes to operate, such as applying a voltage lower than the GND voltage to an input pin (and thus to the P substrate) should be avoided.

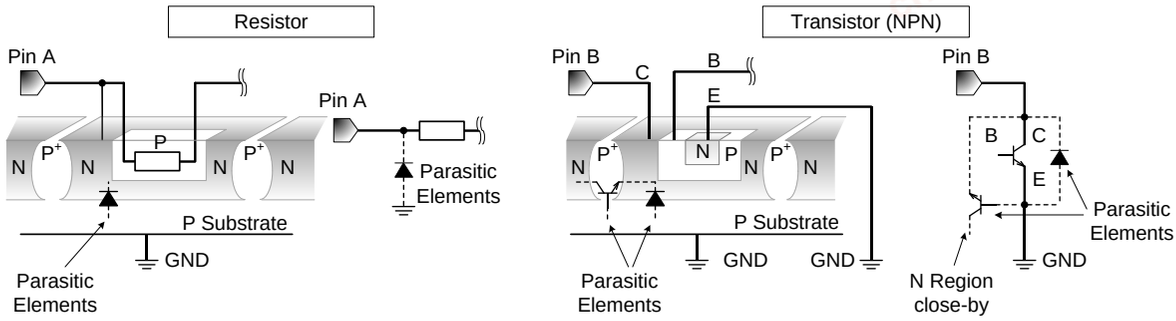


Figure 74. Example of Monolithic IC Structure

11. Ceramic Capacitor

When using a ceramic capacitor, determine a capacitance value considering the change of capacitance with temperature and the decrease in nominal capacitance due to DC bias and others.

12. Thermal Shutdown Circuit (TSD)

This IC has a built-in thermal shutdown circuit that prevents heat damage to the IC. Normal operation should always be within the IC's maximum junction temperature rating. If however the rating is exceeded for a continued period, the junction temperature (Tj) will rise which will activate the TSD circuit that will turn OFF power output pins. When the Tj falls below the TSD threshold, the circuits are automatically restored to normal operation.
Note that the TSD circuit operates in a situation that exceeds the absolute maximum ratings and therefore, under no circumstances, should the TSD circuit be used in a set design or for any purpose other than protecting the IC from heat damage.

13. Over Current Protection Circuit (OCP)

This IC incorporates an integrated overcurrent protection circuit that is activated when the load is shorted. This protection circuit is effective in preventing damage due to sudden and unexpected incidents. However, the IC should not be used in applications characterized by continuous operation or transitioning of the protection circuit.

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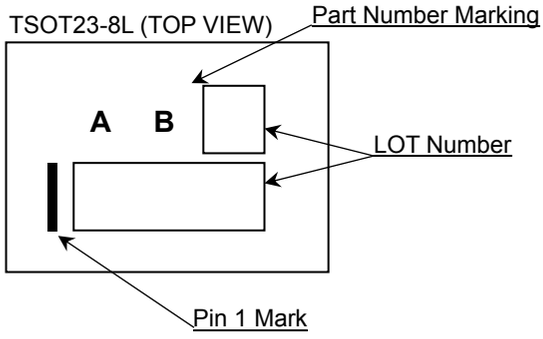
Ordering Information

B	D	9	E	3	0	4	F	P	4	-	L	B	Z	T	L

Package
TSOT23-8L

Product class
LB: for Industrial applications
Packaging and forming specification
TL: Embossed tape and reel

