

## SPICE Modeling Report

# 4.5 V to 36 V Input, 3.0 A Integrated MOSFET Single Synchronous Buck DC/DC Converter BD9E304FP4-LBZ

## General Description

In this report, the characteristics that can be confirmed by the simulation using the SPICE model of the regulator IC BD9E304FP4-LBZ will be described.

## Simulation Environment

- Circuit Simulator : PSpice / Cadence Design System, Inc.
- Version Information : 17.2-2016
- OS Information : Windows 10 64-bit Edition
- Target Datasheet : TSZ02201-0T7T0AJ01550-1-2

## File Information

- Library File Name : BD9E304FP4-LBZ.lib
- Symbol File Name : BD9E304FP4-LBZ.olb
- Subcircuit and Symbol

**Table 1 Correspondence Table**

Product Name	Subcircuit	Symbol
BD9E304FP4-LBZ	BD9E304FP4LBZ (Model for Transient Analysis)	BD9E304FP4-LBZ
		BD9E304FP4-LBZ_CAD (Note2)
	BD9E304FP4LBZ_AVE (Note1) (Model for AC Analysis)	BD9E304FP4-LBZ_AVE (Note3)
		BD9E304FP4-LBZ_AVE_CAD (Note2) (Note3)

(Note 1) BD9E304FP4-LBZ\_AVE is the spice macro model for Frequency Characteristic (AC simulation). Refer to Page 11 to 13 for simulation detail.

(Note 2) Symbol with \_CAD at the end of the name conform to IEC60617, and were designed so that signals flow from left to right.

(Note 3) Pin information for BD9E304FP4-LBZ\_AVE is same like Table 2.

## Caution

- These model characteristics are specifically at Ta = 25 °C. Thus, the simulation result with temperature variances may significantly differ from the result with the one done at actual application board (actual measurement).
- The simulation result and characteristics described in this report may differ depending on the board design. It is recommended to perform the measurement on the actual board to verify the result.
- The values from the simulation results are not guaranteed. Use these results as a guide for your design.
- Actual measurement was done using a specific sample, thus the measured data is just as a reference.

## BD9E304FP4-LBZ Spice Model

### ■ Pin Information

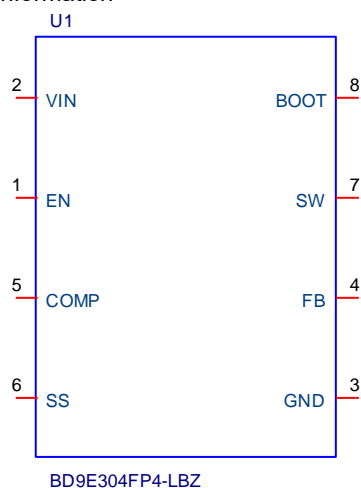


Figure 1 Symbol of BD9E304FP4-LBZ

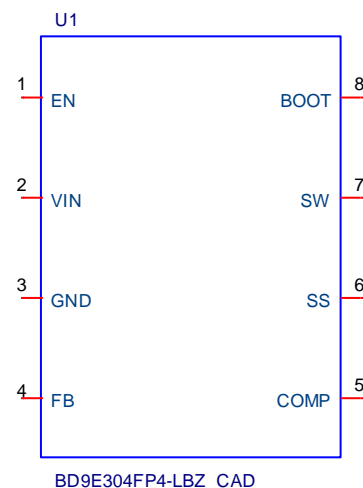


Figure 2 Symbol of BD9E304FP4-LBZ\_CAD

Table 2 Subcircuit Pin Table

Pin No.	Pin Name	Pin No.	Pin Name
1.	EN	5.	COMP
2.	VIN	6.	SS
3.	GND	7.	SW
4.	FB	8.	BOOT

### ■ Model Parameter

Table 3 Model Parameter Table

Parameter	Default Value	Description
BD9E304FP4-LBZ		
-	-	-
BD9E304FP4-LBZ_AVE		
I	15u	Set the inductor value connected to the SW pin.
v_vo	5	On Duty parameter for the Numerator.
v_vin	12	On Duty parameter for the Denominator. On Duty is given as { v_vo / v_vin }.

**Verifiable Characteristics**

■	Electrical Characteristics (vs. Datasheet) .....	4
■	Characteristic in SPICE (vs. Measured Waveform) .....	5
➤	BD9E304FP4-LBZ	
✓	Output Ripple Voltage (VIN = 12 V, VOUT = 3.3 V) .....	5
✓	Output Ripple Voltage (VIN = 12 V, VOUT = 5 V) .....	6
✓	Output Ripple Voltage (VIN = 24 V, VOUT = 12 V) .....	7
✓	Load Response (VIN = 12 V, VOUT = 3.3 V) .....	8
✓	Load Response (VIN = 12 V, VOUT = 5 V) .....	9
✓	Load Response (VIN = 24 V, VOUT = 12 V) .....	10
➤	BD9E304FP4-LBZ_AVE	
✓	Frequency Characteristic (VIN = 12 V, VOUT = 3.3 V) .....	11
✓	Frequency Characteristic (VIN = 12 V, VOUT = 5 V) .....	12
✓	Frequency Characteristic (VIN = 24 V, VOUT = 12 V) .....	13

## Electrical Characteristics (vs. Datasheet)

Table 4 Electrical Characteristics Comparison

(Unless otherwise specified Ta = 25 °C, Vin = 12 V, VEN = 3 V)

Parameter	Modeled (Note 1)	Design Value		Unit	Error	Condition
		Datasheet	SPICE			
Input Supply						
Shutdown Current	Yes	3	3	μA	0%	V <sub>EN</sub> = 0 V
Operating Quiescent Current	Yes	45	45	μA	0%	I <sub>OUT</sub> = 0 A, No switching
UVLO Detection Threshold Voltage	Yes	3.9	3.9	V	0%	V <sub>IN</sub> falling
UVLO Release Threshold Voltage	Yes	4.25	4.25	V	0%	V <sub>IN</sub> rising
UVLO Hysteresis Voltage	Yes	350	350	mV	0%	
Enable						
EN Threshold Voltage High	Yes	1.2	1.2	V	0%	V <sub>EN</sub> rising
EN Threshold Voltage Low	Yes	1.1	1.1	V	0%	V <sub>EN</sub> falling
EN Hysteresis Voltage	Yes	100	100	mV	0%	
EN Input Current	Yes	0	0	μA	0%	V <sub>EN</sub> = 3 V
Reference Voltage, Error Amplifier, Soft Start						
FB Threshold Voltage	Yes	0.6	0.6	V	0%	
FB Input Current	Yes	-	0	nA	-	V <sub>FB</sub> = 0.6 V
COMP Source Current	Yes	10	10	μA	0%	
COMP Sink Current	Yes	10	10	μA	0%	
Soft Start Time	Yes	2.5	2.5	ms	-	The SS pin is open.
Soft Start Charge Current	Yes	2.5	2.5	μA	0%	
SW (MOSFET)						
Switching Frequency	Yes	300	300	kHz	0%	
Maximum Duty Ratio	Yes	-	-	%	0%	
High Side FET ON Resistance	Yes	100	100	mΩ	0%	
Low Side FET ON Resistance	Yes	60	60	mΩ	0%	V <sub>BOOT</sub> - V <sub>SW</sub> = 5 V
Protection						
High Side Over Current Limit	Yes	5	5	A	0%	
Low Side Over Current Limit	Yes	3.5	3.5	A	0%	

(Note 1) Yes: Model available (supported), No: Model not available (not supported).

## Characteristic in SPICE (vs. Measured Waveform)

1. Output Ripple Voltage ( $V_{IN} = 12\text{ V}$ ,  $V_{OUT} = 3.3\text{ V}$ )

## Simulation Setting

Type: Transient

Run Time: 5 ms

(Maximum Step Size: 10 ns)

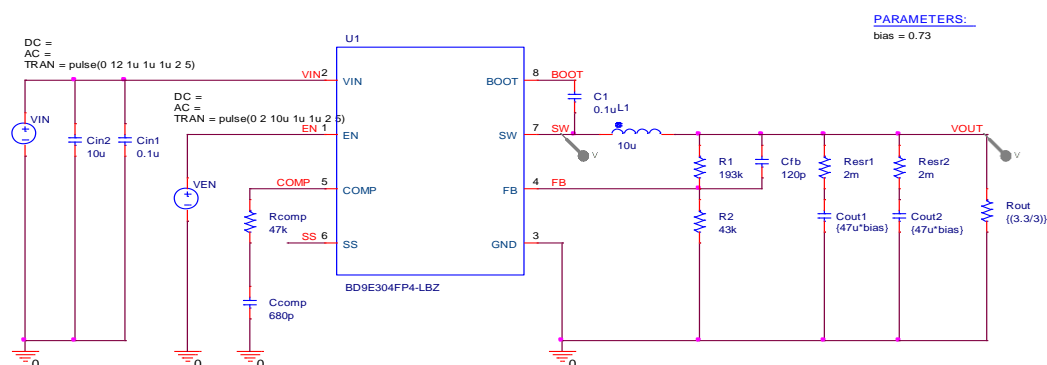
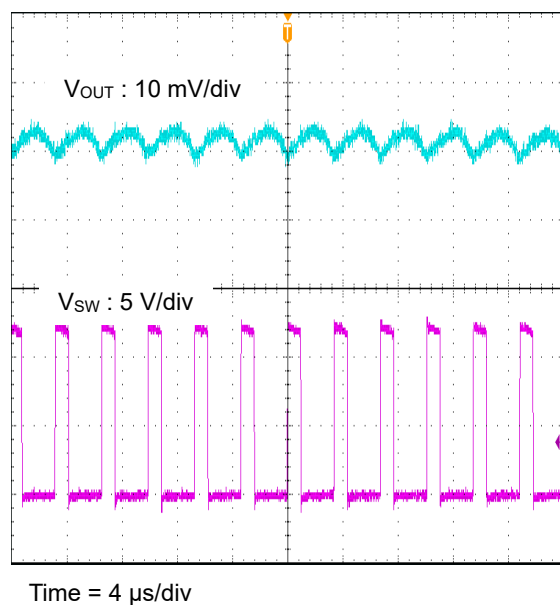
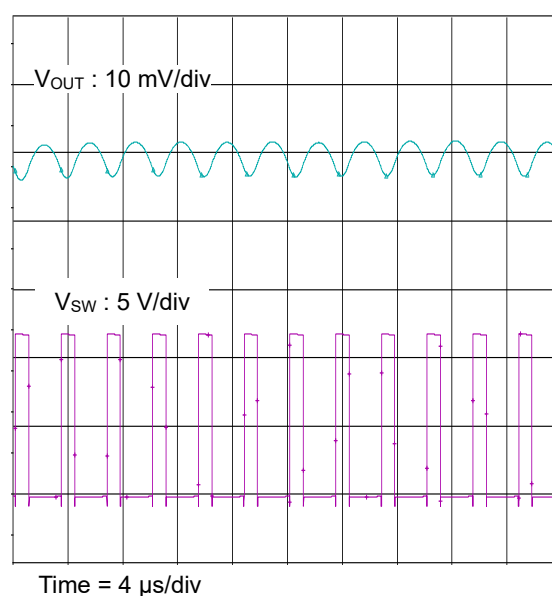
Figure 3.  
Simulation Schematic 1Figure 4.  
Output Ripple Voltage ( $V_{IN} = 12\text{ V}$ ,  $V_{OUT} = 3.3\text{ V}$ )  
(Measured Waveform)Figure 5.  
Output Ripple Voltage ( $V_{IN} = 12\text{ V}$ ,  $V_{OUT} = 3.3\text{ V}$ )  
(SPICE Simulation)

Table 5 Characteristics Comparison

Parameter	Measured Result (Note1)(Note2)	SPICE Simulation Result	Unit	Error	Condition
Output Ripple Voltage	4.3	5	mV	16.3 %	$V_{IN} = 12\text{ V}$ , $V_{OUT} = 3.3\text{ V}$ , $I_{OUT} = 3\text{ A}$

(Note 1) The above data is based on a specific sample and it is not a guaranteed value.

(Note 2) These characteristics depend on some dynamic characteristics of external components, input signal speed, PCB pattern and mounting condition of each on-board parts.