Marking Diagram

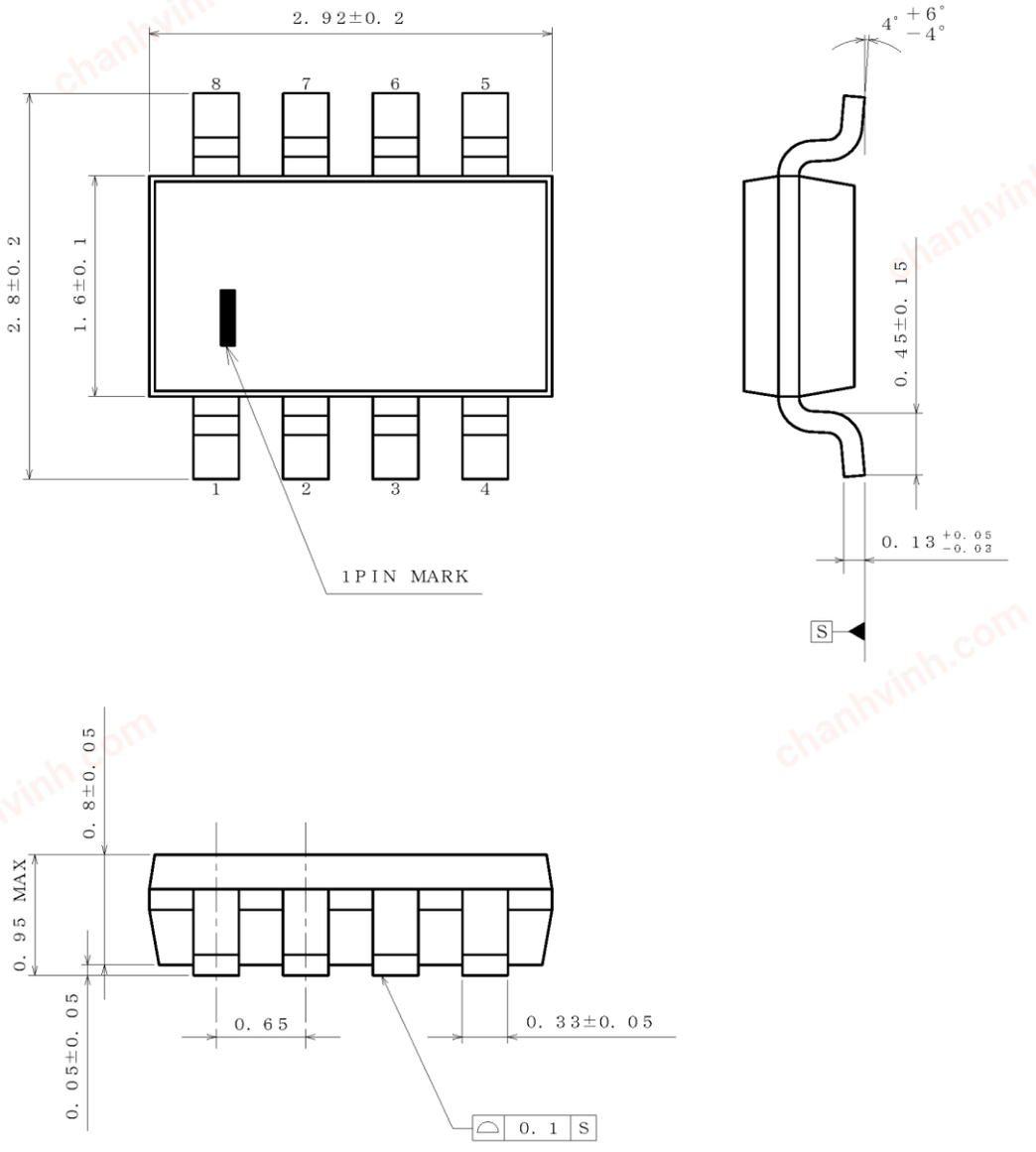


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Physical Dimension and Packing Information

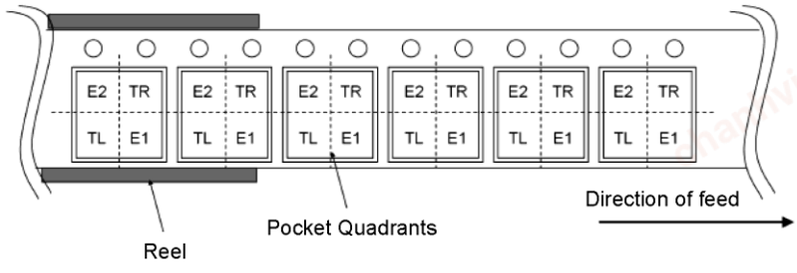
Package Name	TSOT23-8L



(UNIT:mm)
PKG:TSOT23-8L
Drawing No. EX001-0111-1

< Tape and Reel Information >

Tape	Embossed carrier tape
Quantity	3500pcs
Direction of feed	TL The direction is the pin 1 of product is at the lower left when you hold reel on the left hand and you pull out the tape on the right hand