2. Output Ripple Voltage (VIN = 12 V, VOUT = 5 V)

Simulation Setting  
Type: Transient  
Run Time: 5 ms  
(Maximum Step Size: 10 ns)

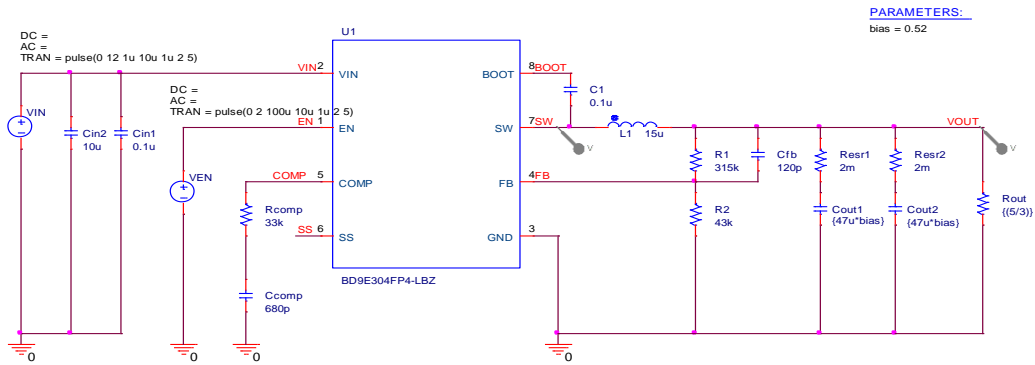


Figure 6.  
Simulation Schematic 2

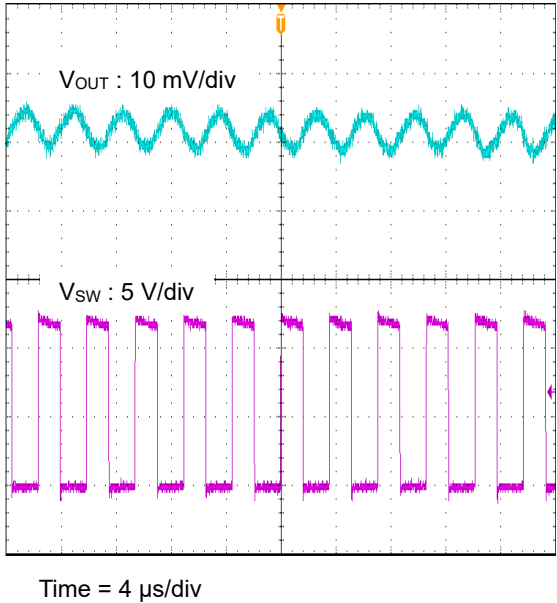


Figure 7.  
Output Ripple Voltage (VIN = 12 V, VOUT = 5 V)  
(Measured Waveform)

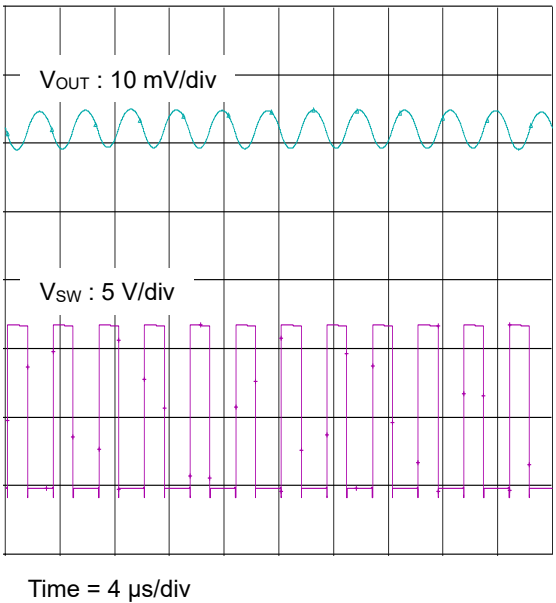


Figure 8.  
Output Ripple Voltage (VIN = 12 V, VOUT = 5 V)  
(SPICE Simulation)

Table 6 Characteristics Comparison

Parameter	Measured Result (Note1)(Note2)	SPICE Simulation Result	Unit	Error	Condition
Output Ripple Voltage	5.2	5.4	mV	3.8 %	V <sub>IN</sub> = 12 V, V <sub>OUT</sub> = 5 V, I <sub>OUT</sub> = 3 A

(Note 1) The above data is based on a specific sample and it is not a guaranteed value.  
(Note 2) These characteristics depend on some dynamic characteristics of external components, input signal speed,  
PCB pattern and mounting condition of each on-board parts.

3. Output Ripple Voltage (VIN = 24 V, VOUT = 12 V)

Simulation Setting  
Type: Transient  
Run Time: 5 ms  
(Maximum Step Size: 10 ns)

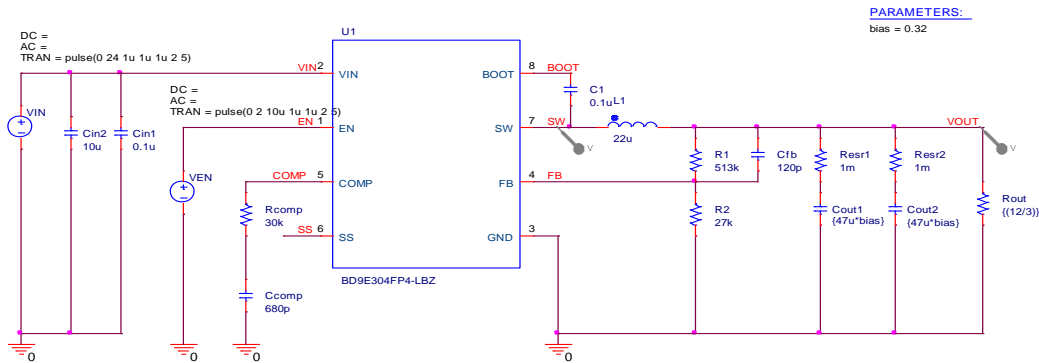


Figure 9.  
Simulation Schematic 3

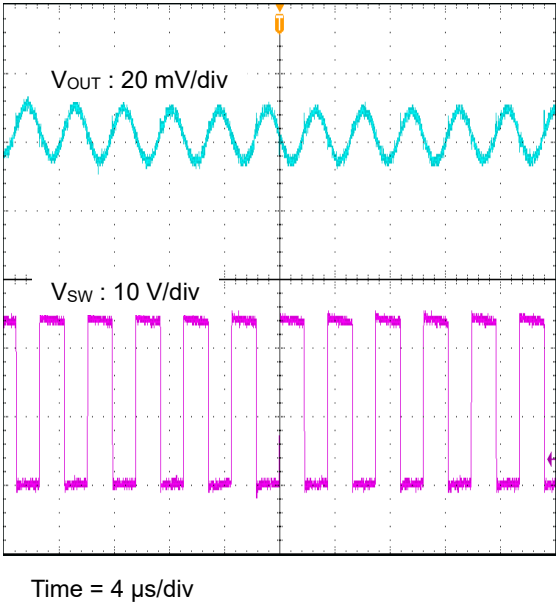


Figure 10.  
Output Ripple Voltage (VIN = 24 V, VOUT = 12 V)  
(Measured Waveform)

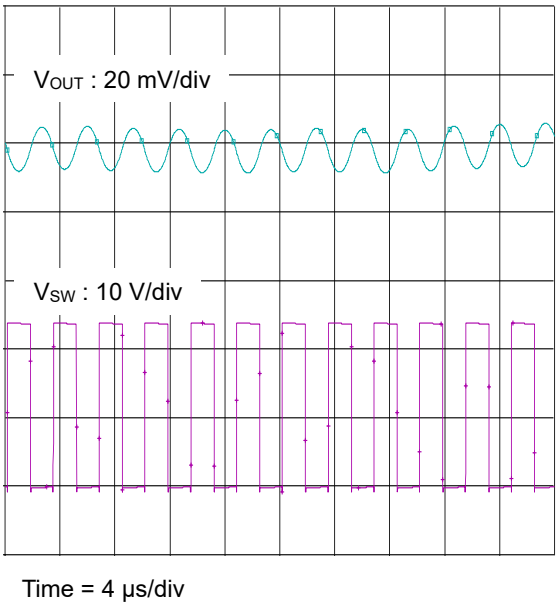


Figure 11.  
Output Ripple Voltage (VIN = 24 V, VOUT = 12 V)  
(SPICE Simulation)

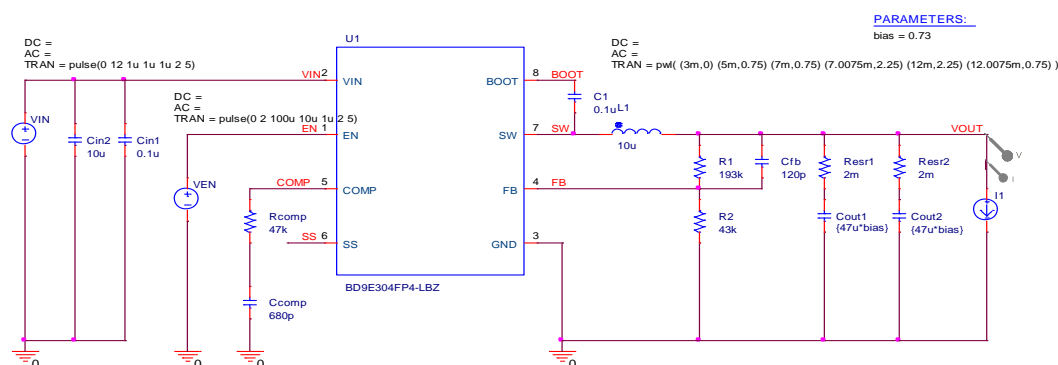
Table 7 Characteristics Comparison

Parameter	Measured Result (Note1)(Note2)	SPICE Simulation Result	Unit	Error	Condition
Output Ripple Voltage	14	12.3	mV	-12.1 %	VIN = 24 V, VOUT = 12 V, IOUT = 3 A

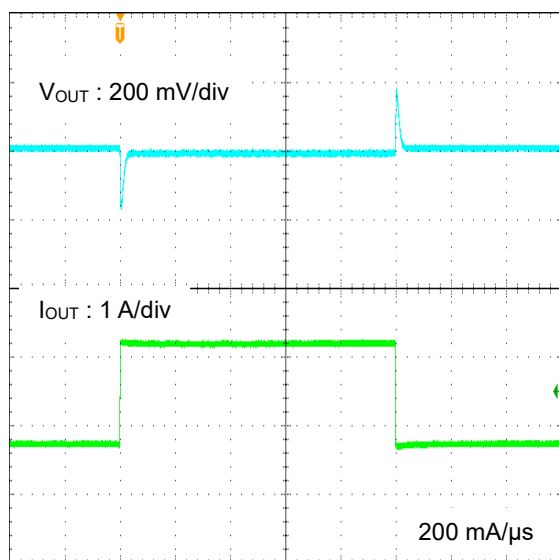
(Note 1) The above data is based on a specific sample and it is not a guaranteed value.  
(Note 2) These characteristics depend on some dynamic characteristics of external components, input signal speed,  
PCB pattern and mounting condition of each on-board parts.

4. Load Response ( $V_{IN} = 12\text{ V}$ ,  $V_{OUT} = 3.3\text{ V}$ )

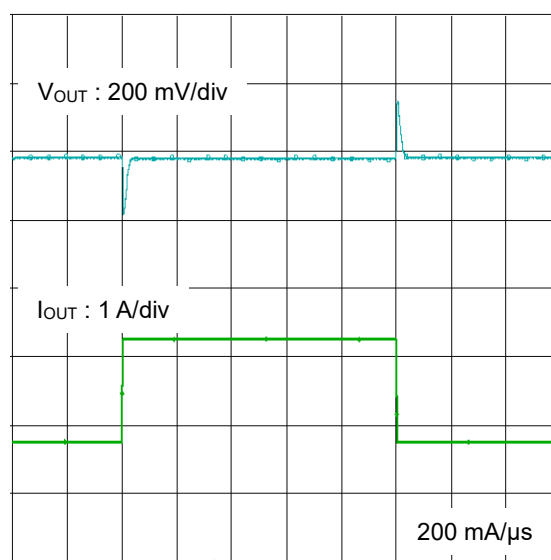
**Simulation Setting**  
 Type: Transient  
 Run Time: 15 ms  
 (Maximum Step Size: 10 ns)