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Revision History

Date	Revision	Changes
29.Jan.2021	001	New Release
20.May.2022	002	Page 19: Recommended Component Value C_{COMP} Value and Part Name 390 pF → 680 pF GRM0335C1E391JA01 → GRM0335C1E681JA01 R_{COMP} Value and Part Name 56 kΩ → 51 kΩ MCR01MZPF5602 → MCR01MZPF5102 Page 20: Update data Figure 39: Output Ripple Voltage Figure 40: Frequency Characteristics Figure 41: Load Transient Response Page 21: Recommended Component Value C_{COMP} Value and Part Name 390 pF → 680 pF GRM0335C1E391JA01 → GRM0335C1E681JA01 R_{COMP} Value and Part Name 120 kΩ → 91 kΩ MCR01MZPF1203 → MCR01MZPF9102 Page 22: Update data Figure 44: Output Ripple Voltage Figure 45: Frequency Characteristics Figure 46: Load Transient Response Page 24: Update data Figure 49: Output Ripple Voltage Figure 51: Load Transient Response Page 26: Update data Figure 54: Output Ripple Voltage Figure 56: Load Transient Response Page 27: Recommended Component Value – L Part Name and Size Code DEM8045C → DEM10050C 8080 → 100100 Page 28: Update data Figure 59: Output Ripple Voltage Figure 60: Frequency Characteristics Figure 61. Load Transient Response Page 29: Recommended Component Value – L Part Name and Size Code DEM8045C → DEM10050C 8080 → 100100 Page 30: Update data Figure 64: Output Ripple Voltage Figure 65: Frequency Characteristics Figure 66. Load Transient Response Page 32: Recommended external parts value Table 14: Update R_{COMP} and C_{COMP} values for V_{OUT} = 1.2 V and V_{OUT} = 1.8 V Page 33: Output Voltage Setting, FB Capacitor Correction of wording.
20.Dec.2022	003	Page 6: 150 °C → 125 °C Page 33: Change R_{CMP} (R_1) → R_{CMP}, C_{CMP} (C_1) → C_{CMP}

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(Note1) Medical Equipment Classification of the Specific Applications

JAPAN	USA	EU	CHINA
CLASSⅢ	CLASSⅢ	CLASSⅡb	CLASSⅢ
CLASSⅣ		CLASSⅢ	

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   [c] Use of our Products in places where the Products are exposed to sea wind or corrosive gases, including Cl_2, H_2S, NH_3, SO_2, and NO_2
   [d] Use of our Products in places where the Products are exposed to static electricity or electromagnetic waves
   [e] Use of our Products in proximity to heat-producing components, plastic cords, or other flammable items
   [f] Sealing or coating our Products with resin or other coating materials
   [g] Use of our Products without cleaning residue of flux (Exclude cases where no-clean type fluxes is used. However, recommend sufficiently about the residue.); or Washing our Products by using water or water-soluble cleaning agents for cleaning residue after soldering
   [h] Use of the Products in places subject to dew condensation

4. The Products are not subject to radiation-proof design.

5. Please verify and confirm characteristics of the final or mounted products in using the Products.

6. In particular, if a transient load (a large amount of load applied in a short period of time, such as pulse, is applied, confirmation of performance characteristics after on-board mounting is strongly recommended. Avoid applying power exceeding normal rated power; exceeding the power rating under steady-state loading condition may negatively affect product performance and reliability.

7. De-rate Power Dissipation depending on ambient temperature. When used in sealed area, confirm that it is the use in the range that does not exceed the maximum junction temperature.

8. Confirm that operation temperature is within the specified range described in the product specification.

9. ROHM shall not be in any way responsible or liable for failure induced under deviant condition from what is defined in this document.

Precaution for Mounting / Circuit board design

1. When a highly active halogenous (chlorine, bromine, etc.) flux is used, the residue of flux may negatively affect product performance and reliability.

2. In principle, the reflow soldering method must be used on a surface-mount products, the flow soldering method must be used on a through hole mount products. If the flow soldering method is preferred on a surface-mount products, please consult with the ROHM representative in advance.

For details, please refer to ROHM Mounting specification

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This Product is electrostatic sensitive product, which may be damaged due to electrostatic discharge. Please take proper caution in your manufacturing process and storage so that voltage exceeding the Products maximum rating will not be applied to Products. Please take special care under dry condition (e.g. Grounding of human body / equipment / solder iron, isolation from charged objects, setting of Ionizer, friction prevention and temperature / humidity control).

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1. Product performance and soldered connections may deteriorate if the Products are stored in the places where:
   - [a] the Products are exposed to sea winds or corrosive gases, including Cl_2, H_2S, NH_3, SO_2, and NO_2
   - [b] the temperature or humidity exceeds those recommended by ROHM
   - [c] the Products are exposed to direct sunshine or condensation
   - [d] the Products are exposed to high Electrostatic

2. Even under ROHM recommended storage condition, solderability of products out of recommended storage time period may be degraded. It is strongly recommended to confirm solderability before using Products of which storage time is exceeding the recommended storage time period.

3. Store / transport cartons in the correct direction, which is indicated on a carton with a symbol. Otherwise bent leads may occur due to excessive stress applied when dropping of a carton.

4. Use Products within the specified time after opening a humidity barrier bag. Baking is required before using Products of which storage time is exceeding the recommended storage time period.

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