**Figure 12.**  
**Simulation Schematic 4**



**Figure 13.**  
**Load Response ( $V_{IN} = 12\text{ V}$ ,  $V_{OUT} = 3.3\text{ V}$ )**  
**(Measured Waveform)**



**Figure 14.**  
**Load Response ( $V_{IN} = 12\text{ V}$ ,  $V_{OUT} = 3.3\text{ V}$ )**  
**(SPICE Simulation)**

**Table 8 Characteristics Comparison**

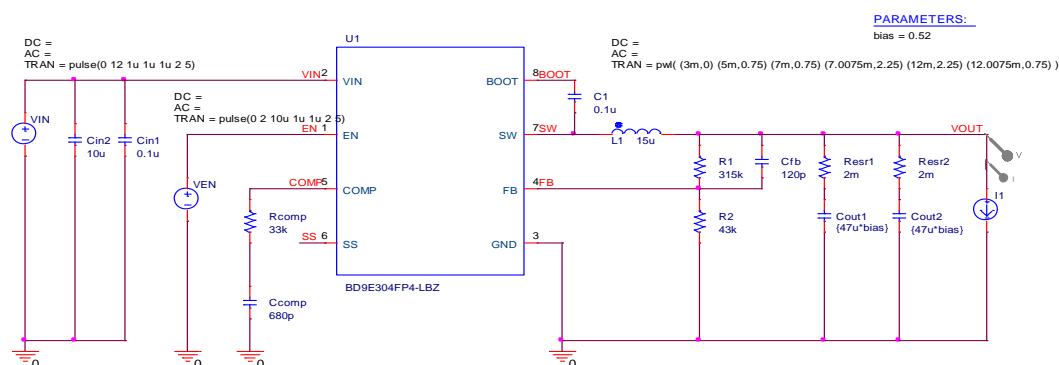
Parameter	Measured Result (Note1)(Note2)	SPICE Simulation Result	Unit	Error	Condition
Undershoot	152	163.1	mV	7.3 %	$V_{IN} = 12\text{ V}$ , $V_{OUT} = 3.3\text{ V}$ , $I_{OUT} = 0.75\text{ A to } 2.25\text{ A}$
Overshoot	155	167.7	mV	8.2 %	

(Note 1) The above data is based on a specific sample and it is not a guaranteed value.

(Note 2) These characteristics depend on some dynamic characteristics of external components, input signal speed, PCB pattern and mounting condition of each on-board parts.



Simulation Setting  
Type: Transient  
Run Time: 15 ms  
(Maximum Step Size: 10 ns)



$V_{OUT} : 200 \text{ mV/div}$

$I_{OUT} : 1 \text{ A/div}$

200 mA/ $\mu$ s

Time = 1 ms/div

$V_{OUT} : 200 \text{ mV/div}$

$I_{OUT} : 1 \text{ A/div}$

200 mA/ $\mu\text{s}$

Time = 1 ms/div

**Figure 17.**  
**Load Response ( $V_{IN} = 12\text{ V}$ ,  $V_{OUT} = 5\text{ V}$ )**  
**(SPICE Simulation)**

### Table 9 Characteristics Comparison

Parameter	Measured Result (Note1)(Note2)	SPICE Simulation Result	Unit	Error	Condition
Undershoot	232	250	mV	7.8 %	V <sub>IN</sub> = 12 V, V <sub>OUT</sub> = 5 V, I <sub>OUT</sub> = 0.75 A to 2.25 A
Overshoot	220	255	mV	15.9 %	

(Note 2) These characteristics depend on some dynamic characteristics of external components, input signal speed, PCB pattern and mounting condition of each on-board parts.

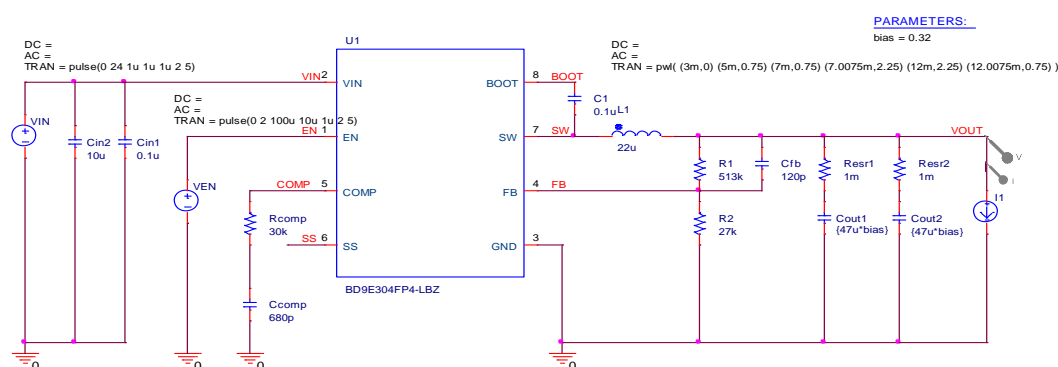
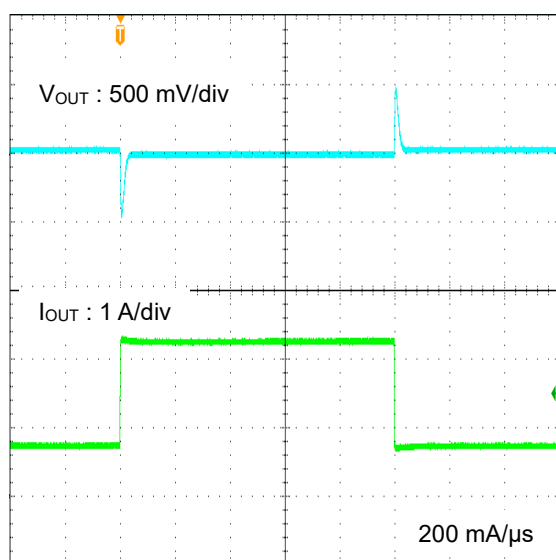
6. Load Response ( $V_{IN} = 24\text{ V}$ ,  $V_{OUT} = 12\text{ V}$ )

## Simulation Setting

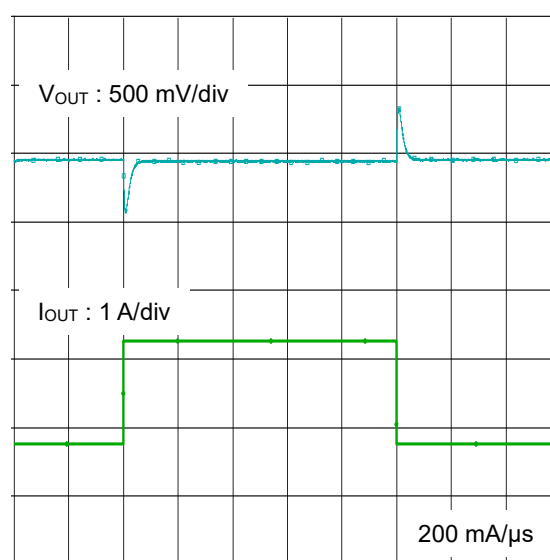
Type: Transient

Run Time: 15 ms

(Maximum Step Size: 10 ns)

Figure 18.  
Simulation Schematic 6

Time = 1 ms/div

Figure 19.  
Load Response ( $V_{IN} = 24\text{ V}$ ,  $V_{OUT} = 12\text{ V}$ )  
(Measured Waveform)

Time = 1 ms/div

Figure 20.  
Load Response ( $V_{IN} = 24\text{ V}$ ,  $V_{OUT} = 12\text{ V}$ )  
(SPICE Simulation)

Table 10 Characteristics Comparison

Parameter	Measured Result (Note1)(Note2)	SPICE Simulation Result	Unit	Error	Condition
Undershoot	472	382.6	mV	-18.9 %	$V_{IN} = 24\text{ V}$ , $V_{OUT} = 12\text{ V}$ , $I_{OUT} = 0.75\text{ A}$ to $2.25\text{ A}$
Overshoot	478	389.7	mV	-18.5 %	

(Note 1) The above data is based on a specific sample and it is not a guaranteed value.

(Note 2) These characteristics depend on some dynamic characteristics of external components, input signal speed, PCB pattern and mounting condition of each on-board parts.

7. Frequency Characteristic (VIN = 12 V, VOUT = 3.3 V)

Simulation Setting  
Type: AC  
Frequency Range:  
1 kHz to 1 MHz  
(Points/Decade: 20)

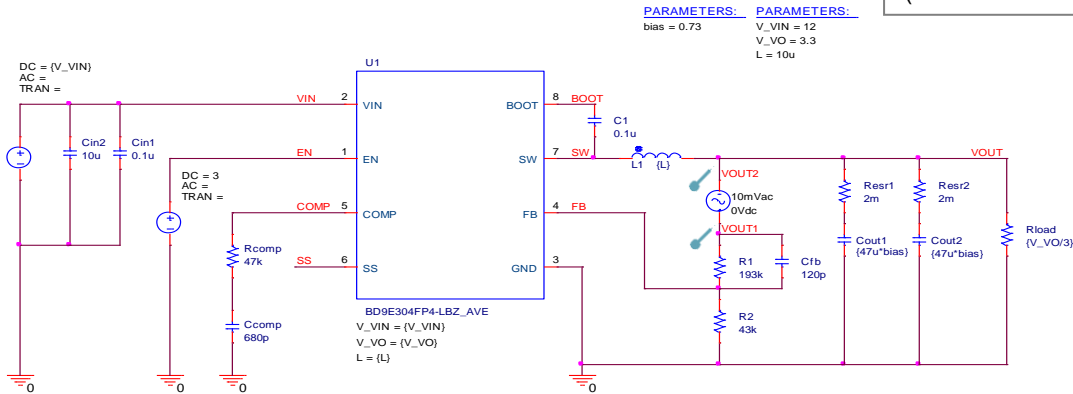


Figure 21.  
Simulation Schematic 7

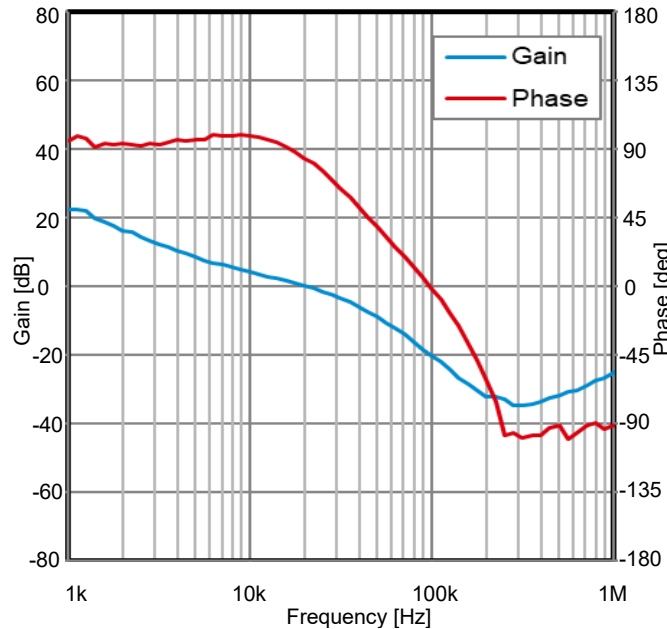


Figure 22.  
Frequency Characteristic (VIN = 12 V, VOUT = 3.3 V)  
(Measured Waveform)

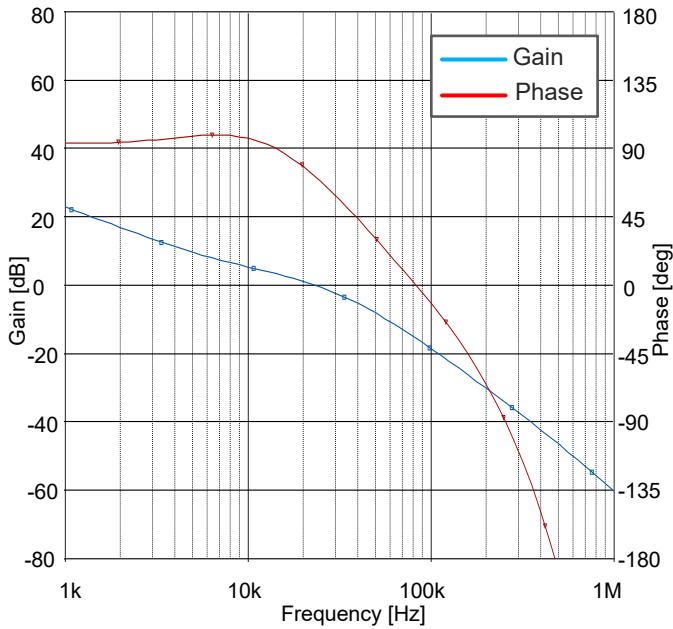


Figure 23.  
Frequency Characteristic (VIN = 12 V, VOUT = 3.3 V)  
(SPICE Simulation)

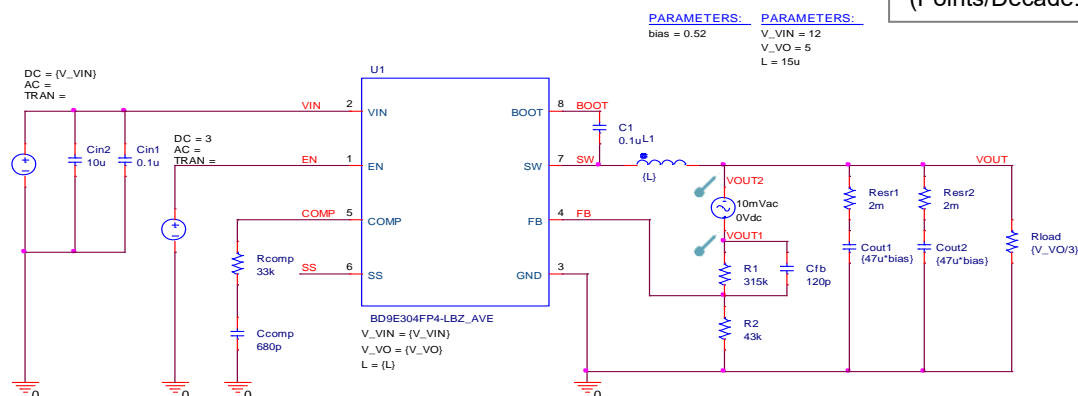
Table 11 Characteristics Comparison

Parameter	Measured Result (Note1)(Note2)	SPICE Simulation Result	Unit	Error	Condition
Phase Margin	85	71.6	degree	-15.8 %	VIN = 12 V, VOUT = 3.3 V, IOUT = 3 A
Crossover Frequency	20	23.3	kHz	16.5 %	

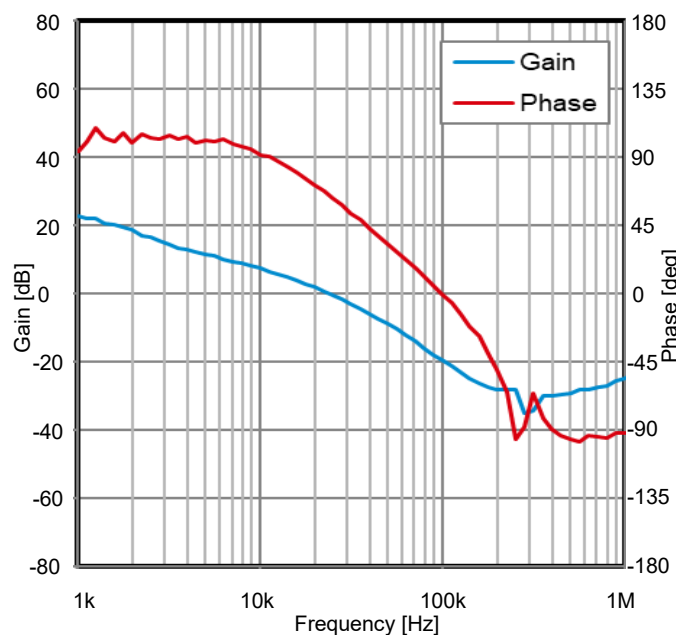
(Note 1) The above data is based on a specific sample and it is not a guaranteed value.  
(Note 2) These characteristics depend on some dynamic characteristics of external components, input signal speed,  
PCB pattern and mounting condition of each on-board parts.

8. Frequency Characteristic ( $V_{IN} = 12\text{ V}$ ,  $V_{OUT} = 5\text{ V}$ )

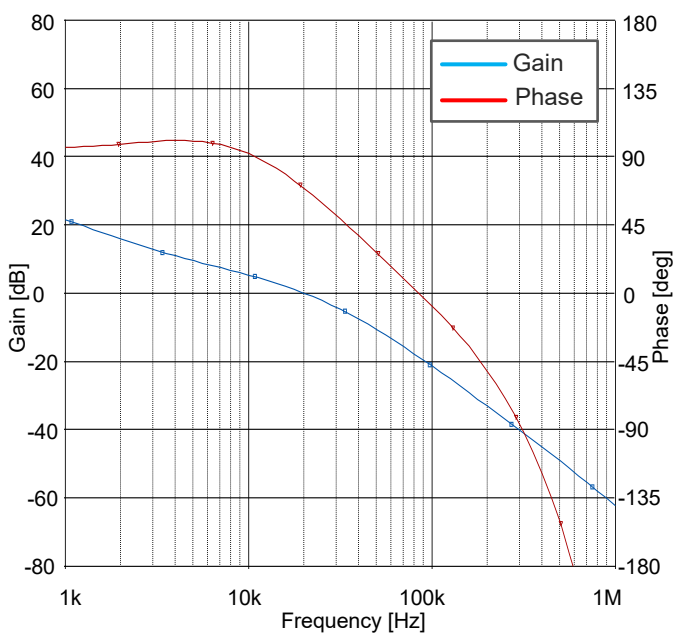
**Simulation Setting**  
 Type: AC  
 Frequency Range:  
 1 kHz to 1 MHz  
 (Points/Decade: 20)



**Figure 24.**  
**Simulation Schematic 8**



**Figure 25.**  
**Frequency Characteristic ( $V_{IN} = 12\text{ V}$ ,  $V_{OUT} = 5\text{ V}$ )**  
**(Measured Waveform)**



**Figure 26.**  
**Frequency Characteristic ( $V_{IN} = 12\text{ V}$ ,  $V_{OUT} = 5\text{ V}$ )**  
**(SPICE Simulation)**

**Table 12 Characteristics Comparison**

Parameter	Measured Result (Note1)(Note2)	SPICE Simulation Result	Unit	Error	Condition
Phase Margin	68.5	69.1	degree	0.9 %	$V_{IN} = 12\text{ V}$ , $V_{OUT} = 5\text{ V}$ , $I_{OUT} = 3\text{ A}$
Crossover Frequency	22	20.2	kHz	-8.2 %	

(Note 1) The above data is based on a specific sample and it is not a guaranteed value.

(Note 2) These characteristics depend on some dynamic characteristics of external components, input signal speed, PCB pattern and mounting condition of each on-board parts.

9. Frequency Characteristic (VIN = 24 V, VOUT = 12 V)

Simulation Setting  
Type: AC  
Frequency Range:  
1 kHz to 1 MHz  
(Points/Decade: 20)

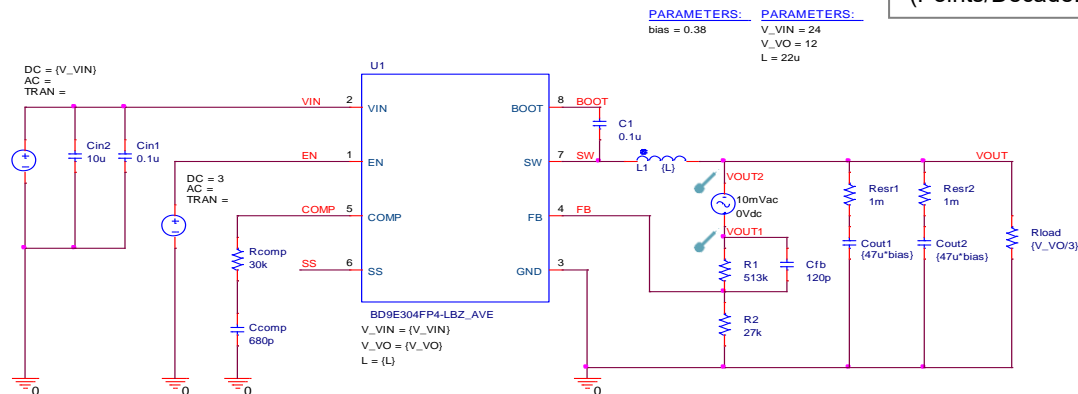


Figure 27.  
Simulation Schematic 9

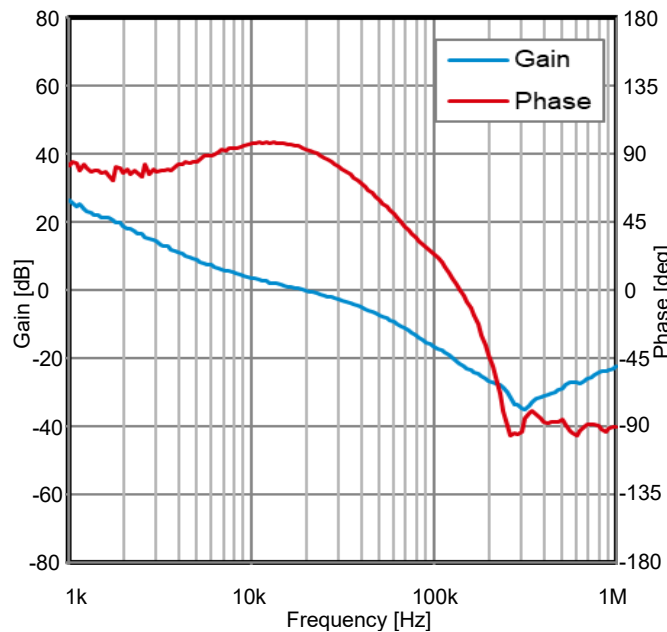


Figure 28.  
Frequency Characteristic (VIN = 24 V, VOUT = 12 V)  
(Measured Waveform)

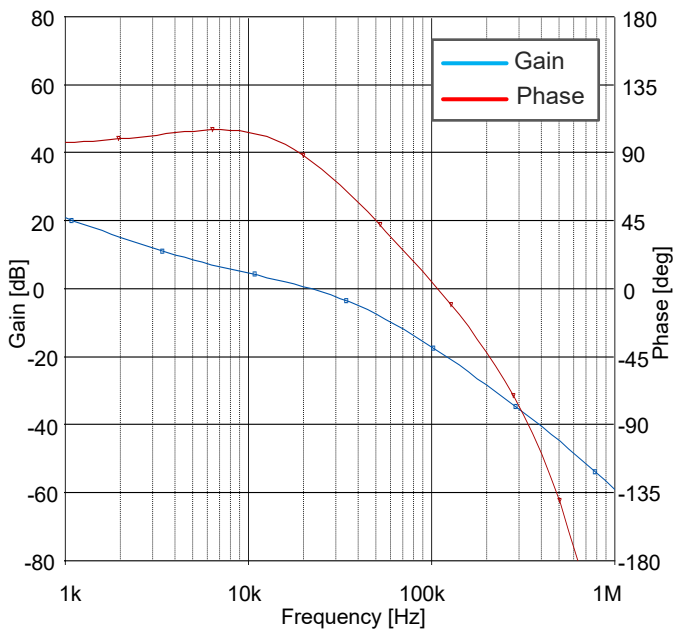


Figure 29.  
Frequency Characteristic (VIN = 24 V, VOUT = 12 V)  
(SPICE Simulation)

Table 13 Characteristics Comparison

Parameter	Measured Result (Note1)(Note2)	SPICE Simulation Result	Unit	Error	Condition
Phase Margin	95	84.3	degree	-11.3 %	VIN = 24 V, VOUT = 12 V, IOUT = 3 A
Crossover Frequency	21	22.2	kHz	5.7 %	

(Note 1) The above data is based on a specific sample and it is not a guaranteed value.  
(Note 2) These characteristics depend on some dynamic characteristics of external components, input signal speed,  
PCB pattern and mounting condition of each on-board parts.

**Revision History**

Date	Revision	Changes
Jun.2022	001	New Release

## Notes

- 1) The information contained herein is subject to change without notice.
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